The cover shows the lattice structure of the cubic closest packing and hexagonal closest packing of spheres, with the centres of the spheres marked by the red vertices, and the edges denoting contact between the spheres. These are two of the most effective ways of arranging spheres in space.
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# APPENDICES

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The Centre has now completed its first full year of existence. It has been an exciting and successful period, characterised by rapid developments, increasing staff numbers and burgeoning activity. In May the Centre was officially opened by the Minister for Science, the Hon. Peter McGauran, in a ceremony held in the backyard of 139 Barry Street headquarters, prompting the Minister to quip that this was the first opening ceremony he had performed in a backyard.

In June we were reviewed by the ARC with special emphasis being paid to our efforts at engaging with industry. The interview panel spoke to a number of Chief Investigators, Associate Investigators, Research Fellows and graduate students, and advised us to “maintain our current trajectory,” which was a pleasing outcome.

During 2004 we ran a dozen or so workshops/symposia of varying duration from a single day to more than a week. These are described in more detail within. A Complex System seminar series, started in Melbourne in 2003 has been continued, and expanded to other nodes. This has exposed Centre staff to a number of interesting problem areas, so much so that it has become increasingly important to maintain focus, as there are just so many fascinating and apparently rewarding target areas. It would be inappropriate for me to single out research highlights, as we have continued to work at a very high level across a broad range of Complex Systems areas and applications. Details are given in the body of this report.

Increased interest in Complex Systems is evidenced by the creation of the ARC Network for Complex Systems COSnet, and the Complex Systems Science activity of CSIRO. Many investigators in MASCOS are members of COSnet, and we are developing an association with the CSIRO group.

In October and November I visited the Canada based Pacific Institute for Mathematics (PIMS), the Fields Institute and the German Centre for Key Technologies (MATHEON). I was particularly interested to see how these institutes organised their interactions with industry, as well as their delivery of enhanced research and outreach activities. The industry interactions of the two Canadian institutes was not as large a component of their activities as I had been led to believe, while for MATHEON the reverse was the case. In November the Director of MATHEON, Professor Martin Grötschel and I signed a joint agreement between our two Centres, with our first activity planned to be a visit by Prof. Grötschel in 2005 to give a series of seminars and two industry-focused workshops on Logistics and Supply Chain Planning. That agreement was organised by Professor Ian Sloan, to whom I am most grateful.

This year saw the creation of a joint Fellowship scheme with AMSI (the Australian Mathematical Sciences Institute) which supports the visit of Australian academics to the home institution of a MASCOS CI with whom they have a joint research project. Two such fellowships were awarded in 2004. As part of our outreach activities, we have also created the AMSI/MASCOS lectureship, which funds a national tour of a prominent mathematician to give Public Lectures and research seminars around the country. The first such lecturer was Professor Wayne Getz of the University of California at Berkeley.

Two state governments, NSW and Queensland, became sponsors of MASCOS during 2004, and we are grateful for their support. Dr. Thomas Montague was appointed as our Business/Industry Manager (jointly with AMSI) during 2004, and we look forward to an enhanced level of engagement with industry as a result. I am delighted to see a strong increase in the number of research fellows and graduate students in MASCOS, as well as a welcome increase in Associate Investigators. Associate Investigators are appointed for a calendar year, and each have an active research collaboration with one or more Chief Investigators.
Once again, I have received tremendous support from our Advisory Board, chaired by Mr. Peter Laver, AM, the Executive Committee, comprising Peter Taylor and Peter Hall, and our Executive Assistant, Emma Lockwood. Richard Brak’s excellent redesign of our web site has contributed greatly to our ability to communicate our activities to the world. While 2004 has been a good year, I look forward to an even better 2005.

Tony Guttmann, MASCOS Director, and Martin Grötschel, Director of MATHEON Center for Key Technologies, Berlin, after signing a Cooperative Agreement between the two Centres.
The Centre was established by an ARC grant of approximately $10.9 million dollars over five years to maintain and develop Australia’s research output in the area of Complex Systems. The Centre is comprised of researchers from five institutions: The University of Melbourne, the University of NSW, the Australian National University, The University of Queensland and La Trobe University, as well as the Australian Mathematical Sciences Institute (AMSI).

**FINANCIAL SUPPORT**

The Centre’s two chief sources of income are the ARC grant as described above, and cash contributions from its member institutions. Specifically, the ARC grant provides $2,181,315 per year for the years 2003 to 2007, which is distributed among the Centre’s member institutions taking into account the number of personnel at each institution and expenses incurred in surrendering previous grants. The Centre also generates income through consulting work and State Government support.

Each member institution has made a further contribution, as detailed in Table 1. These funds are then redistributed among the member institutions as above, and according to their administrative function. The in-kind contributions include a percentage of the relevant Chief Investigators’ salaries, office space and administrative support.

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Table 1: Member Contributions 2003 – 2007
MASCOS STRUCTURE cont'd.

STATE GOVERNMENT SUPPORT

MASCOS gratefully acknowledges the support of the NSW and Queensland State Government. The NSW Department of State and Regional Development provides $258,000 over five years, while the Queensland State Government provides $125,000 over five years. These funds are disbursed to The University of NSW and The University of Queensland respectively.

MASCOS Staff and Students at The University of Queensland
OFFICIAL OPENING OF MASCOS’s PREMISES AT 139 BARRY ST, THE UNIVERSITY OF MELBOURNE

MASCOS’s Melbourne premises were officially opened by the Federal Minister for Science, the Hon. Peter McGauran on Friday 14 May 2004.

The function was attended by approximately 80 guests, drawn from academia, business, government and within the Centre.

“Innovative mathematical modelling techniques are now allowing us to gain a deep understanding of processes that were once considered beyond human understanding,” Minister McGauran said.

“Some of Australia’s most highly-regarded and talented mathematical scientists are involved in the Centre. Their work provides economic and social benefits to the Australian community.

“Projects that increase our understanding of meteorology and oceanography, predict long-term environmental problems, analyse financial risk in relation to insurance and control traffic queues are some of the research projects being undertaken.

The new premises, a terrace house at 139 Barry, Carlton, just south of The University of Melbourne’s Parkville campus, currently accommodates MASCOS’s Director, Executive Assistant and several locally-based Research Fellows. As the administering institution, The University of Melbourne had generously provided the Centre with the premises and co-ordinated its fit-out to include a kitchen, a tearoom with overhead projection facilities, a rear yard and balcony access. The refurbishment of the building was overseen by Jen Rippon and Tony Styant-Browne of Anthony Styant-Browne Architect Pty Ltd.
INFRASTRUCTURE CONT'D.

COMPUTING EQUIPMENT

Early in 2003, MASCOS purchased a Beowulf cluster to meet its high-volume computing needs. The cluster, “Fractal”, is located at the General Motors Holden facility at Fisherman’s Bend in Melbourne and is managed on the Centre’s behalf by the Victorian Partnership for Advanced Computing (VPAC).

In addition, ‘Turan’, an IBM e325 server with dual 2.4GHz Opteron processors and 12Gb of memory was purchased late in 2004 to allow for large memory calculations. This has begun to be used for Monte Carlo simulations of polymers and the calculation of series for the Ising model quantities.

OTHER MEMBER INSTITUTIONS

The other member institutions have also provided office space within existing Departments valued at more than $100,000 p.a.

The University of NSW’s School of Mathematics provided space and computing equipment for MASCOS Research Fellows and administrative staff.

MASCOS has been allocated two rooms by The University of Queensland, which are occupied by Research Fellows Hanjun Zhang and Martin O’Hely. All Research staff and PhD scholars have their own desktop or portable computers, which are linked to the Department of Mathematics network. MASCOS’s UQ node has also received in-kind support from the Advanced Computational Modelling Centre, which allows its staff access to its supercomputing and visualization facilities. The University of Queensland also supports MASCOS by providing it with access to the finance and personnel services of the School of Physical Sciences, as well as the services of Faculty computer support staff, without charge.

La Trobe University has provided MASCOS with a large office with four desks for its use.
MANAGEMENT STRUCTURE

EXECUTIVE COMMITTEE

The MASCOS Executive Board is responsible for the day-to-day management of the Centre, subject to
input by the Advisory Board, and the formulation of policies to be applied in the conduct of its
activities. Specifically, the Executive Board is responsible for approving research projects, postdoctoral
fellows, postgraduate students, visitors and other appointees, as well as organizing workshops and
courses.

The 2004 Executive Committee comprised:

Professor Tony Guttmann (Director)
Professor Peter Hall (Deputy Director)
Professor Peter Taylor

Professor Tony Guttmann is a Professor of Mathematics (Personal Chair)
at The University of Melbourne. He is currently Vice-President of the
Australian Mathematical Society (AustMS) and was formerly Deputy
Director (and foundation Interim Director) of the Australian Mathematical
Sciences Institute (AMSI). He is a Fellow of the Australian Mathematical
Society, the Australian Academy of Science and a member of the
National Committee for Mathematics of the Australian Academy of
Science. In 1998, Tony was awarded the Hannan Medal of the
Australian Academy of Science for his research in applied and
computational mathematics and in 2004 the B H Neumann Prize for his
contribution to the enrichment of mathematics education in Australia.

Professor Peter Hall is a Professor in the School of Mathematical Sciences
at the Australian National University. Over the last 25 years, he has
published four books and over 400 papers on mathematical statistics. He
received the Australian Mathematical Society (AustMS) Medal and the
Rollo Davidson Prize of the University of Cambridge in 1986, the
Committee of Presidents of Statistical Societies Award in 1989 and the
Pitman Medal of the Statistical Society of Australia in 1990. Further,
Peter was awarded the Lyle Medal and the Hannan Medal of the
Australian Academy of Science in 1989 and 1995 respectively. He is an
elected Fellow of the Institute of Mathematical Statistics, the Australian
Academy of Science, the American Statistical Association, the
Royal Society of London and the Royal Society of Edinburgh.

Professor Peter Taylor is a Professor in the Department of Mathematics and
Statistics at the University of Melbourne. Prior to this he was based at the
University of Adelaide, where he was the Director of the Teletraffic
Research Centre, which undertakes research and consulting activities for
the telecommunications industry, and of Adstat Solutions, a statistical
consulting group. In 1987, Peter was awarded the William Culross Prize
for submitting the best PhD thesis in the fields of Mathematical and
Physical Sciences and Engineering at the University of Adelaide. He was
invited to the University of Queensland as a Raybould Visiting Fellow in
1995 and held the IBM International Chair in Computer Science at the
Université Libre de Bruxelles in 1999. Peter is the Editor-in-Chief of
Queueing Systems.
ADVISORY BOARD

MASCOS’s Advisory Board is responsible for providing guidance for the decision making of the Executive Board. Specifically, the purpose of the Advisory Board is to provide an end-user’s perspective on the operation of MASCOS, to suggest fruitful lines of enquiry and to maintain and enhance MASCOS’s industry links. In particular, the Advisory Board has assisted MASCOS with its response to its review by the ARC, the appointment of its Industry/Marketing Manager, and the development of its Business Plan and IP Policy, and of promotional material such as newsletters and presentations.

The 2004 Advisory Board comprised:

Mr Peter Laver AM (Chair)
Mr Malcolm Crozier
Professor Tony Guttmann (Centre Director)
Professor Peter Hall (Centre Deputy Director)
Professor Frederick Mendelsohn
Dr William Schofield
Mr Neville Stevens
Professor Peter Taylor (Executive Committee)
Dr John Zillman

Peter Laver is the Chair of the Victorian Learning and Employment Skills Commission. He was previously a BHP senior executive, Chair of the National Board of Employment, Education and Training, and Chancellor of the Victoria University of Technology.

Mal Crozier is a Chief Designer at BAE Systems. He was recently awarded the Clunies Ross Prize for inventing a ship defence missile that can stop and hover midair.

Professor Fred Mendelsohn is a Professor of Experimental Physiology and Medicine at the University of Melbourne and the Director of the Howard Florey Institute.

Dr Bill Schofield was formerly Director of DSTO’s Aeronautical and Maritime Research Laboratory and First Assistant Secretary (Science Policy) to the Federal Government.

Neville Stevens is a Director of National ICT Australia, a consortium chosen by the ARC and the Department of Communications, Information Technology and the Arts to establish the ICT Centre of Excellence. He has also had a distinguished career in the Federal Public Service.

Dr John Zillman is a former Director of Meteorology at the Commonwealth Bureau of Meteorology and President of the World Meteorological Organization. He is currently President of the Australian Academy of Technological Sciences and Engineering.

The Advisory Board met on 1 April and 19 November 2004.
MANAGEMENT STRUCTURE CONT'D.

INDUSTRY / MARKETING MANAGER

Dr Thomas Montague

Tom is responsible for coordinating the Centre’s industry outreach program. This involves seeking industrial, commercial and government research opportunities for MASCOS, and the promotion of its expertise and the advantage and benefits of mathematics research to potential clients. He also assists the Executive Committee with strategic planning, commercialisation, research project management, contract negotiations, compliance and IP issues.

Prior to joining the Centre, Tom was a Policy Advisor to the Victorian State Government, a company director and a Research Fellow in the Department of Ecology and Evolutionary Biology at Monash University.

EXECUTIVE ASSISTANT

Emma Lockwood

Emma is responsible for co-ordinating the day-to-day activities of the Centre’s main office at The University of Melbourne, including the organization of meetings, seminars and workshops, the management of its financial and human resources, the preparation of its annual reports and newsletters, and the development of its administrative policies and procedures. She is also a part-time Honours student in the Department of Mathematics and Statistics at The University of Melbourne.
MASCOS STAFF 2004

CHIEF INVESTIGATORS

Professor Tony Guttmann (Director)
Professor Peter Hall (Deputy Director)
A/Professor Kostya Borovkov (The University of Melbourne)
Dr Richard Brak (The University of Melbourne)
Professor Tony Dooley (The University of New South Wales)
Professor Chris Heyde (Australian National University)
A/Professor Aleks Owczarek (The University of Melbourne)
Professor Phil Pollett (The University of Queensland)
Professor Reinout Quispel (La Trobe University)
Professor Colin Rogers (The University of New South Wales)
Professor Ian Sloan (The University of New South Wales)
Professor Peter Taylor (The University of Melbourne)
A/Professor Aihua Xia (The University of Melbourne)

ASSOCIATE INVESTIGATORS

Professor Michael Barnsley (Australian National University)
Professor Michael Cowling (The University of NSW)
Dr Ben Goldys (The University of NSW)
Dr Frances Kuo (The University of NSW)
Professor Ross Maller (Australian National University)
Professor Alex Novikov (University of Technology Sydney)
Dr Thomas Prellberg (Queen Mary, University of London)
Professor Liqun Qi (Hong Kong Polytechnic University)
Dr Andrew Rechnitzer (The University of Melbourne)
A/Professor Wolfgang Schief (The University of New South Wales)
Professor Colin Thompson (The University of Melbourne)
Dr Darryl Veitch (The University of Melbourne)
Professor Matt Wand (The University of NSW)
A/Professor Rob Womersley (The University of NSW)

PROFESSORIAL FELLOW

Professor Ian Enting (The University of Melbourne)

ARC CENTRE FELLOWS

Dr Iwan Jensen (The University of Melbourne)
Dr Hanjun Zhang (The University of Queensland)

AMSI/MASCOS FELLOWS

Dr John Roberts (The University of NSW)
Dr Michael Stewart (The University of Sydney)
MASCOS STAFF 2004 CONT'D.

RESEARCH FELLOWS

Dr Boris Buchmann (Australian National University)
Dr Ming-Yen Cheng (Australian National University)
Dr Nathan Clisby (The University of Melbourne)
Dr Andre Costa (The University of Melbourne)
Dr William Cruickshank (The University of NSW)
Dr Josef Dick (The University of NSW)
Dr Jan de Gier (The University of Melbourne)
Dr Nick Dungey (The University of NSW)
Dr Ryan Elmore (Australian National University)
Dr Q Thong LeGia (The University of NSW)
Dr Alexander Meister (Australian National University)
Dr Kassem Moustapha (The University of NSW)
Dr Robert Parviainen (The University of Melbourne)
Dr Peihua Qiu (Australian National University)
Dr Christian Rau (Australian National University)
Dr Alvise Sommariva (The University of NSW)
Dr Theo Tuwankotta (La Trobe University)
Dr Celine Vial (Australian National University)

CENTRE PhD SCHOLARS

Mr Ben Cairns (The University of Queensland)
Mr Yao-Ban Chan (The University of Melbourne)
Mr John Dethridge (The University of Melbourne)
Mr Benjamin Gladwin (The University of Queensland)
Mr Zhi Jun Guo* (The University of NSW)
Mr Kirk Hampel (Australian National University)
Mr Mohammad Hosseini-Nasab (Australian National University)
Mr Terence Jegaraj* (The University of NSW)
Mr Ming Li (Australian National University)
Mr Allan Motyer* (The University of Melbourne)
Ms Ana Novak (The University of Melbourne)
Mr Reza Pakyari (Australian National University)
Mr Nathan Pearce* (The University of NSW)
Ms Maya Ramakrishnan (The University of Melbourne)
Mr Joshua Ross* (The University of Queensland)
Mr Antony Stace (The University of Queensland)
Mr Kevin Sun* (The University of NSW)
Mr Robert Taggart* (The University of NSW)
Mr Ben Waterhouse* (The University of NSW)

OTHER POSTGRADUATE STUDENTS

Mr Khanhav Au (Australian National University)
Mr Zaeem Burq (The University of Melbourne)
Ms Priya Dev* (Australian National University)
Mr Nicholas Denman (The University of Queensland)
Ms Wendy Ensink** (The University of Melbourne)

*Commenced in 2004
** Completed in 2004
MASCOS STAFF 2004 CONT'D.

Mr Peter Fox (The University of Melbourne)
Mr Will James (The University of Melbourne)
Ms Olena Kravchuck (The University of Queensland)
Mr Paul Leopardi (The University of NSW)
Dr David Odell** (The University of Melbourne)
Ms Judy-anne Osborn (The University of Melbourne)
Mr Mark Seeto (The University of Queensland)
Mr Bernard Wong (Australian National University)

HONOURS/VACATION STUDENTS

Mr Reagan Chai (The University of Melbourne)
Mr Allen Chung (The University of Melbourne)
Mr Michael de Graaf (The University of Melbourne)
Mr Nick Denson (The University of Melbourne)
Mr Andrew Downes (The University of Melbourne)
Mr Nathan Jackson (The University of Queensland)
Ms Caitlin James (The University of Queensland)
Mr Jeffrey Li (Australian National University)
Mr Allan Sly (Australian National University)
Mr Thomas Taimre (The University of Queensland)
Ms Xiao Win Wang (The University of Melbourne)
Mr Han Zhang (The University of NSW)

INTERNATIONAL VISITORS

Soren Asmussen (University of Aarhus)
Andrew Barbour (University of Zurich)
Tony Cai (University of Pennsylvania)
Raymond Carroll (Texas A & M University)
Vydas Cekanavicius (Vilnius University)
Anyue Chen (University of Greenwich)
Robert Conte (CEA Saclay)
Sylvie Corteel (Universite de Versailles)
David Cox (University of Oxford)
Massimo Cutaia (University of St Gallen, Switzerland)
Percy Deift (New York University)
John Essam (The University of London)
Rolf Grigorieff (Technical University of Berlin)
David Gurarie (Case Western University)
Moshe Haviv (The Hebrew University of Jerusalem)
Willy Hereman (Colorado School of Mines)
Joel Horowitz (Northwestern University)
Martin Jacobsen (University of Copenhagen)
Iain Johnstone (Stanford University)
Kee-Hoon Kang (Hankuk University of Foreign Studies)
Maurice Kleman (Universite Pierre et Marie Curie)
Anthony Krzesinski (University of Stellenbosch)
Javis Pik Ying Lai (The University of Hong Kong)
Guy Latouche (Universite libre de Bruxelles)
Douglas Lind (University of Seattle)
Jeremy Lovejoy (Universite Bordeaux)
Ruyun Ma (Northwest Normal University, China)
Yoshihiko Maesono (Kyushu University)

*Commenced in 2004
** Completed in 2004
MASCOS STAFF 2004 contd.

Klaus Miescke (University of Illinois at Chicago)
Adriano Montanaro (University of Padua)
Guiseppe Mussardo (SISSA/ISAS)
Byeong Park (Seoul National University)
Allan Pinkus (Technion, Israel)
Anthony Quas (University of British Columbia)
Svetlozar Rachev (University of Karlsruhe, Germany)
Vladimir Rittenberg (Bonn University)
Richard Samworth (University of Cambridge)
Edna Schechtman (Ben Gurion University of the Neger)
Ho Hoi Sheung (The University of Hong Kong)
Gordon Slade (University of British Columbia)
K M Tamizhmani (University of Pondicherry)
Kangrong Tan (Kurume University, Japan)
Nick Trefethen (University of Oxford)
Dongsheng Tu (Queen’s University)
Stu Whittington (University of Toronto)
Erik van Doorn (University of Twente)

INDUSTRY FELLOWS

Mr Bernard Kachoyan (DSTO, Pyrmont)
Mr David Shteinman (Stamen Paper Pty Ltd)

GENERAL STAFF

Mr John Baldock – Network Administrator (The University of Melbourne)
Dr Bryan Beresford-Smith – Consultant (The University of Melbourne)
Ms Deborah Bordeaux – Administrator (Australian National University)
Mrs Lyn Forsyth – Marketing Consultant (The University of New South Wales)
Ms Jen Holloway – Administrator (Australian National University)
Ms Jane James – Administrator (Australian National University)
Ms Emma Lockwood – Executive Assistant (The University of Melbourne)
Dr Thomas Montague – Industry/Marketing Manager (The University of Melbourne)
Ms Mayda Shahinian – Administrative Assistant (The University of New South Wales)
Ms Maake Wienk – Secretary (La Trobe University)

NEW STAFF IN 2005

The recruitment of outstanding academic staff to assist the Centre with its research program is a high priority. Four of its participating universities have either appointed new staff in 2005 or made firm arrangements to do so:

THE UNIVERSITY OF MELBOURNE

The University of Melbourne has recently appointed Dr Jarek Krawczyk, Dr David Odell, Dr Munish Goyal and Dr Fuxi Zhang as Research Fellows. Their research interests span statistical mechanics, stochastic networks and probability approximation theory. Jarek and David have already taken up their positions, while Munish and Fuxi will commence in April and August 2005 respectively.
NEW STAFF IN 2005 CONTD.

Natasha Boland, Director of Melbourne Operations Research, has been appointed as an Associate Investigator. Natasha’s consulting experience will be of considerable assistance to MASCOS, particularly in developing its industry outreach program.

Dr Andrew Conway, ex-CEO of Silicon Genetics, has been appointed as an Industry Fellow.

Andrew Downes, Paul McCormick, Will James and Alana Moore have been awarded MASCOS PhD Scholarships for 2005.

THE UNIVERSITY OF NSW

The University of NSW has recently appointed Dr Adam Szereszewski and Dr Subramaniam Muragesh as Research Fellows.

Dr John Roberts and Dr Gary Froyland have been appointed as Associate Investigators. John, an AMSI/MASCOS Fellow (see page 69), will collaborate with Chief Investigator Professor Reinout Quispel on research into dynamical systems, while Gary’s operations research expertise will be of vital assistance to MASCOS’s industry outreach program.

THE UNIVERSITY OF QUEENSLAND

Dharma Lesmono, David Sirl and Thomas Taimre have been awarded MASCOS PhD Scholarships for 2005.

AUSTRALIAN NATIONAL UNIVERSITY

Professor Markus Hegland, of Centre of Mathematics and its Applications, Australian National University, has been appointed as an Associate Investigator.

Emma Dowling has been appointed as the MASCOS Administrator at ANU.

MASCOS staff at ANU (from left to right): Emma Dowling, Christian Rau, Chris Heyde, Alex Meister, Ryan Elmore, Boris Buchmann, Natalie Neumeyer, Peter Hall.
INTRODUCTION

Complex systems play an integral role in providing society with a variety of amenities such as the internet, air traffic control, irrigation, robotics, power distribution, telecommunications, defence, manufacturing and finance. They also provide models for ecological and biological systems of all types. It is of pivotal interest to society to have a greater understanding of complex systems and the ability to model and predict their behaviour.

In the ARC’s definition of complex/intelligent systems, the following fields of research are specifically mentioned: system analysis and control theory, mathematical and statistical modelling, system and software engineering, software-hardware co-design, intelligent systems, and communications engineering. The boundaries between these fields are obviously blurred but they may still be thought of as lying along a continuum. This ranges from very analytical approaches, such as those embodied in mathematical and statistical modelling, to very practical approaches, such as those embodied in software engineering, software-hardware co-design and communications engineering. In all these research areas, mathematics plays an essential role as a provider of the modelling language and analysis tools, and as a source of new fruitful ideas.

MASCOS has situated itself toward the analytical end of the above-mentioned spectrum. Its mission has been to stimulate research activity in mathematical and statistical modelling of complex systems, and to encourage the cross-fertilisation of ideas and techniques from different areas of mathematics and statistics and apply them to the analysis of complex systems.

MASCOS’s specific objectives are:

• To formulate and analyse mathematical and statistical models for both natural and artificial complex systems

• To use these models to develop an understanding of the behaviour of these systems

• To incorporate this understanding into strategies for the management and control of complex systems.

MASCOS is multinodal and spread across different mathematical and statistical disciplines. To draw these distributed aspects together, the Centre has defined a number of research themes, specifically chosen because of their impact on knowledge advancement or applicability to industry, and because they are amenable to attack by one or more of the mathematical and statistical disciplines covered by MASCOS.

Those themes are:

• Critical Phenomena
• Monte Carlo Methods
• Dynamical Systems
• Risk Modelling
• Scientific Computation
• Statistical Modelling of Complex Systems
• Modelling and Control of Complex Systems

Below, MASCOS’s progress with respect to each of these themes is described.
RESEARCH THEME 1

CRITICAL PHENOMENA

INTRODUCTION

It is typical of complex systems that situations exist in which they can exhibit gross changes in macroscopic properties as a result of small changes in the nature of local interactions. Such a phenomenon occurs, for example, when a statistical mechanical system undergoes a phase-change, or when an engineering system moves from stability to instability. Such critical changes are important from a practical point of view: the macroscopic properties that determine the utility of the system are often the same properties that undergo a phase change. Also, it is often necessary to answer questions about critical phenomena before an investigator can go on to characterise more complicated system behaviour. For example, an engineer usually needs to know whether a system is stable before its level of performance can be investigated.

Questions about critical phenomena have been approached differently by various mathematical and statistical disciplines. A researcher working in stochastic processes might investigate whether an appropriate model is recurrent or transient, a statistical mechanic may study the emergent behaviour that leads to phase changes, a control engineer will analyse stability, and a statistician might investigate the limiting behaviour of sequences of random variables. Each of these approaches is related, and often they lead to similar underlying mathematical formulations.

The mathematical techniques developed to solve problems in critical phenomena have proved to be exceptionally wide-ranging, and hence applicable to other fields. A specific example is the method of simulated annealing, which has now become a powerful technique in Operations Research. The concept of ergodicity in statistical mechanics has proved fundamental in devising better Monte Carlo algorithms. The transfer matrix technique, first developed in statistical mechanics, has been applied to a variety of problems in condensed matter physics, theoretical chemistry and algebraic combinatorics.

The notion of universality has allowed lattice models to be used to answer computationally intractable problems in lattice field theory, such as the determination of the order of the phase transition of the finite temperature four-dimensional SU(3) lattice gauge theory. An important part of MASCOS's activity is the continuing development and dissemination of powerful techniques applicable to other areas of complex systems. Its co-operative nature maximizes the opportunity for such dissemination to be effective.

A further problem in critical phenomena that relates to MASCOS's other research themes occurs in the study of the change in limiting behaviour of estimators of an intensity parameter as it passes through a critical value. Well-known special cases occur in the contexts of traffic intensity in queueing processes, in epidemic thresholds, in autoregression when passing from stationary behaviour first to a random walk and then to explosive behaviour, and in the neighbourhood of critical values in branching processes. Recent work by one of the Chief Investigators (Heyde) has shown that this limit behaviour can exhibit unusual and interesting properties. A more comprehensive investigation of this phenomenon is likely to prove fruitful.

By making a study of critical phenomena one of its themes, MASCOS focuses a broad variety of expertise from different disciplines onto related problems. In 2004, MASCOS researchers undertook the following projects:

PICKARD RANDOM FIELDS

Ian Enting (Professorial Fellow)

The Pickard random fields are discrete-state lattice models, expressed in terms of a uni-directional growth, which have special solubility conditions that lead to one-dimensional Markov chain behavior in one or more directions. They are studied as tractable models of spatial statistics in
fields ranging from image processing to X-ray crystallography. A particular motivation for our studies is the link between Pickard random fields and the lowest-order case of the corner transfer matrix methods of approximating critical behaviour. A new result is that the Pickard conditions are equivalent to symmetries that induce an additional growth direction. A symmetry classification of binary models has clarified relationships between a number of special solutions of growth models. The symmetry classification provides a possible starting point for higher-order generalisations of Pickard random fields and a stochastic characterisation of the variables occurring in the corner transfer matrix formalism.

ASYMPTOTIC BEHAVIOUR OF RANDOM WALKS AND DIFFUSIONS ON GROUPS

Nick Dungey (Research Fellow)

The broad aim of this project is to investigate the large time behaviour of discrete time random walks, or of continuous time diffusions, on certain groups (including Lie groups but also discrete groups). For example, Dungey has obtained new estimates on the kernels of centered random walks on certain classes of Lie groups. There are interesting connections between the random walk behaviour and the algebraic structure of the group.

SELF-AVOIDING POLYGONS

Tony Guttmann (Chief Investigator), Iwan Jensen (Research Fellow), Christoph Richard (University of Bielefeld) and John Dethridge (MASCOS PhD Scholar)

The exact scaling functions conjectured for the problem of two-dimensional self-avoiding polygons (SAP) have been further refined. A study of perimeter moments has revealed the addition of an additive function of integration, while refined algorithms have permitted the conjectured scaling forms to be subjected to stringent numerical testing.

For three-dimensional SAP, improved algorithms have been developed by John Dethridge and Iwan Jensen to extend the known enumerations very significantly. This work is ongoing. Following the ultimate current refinement of the algorithm, it will be parallelised and run on a large scale state or national facility, respectively VPAC or APAC. The eventual enumerations will then be studied in order to predict the asymptotic behaviour.

LATTICE ANIMALS OR POLYOMINOES

Iwan Jensen (Research Fellow), Andrew Rechnitzer (Associate Investigator) and John Dethridge (MASCOS PhD Scholar)

Lattice animals are of great interest in combinatorics and statistical mechanics, both in their own right and also because of their close relationship to percolation. Jensen has enumerated lattice animals up to size 56 on the square lattice. He has developed a very efficient parallel version of the algorithm for this problem and extended his investigation to the hexagonal and triangular lattices as well as to the case of bond animals.

John Dethridge and Andrew Rechnitzer have proved that the generating function of polyominoes on an anisotropic square lattice is not differentiably finite (D-finite). This proof involves an eclectic mixture of analytical and numerical techniques, and extends an analogous earlier result of Rechnitzer for SAPs.
CRITICAL PHENOMENA CONT'D.

UNIVERSAL AMPLITUDE RATIOS AND SCALING FUNCTIONS IN PERCOLATION PROBLEMS

Iwan Jensen (Research Fellow) and Robert M Ziff (University of Michigan)

Percolation is one of the fundamental problems in statistical mechanics and is of great theoretical interest in its own right as well as being applicable to a wide variety of problems in physics, biology and many other areas of science. Percolation is commonly formulated as a problem on a lattice in which the edges and/or vertices are occupied (or vacant) with probability \( p \) (or \( 1-p \)).

Jensen and Ziff studied bond and site percolation on the square lattice by calculating the perimeter polynomials up to size 35 (bond) and 40 (site). They used these to study the scaling limit of the cluster size distribution and demonstrate that the perimeter polynomials can be used to calculate the universal amplitude ratio \( \Gamma^-/\Gamma^+ \), where \( \Gamma^-/\Gamma^+ \) is the amplitude of the second size-moment in the low- and high-density phases, respectively. They also estimated these amplitudes directly from low-density series (derived from the perimeter polynomials) and high-density series calculated separately to order 51 (bond) and 55 (site).

DIRECTED PERCOLATION

Iwan Jensen (Research Fellow) and John Dethridge (MASCOS PhD Scholar)

Directed percolation (DP) is a specialisation of the ordinary percolation problem to directed lattices. In this case connections are allowed only along a preferred direction given by an orientation of the edges of the lattice. Jensen used generalisations of his recently devised and very efficient algorithm to calculate long low-density series for the average cluster size and other properties of directed percolation on various two-dimensional lattices. He has also extended this work to problems with temporal disorder in which the probability of spreading from a vertex \((t,x)\), (where \(t\) is the time and \(x\) is the spatial coordinate), is independent of \(x\) but depends on \(t\).

THE CORRECTION-TO-SCALING EXPONENT FOR SELF-AVOIDING WALKS

Sergio Caracciolo (Università di Milano), Tony Guttmann (Chief Investigator), Iwan Jensen (Research Fellow), Andrew Rogers (The University of Melbourne), Andrea Pelissetto (Università di Roma I) and Alan Sokal (New York University)

The researchers developed algorithms for the enumeration of self-avoiding walks (a model relevant to polymer science) on various lattices. They have significantly extended the series for the square, triangular and honeycomb lattices including series for properties such as the end-to-end distance and radius of gyration. They undertook a careful and extensive study of the series (supplemented by Monte Carlo simulations) of the correction-to-scaling exponent of self-avoiding walks on two-dimensional lattices. This has laid to rest a long-standing controversy about the value of the correction-to-scaling exponent for two-dimensional SAW, and has highlighted other unexpected properties of the various generating functions.
CRITICAL PHENOMENA CONT'D.

SOLVABILITY OF LATTICE MODELS

Andrew Rechnitzer (Associate Investigator)

Many statistical mechanical models that are simple to describe are extremely difficult to solve. Despite a great deal of effort there are a great number of models for which we know neither an explicit or useful implicit solution. In this work Rechnitzer seeks to explain the reason for this difficulty - by demonstrating that the solutions of certain models lie outside the most common functions of mathematical physics, the class of differentially finite functions.

M-CONVEX POLYGONS

Tony Guttmann (Chief Investigator), Iwan Jensen (Associate Investigator) and Will James (The University of Melbourne)

An exact and asymptotic solution of the number of m-convex polygons has been obtained for \( m = 0, 1 \) or \( 2 \). Extension of this work to \( m > 2 \) is under study. An extension to so-called L-convex polygons has been obtained. A general framework for studying such problems has been developed by James.

LATTICE MODELS OF BIOLOGICAL PHENOMENA

Iwan Jensen (Research Fellow), Tony Guttmann (Chief Investigator), Christoph Richard (University of Bielefeld) and J. Jacobsen (Université de Paris-Sud)

Guttmann and Richard studied the Poland-Scheraga model of DNA denaturation and showed that a proper formulation could display either a first or second order phase transition, depending on details of the model.

A careful numerical study by Jensen, Guttmann and Jacobsen of the stretching of macromolecules such as DNA pinned to a wall has revealed a re-entrant phase diagram for the two-dimensional system. Previous work has failed to see evidence of re-entrance—a characteristic of the three-dimensional system—and we have shown that this is due to our development of much longer enumerations than previous workers.

CROSSING LOOPS, BRAUER ALGEBRA AND THE COMMUTING VARIETY

Jan de Gier (Research Fellow) and Bernard Nienhuis (The University of Amsterdam)

In this project a model of crossing loops which results from the low temperature \( O(n) \) model and is related to supersymmetry was investigated. Surprisingly the groundstate of this model turned out to be related to the variety of commuting matrices, an object studied in algebraic geometry. The model also turned out to be a very efficient computational tool for the multi-degrees of the commuting variety, which were only known for very small matrix dimensions.
CRITICAL PHENOMENA CONT'D.

BOUNDARY INTEGRABILITY, BETHE ANSATZ

Jan de Gier (Research Fellow) and Pavel Pyatov (Bogoliubov Laboratory of Theoretical Physics, Russia)

The spectrum of the Hamiltonian of the quantum XXZ spin chain with open boundaries was determined exactly using a coordinate Bethe Ansatz calculation. The method is unconventional in that the calculation is carried out in the loop representation of the underlying Temperley-Lieb algebra. This project has uncovered two subtleties: (i) a constraint on the parameters, appearing but not understood in the literature, has a natural interpretation in the Temperley-Lieb algebra with boundary generators; ii) the complete spectrum is only obtained by combining two sets of Bethe equations, which are obtained using two different pseudo-vacua. Furthermore, a connection with recent results for the two-boundary sine-Gordon integrable quantum field theory was observed.

BLOB ALGEBRA, SPECTRAL IDENTITIES AND EXCEPTIONAL REPRESENTATION THEORY

Jan de Gier (Research Fellow), A. Nichols (Bonn University) and Vladimir Rittenberg (Bonn University)

An exact spectral equivalence is given between the $U_q(sl(2))$ invariant XXZ Hamiltonian with arbitrary left boundary term and the same XXZ Hamiltonian with purely diagonal boundary terms. This equivalence, and a further one with a link pattern Hamiltonian, can be understood as arising from different representations of the blob algebra (one-boundary Temperley-Lieb algebra). Generically these representations are equivalent, but at exceptional points of the algebra they can possess different indecomposable structures. The main outcome of this study is a simple and well understood central object in the blob algebra, whose indecomposable part leads to degeneracies in the three mentioned Hamiltonians.

SELF-AVOIDING WALKS IN CONSTRAINED GEOMETRIES

Iwan Jensen (Research Fellow)

Jensen studied walks attached to a surface or constrained to a wedge. He has calculated series for bridges (SAWs which start at the bottom and end at the top of a strip). Among other things this has lead to more precise exact lower bounds for the connective constant.

EXACT SOLUTION OF SENSITIZED FLOCCULATION AND STERIC STABILISATION

Richard Brak (Chief Investigator), Aleks Owczarek (Chief Investigator), Andrew Rechnitzer (Associate investigator) and Stu Whittington (University of Toronto)

A directed walk model of the steric stabilisation and sensitised floculation has been analysed with one manuscript submitted for publication. We find that both phenomena can occur depending on the attraction of the polymers to the colloidal particles. This project will continue into 2005.
CRITICAL PHENOMENA CONT'D.

FULLY PACKED LOOPS, EXACT CONJECTURES, AND CRITICAL PERCOLATION

Jan de Gier (Research Fellow), Murray Batchelor (Australian National University), Saibal Mitra (The University of Amsterdam), Bernard Nienhuis (The University of Amsterdam) and Vladimir Rittenberg (Bonn University)

Conjectures for analytical expressions for correlations in the dense $O(n=1)$ loop model on semi infinite square lattices were obtained. This model describes both critical bond percolation and the dynamics of a fluctuating interface. Some of the results can be nicely reformulated in terms of expectation values of correlators of fully packed loop diagrams. For example, an explicit expression for the nest probability distribution function is obtained. Nests are clusters of loop lines that start and end on a connected part of the boundary of a fully packed loop diagram:

Some of the observations have been generalised to include parameters. These play the role of fugacities in the loop configurations, but are transition rates in the related interface model.

ORTHOGONAL POLYNOMIALS, LATTICE PATHS, GREENS FUNCTIONS AND COMBINATORICS

Richard Brak (Chief Investigator)

This project aims to provide a systematic way of calculation orthogonal polynomials associated with lattice path problems. Ratios of these polynomials form the generating function for path models. The Greens function approach permits a systematic method for computing the polynomials if they can be considered a finite perturbation of some simpler, directly solvable problem. In particular it has been shown how to solve the paths in a strip with two interactions as a linear combination of Fibonacci polynomials. There is also a strong bijective combinatorial interpretation of the resulting equations.
A combinatorial derivation and interpretation of the algebra associated with the stationary distribution of the partially asymmetric exclusion process is studied. The derivation works by constructing a larger Markov chain on a larger set of generalised configurations. A bijection on this new set of configurations allows us to study the stationary distribution of the new chain and show that a subset of the generalised configurations is equivalent to the original chain and that the stationary distribution on this subset is simply related to that of the original chain. With this derivation, expressions for the normalisation using both recurrences and path models can be computed, giving results exhibiting classical combinatorial numbers such as $n!$, $2^n$ and the Catalan numbers.

The extend Markov chain for the two site partially asymmetric simple exclusion process. Each marked state is written as the particle configuration with its direction (N,L,R) in each position. The dashed lines show the action of the certain bijection.

MAPPINGS OF SELF-AVOIDING WALKS

The (unknown) number of self-avoiding walks a lattice can sometimes be bounded by the (known) number of walks on a related lattice, by a mapping of walks. This was demonstrated for a variety of two-dimensional lattices. A paper reporting these results will appear in J. Phys. A in 2005.
ASYMMETRIC EXCLUSION MODEL AND WEIGHTED LATTICE PATHS

Richard Brak (Chief Investigator), Jan de Gier (Research Fellow) and Vladimir Rittenberg (Bonn University)

It was recently suggested by Blythe and Evans that a properly defined steady state normalisation factor can be seen as a partition function of a fictitious statistical ensemble in which the transition rates of the stochastic process play the role of fugacities. In analogy with the Lee-Yang description of phase transition of equilibrium systems, they studied the zeroes in the complex plane of the normalisation factor in order to find phase transitions in nonequilibrium steady states. This project has shown that as for equilibrium systems, the “densities” associated with the rates are non-decreasing functions of the rates and therefore one can obtain the location and nature of phase transitions directly from the analytical properties of the “densities”.

AREA DISTRIBUTION OF DIRECTED PERCOLATION CLUSTERS

Robert Parviainen (Research Fellow)

A certain constant related to the area (different from the size) has been shown to be universal in ordinary (undirected) percolation. The universality of the analogous constant in directed percolation is investigated, by mainly counting clusters by area, via

1) Monte Carlo simulations, by a new algorithm based on
2) Transfer Matrix computations for series analysis.

The algorithm is similar to that used for counting clusters with respect to size, but with several complications.

CRITICALITY THEOREMS

Chris Heyde (Chief Investigator)

Criticality seems to be associated with the onset of non-standard limit theorems and long-range dependence. An interesting and statistically important example has been published in the Australian and New Zealand Journal of Statistics.
FUTURE RESEARCH IN CRITICAL PHENOMENA

CRITICAL BEHAVIOUR IN FINANCIAL SYSTEMS

*Peter Taylor (Chief Investigator), Andre Costa (Research Fellow), A. E. Krzesinski (University of Stellenbosch, South Africa) and Maya Ramakrishnan (MASCOS PhD Scholar)*

In this project we hope to expose as trivial some claims about critical phenomena in data from the New York stock exchange, that were made in a paper which appeared in *Nature*.

THREE-CHOICE AND PUNCTURED STAIRCASE POLYGONS

*Iwan Jensen (Research Fellow) and Tony Guttmann (Chief Investigator)*

Jensen and Guttmann studied two simple models for polygons on the square lattice. Three-choice polygons are defined as closed self-avoiding polygons on a square lattice such that after a step upwards or downwards one can take a step in any direction (except directly backwards) while after a step left or right one cannot turn right. Punctured staircase polygons are staircase polygons with a staircase hole. Starting from a long series expansion they have found that the generating functions satisfy an 8th order ODE with polynomial coefficients. They are currently in the process of analysing this ODE in order to extract further analytic information about the behaviour of the generating functions. New algorithms and methods of analysis were needed to discover such a massive and unwieldy solution and determining the asymptotic behaviour is also rather complex. However they have verified the exact form of the dominant term, as conjectured by Guttmann in 1997.

ISING MODEL SUSCEPTIBILITY

*Tony Guttmann (Chief Investigator), John Dethridge (MASCOS PhD Scholar), Iwan Jensen (Research Fellow) and Jean-Marie Maillard (Universite de Paris VI)*

Following recent breakthroughs by Maillard and his co-workers in France and Algeria, two new n-particle susceptibility series have been discovered. These are expressible as the solution of ODEs of almost unimaginable size. Efficient algorithms to confirm these results have been designed and implemented by Dethridge. The analysis of some of the singularity structure has been studied by Jensen and Guttmann, and all investigators are collaborating to continue this work.

PERCOLATION, LATTICE WALK AND RELATED MODELS

*Richard Brak (Chief Investigator), Aleks Owczarek (Chief Investigator), John Essam (University of London) and Peter Fox (The University of Melbourne)*

Results from models related to ASEP stochastic models (discussed elsewhere in this report) are being investigated in the context of lattice polymer and percolation models. In particular, the investigation of directed compact percolation near dry, wet and damp walls is in progress.
RESEARCH THEME 2

MONTE CARLO METHODS

INTRODUCTION

The simulation of random elements (random variables or even trajectories of stochastic processes) plays a crucial role in modelling and analysing complex systems that are intractable using analytical methods only. For example, to optimise the performance of a complex system, it is often necessary to find the maximum of or to integrate a function. In such circumstances, there is no hope of being able to perform maximization or integration analytically. At the simplest level, Monte Carlo integration methods work by sampling points randomly from a larger space and then estimating the value of the integral by looking at the proportion of sampled points that lie within the region of interest. However, for Monte Carlo methods to work in a practical sense, it is generally necessary to adopt appropriate modifications of this basic idea.

In Markov chain Monte Carlo simulation, the sampled points come from a realisation of a Markov chain. This idea was discovered independently in theoretical physics by Metropolis et al and in statistics by Hastings. Many modifications have occurred since, and the related literature is still growing. Monte Carlo methods have also been used to analyse non-linear differential equations and, in the field of stochastic processes, many different modifications, such as importance sampling, regenerative simulation, perfect simulation and RESTART have expanded on the underlying idea.

Of further interest are the deterministic alternatives to Monte Carlo methods, known as ‘nets’ and ‘lattices’ and related techniques. In the mid 1990s, computer science researchers at Columbia University showed experimentally that certain very high dimensional integrals from finance are more effectively treated by deterministic methods than by Monte Carlo methods. As a consequence, Columbia University patented the application of ‘low discrepancy sequences’ to problems of finance. More recently, Owen at Stanford University has devised randomised versions of deterministic methods (‘scrambled nets’), which combine the probabilistic benefits of the Monte Carlo method with the potentially greater accuracy of deterministic methods. High dimensional methods of this kind, along with the ‘randomised lattice methods’ recently developed in Australia and New Zealand, will be applied to a variety of complex interdisciplinary problems.

Because of its ubiquity across MASCOS’s disciplines, Monte Carlo simulation is an ideal theme to engender fruitful interaction across all areas of its focus. In 2004, MASCOS researchers undertook the following projects:

WEIGHTED SPACES AND CONSTRUCTION OF LATTICE RULES

Josef Dick (Research Fellow), Frances Kuo (Associate Investigator), Xiaoqun Wang (Tsinghua University, China) and Henryk Wozniakowski (Columbia University / University of Warsaw)

This project was concerned with the construction of lattice rules for weighted Sobolev and Korobov spaces. The researchers obtained tractability and strong tractability results for multivariate integration in those spaces.
MONTE CARLO METHODS CONTD.

DIGITAL LATTICE RULES, POLYNOMIAL LATTICE RULES, CYCLIC NETS AND CONSTRUCTION ALGORITHMS

Josef Dick (Research Fellow), Frances Kuo (Associate Investigator), Gunther Leobacher (University of Linz, Austria), Harald Niederreiter (National University of Singapore), Friedrich Pillichshammer (University of Linz, Austria) and Gottlieb Pirsic (Radon Institute, Austria)

In this project, the researchers demonstrated how results previously only known to hold for lattice rules are also true for digital lattice rules. They provided construction algorithms of the same form for polynomial lattice rules and in a much more general form for cyclic nets. They also obtained tractability and strong tractability results for their digital net constructions.

DISCREPANCY OF LOW DIMENSIONAL DIGITAL NETS

Josef Dick (Research Fellow), Friedrich Pillichshammer (University of Linz, Austria) and Peter Kritzer (University of Salzburg, Austria)

The researchers investigated the discrepancy of two dimensional digital nets. They demonstrated that the so-called Hammersley net is essentially the worst net and hence proved the existence of a sharp upper bound on the star discrepancy of a large class of nets in dimension two. These results were then used to obtain results on two dimensional low-discrepancy sequences.

UNCERTAINTY ANALYSIS OF GLOBAL CHANGE

Ian Enting (Professorial Fellow) and Andrew Rechnitzer (Associate Investigator)

The increase in atmospheric concentrations of greenhouse gases and the consequent change in the global climate is arguably the world’s most serious environmental threat. The various processes involved are subject to significant uncertainty. The probability of effects where critical thresholds determine instabilities that lead to abrupt climate change is particularly poorly quantified. (The analysis is further complicated by politicised mis-representation of the uncertainties). Monte Carlo techniques are being adapted to perform systematic uncertainty analysis of global change. This uses a Bayesian approach, analysing process uncertainty constrained by observational data. Initial proof-of-concept calculations have been presented at several international meetings. The longer term objective is to adapt Monte Carlo techniques developed for studying critical phenomena in order to perform risk analysis for abrupt climate change. As well as providing comprehensive characterisation of the range of uncertainty, Monte Carlo techniques can play an important role in public communication is this area because the basic principle is relatively simple to understand.
MONTE CARLO METHODS CONTD.

MONTE CARLO SIMULATION OF COMPLEX STATISTICAL MECHANICS MODELS

Aleks Owczarek (Chief Investigator), Andrew Rechnitzer (Associate Investigator), Thomas Prellberg (Associate Investigator) and Jarek Krawczyk (Research Fellow)

Under the previous Fellowship work of both Owczarek and Rechnitzer a novel general Monte Carlo algorithm combining the flat histogram method and the stochastic growth method of PERM has been created. This has been used to simulate polymers in various types of solution near an attractive surface under tension. Novel layering transitions have been found. Several manuscripts have been submitted for publication. This project will continue into 2005.

ESTIMATING PERSISTENCE TIMES IN STOCHASTIC POPULATION MODELS

Phil Pollett (Chief Investigator) and Caitlin James (Honours student)

Pollett and James have proposed a new measure of population persistence: the probability that a population reaches a pre-defined population size before it becomes extinct. They have assessed its effectiveness by comparing it with the expected extinction time for a variety of population models. They have developed an efficient method for estimating these and other measures of persistence based on rare event simulation techniques: Importance Sampling coupled with the Cross-Entropy Method.
RESEARCH THEME 3

DYNAMICAL SYSTEMS

INTRODUCTION

The theoretical study of dynamical systems started with Hamilton's investigations of systems of many particles, which grew into the area of statistical mechanics. In the modern theoretical approach, the area of dynamical systems has split into two areas, measurable dynamics and continuous dynamics. The former has grown into the complex area of ergodic theory, the latter has connections with partial differential equations via Hamiltonian theory and the theory of evolution equations.

In the former approach, the uncertainty present in a dynamical system is captured by the use of a measure space, and ergodic systems are seen as the basic building blocks. A great deal of the extant theory has concerned the case where time evolution leaves the measure invariant, but recent work by some of MASCOS's Chief Investigators has concerned non-singular systems, where the measure changes with time. New versions of entropy and other invariants have been investigated. While these new perspectives need further theoretical development, it is already clear that they have practical applications. For example, they have been used in coding theory.

Analytical methods such as Bäcklund transformations and symmetry analysis have recently been applied by MASCOS’s University of NSW researchers to nonlinear physical models. An underlying integrable structure has been revealed in a diversity of application areas of engineering importance such as the theory of fibre-reinforced materials, the deformation of shell membrane structures and toroidal configurations in magnetohydrostatics. The methods adduced, which were geometric in nature, are available through collaborations within MASCOS to analyse other nonlinear physical models.

A further example of successful interaction between MASCOS’s disciplines has occurred in the use of stochastic differential equations as a tool in partial differential equations and harmonic analysis. The incorporation of knowledge about these stochastic models has led to new insights into various applications, particularly in finance. For example, Brownian motion on the upper half plane has been used to solve the heat equation and hence to price Parisian options and other exotic options. As part of this general theme, MASCOS researchers plan to push this theory further, to promulgate it and to attack new problems from industry.

A question which cuts across MASCOS’s other themes is that of being able to distinguish properties of stochastic systems from those of deterministic ones, which often appear random. It is possible for the introduction of noise to change system characteristics, sometimes stabilizing systems and sometimes destabilizing them. A classical example of the distinction between these modes of thinking about systems comes from tracking the often dramatic difference in behaviour of a stochastic process and the corresponding mean value process. A cooperative effort from MASCOS researchers has been used to address this question.

In 2004, MASCOS researchers undertook the following projects:

FIBRE-REINFORCED MATERIALS

Colin Rogers (Chief Investigator) and Wolfgang Schief (Associate Investigator)

The kinematic conditions that attend the liquid formation process of fibre-resin systems have been shown to admit remarkable integrable reductions. Attention is currently focussed on non-steady processes in a search for more general 2+1-dimensional integrable reductions amenable to the methods of soliton theory.
DYNAMICAL SYSTEMS CONTD.

MAGNETOHYDROSTATICS & MAGNETOHYDRODYNAMICS

Colin Rogers (Chief Investigator), Wolfgang Schief (Associate Investigator) and Kassem Mustapha (Research Fellow)

A geometric formulation of the Lundquist equations of magnetogasdynamics has been investigated with a view to the isolation of hidden structure and the construction of novel physically important solutions with nested helicoidal geometry.

Nested helicoidal flux surfaces corresponding to an isodynamic magnetohydrostatic equilibrium

PAINLEVÉ STRUCTURE IN ELECTRODIFFUSION

Colin Rogers (Chief Investigator) and Wolfgang Schief (Associate Investigator)

The theory of electrodiffusion has its origin in the work of Nernst and Planck and describes the transport of charged particles through material barriers. Integrable Painlevé structure is currently being investigated for a system of nth order coupled nonlinear systems arising in multi-ion electrodiffusion.
**DYNAMICAL SYSTEMS CONT'D.**

**THE EQUILIBRIUM OF SHELL MEMBRANES**

*Colin Rogers (Chief Investigator) and Wolfgang Schief (Associate Investigator)*

The analysis of the equilibrium of elastic shell membranes has a long history going back to the work of Lamé and Clapeyron on the symmetric loading of shells of revolution. Elastic membrane models are of current interest in the analysis of deformation states in smectic liquid crystals. Current work involves a discrete model describing the equilibrium of plated membranes.

**PERIODIC VORTEX STRUCTURE IN GASDYNAMICS AND MAGNETOGASDYNAMICS**

*Colin Rogers (Chief Investigator) and Wolfgang Schief (Associate Investigator)*

There is much current research interest in novel two-dimensional vortex structures related to relaxation states as well as in the effects of compressibility and conductivity on, *inter alia*, the Stuart and Mallier-Maslowe vortex configurations. Here, multi-parameter reciprocal transformations have been allied to Bäcklund transformations to construct, in particular, novel breather type vortex solutions in both gasdynamics and super-Alfvénic magnetogasdynamics.

*A double pole solution of a sinh-Poisson vorticity equation in hydrodynamics*

**CONTRACTIONS OF LIE GROUPS**

*Nick Dungey (Research Fellow) and Tony Dooley (Chief Investigator)*

Contractions of Lie groups are a kind of deformation of one Lie group into another Lie group. In this project, the researchers are trying to understand a more general notion of contraction than has been previously studied, and to apply this to study analysis on Lie groups of polynomial volume growth.
**Dynamical Systems Contd.**

**Discrete Integrable Systems**

Reinout Quispel (Chief Investigator), Theo Tuwankotta (Research Fellow) and John Roberts (AMSI/MASCOS Fellow)

Piecewise-linear and ultra-discrete dynamical systems are currently a hot topic. Extending earlier work by Quispel, Capel and Scully to 3 dimensions Tuwankotta, Quispel and Tamizhmani (Pondicherry) published “Dynamics and bifurcations of a three-dimensional piecewise-linear integrable map” (J. Phys. 37A (2004) 12041-12058). The Institute of Physics has selected this article for inclusion in IOP Select (http://select.iop.org). Quispel, Capel and Roberts submitted “Duality for discrete integrable systems” to J. Phys. A. Quispel and Roberts have instigated a very successful investigation of three-dimensional integrable maps. This study promises to produce much more general 3D integrable maps, plus a variety of novel methods for constructing them.

**Mathematical Biology and Medical Mathematics**

Reinout Quispel (Chief Investigator)

With Volker Grimm (La Trobe University) and David Liley and his group at Swinburne University, Quispel initiated a preliminary study of Liley’s mathematical EEG model.

**Borel Dynamics and Cantor Dynamics**

Tony Dooley (Chief Investigator), S. Bezuglyi (Kharkov), J. Kwiatkowski (Torun) and K. Medynets (Kharkov)

Three papers were written, analysing various topologies on the set of Borel automorphisms of a Borel space, and on the set of continuous automorphisms of a Cantor space, and proving a Rokhlin type lemma for Borel automorphisms. These present an approach to Borel dynamics which is akin to “measurable dynamics without measures”. The papers have been accepted for publication.

**Approximate Transitivity**

Tony Dooley (Chief Investigator) and Anthony Quas (University of British Columbia)

Dooley and Quas analysed the approximate transitivity (AT) properties of the Morse transformation and resolved an old problem when they showed that it was AT. They also gave a construction of a cocycle which gives a two-point extension of the odometer which is not AT.

**Non-Singular Entropy**

Tony Dooley (Chief Investigator) and Genevieve Mortiss (DSTO)

Dooley and Mortiss followed up previous work of Mortiss, showing that the order of growth of sums of Radon-Nikodym derivatives, the “critical dimension”, yields a kind of non-singular entropy. This is established for product odometers and for Markov odometers.
DYNAMICAL SYSTEMS CONT'D.

COMPLETELY POSITIVE ENTROPY

Tony Dooley (Chief Investigator), V. Y. Golodets (University of NSW), D. J. Rudolph (Maryland) and S. D. Sinelshchikov (Kharkov)

The researchers demonstrated that an infinite countable amenable group which contains an element of infinite order must have uncountably many non-Bernoulli actions of completely positive entropy. This generalises an old theorem on the integers, due to Ornstein and Shields.

BRATTELI–VERSHIK SYSTEMS

Tony Dooley (Chief Investigator), T. Hamachi (Kyushu) and William Cruickshank (Research Fellow)

Dooley and Hamachi showed that every non-singular dynamical system is orbit equivalent to a Markov odometer on a Bratteli-Vershik system. Cruickshank has extended this to replace “orbit equivalence” with the stronger “metric equivalence”. He has also managed to classify all systems of width 2 up to metric equivalence.

HARMONIC ANALYSIS ON LIE GROUPS

Tony Dooley (Chief Investigator), Rafoul Raed (University of NSW), Kevin Sun (MASCOS PhD Scholar), Norman Wildberger (University of NSW)

Dooley showed a boundedness result for intertwining operators on rank one semi-simple Lie groups. Dooley and Wildberger analysed the wrapping map for compact times vector semidirect products. Sun is working on an analogue of Young tableaux for the group G2. Raed has proved a version of Cazzaniga’s “non-commutative Kirillov formula” for the groups SU(n).

BROWNIAN MOTION AND HEAT KERNELS ON LIE GROUPS

Tony Dooley (Chief Investigator), D. Maher (UNSW) and H. Zhang (UNSW)

Dooley and Maher investigated wrapping Brownian motion and other processes onto a compact Lie group from its Lie algebra. Zhang completed his honours thesis on Malliavin calculus, a version of “stochastic differential geometry".
FUTURE RESEARCH IN DYNAMICAL SYSTEMS

HIDDEN INTEGRABLE STRUCTURE IN NONLINEAR PHYSICAL SYSTEMS

Colin Rogers (Chief Investigator), Wolfgang Schief (Associate Investigator) and Murugesh Sabramanian (Research Fellow)

This group will continue their research on hidden structures in nonlinear physical systems. New directions will involve:

• The resonant nonlinear Schrödinger equation (NLS) as a model of the dynamics of capillarity fluids, and
• The study of coupled nonlinear Schrödinger systems in connection, with the potential modelling of smoke ring interaction.

DYNAMICAL SYSTEMS

Reinout Quispel (Chief Investigator)

It is expected that two new Research Fellows and one new postgraduate student will join MASCOS at La Trobe University in 2005. It is intended that they will work on integrable and non-integrable dynamical systems, mathematical biology, turbulence, and possibly scientific computation. In addition to this, they will continue the very successful collaboration with John Roberts of the University of NSW on discrete integrable systems.

THEORY OF COSTS

Tony Dooley (Chief Investigator), V. Y. Golodets (The University of NSW), D. Gaboriau (ENS-Lyon) and G. Hjorth (UCLA)

A detailed study of Gaboriau’s theory of costs of non-amenable group actions has been made, and results have been proved relating the cost of a finite extension of an equivalence relation to that of the relation itself. This material will be finalised for publication.

CRITICAL DIMENSION ENTROPY

Tony Dooley (Chief Investigator) and Genevieve Mortiss (DSTO)

Dooley and Mortiss will continue their analysis, treating Hamachi shifts, and considering applications to information theory.

AMOEZAS ON COMPACT LIE GROUPS

Tony Dooley (Chief Investigator) and D. Lind (Seattle)

The theory of amoebas has become a key part of algebraic dynamics, based on Ledrappier’s famous example. This may be considered as a class of examples on the circle group, and it is natural to try to extend the results to SU(2) actions.
FUTURE RESEARCH IN DYNAMICAL SYSTEMS
CONT'D.

HARMONIC ANALYSIS ON LIE GROUPS

Tony Dooley (Chief Investigator) Rafoul Raed (The University of NSW), Kevin Sun (MASCOS PhD Scholar) and Norman Wildberger (The University of NSW)

Raed will extend his results to other compact Lie groups, essentially developing a version of the Weyl calculus. Sun is expected to write up his Masters’ thesis. Dooley and Wildberger plan to extend the theory of wrapping and character formulae to nilpotent groups.

BROWNIAN MOTION AND HEAT KERNELS ON LIE GROUPS

Tony Dooley (Chief Investigator), D. Maher (UNSW) and H. Zhang (UNSW)

Maher will try to extend his theory to compact symmetric spaces using Rouviere’s e-functions. Zhang is starting his PhD, analysing a model of loop groups via Malliavin calculus. The aim is to be able to price financial options using this theory.
RESEARCH THEME 4

RISK MODELLING

INTRODUCTION

Any complex system, be it a computer program, the Internet, a financial system or a high-rise building is subject to various kinds of risks associated with different aspects of its functioning. Taking into account the fact that most such systems operate under conditions of uncertainty, the most appropriate models for studying such risks are stochastic models in which a swarm of random events represent undesirable outcomes of different severity. In such a formulation, undesirable events are usually identified with the process either entering certain regions of the state space, experiencing large changes in its value or passing through a critical point (see Research Theme 1).

Most of the risk evaluation procedures that are currently used are based on elementary, and therefore crude and often inappropriate, stochastic models, for which the analytic solutions of the relevant problems are known. An example is the currently-accepted model for finding the probability of ruin of an insurance company. Alternatively, simulation is used to estimate the quantities of interest. Both approaches give unreliable answers and there is substantial pressure, from both applied and theoretical viewpoints, to extend the class of stochastic models for which either analytical or efficient numerical solutions are available.

MASCOS aims to concentrate its efforts on attacking a number of important problems in risk analysis. They include boundary crossing problems for stochastic process models in insurance and reliability contexts. Of particular significance are models taking into account random interest rate environments. Further problems of interest occur in the context of modelling and analysing risks of loan-default or company collapse, which, in view of the recent events in the corporate world, have obvious significance.

In 2004, MASCOS researchers undertook the following projects:

RISKY ASSET FINANCE MODELS

Chris Heyde (Chief Investigator), Boris Buchmann (Research Fellow), S. Kou (Columbia University) and E. Seneta (University of Sydney)

This project focused on the requirements for a minimal description model, in particular on the heaviness of the tails of the returns distribution and various fractal and scaling properties. Detailed statistical investigations have been carried out. None of the widely used models match all the features of the empirical evidence.

EQUIVALENT MARTINGALE MEASURES

Chris Heyde (Chief Investigator) and B. Wong (University of NSW)

This methodology provides a key tool for the pricing of derivatives, enabling calculations to be done in a risk-neutral world rather than the real world. However, the existence of an equivalent martingale measure requires a certain stochastic exponential to be a true martingale. A new necessary and sufficient condition for this has been found and published in the Journal of Applied Probability.
STOCHASTIC PROCESSES MODELS IN FINANCIAL MATHEMATICS

Kostya Borovkov (Chief Investigator) and Alex Novikov (Associate Investigator)

One of the most fruitful approaches to problems of mathematical finance is based on the theory of stochastic processes. Borovkov and Novikov used models from that theory to find exact or approximate solutions to hard option pricing problems. In particular, they reduced the difficult problem of pricing general barrier options in the general Black-Scholes framework to the task of finding the probabilities of crossing certain boundaries by the Brownian motion process. Their solution includes a working technical approach to finding these probabilities.

LARGE DEVIATION PROBABILITIES FOR HEAVY-TAILED RANDOM WALKS AND RELATED PROCESSES

Kostya Borovkov (Chief Investigator) and Alexander Borovkov (Sobolev Institute of Mathematics, Russia)

The most popular models in risk theory are constructed from random walks, modelling premium payments, insurance claims times and sizes. One of the main mathematical problems in that context is to find the probability that such a risk process will not cross a certain remote boundary (the event being interpreted as bankruptcy of the modelled insurance company). Such probabilities are usually very small, and the problem itself belongs to the area of “large deviations”. In applications, the most interesting case is when the claim size distributions are “fat-tailed”, which means that very large claims are rather likely. The theory of large deviations for risk processes and similar objects in this case is still under development. Borovkov and Borovkov worked on a number of problems in that area, with obtained results including first-order approximations for probabilities of crossing remote curvilinear boundaries and low order asymptotic expansions for probabilities of simpler form.

PROCESSES WITH MEMORY/FRACTIONAL BROWNIAN MOTION (FBM)

Boris Buchmann (Research Fellow) and Claudia Kluppelberg (Munich University of Technology)

Buchmann and Kluppelberg introduced and analyzed a class of such equations for which one may construct stationary solutions from monotone transforms and Ornstein-Uhlenbeck processes driven by FBM (FOUP). This class contains a fractional Vasicek model, but also models with arbitrary state spaces. Stationary densities are given explicitly. Typically, the stationary solutions inherit long range dependence and, therefore, may find applications in volatility modeling. They analyzed these models from the viewpoint of extreme value theory, and gave a complete characterization of the domain of attraction of their partial maxima. In particularly, all types of extreme value distributions occur in the limit. In contrast to standard assumption in the literature, existence of strong solutions were derived under very weak conditions on drift and volatility. A necessary and sufficient condition for uniqueness is strict positivity of the volatility function. Whenever uniqueness is lost, an open problem still is how to describe all solutions. In particular, it is interesting to look for an explosion theory. Buchmann obtained a necessary condition on the volatility, but it is still an open problem whether this criterion is sufficient (and this is under investigation).
RISK MODELLING CONTD.

NONPARAMETRIC ESTIMATION OF LEVY MEASURES

Boris Buchmann (Research Fellow), Ross Maller (Associate Investigator) and Alexander Szimayer (University of Western Australia)

In recent years, Levy processes have been of considerable interest to financial mathematicians. The distribution of Levy processes of pure jump type is described by a drift parameter and the Levy measure. The researchers worked on nonparametric estimates of the Levy measure in the case of infinite activity, i.e. the Levy measure is an infinite measure, equivalently, the Levy process inherits infinitely many small jumps on all compacts with probability one. The current literature does not answer the important question of how to estimate the Levy measure itself, neither does it give weighted confidence bounds for estimators. This is an interesting question from the viewpoint of functional data analysis, as it is not clear how to choose these bounds in the critical region near zero. The researchers considered a sampling scheme based on observations of jumps. This sampling scheme includes the more realistic possibility of dropping infinitely many small jumps from the observations. Consistency and asymptotic normality in Banach spaces with weighted supremum norms were obtained by theorems on empirical processes for point processes. As a by-product, a family of goodness-of-fit test statistics was introduced, which was indexed by contrast functions.

FUTURE RESEARCH IN RISK MODELLING

RISKY ASSET FINANCE MODELS

Chris Heyde (Chief Investigator), Boris Buchmann (Research Fellow), S. Kou (Columbia University) and E. Seneta (University of Sydney)

Comparisons are being made with the newly developed CGARCH and CARMA models to check their scaling and long range dependence capabilities. A critique of multifractal models, in particular the type developed by Mandelbrot and various colleagues is being developed.

EQUIVALENT MARTINGALE MEASURES

Chris Heyde (Chief Investigator) and B. Wong (University of NSW)

This methodology provides a key tool for the pricing of derivatives, enabling calculations to be done in a risk-neutral world rather than the real world. However, the existence of an equivalent martingale measure requires a certain stochastic exponential to be a true martingale. A new necessary and sufficient condition for this has been found and published in the Journal of Applied Probability. Extension of the work is being carried out to extend it to the case where jumps are allowed.
FUTURE RESEARCH IN RISK MODELLING CONT'D.

PROCESSES WITH MEMORY/FRACTIONAL BROWNIAN MOTION (FBM)

Boris Buchmann (Research Fellow) and Ngai Hang Chan (Chinese University of Hong Kong)

In future research Buchmann aims to develop a Freidlin-Wentzell theory and to compare the results to the classical theory.

FOUP also arises in the following problem in time series analysis (the unit root problem). Under appropriate conditions on an uncorrelated noise sequence, functionals of Ornstein-Uhlenbeck processes (driven by Brownian motion) occur in the limits of least square estimators in AR(1) models when the autoregression coefficient is close to one (so-called unit root problem). Here close to one is interpreted in sense of local alternatives. Buchmann and Chan will consider a similar question under the hypothesis that the partial sum process is in the domain of attraction of FBM with Hurst parameter larger than 1/2. The hypothesis holds for fractional differentiated noise, but also includes stationary sequences obtained via transforms of correlated Gaussian noise with appropriate Hermite rank. Under rescaling the ordinary least square estimator still converges to the same functional, where the classical Ornstein-Uhlenbeck process and participating Ito integrals have to be replaced by FOUP and Riemann-Stieltjes integrals, respectively. In contrast to the classical theory, if the mean reversion parameter of FOUP tends to infinity, which can be interpreted as return to the stationary regime on an infinitesimal scale, the functionals are asymptotically biased and besides normal also Rosenblatt distributions occur as limits.

NONPARAMETRIC ESTIMATION OF LEVY MEASURES

Boris Buchmann (Research Fellow), Ross Maller (Associate Investigator) and Alexander Szimayer (University of Western Australia)

In order to make their earlier results applicable, the researchers will focus on resampling methods to obtain asymptotically correct uniform confidence bounds for their estimator. Furthermore optimality criterion for a choice of the contrast functions have to be developed. They will study large deviations of the error of the second kind. In further research, simulation studies and applications to financial high frequency data sets need to be investigated.
RESEARCH THEME 5

SCIENTIFIC COMPUTATION

INTRODUCTION

It is indeed almost universally true that the task of analysing the performance of a mathematical or statistical model of a complex system requires computational implementation.

The role of scientific computation is two-fold: First it is important to validate the approximations made in the modelling process. This is usually done by comparing model outcomes with numerical simulations. If necessary the modelling and validation processes are iterated. Once a consistent model is attained the crucial second role of scientific computation is prediction, upon which actions and recommendations are based. Each of these two roles requires the development, analysis and implementation of sophisticated models and software which exploits the capabilities of current high-speed computers. Computational techniques are often developed within the context of a particular discipline without reference to the general area of scientific computation. For example many of the algorithms that make up the field of matrix-analytic methods in block-structured Markov chains were developed by applied probabilists rather than numerical analysts.

The effect of this can be both good and bad. On the downside there is a danger that researchers working in a particular area might 're-invent the wheel' or design algorithms that might seem sensible mathematically but have poor numerical properties, while on the upside the particular class of models that they are working on might constitute a model analysts have not thought to investigate and where algorithms have special properties. There is evidence that this is the case with algorithms for solving matrix polynomial equations in a stochastic setting and with the numerical inversion of Laplace transforms of probability distributions. The above observations indicate the desirability of encouraging dialogue between experts in scientific computation and practitioners who are working in one or more of the disciplines of complex system modelling. As with the educational role of the statistical modelling theme, the benefits of such collaboration will be two-way in that the computational experts can take an educational role and the practitioners can alert the computational experts to interesting problems that are likely to have a wider significance in the numerical modelling community.

Scientific computing covers a vast area, ranging from applied linear algebra and advanced optimization to the efficient solution of stochastic differential equations. While the specific projects indicated below touch only a tiny part of scientific computing, it is expected that the coverage of scientific computing within MASCOS will grow in future.

In 2004, MASCOS researchers undertook the following projects:

INTEGRATION BY RADIAL BASIS FUNCTIONS OVER THE SPHERE

Robert Womersley (Associate Investigator), Ian Sloan (Chief Investigator) and Alvise Sommariva (Research Fellow)

The researchers considered the problem of approximating the integral of a function $f : S^2 \rightarrow \mathbb{R}$ when the values of $f$ are known only on scattered data $X = \{x_i\} \subset S^2$, where $S^2$ denotes the unit 2-sphere. It can be proved that such cubature rules are optimal in the sense of Golomb-Weinberger.
NUMERICAL CUBATURE ON SCATTERED DATA BY RADIAL BASIS FUNCTIONS

Alvise Sommariva (Research Fellow) and Marco Vianello (University of Padua, Italy)

In this investigation, the researchers considered the abovementioned cubature problem on the square \([0,1] \times [0,1]\); such an investigation is fundamental to the analysis over the unit 2-sphere \(S^2\).

APPROXIMATION OF THE NAVIER–STOKES EQUATIONS ON THE UNIT SPHERE

Q. Thong Le Gia (Research Fellow), Ian Sloan (Chief Investigator) and M. Ganesh (Colorado School of Mines)

The functional setting of the Navier-Stokes equation on the unit sphere has been developed. The researchers have obtained new error estimates (unreported in the known literature on Navier-Stokes equations on the unit spheres). The results were announced at the conference on Constructive Function Theory at Georgia Tech University in Atlanta, November 2004. The implementation of the spectral method using vector spherical harmonics on Matlab 6.0 is in progress.

PRECONDITIONERS FOR SOLVING ELLIPTIC PDES ON THE UNIT SPHERE

Q. Thong Le Gia (Research Fellow), Ian Sloan (Chief Investigator) and T. Tran (The University of NSW)

The researchers took the real scattered data from NASA’s satellite MAGSAT and applied their new preconditioning algorithm on selected global subsets of initially very large data sets. The algorithm gave good results in all cases up to 7663 points, in which the CPU times and number of iterations has been reduced compared to the conjugate gradient method without preconditioners. The theory is under development.

SELF–AVOIDING POLYGONS

Iwan Jensen (Research Fellow), Tony Guttmann (Chief Investigator) and Christoph Richard (University of Bielefeld, Germany)

The researchers have developed very efficient parallel algorithms for the enumeration of self-avoiding polygons and applied these to several two-dimensional lattices. They have conjectured the exact scaling function for self-avoiding polygons. The theoretical predictions were confirmed by high quality numerical calculations based on extensive series expansions. This work is continuing in order to further investigate the properties of the scaling function and relies heavily on series expansions for the full area and perimeter generating functions.
The availability of extremely long series for some problems in critical phenomena has made it appropriate to develop new techniques to determine the asymptotic behaviour from the series coefficients. In particular, for Ising n-particle susceptibilities, 3-choice polygons and punctured staircase polygons, there exist confluent logarithmic terms. Jensen and Guttmann have developed and implemented algorithms to discover precisely which such terms are present and which are absent. While such information is in principle obtainable from the underlying ODE, the required analysis is much more complex and time consuming than their algorithm.
RESEARCH THEME 6

STATISTICAL MODELLING OF COMPLEX SYSTEMS

INTRODUCTION

In almost every situation in which an investigator is using a mathematical model to gain insight into the operation of a real-world complex system, a statistical inference must be made about the properties of the system. This could be relatively straightforward, at the level of parameter estimation within a well-defined model, or it could be more fundamental, at the level of model construction itself.

An example of the latter approach is the use of highly adaptive nonparametric statistics, and allowing the data itself to select and construct models. This is ideally suited to complex systems, where the imposition of a conventional model from outside will usually fail to recognize the important intricacies and interactions that determine the system's operation. Nonparametric statistical methods enjoy a very wide range of applications to complex systems arising in the natural sciences, engineering and the social sciences. In particular, new techniques for signal transmission, storage and analysis demand nonparametric methods in order to respond adequately to complex systems.

Another question of interest is how noise is best incorporated into models. In its simplest form, this is often a choice between additive and multiplicative noise. Many models require the incorporation of noise from different sources, such as population models requiring the modelling of both demographic stochasticity and environmental stochasticity. Noise can also be a beneficial process: for example it can induce stochastic resonance under which a weak signal that is normally undetectable in a noisy environment can be rendered detectable.

In addition to enabling the investigation of fundamental questions of interest to statistical modellers, this theme plays an educational role within MASCOS. Knowledge of the most up-to-date statistical modelling techniques is essential for researchers working across the entire complex systems area. MASCOS’s statistical modelling experts are able to inform other members as to the most advanced techniques in their discipline. In turn, feedback from other disciplines has motivated new research in statistical modelling.

In 2004, MASCOS researchers undertook the following projects:

STATISTICAL DIAGNOSTICS OF TRACE GAS INVERSIONS

Ian Enting (Professorial Fellow) and Anna Michalak (University of Michigan)

The problem of using concentration measurements to estimate the space-time distribution of sources and sinks of greenhouse gases such as CO₂ is of great importance in projecting responses to future emissions of these gases. However the sparse data set and the ill-conditioned nature of the estimation problem lead to large but poorly characterised uncertainties. This project is investigating statistical diagnostics that can be applied to such inversion calculations in order to improve the current practice. Initial studies have identified diagnostics that can detect some of the most serious problems in past practice.
CALCULATION OF CLUSTER AND VIRIAL COEFFICIENTS FOR HARD SPHERES IN D DIMENSIONS

Nathan Clisby (Research Fellow) and Brendan D. McKay (Australian National University)

An algorithm has been developed to extend the number of known coefficients for the virial and cluster series of the hard sphere system in D dimensions.

NONPARAMETRIC INFERENCE FOR DATA WITH DEPENDENT TRUNCATION

Peter Hall (Chief Investigator) and Ming-Yen Cheng (Research Fellow)

This work addressed nonparametric inference in truncated survival-data problems, where the time of onset of a disease, and the time of death, were observable if and only if the onset time fell to the left of a time-point t, and the time of death lay to the right of t. Methods were developed for obtaining, from these crude data, detail about the survival-time distribution and the hazard rate, without making parametric assumptions.

CONFIDENCE BANDS FOR HAZARD RATE UNDER RANDOM CENSORSHIP

Peter Hall (Chief Investigator), Ming-Yen Cheng (Research Fellow) and Dongsheng Tu (Queen’s University)

A completely empirical approach was suggested for constructing confidence bands for the hazard rate, based on smoothing the Nelson-Aalen estimator. For this purpose, a local bandwidth-choice method was introduced. The method used undersmoothing to alleviate difficulties caused by bias.

CROSS-VALIDATION

Peter Hall (Chief Investigator), Jeff Racine (Syracuse University) and Qi Li (Texas A&M University)

In problems involving the estimation of conditional densities, and hence also in problems of prediction, it is desirable to eliminate “explanatory” variables that have no, or negligible, explanatory power. It can be shown that the method of cross-validation does this very effectively, by automatically choosing a bandwidth that “smooths away” such variables. In this project, theory is being developed to explain this phenomenon, and numerical work is being undertaken to illustrate implications of the theory.
An edge in an image is a curve which separates two substantially different levels of brightness, or grayscale value. This viewpoint is non-standard in the literature on computer vision, in that the researchers do not describe the edge simply by a set of points which satisfy some sort of threshold condition, for example after taking a numerical derivative. Estimating a curve as an edge is attractive for several reasons, one of which is that the need for post-processing is much reduced in comparison to the derivative-based methods. What the researchers have added to the statistical methodology in their most recent work is that the estimator can deal with the practically highly relevant situation where several edges meet to form what may be called a ‘knot’, for example a T-junction. In connection with this, Rau investigated estimation methods for surfaces which are cut by edges where the goal is to restore the complete surface, not just the edge alone.

Panels (a)-(c) show estimates of the edge obtained by the Sobel, Laplacian of Gaussian (LoG), and the method of this paper respectively. Panel (d) shows the results after linearly connecting the sequence of points from (c), alongside with the knots and the corners. In each of the panels (a)-(d), a small rim around the estimation window is added for visual purposes.
DISCRIMINATION OF RADAR IMAGES

Christian Rau (Research Fellow) and Jeff Wood (Australian National University)

Rau investigated the discrimination of radar images, with the aid of principal components and image processing techniques such as wavelet denoising, for DSTO (Defence Science and Technology Organisation). Techniques of functional data analysis, which played an important role from early on in this consultancy, will also be applied on a much wider scale in ongoing work with Dr Jeff Wood of the Statistical Consulting Unit, Australian National University.

BUMP HUNTING

Peter Hall (Chief Investigator), Michael C. Minnotte (University of Utah) and Chunming Zhang (University of Wisconsin)

Bump hunting is the science of searching for, and assessing the significance of, local maxima in density functions. It has been known for more two decades that many kernels that are commonly used for density estimation, can have problems when employed for bump hunting – they tend to add spurious bumps themselves, and so confound the process of identifying real bumps. This project is providing the first theoretical account of the nature and extent of the problem.

ATTRIBUTING A PROBABILITY TO THE SHAPE OF A PROBABILITY DENSITY

Peter Hall (Chief Investigator) and Hong Ooi (Australian Insurance Group)

Related to the problem of bump hunting, it is often desirable to assign a probability to the shape of a probability density, for example so that we can say that “This density has probability at least 0.90 of having at least two peaks.” This project is studying theoretical issues associated with this concept of “bump likelihood,” and suggesting a way of attributing probability to shape.

PREDICTION FOR MULTIVARIATE EXTREME EVENTS

Peter Hall (Chief Investigator) and Nader Tajvidi (University of Lund, Sweden)

Prediction is an increasingly important problem in extreme-value theory, and the problem of prediction in multivariate cases is especially challenging. In this project, methods for predicting extreme vectors are being developed.

TESTS FOR SINGLE INDEX MODELS

Peter Hall (Chief Investigator) and Celine Vial (Research Fellow)

Hall and Vial developed a test for the Single Index Model, which links an explained variable to other explanatory variables; the model has econometric applications. The method they proposed is based on a geometrical approach and a bootstrap selection of the critical value.
DECONVOLUTION ESTIMATION

Peter Hall (Chief Investigator) and Alexander Meister (Research Fellow)

Meister studied the problem of estimating the support of a density based on contaminated data. The applications of this theoretical issue concern econometric frontier estimation, for example. He developed some new procedures, which perform well in the problem (both theoretically and practically) under less restrictive conditions compared to existing methods. Two papers related to this topic were submitted to statistical journals.

Furthermore, Meister and Hall were concerned with function estimation from measurement error, whose Fourier transform has some zeros. That technical difficulty requires significant modifications to classical deconvolution procedures, and the estimation problem becomes harder.

FUNCTIONAL DATA ANALYSIS

Peter Hall (Chief Investigator) and Celine Vial (Research Fellow)

Hall and Vial worked on a project concerning functional data analysis (for example, analysis of the curve of temperature during a year). For studying such data a classical approach is to consider a special basis of functions, e.g. the empirical principal factor functions. The knowledge of the extrema - for every function of the basis - is of major importance. Moreover the researchers are investigating how many functions are needed to reconstruct the curve.

TAIL HEAVYNESS

Chris Heyde (Chief Investigator), S. G. Kou (Columbia University) and K. Au (The University of Melbourne)

Many processes in insurance, communications and finance have nonstandard asymptotics because of heavy tails. However, checking for heavy tails requires unexpectedly large samples. A paper which clarifies the sample size issue has been published in Operations Research Letters. Work has also been carried out on measuring closeness of tails of distributions.

SELF-SIMILARITY AND LONG-RANGE DEPENDENCE

Chris Heyde (Chief Investigator), Allan Sly (Australian National University) and N.N. Leonenko (University of Cardiff)

Stochastic systems showing asymptotic stability but for which the central limit theorem fails typically display self-similarity and often long-range dependence. A paper is under preparation in which it is shown that most self-similar processes are not semimartingales, a property which has major implications for their use in modelling. Local self-similarity properties have been investigated and a new class of multifractional Gaussian processes defined.
CLIMATE CHANGE

Chris Heyde (Chief Investigator), I. Castles (Academy of Social Sciences of Australia) and John Zillman (Academy of Technological Sciences and Engineering)

The question of whether there is antipersistence present in controlling temperature swings in the lower troposphere is under investigation. Reports of such an effect have been used by anti-global warming pressure groups as a major support for their argument. Initial investigations of temperature anomaly data suggest that no significant antipersistence is present.

IMPROVED RESULTS ON POISSON PROCESS APPROXIMATION IN JACKSON NETWORKS

Aihua Xia (Chief Investigator), Tim Brown (Australian National University) and Mark Fackrell (The University of Melbourne)

Melamed (1979) proved that for an open migration process, a necessary and sufficient condition for the equilibrium flow along a link to be Poissonian is the absence of loops: no customer can travel along the link more than once. Barbour and Brown (1996) quantified the statement by allowing the customers a small probability of travelling along the link more than once and proved Poisson process approximation theorems analogous to Melamed’s Theorem. Amongst the three bounds presented in Barbour and Brown (1996), the one in terms of the Wasserstein metric is of particular interest since it reveals more insightful information about the closeness between the process of flows and an approximating Poisson process, and it is small when the parameter of the system is small, except for a logarithmic factor in terms of time in which the flows are considered. The bound was later improved by Brown, Weinberg and Xia (2000) who showed that the logarithmic factor in terms of time can be lifted at the cost of an extra parameter being introduced into the bound. In this project, we present a new bound which simplifies and sharpens the bounds in the above-mentioned two papers and compare the performance of these bounds for a simple open migration process.

ZERO BIASING AND A DISCRETE CENTRAL LIMIT THEOREM

Aihua Xia (Chief Investigator) and Larry Goldstein (University of Southern California)

We introduce a new family of distributions to approximate $P(W \in A)$ for $A \subset \{\ldots, -2, -1, 0, 1, 2, \ldots\}$ and $W$ a sum of independent integer-valued random variables $\xi_1, \xi_2, \ldots, \xi_n$ with finite second moments, where with large probability $W$ is not concentrated on a lattice of span greater than 1. The well-known Berry–Esseen theorem states that for $Z$ a normal random variable with mean $E(W)$ and variance $\text{Var}(W)$, $P(Z \in A)$ provides a good approximation to $P(W \in A)$ for $A$ of the form $(-\infty, x)$. However, for more general $A$ such as the set of all even numbers, the normal approximation becomes unsatisfactory and it is desirable to have an appropriate discrete, non-normal, distribution which approximates $W$ in total variation, and a discrete version of the Berry–Esseen theorem to bound the error. In this project, using the concept of zero biasing for discrete random variables (cf. Goldstein and Reinert (2004)), we introduce a new family of discrete distributions and provide a discrete version of the Berry–Esseen theorem showing how members of the family approximate the distribution of a sum $W$ of integer valued variables in total variation.
FUTURE RESEARCH IN STATISTICAL MODELLING OF COMPLEX SYSTEMS

TAIL HEAVINESS

Chris Heyde (Chief Investigator), S.G. Kou (Columbia University) and K. Au (The University of Melbourne)

Research continues on tail index estimation methodology and in particular the use of medians to provide stability for tail index estimates.

SELF-SIMILARITY AND LONG-RANGE DEPENDENCE

Chris Heyde (Chief Investigator), Allan Sly (Australian National University) and N.N. Leonenko (University of Cardiff)

Several papers are in draft form and will be completed. Research on clarifying the basic concepts, such as multifractality, will be continued.

CLIMATE CHANGE

Chris Heyde (Chief Investigator), I. Castles (Academy of Social Sciences of Australia) and John Zillman (Academy of Technological Sciences and Engineering)

The question of whether there is antipersistence present in controlling temperature swings in the lower troposphere is under investigation. Initial investigations of temperature anomaly data suggest that no significant antipersistence is present. The investigations continue. Detailed discussion of the statistical analysis with climatologists is required.

NORMAL APPROXIMATION FOR RANDOM SUMS

Aihua Xia (Chief Investigator) and A. D. Barbour (University of Zurich)

The project focuses on the quality of normal approximation to random variables resulting from integrating a random field with respect to a point process under various local dependent structures.

PBD APPROXIMATION FOR UNBOUNDED FUNCTIONS

Aihua Xia (Chief Investigator) and Tim Brown (Australian National University)

In 2001 Brown and Xia introduced a class of approximating distributions called polynomial birth-death (PBD) distributions. The class is very convenient to use and includes many well-known distributions such as Poisson, binomial and negative binomial distributions. For PBD approximation to the sum $W$ of independent Bernoulli trials with respect to the total variation metric, it was shown that, with suitable choice of two parameters, the distribution performs much better than Poisson, binomial and equally as well as compound Poisson signed measures. Barbour, Chen and Choi (1995) estimated errors for Poisson approximation to $\operatorname{Eh}(W)$ for unbounded functions $h$ and one theorem says that a better approximation can be achieved with second order approximation. This project aims at PBD approximation to $\operatorname{Eh}(W)$ for unbounded functions $h$. 
RESEARCH THEME 7

MODELLING AND CONTROL OF COMPLEX SYSTEMS

INTRODUCTION

Modelling and Control of Complex Systems was not one of the original six themes that were proposed in MASCOS’s ARC application. However, as its Chief and Associate Investigators gave up ARC Discovery Grants in this area due to their proposed activities being too close to MASCOS’s goals, MASCOS has adopted a seventh theme, entitled Modelling and Control of Complex Systems.

The work under this theme involves the development and analysis of stochastic models that reflect various aspects of the behaviour of complex systems. Crucial to this endeavour is an attempt to understand how local, short-term relationships interact to produce global, long-term outcomes. Also included under this theme is a large amount of work in modelling specific complex systems, whether they exist as concrete entities, such as the Internet, or whether they exist as more abstract concepts, such as a complex Markov chain.

In 2004, MASCOS researchers undertook the following projects:

DYNAMIC CAPACITY RE-ALLOCATION SCHEMES IN LOGICAL NETWORKS

Andre Costa (Research Fellow), Peter Taylor (Chief Investigator) and Maya Ramakrishnan (PhD Scholar)

This project investigated approaches for the dynamic re-allocation of capacity between routes in a logically connected telecommunications network. Specifically, the researchers considered the situation where a network operator creates dedicated end-to-end routes between origin-destination node pairs of the network by partitioning and allocating the underlying link capacities in an appropriate manner. This research focuses on distributed schemes for dynamically re-allocating capacity from one route to another, based on local information about the current network conditions and utilisation. The goal is to design schemes which maximise the average rate of successful connections, subject to certain “quality of service” guarantees for each path.

ANALYTIC MODELLING OF NETWORK ROUTING ALGORITHMS THAT EMPLOY “ANT-LIKE” MOBILE AGENTS

Andre Costa (Research Fellow), Peter Taylor (Chief Investigator) and Nigel Bean (University of Adelaide)

Interest in adaptive and distributed systems for routing control in networks has led to the recent development of a new class of algorithm, which is inspired by the problem-solving behaviours observed in biological ant colonies. This class of algorithm utilises ant-like agents which traverse the network and collectively construct routing policies. This project focuses on the development of analytic models for the study of this class of algorithm. The theoretical insights gained through this approach have led to a number of proposed design improvements for routing algorithms of this type. There exist a number of interesting connections between “ant-based routing” methods, and the fields of reinforcement learning and game theory.
DIFFUSION APPROXIMATIONS TO MODELS FOR THE EVOLUTION OF DUPLICATE GENES

Martin O'Hely (Research Fellow)

The duplication of an entire gene at a new genomic locus is thought to be an important mechanism underlying the development of new functions for genes. Recent simulation studies show that the probability a duplicated gene can persist in a population varies (relative to similar probabilities for other, neutral mutations) according to the size of the population and the genomic distance between the original and duplicate loci. Diffusion approximations of the underlying stochastic processes have been used in an effort to duplicate these results in a mathematically rigorous setting.

SAMPLING USING VARIABLE SAMPLING RATES

Peter Hall (Chief Investigator), Gerard Kerkyacharian (University of Paris X), Spiridon Penev (University of NSW), Dominique Ricard (University of Paris VII) and Jiying Yin (ANU)

Standard technologies for digital audio, and video, rely on sampling signals at a uniform rate, for example 44 kHz for an audio CD, and 96 kHz for DVD audio. Prospective new technologies involve sampling in an adaptive way, using higher sampling rates when the signal is complex, and lower rates otherwise. This project is developing theory for such procedures, and suggesting rules that should be followed to ensure optimal, or near-optimal, performance.

ESTIMATING PERSISTENCE IN POPULATION PROCESSES

Phil Pollett (Chief Investigator) and Ben Cairns (MASCOS PhD Scholar)

Pollett and Cairns have developed a general framework for estimating persistence in populations which may be affected by catastrophic events, and which are either unbounded or have very large ceilings. They model the population using a birth-death process modified to allow for downward jumps of arbitrary size. For such processes, it is typically necessary to truncate the process in order to make the evaluation of expected extinction times (and higher order moments) computationally feasible. They have identified a method for selecting a cut-off point at which to truncate the process, as well as a simple method for obtaining quantitative indicators of the suitability of a chosen cut-off.

DYNAMICS OF EVOLVING SPATIAL POINT PROCESSES

Kostya Borovkov (Chief Investigator) and David Odell (The University of Melbourne)

This project is devoted to studying the evolution of spatial point processes that change their configuration depending on the current positions of their points. Such models have applications in biology, ecology, crystallography and other areas. One of the models we studied was a dynamic version of the von Neyman contagious point process, that originally appeared as a model for insect distribution. Another model was Voronoi cell dependent cull-immigration process that can be used to model competition of plants in a forest: points are removed from the process at random, depending on the size of their “zone of influence” (or “catchment area”), and new points are added at random, to keep the population at a constant level.
Evolution of a 2-dimensional Voronoi cell area based culling-immigration process; colour corresponds to the size of a cell

Snapshot of a process of that kind with saturation inversely proportional to the cell size
CONVERGENCE PROPERTIES OF THE CROSS-ENTROPY
METHOD FOR DISCRETE STOCHASTIC OPTIMISATION

Andre Costa (Research Fellow) and Dirk Kroese (University of Queensland)

The Cross-Entropy (CE) method is a novel stochastic search method that can be applied to continuous and discrete optimisation problems. The method was originally developed for the purpose of estimating the probability of rare events via simulation, but its potential as a tool for stochastic optimisation was soon realised and exploited by researchers. The CE method involves an iterative procedure, whereby a collection of candidate solutions are generated according to a probability distribution, and subsequently the parameters of the distribution are updated so as to increase the probability of obtaining the “best” of these candidates at the next iteration. This aim of this research project is to establish results regarding the convergence of the CE method to an optimal solution.

UNIQUENESS CRITERIA FOR THE WEIGHTED MARKOV
BRANCHING PROCESSES

Phil Pollett (Chief Investigator), Hanjun Zhang (Research Fellow), Anyue Chen (University of Greenwich) and Junping Li (University of Greenwich)

The basic property that governs the evolution of Markov branching processes is the branching property: that particles behave independently producing descendants according to the same rule. It greatly simplifies their analysis. However, since particles may interact, through collision or other mechanisms, the branching property may be lost. For this reason, more general branching models have been proposed. The researchers considered a particularly interesting class, called weighted Markov branching processes (WMBPs). They have established criteria for the uniqueness of these processes.

THE EXISTENCE OF UNI-INSTANTANEOUS MARKOV
CHAINS

Phil Pollett (Chief Investigator), Hanjun Zhang (Research Fellow), and Brenton Gray (Pacific Outsourcing Solutions Australia)

The researchers considered the problem of identifying time-homogeneous Markov chains which have a single instantaneous state and a given µ-invariant measure (quasi-stationary distribution). They have settled the question of the existence of these random processes. They explored the notion of almost-invariance for measures associated with uni-instantaneous Markov chains, and further developed and exploited resolvent decomposition theorems for these processes. In doing so they have obtained new results for the Kolmogorov K1 chain, and a birth-death process with catastrophes and instantaneous resurrection.
In some applications involving queuing theory, for example to internet traffic, it is desired to estimate the distribution of service time from data on busy periods. Methods for doing this successfully, and information-theoretic bounds for the limitations of any method for solving this problem, are being developed in this project.

**STOCHASTIC MODELS FOR MAINLAND–ISLAND METAPOPULATIONS**

*Phil Pollett (Chief Investigator) and Joshua Ross (MASCOS PhD Scholar)*

This work extends existing mainland-island metapopulation models to incorporate a dynamic landscape. Pollett and Ross have derived functional limit laws that provide deterministic and normal approximations for the density of occupied patches, and for the densities of suitable and occupied patches, in the respective static and dynamic landscape versions of our model. They have assessed the quality of the approximations by showing how closely, for how long, and over what ranges, the distributional approximations are faithful. Thus, they have established an effective means for studying metapopulation dynamics and how it is affected by immigration and changes in habitat.
COSTS AND DECISIONS IN POPULATION MODELS

Phil Pollett (Chief Investigator) and Joshua Ross (MASCOS PhD Scholar)

Many populations have a negative impact on their habitat, or upon other species in the environment, if their numbers become too large. Pollett and Ross have examined two control regimes designed to maintain a population close to a given threshold, and have derived models that allow them to study the effects of each regime on population viability. They have derived a general method for estimating the total cost of controlling the population over its lifetime and used this to compare control methods.

Simulation of a controlled population process

SUBGEOMETRIC RATES OF CONVERGENCE FOR MARKOV PROCESSES

Hanjun Zhang (Research Fellow), Zhenting Hou (Central South University, China) and Yuanyuan Liu (Central South University, China)

The researchers have considered a Harris ergodic continuous-time Markov process on a general state space, and have investigated subgeometric rates of convergence of the transition function to its invariant probability measure. They have derived sufficient conditions for the convergence in terms of the existence of suitable points on which the first hitting time moments are bounded. Specifically, for stochastically ordered Markov processes, explicit bounds on subgeometric rates of convergence have been obtained.
FUTURE RESEARCH IN MODELLING AND CONTROL OF COMPLEX SYSTEMS

DIFFUSION APPROXIMATIONS FOR SPATIALLY REALISTIC STRUCTURED METAPOPULATION MODELS

Phil Pollett (Chief Investigator) and Joshua Ross (MASCOS PhD Scholar)

Pollett and Ross are presently studying a stochastic metapopulation model for the number of individuals at each patch in a $k$-patch metapopulation network. Local population dynamics are governed by a stochastic logistic term and spatial structure is incorporated through a density-dependent migration term, which allows migration to be dependent upon the distance between patches. They aim to find a suitably scaled version of the model that will converge, uniformly in probability over finite time intervals, to a system of $k$ differential equations. They then aim to model the fluctuations about equilibrium points of this system using a $k$-dimensional normal approximation.

BOUNDS ON THE DECAY PARAMETER FOR GENERAL BIRTH–DEATH PROCESSES

Phil Pollett (Chief Investigator) and Hanjun Zhang (Research Fellow)

Pollett and Zhang are currently studying the phenomenon of exponential ergodicity in the context of transient birth-death processes with a single absorbing state. They aim to give criteria for the decay parameter to be positive in terms of the birth and death rates, and, more specifically, to determine the value of the decay parameter, or at least bounds on it, in terms of these rates.

ESTIMATING TRAFFIC PARAMETERS USING ACTIVE PROBING

Peter Taylor (Chief Investigator), Darryl Veitch (Associate Investigator) and Ana Novak (MASCOS PhD Scholar)

In this project, Taylor, Veitch and Novak are investigating how to analyse packet pair probing experiments in the Internet.

DECAY RATES OF MATRIX–ANALYTIC MODELS

Peter Taylor (Chief Investigator) and Allan Motyer (MASCOS PhD Scholar)

Taylor and Motyer are extending some recent results of Kroese, Scheinhardt and Taylor that enable one to determine the range of possible decay rates of matrix-analytic models with infinitely many phases.
INDUSTRY LINKS

INDUSTRY/MARKETING MANAGER’S REPORT

MASCOS’s Industry outreach and linkage program was progressed this year by the appointment of Thomas Montague as the MASCOS/AMSI Industry-Marketing Manager. In addition to this appointment, Lyn Forsyth works one day a week for MASCOS as Marketing Consultant at the University of NSW.

This year MASCOS supported several industry related events across Australia, including a Sydney-based event Managing Fraud, Risk and Churn - Data Mining in the Real World, workshops in Brisbane on Mathematics and Computational Biology and on Metapopulations, and a short course on the use of Monte Carlo Methods in Finance in Melbourne (see MASCOS Conferences, Workshops and Symposia below for details).

In October, MASCOS’s Director Tony Guttmann visited three institutes in North America and Germany to learn and compare how they undertake their industry linkage programs and how successful they have been in securing industry support. Surprisingly North American institutes, such as the Pacific Institute for the Mathematical Sciences (PIMS) and the Fields Institute do not appear to undertake direct consulting activities. Rather they have established a separate institution, Mathematics of Information Technology and Complex Systems (MITACS) to focus directly on this task.

In contrast, Tony’s visit to Germany revealed quite a different situation. Many of the 70 researchers employed at the German Centre for Key Technologies MATHEON are totally funded by Industry. However, the enduring message from the MATHEON visit was that successful industry linkages are based on personal relationships built-up over extended periods of time. Looking forward and with the above in mind it seems clear that in the future the Centre will have to focus on developing industry projects with long-term rather than short-term horizons. To this end MASCOS and AMSI will combine in 2005 to undertake a series of Industry Forums that will focus on a range of industry themes such as risk management. It will also undertake an internal Industry Workshop to promote industry participation of Centre staff and students and identify areas of opportunity.

INDUSTRY RESEARCH COLLABORATIONS

Industry activities of the Centre in 2004 included the following:

WITH A MAJOR BANK:

This year Colin Thompson and Bryan Beresford-Smith continued to work with the financial sector by undertaking a project that examined the robustness and performance requirements for credit risk by developing a simple envelope-bound uncertainty model for client default probabilities. This project built on the work undertaken last year by Peter Hall, Peter Taylor and Kostya Borovkov, on a methodology for modelling the time-dependent evolution of customer credit ratings (CCRs) and risk.

Kostya Borovkov and Aihua Xia ran a seminar series on stochastic volatility models in financial mathematics, jointly with a research group at the ANZ Bank, Melbourne. As a result, Andrew Downes will take up a MASCOS PhD Scholarship in 2005, with stochastic volatility modelling as his research project. The seminar series will continue in 2005.

Kostya Borovkov also participated in a credit ranking workshop at ANZ, gaining first-hand experience of the methodology used in financial industry for credit risk management.
INDUSTRY LINKS CONTD.

WITH THE HOWARD FLOREY INSTITUTE:

This project seeks to measure variations in nuclear magnetic resonance spectra of body fluids of people with and without neuropsychiatric diseases such as Alzheimer’s and schizophrenia, using metabonomics and other techniques. This project, still in its early stages, involves participants from 6 collaborating bodies and 14 participating scientists. The MASCOS contribution (in association with Bob Anderssen, CMIS CSIRO) focuses on master curve deconstruction and subtraction technology.

WITH THE DEPARTMENT OF PRIMARY INDUSTRIES, VICTORIA:

This project sought to develop a new cost-effective numerical method and software for estimating age composition of fish populations using otolith (ear stone), body weight and length measurements. DPI staff presented results to the 3rd International Symposium on Fish Otolith Research and Application in July 2004. Peter Hall and Ryan Elmore conducted this project in association with Vladimir Troyinkov (DPI) who provided the data. DPI intends to extend the collaboration through a Fisheries Research and Development Corporation research grant.

WITH THE FINANCE INDUSTRY:

MASCOS at The University of NSW, in association with Pricewaterhouse-Coopers, ran a one-day workshop Managing Fraud, Risk and Churn - Data Mining in the Real World on 13 August 2004. Held at the PwC Corporate Training Centre in Sussex Street, Sydney, it gained considerable profile in the commercial world through a full-page advertisement in the Australian Financial Review, as well as by sponsorship by PwC, which provided the venue, SAS Software and the Institute of Analytics Professionals of Australia. Additional MASCOS and AMSI sponsorship made it possible for postgraduate students to attend. The speakers, Dr Inna Kolyshkina and Richard Brookes of PwC, Jolie Reichel of SAS, and Westpac fraud expert Dr Peter O’Hanlon brought a combination of practical experience and mathematical insight to their presentations of methods to detect fraud and predict churn in large and messy databases. The workshop was opened and participants welcomed by Michael Cowling, MASCOS Associate Investigator and Head of the School of Mathematics at the University of NSW.

MASCOS’s efforts to engage the banking sector were further enhanced by a six-lecture series on Monte Carlo Methods in Finance in Melbourne in July. The series given by Anthony Brockwell of Carnegie-Mellon University, facilitated by Kostya Borovkov and sponsored by AMSI drew an audience of 30.

WITH STAMEN PAPER PTY LTD

David Shteinman, MASCOS Industry Fellow and Managing Director of Stamen Paper Pty Ltd, spoke at the University of NSW on August 19 at a joint Applied Maths/MASCOS seminar entitled “Understanding a Complex Industrial Process: Successes and Difficulties in Model Building and Implementation”. This talk focused on the actual experience of using mathematical and statistical methods to understand a real manufacturing process.

Stamen’s Consumer Packaging Division produces round, oval and specially shaped paper containers for food, cosmetics and other industries. The Division had experienced excessive variation and lack of robustness in key variables in this process.
INDUSTRY LINKS CONT'D.

Classic statistical quality control methods were used to reduce variation in the system. Then Design of Experiments was used to build an empirical model of the process.

David described the initial success with the experiments, and other possible statistical methodologies for further experiments were outlined. Various methods of displaying and interpreting the results of the model were discussed including Response Surface methods. An area to be further researched is the various methods of modelling the effects of uncontrollable noise variables.

The focus of David’s research at MASCOS is on a generic methodology to assist building an “expert system” of an industrial process based on a valid model of the process, rather than historical data. The experience of his own company is being used as a guide.

He plans collaborative work with researchers in the University of NSW’s Schools of Mathematics and Mechanical and Manufacturing Engineering.

WITH ERGON, QUEENSLAND:

Martin O’Hely and Phil Pollett of The University of Queensland undertook a consulting project on stochastic modeling of electricity supply performance indices taking into account seasonal variations in patterns of supply interruptions. They are in the process of negotiating a further collaborative agreement for estimating this year’s performance indices. Their eventual aim is to provide Ergon with a product that automates target prediction.

WITH DSTO, PYRMONT:

Bernard Kachoyan, Head of the Warfare group at DSTO in Pyrmont, spent three weeks visiting the Centre this year as a MASCOS Industry Fellow. It is anticipated that the collaboration will continue and be strengthened by a DSTO-sponsored PhD student working on modelling a battlefield as a dynamical system.

PATENTS

FRAC TALS / IMAGE GENERATORS

Michael Barnsley, an Associate Investigator supported by MASCOS, filed an Australian Provisional Patent (Application No. 2003905602) in 2003. In March this year an International Patent Application was filed and at the same time the ACT Government provided a Knowledge Fund grant of $25,000 to support its further development. A proof of concept DVD was developed to promote the invention to potential investors and this was demonstrated to ANUtech in October.

FATGBM RISKY ASSET MODEL

As reported last year a US Patent (6,643,631; Method and system for modeling financial markets and assets using fractal activity time) was granted to Chris Heyde in 2003 for the FATGBM risky asset model. The patent covers a method and apparatus for improved modelling of random or stochastic systems such as financial markets and instruments. It replaces the Black-Scholes model for the price of a risky asset by an improved model that uses a fractal activity time process instead of a conventional time parameter. Development work continues as a prelude to the commercialization of software containing the FATGBM risky asset model.
OTHER END-USER LINKS

MASCOS CONFERENCES, WORKSHOPS AND SYMPOSIA

The following conferences were sponsored or co-sponsored by MASCOS in 2004. Further information on each can be found at www.complex.org.au.

MATHEMATICAL PHYSICS AND LIE THEORY 2004

Calypso Plaza, Coolangatta, 30 November - 4 December 2004

This workshop featured lectures and contributed talks from international speakers on topics that underpin current trends in mathematical physics and Lie theory. The program covered a wide range of subjects including Lie groups and algebras, quantum algebras, geometric methods, category theory, quantum field theory, conformal field theory, integrable systems, statistical mechanics and quantum information theory.

MULTI-AGENT SYSTEMS AND MACHINE LEARNING

The University of Queensland, 26 November 2004

The fields of probability and statistics, computer science and information technology are becoming increasingly intertwined. A major driving force is the fast growing development and application of new probabilistic and information theoretical approaches to solve complex problems in a wide rage of areas. Applications can be found everywhere: in information technology, applied probability and statistics, engineering, biotechnology, management science, computational science, financial mathematics, economics, physics, machine learning and artificial intelligence.

This workshop, organised by Phil Pollett and co-sponsored by the University of Queensland’s School of Physical Sciences, brought together researchers and students working in the general area of Multi-Agent systems. There were 45 participants, from academia, government and industry.

METAPOPULATIONS

The University of Queensland, 2 September 2004

A metapopulation is a population that occupies several geographically separated habitat patches. Although the individual patches may become empty through local extinction, they may be recolonized through migration from other patches. There is considerable empirical evidence which suggests that a balance between migration and extinction is reached that enables metapopulations to persist for long periods and there has been considerable interest in developing methods which account for the persistence of these populations and which provide an effective means of studying their long-term behaviour before extinction occurs.

This workshop, organised by Phil Pollett, brought together ecologists and mathematicians to examine recent international developments in metapopulation modelling.
OTHER END-USER LINKS CONT'D.

SHORT COURSE ON MONTE CARLO METHODS IN FINANCE

The University of Melbourne, 6-23 August 2004

This short course, conducted by Anthony Brockwell of Carnegie-Mellon University, was organised by Kostya Borovkov and co-sponsored by the Australian Mathematical Sciences Institute.

It was targeted at honours and postgraduate students in quantitative disciplines (mathematics & statistics, actuarial studies etc) and academic staff. The course covered Monte Carlo Integration, Models for Share Prices and Option Pricing.

INTEGRABLE SYSTEMS, RIGOROUS ASYMPTOTICS AND APPLICATIONS

The University of Melbourne, 22-23 August 2004

The study of integrable systems, whilst having a long history, continues to occupy a central role in many areas of contemporary mathematics. Random matrix theory is a subject undergoing rapid development and now lies at the crossroads of many disciplines in mathematics - combinatorics, representation theory, probability theory, statistics, and number theory. It is also a paradigm for complex systems in the quantum domain that are intensively studied in the physical sciences.

This workshop featured Professor Percy Deift, Courant Institute of Mathematical Sciences, New York University who has been central to many of the developments in rigorous asymptotics and is well known for the formulation of the Deift-Zhou method for Riemann-Hilbert problems.

MANAGING FRAUD, RISK AND CHURN - DATA MINING IN THE REAL WORLD

PricewaterhouseCoopers, Sydney, 13 August 2004

This one-day workshop explored how industrial analytics can be used to detect fraud, reduce churn and minimise risk through recent business case studies illustrated using SAS data mining software. The speakers, Dr Inna Kolyshkina and Richard Brookes of PricewaterhouseCoopers, Jolie Reichel of SAS, and Westpac fraud expert Dr Peter O'Hanlon brought a combination of practical experience and mathematical insight to their presentations on methods to detect fraud and predict churn in large and messy databases. This workshop was co-sponsored by PricewaterhouseCoopers, SAS Software and the Institute of Analytics Professionals of Australia.

MATRIX-ANALYTIC METHODS IN STOCHASTIC MODELLING

The University of Melbourne, 23 August 2004

Matrix-analytic methods are fundamental to the analysis of a family of stochastic processes rich in structure and of wide applicability. They are extensively used in the modelling and performance analysis of computer systems, telecommunication networks, network protocols and many other stochastic systems of current commercial and engineering interest.

This tutorial workshop, organised by Peter Taylor, was aimed at graduate students in mathematics, statistics, engineering and related fields. One of the world's foremost experts in these techniques, Professor Guy Latouche of the Universite Libre de Bruxelles, was a presenter.
WINTER SCHOOL IN MATHEMATICS AND COMPUTATIONAL BIOLOGY

The University of Queensland, 5-9 July 2004

The AMSI Winter School was directed primarily at PhD, MSc, and Honours students in scientific disciplines who are interested in Mathematics and Computational Biology. It aimed to introduce concepts, skills, and research problems in forefront areas to the participants other than the direct topics of their study. Topics explored included complex biological systems, pattern analysis and discovery, computational modelling and visualisation of cells, computational complexity and parallel computing and simulation.

WORKSHOP ON PROBABILITY AND ITS APPLICATIONS

The University of Melbourne, 14 May 2004

This workshop, organised by Phil Pollett and Peter Taylor, provided an opportunity for MASCOS PhD students at The University of Melbourne, The University of Queensland and the Australian National University to present their work to their peers. A range of topics including boundary crossing problems, birth and death processes and bandwidth allocation in logical networks were covered.

THE CROSS-ENTROPY METHOD: A NEW APPROACH TO RARE EVENT SIMULATION AND RANDOMIZED OPTIMIZATION

The University of Queensland, 22 January 2004

The cross-entropy method is a powerful and versatile technique for both rare-event simulation and combinatorial optimisation. This symposium, organized by Phil Pollett and featuring Soren Asmussen of the University of Aarhus, highlighted recent developments in the area, including the application of the cross-entropy method to continuous optimization; heavy tails, importance sampling and cross-entropy and the cross-entropy method for network reliability estimation, as well as providing a tutorial introduction to the cross-entropy method.

PROBABILITY APPROXIMATION IN COMPLEX SYSTEMS

The University of Melbourne, 12-14 January 2004

This three-day workshop, organised by Kostya Borovkov and Aihua Xia, comprised invited and contributed talks from international and local speakers which were sparsely distributed so that participants had the opportunity to converse and collaborate with others during recess time. Participants were invited to present talks that focus on probability modelling of problems in complex systems, in which the quality of the modelling is evaluated.
OTHER END-USER LINKS CONTD.

CONFERENCE AND SEMINAR PARTICIPATION

The following MASCOS researchers were invited to present talks at local and international conferences, workshops and seminars:


Josef Dick, Construction algorithms for polynomial lattice rules, MCM, Bedlewo, Poland, June 2004.


Tony Dooley, Approaches to non-singular entropy, Max Planck Institute Bonn, June 2004.

Tony Dooley, Non-Bernoulli systems with completely positive entropy, Max Planck Institute, Bonn, June 2004.

Tony Dooley, The primes contain arbitrarily long arithmetic progressions: d’après Green and Tao, Max Planck Institute, Bonn, June 2004.

Tony Dooley, Wrapping maps and the Kirillov method of orbits, University of Bielefeld, June 2004.


Tony Dooley, Approaches to non-singular entropy, Joint New Zealand-Israel Mathematical Society Meeting, University of Wellington, January 2004.

Ian Enting, Forty years of CO2 inversions: What have we learned? Transcom working group meeting, Tsukuba, Japan, June 2004.
Tony Guttmann, *Correction-to-scaling exponent of SAWs*, University of Bielefeld, Germany, 4 May 2004.

Tony Guttmann, *A canonical model of phase transitions*, University of Bielefeld, Germany, 5 May 2004.


Phil Pollett and Joshua Ross, Costs and decisions in population models, Workshop on Stochastics and their Applications, University of South Australia, 27 September-1 October 2004.


Andrew Rechnitzer, Haruspicy and solvability of lattice models, LaBRI - University of Bordeaux 1, France.

Andrew Rechnitzer, Haruspicy and solvability of lattice models, Department of Mathematics and Statistics, University of St. Andrews, UK.

Andrew Rechnitzer, Haruspicy and solvability of lattice models, Department of Mathematics, Queen Mary, University of London, UK.

Andrew Rechnitzer, Haruspicy and solvability of lattice models, Department of Chemistry, University of Toronto, Canada.

Andrew Rechnitzer, Haruspicy and solvability of lattice models, Special Session on Complex Systems, 48th Annual Meeting of the Australian Mathematical Society, RMIT University, Melbourne, 28 September-1 October 2004.


Colin Rogers, Hidden Structure in Systems with Engineering Applications, Hong Kong University (as William Mong Visiting Research Fellow) June 2004.


Colin Rogers, An Elastic Membrane Model of Liquid Crystal Deformations, Institute of Applied Mechanics, National Taiwan University, September 2004.


Wolfgang Schief, Integrable discretization of harmonic maps. Application to Willmore surfaces, University of Bath, United Kingdom, January 2004.

OTHER END-USER LINKS CONTD.

David Sirl, Quasi-stationary distributions for continuous-time Markov chains, Centro de Modelamiento Matematico, Universidad de Chile, 9 August 2004.


Peter Taylor, AMSI Workshop on Stochastics and Their Applications, University of South Australia, 29 September – 1 October 2004.


Colin Thompson, Spatial optimization for ecological sampling, Setting Priorities and Making Decisions for Conservation Risk Management, UC Santa Barbara, USA, 20-28 March 2004

Darryl Veitch, A Tricky Problem, ISMA 2004 Workshop on Internet Signal Processing (WISP), University of San Diego California, 11-12 November 2004.


Matt Wand, Statistical Learning for Statisticians, XXIIInd International Biometric Conference, Cairns, July 2004


SEMINARY SERIES

The seminar series on Complex Systems initiated by Kostya Borovkov in 2003 continued successfully throughout 2004. Researchers from cognate areas spoke on a variety of subjects relating to complex systems, such as economics and finance, psychology, telecommunications, bio/neuroinformatics, meteorology etc. The audience consisted of honours level and above students, University of Melbourne academics and representatives of R&D departments from companies based in Melbourne.

In addition, Phil Pollett organised a seminar series at The University of Queensland for researchers and postgraduate students in the area of complex systems. This enabled MASCOS PhD Scholars and other research students to network with others with similar interests and to develop their presentation skills.

At the University of NSW Ian Sloan organised an occasional series of seminars with a complex systems theme.

Details of individual talks at both seminar series are as follows:

Matthew Roughan (University of Adelaide):  
Problems in the study of duplicate gene preservation

Martin O’Hely (The University of Queensland):  
Network tomography and internet traffic matrices

Aidan Sudbury (Monash University):  
Annihilating, dimer and blocking processes on lattices and trees

Ian Wilkinson (The University of NSW):  
Complexity and Modelling the Dynamics and Evolution of Business Networks

Antony Stace (The University of Queensland):  
The Volume Weighted Average Option

Joshua Ross (The University of Queensland):  
Diffusion approximation for a metapopulation model with habitat dynamics

Mark S Joshi (QUARC, Royal Bank of Scotland Group Risk Management):  
Pricing discretely sampled path-dependent exotic options using replication methods

David Sirl (The University of Queensland):  
Quasi-stationary distributions for continuous-time Markov chains

Mark Seeto (The University of Queensland):  
The Collision Branching Process and related problems

Peter J. Stemp (The University of Melbourne):  
Solving Economic Models with Saddle-Path Instabilities

Hanjun Zhang (The University of Queensland):  
The decay parameter and the smallest Dirichlet eigenvalue of a birth-death process
R. J. Williams (University of California at San Diego):  
Fluid and Brownian Models of Congestion at Flow Level

John Galloway (NetMap Analytics):  
Train of Thought Analysis using NetMap's Discovery Visualisation Approach

Olena Kravchuk (The University of Queensland):  
Brownian Bridge, the Cramer-von Mises test and the trigonometric score rank test of location

Ben Cairns (The University of Queensland):  
Extinction in metapopulations with environmental stochasticity driven by catastrophes

Darryl Veitch (The University of Melbourne):  
The Internet as Statistical Inspiration

Phil Pollett (The University of Queensland):  
Path integrals for continuous-time Markov chains

David Shteinman (The University of NSW):  
Understanding a complex industrial process: successes and difficulties in model building and implementation

Martin Jacobsen (University of Copenhagen, Denmark):  
The Time To Ruin for a Class of Markov Additive Processes

Lynne Billard (University of Georgia):  
Life expectancies for HIV-infected individuals: a multi-stage model

L. Nick Trefethen (Oxford University):  
Scientific Computing: Past, Present and Future

David T. J. Liley (Swinburne University of Technology):  
Brain dynamics and the electroencephalogram

Andre Costa (The University of Melbourne):  
Exploration, robustness and optimality of network routing algorithms which employ "ant-like" mobile agents

Alex A Sergejew (Mental Health Research Institute):  
Functional cortical connectivity: conceptual comparison of electroencephalographic (EEG) coherence estimates and functional magnetic resonance imaging (fMRI) path

Victor Korotkikh (Central Queensland University):  
Integers for a Unified Theory of Complex Systems

Barry D Hughes (The University of Melbourne):  
Power-law distributions in natural and social systems

Graham Byrnes (The University of Melbourne):  
Estimation of relative frequency of splice variants using real-time rt-PCR
ABOUT THE PROGRAM

MASCOS, in association with the Australian Mathematical Sciences Institute (AMSI), funds a number of Fellowships to enable workers in complex systems from within Australia other than MASCOS Chief Investigators to work full-time for a period of up to 3-4 months with MASCOS Chief Investigators and other MASCOS researchers. These Fellowships provide research-intensive time either as part of or separate from the usual outside studies programs. Fellowships are not restricted to staff of university mathematics and statistics departments.

The fellowships are tenable at the site of the collaborating MASCOS Chief Investigator, i.e. at The University of Melbourne, La Trobe University, the Australian National University, the University of NSW, or The University of Queensland. A flexible financial assistance package is negotiated with each successful applicant, which may include travel and accommodation costs if the Fellow is based elsewhere from the site.

2004 FELLOWS

John Roberts of The University of NSW and Michael Stewart of the University of Sydney were awarded AMSI/MASCOS Fellowships in 2004.

John Roberts’s Fellowship enabled him to collaborate with Reinout Quispel at La Trobe University on the creation of discrete integrable dynamical systems. In particular, their project focused on finding higher dimensional integrable maps. It built on their recent joint work that extended the methods used to create the so-called QRT family of planar integrable maps. Quispel and Roberts have had a long and successful collaboration, having jointly produced five significant publications in the area of discrete integrable systems.

Michael Stewart’s Fellowship enabled him to work with Peter Hall at the Australian National University in the area of inference for mixture models. Hall and Stewart had earlier demonstrated that the statistical problem of distinguishing between a two-component mixture of normal distributions with unknown means and known variances and a pure, single normal distribution (i.e. no mixture) is harder than one might first believe based on standard statistical theory. In 2004, they sought to generalise/expand upon this result through the implementation of appropriate tests and extending it to the multivariate case.

HOW TO APPLY

Applications, including the proposed scientific program, endorsed by the collaborating Chief Investigator, a CV of the applicant and a requested budget should be forwarded to the Director of AMSI, Professor Garth Gaudry, at AMSI, 111 Barry St, c/o The University of Melbourne, Victoria, 3010.

For further information about the AMSI/MASCOS Fellowship program, please contact Tony Guttmann at director@complex.org.au, or Garth Gaudry at garth.gaudry@amsi.org.au.
OTHER END-USER LINKS CONTD.

COOPERATIVE AGREEMENTS

DFG RESEARCH CENTRE FOR KEY TECHNOLOGIES (MATHEON)

On 2 November 2004, MASCOS entered into a cooperative agreement with DFG Research Center for Key Technologies (MATHEON).

This agreement, brokered on behalf of MASCOS by Ian Sloan, establishes a framework for collaboration between MATHEON and MASCOS and builds upon a long history of close cooperation between German and Australian mathematicians, such as the joint Australian/German Workshop on boundary integral equations and Applications, held in Sydney in 1999 and supported by the DFG and the ARC. It has a wider aim to strengthen cooperation between German and Australian mathematicians in areas relevant to key technologies and complex systems.

The cooperation will occur via joint workshops (at least one per year), collaborative research, the development of industry-focused joint projects and an exchange program for researchers and students. Collaboration has already commenced, with MATHEON’s Director Professor Martin Grötschel visiting Sydney and Melbourne in February 2005 to participate in two industry-focused workshops on logistics optimisation.

MATHEON began operating in 2003 with funding of 5 million Euro per annum from the Deutsches Forschungsgemeinschaft (DFG), and additional funding from three cooperating Berlin universities (the Free, Humboldt and Technical Universities) and two research institutes (the Konrad-Zuse Zentrum für Informationstechnik, and the Weierstrass Institute for Applied Analysis and Stochastics). The Key Technologies Center involves more than fifty professional mathematicians. Its research themes include:

- Life sciences (computer-assisted surgery; patient-specific therapies; protein data base analysis; protein conformation dynamics)
- Traffic and communication networks (planning of multi-level and multi-layer communication networks; planning of the UMTS radio interface; line planning, periodic time-tableing, and revenue management in public transport)
- Production (shape memory alloys in airfoils; production of semiconductor crystals; methanol fuel cell optimization; online production planning)
- Electronic circuits and optical technologies (quantum mechanical modelling of optoelectronic devices; design of nano-photonic devices; integrated circuits for future chip generations)
- Finance (measurement and hedging of risks; interaction models for asset price fluctuation)
- Visualization (discrete differential geometry; image processing)
EDUCATION AND TRAINING

MASCOS PhD SCHOLARSHIPS

MASCOS PhD scholarships provide a living allowance of $25,000 p.a. plus an additional $3,000 to meet study-related expenses. Alternatively, MASCOS offers top-ups to students in receipt of Australian Postgraduate Awards to match the value of MASCOS the scholarships.

BEN CAIRNS

Ben Cairns is presently a PhD candidate at the University of Queensland, under the supervision of Phil Pollett.

Ben has worked on continuous-time Markov chains with application to the modelling of populations and analogous processes. He has worked on general upwardly skip-free processes, with particular attention to hitting times and the explosivity of such processes. He has developed a numerical approach to evaluating hitting times for upwardly skip-free processes based on a comparison of two different approaches to truncating from countably infinite to finite state spaces. Ben has also collaborated with members of the Ecology Centre at the University of Queensland, working to applying more complex Markov chains to modelling metapopulations in stochastic environments.

In March 2004, Ben attended the International Workshop in Applied Probability in Piraeus, Greece, as an invited speaker.

YA0-BAN CHAN

Yao-ban Chan is currently in the fourth year of his PhD at The University of Melbourne, under the supervision of Tony Guttmann, Ian Enting, and Andrew Rechnitzer.

He is working on several topics, the most important (but possibly least successful) of which is the corner transfer matrix method for generating series expansions. Other projects include directed n-friendly walkers in a horizontal strip of finite width, mean unknotting times of random knots, phase boundaries in the second-neighbour Ising model, and maximum loop sizes in self-avoiding walks.

JOHN DETHRIDGE

John Dethridge is currently undertaking a PhD at The University of Melbourne under the supervision of Tony Guttmann.

John has worked on the computation of various series related to combinatorial objects on lattices using transfer-matrix and other algorithms. In particular, he has computed series for the mean cluster size and percolation probability for directed and undirected percolation processes, and the generating functions for the number of animals, directed animals, self-avoiding walks, and self-avoiding polygons on different lattices. He is also working on the computation of series related to the Ising model.

He has adapted known algorithms for some of these problems on two-dimensional lattices for use on three-dimensional lattices, which can be computationally much more difficult. John has also investigated exact formulae for the generating functions of combinatorial objects such as self-avoiding polygons on lattices, and sought proofs that certain classes of formulae do not exist or are unlikely to exist for these problems.
EDUCATION AND TRAINING CONT'D.

BENJAMIN GLADWIN

Benjamin Gladwin is undertaking a PhD in the Department of Mathematics at The University of Queensland under the supervision of Thomas Huber and Phil Pollett.

Ben works primarily on long time-scale molecular dynamics. Traditionally, molecular processes are seen from a classical physics perspective and use various forward integration algorithms to provide thermodynamic information from trajectories. These techniques are primarily limited by computational resource constraints.

A series of new algorithms has been proposed which achieve low resolution trajectories of any time scale. One of the difficulties of these approaches is estimation of the overall time in which a molecular process takes place. Ben is using mean first passage times to provide an initial trajectory through the molecules conformation space. This approach reduces errors introduced by poor time-scale estimation. The user is also provided with a starting point for a trajectory search using more traditional deterministic algorithms.

In January 2005, this work was presented as both a contributed talk and poster at the World Association of Theoretically Oriented Chemists triennial Congress in Capetown, South Africa.

Three hole potential used to find initial stochastic approximation to a deterministic path. Transitions between states are selected so that the overall path has the shortest expected total time (Ben Gladwin, 2004)
EDUCATION AND TRAINING CONT'D.

ZHI JUN GUO

Zhi Jun Guo is studying for a PhD at The University of New South Wales under the joint supervision of Ben Goldys and Robert Womersley.

With a focus on implied volatility, he has been reviewing various market-based Markovian local volatility models. He has also been investigating the equivalence between modelling the stock price process directly and modelling its implied volatility. In either case, the underlying stock price process is assumed to follow a one-dimensional diffusion process that may also depend on a number of extra random factors. Exploiting the boundary properties of the squared Bessel process, he has determined the conditions under which equivalent martingale measures can exist in some Cox-Ingersoll-Ross-type financial models, proving that under these models the arbitrage-free condition is not always guaranteed.

KIRK HAMPEL

Kirk Hampel is currently undertaking a PhD at the Australian National University under the supervision of Peter Hall.

Kirk has worked on forecasting the Roll Angular Motion, or side-to-side rocking motion, of ships at sea. Previous work on RAM time series has shown that an ARMA methodology works best. The interpretation of the ARMA model, however, is unrepresentative of the process being modelled. The current State Space reconstruction of the process has led to a better fit of the data, but no consistent gain at the required forecasting interval.

Future work will focus on including mathematical water wave models in the State Space model. Preliminary analysis has been promising.

MOHAMMAD HOSSEINI-NASAB

Mohammad Hosseini-Nasab is undertaking a Ph.D at the Australian National University under the supervision of Peter Hall.

Mohammad's topic is Functional Data Analysis (FDA); specifically he has investigated some properties of Functional Principal Components analysis (PCA) which can be elucidated through stochastic expansions and related results. Mohammad and his supervisor have explored the effect of spacings among eigenvalues on statistical performance of the estimator of the slope in a linear functional regression. They have also suggested bootstrap methods for constructing simultaneous confidence regions for infinite number of eigenvalues as well as for individual eigenvalues and eigenfunctions. Moreover, they have obtained a better rate of convergence for the slope estimator in the functional linear regression. Their work has been accepted as a paper titled "On Properties of Functional Principal Components Analysis" at Journal of Royal Statistical Society, Series B.

When regarding smoothing for estimation of PCA, Mohammad has found out by both theoretical and numerical work that considering another parameter with the smoothing parameter gives a better estimation of eigenfunctions.
TERENCE JEGARAJ

Terry Jegaraj is working towards a PhD under the supervision of Ben Goldys at UNSW. He is currently studying the short time asymptotics of solutions of linear stochastic equations in Hilbert spaces, Ornstein-Uhlenbeck processes. His aim is to find large deviations type results with few assumptions. It is envisaged that this will lead to the investigation of short time asymptotics of solutions of equations with non-linear terms.

MING LI

Ming Li is currently undertaking a PhD at The Australian National University under the supervision of Peter Hall.

Properties of the periodogram, which is widely applied to estimate the period of brightness curves in astronomy, are seldom studied in the setting of nonparametric regression. Ming has worked on the estimation period in nonparametric regression using the periodogram. In particular, Ming has investigated the asymptotic properties of the maximum-periodogram period estimators for uniform design and periodic design and proved that the estimators converge at a fast rate. He also extended the approach to the multi-periodic case and provided a quantitative method to identify the number of periods and determine the periods in the underlying model. Ming has also discussed and illustrated the method by numerical simulations and application to a real dataset.

In 2004, Ming presented "Using the periodogram to estimate period in nonparametric regression" to the sixth International Chinese Statistical Association (ICSA) meeting in Singapore.

ALLAN MOTYER

Allan Motyer commenced as a MASCOS PhD scholar at the University of Melbourne in February 2004. Allan is studying Quasi-Birth-and-Death (QBD) processes with an infinite phase space, under the supervision of Peter Taylor.

A QBD process is a two-dimensional continuous-time Markov chain for which the generator has a block-tridiagonal structure. The first component of the QBD process is called the level, the second component the phase. It is known that the level process of a positive-recurrent QBD process with a finite phase space possesses a stationary distribution which decays geometrically as the level is increased. For QBD processes with an infinite phase space, the focus of Allan’s research, the situation becomes more complicated. Allan has worked on formulating conditions that must be satisfied by the stationary distribution decay rate of an infinite phase space QBD process.

In 2004, Allan was awarded the Stella Mary Langford Scholarship at the University of Melbourne, a postgraduate scholarship held in conjunction with his MASCOS top-up scholarship.
ANA NOVAK

Ana Novak is currently undertaking a PhD at The University of Melbourne under the supervision of Peter Taylor (Dpt. Mathematics and Statistics) and Darryl Veitch (CUBIN).

Ana Novak is working on an Active Probing Project with an aim to develop a generic multiple hop route model. Active probing is a technique which involves injecting an artificial stream of packets (or probes) into the network and monitoring its behaviour at different controlled exit points. The primary advantage of using active measurement (or active probing) is its end-to-end nature, which allows non-privileged users to probe the structure of Internet traffic. Active probing can be used to extract various types of information from the network, such as: bandwidth, background or cross traffic rate, network load and packet size.

Ana has commenced the analysis of the network by first considering the single hop model. She has developed new techniques used to estimate the size and the arrival rate of the underlying traffic of a single-hop network. She also found the exact distribution that models the number of packets that arrive between the probes in a busy period of a single server queue. She is now working on a tandem-queue problem with the aim of extending to a generalized network model.

REZA PAKYARI

Reza Pakyari is currently undertaking a PhD at the Australian National University under the supervision of Peter Hall.

Reza has worked on the nonparametric inference in mixture models. In particular, he has focused on a novel nonparametric estimation method of the mixing proportions and the component distributions in multivariate mixtures. His method is based on solving simultaneous equations, involving sub-populations, that arise from a multivariate mixture under the assumption on independent marginals. A lot of simulation work has been done to evaluate the performance of his proposed estimators under various distributions.

A research paper based on Reza’s thesis together with work by Peter Hall, Amnon Neeman and Ryan Elmore has been accepted for publication in the journal Biometrika.

NATHAN PEARCE

Nathan Pearce is a PhD candidate at the University of New South Wales, under the supervision of Matt Wand.

Nathan has been undertaking research in the field of Support Vector Machines for classification. Of particular interest is low-rank Support Vector Machines. Methods for kernel parameter selection, as well as feature selection play a role. He has applied some of his research to real-life data sets. Nathan has also investigated the relationship between penalised splines and reproducing kernel methods.
MAYA RAMAKRISHNAN

Maya Ramakrishnan is currently undertaking a PhD at The University of Melbourne under the supervision of Peter Taylor and Andre Costa.

Maya is working in the area of telecommunication systems modelling. In particular, she has considered distributed bandwidth re-allocation schemes that are able to operate in logically connected networks. When parameters are static or slowly time-varying, the problem can be solved using non-linear optimisation techniques. Heuristic algorithms that are based on these methods have also been investigated. Improved schemes, utilising current information about the state of the network have been considered. Distributions of various transient characteristics of the Erlang loss model have been derived for this purpose, primarily through the use of transforms and numerical inversion.

In 2004, Maya presented work at the Melbourne - Adelaide tele-traffic workshop. More recently, she has presented her work at The Australian Postgraduate Workshop on Stochastic Processes and Modelling in Brisbane, and at the Australia-New Zealand Industrial and Applied Maths (ANZIAM) Conference in Napier, where she received an honourable mention for her presentation.

JOSHUA ROSS

Joshua Ross commenced his PhD studies in 2004 at the University of Queensland. Supervised by Phil Pollett, his research is in the area of stochastic modelling with applications to ecological systems.

Joshua has developed stochastic models, for classical and mainland-island metapopulations, that incorporate habitat dynamics. He has shown that suitably scaled versions of the models converge, uniformly in probability over finite time intervals, to unique deterministic models. He derived limit laws for the densities of suitable and occupied patches and was able to conclude, under quite general conditions, that the densities have approximate bivariate normal distributions. Joshua used these results to investigate the effects of habitat dynamics on metapopulation dynamics, and the effects of a mainland on metapopulations in dynamic landscapes. He has submitted two papers to international journals, was awarded an IMS Laha Travel Award to present his work at the 6th Joint Meeting of the IMS and the Bernoulli Society in Barcelona, and has also given an invited talk on the topic.

Joshua has presented a further three invited talks. One on a diffusion approximation for a spatially realistic structured metapopulation model, and two on joint work with Phil Pollett investigating the costs and decisions of controlling populations.
ANTONY STACE

Antony Stace is currently undertaking a PhD at The University of Queensland under the supervision of Graeme Chandler, Phil Pollett and Elliot Tonkes.

Antony is working on the valuation of a Volume Weighted Average Price option (VWAP). This is an option which has a strike which is a VWAP. He has obtained a number of results about these options including an approximation to the price by moment matching and also a series solution.

Antony is currently investigating a numerical solution to the partial differential equation which describes the price of the option by finite differences which presents a number of challenges. Simple finite difference methods are impractical due to the curse of dimensionality. So alternating direction implicit and splitting methods are being investigated.

Moment matching approximation to the price of a volume weighted average price fixed strike option (Antony Stace, 2004)
EDUCATION AND TRAINING CONTD.

ROBERT TAGGART

Robert Taggart is currently undertaking a PhD at The University of New South Wales under the supervision of Michael Cowling and is just completing his first year of study.

Robert is studying abstract semigroup theory with the aim of finding connections to partial differential equation theory. In particular, inequalities known as Strichartz estimates can be used to prove the existence of solutions to the heat, wave and Schrodinger equations in certain settings.

Robert is using semigroup theory to investigate conditions under which such estimates exist or fail to exist. In connection with these investigations Robert has adapted certain techniques, such as transference and interpolation, for fruitful use in the setting where he works.

BEN WATERHOUSE

Ben Waterhouse has been pursuing a PhD in applied mathematics with Ian Sloan and Frances Kuo. He began his studies in early 2004.

Ben is working in the area of quasi-Monte Carlo methods for high-dimensional numerical integration. Ben is about to submit his first paper which is co-authored with Ian Sloan and Frances Kuo. This paper generalises the function spaces for numerical integration to include functions which are unbounded on the boundaries of the unit cube. This is a known feature of many problems encountered in mathematical finance and thus has a wide range of applications.

Ben attended the MC2QMC conference in Juan-les-Pins, France and the MCM2004 in Bedlewo, Poland in June 2004 and gave a talk at the workshop for High Dimensional Approximation at the ANU in February 2005.

OTHER EDUCATIONAL ACTIVITIES

In 2004, Tony Guttmann co-ordinated The University of Melbourne/BHP Billiton School Mathematics Competition with Allen Russell and Paul Norbury. On 13 August 2004, he was presented with an Australian Mathematics Trust B H Neumann Award by The University of Melbourne’s Deputy Vice-Chancellor (Academic) Peter McPhee and AMT Director Dr Peter Taylor in recognition of his work during the past decade in this regard. He also lectured to gifted high school students as part of an enrichment program conducted by the Department of Mathematics and Statistics at The University of Melbourne.

MASCOS has worked cooperatively with ICE-EM (International Centre of Excellence for Education in Mathematics) in responding to requests for mathematical enrichment from schools. Case studies for career posters and brochures have also been provided.

Ben Cairns and Ben Gladwin (MASCOS PhD Scholars) recently served as presenters as part of The University of Queensland’s Experience Science, a series of workshops for year 11 and 12 students interested in enrolling in a science degree. They also presented a workshop at this year’s Siemens Science Experience (for year 9 students).


