IMPRINTS

INSTITUTE FOR MATHEMATICAL SCIENCES

APRIL 2006

# Birthday Celebration for Roger Howe >>>

A Grand Occasion

Roger Howe has had a long and deep connection with the National University of Singapore (NUS). Not only has he served as the Chair of the Scientific Advisory Board of the Institute for Mathematical Sciences (IMS) at NUS since 2000, four of his students are also on the faculty at the Department of Mathematics, including the current Dean of Science. It was therefore befitting that the IMS should organize a conference in Roger's honor on the occasion of his sixtieth birthday. Thus was held the International Conference on Harmonic Analysis, Group Representations, Automorphic Forms and Invariant Theory from 9 - 11 January 2006 at NUS. It was a joyous celebration of the man and his achievements, both as a distinguished scholar and as an exemplary educator.

Roger's major research interest is in applications of symmetry, particularly harmonic analysis, group representations, automorphic forms and invariant theory. The membership citation at his election to the National Academy of Sciences, USA, summed up the importance of his work succinctly: "His pathbreaking contributions to the representation theory of *p*-adic groups and of dual reductive pairs establish him as a principal architect of a theory of central and growing importance. His originality and depth have far-reaching consequences."

Roger is also an exceptional teacher. "If mathematics is a language, you certainly speak it beautifully. Fortunately for those who are not themselves native speakers, you have demonstrated a gift for making fundamental concepts in the structure of mathematics become familiar and intelligible ...." (From award citation when Roger was named William R. Kenan Jr. Professor of Mathematics).

The master and his students: (From left) Steven Jackson, Soo Teck Lee, Jian-Shu Li, Roger Howe, Eng-Chye Tan, Sangjib Kim, Chen-Bo Zhu

For three days in January, friends, colleagues, collaborators and students (these categories being by no means mutually exclusive) of Roger's gathered at the brand new University Hall auditorium on the NUS campus to celebrate Roger's birthday in the most appropriate way – discussing and doing

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## Infinite Prospects of Logic >>>

Infinite prospects

The Institute for Mathematical Sciences organized a logic program *Computational Prospects of Infinity* from June 20 to August 15 2005. The program consisted of two workshops: Set Theory (June 20–July 15) and Recursion Theory (July 8–August 15). For the Set Theory Workshop, 25 participants from 11 countries took part, while for the Recursion Theory Workshop there were 34 participants from 16 countries. In all, 10 graduate students from six countries, including Singapore, attended the Logic Program.

Professors John Steel and W. Hugh Woodin, both of University of California at Berkeley, each gave four tutorial talks, on *Suitable Extender Sequences* and *Derived Models Associated to Mice* respectively. In addition, almost all the participants gave one or two talks. There were also two panel discussions devoted to the broad general topic of the future of Set Theory, led by William Mitchell (University of Florida), John Steel and W. Hugh Woodin, and by William Mitchell and Menachem Magidor (Hebrew University of Jerusalem) respectively. Talks were given by the participants on a wide range of topics: the Omega conjecture, iterated forcing, fine structure theory, combinatorial set theory and determinacy.

In the Recursion Theory Workshop, Professor Rod Downey (Victoria University of Wellington) gave five tutorial lectures on *Algorithmic Randomness* and Professor Theodore A. Slaman (University of California at Berkeley) gave four tutorial lectures on *Definability of the Turing Jump*. Talks ranging from topics in randomness, the structure of Turing degrees, hyperarithmetic theory, reverse mathematics and Ramsey's Theorem were given by participants. A panel discussion on the future of Recursion Theory was also organized. This was led by Carl Jockusch (University of Illinois), Richard Shore (Cornell University), Stephen Simpson (Pennsylvania State University), and Theodore A. Slaman.

The Institute also organized a Math Camp for high school students in June. This was conducted by Professors Woodin and Qi Feng (Chinese Academy of Science and National University of Singapore). A public lecture was given by Professor Slaman in July.

Overall, the participants were very pleased with the Logic Program. Many commented that this was one of the best they had attended, and the visit to Singapore was mathematically rewarding and productive. Outings to Sentosa Island, the MacRitchie Reservoir and a barbeque on the occasion of the Singapore National Day provided much needed breaks from the pressures of mathematical research.

The Organizing Committee of the Logic Program consisted of: Chi Tat Chong, Qi Feng and Yue Yang (National University of Singapore), and Theodore A Slaman and W Hugh Woodin (University of California, Berkeley).

Chi Tat Chong

Cheering for Logic and Computation

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A taste of durian cake

mathematics. Twelve renowned mathematicians in areas of Roger's major research interest, coming from as far afield as Australia, France, Hong Kong, Israel, Japan, Switzerland and the United States, spoke at the conference. In total, the conference attracted 50 participants, of whom 27 were from overseas. Many have had a close professional relationship with Roger, in some cases extending as far back as the 1960s. To add a touch of local flavor, participants, many for the first time, were introduced to the delights of the Durian Cake during the cake-cutting ceremony. It was indeed a memorable occasion!

## "Come Prima" >>>

The Director of IMS, Louis Chen, attended the Pacific Rim Mathematical Forum at the Banff International Research Station (BIRS) in Canada on 14-15 October 2005. It was a meeting of representatives of a number of leading mathematical institutions in the Pacific Rim. The purpose of the Forum was to discuss ways of making well coordinated and concerted efforts to promote and facilitate the development of the mathematical sciences and their applications in the Pacific Rim, with the objective of creating a great impact on the development of science and technology in this region. The representatives at the meeting had been invited jointly by David Eisenbud, Director of the Mathematical Sciences Research Institute (MSRI) at Berkeley, and Ivar Ekeland, Director of the Pacific Institute for the Mathematical Sciences (PIMS) at Vancouver. A joint venture of MSRI and PIMS, BIRS is a center for research workshops. Its Director is Nassif Ghoussoub of the University of British Columbia.

The Forum was chaired by Alejandro Adem, Deputy Director of PIMS. It began with a dinner on 13 October followed by an informal welcome by the Directors of MSRI and PIMS in the Corbett Hall Lounge. The activities of the following two days consisted of presentations by representatives, open discussions, brainstorming and breakout sessions, and two mathematical lectures given by Ivar Ekeland and Gang Tian of Princeton University. The coffee breaks between sessions provided an excellent opportunity for networking and for the participants to get to know one another. By the end of the two-day meeting, many of participants had become more than just acquaintances of one another. Some of them met again at breakfast on 16 October before leaving BIRS.

The meeting was a great success. It agreed to form an organization, to be known as Pacific Rim Mathematical Association (PRIMA), the members of which would comprise mathematical institutes, departments of mathematical sciences and national mathematical societies in the Pacific Rim. A resolution incorporating its vision, organization and action plans was also drafted. Among the actions plans were: (i) organizing summer schools for graduate students in the Pacific Rim, (ii) exchange of scholars, (iii) holding of a Pacific Rim Congress once every four years, and (iv) sharing of benefits of expertise among institutes. With the formation of PRIMA, one can look forward to a more vibrant interconnected mathematical community whose activities should have an unprecedented impact on the development of science and technology in the Pacific Rim region.

More information on PRIMA can be obtained from its website at http://www.primath.org/.

Courtesy PRIMA

## Thanks and Well Done, YK >>>

Regular readers of *Imprints* would have noticed some changes in this issue. YK Leong, the founding editor of *Imprints*, has relinquished his post after rendering distinguished service for the past two and a half years. YK's contributions to the success of the newsletter have been immense. Recognizing the YK's talent, the Director took the decision at the startup of *Imprints* to produce a newsletter that would go beyond merely reporting the goings on at the Institute. Thus was born the interviews that are featured in every issue of the *Imprints* which give the newsletter its distinctive signature. Using a combination of thorough preparation and careful selection of questions, the interviews paint vivid pictures of some top scientists' personal development and engagement with their subjects. They also provide valuable insight into these leading scientists' global views on their disciplines. Many readers of *Imprints* have commented on the remarkable quality of its interviews section. In fact, *Imprints* was one of two items specifically mentioned as a benefit to be shared among members in the founding resolution of the recently formed Pacific Rim Mathematical Association (PRIMA). We are therefore very glad that YK will continue to conduct interviews on behalf of *Imprints*. The Director and I will jointly share the task of attending to editorial matters.

Denny H. Leung

## People in the News >>>

**Award for Roger Howe**
Roger Howe, Chair of the Scientific Advisory Board of IMS, has received the American Mathematical Society's 2006 Distinguished Service Award for "his multifaceted contributions to mathematics and to mathematics education". Our heartiest congratulations to Roger for the most deserved honor!

**New Administrative Officer**
Cindy Tok, an administrative officer of the Institute, left the Institute on 30 September 2005. Her work was much appreciated by staff and visitors alike and we wish her the best for the future. Wendy Tan, who joined the Institute on 26 September 2005, has since assumed the duties.

## Program & Activities >>>

### Past Programs in Brief

### Mathematical Modeling of Infectious Diseases (15 Aug – 9 Oct 2005)

*Website: http://www.ims.nus.edu.sg/Programs/infectiousdiseases/index.htm*

Chair:
Bryan T. Grenfell, *Pennsylvania State University*
Co-chairs:
Stefan Ma, Ministry of Health, *Singapore*
Yingcun Xia, *National University of Singapore*

The program comprised five main themes with breaks in between for interaction and in-depth discussions.

- New development of the SEIR models for the transmission of infectious diseases (15 - 19 Aug 2005)
- Influenza-like diseases (22 - 26 Aug 2005)
- Immunity, vaccination, and other control strategies (5 - 9 Sep 2005)
- Molecular analysis of infectious diseases (12 - 16 Sep 2005)
- Clinical and public health applications of mathematical modeling (26 - 30 Sep 2005)

Modelers of influenza-like diseases: (From left) Yingcun Xia, Lin Yang, Stefan Ma, Valerie Isham, Daryl Daley, Bryan Grnefell, Anthony Kuk, Carlos Castillo-Chavez

### Semidefinite Programming and its Applications (15 Dec 2005 - 31 Jan 2006)

*Website: http://www.ims.nus.edu.sg/Programs/semidefinite/index.htm*

Chair:
Michael J. Todd, *Cornell University*
Co-chairs:
Kim-Chuan Toh, *National University of Singapore*
Jie Sun, *National University of Singapore*

The objective of the tutorial and workshop was to review and discuss recent developments and advancements in theory, applications, algorithms (both interior-point and other methods), and software development of SDP by a panel of experts, as well as to foster the exchange of ideas and collaboration among the participants. The scientific program consisted of a 2-day tutorial and a 3-day workshop, including a panel discussion.

(panelists, from left) Kim-Chuan Toh, Katsuki Fujisawa, Johan Löfberg, Samuel Burer, Tamás Terlaky, Christoph Helmberg, Steven Benson (moderator) Didier Henrion

### Random Matrix Theory and Its Applications to Statistics and Wireless Communications (1 Feb to 31 Mar 2006)

*Website: http://www.ims.nus.edu.sg/Programs/randommatrix/*

Co-chairs:
Zhi-Dong Bai, *National University of Singapore*
Yang Chen, *Centre for Combinatorics, Nankai University, Tianjin, China and Imperial College London, United Kingdom*
Ying-Chang Liang, *Institute for Infocomm Research, Singapore*

The main theme of the program was the applications of random matrix theory to mathematical statistics and wireless communications. Workers in probability, mathematical statistics, mathematical physics and wireless communications were invited to participate in a cross-fertilization of ideas.

A not-so-random gathering

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## Next Program

### Random Graphs and Large-Scale Real-World Networks (1 May - 30 Jun 2006)

Website: http://www.ims.nus.edu.sg/Programs/randomgraphs/index.htm

Chair:
Bela Bollobas, *University of Memphis and University of Cambridge*
Co-chairs:
Khee-Meng Koh, *National University of Singapore*
Oliver Riordan, *University of Cambridge*
Chung-Piaw Teo, *National University of Singapore*
Vikram Srinivasan, *National University of Singapore*

In the last few years, many hundreds of papers have been written studying networks in the real-world and attempting to understand their properties using random graphs as models. Complex networks tend to look very different from classical random graphs. This has led to the introduction of many new (often "scale-free") mathematical models. The development and mathematical study of new models for complex networks is currently a very important area that is still in its infancy. This program will bring together mathematicians, particularly those with experience of classical random graphs, with others working on complex networks, to encourage the development of this new area.

Activities:

**Summer School** (jointly Organized with the Department of Mathematics)

- **Tutorials:** 8 - 19 May 2006
  Speakers – Bela Bollobas, Paul Balister, Svante Janson, Yuval Peres, Oliver Maxim Riordan, Devavrat Shah and Sanjay Shakkottai

- **Seminars and Other Activities:** 22 – 26 May 2006
  Venue: Department of Mathematics, NUS

- **Workshop:** 12 - 16 Jun 2006

- **Public Lectures:** Speaker - J.T. Chayes

## Programs & Activities in the Pipeline

### Algorithmic Biology: Algorithmic Techniques in Computational Biology (1 Jun to 31 Jul 2006)

Website: http://www.ims.nus.edu.sg/Programs/algorithmicbiology/

Co-chairs:
Hon Wai Leong, *National University of Singapore*
Pavel Pevzner, *University of California, San Diego*
Franco Preparata, *Brown University*
Ken W. K. Sung, *National University of Singapore*
Louxin Zhang, *National University of Singapore*

The theme of this program is algorithmic biology: algorithmic techniques in computational biology. The program will bring together researchers in algorithmic biology from a wide spectrum of application areas including, but not limited to, sequence comparison and analysis, microarray design and analysis, whole genome alignment, motif finding, recognition of genes and regulatory elements, motif finding, gene network, phylogeny reconstruction, phylogenetic networks, molecular evolution, computational proteomics, and systems biology.

Activities:

- **Workshop 1:** Workshop on BioAlgorithmics (12 - 14 Jul 2006)

- **Workshop 2:** RECOMB Satellite Workshop on Regulatory Genomics (17 - 18 Jul 2006)

- **Tutorials:** There will also be several tutorials aimed at introducing beginners (especially, graduate students) to algorithmic approaches in several problem domains in computational biology as well as to highlight recent advances.



### Dynamical Chaos and Non-Equilibrium Statistical Mechanics: From Rigorous Results to Applications in Nano-Systems (1 Aug - 30 Sep 2006)

Website: http://www.ims.nus.edu.sg/Programs/chaos/

Organizing Committee:
Leonid Bunimovich, *Georgia Institute of Technology*
Giulio Casati, *University Insubria, Italy, and National University of Singapore*
Lock Yue Chew, *Nanyang Technological University*
Baowen Li, *National University of Singapore*
George Zaslavsky, *New York University*

The following areas would be the core issues of the program:
I. Non-equilibrium statistical physics.
II. Directed and anomalous transport in nano-systems.

Activities:

**Collaborative research:** 1 Aug - 31 Sep 2006

**Conference:** The First International Workshop on Transmission of Information and Energy in Nonlinear and Complex Systems (TIENCS), 1 - 4 Aug 2006

**Tutorials:** 7 - 11 Aug 2006
Recent developments in dynamical chaos and non-equilibrium statistical mechanics.

## Geophysical Fluid Dynamics and Scalar Transport in the Tropics (27 Nov - 22 Dec 2006)

Website: http://www.ims.nus.edu.sg/Programs/geophysical/index.htm

Organizing Committee:
Peter Haynes, *University of Cambridge*
Tieh-Yong Koh, *Nanyang Technological University*
Hock Lim, *National University of Singapore*
Pavel Tkalich, *National University of Singapore*

This one-month program is a small effort to address the dearth of knowledge in tropical dynamics. Over two workshops interspersed by two mini-courses, an international gathering of scientists and applied mathematicians would review recent theoretical ideas on geophysical fluid dynamics (GFD) and scalar transport within the tropics and incubate new ideas. Some or all of the listed topics below will be covered.
I. Hamiltonian and Lagrangian Approach to GFD
II. Simplified Models of Tropical Atmosphere
III. Turbulent Scalar Transport
IV. Chaotic Tracer Advection



### Activities:
**Collaborative research:** 27 Nov - 22 Dec 2006

**Workshops*:**
- Understanding the Dynamics of the Tropical Atmosphere and Oceans, 4 - 8 Dec 2006
- Chaotic and Turbulent Scalar Transport in the Tropics, 18 - 22 Dec 2006

**Tutorials*:**
- Lagrangian and Hamiltonian Approach to Geophysical Fluid Dynamics, 27 - 30 Nov 2006
- Chaotic and Turbulent Scalar Transport, 11 - 14 Dec 2006

* Exact dates of workshops and lecture-tutorials are to be confirmed.

## Braids (14 May - 13 Jul 2007)

Website: http://www.ims.nus.edu.sg/Programs/braids/index.htm

Co-chairs:
Jon Berrick, *National University of Singapore*
Fred R. Cohen, *University of Rochester*

The main theme of the program is the mathematical structure of the braid group, together with applications arising from this structure both within mathematics, and outside of mathematics such as (a) magnetohydrodynamics, (b) robotics and (c) stereochemistry.

### Activities:
**Tutorials:**
Week 1 (4 - 8 Jun 2007)
(a) Braids - definitions and braid groups: Joan Birman
(b) Simplicial objects, homotopy groups (Part 1): Jie Wu

Week 2 (11 - 15 Jun 2007)
(a) Simplicial objects, homotopy groups (Part 2): Jie Wu
(b) Stereochemistry: Kurt Mislow
(c) Configuration spaces: Fred Cohen

Week 3 (18 - 22 Jun 2007)
(a) Magnetohydrodynamics: Mitch Berger
(b) Configuration spaces and robotics: Robert Ghrist

**Conference:** 25 - 29 Jun 2007

**Public Lecture:**
Braids and robotics by Robert Ghrist (University of Illinois, Urbana-Champaign)

# Highlights of other activities

## Workshop on Computational Finance (29 -30 August 2005)

Website: http://www.ims.nus.edu.sg/activities/wkcf/

Organizing Co-Chairs:
Kian-Guan Lim, *Singapore Management University*
Yeneng Sun, *National University of Singapore*

The applicability of financial mathematics in the banking and financial industry in the last 20 years has drawn tremendous interest and participation from both applied mathematicians as well as quants or financial "rocket scientists". The 2-day workshop brought together both academic researchers in all the major universities in Singapore as well as participants from the banking industry. Professor Albert Shiryaev, the

Albert Shiryaev: Predicting stock prices

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Kian-Guan Lim: His credit's not at risk

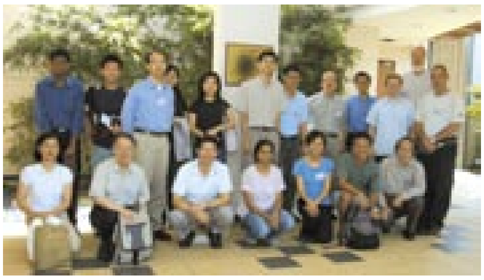
Financing a cup of tea

keynote speaker, gave several interesting characterizations of time predictability of two well-known Japanese methods of technical analyses, namely the Kagi and Renko charts. Other speakers contributed their expertise on a wide range of topics in computational finance.

## Workshop on Genomics (14 - 17 Nov 2005)

Website: http://www.ims.nus.edu.sg/activities/wkgenomics/

Chair:
David Siegmund, *Stanford University and National University of Singapore*
Co-chairs:
Louis Chen, *National University of Singapore*
Louxin Zhang, *National University of Singapore*



A collection of genes posing

The 4-day workshop brought together scientists from overseas and local researchers from NUS departments and Genome Institute of Singapore to interact and exchange

David Siegmund: How to select a model

Nancy Zhang: Maximizing the score

ideas across different disciplines. The workshop covered gene mapping, sequence analysis, evolutionary genetics, and functional genomics. A total of 5 overseas and 8 local speakers delivered lectures. The workshop was attended by 66 participants.

## Figuring Out Life: NUS - Karolinska Joint Symposium on Application of Mathematics in Biomedicine (28 - 29 Nov 2005)

Website: http://www.ims.nus.edu.sg/activities/symfigure/index.htm

Organizer:
Martti Tammi, *National University of Singapore and Karolinska Institutet, Sweden*

This interdisciplinary workshop represented a unique opportunity to further explore the twilight zone between mathematics and biology in the post-genomics era. Lectures were delivered by 5 overseas and 9 local speakers. The 2-day joint Symposium was attended by 34 participants.

## International Conference on Harmonic Analysis, Group Representations, Automorphic Forms and Invariant Theory (9 - 11 Jan 2006)

## On the occasion of Professor Roger Howe's 60th Birthday

Website: http://www.ims.nus.edu.sg/activities/rogerhoweconf/index.htm

Organizing Committee
Jian-Shu Li, *Hong Kong University of Science and Technology*
Eng-Chye Tan, *National University of Singapore*
Nolan Wallach, *University of California, San Diego*
Chen-Bo Zhu, *National University of Singapore*

For details, please refer to the separate article on the conference in this issue of *Imprints*.

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## Mathematical Conversations

# Bryan Grenfell: Viral Visitations, Epidemic Models >>>

Bryan Grenfell

Interview of Bryan Grenfell by Y.K. Leong



Bryan T. Grenfell made important contributions to population dynamics with his pioneering work on the mathematical modeling of infectious diseases like measles and whooping cough, foot and mouth disease in farm animals and influenza of avian, equine and human types. He has done extensive collaborative multidisciplinary work at the interface between theoretical models and empirical data in population biology.

He has worked at York University, Imperial College, Sheffield University and Cambridge University, where he was Professor of Population Biology, before moving to the Center for Infectious Disease Dynamics at Pennsylvania State University in 2004 to become the Alumni Professor of Biology. He has played advisory roles to the British government on the foot and mouth epidemic in 2001 and to the National Institute of Health (United States) since 2002. He is also active in organizational work of scientific meetings. He has served on editorial boards of leading journals in theoretical biology and ecology, and currently of *Public Library of Science Biology*.

His scientific contributions have earned him the T.H. Huxley Medal, Scientific Medal of the Zoological Society of London and Fellowship of the Royal Society. He was also awarded the Order of the British Empire for his services to epidemiology and the control of infectious diseases.

He was chair of the Institute's program (August – October 2005) on the mathematical modeling of infectious diseases and was interviewed by Y.K. Leong for *Imprints* on 24 August 2005. The following is an edited and enhanced version of the transcript of the interview, in which he traced his transition from traditional zoology to his pioneering modeling work in population dynamics on infectious diseases. Here he gives us an insight into the multidisciplinary richness of a fast-growing area that is not only of immediate importance and urgency but also intellectually challenging.

***Imprints:*** Was your original training in zoology a traditional one? How did you get into your present research interest?

***B. T. Grenfell:*** My training was indeed a traditional one. It was a zoology degree in Imperial College, London. I wasn't a great field zoologist or person in the lab, so when we then had a course in the final year on population dynamics in ecology, I seized on it with open arms. I then did a PhD on applied ecology, specifically the application of models and statistics to assessing whale population sizes in the Southern Ocean. For my first postdoc, I worked, again at Imperial, on parasitic worms and childhood infections. I then got a faculty job in Sheffield University and I've worked on infectious diseases since. So the disease theme is since the 1980s.

***I:*** Practically from the beginning, you were already quite theoretical.

***G:*** Yes, reasonably, though I'm a biologist, not a statistician or a mathematician.

***I:*** How old or recent is your field of research?

***G:*** It really goes back to Daniel Bernoulli in the 1700s and then a body of work in the 19th and 20th century on infections like small pox, malaria and measles. The importance of these infections in public health terms and the quality of the data and simplicity of some of the mathematical patterns led people to use statistical and mathematical modeling approaches. I guess we can think of giant figures like Ross, Bartlett, in the 20th century. And in the late 20th century, the importance of infectious diseases that we all know about has led to another explosion in applications of mathematics and statistics in this area. There's been an explosion in disease dynamics work since the late 1970s, catalyzed by the seminal research of Anderson and May. I think it is a very lively field and it melds basic questions and applied questions in fields all the way from mathematics and statistics to immunology, virology, population dynamics and evolutionary biology. So I think it is a very exciting field.

***I:*** So it's really quite an old field.

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*G:* Yes, older than many others in terms of applications of population dynamics.

*I:* In your modeling work on infectious diseases, which came first – the empirical data or the theoretical model? In other words, do you look at the data and then formulate the model, or do you first form an intuitive model with which to compare the data and then subsequently refine it?

*G:* I think the overall answer is that one does both: the model and the data should be very closely linked and co-evolve. A lot of these biological systems, particularly the ones which manifest themselves at the level of interactions between people, are very complex, potentially with many parameters. The more we can tie up by comparing models with data the better. We are lucky that, because of historical notifications for many important diseases, there are sometimes very good data; for measles for example. But I must admit that I often go into the preliminary statistical analysis and so on with an intuitive model, then build a more formal structure.

*I:* Where do you get the data from?

*G:* A lot of infections were notifiable; they had to be notified: measles and pertussis (which is whooping cough) in the UK for example. Today, such incidence data are supplemented by freely available data on the genomic variation of influenza and other viruses. The explosion in molecular genomic data is very exciting.

*I:* Are new statistical techniques needed to deal with the large data sets that you are faced with?

*G:* Definitely; I guess there are there are three parts to the answer. Focusing on our work, we use wavelet analysis to explore highly nonstationary epidemic dynamics in the frequency domain. We then use mechanistic nonlinear autorepressive models to estimate epidemiological parameters. Your colleague Yingcun Xia has done seminal work here. Finally, we are now trying to unify these population dynamic analyses with phylogenetic approaches to viral molecular data.

*I:* It sounds very cross-disciplinary.

*G:* Very, because it blends statistics and mathematics with epidemiology, virology, immunology and evolutionary biology.

*I:* Did you have to pick up the mathematical ideas and techniques on your own?

*G:* Yes, though I've also been very lucky with wonderful technical collaboration.

*I:* Is your field connected with evolutionary biology?

*G:* Yes. Originally a lot of my work was on straight population dynamics. Once you get into influenza, you've got to think about evolution. I'm increasingly getting interested in that.

*I:* Is biology getting more mathematical and statistical?

*G:* I hope so. After the genomics revolution, biologists are very interested in systems biology now, which is the interaction between genes and their products leading to gene regulatory networks. If you have huge networks, you have to have some theory. So I think that the laboratory people are now using dynamic approaches.

*I:* Can computer simulation models be used for predictive purposes?

*G:* Let's imagine the case where you make these models before an epidemic. I certainly think they are very useful for projective purposes. They are very useful for saying, based on our assumptions about how people mix and the characteristics of the disease, what would we project would happen under different control scenarios. I certainly think that it's great to have such complex computer models but you also must have simple models – more reductionist models, just so you can interpret things. Quantitative prediction before a disease has hit is very hard; however, simpler "operational" models, fitted to the early part of an epidemic can be useful.

*I:* Do I understand that they have actually been applied in actual projections?

*G:* Yes; for example, we and others worked on the foot and mouth disease epidemic in the UK in 2001. A family of models was used with a range of level of complexity to project what was going to happen and they tended to be useful in making qualitative inferences about what sort of control policies one might have to adopt. Having a range of models which all pointed in the same direction was useful for the policy makers here.

*I:* Are there any specific models being formulated for the recent SARS outbreak?

*G:* I think if you look at the literature, there's a range of models that have been made by many groups, particularly using the high quality data from the major outbreaks.

*I:* Has any work been carried out to determine whether epidemics play a role in the evolutionary history of birds and animals?

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*G:* Oh, certainly. Again it's not central to my work, but a lot of research has been done by geneticists, for example, looking at how some relatively stable parasites like herpes viruses co-speciate with their hosts, but also the impact of malaria, for example, and its interaction with human genetics. Then, more fundamentally, there's a lot of work on the possible role of parasitism in the evolution of sex for example.

***I:*** Are most epidemics in human history the result of human actions?

*G:* Not in any simple sense, no; though colonization, anthropogenic changes like deforestation can play a role.

***I:*** Are there any models for cross-species pathogenic evolution?

*G:* Not so much models, but I think the biologists are getting closer and closer to understanding the species barrier – why does a virus grow in one species and not in another – sexually transmitted is all we care about. The flu virologists are getting closer to understanding what those barriers are, and that's true for a variety of other viruses as well. But there are still always going to be the big questions to answer, particularly for more complex parasites.

***I:*** Are there any past records, from paleontology say or something, to show that epidemics could have wiped out a whole species?

*G:* I can't think out of the top of my head that there are certain cases like that. What you might expect is that if it is a self-sustaining epidemic in a population of hosts, the epidemic often drops out before the hosts do. But if you have a big population of one species and a small population of another living cheek by jowl with it, and then you have a species jump from the big species and which could continue to jump across, you can then imagine that the small population would be very endangered by the disease. African wild dogs' diseases are certainly a problem in small populations. [The same goes for] gorillas in Rwanda and measles and so on. In small populations, of course, there's always a danger that the disease will just exert back extra toll and wipe the infection out. But I don't know of any example – there might well be one in history of a big population that's been wiped out by its own diseases. Because the disease co-evolves, it often becomes less pathogenic.

***I:*** Are there any models that predict the onset of resistance to certain diseases say in an epidemic?

*G:* You mean things like antibiotic resistance? There are certainly models that people have used to try and understand how the evolution of antibiotic resistance is facilitated by how hospitals are managed or how the development of resistance against drugs which control parasites in farm animals, for example, depend on how the drug is used. Often though, it's direct statistical experimental evidence that's needed there for such models.

***I:*** How much of the models are related to dynamical systems?

*G:* Pretty much all of it. For example, measles is a classical example of a (seasonally) forced oscillator. However, as we add more biology, things become more complex. For instance, measles can go [through] extinction epidemic troughs, implying a discrete state space system. As another complex, spatial heterogeneity and network mixing are often important. However, the very simplest models can still give insights.

***I:*** Do you do consultation work for the government and others?

*G:* For the foot and mouth epidemic, I was a member of one of the modeling groups that advised the government. I also do some advisory work for WHO.

***I:*** Do you have many students?

*G:* In Cambridge, I had a big group. There were 15 or 16 of us – maybe 8 or 9 postdocs and the rest graduate students. Having moved to the US, I'm building up the group again now.

***I:*** What you do is very critical for health control in populations …

*G:* It's certainly got a strong applied aspect, but all the people in this field also do it because the questions are very interesting. I love dynamic processes and spatial processes, and the epidemiology is very interesting in that way.

***I:*** Do you have any advice for people who want to study these things?

*G:* I certainly think it is a growing field and will grow much more over the next decade. There are great problems, wonderful data and great opportunities for people, particularly people with the right technical training in statistics or physics or mathematics. I know a lot of brilliant young people who have jumped across from these fields.

***I:*** Will it be easy for a mathematician who knows nothing about biology to cross over?

*G:* Certainly I have several people that I can think of who've

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# Daniel McFadden: Choice Models, Maximal Preferences >>>

Daniel McFadden

Interview of Daniel McFadden by Y.K. Leong

Daniel McFadden made fundamental and important contributions to behavioral economics in general and to choice theory in particular. He is an active proponent and exponent of the use of mathematics and statistics in solving problems of economic measurement and analysis arising in applied economics. The econometric models that he developed in choice theory have been widely used in economics and other social sciences; for example, to practical problems concerning transportation, choice of occupation, brand of automobile purchase, and decisions on marriage and number of children. He has developed scientific methods for conducting and interpreting surveys on social and economic issues. His numerous publications cover a wide range of areas in economics and econometrics. For his contributions to the development of theory and methods for analyzing discrete choice, he was awarded the 2000 Nobel Prize in Economics, which he shared with Jim Heckman.

Originally trained in physics and having made some innovative hardware contributions in the study of cosmic ray physics while still an undergraduate at Minnesota, McFadden switched to behavioral economics for his graduate studies. After a year at the University of Pittsburgh, he joined the University of California at Berkeley and then joined MIT where he was Professor of Economics, held the James R. Killian Chair and was Director of the Statistics Research Center. He returned to Berkeley in 1991 to establish the Econometrics Laboratory which is devoted to providing and improving computational techniques for applications in economics and of which he has been (except for one year) its director since then. He is currently the E. Morris Cox Professor of Economics at Berkeley.

McFadden has received numerous awards, prizes and honors from scholarly and professional bodies for his research work, among them the John Bates Clark Medal, Frisch Medal, Nemmers Prize, Richard Stone Prize, and, of course, the Nobel Prize . He has been invited to give distinguished lectures such as the Fischer-Schultz Lecture and the Hooker, Smith and Jahnsson Foundation Lectures. He is an elected Fellow of the Econometrics Society and a member of the American Academy of Arts and Sciences and of the National Academy of Science. He has served on the editorial boards of leading journals such as Journal of Statistical Physics, American Economic Review, Journal of Mathematical Economics and Journal of Econometrics. He has contributed his expertise and advice to many professional committees, advisory boards and public bodies. He was President of the Econometric Society and of the American Economic Association.

He was interviewed by Y.K. Leong on behalf of *Imprints* at the Swissotel, Singapore on 20 March 2005 when he was at the Institute to give an invited lecture during the program on semi-parametric methods. The following is an edited but unvetted transcript of the interview which gives us an insight into a creative mind of wide versatility and a glimpse of new interdisciplinary vistas that are opening up in economics.

***Imprints:*** Could you tell us why and how you moved from physics to economics?

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done it brilliantly. Several people – again, Dr Xia for example knew no biology and did some wonderful work. Another postdoc did his PhD in astrophysics on galaxy simulation and now has a faculty job doing epidemic modeling. But, as these people did, you have to be prepared to learn and to realize that biology is complicated and that a key thing is to really get in amongst the data.

***I:*** The mode of thinking in biology is very different …

***G:*** It certainly is. A lot of the ideas are qualitative and you have to respect the fact that the folks who have been in the field or lab for a long time have got a sophisticated model understanding what is going on. As more and more data are collected on dynamic processes, quantitative skills are really important to interpret them. So I think it's a great field to get into. I encourage people to do that.

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***Daniel McFadden:*** A little background on how I had very broad interests as a student in many subjects. I studied mathematics, psychology and physics, but I chose to take my degree in physics. I could have taken it in mathematics or psychology. In physics I was working in an experimental laboratory as an undergraduate and I continued that as a graduate student and started teaching physics right away. But I was only 19 years old. I still didn't know exactly what to do with my life. When an opportunity came to go into very a broad program in behavioral science, I just switched. I didn't think of that as a big change because it's all science and uses mathematical tools. I already had many courses in all these subjects. So it was an easy transition. I moved to psychology really to do psychology, not to do economics. So I began work in this behavioral science program with the intention of getting a PhD in psychology, but I was also very interested in mathematical modeling. I found that mathematical modeling was somewhat at the fringe of psychology. I found that the people in the economics department of my university were closer to my interests. I moved to economics primarily to do psychology using mathematical modeling. This was at the University of Minnesota. It was only after I had done that that I had to take the special economics requirement to write a PhD thesis in economics, which I did, and I thought that economics was very interesting. It was rather an accident that I came to economics, I went through it very quickly – I did all my coursework in one year and I wrote a thesis in my second year. I was still not very knowledgeable about economics when I got my PhD in economics. So that's the background. I don't view it as a big change in career and I think that in the things I do, I would probably have been a successful physicist or psychologist.



***I:*** You actually did some research in physics?

***M:*** I did, I designed an X-ray telescope and it was used in a first demonstration that the aurora borealis was an X-ray discharge. I designed some of the computers that were used in the van Allen satellites. In those days I was very much into the engineering and experimental side of physics. One of the reasons that I made the transition was that I was very interested in psychology and I was also very interested in theory. I thought that I was a better theorist than I was as an experimentalist. So in a way I was more attracted to behavioral science than I was to experimental physics.

***I:*** Did your original training in physics influence the way you look at problems in economics?

***M:*** Very definitely. I learned a great deal about how to be an empirical scientist and I learned a great deal about the interactions between theory and measurements and about testing hypotheses about your theory and keeping the integration of your theory into your empirical work. I've made that one of the themes in my work in economics which is to try to bind theory and measurement close together.

***I:*** Is behavioral economics a science? How does it differ from traditional or classical economics?

***M:*** I say that behavioral economics is a science if by science you mean that there is some theory and there is a measurement method and you use scientific methods to test your theory using the measurements. I think that traditional and behavioral economics have this scientific core, but classical economics is more like mathematics, it is more axiomatic. It takes the principles as self-evident axioms and makes logical derivations from them and then applies them to economic problems. The difference between that and behavioral economics is really the use of experimental evidence in closely tying the axioms you accept to the experimental data.

***I:*** How old or how young is behavioral economics?

***M:*** I think it's actually quite old but it's only in the last decade that there are now enough coherent measurement techniques available that are actually useful. Before, it was recognized that there was a need to do empirical testing of economic theory but the problem was that the classical theory was itself, in some ways, too accommodating. It was too easy to explain data without really getting the scientist to test. In earlier periods, people would talk about the need to look at behavior, and some important work was done by Herbert Simon, for example, to recognize and take a serious look at the limitations of fact and theory. But it was not enough of an engine for developing hypotheses to replace the classical theories. But now I think that due to new measurement tools, it is a very effective device.

***I:*** Is it getting more mathematical?

***M:*** In some ways, it's getting less mathematical and more experimental. I think that in the end there will be a wave of new experimental results and then, at some point this will be followed by a wave of new theory, a new mathematization of the subject, to regularize the wave of new results.

***I:*** Do you introduce ideas and methodology from psychology into your research?

***M:*** I do although I would say that I don't do it in a deliberate way. What I do is that I draw on all the subjects that I know. I find that having a rather broad background gives me access to psychology and other areas in behavioral science. I also studied anthropology, political science, sociology, and, of course, mathematics, statistics. I draw very freely from other subjects that seem appropriate.

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***I:*** How do you perform controlled experiments in behavioral economics?

***M:*** I will give you some examples from current research that I am doing. What we do is to interview people on the Internet and in this particular application we were interviewing elderly people regarding their plans about savings and finance for their retirement and medical expenses. There were also questions about what they have done and what positions they have made. In those surveys we design an experimental treatment into the survey questions so that a given subject will get a randomized treatment. In the design of the experiments, the intention is study things like impact on response behavior of question order and question framing. We find, for example, that in asking people a preliminary question about the probability of having to live in assisted living when they are old, you influence their response to a key question later on when they are asked what positions they have actually made. Based on how you frame a few questions earlier on, you can change people's report about their actual behavior. That's really classic experimental design, and in this case, we find that the questions will make a big difference. Our aim here is to try to improve survey techniques for economic surveys and discover first what are the biases that can recur and secondly, to try to build experimental treatment into surveys in an essential way within a questionnaire.

***I:*** Has any of your models on choice behavior ever been applied on a big scale by large business or national organizations? Are the results as predicted by theory?

***M:*** The answer to that is that they are widely applied. The model that I am best known for is the multinomial logit model, which is, in fact, not really original to me. I think there were some other things almost contemporaneous in the literature. The reason my particular version of that model became popular, initially among the economists, is that I showed how you could use the estimation of that model to derive preference maximization. You could draw inferences about people's tastes from the empirical model. That made it popular among economists. But that model is a pretty elementary model. What I did in the 1960s was that I also wrote software to estimate it. In those days there was no good software for statistical analysis. One of the reasons that the model became popular is that I provided a way to actually use it to test the estimator. But now what happens is that that particular kind of model is almost as common as linear regression. And like linear regression, it is sometimes used very badly and produces some very bad results. But sometimes it's quite useful for forecasting purposes. When I first developed it, one of the first applications I made was to transportation planning, predicting demand for transportation alternatives.

***I:*** Were you commissioned to do the modeling or did you do it on your own?

***M:*** I did that on my own, but I took advantage of the fact that there was research money available in the area because there was a new system under development. I was able to use the existence of that new system to get funding for a large project. Well, that original application in transportation has continued. Some of the most common uses of my methods continue to be in transportation. For example, in Paris and Hong Kong, it is used systematically, as I understand it, as an operational management tool to do things like real-time traffic management. I think it is also used for traveling planning. It's just a physical model – they are not using any deep theory. Like generic statistical tools, I don't have a single way of using it – people use it as they wish.

***I:*** If you have patented those methods, it could have brought in some money.

***M:*** Some people have told me that if I had patented it, I could have become wealthy. But I have a different philosophy. In everything that I do, I make it a point of giving it away freely. I'm a member of the open software philosophy, so all my software is openly available to everybody.

***I:*** Are your methods part of the standard material in books?

***M:*** Certainly in econometrics books, yes. They are standard procedures within most statistical packages.

***I:*** In your research on behavior of choice, is there any finding that you consider to be counter-intuitive?

***M:*** I would say that the most counter-intuitive thing that I have found (this is not my personal research but by a group of people in this area) is the finding that relatively high level economic decisions which seem to be a very complex cognitive activity involving a lot of learned activity and so forth seem to be tied to very primitive pathways in the brain – very direct connections to rewards in the brain. So you get the phenomenon that, for example, people will respond to play in lotteries or economic games in ways which seem to be very primitive, very fundamental in terms of their positions within the structure of the brain. That, to me, is very surprising. I would have thought that economic decisions would be very broad, high-level, dispersedly processed things but instead it is said that there are direct connections between economic decisions we make now and probably the earlier evolutionary development in humans of the pathways developed for reward or avoiding risk. It explains some of the strongest anomalies in economic behavior – the asymmetry between how people make judgments about

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gains and losses, the willingness of people to be altruistic and to trust other people. Some of these things are quite anomalous in terms of classical economics but when they study the pathways to reward in the brain, it corresponds exactly to economic behavior.

***I:*** Could you tell us something about the Econometrics Laboratory of which you are the director?

***M:*** My laboratory is primarily a service laboratory. My view of applied econometrics is that in the past, one of the limitations in economics has always been the difficulty of processing the large data sets collected. Economic data that is traditionally collected tends to be very large scale, like census data. Traditionally, economists are hindered in their ability to work with these; they had limited computers and limited skills. When I established this laboratory, my intention was really to provide a good background facility for economists to do large-scale empirical work and to use computationally intensive methods in econometric analysis. That's largely what we do. We have very large file servers, high powered computers and we service the large community of economists at Berkeley. Within the university, the laboratory is pretty open – certainly open to all members of the departments and students. When people not within the university need high powered computation, I try to accommodate them.

***I:*** How often do you go back to your farm or ranch?

***M:*** I have a little farm, about one hour's drive from Berkeley. I go there every weekend. When I'm there, I work very hard in my vineyard and garden. To me this is refreshing. I grew up on a farm. Before I left for college, I worked very intensely on the farm. When I was young, I thought I would – I didn't plan to be a farmer because the work was too hard – I thought I would be doing something related to farming, like being a county agent. I always said that. Now I enjoy being back on the land.

***I:*** When you are back at the farm, do you still think about your scientific work?

M: I do, yes. My own experience is that if you actually sit at a desk and try to prove theorems, sometimes you just go slower and slower. It's very hard to be completely linear in developing mathematical results. Sometimes I find that if I put a problem down, go out and work hard physically, then either in the following working or when I wake up the following morning, the solution is there. I don't think it (farm work) slows me down at all; it probably helps me scientifically.

***I:*** Can you say you have found some insights into your scientific work while you were working on the farm?

***M:*** Definitely; not because of the farm work I'm doing, but simply because, at least for me, when I'm trying to prove a theorem that is difficult or challenging, I often have to do it almost subconsciously. I have to work very hard to prepare my brain and then to make the final connections, I almost have to walk away from the problem and then the pieces come together. And the farm is a good place for that.

***I:*** Are you optimistic about the economic behavior of human beings?

***M:*** I'm certainly optimistic about our ability to study behavior. Behavioral science has made great advances – a lot of good tools are available and computers allow us to build better models. We have learned a great deal about experimental techniques and from doing experiments. Game theory is becoming an important empirical tool, it used to be primarily a theoretical tool. Empirical game theory is becoming very useful, and there are now very strong interactions between economics and biology (brain science). It raises the possibility of doing experiments in which we use biological treatment (hormone treatment) as an experimental device to study behavior. I think this is a marvelous opportunity to learn how the mind works.

***I:*** Has anybody actually tried to make connections between certain type of economic behavior with certain activity in the brain?

***M:*** Yes, very definitely. It's not my own research, but I have followed with terrific interest the work of Ernst Fehr at the University of Zurich. He's doing experiments in which people are administered particular hormones and then asked to play an economic game, some kind of ultimatum game, which involves trust. It's a game where the Nash solution – you don't trust anyone – is expected to be played but, in fact, people do not play the Nash solution. What he finds is that by changing the level of hormones in different treatments, you can drastically change the way people play this game. It is a striking demonstration of a direct link between buffer brain chemistry and human behavior – altruistic behavior, trust, social behavior.

***I:*** Is psychology becoming physiologically related?

***M:*** Well, I think it's becoming so, very strongly. I think that's a powerful scientific advance because it gives you so many more possibilities for good experiments.

***I:*** In some sense, it's also a bit pessimistic that you cannot run away from certain aspects of the brain's malfunction.

***M:*** It does suggest that there is a lot of chemistry involved in our tastes and in our behavior, and to some extent, the

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# Albert Nikolaevich Shiryaev: On the Shoulder of a Giant >>>

Interview of Albert Nikolaevich Shiryaev by Y.K. Leong

Albert Nikolaevich Shiryaev is well-known for his important contributions to probability theory, mathematical and applied statistics and financial mathematics, and in particular, to statistical sequential analysis and optimal stochastic control. He has published more than 160 main scientific papers and is the author or co-author of numerous definitive books and monographs in those fields.

He has received numerous prizes and awards such as the Markov Prize, Kolmogorov Prize, Humboldt Research Award, Honorary Fellow of Royal Statistical Society and honorary doctorates from Freiburg University and Amsterdam University. He has served and continues to serve on the editorial boards of many leading journals in probability theory, statistics and mathematical finance. He had been president of the Bernoulli Society, the Actuarial Society of Russia and the Bachelier Finance Society.

Shiryaev has a long and illustrious career at Moscow State University (as professor since 1970, head of the Probability Department since 1996 and Distinguished Professor since 2003) and at the Steklov Mathematical Institute (head of the Laboratory "Statistics of Stochastic Processes" from 1986 to 2002). Even at the present age of 71, retirement is not on his cards.

When Shiryaev was at the Institute to give keynote lectures at the Institute's workshop on computational finance, Y.K. Leong interviewed him for *Imprints* on 26 August 2005. The following is an edited transcript of an unusual interview which gives us some insights into the scientific legacy of the legendary A.N. Kolmogorov (1903 – 1987), probably the last great universalist of the 20th century. Shiryaev may be considered to be the successor and upholder of the Russian tradition in probability theory established by Kolmogorov.

***Imprints:*** When did your attraction to probability theory

Albert Nikolaevich Shiryaev

begin? How did you choose the topic for your doctoral dissertation?

***A.N. Shiryaev:*** Before I explain how I chose probability as my specialization, maybe I should say how I became a mathematician. When I was in secondary school, I had many interests. I had a strong interest in sports – I played soccer, I did figure skating and for some years I took lessons in ballet. Twice I danced with the ballet group in the Bolshoi Theatre – my instructress worked in the Bolshoi Theatre. At the same time, because of my relatives, I had an interest in rocketry. I lived in Moscow near the famous rocket center and my uncle's father and many others worked in this place. Also I had a strong interest in a diplomatic career and many times I visited the Moscow Institute of International Relations, but finally, of course, I decided to become a mathematician. I participated in different kinds of Olympiad and finally when I got a medal in secondary school, I entered Moscow State University without examination – they accepted me after an interview with the professors.

As a student at the department of mathematics and mechanics, I did not spend much time in mathematics. In some sense, I began to work in mathematics only after five years of university. The reason was very simple. At that time, the ski coach of Moscow University invited me to be a member of the downhill ski team. I was in very good physical condition and very quickly, after three years, I was the champion in Moscow, and in 1957 I even participated in the Second International Winter Universiade in Grenoble. There were 42 participants and I was placed number 4 and number 7 in slalom and giant slalom. For the Russian people, it was quite good because at that time our country was not very well-known in that sport. So, for three years, I spent a lot of time skiing instead of attending lectures. But at the end of the last (fifth) year, I wrote a diploma paper and it was a good piece of work. Then after many conversations,

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chemistry is heavily involved in the mind's function. On the other hand, if you look at it positively, what it suggests is that if we understand our own chemistry, there is a possibility that we can control it, hopefully for the good. This line of research raises some deep ethical issues. If one learns how to manipulate the brain and manipulate taste, it raises the ethical issue of whether one should do that or want to do that.

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A.N. Kolmogorov finally said to me, "I want to take you as a member of my department at the Steklov Mathematical Institute, but you must select either sports or science."

I was already 23 and not very young for sports; so I decided to stop my active sports life and work in Kolmogorov's department. Kolmogorov gave me many problems and after one year of work I wrote my first paper with my friend Victor Leonov on the technique of calculation of cumulants. Very soon Kolmogorov directed me to some applied problems. As a result, I wrote several papers on the quickest detection problem. The first paper was entitled "The quickest detection problem of the spontaneous effects" and this paper became very popular and many people used it and referred to it. D. Siegmund and B. Yakir, who are here, wrote a lot of papers on problems of that type, very often referring to my paper. After two or three years, Kolmogorov said to me, "You already have all you need for your dissertation." So shortly, I wrote my dissertation, and after that, I took the examinations. It was a little bit of an "inverted" situation. Usually you prepare for and take the examinations in mathematics, languages, philosophy and so on before you do the dissertation, but mine was an "inverse" story.



So I defended my (candidate) dissertation, and in my work for the dissertation, I solved some optimal stopping problems in the Markovian setting. It turned out that stochastic calculus was very important for these problems and I began to work very actively in this direction. I organized special seminars in the Steklov Institute and they were very popular for many years. We published our proceedings and as a result more than 50 of my students defended their theses effectively. They are not "PhD" theses in your sense. In Russia, we have two dissertations – the "PhD" dissertation and then the "Doctor of Science" dissertation. Generally, out of 10 who wrote the first dissertation, only one will go on to write the Doctor's dissertation.

As a result, I published a book on optimal stopping rules – two editions in Russian, and one translation into English for Springer. I also wrote with my pupil Robert Liptser books on stochastic processes and our main interest was in non-linear filtering. At that time we realized the importance of the theory of martingales, and we worked actively in this area. As a result, we also wrote a little book on the theory of martingales and with my French co-author Jean Jacod the book *Limit Theorems for Stochastic Processes*. I began to work in the Steklov Institute in 1957 and I am still its member.

***I:*** Were you also a member of the mathematics department of Moscow University?

***S:*** Yes. Kolmogorov attracted me to Moscow University simply for his lectures on probability theory. He was in both places – Moscow University and the Steklov Institute. He was chair of the department of probability in Moscow University. After him the chair was B. Gnedenko. Now I am the chair of that department. It is a very big department. Every year we accept more than 50 students for specializing in probability, and we have two groups of students – one for probability theory and the other for actuarial and financial mathematics. In 1994, I began to work in financial mathematics and was probably the first to give lectures on financial mathematics in Moscow University. I wrote a big book, published here in Singapore, on *Essentials of Stochastic Finance*. This was reprinted five times and is popular. Recently, the second Russian edition has been published, and World Scientific has asked me about the second English edition, but I have no time because I am writing several books, one book with my colleague from Denmark Goran Peskir on optimal stopping free-boundary problems, another book with Ole E. Barndorff-Nielsen on change of time and change of measures, which will be published by World Scientific.

***I:*** Was your Russian book on financial mathematics the first book published on the subject in Russia?

***S:*** It was first published in English, and it was the first book on financial mathematics published in Russia. Even the great Russian newspaper *Izvestia* published good reviews of the book, and they said that it was important for the development of the Russian economy. At the same time that I was working on the book, I was involved with several publications and books about Kolmogorov. Before the death of Kolmogorov in 1987, we published three volumes on the selected works of Kolmogorov. I was involved in it and I felt that I had to do it. Now we plan to publish six volumes of his selected works: the first volume embraces the papers by Kolmogorov in mathematics and mechanics, the second on probability theory and mathematical statistics, the third on the theory of information and the theory of algorithms, the fourth about mathematics and mathematicians, and we have plans to publish also volumes 5 and 6.

***I:*** Are the complete works of Kolmogorov published?

***S:*** Not all. Of course, not. In fact, the archives of Kolmogorov belong to me in some sense. Kolmogorov's widow wrote in a testimony that all the archives of Kolmogorov's work belong to me. I must say the following. Two years ago, in 2003, we had a very big conference dedicated to the centennial of the birth of Kolmogorov. I was essentially involved in its organization, and we published before this conference three books related to Kolmogorov. The first volume consists of two parts: the first part is the biography of Kolmogorov written by me (more than 200 pages) and the second part is a bibliography of his work (mathematical papers, papers in encyclopedias, textbooks and papers for secondary schools and so forth). The second volume is a big volume on the

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correspondence between Kolmogorov and Paul Alexandrov, the creator of general topology. They were friends and had a very interesting correspondence with a lot of mathematical visions. Finally, the third volume is very interesting – it's the diary of Kolmogorov. Practically nobody had seen it before. I found the diary in Kolmogorov's country house. So we published it and now I want to propose to World Scientific to publish an English translation. The diary is very interesting and unusual – he began to write the diary when he was 40. At the beginning, Kolmogorov wrote the following: that he dedicated his diary to his 80th anniversary in the hope that he will understand what he wrote in his forties. In this book, you will find a lot of interesting pages. One page is of the following type – "what I must do to be a great person". Of course, he wrote this ironically. I want to show you an interesting page – his future mathematical plans.

***I:*** How many years did the diary cover?

***S:*** Not too much – two to three years. Here it is very detailed. But later he wrote, not very periodically – his plans on what he should do from 44 to 53, from 54 to 63, etc.

***I:*** Did he follow his plans?

***S:*** Yes, surprisingly, surprisingly. For example, everybody was surprised why he practically stopped working in mathematics after 60 when he started working for secondary schools. But he wrote this down and he planned it. He "predicted" that he should work in this area.

***I:*** Did he stop working completely in mathematics after 60?

***S:*** Of course, he worked in mathematics, but he spent a lot of time writing textbooks on algebra and geometry for secondary schools. He organized a special school and a journal for students of 15-17 years of age and with special abilities in mathematics and physics. He worked and gave classes like the usual teachers.

***I:*** Was it in Moscow or all over Russia?

***S:*** It was in Moscow but the boys and girls were from different cities in Russia. Even students from Moscow may not be selected. They were specially selected by local or All-Union Olympiads.

***I:*** Was Kolmogorov a good lecturer in schools?

***S:*** It's a bit difficult to say. In fact, his manner of speaking was very fast. Very often he jumped and omitted intermediate steps. It was his usual style, and many people said that it was very difficult to follow him.

***I:*** It must be very interesting working with Kolmogorov.

***S:*** It was, of course, very interesting but it was not simple. It was definitely clear that if you did not work very successfully, he would lose interest in you. In some sense, you should be at a good level and have initiative and as a result we had to spend a lot of time mathematically when we were young.

***I:*** Were you very close to Kolmogorov personally?

***S:*** Of course, I know Kolmogorov personally very well. When I began to work at the Steklov Mathematical Institute together with my friend Victor Leonov, Kolmogorov asked us to be his informal secretaries. We attended his lectures and wrote lecture notes for students. As a result, we lived practically two days every week in his country house. We skied with him, and later, I had a car and we visited many Russian cities because Kolmogorov had a vast knowledge of Russian icon art. He knew a lot about Russian churches and the details about their construction and so forth. Communication with him was not very simple because often you have the feeling that there was some kind of screen between you and him. You always feel that in front of you is a brain which works continuously and it was amazing that at the same time he has the ability to think about different topics.

***I:*** You must have felt tense.

***S:*** Yes, at all times you would feel the tension. He was so "non-trivial" that you could not say some trivial thing. He knew music very well – also literature, poetry, archaeology, history, geography. He had a fantastic memory, especially for geography, history and so on. You know that his beginning was very unusual – his mother died two hours after he was born. His father was killed during the civil war, and essentially, his mother's sister brought him up. When he was 5 years old, he made a lot of unusual observations. He discovered, for example, that $1 + 3 = 2^2$, $1 + 3 + 5 = 3^2$ and so forth. I asked him how he understood those things. It turned out that his solution was purely geometric. He also solved the following problem when he was only 5 years old: Suppose you have a button. You can fix it to the coat if the thread goes through at least two button holes. The question is: in how many ways? He arrived at an absolutely correct answer. He was only 5 years old. From the beginning, he had a strong mathematical ability.

***I:*** Nobody taught him?

***S:*** No, he did it all by himself. When he was 12 or 14, he studied mathematics at a very high level, reading mathematical texts in encyclopedias and trying to reconstruct the proofs. So he began very, very early to do mathematics.

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***I:*** Nowadays mathematics is so wide and highly specialized and yet Kolmogorov did so many fields.

***S:*** Two years ago, we had a conference with the title of *Kolmogorov* and *Contemporary Mathematics*. We had six sections in which Kolmogorov worked: dynamical systems and ergodic theory, theory of functions and functional analysis, theory of probability and mathematical statistics, mathematical logic and complexity, turbulence and hydrodynamics, geometry and topology. He wrote a lot of papers in all these areas and he essentially created many fields. He is the father of modern probability theory. Even the topological notions in cohomology were introduced by him. In turbulence, there is a famous law called the "two-thirds law" of the type of Newton's laws, and it is his contribution. He introduced the notion of complexity which gives the possibility of applying probability even to non-probabilistic objects. The notion of complexity is the crucial clue. I remember that before the organization of the Kolmogorov conference, I was thinking about getting money for the organization. At one point, I asked Microsoft for money and they gave the money, saying – "Yes, Kolmogorov! It's very important in complexity, mathematical logic, computing…" I also asked money from Boeing and they also gave us money (because of turbulence of Kolmogorov).



***I:*** Do you think that in the future somebody can be like Kolmogorov, versatile in so many fields and with so much impact?

***S:*** It's hard to say. In some sense, it is difficult to predict that we will have a person of the following type. Let's look at the "encyclopedic mathematicians" [universalists] – Poincaré, Hilbert, von Neumann, Kolmogorov. It's practically very difficult to give another name.

***I:*** What about Norbert Wiener?

***S:*** He was broad, but I think Kolmogorov worked in many, many different areas. We know Wiener's work in filtration, interpolation but Kolmogorov did that before him. Wiener wrote in his books I am a mathematician and Ex-prodigy that Kolmogorov discovered it a little bit earlier. Wiener, of course, did something in probability – he introduced Wiener measures and the properties of the so-called Wiener trajectories, but in some sense they were particular cases. Kolmogorov was very wide and he was great in the creation of new concepts like complexity in mathematics. Probability space, conditional probability and expectation belong to him. I wrote that if we take a Russian mathematical encyclopedia, we find Kolmogorov axioms, K duality, K integral, K criterion, K inequality, K space, K equation, K-Smirnov criterion, K-Chapman equations. If you take any encyclopedia on probability and mathematical statistics, you will find Kolmogorov axiomatization, K self-similarity, K law of two-thirds, K criterion, K matrix, K model, K distribution, K statistic, K law of five-thirds, K self-similarity, K spectral theory.

***I:*** Did Kolmogorov ever meet von Neumann?

***S:*** Yes, von Neumann gave the opening talk at the Amsterdam Mathematical Congress and Kolmogorov gave the last talk. They had a very short conversation. As I understood, it was not a very long discussion. As for Wiener, Kolmogorov met him in Moscow, but with Wiener it was a very strange story. When Wiener arrived he made a call to Kolmogorov and said, "I want to meet and have a talk with you." Kolmogorov said, "Please come tomorrow at six o'clock." And Wiener came but at six o'clock in the morning. [Laughs] For us it is clear that it must be 6.00 pm.

***I:*** Could the Kolmogorov "phenomenon" be a result of the Russian system and environment?

***S:*** It is difficult to say. In some sense, he was a genius from the beginning. When he was a student of Moscow University, the mathematical school of Lusin flowered and many well-known mathematicians appeared at that time – Lusin, Khinchin, Kolmogorov, Novikov, Petrovskii and many others. It was a special period when the Moscow mathematical school understood that the methods of the theory of functions are very important. In some sense, Kolmogorov said that his success in the creation of probability theory was based on the understanding that the theory of functions and theory of measures play a very important role. Kolmogorov was not a member of the Communist Party but the high-ranking leaders of the Party realized how great Kolmogorov was.

***I:*** The Soviet government appreciated and understood the value of Kolmogorov …

***S:*** Yes, exactly. In the Soviet Union, the highest decoration for anyone is the Order of Lenin. It was awarded to Kolmogorov seven times for his contributions and work in mathematics. There is a famous international story: in 1940 when we had a person called Lysenko who wanted to close genetics down. But at that time Kolmogorov wrote a paper about the brilliant confirmation of Mendel's laws. Politically, it was very dangerous but nobody arrested him. In the beginning of the Second World War, Stalin asked Kolmogorov to begin work – not military work, but work related to the defense force. By the way, two years ago, there was a conference entitled Mathematics and war. They invited me and I wrote a paper about the defense work of Kolmogorov during the Second World War.

***I:*** It was not classified work? The Russian government allowed it to be published?

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***S:*** It was a mathematical problem. In the beginning of the war, we had in Russia many light small planes. Suppose we use these planes for bombing and it is necessary to predict where the bombs will land. It depends on the velocity and so on. It was necessary to create ballistic tables for bombing. Kolmogorov did it by himself and he discovered the following interesting phenomenon. Suppose you have a bridge and want to destroy the bridge. Usually we would want to hit the center of the bridge. But Kolmogorov discovered that, in fact, it was necessary to create an "artificial" bombing. You would try to aim at one point, but he said, "No, it's not correct. Sometimes it is necessary to try to hit here or try to hit there." In other words, it is necessary to create an "artificial deviation". It was the beginning of much work of this type and he created the tools for this work.

***I:*** It seems that the Russian system of education is very successful in developing problem-solving skills. What is it due to?

***S:*** In some sense, it is true. The basic reason is that Russian mathematics has a very good tradition in the secondary school education and in the universities. We had a lot of great mathematicians who created many different schools of mathematics. Kolmogorov created the school of probability theory, Petrovskii created the school of differential equations, Novikov and Markov created the school of algebra and mathematical logic, Pontryagin created the school of continuous group theory and after that, he worked in the theory of optimization (the Pontryagin maximum principle). And simply, we have great people who created scientific schools and they were related to the education in the universities.

It reminds me of the following. At the end of the Second World War, Lysenko or Stalin (I don't know exactly who) said that science is the enemy of randomness in the sense that science is trying to make order in everything. But the representative of the philosophy school began to attack probability theory, saying that probability theory investigated the notion of independence, but everything in the world is related, and so the notion of independence is nonsense. They then said that Kolmogorov's department of probability is dealing in idealism. Kolmogorov was invited to the conference, and there was a discussion about independence and randomness. And Kolmorogov told them. "Let's take the government lottery. The randomness that you will win is guaranteed by government. Suppose that it is not true. Then it means that the government creates unfair lotteries."

***I:*** Your faculty is called the "Faculty of Mechanics and Mathematics". For us, mechanics and mathematics seem to be a strange combination …

***S:*** It's theoretical mechanics. We have in this faculty two sections. One section is in mathematics, and it is clear what they are doing. The other section is in mechanics; they are doing turbulence, hydrodynamics, elasticity … – in some sense, partial differential equations with applied aspects. They investigate what the form of the airplane should be, how it depends on the velocity and so on, but by using mathematical methods. They have some part of the engineering aspects, but it's mainly the theory.

***I:*** Do you consider yourself to be an applied probabilist now?

***S:*** No, of course, not. I remember that at a banquet after defending my doctor's dissertation, several people proposed toasts. One person said that Shiryaev was a probabilist, Another said that he was a statistician, another said he worked in applied probability. But Kolmogorov said, "We are mathematicians, and if you are a good mathematician, you should be able to solve any problem – theoretical problems, applied problems and so on." Now I am doing financial mathematics, but I don't work directly in the bank or for the banks. Simply, we understood that financial mathematics and financial engineering give rise to a lot of new theoretical problems, and we are trying to solve them. In the coming conference on Monday and Tuesday, the talks will be exactly about this.

***I:*** But now you are more interested in financial mathematics.

***S:*** Not exactly. I think it will be very bad if I will concentrate only in financial mathematics because, first of all, around me there are a lot of students, and as head of the department of probability, I should have a good orientation in many different theoretical aspects. I cannot give them only problems in financial mathematics because I must think about developing probability theory as a science and developing mathematical statistics as a science. From some point of view, financial mathematics is now very attractive because of its many new problems and more job opportunities. It is also necessary to mention not only financial mathematics but also actuarial or insurance science. In Russia, I was the president of the Actuarial Society for four years, and so we began to work in this direction. It's true that our students were able to get good salaries after university. That is, of course, important, but in some sense it is a pity that a lot of our good students leave Russia to continue their education mainly in the United States and England. Many of them got jobs in the United States and other countries.

***I:*** Is your department doing anything to retain your talents and encourage them to stay in Russia?

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***S:*** It's a very difficult question. I know that several people have returned to Russia, but look, you have young people going to the United States for their dissertation and it is a period when they begin to have families, children, houses, and life is life. So they continue to stay in those places. But I know several cases, not young people, who retired in Russia. But now, it is not easy to get good positions in Russia. For example, our Steklov Mathematical Institute is very small. It's a good institute; in some sense, it's like the Institute for Advanced Study in Princeton. We are doing theoretical work and we are proud to be members of this Institute.

***I:*** How many members are there in the Steklov Institute?

***S:*** We have 12 departments in the institute and about 120 research members. They are permanent members. We have practically no visitors. I worked in the Steklov Institute all my life and I am very happy. The Institute belongs to the Academy of Science and if we ask for a new position for a good young person, usually we get it.

***I:*** What do you think of the future of mathematics in Russia?

***S:*** Of course, we want to continue the good Russian tradition in mathematics. I want to say that our administration of the Academy of Science, for example, is trying to do it. Who is the president of the Russian Academy of Science? Academician Yu. Osipov who is a mathematician. Who is director of the Steklov Mathematical Institute? Academician V. Kozlov who is vice-president of the Academy of Science. Who is the rector of Moscow State University? Academician V. Sadovnichy who is also a mathematician. They have a lot of power and they are trying to preserve the tradition, not only for mathematics but in Russian science. As a result, we have a good administrative group for mathematics. Of course, they are doing a lot of things for many other fields, but I think that it is a positive point for preserving the good Russian tradition in mathematics. Also, many academic people paid a lot of attention to education in secondary school and in university. This is to keep the good Russian tradition. That is why, for example, in the 40s and 50s, mathematics in Russia was good. For example, Kolmogorov worked purely in research in the Academy of Science and at the same time worked for education in Moscow University. Good scientists in research at the same time gave lectures and seminars at the universities. As a result, students get a good opportunity in understanding in which direction it is necessary to work. There is consolidation and interplay between the Academy of Science and education. This is very important and, in some sense, it increases the possibility of keeping our good Russian tradition in mathematics.



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