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Asymptotic Theory: The Legend of Self-Normalization >>>

Qi-Man SHAO

[Editor's note: In May 2014, the Institute hosted the program "Self-normalized Asymptotic Theory in Probability, Statistics and Econometrics". One of the program co-chairs, Qi-Man Shao, contributed this invited article to Imprints *as a follow-up to the program.]*

Asymptotic theory has played an important role in the development of probability and statistics. The classical limit theorems such as the law of large numbers, the central limit theorem, large and moderate deviations are fundamental results in probability theory, which also provide powerful tools for statistical analysis. However, the normalizing coefficients in these classical limit theorems are deterministic and given by a sequence of constants. It is well-known that moment conditions or related assumptions are necessary for these theorems. For example, a central limit theorem holds for sums of independent random variables if and (nearly) only if the Lindeberg condition is satisfied; a large deviation theorem is valid if and only if the moment generating condition is finite. On the other hand, the normalizing coefficients in many commonly used statistics are typically random. A prototypical example is Student's *t*-statistic introduced in 1908 by Student (Gosset)[1]. This is because the statistic under consideration usually involves some unknown nuisance parameters; in particular, one needs to estimate these nuisance parameters first and then substitute the estimators into the statistic. The statistic with the estimated nuisance parameters is said to be Studentized or self-normalized. To study the asymptotic properties of the self-normalized statistics, since the estimated nuisance parameters are random, one usually assumes more moment conditions so that the estimators can be replaced by the deterministic parameters and some classical asymptotic theorem can then be applied. Thus, the assumptions for self-normalized asymptotic theorems used to be more restrictive than the classical limit theorems. On the other hand, the active developments of a rich probability theory of self-normalized processes in the past three decades have shown a completely new aspect of self-normalization. In contrast to the classical limit theorems, the self-normalized limit theorems may hold under no moment assumptions

[1] W.S. Gosset (Student), The probable error of a mean, *Biometrika* **6** (1908), 1-25.

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or much weaker moment assumptions. Griffin and Kuelbs (1989)[2] obtained the laws of the iterated logarithm for self-normalized sums of independent and identically distributed variables belonging to the domain of attraction of a normal or stable law; Shao (1997)[3] established the self-normalized large deviation theorem without any moment assumptions; Jing, Shao and Zhou (2004)[4] further derived saddlepoint approximations for Student's *t*-statistic with no moment assumptions; Bercu, Gassiat and Rio (2002)[5] obtained large and moderate deviation results for self-normalized empirical processes; Jing, Shao and Wang (2003)[6] established the self-normalized Cramér type moderate deviation theorems for independent random variables, which have been extended to general self-normalized processes by Shao and Zhou (2013)[7]. The book by de la Peña, Lai and Shao (2009)[8] is the first one that systematically treats the theory and applications of self-normalization.

The self-normalized asymptotic theory usually requires much weaker assumptions and hence provides much wider applicability of self-normalized statistics. The theory also provides theoretical justification for many commonly used statistical methods and procedures. The self-normalized asymptotic theorems have been successfully applied to statistical inference, high dimensional data analysis, multiple hypothesis testing, and econometrics; see, e.g., Fan, Hall and Yao (2007)[9], Belloni, Chernozhukov and Wang (2011, 2014)[10,11], Liu and Shao (2013)[12], and Belloni, Chen, Chernozhukov and Hansen (2012)[13].

The achievements on self-normalized asymptotic theory in the past three decades are significant; however, the theory is far from complete. To solve a wide range of practical problems, including the control of false discovery rate in multiple simultaneous tests and finding useful laws in big data, one needs further and more systematical developments by researchers from different fields, including probability theory, statistics, econometrics, computer science, engineering, biology and finance.

Qi-Man Shao
The Chinese University of Hong Kong

[2] P.S. Griffin and J. D. Kuelbus, Self-normalized laws of the iterated logarithm, *Ann. Probab.* **17** (1989), 1571-1601.

[3] Q.M. Shao (1997), Self-normalized large deviations, *Ann. Probab.* **25** (1997), 285-328.

[4] B.Y. Jing, Q.M. Shao and W. Zhou, Saddlepoint approximation for Student's *t*-statistic with no moment conditions, *Ann. Statist.* **32** (2004), 2679-2711.

[5] B. Bercu, E. Gassiat and E. Rio, Concentration inequalities, large and moderate deviations for self-normalized empirical processes, *Ann. Probab.* **30** (2002), 1576-1604.

[6] B.Y. Jing, Q.M. Shao and Q.Y. Wang, Self-normalized Cramér-type large deviations for independent random variables, *Ann. Probab.* **31** (2003), 2167-2215.

[7] Q.M. Shao and W.X. Zhou. Cramér type moderate deviation theorems for self-normalized processes, *Bernoulli* (to appear).

[8] V.H. de la Peña, T.L. Lai and Q.M. Shao, *Self-normalized Processes: Limit Theory and Statistical Applications,* Springer, 2009.

[9] J. Fan, P. Hall and Q. Yao, To how many simultaneous hypothesis tests can normal, Student's *t* or bootstrap calibration be applied? *J. Amer. Statist. Assoc.* **102** (2007), 1282–1288.

[10] A. Belloni, V. Chernozhukov and L. Wang, Square-root lasso: pivotal recovery of sparse signals via conic programming, *Biometrika* **98** (2011), 791–806.

[11] A. Belloni, V. Chernozhukov and L. Wang, Pivotal estimation via square-root Lasso in nonparametric regression, *Ann. Statist.* **42** (2014), 757–788.

[12] W.D. Liu and Q.M. Shao, A Cramér moderate deviation theorem for Hotelling's T^2-statistic with applications to global tests, *Ann. Statist.* **41** (2013), 296–322.

[13] A. Belloni, D. Chen, V. Chernozhukov and C. Hansen, Sparse models and methods for optimal instruments with an application to eminent domain, *Econometrica* **80** (2012), 2369–2429.

IMS Receives a Gift in Memory of Mr Ng Kong Beng >>>

The Ng family

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 gift is also expected to be eligible for a dollar-for-dollar matching grant from the Singapore Government.

Mr Ng Kong Beng [1912-2003] was born in Fujian, China. He came to Singapore in 1931 and worked as a school teacher. In 1940, Mr Ng ventured into the rubber industry and subsequently became a very successful businessman in the sector. In the late 1960's he also started an electronic business which manufactured electronic components. During his lifetime, he contributed in various capacities to many educational institutions and charitable organizations, including serving on the boards of several of these establishments.

Mr Ng's sons, Kok Lip and Kok Koon, are both alumni of the Department of Mathematics, National University of Singapore (NUS). Mr Ng Kok Lip is an entrepreneur and a long-time supporter of the IMS, serving as a member of the Institute's Management Board since 2001. Kok Koon had a 27-year career at the NUS Libraries, playing a key role in many of their developmental milestones.

Each year, IMS organizes graduate summer/winter schools to provide training for mathematics graduate students. Each summer/winter school typically lasts several weeks, and student participants benefit from attending daily lectures on selected advanced research topics presented by leading mathematical scientists. The schools also broaden the learning experience of the student participants through their interactions with peers and experts in the field. With the gift, it is envisaged that the graduate summer/winter schools will expand in both size and scope, and more student participants will receive the desired financial support.

As part of its outreach program, the Institute organizes several public lectures each year. Delivered by prominent mathematical scientists, the public lectures contribute to raise public awareness and understanding of recent mathematical development and the role of mathematics in science, engineering, technology and industry. These lectures have attracted a wide range of attendees, including students, research scientists, professionals and the general public. The inaugural Ng Kong Beng Public Lecture was presented by Professor Tamás Hausel (École Polytechnique Fédérale de Lausanne, Switzerland) at NUS on 7 August 2014.

Professor Chong Chi Tat, Director of IMS, expresses the Institute's gratitude for this generous gift. He says that the Ng Kong Beng Memorial Fund will help IMS strengthen its public lecture and summer/winter school programs. These two programs constitute a major part of the IMS mission to nurture mathematical talents and reach out to the public. There are plans of expanding them and the additional resources coming in from the Fund will facilitate their implementation. He also hopes that this gift will inspire others to support the IMS in carrying out its mission.

Wing-Keung To and Kwok Pui Choi
National University of Singapore

New Management Board Members >>>

The Institute is pleased to welcome three new members to its Management Board: Professor San LING (Nanyang Technological University), Professor David Rosenblum (National University of Singapore (NUS)) and Associate Professor Kwok Pui CHOI (NUS).


San LING

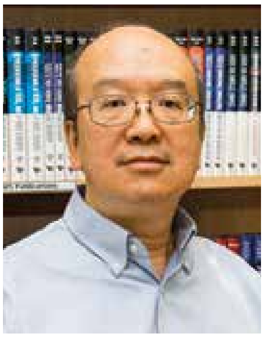
Professor San Ling is currently the Dean of the College of Science at the Nanyang Technological University. His research interests revolve around the applications of algebra and number theory to combinatorial designs, coding theory, cryptography and sequences; and the arithmetic of modular curves and Galois representations.

Professor Ling, who is the current President of the Singapore Mathematical Society, served in a number of scientific advisory boards and professional bodies, including the Singapore National Academy of Science and the Southeast Asian Mathematical Society.


David Rosenblum

David S. Rosenblum, a professor in the Department of Computer Science, is the Dean of the School of Computing at the National University of Singapore. He is also the director of the Felicitous Computing Institute and a member of the NUS Graduate School for Integrative Sciences and Engineering.

Professor Rosenblum's current research focuses on the scalability of architectures for large-scale software systems; probabilistic verification of software systems; and the design and validation of mobile, context-aware adaptive systems for ubiquitous computing. In 1997 he received a CAREER Award from the US National Science Foundation for his work on distributed component-based software, and from 2004-2009 he held a Wolfson Research Merit Award from the Royal Society.


Kwok Pui CHOI

Kwok Pui Choi is currently Associate Professor of the Department of Statistics and Applied Probability at NUS. He joined NUS in 1986, and was a member of the organizing committee of several IMS programs - most recently the "Networks in Biological Sciences" (June 2015). Associate Professor Choi's research interests are in the areas of computational biology and probability.

The Institute would like to express its thanks to the outgoing members of the Management Board: Professor Tow Chong CHONG and Professor Lim Soon WONG. Professor Chong joined the Board in 2005, while Professor Wong had been a Board member since 2013. Both members contributed substantially in overseeing the Institute's operations and activities.

The Institute looks forward to continuing its smooth running and making further strides under the mentorship of the new and incumbent members of the Management Board.

Kwok Pui Choi
National University of Singapore

News Highlights >>>

Forging Ties with Mathematics Institutes in the Asia Pacific Region

In the past six months, 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.

MOU signing with VIASM: (clockwise from top left) Soo Teck LEE, Chengbo ZHU, Ngô Bảo Châu and Chi-tat CHONG

The ceremony was held during Professor Ngo's visit to IMS and the Department of Mathematics. He delivered the Inaugural Oppenheim Lecture, and a lecture in the Workshop on Representation Theory & Automorphic Forms held from 27 to 29 January 2015.

Personnel movements at IMS

Wing Keung To, who served as the Institute's Deputy Director from 1 January 2011 to 31 December 2014, relinquished his position to resume full-time duties at the Department of Mathematics. Professor To is succeeded by Kwok Pui Choi of the Department of Statistics and Applied Probability.

Lim Shi Qing joined IMS as management assistant officer on 10 November 2014. She will be the new housing officer.

Programs & Activities >>>

Past Programs & Activities in Brief

Algorithmic Randomness (2 – 30 June 2014)

Website: http://www2.ims.nus.edu.sg/Programs/014algo/index.php

Chair:
Frank Stephan, *National University of Singapore*

Algorithmic randomness is a field which investigates the notion of randomness less from the statistical viewpoint but more from the question which algorithmic properties sufficiently random sequences can have or cannot have.

The CCR (Computability, Complexity and Randomness) conference-series, a regular and important meeting for the field of algorithmic randomness, was embedded into this one-month program. It brought together scientists from both traditional algorithmic randomness as well as related fields, and aimed to foster the collaboration between the participants, in particular among those who stayed beyond the conference period. For the local community, the CCR conference provided the opportunity to raise the visibility of their work in the field and to renew and improve contacts with colleagues from other (overseas) institutions.

There were 30 invited talks presented during the CCR conference held from 9-13 June 2014. In the weeks before and after the CCR 2014 conference, each morning was planned with two hours of informal discussions. There were a total of six talks. In general, the discussions which revolved around open problems and research directions were fruitful as results from a feedback survey listed 22 tentative projects/papers which were started or continued during the program.

There were a total of 62 participants and among them were eight graduate students. Several graduate students and young researchers who participated in the Summer School in Logic took the opportunity to meet and discuss with senior colleagues in the field as there was a week of interaction between the "Algorithmic Randomness" program and the "IMS Graduate Summer School in Logic".

Andre Nies: Cardinal characteristics and highness properties of oracles

Cristian Sorin Calude: Finite state incompressible infinite sequences

Sharing algorithmic thoughts
(From left: Andre Nies, Rupert Hölzl and Bjørn Kjos-Hanssen)

Sharing light moments
(From left: Theodore Slaman and Veronica Becher)

Contemplating algorithms in a finite space

IMS Graduate Summer School in Logic (23 June – 4 July 2014)

... Jointly organized with Department of Mathematics, NUS

Website: http://www2.ims.nus.edu.sg/Programs/014logicss/index.php

The Summer School bridges the gap between a general graduate education in mathematical logic and the specific preparation necessary to do research on problems of current interest in the subject.

The summer school consisted of 8.5 hours of lectures conducted by Yu Liang (Nanjing University), 5 hours of lectures by Feng Qi (Chinese Academy of Sciences) and 12.5 hours of lectures by Hugh Woodin (University of California at Berkeley, USA and National University of Singapore).

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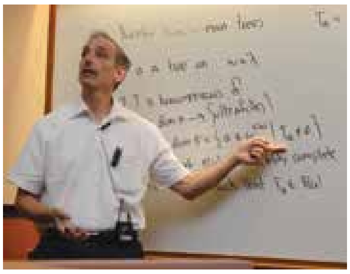
The summer school was well attended by 50 participants and among them were 32 graduate students.



Hugh Woodin: Set theory

Qi FENG: Set theory

Logical discussions over coffee
(From left: Rodney Downey Feng Qi and Yang Yue)

Extending logical thoughts
(From left: Michael McInerney and Nadine Losert)

Having recurring interest in logic

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

Website: http://www2.ims.nus.edu.sg/Programs/014geometry/index.php

Co-chairs:
Richard A. Wentworth, *University of Maryland*
Graeme Wilkin, *National University of Singapore*

The subject of this program was the moduli space of Higgs bundles and its connections with different areas of mathematics and physics. This program aimed to bring together experts who study the geometry, topology and physics of Higgs bundles; to have experts delivering mini-courses explaining the background to their fields; to encourage collaborative work among the program participants and to introduce graduate students and young researchers to the latest research and open problems in the field. A summer school, workshop and conference were planned amidst the program period. The conference was accepted as a satellite conference to the International Congress of Mathematicians held in South Korea from 13 - 21 August 2014.

There were a total of eight tutorial speakers and seven invited talks held in the summer school (7 – 18 July 2014). The tutorials were delivered by Olivier Guichard (Université de Strasbourg, France), Motohico Mulase (University of California, Davis, USA), Olivia Dumitrescu (University of Hannover, Germany), David Hyeon (Pohang University of Science and Technology, Korea), Siye Wu (The University of Hong Kong, Hong Kong), Tony Pantev (University of Pennsylvania, USA), Sebastian Casalaina-Martin (University of Colorado at Boulder, USA) and Laura Schaposnik (University of Illinois at Urbana Champaign, USA). During the summer school, there were four problem sessions where students could work on problems associated to Olivier Guichard's course on Higgs bundles. Younger mathematicians also contributed talks during the summer school and workshop. A number of the workshop speakers were postdocs speaking about their thesis topics.

There were a total of 19 invited talks in the workshop (21 – 31 July 2014). Philip Boalch (École Normale Supérieure and CNRS, France) also gave a 4-part lecture mini-course on "Wild character varieties and wild mapping class groups" in the week between the workshop and conference.

There were a total of 21 invited talks in the conference (4 – 8 August 2014). The conference contained a number of talks from leading researchers on the latest developments in the field such as Tamas Hausel (École Polytechnique Fédérale de Lausanne, Switzerland), Takuro Mochizuki (Kyoto University, Japan) and Jochen Heinloth (Universität Duisburg-Essen, Germany). There were a total of six invited talks held after the conference period.

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There was plenty of time for collaborative work during the program. Seven projects/papers and five preprints were started or continued from the activities during the program. There were a total of 103 participants and among them were 22 graduate students.


Motohico Mulase: Spectral curves of Higgs bundles


Olivier Guichard: Introduction to Higgs bundles


Oscar García-Prada: Involutions of Higgs bundle moduli spaces


Marked points in conversation (From left: Takuro Mochizuki and Xi ZHANG)


Direct attention on moduli spaces (From left: Richard Wentworth and Motohico Mulase)


Working out the potential applications (From left: Marina Logares and Sukhendu Mehrotra)


Universal cover of the moduli spaces

IMS-JSPS Joint Workshop in Mathematical Logic and Foundations of Mathematics (1 - 5 September 2014)

Website: http://www2.ims.nus.edu.sg/Programs/014wlogic/index.php

Organizing Committee:
Chi Tat Chong, *National University of Singapore*
Frank Stephan, *National University of Singapore*
Kazuyuki Tanaka, *Tohoku University*
Yue Yang, *National University of Singapore*

This workshop is jointly sponsored by the Japan Society for the Promotion of Science and the National University of Singapore. This workshop provided an opportunity to 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).

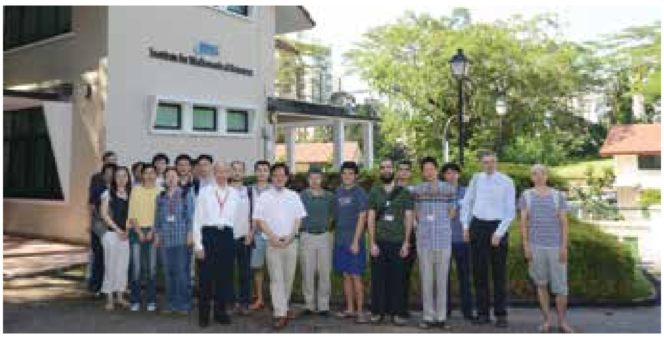
There were a total of 22 invited talks held amidst the workshop. There were a total of 29 participants and among them were eight graduate students.


Chi-tat CHONG: Randomness in the absence of full induction


Kazuyuki Tanaka: Infinite games and their strengths


Shohei Okisaka: Simple unary generalized quantifier


Constructive mathematics (From left: Keita Yokoyama and Takeshi Yamazaki)


Logic Theorists with style

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Scalar Curvature in Manifold Topology and Conformal Geometry (1 November - 31 December 2014)

Website: http://www2.ims.nus.edu.sg/Programs/014scalar/index.php

Organizing Committee:
Fei Han, *National University of Singapore*
Wei-ming Ni, *University of Minnesota*
Xingwang Xu, *National University of Singapore*
Weiping Zhang, *Nankai University*

This program focused on the analytical and topological aspects of the scalar curvature of a Riemannian manifold.

Analytically our attention focused on the scalar curvature related geometric differential equations. These partial differential equations stimulate a lot of interest. Typical equations include elliptic and parabolic type, normally nonlinear on curved spaces. Hence curvature always plays an important role. Since the scalar curvature is just a real valued function, the conformal changes of the metrics naturally connect to scalar curvature or more generally the Q-curvature function. Recently, the parabolic type equations as well as the fully nonlinear equations also come to play, creating new possibilities for further research in this rich and interesting field.

The topological side is to consider the connections between various curvatures and index of metric related elliptic operators. The pioneering work of Lichnerowicz in the early sixties has shown that the scalar curvature is related to the index of Dirac operators on spin manifolds. The celebrated Atiyah-Singer index theorem tells us that the index of Dirac operator is a topological invariant of the manifold. This gives topological obstruction to the existence of positive scalar curvature metric on spin manifolds. Some driving forces for recent developments are the efforts of generalizing these known results about positive scalar curvature to infinite dimensional spaces and non-commutative spaces.

The program provided a platform for researchers working on these areas to communicate ideas and stimulate new research collaboration.

This program consisted of two workshops and had a total of 40 invited talks. The second workshop followed with a four-day winter school, which had four tutorial lectures delivered by Paul Yang (Princeton University), Juncheng Wei (University of British Columbia), Xuezhang Chen (Nanjing University) and Quoc Anh Ngo (Vietnam National University) and one talk by a winter school participant.

There were a total of 89 participants and among them were 18 graduate students.


Mathai Varghese: Spin manifolds and proper group actions

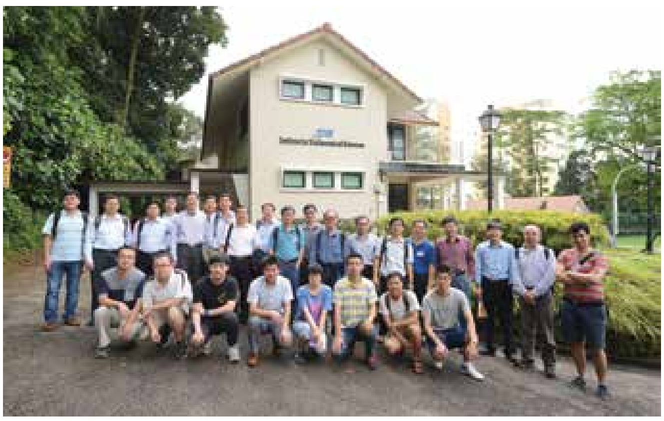

Michael Joachim: The Gromov-Lawson-Rosenberg conjecture


Bo GUAN: Estimates for complex fully nonlinear elliptic equations


Paul YANG: Equations in conformal geometry


Small-scale conversations (From left: Weimin SHENG, Chengbo ZHU and Guofang WANG)

Sketching the connections for problem solving (From left: Boris Vertman and Xianzhe DAI)


Achieving maximal value from scalar curvature equations

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Public lecture:

Tamas Hausel: Magic Pictures About Higgs Bundles

Professor Tamás Hausel of École Polytechnique Fédérale de Lausanne, Switzerland delivered a public lecture titled "Magic Pictures about Higgs Bundles" at NUS on 7 August 2014. In the lecture, Professor Hausel gave a glimpse of the mathematical theory of Higgs bundles, which are at the center of investigations in theoretical physics and many fields of mathematics, including geometry, number theory and representation theory. He also mentioned briefly how the original definition of Higgs bundles was motivated by the mathematical theory of the Higgs particle. A total of 44 people attended the lecture.

Current Program

High Performance and Parallel Computing for Materials Defects and Multiphase Flows (1 January - 31 March 2015)

... Jointly organized with Department of Mathematics, NUS

Website: http://www2.ims.nus.edu.sg/Programs/015hiper/index.php

Co-chairs:

Weizhu Bao, *National University of Singapore*
Weiqing Ren, *National University of Singapore and Institute of High Performance Computing, A*STAR*
Ulrich Rüde, *Universität Erlangen-Nürnberg*

The three-month program will bring computational and applied mathematicians, computer scientists, computational materials scientists and other computational scientists together to review, develop, and promote interdisciplinary research on high performance and parallel computing with applications in the simulation of materials defects, material-related processes, multiphase flows, and complex fluids. The program will provide a forum to highlight progress in a broad range of application areas, especially in the simulation of materials defects and multiphase/complex fluids, within a coherent theme and with strong emphasis on high performance and parallel computing.

Activities

- Collaborative Research: 1 January - 31 March 2015
- Embedded meeting (The 9th International Conference on Computational Physics, National University of Singapore, Singapore): 7-11 January 2015
- Workshop I (Recent Advances in Parallel and High Performance Computing Techniques and Applications): 12 - 16 January 2015
- Tutorial on Parallel Domain Decomposition Methods and Parallel Hierarchical Grid (PHG): 19 - 20 January 2015
- Special Talks: 30 January, 6, 11 and 17 February 2015
- Workshop II (High Performance and Parallel Computing Methods and Algorithms for Materials Defects): 9 - 13 February 2015
- Workshop III (High Performance and Parallel Computing Methods and Algorithms for Multiphase/Complex Fluids): 2 - 6 March 2015
- Winter School (Computational and Mathematical Methods for Materials Defects and Multiphase lows): 23 February - 12 March 2015

Inaugural Oppenheim Lecture (28 January 2015)

... Jointly organized with Department of Mathematics, NUS

Website: http://ww1.math.nus.edu.sg/events/Poster-OppenheimLectures.pdf

The Oppenheim Lectures is a distinguished lecture series which starts in the Academic Year 2014/2015, and is held in honour of Sir Alexander Oppenheim, who held the position of Professor and first Head of the Department from 1931, at the time of Raffles College, until 1959. Professor Oppenheim was also Vice Chancellor of the University of Malaya (the predecessor of NUS) from 1957 to 1963. He was a well-known number theorist, notably for the Oppenheim Conjecture, which was settled by Gregori Margulis in the affirmative in 1986.

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Professor Ngo Bao Chau (University of Chicago and Vietnam Institute for Advanced Study in Mathematics) will give a lecture titled "On the average rank of elliptic curve over function field".

Workshop on Representation Theory & Automorphic Forms (27 – 29 January 2015)

... Jointly organized with Department of Mathematics, NUS (in conjunction with the Oppenheim Lecture)

Website: http://ww1.math.nus.edu.sg/events/Programme-OppenheimLectures%20and%20Workshop.pdf

Speakers:

- Ngo Bao Chau, University of Chicago and Vietnam Institute for Advanced Study in Mathematics
- Kaoru Hiraga, Kyoto University
- Wen-Wei Li, Chinese Academy of Sciences
- Sergey Lysenko, Institut Elie Cartan Nancy
- Chung Pang Mok, Purdue University and Morningside Center of Mathematics
- Arvind Nair, Tata Institute of Fundamental Research
- Dipendra Prasad, Tata Institute of Fundamental Research
- Martin Weissman, Yale-NUS College
- Lei Zhang, National University of Singapore

Next Program

Joint international workshop of the National University of Singapore

Institute for Mathematical Sciences and Yong Siew Toh Conservatory of Music
Mathemusical Conversations: Mathematics and Computation in Music Performance and Composition (13-15 February 2015)

... Jointly organized with Centre for Digital Music, Queen Mary University of London, UK, Science and Technology of Music and Sound Lab, IRCAM, CNRS, UPMC, France

Website: http://www2.ims.nus.edu.sg/Programs/015wmusic/index.php

Program Chairs:
Gérard Assayag, *Institut de Recherche et Coordination Acoustique/Musique*
Elaine Chew, *Queen Mary University of London*

Mathemusical Conversations is an international workshop bringing together world experts and emerging scholars in and across mathematics and music, with a special focus 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.

Programs & Activities in the Pipeline

Sets and Computations (30 March - 30 April 2015)

Website: http://www2.ims.nus.edu.sg/Programs/015set/index.php

Organizing committee:
Raghavan Dilip, *National University of Singapore*
Sy David Friedman, *University of Vienna*
Yue Yang, *National University of Singapore*

Two extremely active areas of modern mathematical logic are Computability Theory and Set Theory. One purpose of this program is to bring leading researchers in these fields to the IMS for collaboration with researchers from Singapore and other parts of Asia. A second purpose is to develop newly-emerging and valuable connections between these fields. The result will be to strengthen cooperation between Singapore and research groups elsewhere, as well as to forge new connections between computability-theorists and set-theorists.

Recently, important connections between these fields have emerged: computable descriptive set theory, computability theory for uncountable structures, forcing in computational complexity theory, complexity theory for computations on sets, infinite-time Turing machines.

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Activities

- Week 1 - 2 (30 March - 10 April 2015): Set theory (forcing, large cardinals, descriptive set theory)
- Week 3 (13 - 17 April 2015): Interactions between set theory and computability theory (computational complexity in set theory, computational descriptive set theory, forcing in computational complexity theory, etc)
- Week 4 - 5 (20 - 30 April 2015): Computability theory (degree theory, reverse mathematics, higher recursion theory)

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

Website: http://www2.ims.nus.edu.sg/Programs/015wrandom/index.php

Co-Chairs:
Gleb Oshanin, *Université Pierre et Marie Curie*
Rongfeng Sun, *National University of Singapore*
Dong Wang, *National University of Singapore*

In recent years, many branches of probability theory (including interacting particle systems, disordered systems, random matrices, reaction-diffusion systems, etc) have witnessed tremendous progress. Cross fertilization of ideas arising from the interaction between the physics and the probability communities play essential roles in these developments. Many models of interest to probabilists and physicists also have applications in biology, such as the modeling of molecular motors and the application of Random Matrix Theory to biostatistics. In turn, there is active research in the physics and probability communities on models inspired by biology.

The workshop aims to bring together researchers from both the physics and probability communities and to promote further interaction between them. The central themes of the workshop will include (but not restricted to): dynamics of reaction-diffusion systems, including biophysical applications of such processes; random polymers and related systems; the Kardar-Parisi-Zhang universality class, and random matrix models.

Activities

The first week will be a workshop consisting of 25-30 talks. The second week will have fewer talks and more free time and discussion sessions to encourage collaboration.

Workshop on New Directions in Stein's method (18 - 29 May 2015)

Website: http://www2.ims.nus.edu.sg/Programs/015wstein/index.php

Chair:
Larry Goldstein, *University of Southern California*
Adrian Röllin, *National University of Singapore*

One of the greatest accomplishments of probability theory is its success in expressing specific aspects of complicated random phenomena by means of relatively simple limiting distributions. These limits often exhibit certain "universality" in that they depend only on the most fundamental properties of the models of interest. The classical central limit theorem is the prototype of such results. With approximations of finite systems by their limits, both in theory and applications, comes the need to bound the approximation error, and it is here where Stein's method, introduced in 1970 by Charles Stein, has played an important role over the last few decades.

The combination of Malliavin calculus and Stein's method has proved to be very fruitful, having been applied not only to functionals of Gaussian fields, but also to functionals of Rademacher sequences and Poisson point processes. The use of Stein couplings to prove concentration of measure inequalities has opened a new avenue for handling complicated systems exhibiting genuine dependence. Stein's method has also been extended to obtain very refined moderate deviation results. Multivariate normal approximation, technically notoriously difficult, has seen important developments, for example pushing the dependence on the dimensionality towards the optimal range. Various new distributional transforms have been discovered and successfully combined with Stein's method.

This program aims to bring together not only active researchers directly working in the area, but also those who apply Stein's method in their work in order to stimulate, strengthen and develop existing interactions between theory and practice.

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

Website: http://www2.ims.nus.edu.sg/Programs/015bio/index.php

Chair:
Louxin Zhang, *National University of Singapore*

The proposed program will focus on the mathematics for network models in biology. After a wide variety of genomes have been fully sequenced and annotated, networks of different types have been used to study cellular biological processes as well as genetic diseases. In this network view, each node represents a molecule, such as a gene, RNA or protein, or an organism. The edge between two nodes represents a relationship, such as an enzymatic reaction, physical interaction, a transcriptional regulation, or an evolutionary relationship. It has been repeatedly demonstrated that protein interaction information is very useful for determining specific functions of proteins, classifying cell lineages, and identifying valuable biomarkers for disease classification and diagnosis.

The program brings together researchers in complex networks and systems biology to enable knowledge transfer in the study of cellular networks. Analyses of dynamic and topological properties of complex networks have produced insightful concepts which should be useful in systems biology. On the other hand, systems biology provides interesting questions and ideas for complex network analysis.

Another focus of our program is on the systematic methods for phylogenetic networks. In the study of evolution, network provides biological explanations that go beyond what can be accommodated by the tree model. However, network modeling is extremely challenging. It offers excellent opportunities for mathematicians and statisticians to develop fast and robust programs for inferring an evolutionary network model from sequence data. Statistical methods are required to distinguish genuine horizontal genetic transfers from background noise such as incomplete lineage sorting.

Activities

- Tutorial I: 3 - 5 June 2015
- The Protein Network Workshop: 8 - 12 June 2015
- Tutorial II: 22 - 24 July 2015
- The Phylogenetic Network Workshop: 27 - 31 July 2015

IMS Graduate Summer School in Logic (15 June - 3 July 2015)

... Jointly organized with Department of Mathematics, NUS

Website: http://www2.ims.nus.edu.sg/Programs/015logicss/index.php

The Summer School bridges the gap between a general graduate education in mathematical logic and the specific preparation necessary to do research on problems of current interest in the subject.

Activities

- Week 1: Lectures by Hugh Woodin, Harvard University
- Week 2: Lectures by Andrew Marks, California Institute of Technology
- Week 3: Lectures by Theodore A. Slaman, University of California at Berkeley

Combinatorial and Toric Homotopy (1 - 31 August 2015)

... on the occasion of Professor Frederick Cohen's 70th Birthday

Website: http://www2.ims.nus.edu.sg/Programs/015homo/index.php

Co-chairs:
Jelena Grbic, *University of Southampton*
Zhi Lu, *Fudan University*
Jie Wu, *National University of Singapore*

This program aims to explore toric homotopy theory and combinatorial homotopy theory as well as their connections with other areas of mathematics. Leading experts from different backgrounds will come together to talk about the latest developments in algebraic topology while paying attention to the applications of algebraic topology to high technology and sciences, and chart out new directions for research in toric and combinatorial homotopy theory.

Activities

- Young Topologist Seminar: 11 - 21 August 2015
- Workshop on Applied Topology: 20 - 21 August 2015
- International Conference on Combinatorial and Toric Homotopy: 24 - 28 August 2015

Mathematical Conversations

Menachem Magidor: Mathematical Logic, Common-Sense Logic >>>

Menachem Magidor

Interview of Menachem Magidor by Y.K. Leong

Menachem Magidor made important contributions to mathematical logic and set theory and to applications of logic in computer science and artificial intelligence.

Magidor received his university education and PhD (in set theory) from the Hebrew University of Jerusalem. He subsequently held various positions in the United States such as Massachusetts Institute of Technology, California Institute of Technology, University of California at Los Angeles and University of California at Berkeley.

He obtained important consistency results on large cardinals in set theory, and gave a negative solution of the singular cardinals hypothesis. He has done seminal work on cardinal arithmetic, infinitary logic, forcing axioms and saturated ideals. His work on non-monotonic logic is influential in computer science, artificial intelligence and semantics of distributed computing.

He has been invited to give numerous lectures at scientific meetings, conferences and workshops, and in particular, he delivered the Tarski Lectures. Aside from his many scholarly contributions, he is recognised for his organizational contributions. He was the first non-American scientist to be appointed President of the International Association of Symbolic Logic.

From 1997 to 2009 Magidor served as President of the Hebrew University of Jerusalem and took on a role that might seem to be logically at odds with his own mathematical training. Founded in turbulent times, the Hebrew University was steered by him through even more turbulent years to become one of the leading academic institutions, not only in Israel, but also in the world. Returning from the real world of organization, he once again devotes himself to the surreal world of logic and set theory and turned his sights to applications of logic to computer science and artificial intelligence. In 2011 he received the Humboldt Research Award for his extensive mathematical contributions. He is currently Professor of Mathematics at the Einstein Institute of Mathematics of the Hebrew University of Jerusalem.

He was invited as Visiting Professor at National University of Singapore from 9-24 July 2010 and gave lectures at the *Asian Initiative for Infinity (AII) Graduate Summer School* (28 June-23 July 2010) which was jointly funded by the John Templeton Foundation. On behalf of *Imprints*, Y.K. Leong took this opportunity to interview him on 21 July 2010. The following is an edited and unvetted transcript of an engaging interview in which he talks about various (and some speculative) aspects of set theory and mathematical logic and, in particular, a "common sense" type of logic. The interview also gives us a peek into the mind of a mathematician who has been given the task of running a university amidst trying conditions and has done so tremendously successfully.

Imprints: How did you get interested in mathematical logic?

Menachem Magidor: Actually we should extend the interest to mathematics. It has to do with the book by Abraham Fraenkel [(1891-1965)] (you know, of Zermelo-Fraenkel Set Theory), called "Introduction to Mathematics", published in Hebrew in the late forties. As a very young boy, around 14, I went to the bookstore and right there I was fascinated by the book and thought that I would do mathematics. I still have a copy. It has a very nice section about set theory. I think it is a fantastic book. It was later translated into English and other languages. It has some proofs, nice arguments, philosophical remarks, historical remarks and puts everything into perspective. I was really fascinated by it and immediately attracted to set theory. This was the beginning really.

I: Many of the original and creative minds in logic are of Jewish descent. Do you think there could be something in the Jewish tradition that encourages logical thought?

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M: I don't know. Usually I am very reluctant to associate any particular property to a particular people. By the way, logicians in mathematics came from [different] cultures and different origins. If at all there is something about it [the Torah] – I don't know if you know about the Talmudic tradition – it's essentially a religious text. The style reminds you of logical mathematics. In some sense, it is both a legal and literary text. The style looks like this. There is a rule that you should behave in a certain way or something like that, and somebody comes along and say, if you apply this rule, then there is another rule in some other place – there is a contradiction. So now the answer is, well, there is no real contradiction because this applies only to this case; you try to separate them. Then there is a counter argument: well, if there is separation into two cases, then there is a rule in another place which contradicts this. So this argument of trying to pit one principle against another to see whether they are consistent or not – maybe this prepares you for logical or mathematical thinking.

I: Is it some sort of axiomatic approach?

M: It is not so much axiomatic as the fact that all the time you raise issues of inconsistency and validity. This forces you into logical thinking.

I: Many of the early set theorists were Jewish …

M: Robinson [Abraham Robinson (1918-1974)] was, Fraenkel was, but Cantor [Georg Cantor (1845-1918)] was not despite the fact that he introduced Hebrew letters into sets. Not everybody was Jewish.

I: Many problems in set theory originally came from mainstream mathematics, but nowadays set theory seems to be developing in its own direction away from other areas of mathematics. Is there any danger that research in set theory is becoming a closed circle or an intellectual game for its own sake?

M: First I should say it is not an intellectual game as you call it. Like many subjects there is always a tension on the one hand between the original motivation and the problems where it merges into [on the other hand], and then you start developing the subject by itself and generate its own problems. But then many times in the development, somehow you go back to those problems and shed new light on them. It is very natural and there are many things in, for instance, analysis which merge with mathematical physics. Let's go back to history. When Riemann [Georg Bernhard Riemann (1826-1866)] was doing Riemannian geometry, he didn't think at all that it has anything to do with physical space and now it turns out to be a good model for general relativity. Then there is something in differential topology in dimension higher than 4 and it has something to do with mathematical physics. Some things develop on its own track but then you find some applications. I'm pretty sure in set theory this happens as well. There is a very interesting connection between large cardinals and the structure of the real line; there are potential connections with other fields.

I: Are there any direct applications of large cardinals outside set theory?

M: Not right now but there could be. There are some problems in mathematical economics where the theory becomes more streamlined when you use large cardinals. That doesn't mean you must have the large cardinals but they make things more smooth and so on. I'm not saying this is very common but that could happen in the future. In mathematics you never know; things which look remote from applications could eventually have applications.

I: Some people think that the foundations of mathematics should be based on category theory rather than on set theory. What is your view on that?

M: Category theory is a very important theory. It is really a language for expressing a lot of things, but I think it will be very difficult (of course, I admit I'm biased) to base mathematical results completely without talking about sets and elements and just considering morphisms between structures. You can't avoid talking about elements of sets altogether. It will also be intrinsically difficult. Let me give you an example. Suppose you think about the category of groups. You want to identify groups which are isomorphic, really what you care are the morphisms of groups. You have a collection of direct products, let's say, which can be defined in set theory but not in category theory. How do you prove that the category of groups is closed under products? Not every category has a product. The only reasonable way is to say, well, the groups are made of elements and then you look at the Cartesian product of groups and so on. It will be

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very difficult to base mathematics, especially the teaching of mathematics solely on category theory. I'm not saying that it is not important or that it should not be studied. It gives you a very effective language for many, many things.

I: But apparently category theory does not give rise to contradictions or paradoxes you get in set theory.

M: The way it's done in axiomatic set theory (Zermelo-Frankel Set Theory) we do not know of any contradictions.

I: Has mathematical logic contributed any new breakthrough in artificial intelligence?

M: I don't think there is sophisticated methodology [in artificial intelligence] but in the general framework of mathematical logic, it is very important. You try to model reasoning, the way people draw conclusions from assumptions. Mathematical logic provides quite a good mathematical model for this. I don't think you could have any kind of attempt to imitate that process without any model. That is a very important contribution of mathematical logic. It does not necessarily mean that the mathematical model you use for reasoning in the mathematical domain is the same one you use for everyday reasoning. It may be a different model, but basically you try to give a model for drawing conclusions from assumptions.

I: Apparently artificial intelligence is now based more on a computational basis.

M: Based on computation, but the point is, for any computation you need a model, a conceptual model – what are you trying to compute? You try to describe what you are trying to compute. You have some facts and you try to draw conclusions from them. So you try to compute; you are trying to imitate the process of drawing conclusions from your computations. I think that mathematical logic provides the right model of analysing this.

I: I believe that your work on non-monotonic logic has some influence on computer science. Please tell us briefly what non-monotonic logic is and what kind of applications your work has had on computer science.

M: Non-monotonic logic, I think, is a bad term. I use it because really what you are trying to do is everyday reasoning or common-sense reasoning rather than monotonic [reasoning]. The reason you specify monotonic is because everyday reasoning does not have the property of monotonicity. What do I mean by monotonicity? In formal mathematical reasoning, when you have a set of assumptions then you draw some conclusions, and now somebody comes and add more assumptions. The previous derivation is still valid. For instance, you prove something about groups and somebody comes along and tells you that the group is abelian, say. Then the general theory of groups is still true. In everyday reasoning it is not really so. You see a doctor, you probably have a cold. He gets extra information; he may decide it's something else. It changes the conclusion and it's not valid anymore. So everyday reasoning or common-sense reasoning is not monotonic in that sense. Adding assumptions can change the conclusion. You try to use monotonic logic in common-sense reasoning, you try to model this process of review. In other words, part of this contribution to logic is essentially the way of analysing the many systems of logic in everyday reasoning. I think you base the construction of expert systems on such kind of things and potentially there are more applications.

I: You mention expert systems. These were introduced quite some years ago. Are there any new developments in that area?

M: I must say I'm not an expert. I just follow these things but I think it's needed in the major developments.

I: Just now, you also mention about adding something extra to the assumptions. How do you know that the extra assumptions that you add may not contradict the existing assumptions?

M: Some of them do. There is a theory of revision, which was done in collaboration with some colleagues. You get some information that contradicts some things before. How do you revise the original theory? It's a different logic.

I: So the model keeps changing in that sense. It's almost empirical, isn't it?

M: It's not really empirical. The empirical thing is representing things that are actually happening. It represents the way people reason. You try to build a model, an intellectual, conceptual, mathematical model for reasoning. It is no

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different from, for instance, physical theory. You make a theory; you test it in practice.

I: You were President of the Hebrew University from 1997 to 2009. That is, by any standard, a remarkably long period of administrative service at a very high level. This is rather exceptional for a mathematician. Was it by choice?

M: I didn't look for it. I did some administrative job. I was chairman of the department. Every person is expected to be chairman or vice-chairman of teaching for a number of years. It's part of the duty. In the United States some people make a career of it, but that's not the way in Israel. Then I was made the dean of science. I did it for a number of years. I was actually on sabbatical leave in the United States after being the dean. There was a search for president going on and they asked me to come for an interview. I said that I was not interested but somehow I went to the interview. Very quickly they decided I was the candidate. I have stepped down as president for two years and was concerned about my research. I found that it was not too bad. We have had physicists, economists, medical faculty as presidents. The present president is a historian. The university is very complicated and diverse. You have to satisfy the politicians and an independent board of governors. We have a very large group of donors from around the world. All universities in Israel are independent. But we get a major part of our money from the government. They give you money based on the number of students and your research output. We also get our own by fund raising, from donors and from our own commercial activities. The government has some control but not completely. For instance, it is completely up to the university to decide what to do with the money, whether we want to have more students in physics than in medicine or something like that. It will affect the money you get from the government.

I: How did you manage to reconcile the rigor of your logical thinking with the inconsistencies and incompleteness of the real world that must have manifested during your years as President?

M: That's a very good question. It is not that exceptional for a mathematician. Hebrew University was established in 1925. I was the tenth president. Out of the ten, three have been mathematicians. There were two analysts. [Selig] Brodetsky was an applied mathematician and mathematical physicist. [Ammon] Pazy was an analyst in operator algebras. There is some kind of tension between mathematical thinking and the way administration thinks because you have to be satisfied with solutions which are not so absolute and sharp as in mathematics, not clear cut, not so acceptable to mathematics. There is also another issue. If you have an administrative job, especially if you run a complicated operation like a university, it is a fact that you don't have time to give attention to any particular problem. In one day you have to deal with multiple issues. In mathematics, maybe you spend a day, a month or a year on one particular problem. You don't have that luxury in the presidency. You have to separate mathematical work from administrative work. But there is one thing in mathematics that helps you in administration. It's a fact that mathematics trains you not to fudge things. You have to make things very sharp and very clear. But sometimes you can't do so in administration. Many times an issue comes up; people say it can't be exactly like this, so you start asking questions. In some cases you try to get a clear definition of what people want. What do you mean by that? I give you a very simple example. When you ask people the question, "What is the size of your faculty?", people give you an answer, some number. But you think about it mathematically, what do you mean the university has 1,300 professors? You mean full-time, tenure track, adjunct professors? Your mathematical training directs you to start asking questions and makes it very sharp. Sometimes this helps you in administration. So it's a matter of finding the right balance between, on the one hand, being satisfied with or accepting things which are vague and, on the other hand, in some cases you try to clarify things to the very last detail. I hope I managed to do it to some extent.

I: At one time nonstandard set theory appeared to be a promising alternative approach to present classical analysis and some other areas of mathematics. Why has this not been generally accepted?

M: I don't know a good answer to that. The reason is basically whatever you do in nonstandard analysis you can eliminate it later and do without it. You can replace a nonstandard proof by a standard proof. Sometimes the [nonstandard] argument is more intuitive. I don't know the explanation why it is not more common. Let me just say, since you mention nonstandard analysis, now there is a connection with non-monotonic logic. Together with my partner, we introduced nonstandard probability theory

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into a model of everyday reasoning. For instance, suppose you say, you have this assumption and you are very likely to have this conclusion. One way of saying this is that the probability of the conclusion following from the assumption is very close to 1. How close to 1? You mean, 90 percent, 95 percent, 97 percent? A particular number doesn't make sense. So we suggested that a good model (an intellectual, conceptual model) is to say that what you are really talking about is the integration of the probability of failure is very close to zero, an infinitesimal. So you say the conclusion almost follows from the assumptions if the probability of failure is infinitesimal. It's an intellectual, conceptual model. It doesn't mean that in everyday life you really do it. In some sense, if there is any physical theory that is an abstraction of reality, then the nonstandard theory in probability theory gives you a good abstraction of the way people reason about things being very likely or very unlikely. I think it gives a very good model for this.

I: I believe that nonstandard analysis was also used not just in mathematics but in other areas like hydrodynamics.

M: Robinson did something in hydrodynamics. There is an intuitive appeal [with nonstandard analysis].

I: Just a wild thought. I don't know whether nonstandard analysis could be applied in turbulence.

M: Well, maybe. In a sense you try to get the idea of something very small, not completely zero but very, very small. Of course, in classical mathematics, you talk about limiting processes. But originally when Newton [Isaac Newton (1642-1727)] or Leibniz [Gottfried Wilhelm Leibniz (1646-1716)] was thinking about calculus it was in terms of infinitesimals. A coherent theory of infinitesimals is fairly recent.

I: Is there any probabilistic interpretation in your work on non-monotonic logic?

M: Some of the models do have probabilistic interpretation but the most natural one is in terms of nonstandard probability space. The probability values are not necessarily ordinary numbers; they are extended numbers where you have infinitesimals and so on.

I: What about fuzzy logic? At one time there was something called fuzzy logic. Is it the same thing?

M: It's not the same thing. Fuzzy logic is another model in which statements are not proved to be true but somewhere in between. You are not trying to get the idea of "almost true". It is a different model of thought.

I: It is believed that logic is somehow hard-wired in the human brain. Has any new finding in neurobiology led to the formulation of new logical frameworks? If not, do you think logicians should look into this area?

M: That's a very interesting question. I'm not an expert on that. My university has got a very big group of brain researchers; the president initiated a big group on brain research. The model they use now, I don't think that logic is hard-wired in the brain. The model now is based on neural networks. You don't hard-wire a particular way of reasoning, but somehow through experience, the system level adjusts. You talk about neurons connected to each other. What changes is the level of connection between the neurons. You have certain input and certain interaction, and maybe somehow the system converges to a particular way of reasoning. But one should try to think about (now I'm on shaky ground) there might be some previous position for the system to converge to a particular way of thinking, a particular logic. Then there is this philosophical problem. The logic that we do in mathematics – is there something that is wired in our brain? Suppose you talk about a completely different group of people (people who are disconnected but with the same brain). In the mathematics of the Egyptians, Babylonians, Greeks and Chinese, somehow there are connections between their traditions. Suppose that you go to a group of people not connected to them. Will they develop the same kind of mathematics? Another possibility is that there is some philosophical necessity in mathematics. Is there something essential in the particular mathematics that we do? I don't know whether it is hard-wired in the brain or whether there is something physical in the brain prior to traditional mathematics. But definitely I think logicians should look into it. By the way, logic could be hard-wired in the brain in some way close to the Chomskyan idea [Noam Chomsky] based on the structure of language (not any particular language). There is a certain set of fixed linguistic parameters that make you study Hebrew or English or

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Chinese and so on. Maybe something like that could be true of logic. The model they are trying now in brain research is not exactly in this direction. Maybe they should look at this.

I: It would be interesting if there is life on another planet. Will they develop the same kind of mathematics similar to ours?

M: Ok, that's another thing. We were talking about a group of people not connected with any particular tradition: would they develop the same mathematics, the same mathematical logic? Suppose there is another civilization (with a completely different brain structure) will they necessarily develop the same logic? I don't know. I cannot justify it, but somehow I believe it would be very similar to ours – maybe because I'm so attached to a particular logic that I decide that nothing else could exist. Or at least if you look at formal assertions, you know you could define and develop mathematics at a lower level in one way and rephrase it in a different way in a different language.

I: It seems that the study of logic as a subject is somewhat neglected in schools. Do you think that educators should do something about this?

M: I'm not sure. It depends on what you mean by "schools" – elementary school, high school? I think that initially logic studied should not be logic per se, by itself. I don't think learning logic without any subject matter will be very successful. I think you should learn reasoning in whatever you do, whether it is mathematics, physics or even politics . . . you know, what is the correct logical conclusion? Nowadays you learn about reasoning through all kinds of examples. The teacher should at all times be concerned whether they are teaching reasoning or not. One thing I'm troubled by the teaching of mathematics is that in many countries, including Israel, there is a downgrading of (they teach much less) formal geometry, proving things from axioms. Geometry is a very good way of learning about orderly, rigorous reasoning especially if it trains you to get intuition from the pictures but not to rely too much on the drawing. You have to have a good argument even if it is intuitively very convincing. The fact that they teach and study less and less geometry, I think, is a mistake.

I: I think one experience we have here in undergraduate teaching is that somehow the logic of students is deficient. They make very simple errors like converse and so on.

M: There are typical mistakes which people make in logic. People also make mistakes about quantifiers, for instance, understanding the difference between continuity and uniform convergence. But I think the way to teach logic is to study logic only after you have got the examples, and then you say that's the correct way to reason.

Zhouping Xin: Courant in Hong Kong – Shock Waves, Nonlinear Waves >>>

Zhouping XIN

Interview of Zhouping Xin by Y.K. Leong

Zhouping Xin made fundamental contributions to the mathematical and numerical analysis of partial differential equations of continuum mechanics, in particular, nonlinear waves and shock waves.

Xin belongs to the first generation of students to have received a more normal undergraduate education in China shortly after a long academic hiatus brought about by the Cultural Revolution whose revolutionary fervor spanned almost a whole decade from 1966 to 1976. Armed with a bachelor's degree from Northwest University in Xian, China and a master's degree from the Chinese Academy of Sciences (Academia Sinica), he went to Michigan University in the United States for graduate study. Under the suggestion and influence of Joel Smoller, he began a life-long interest in nonlinear partial differential equations originating from continuum mechanics and mathematical physics.

After obtaining his PhD, he went to Courant Institute of Mathematical Sciences of New York University where he became full professor and established a world-wide reputation for his mathematical contributions to the study of shock waves and nonlinear waves. Then in 1995, he was on sabbatical in Harvard University. There he met Shing-Tung Yau who, on learning that he would be in Hong Kong in 1998 for family reasons, suggested that he visit the Chinese University of Hong Kong and offered him the position of associate director of the university's Institute of Mathematical Sciences (of which Yau is the director). Xin took up the offer and the rest, as they say, is history. From 2000 he held a joint professorial appointment at the Chinese University of Hong Kong (CUHK) itself and has been the William M.W. Mong Professor of Mathematics since 2004. His alma mater (Northwest University at Xian) invited him as Chang Jiang Professor from 2005 to 2009.

Xin has built up a vibrant research group of postdoctorals and graduate students in Hong Kong and they collectively made significant advances in his field of applied mathematics. Following the tradition of Richard Courant (who trained a total of 36 doctoral students, of whom 20 were in New York University), Xin has trained and continue to train many graduate students in Hong Kong (30 PhDs, 16 MPhils up to 2015). As S.T. Yau said, his research group "has shown that China can certainly develop advanced level mathematics on our own." In recognition of Xin's efforts, Yau initiated the Xin-Lu Visitorship for young people from China to do research in the Institute of Mathematics, CUHK.

His indefatigable energy in sharing his knowledge is clearly shown in the more than 150 invited lectures that he has given since 1992 throughout the world in North and South America, Europe and Asia. Ever since he moved to Hong Kong, he has kept to a heavily packed schedule of talks in major cities in China from Guangzhou and Wuhan to Shanghai and Beijing. He was visiting professor not only in China but in Europe and the United States. He was the first Hong Kong based mathematician to give an invited address at the International Congress of Mathematicians in 2002. He received the US Presidential Fellowship and Sloan Research Fellowship awards and the Chinese Morningside Gold Medal in Mathematics.

His prodigious collaborative work has produced more than 130 research papers and deals not only with theoretical mathematical analysis but also applications to concrete problems in aerodynamics and fluid dynamics. With his collaborators, he has advanced the understanding of the compressible Navier-Stokes equations, Boltzmann-type equations in statistical mechanics, and made inroads into the phenomena of small effects on large scale structure, stability of shock waves and nonlinear waves and multi-dimensional hyperbolic conservation laws. He gave the first blow-up result of the full multi-dimensional compressible Navier-Stokes system in the presence of vacuum. He and

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his students proved the global well-posedness of classical solutions with large oscillations and vacuum for the isentropic compressible Navier-Stokes system with small energy. With Liqun Zhang, he solved a long-standing problem on the well-posedness of the classical solution of the 2-dimensional unsteady Prandtl's boundary layer system. He and Huicheng Yin made substantial progress on the transonic shock problem of Courant and Friedrichs for a class of curved nozzles with given exit pressure and solved this problem in the 2-dimensional case completely. He also developed a theory for global subsonic and transonic flows in a curved nozzle for potential equations and the full steady Euler system. Their results on nozzle flows have important applications in aerodynamics. He has contributed to the analysis and implementation of numerical methods in fluid dynamics, the most well-known result being the widely used Jin-Xin scheme (developed with Shi Jin) for systems of hyperbolic conservation laws.

Xin gave invited lectures in the Workshop on "Nonlinear Partial Differential Equations: Analysis, Computation and Applications" (3-6 May 2005), which was jointly organized by his Institute and NUS's IMS. In the following year, he was again invited to lecture at the International Workshop on "Multiscale Analysis and Applications" (18-22 December 2006), organized by Institute of Advanced Studies, Nanyang Technological University.

He was back in Singapore for the Conference on "Hyperbolic Conservation Laws and Kinetic Equations: Theory, Computation, and Applications" (1 November-19 December 2010). Then, on behalf of *Imprints*, Y.K. Leong interviewed him on 10 January 2012 while he was at the Institute's workshop for the Winter School on "Multiscale Modeling, Simulation, Analysis and Applications" (12 December 2011-13 January 2012), which was co-sponsored by the Institute of High Performance Computing, A *STAR.

The following is an edited and enhanced version of the interview in which Xin talks about his early beginning at Northwest University in Xian and the Chinese Academy of Sciences (Academia Sinica) in the late 1970s and how he made the crucial decision to relocate from Courant Institute, where he was already well established, to a comparatively new research institute in Hong Kong. In the interview, he exudes an infectious enthusiasm and eagerness to share his passion for his field and work, the effect of which on his research group one is prone to describe in terms of a hydrodynamic metaphor as "a small scale effect producing large scale effects".

Imprints: You obtained a master's degree in Academia Sinica and then went to University of Michigan, Ann Arbor for your PhD. Why did you choose Michigan?

Zhouping Xin: At that time in China, information was not so well supplied. I didn't know much about universities or colleges in the United States. I was told by my advisor Ling Hsiao, who was Professor in Academia Sinica, "Well, I know somebody in Michigan who is doing very well in PDE [partial differential equations]. Probably you should go there." I applied to the school as suggested by my advisor. I didn't know anybody, so everybody is the same. It was a teaching assistantship with full support, and I didn't have to worry about money.

I: What about your master's? What was the topic of your master's?

X: In China, just after the Cultural Revolution I was among the first group of students who went to college. We didn't know much about mathematics research outside. I was studying partial differential equations for chemical reactions and diffusions under Professor Ling Hsiao. It was the fashion at that time. I got a master's degree and then went to the United States.

I: Is Professor Ling Hsiao a mathematician?

X: Yes, she is a very good mathematician in China. She is very nice, and after China opened up, she travelled very often to the United States and Europe for conferences and kept up with all the developments.

I: Were you in the same batch as Fanghua Lin?

X: I think Fanghua Lin went to America a little bit earlier than me. He went there immediately after undergraduate study. When I was a Courant Instructor in Courant Institute, he was already an associate professor.

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I: Who was your PhD advisor and what was the topic of your PhD thesis?

X: At my time the distinction between pure and applied mathematics was not so clear in China and people looked down on applied mathematics somehow. When we were students in China we did as "pure" as possible and I loved algebra and Galois theory and all those things. But I studied PDE because she [Ling Hsiao] said, "You are good in analysis. PDE is probably something good for you." I had no idea whether PDE was applicable or not. Professor Hsiao knew Professor Joel Smoller very well. He is one of the leading experts in Michigan, even right now, in shock wave theory, reaction-diffusion equations and relativity. When I went to Michigan, I had already studied some PDEs. There were many people in Michigan doing applied mathematics. In PDE, I could choose Professor Smoller or Professor Jeffrey Rauch. Both of them were doing some kind of hyperbolic partial differential equations. I found the American system very attractive in the sense that you don't have to study a major actually. It was different from China. I went to study all kind of subjects, topology, number theory, algebra. Actually in my qualifying exam, I did better in algebra than in analysis. Anyway, I decided to study with Joel Smoller. One reason is Professor Hsiao's recommendation. Another thing was that I was getting more and more applied and I began to love applied math. PDE is between pure mathematics and engineering applications and physics. I was very much interested in so-called applied mathematics which was more like mathematical physics. I took a lot of courses from both professors. The first year, Professor Rauch was in France, so I took more courses from Professor Smoller, two on partial differential equations. He said, "Well if you want to study with me, pass your exam and become my student." Professor Smoller gave me some topic, and at that time, his main focus was not on fluid equations but on relativity and elliptic equations. He said I could work on reaction-diffusion equations and elliptic equations, another one on relativity and a further one on shock wave theory, and he said, "I think you should do shock wave theory." That's why I chose shock wave theory. He assigned me a problem, but essentially I chose the thesis topic by myself and didn't work on the problem assigned to me although I did write a paper with Professor Smoller and Blake Temple later on the problem Professor Smoller gave me at the beginning. It turned out to be good for me. Professor Smoller is a great teacher, very encouraging, and has the ability to see whether you are good at something. Whenever you get some result, he would say something positive, and I learnt a lot from him both mathematically and in other aspects. His passion and insights on mathematics always inspire me.

I: You were working mostly on your own, isn't it?

X: I was working mostly on my own. However, I always got encouragement from Professor Smoller. I was working on the nonlinear stability of rarefaction waves in fluid dynamics. I worked very hard and found it very interesting, and that became my thesis.

I: You were in Courant Institute for a number of years before moving to Hong Kong in 1998 and have been there since then. What are the factors that made you take this decision?

X: After I graduated from Michigan, that was a very good time and easy for me to get a job. I applied to several places and they all gave me offers. I was very lucky at Courant Institute with its postdoctoral structure. I was very inclined to broaden my vision and began to read a lot of applied analysis and appreciate applied mathematics instead of being a pure mathematician. The reason is that there were so many superstars in Courant like Peter Lax, Cathleen Morawetz and George Papanicoulou. They were positive in my direction and were, in a way, really my mentors. I was there as a Courant Instructor. I leaned a lot of things, became more mature, began to do research, got tenure and became a professor. Actually, for me, Courant was like my home. I had many friends and collaborators. I learned a lot from my colleagues. They taught me not only mathematics but also mathematical thinking and philosophy. During my 10 years in Courant, it was where I grew up mathematically. Besides one year (I was on sabbatical on a fellowship at Harvard), I was in Courant all those years. For family reasons, I left Courant in 1998 and went to Hong Kong as a visitor. When I was on sabbatical at Harvard, I knew Professor Shing-Tung Yau pretty well and had time to learn geometry from him and hoped to do some relativity. He was the director of the Institute [of Mathematical Sciences] at Chinese University of Hong Kong. He knew I would be in Hong Kong and asked me whether I could visit the Institute for one year. I did and I found out that Hong Kong was good for my family and my kids. That was the main reason I went to Hong Kong.

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Then I found Hong Kong is a very good place, not only for my family but also culturally. It is a unique place that combines oriental and western culture. Even though the Institute is small, it is able to bring in people from both sides easily, westerners can live easily and we can communicate with people from mainland China. We wanted a have a proper place where people can mix very easily. I began to like this place. I was able to bring in my collaborators and postdoctorals and to have my own graduate students. I developed a research group to do my own mathematics. Of course, Hong Kong is nowhere compared to Courant which is a centre of applied mathematics, at least in my field, with so many people from around the world. But Hong Kong is different. I can concentrate on my own things and organize my own group.

I: Are you in both the Institute and the Department of Mathematics?

X: Financially I was completely paid by the Institute but I am also a joint professor at the Mathematics Department. I teach courses at the university and do some duties and committee work. So it's a joint appointment.

I: Your research is very focused on partial differential equations arising in fluid dynamics. What made you interested in fluid dynamics and not in other type of applied mathematics?

X: Well, I don't know what is the precise answer to the question. First of all, I wouldn't say that my main interest is fluid dynamics. I would say that it's more on continuum mechanics. Fluid dynamics is a typical example of that. At the beginning, I think I am an analyst, I want to do classical PDEs – wave equation, heat equation, Laplace equation. Of course, these kind of equations can come from anywhere but one of the most important sources is continuum mechanics – from conservation of mass, momentum and energy. As special cases, you have those special equations. Of course, they could come from geometry and other things. Indeed, this kind of PDE occurs everywhere, like airplanes, tsunamies, weather prediction, music, space shuttles, space satellites and many basic things. I found it really complex and the theory is very deep. In a way you can say that at the early stage of PDEs it is nothing more than fluid mechanics or continuum mechanics. When I was studying the so-called elliptic equations in China, I had no idea where they came from. Later I found that all those equations came from continuum mechanics. If you study subsonic flows, you get elliptic equations. For supersonic jet, you need to know hyperbolic PDEs. I found it really amazing. That is one thing that motivated me. Another thing is that the mathematical theory is very rich and has a beautiful mathematical structure, and very wild phenomena can be modelled by such equations. It is a fascinating thing. Nowadays it is a popular thing to do mathematical modelling. The best example you can learn is from fluid mechanics where you applied your mathematical knowledge to the real world. Even though it's very old, it is still very exciting and challenging for mathematicians. It is a source of problems and produces many PDEs which nobody can solve. The equations from fluid mechanics have wonderful features which do not come from other general equations. I worked on it for more than 20 years now and still find it a very exciting and stimulating. There are so many open problems in the field. That's why in my whole career I still work a lot in this area. Of course, the field is expanding to many other things but this is still the basis somehow. Things like composite materials, elasticity and other things all depend on the original understanding of these equations.

I: The most famous equations seem to be the Navier-Stokes equations and are famous for their intractability to a complete solution. Would it not be good enough just to solve it for physically meaningful cases?

X: That is a very good question. First of all, it's famous because it is one of the seven centennial problems of the AMS [American Mathematical Society] and because of the prize offered by the Clay Institute [of Mathematics]. I think that in fluid dynamics or continuum mechanics, this is only one of these very interesting problems and systems. For mathematicians, it is a mixed type of equations, an elliptic equation coupled with parabolic equations, and we have a lot of tools, harmonic analysis, topological arguments and many things that we can apply. Therefore, it is a bit embarrassing that even though it has a nice structure we cannot solve it globally. This is one of the reasons why this problem is so attractive to many people. Of course, it is also because it is so difficult to solve that there is a prize attached to it. Nowadays every week you hear someone

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to have solved it; of course, it turns out to be wrong. There are many important mathematical and physical problems. The problem mentioned here is only one of them. This is an important system for fluids at low speed. For many fluid motions, the speed is small when compared to sound, so therefore we can approximate the fluid by incompressible fluids. Incompressible fluid is just a mathematical idealization. There is no fluid which is really incompressible. This is only a model the mathematician can work on. You want to get an ideal, beautiful solution, smooth for all time with no singularities developing. Even for incompressible fluid, it is not solved.

I: Has it been solved for 2-d?

X: It's solved for 2-d but not for 3-d. I'm not sure the engineers think this is the most important problem. Even for 2-d, the so-called small scale-large scale structure is still not solved – so-called turbulence, coming from either the physical boundary or because the fluid is very rough. Turbulence is the thing which the engineers, physicists and fluid dynamicists are all interested in. Mathematicians and engineers still have differences in interest. In fluid dynamics, the mathematical progress is far behind the physicist's or engineer's understanding. For compressible fluids, only one-dimensional theory is pretty well understood. For multiple dimensional, even for 2-dimensional, it is completely open except for some special class of weak solutions. For a long time, Leray [Jean Leray (1906-1998)] solved the weak solution problem in 1934, but after that important progress is by people like [Luis] Caffarelli, [Robert] Kohn and [Louis] Nirenberg. These are the so-called partial regularity theorems: if you have a weak solution then the singularity set is not too large.

I: From a simple-minded point of view, mathematically speaking the general case surely cannot have a solution, isn't it?

X: You're right. If you just look at the equation and don't consider the physics, you can produce finite time blow-up solutions. However, these do not have energy conditions or some other conditions. Whether these solutions have any physical meaning is not clear. The real question for this is: suppose my data has all the nice properties, does it have a solution? That's a generic motion.

I: Are there any examples where there is no solution?

X: Are there any examples where there is no solution for fluid equations? No, you always have a solution. The question is what do you think is the solution. For example, the 3-dimensional incompressible Navier-Stokes equation has a weak solution, and the solution is global in time. This was proved by Leray in 1934. The question is whether there is a regular solution. For nonlinear parabolic equations, if you have a weak solution, it can be proved that it is a regular solution in general. This is what people try to do for the 3-dimensional incompressible Navier-Stokes systems. For compressible fluids, things can be more complicated. For the high-dimensional theory, it is very open: you don't even know if there is a solution in the weak sense for the full compressible Navier-Stokes system.

I: Are there any conditions that you can impose so that the solutions are very wild kind of solutions?

X: Yes, that's turbulence. It's difficult not just for mathematical analysis but also for computations. The trouble is that if there is turbulence, there are many, many scales involved. Even the fastest computer right now cannot deal with the large real-time flows. Even for ideal fluids, where there is no friction and so on, these small-scale effects on large scale fluctuations can be very wild.

I: Intuitively, you know there must be a solution. So why do you want to prove that there must be a solution?

X: The physicist and engineers don't think of problems which have no solution; they are interested in the behavior of the solution. The mathematician thinks differently, they ask whether the equation is well-posed, whether a solution exists and whether the solution is unique. This will provide a basic for further understanding of the behavior of the solutions.

I: Physicists often have powerful intuitions that can lead to mathematically fruitful ideas. Has there been any input from physicists or engineers that contributed to the understanding of the Navier-Stokes equations?

X: Of course, the formulation of the problem comes from physicists and they play a very important role in the

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development of physical ideas and concepts, maybe not in the terminology that mathematicians are involved. But in many important things, physicists have the right concepts – entropy conditions, shock waves – all these things come from physicists. Mathematicians take over and as a result, for example, they develop a whole theory of hyperbolic partial differential equations which apply not only to gases and fluids but also to elasticity and relativity. Eventually you come to a set of similar hyperbolic equations which you can apply systematically and which is more powerful than the original equations. This kind of mathematical theory of fluid dynamics is a multidisciplinary area. It needs contributions from analysis, from modelling, from physicists and from computational scientists in a very essential way. Nowadays many things depend on computations. Without computational fluid dynamics you do not have the Boeing 787. The Boeing 767 took more than 10 years to build; the computational analysis played only a small part; most of the time it's wind-tunnel experiment – you put the model in the wind tunnel 77 times. The Boeing 777 was the first to be done mostly by modelling and computation around 1994 and the wind-tunnel experiments were done only 18 times. For the Lockheed Boeing 787 the computation done was more than 60 times than that of the 777. It depended heavily on computation for the material design, wing design and all the construction. So you see, CFD [computational fluid dynamics] becomes really important in aerodynamics – it's the real thing. So everyone says that the computer is everything. It's not true. In the modelling of these schemes, which is the basis of CFD, you really need mathematical understanding, a lot of mathematical analysis involved, even for physical models. Even the one-dimensional mathematical analysis plays an important role in multi-dimensional design. Multi-scale modelling is very important, not only for pure fluids, but also in turbulence. For example, if you have an atomic bomb, there is a shock wave. But, in reality, there is no such shock; mathematical shock is a jump; it is a profile with large changes in pressure gradient or velocity. It's all multi-scale modelling. Away from the shock front, everything is quiet and smooth, but near the shock front, you really need to do very small-scale details. You can do things numerically, but to prove things is very hard. This is very important for material science because in materials you don't have an equation of state whereas gases and fluids have equations of state. For many problems, such as composite material, the equation of state is unknown. You have to do multiscale modelling. At the continuum level, you don't have an equation of state. At the microscopic level, you need statistical description such as Boltzmann type equations, or even more basic molecular dynamics.

I: Were there any surprises, mathematical or physical, that crop up in your work?

X: That's part of the fun of mathematics. As a mathematician, we do not just prove what the physicists believe is right. Of course, we want to do more than that but at the same time we want to find something, even in my own work, which people don't know. Physicists already know but they don't care. Mathematically, these things are important. At the beginning of my career, I tried to study the stability of viscous shock fronts. There was a theory that if you perturb a shock front generically, time asymptotically, you produce a shifted shock profile and scalar diffusion waves in the transversal directions. This theory looks very reasonable based on hyperbolic theory. We tried to prove it without success. Eventually, with my collaborator, we found out that a generic perturbation produces not only shift shock profile with scalar diffusion waves in the transversal directions, but also a coupled linear diffusion wave in the shock region. Therefore it was completely to our surprise. When I told it to my colleagues, they said, "Are you sure it is correct?" We did a simulation and found that it was there. So sometimes analysis can tell you that your intuition is not correct. Recently we tried to study the design of engine nozzles. You get supersonic flow coming to the nozzle and it becomes subsonic by a shock due to the high pressure at the end. Engineers do these things and assume it is correct, and it is one of the problems proposed by Courant [Richard Courant (1888-1972)] and Friedrichs [Kurt Otto Friedrichs (1901-1982)] in a famous book [*Supersonic Flow and Shock Waves*]. Everybody believed this is correct. So the question is which model are you using? People believed in the so-called potential model in which you assume that the velocity is the gradient of a scalar function. We found that this problem is ill-posed and that you have to go to the full Euler equations to get a well-posed problem.

I: What do you mean by "ill-posed"?

X: It means that either there is no solution or if a solution exists, it is not stable.

I: Has your work been applied in engineering or industry?

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Publications >>>

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X: The theory part is far behind the engineering. I also did some numerical methods with Prof Shi Jin of Wisconsin. Now it's called the Jin-Xin scheme. Given a hyperbolic system of conservation laws, we designed a simpler system to get a so-called relaxation scheme. This is very popular now and people are applying them in real calculations.

I: So this is applied. Did you get any royalties from that?

X: No [*laughs*]. It only gives us satisfaction.

I: You have supervised many doctoral students and postdocs. What advice would you give to researchers entering your discipline of research?

X: Obviously, this field is very old but on the other hand it is still very fresh because many of the multidimensional problems which are really interesting are still not solved. There are many challenging problems. On the other hand if you want to do more fashionable applied mathematics, you may move in the direction of biological and medical science or material sciences. It is basic for doing many other things. One advice I think of is that no matter what you do as a mathematician, analysis is still very important. In many cases, so-called intuitions turn out to be wrong because if you do the analysis it can tell you this is wrong. Of course, at the same time, the real physical problem that you are doing should not be just a mathematical problem; you should have the motivation for doing it.

I: The analysis you refer to is classical analysis, isn't it?

X: Yes, classical analysis is still very, very important. For example, the tornado problem can be modelled as a 2-dimensional area-preserving map. You study the area-preserving maps to fluids. A quick computation indicates that there is a singularity. It turns out to be that by just an application of classical harmonic analysis, there is no singularity if no singularity initially. All you observe is just numerical instability considered as physical. Many patterns and shapes are not stable. Over a long time, the round-off errors, even if they are small, could accumulate and produce a mathematical singularity, not a physical singularity. The analysis is beautiful and has significance in what you are trying to understand.

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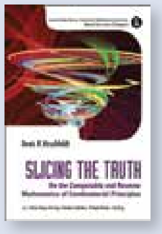

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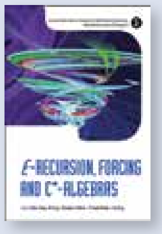

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