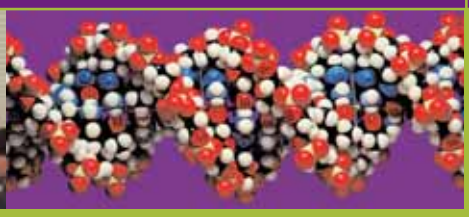




ARC Centre for Complex Systems

annual report 2006

ARC CENTRE FOR
COMPLEX SYSTEMS

Contents

Introduction to the Centre

Complex systems science is an emerging discipline developing new ways of investigating large, highly intricate, dynamically changing systems across diverse areas such as biology, social networks and socio-technological systems, economics, ecology and the environment.

The ARC Centre for Complex Systems (ACCS) was established in 2004 to conduct world-class basic and applied research on questions key to understanding, designing and managing complex systems. The goal is to develop a deeper understanding of fundamental phenomena in complex systems, such as how macro-level system properties and behaviours emerge from relatively simple micro-level interactions, what mechanisms enable complex systems to self-organise, and how complex systems can be managed and controlled.

The Centre provides a focus for complex systems science research in Australia, and is developing strong engineering infrastructure for modelling and analysing network-based systems, including high-performance computing and visualisation facilities, to enable the science to be applied to real-world problems. The resulting methods and tools are being used to understand, manage and control complex systems.

The Centre is headquartered at the University of Queensland in Brisbane, with nodes at Griffith University in Brisbane, Monash University in Melbourne, and the University of New South Wales at the Australian Defence Force Academy (UNSW@ADFA) in Canberra. The Centre brings together leading researchers from a range of disciplines including systems and software engineering, visualisation, human factors, mathematics and statistics, and relevant application domains, including aerospace, economics and biology. Funding is provided by the Australian Research Council (ARC) and the universities involved. Industry collaborations and further funding will be established over the life of the program in order to apply the Centre's research

What is a Complex System?

Complexity is the richness in structure and behaviour often seen in large systems. The property that distinguishes complex systems from systems that are merely large but simple is the emergence of global features from local interactions, as captured in the popular saying 'the whole is greater than the sum of its parts.' For example, a flock of birds emerges when individual birds coordinate their behaviour with each other.

[quoted from Green, D.G. and Bransden, T.G. Complexity Theory, in *McGraw-Hill Encyclopedia of Science and Technology*. McGraw-Hill, New York, 2006. pp. 507-511].

Director's Report

2006 was a big year for the ARC Centre for Complex System (ACCS). The Centre has established itself as one of the leading centres in Australia, if not the world, in studying distributed control in network-based systems from a multi-disciplinary viewpoint.

Three very different forms of distributed control mechanisms have been addressed:

- organic control mechanisms as displayed in biology, such as how genes interact during the development of an organism, to influence the placement and function of cells;
- engineered control mechanisms as displayed in socio-technical systems such as air traffic control, where humans with computer-based tools interact in a highly structured manner to achieve whole-of-system properties such as safety and efficiency; and
- market-based control mechanisms, where agents with partial information interact within a set of rules to optimise economic outcomes.

The Centre's *modus operandi* has been to use modern agent-based computer modelling techniques to simulate complex systems, to study what makes them robust against failures of their components, and conversely, what causes systems to fail. What is particularly notable about the ACCS is that it has successfully brought together researchers from very different research disciplines to work together on problems of national and international significance. We are the only centre nationally, and one of few internationally, with this level of expertise.

The Centre has developed powerful modelling tool-kits that integrate techniques from computational science, grid computing, graph theory, visualisation, data mining and machine learning, to significantly enhance the kinds of analysis that can be undertaken on complex systems. The use of modern software engineering techniques means that the resulting models can be adapted, extended and integrated easily.

Examples of how the Centre's research is contributing to the nation's wellbeing include the following:

- The Genetic Regulatory Networks program is collaborating with CSIRO Livestock Industries to develop innovative new ways of selecting cattle for breeding, based on predictions of muscle yield and resistance to disease. ACCS modelling tools are also enabling biologists to gain fundamental new insights into gene regulation, and to develop and test new hypotheses before undertaking experiments in wet laboratories. This, in turn, is expected to lead to new breakthroughs in health and medicine, as well as making fundamental contributions to the advancement of knowledge.
- The Air Traffic Control program is developing methodologies and tools to help improve the safety and efficiency of Australia's air traffic system. Through its collaboration with the Key Centre for Human Factors and Airservices Australia, the Centre is developing models and tools that will enable en-route control of aircraft to be improved, leading to less delays and shorter travel times. This, in turn, is expected to reduce fuel usage and greenhouse gas emissions, as well as making the system more predictable. Australia is taking a lead international role in the area, being an early adopter of advanced technologies and work practices.
- In the Evolutionary Economic Systems program, one of our projects is concerned with sedimentation flowing from rivers into the Great Barrier Reef marine ecosystem – with implications for the economic, social and cultural wellbeing of the region. Another project is concerned with the recently deregulated electricity market and with overcoming barriers that are currently limiting expansion of the electricity network to include new 'green' energy sources.

The Centre also provides an excellent training environment for postgraduate students, providing them with access to expertise, high performance computing facilities, real-life problems and data in quantities that would not normally be available to researchers working in smaller groups.

In September 2006, the Centre was reviewed by the Australian Research Council (ARC) and came through with flying colours. The ARC Review Panel, chaired by Dr Bob Watts, former Chief Scientist with BHP Billiton, found that 'the Centre provided a supportive and stimulating environment in a broad range of disciplines constructing effective models for a variety of important applications'. I would like to thank everyone who contributed to preparation for the review, particularly the Centre Manager Virginia Garton and the Office of the Deputy Vice Chancellor (Research) at UQ. We were greatly encouraged by the range of high-standing organisations and researchers who joined us in our extension proposal.

2006 was also a year of consolidation for the Centre. We exceeded targets for most of our key performance indicators. One of the main measures of our success is the degree to which our research impacts on thinking about systems and helps solve problems that were previously intractable. As will be evident from the research project reports below and the growing number of people participating in ACCS projects, our methods and tools are at the cutting edge of innovative research in a wide range of problem areas over and above our four main areas. Our research is published widely and our researchers are having great success in demonstrating the value of innovative complex-systems thinking and techniques in many new areas.

This year, new collaborations started with CSIRO Livestock Division and Queensland Health. We also conducted workshops with organisations including Boeing Australia, Airservices Australia, the University of Sydney's Warren Centre and Education Queensland.

This year's Winter School was held in June at UNSW@ADFA in Canberra and attracted 40 participants. I thank Prof Hussein Abbass and his team for organising the event. Prof John Quiggin gave a public lecture on 'Complexity, Climate Change and the Precautionary Principle' in the Brisbane CBD in August 2006 that was well attended. Monash University centre staff held a 3-day Nimrod training course in Brisbane to train centre staff and students in grid computing.

In closing I would like to thank everyone who helped in putting this Annual Report together, but especially Carol Stirk, Virginia Garton, John Hawkins and Leanne Brandis. Thanks to Christine Clarke and Staff from Studio 55 for doing the final layout.

Peter Lindsay
Director, ACCS
March 2007

Why Research Complex Systems?

What do recombining genes have in common with air traffic control and with farmers irrigating their fields?

The answer is that they are all activities involving agents interacting in networks, which result in systems that have very interesting, and often unexpected, properties. The common thread is that the agents act largely autonomously, and yet the system behaves in an apparently controlled manner.

- Biologists have discovered that certain sets of genes work together in networks to regulate cell growth, determining for example what kinds of new cells will be produced when cells split and where the new cells will be positioned. The resulting system – a biological organism – can be fascinatingly complex, as we all know.
- Air travel can be a highly efficient way of travelling from point A to point B but, with the continued growth in air travel, air traffic systems are increasingly coming close to overload. Small changes in traffic flow can lead to large delays further downstream, as the effects propagate through the air traffic network. A storm over Dallas, Texas, for example, can result in flights being grounded thousands of miles away in New York, with all the resulting chaos and missed connections. The traffic network is not as robust as travellers would wish.
- Farmers' use of water and fertiliser can have severe effects on conditions downstream if usage patterns of different farmers happen to combine in unintended ways. Major environmental problems with water quality, salinity and sedimentation have arisen in Australia's major river systems due to measures that have addressed local problems but have failed to take their system-wide impact into account.

In all of these cases, there is a need for better understanding of how high-level properties emerge from largely independent system elements acting in networks.

The ARC Centre for Complex Systems (ACCS) was established to investigate these kinds of problems and to develop methods and tools to help solve them. The Centre's mission is to conduct world-class basic and applied research on questions fundamental to understanding, designing and managing complex network-based systems. To provide focus to its research program, the Centre has four core application areas – genetic regulatory networks, air traffic control, evolutionary economic systems, and dependable computer-based systems – which are described in more detail later in this Report.

Centre Personnel

The ACCS fosters the emerging discipline of complex systems within Australia by creating a critical mass of researchers. Currently the Centre brings together a strong, interdisciplinary team across four major Australian universities.

	School/Unit	Institution
Director		
Prof Peter Lindsay	Information Technology & Electrical Engineering	The University of Queensland
Deputy Director		
Prof Ian Hayes	Information Technology & Electrical Engineering	The University of Queensland
Chief Investigators		
Assoc Prof Hussein Abbass	Information Technology & Electrical Engineering	UNSW @ ADFA
Prof David Abramson	Computer Science & Software Engineering	Monash University
Prof Peter Adams	Mathematics	The University of Queensland
Prof Kevin Burrage	Mathematics	The University of Queensland
Prof Geoff Dromey	Information and Communication Technology	Griffith University
Prof John Foster	Economics	The University of Queensland
Prof David Green	Computer Science & Software Engineering	Monash University
Prof Simon Kaplan	Information Technology	Queensland University of Technology
Prof Geoff McLachlan	Mathematics	The University of Queensland
Prof Bernard Pailthorpe	Mathematics	The University of Queensland
Prof John Quiggin	Economics	The University of Queensland
Prof Penelope Sanderson	Psychology/Information Technology & Electrical Engineering	The University of Queensland
Prof Janet Wiles	Information Technology & Electrical Engineering	The University of Queensland
Partner Investigators		
Prof Kalyanmoy Deb	Mechanical Engineering	Indian Institute of Technology, Dehli, India
Mr Rick Neilson	Chief Engineer	Boeing Australia
Mr Julian Robins	General Manager Engineering & Mission Assurance	Boeing Australia
Dr Guy Theraulaz	Centre de Recherches sur la Cognition Animale	University Paul Sabatier, Toulouse, France
Centre Admin & Technical Support Staff		
Ms Virginia Garton	Centre Manager	The University of Queensland
Ms Leanne Brandis	Education Officer	The University of Queensland
Mr Leighton Brough	Tools Coordinator	The University of Queensland
Mr John Hawkins	Webmaster	The University of Queensland
Mrs Diana Dragisic	Administrative Support	The University of Queensland
Mrs Carol Stirk	Acting Education Officer	The University of Queensland
Collaborators		
Dr Michael Barlow	Information Technology & Electrical Engineering	UNSW @ ADFA
Dr Rodney Beard	Environmental Sciences	The University of East Anglia, Norwich, UK
Dr Christine Beveridge	ARC Centre of Excellence for Integrative Legume Research	The University of Queensland
Dr Mikael Bodén	Information Technology & Electrical Engineering	The University of Queensland
Dr Scott Bolland	Key Centre for Human Factors & Applied Cognitive Psychology	The University of Queensland
Mr Daniel Bradley	Institute for Molecular Bioscience	The University of Queensland
Dr Margot Brereton	Information Technology & Electrical Engineering	The University of Queensland
Dr Darryn Bryant	Mathematics	The University of Queensland
Mr Gerard Champion	Brisbane Operations	Airservices Australia
Dr David Chen	Information & Communication Technology	Griffith University
Dr Peter Corke	Autonomous Systems Laboratory	CSIRO ICT
Dr David Cornforth	Information Technology & Electrical Engineering	UNSW @ ADFA
Dr Richard Davis	Integrated Capabilities Branch	Defence Science & Technology Organisation
Dr Zhao Yang Dong	Information Technology & Electrical Engineering	The University of Queensland
Dr Daryl Essam	Information Technology & Electrical Engineering	UNSW @ ADFA
Dr Marcus Gallagher	Information Technology & Electrical Engineering	The University of Queensland
Mr Slavisa Garic	Computer Science & Software Engineering	Monash University
Prof Peter Gresshoff	ARC Centre of Excellence for Integrative Legume Research	The University of Queensland
Dr Jennifer Hallinan	Centre for Integrated Systems Biology of Ageing and Nutrition	University of Newcastle on Tyne, UK
Dr Karen Harris		Educational Testing Service, Princeton, New Jersey, USA
Dr Jim Haseloff	Department of Plant Sciences	University of Cambridge, UK
Dr George Havas	Information Technology & Electrical Engineering	The University of Queensland
Prof Melvin Hinich	Department of Government	The University of Texas at Austin, USA
Dr Peter Kwantes	Simulation & Modelling (SMART)	Defence Research & Development, Canada

	School/Unit	Institution
Collaborators		
Dr Tatiana Marquez Lago	Advanced Computational Modelling Centre	The University of Queensland
Dr Andre Leier	Advanced Computational Modelling Centre	The University of Queensland
Dr Barbara Maenhaut	Mathematics	The University of Queensland
Mr Greg McDonald	Future Direction Group	Airservices Australia
Dr Stuart McDonald	Social and Information Sciences Laboratory	California Institute of Technology, USA
Dr Keith Mitchelson	Research & Technology	Australian Genome Research Facility
Dr Andrew Neal	Key Centre for Human Factors & Applied Cognitive Psychology	The University of Queensland
Dr Mark Neal	Risk and Sustainable Management Group	The University of Queensland
Dr David Newth	Environmental & Information Sciences	CSIRO Complex Systems Science
Prof Stefano Nolfi	Institute of Cognitive Sciences & Technologies	National Research Council (CNR), Italy
Mr Tom Peachey	Computer Science & Software Engineering	Monash University
Dr Jason Potts	ARC Centre of Excellence for Creative Industries and Innovation	Queensland University of Technology
Prof Mark Ragan	ARC Centre in Bioinformatics	The University of Queensland
Dr Peter Robinson	Information Technology & Electrical Engineering	The University of Queensland
Dr Suzanne Sadedin	Information Technology	Monash University
Dr Ruhul Sarker	Information Technology & Electrical Engineering	UNSW @ ADFA
Dr John Steen	UQ Business School	The University of Queensland
Prof Anne Street	Centre for Discrete Mathematics & Computing	The University of Queensland
Prof Chengzheng Sun	School of Computer Engineering	Nanyang Technological University, Singapore
Dr Jeff Tan	Computer Science & Software Engineering	Monash University
Assoc Prof Kay Chen Tan	Electrical & Computer Engineering	National University of Singapore
Dr Geoff Walker	Information Technology & Electrical Engineering	The University of Queensland
Dr Yubin Yang	Information Technology & Electrical Engineering	UNSW @ ADFA
Prof Xin Yao	Centre of Excellence for Research in Computational Intelligence & Applications	The University of Birmingham, UK
Research Staff		
Ms Maria Aneiros	ACCS	Griffith University
Mr Blair Bethwaite	ACCS	Monash University
Mr Lam Bui	ACCS	UNSW @ ADFA
Mr Clement Chu	ACCS	Monash University
Dr Robert Colvin	ACCS	The University of Queensland
Mr Simon Connelly	ACCS	The University of Queensland
Ms Jingru Dai	ACCS	The University of Queensland
Mr Colin Enticott	ACCS	Monash University
Dr Nic Geard	ACCS	The University of Queensland
Dr Ken Gray	ACCS	The University of Queensland
Dr Lars Grunske	ACCS	The University of Queensland
Dr Jim Hanan	ACCS	The University of Queensland
Mr John Hawkins	ACCS	The University of Queensland
Mr Tim Kastelle	ACCS	The University of Queensland
Ms Diana Kirk	ACCS	Griffith University
Ms Tania Leishman	ACCS	Monash University
Dr Ariel Liebman	ACCS	The University of Queensland
Mr Samuel Macaulay	ACCS	The University of Queensland
Dr Rizah Memisevic	ACCS	The University of Queensland
Mr Martijn Mooij	ACCS	The University of Queensland
Mr Alex Tee Neng Heng	ACCS	Monash University
Dr Minh Ha Nguyen	ACCS	UNSW @ ADFA
Dr Daniel Powell	ACCS	Griffith University
Mr Fan Qi	ACCS	UNSW @ ADFA
Dr Colin Ramsay	ACCS	The University of Queensland
Mr Tim Rudge	ACCS	The University of Queensland
Mr Liam Wagner	ACCS	The University of Queensland
Mr Junhua Wang	ACCS	The University of Queensland
Dr James Watson	ACCS	The University of Queensland
Mr Lian Wen	ACCS	Griffith University
Dr Jacqueline Wicks	ACCS	The University of Queensland
Dr Phillip Wild	ACCS	The University of Queensland
Dr Kai Willadsen	ACCS	The University of Queensland
Dr Kirsten Winter	ACCS	The University of Queensland
Ms Nisansala Yatapanage	ACCS	Griffith University

Research Staff list does not include Summer Students (See page 31)

Management

Management of the Centre involves the Executive, the Research Advisory Committee and the Advisory Board.

The Research Advisory Committee comprises the Centre Chief Investigators and the Chair of the Advisory Board. This Committee meets twice annually to review the Centre's research and research plans. The Chief Investigators also meet on two other occasions throughout the year. A Research Higher Degree (RHD) Committee manages student matters.

Advisory Board

The Advisory Board meets once per year to offer advice regarding the scientific focus and vision of the Centre, its structure and general operating principles, and intellectual property and commercialisation management.

The Advisory Board provides broad representation from the research and end-user communities.

The following people were members of the Advisory Board in 2006:

Dr John Finnigan (Chair)
Director, Centre for Complex System Science, CSIRO, Canberra, ACT

Professor Paul Bailes
Head of School, School of Information Technology & Electrical Engineering, The University of Queensland, St Lucia, Qld

Professor Edwina Cornish
Deputy Vice Chancellor & Vice President, Research, Monash University, Clayton, Victoria

Dr Richard Davis
Research Leader, Integrated Capabilities Branch, Defence Systems Analysis Division, DSTO, Canberra, ACT

Professor John Foster
Head of School, School of Economics, The University of Queensland, St Lucia, Qld

Professor Peter Lindsay (Director)
Boeing Professor of Systems Engineering, School of Information Technology & Electrical Engineering, The University of Queensland, St Lucia, Qld

Mr Julian Robins
General Manager, Engineering & Mission Assurance, Boeing Australia, Brisbane, Qld

Professor David Siddle
Deputy Vice Chancellor – Research, The University of Queensland, St Lucia, Qld

Mr Colin Tuckerman
Manager, Capability Planning, Future Directions Division, Airservices Australia, Canberra, ACT

Professor Stephen Walker
Executive Dean, Faculty of Engineering, Physical Sciences and Architecture, The University of Queensland, St Lucia, Qld

The Centre would like to thank Rick Neilson of Boeing Australia, and Keith Orkney of Airservices Australia, for their valuable contributions to the Centre Advisory Board over the past years.

Recognition of Centre Personnel

Centre PhD student Nic Geard's thesis on computational modelling of developing organisms won the Distinguished Doctoral Dissertation Award from the Computing Research and Education Association of Australasia, the association of university departments of computer science in Australia and New Zealand. Nic completed a 6-month postdoctoral fellowship with the ACCS in 2006 and will take up a prestigious EPSRC-funded postdoctoral position at the University of Southampton in the UK in 2007.


Katherine Duczmal

Centre student Katherine Duczmal was awarded the University Medal and The University of Queensland Australian Computer Society Prize for her academic achievements while undertaking her honours project 'Agent-based virtual insects'. She was advised by Centre personnel Peter Robinson and Jim Hanan. Katherine is now working at the Defence Science and Technology Organisation on artificial intelligence and information security research.

Centre Chief Investigator Peter Adams was awarded a prestigious Carrick 2006 National Associate Teaching Fellowship. He will work on techniques for improving the teaching and learning of quantitative principles in Life Sciences education, with Professor Philip Poronnik from UQ's School of Biomedical Sciences. Peter was also awarded a large grant by the Carrick Institute to improve higher education learning and teaching practices in Australia by helping students overcome a fear of mathematics.

Other Centre Chief Investigator news in 2006 included the following: Hussein Abbass was appointed Founding Director of the Defence & Security Applications Research Centre; David Abramson was awarded an ARC Professorial Fellowship; and David Abramson and John Foster were appointed to the ARC College of Experts.

Research Program

Through joint applied projects with collaborators, the Centre links existing Australian research strengths and builds new capacity for interdisciplinary, collaborative approaches to address the most challenging and significant research problems.

Through its research program, the Centre explores both the science and the engineering of complex systems.

In the science stream of its research program, the Centre aims to develop a coherent set of theories, computational techniques and modelling tools for network-based systems. The aim is to capture how natural systems self-organise and adapt, and then apply those insights to other areas.

The engineering stream of the Centre's research program is concerned with providing a modelling framework, theory, toolset, and infrastructure to enable complex-systems researchers to build powerful models and simulations economically and reliably. The aim is to facilitate the application of the theories to real-world systems, and to develop principles for managing (planning and controlling) complex systems.

The Centre's core ARC-funded program is based around four application areas:

- genetic regulatory networks,
- air traffic control,
- evolutionary economic systems, and
- dependable computer-based systems.

These programs are supported by projects concerned with improved methods and tools for analysing and developing complex systems. External funding is used to apply Centre results to government and industry problems.

Genetic Regulatory Networks

Program Leader: Janet Wiles

Research in the GRN program tackles fundamental questions about growth and form in cellular biology. In this program, computational modelling is used to study how the control of development results from an interaction between each cell's genetic regulatory network and its inputs from neighbouring cells and its environment, and how the process proceeds reliably, while coping with unreliable components, perturbation, injury, and changing environments.

Developmental complexity and bias: modelling and visualisation

Project Leader: Janet Wiles
Researcher: Nic Geard

The development and evolution of biological organisms are highly complex processes. A single egg cell contains in its genome the information to produce an adult form. Evolution, of millions of years, has produced a diverse range of different forms. Biology currently lacks a comprehensive theoretical framework for understanding how development interacts with evolution. Computational modelling is a methodology that, by focusing attention on the core aspects of a complex system, can enable novel insights into its behaviour. The aim of this project is to produce two journal submissions based on Nic Geard's recently submitted PhD thesis. The first will describe the interactive visualisation software tools developed to visualise the complexity of model developmental systems. The second will report the insights obtained into the way in which the intrinsic dynamics of a model developmental system can bias its functional behaviour, and the implications this has for the direction of evolution.

In 2006, a modelling and visualisation framework was developed for exploring the interactions that occur between development and evolution. This framework allowed us to visualise both individual cell lineages and how these lineages vary over evolutionary space. The most important theoretical finding that emerged from this research was the manner in which the dynamics of a developmental system can influence the direction of evolution. Furthermore, the use of computational modelling as a methodology enables a rigorous and quantitative approach to investigating and evaluating hypotheses that are otherwise often framed in a general fashion.

Modelling ontogenetic control points

Project Leader: Janet Wiles
Researcher: James Watson

Biology rarely reinvents the wheel. Evolution has produced points of control, such as hox genes, that enable the effective reuse and adaption of existing biological components, and thus the development and maintenance of increasingly complex organisms. Components from nucleotides through to cells and tissues similarly offer forms of 'biological abstraction' that allow the genetic system to control complex biological systems operating in noisy environments. Being abstractions, computational models of GRNs are most effective when they target these points of control. This project has two goals. The first is to identify and model these control points. A software pipeline connecting ontogenetic levels (nucleotide to regulation to morphology) is being used as the basis for modelling these mechanisms. The second goal is to investigate the application of these mechanisms, which have been honed by millions of years of evolutionary constraints, to the control of other complex systems across the ACCS's programs.

In 2006, to make existing ACCS GRN software available to a wider computational modelling community, a reusable library of in-house modelling software (named CoolKit) has been initiated. This library is being developed in collaboration with Jared Moore, an ACCS summer scholar. A revision of an existing software suite that ties together computational models of a genetic sequence, regulatory network, plant development, and evolution, has been undertaken to capitalise on existing distributed computing facilities. A 3D model of early sponge development, based on simple interactions between cells and simulated annealing, has been implemented.

Applying complex systems models to muscle-specific gene

Project Leader: Janet Wiles
Researcher: Kai Willadsen

This project aims to apply complex systems modelling techniques to existing biological problems of interest to industry through collaboration with researchers within CSIRO Livestock Industries. This research focuses on a gene network model for muscle formation in cattle recently developed by CSIRO researchers. Previous research has explored the structure of this network using an evolutionary technique to determine possible extreme phenotypes when Myogenin is inactivated; Myogenin is a muscle-specific transcription factor whose inactivation is known to cause a severe reduction in muscle development. In this project, complex systems-based approaches, including Boolean networks and neural networks, are being used to explore the dynamics and the robustness of this gene coexpression network.

In 2006, the muscle-specific myogenin gene network provided by CSIRO was adapted for simulation using complex-systems modelling techniques. A modelling framework was developed and used to simulate and analyse this network. Methods for dealing with uncertainty and different interpretations of network behaviour were introduced and software support tools for these methods were written. Preliminary results based on the analyses of the framework were presented to CSIRO researchers. Findings on the methodological challenges involved in this project have been recorded in a technical report, which is in the process of being finalised.

Modelling regulatory networks at cell, tissue and organism level

Project Leader: Jim Hanan
Researchers: Janet Wiles, Kevin Burrage

Computer-aided models of biological regulatory networks are a cornerstone of systems biology, promising to transform biological research by providing a framework for (1) systematic investigation of hypothesised network structures; (2) management of data on large numbers of system components and interactions; and (3) allowing simulation studies to reveal emergent properties and consequences of hypothesised networks. Development and application of an agent-based generative modelling system are being explored, allowing simulation of regulatory networks within a developing spatial structure at cellular, tissue and organism levels. From a computational standpoint, topological connections of structures within a cell and within a layer of tissue can be treated with the same abstractions. Analysis of the complex system models expressed with this special purpose toolkit is being carried out to extract general software engineering principles, particularly for developing further software methodologies and notations, and for investigation of mechanisms for managing and controlling complex systems for transfer to other domains of application.

In 2006, the model of autoregulation of nodulation developed in collaboration with the ARC Centre of Excellence in Integrative Legume Research (CILR) was presented at international conferences in Brisbane, Adelaide and Holland. Carlos Espinosa from the University of Mexico visited, collaborating on genotype-phenotype modelling. A prototype model integrating a Petri net simulation system with L-systems visualisations has been completed, in collaborative work with a student intern at the ARC Centre in Bioinformatics.
A presentation was made at the ComBio 2006 Conference on modelling of signals involved in regulatory systems of plants.

Recent outputs

Birch, C., Hanan, J., Thornby, D., 'Architectural modeling of maize under water stress', *Water to Gold, Proceedings of the Maize Association of Australia, 6th Triennial Conference,* February 2006, 219-225.

Bucciarelli, B., Hanan, J., Palmquist, D., Vance, C., 'A standardized method for analysis of Medicago truncatula phenotypic development', *Plant Physiology,* Vol. 142, 2006, 207-219.

Hanan, J., Bucciarelli, B., Vance, C., 'Sharing phenotypic data: A coding system and a developmental model', *The Medicago Truncatula Handbook,* 2006.

Manson, D., Hanan, J., Hunt M., Bristow, M., Erskine, P., Lamb, D., Schmidt, S., 'Modelling predicts positive and negative interactions between three Australian tropical tree species in monoculture and binary mixture', *Forest Ecology and Management,* Vol. 233, No. 2-3, 2006, 315-323.

Renton, M., Thornby, D., Hanan, J., 'Canonical modelling: An approach for intermediate level simulation of carbon allocation in functional structural models', *Functional-Structural Plant Modelling in Crop Production, Wageningen UR Frontis Series,* Springer Verlag, 2006.

Modelling and mapping genes for complex phenotypes in humans

Project Leader: Jacqueline Wicks
Researchers: Ananthila Anandacoomarasamy, David Duffy, Katrina Scurrah, Susan Wilson

The genotype-phenotype correspondence in humans is difficult to uncover for a number of reasons. For complex phenotypes, there may be hundreds of genes that influence the phenotype, as well as environmental, and the more recently discovered epigenetic influences on phenotypes. This project aims to develop mathematical, statistical and computational approaches to mapping genes that influence phenotypes of interest in humans, and to apply the methods in gene mapping projects currently underway in Australia. The emphasis is on flexible modelling that captures the important influences of complex disease genetics, and allows for multi-gene, environmental, and epigenetic interactions.

In 2006, a paper was completed on the influence of a particular gene, called the P2X7 polymorphism, on the autoimmune disease systemic lupus erythematosus. A paper on mathematical aspects of disease gene mapping was published. Finally, research was undertaken in the highly topical area of epigenetics in human disease. A method for detecting genes under the influence of imprinting is being developed, and the first stages of the design of software to implement the method are underway.

Recent outputs

Wicks, J., 'Genetic modeling assumptions for gene mapping and the triangle constraints', *Proceedings of the 55th Session of the International Statistical Institute: Sydney, 2005,* 2006.

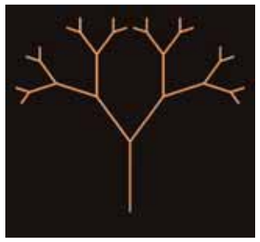
An integrated approach to multicellular development

Project Leader: Janet Wiles
Researchers: Jim Haseloff, Jim Hanan, Nic Geard, Tim Rudge

In this project, we are concerned with the processes in plants and animals that coordinate the formation of shape. How does a single egg or seed cell develop into the shapes that make up an embryo or adult organism? How does it do this so reliably, even in a noisy environment? The key is the interaction of the signals that are passed between cells and the DNA processing (or genetic regulation) that occurs within each cell. We are using complex systems models to study the nature of these interactions and how they control shape formation in a robust way. This analysis will allow us to generalise principles from biological shape formation to apply to the understanding and design of systems in the engineering domain.

Recent outputs

Rudge, T., Geard, N., 'Control and constraint: Cross centre insights from modelling cellular morphogenesis', ACCS Technical Report, No. ACCS-TR-06-01, ARC Centre for Complex Systems, February 2006.

1


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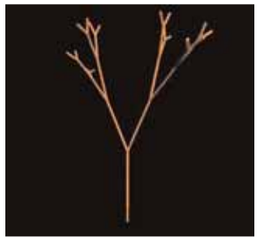

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Modelling Complex Biological Systems

Genes are not blueprints that specify a complete organism. Organism development emerges from a system of complex interactions, where the relationships between genes, the physical environment and individuals in a population are just some of the contributing factors.

It is difficult to fully understand one aspect of this system without knowing how it interacts with the other aspects. But it is also difficult to observe many of these interactions in nature, since some of these processes occur very quickly (for example, chemical signals), while others are slow (such as the evolution of populations).

To help investigate the complex systems underlying organism development, it is therefore necessary to integrate models of molecular biology and population-based biology. Towards this goal, the ACCS is developing a methodological framework that links models of gene interaction, plant development, and evolution (see Figure 1).

The images on the left show, from top to bottom, artificial plants from this framework evolving in an environment of competing selective pressures.

This work is an example of how computational modelling can be used to integrate and test biological theories at disparate scales of space and time. Being artificial, these types of models show possible interactions between genes, the environment and resulting development, and can be used to inspire novel research directions.

For instance, the emergent structure of a growing plant can be studied to help reveal how gene interactions are influenced by environmental factors. Our hypotheses can be encoded in models, and if the visualisations match the real-world data, we can use the models to make further predictions in a modelling/experimental cycle. Figure 2 illustrates an experimental study linking genetics, environment and plant structure. In the example shown here, applying different levels of fertilisation causes very different structures to emerge (see Hanan et al. article in *The Medicago Truncatula Handbook,* 2006, for further details). These techniques will lead to practical applications to help select the best plants for breeding.

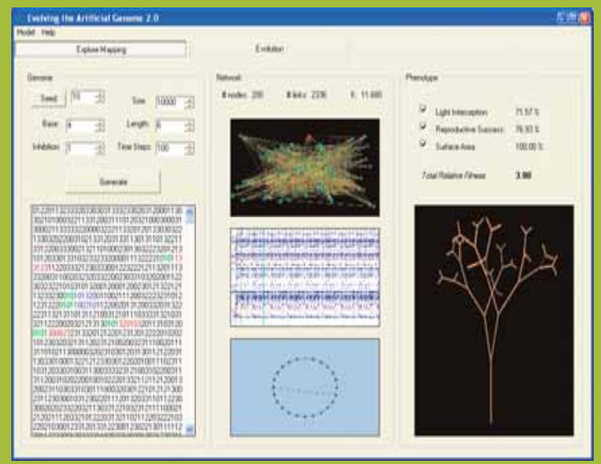


Figure 1: Simulating the interaction between genetic sequence, gene interactions, and plant evolution. This software is available for download from http://www.itee.uq.edu.au/~jwatson/software.html

Figure 2: Side view of an empirical model of Medicago truncatula growth under nitrogen-deficient (N-P+), nutrient sufficient (N+P+) and phosphorus-deficient (N+P-) conditions over 40 days

General GRN Publications

Bauer, D., Bodén, M., Thier, R., Gillam, E.M., 'STAR: Predicting recombination sites from amino acid sequence', *BMC Bioinformatics*, Vol. 7, No. 437, 2006.

Bodén, M., Bailey, T.L., *2006 Workshop on Intelligent Systems for Bioinformatics (WISB 2006), Conferences in Research and Practice in Information Technology*, Vol. 73, Australian Computer Society, 2006.

Bodén, M., Bailey, T.L., 'Identifying sequence regions undergoing conformational change via predicted continuum secondary structure', *Bioinformatics*, Vol. 22, No. 15, 2006, 1809-1814.

Bodén, M., Hawkins, J., 'Evolving discriminative motifs for recognizing proteins imported to the peroxisome via the PTS2 pathway', *2006 IEEE Congress on Evolutionary Computation*, July 2006.

Geard, N., Wiles, J., 'Investigating ontogenetic space with developmental cell lineages', *Proceedings of the 10th International Conference on the Simulation and Synthesis of Living Systems (ALIFE X)*, 2006.

Hawkins, J., Davis, L., Bodén, M., 'Predicting nuclear localization', *Journal of Proteome Research*, 2007.

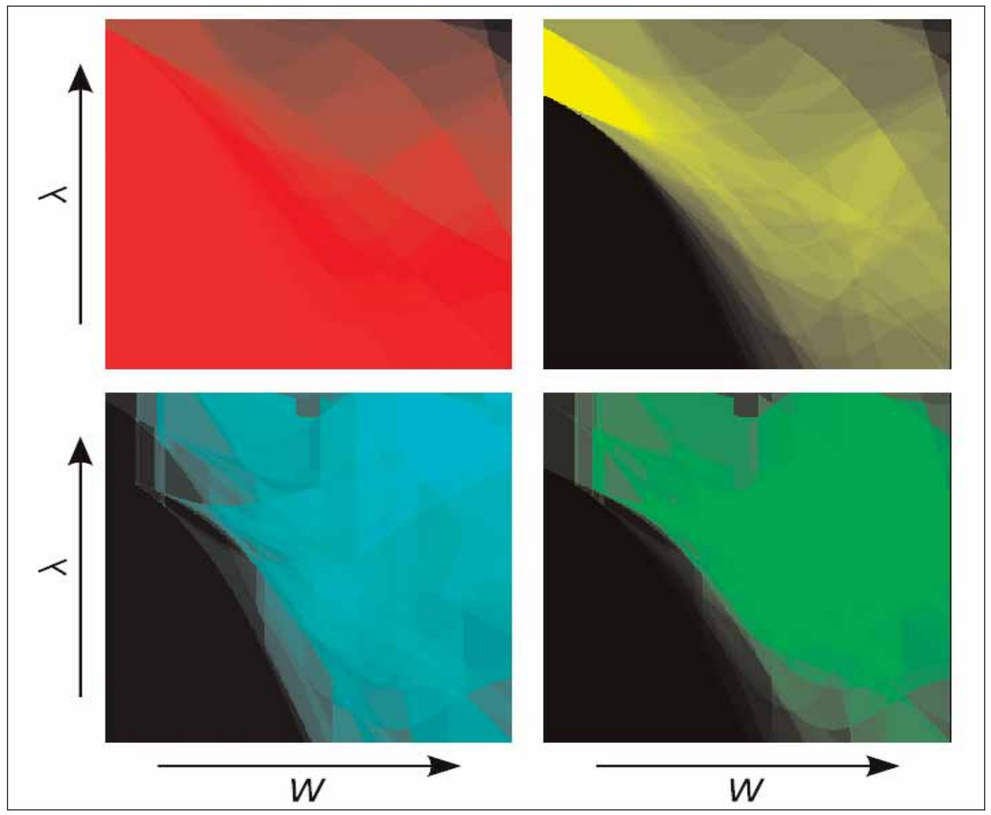
Hawkins, J., Mahony, D., Maetschke, S., Wakabayashi, M., Teasdale, R.D., Bodén, M., 'Identifying novel peroxisomal proteins', *Proteins: Structure, Function, and Bioinformatics*, 2007.

Hawkins, J., Bodén, M., 'Detecting and sorting targeting peptides with recurrent networks and support vector machines', *Journal of Bioinformatics and Computational Biology*, Vol. 4, No. 1, 2006, 1-18.

Hawkins, J., Bodén, M., 'Multi-stage redundancy reduction: Effective utilisation of small protein data sets', *Proceedings of the Workshop on Intelligent Systems for Bioinformatics,* 2006; *Conferences in Research and Practice in Information Technology*, Vol. 73.

Maetschke, S., Bodén, M., Gallagher, M., 'Higher order HMMs for localization prediction of transmembrane proteins', *Workshop on Intelligent Systems for Bioinformatics*, 2006; *Conferences in Research and Practice in Information Technology*, Vol. 73.

Wiles, J., Tonkes, B., 'Hyperspace geography: Visualizing fitness landscapes beyond 4D', *Artificial Life*, Vol. 12, No. 2, 2006, 211-216.



Four Complexity heatmaps for the slice of ontogenetic space around the network (N = 8, K = 8, λ= [0, 1.0], W = [0.01, 2.0]). The four complexity metrics are: number of terminal cells (top left), number of differentiated cells (top right), non-deterministic complexity (bottom left) and weighted complexity (bottom right)

Air Traffic Control

Program Leader: Peter Lindsay

As more vehicles take to the air, air traffic control will be a constraining factor on the number of aircraft that can be accommodated and on the paths that they fly. Europe, the USA and Australia are all considering fundamentally new ways of managing air traffic with a view to improving efficiency without compromising safety. We are applying complex systems science to the problem by modelling air traffic systems as networks of interacting air-traffic controllers and flight crews, and developing new approaches to assurance of system-level properties including safety and efficiency. This work builds on the group's existing work in human factors and human-computer interaction in air-traffic control.

Evaluation of future Air Traffic Management concepts

Project Leader: Peter Lindsay
Researchers: Ariel Liebman, Colin Ramsay, Martijn Mooij, Peter Robinson

The aim of this project is to use modelling and simulation to explore new operational concepts for Air Traffic Management (ATM). It builds on the conceptual framework developed in an earlier ACCS project, and uses the ATC simulation toolkit being developed in the Centre. The 2003 Australian ATM Strategic Plan proposes a notion of User Preferred Trajectories, whereby airspace users have more direct influence over the 4D trajectory that they fly which, in turn, is expected to lead to large operational efficiency gains. The challenge is to understand how to implement this concept, which will involve a fundamental change of conceptual viewpoint, from distance-based air traffic control to time-based trajectory management.

In 2006, the project developed an agent-based modelling framework for exploring a timing-based approach to air traffic control. The idea was to try to integrate conflict resolution strategies into a 4D trajectory-based approach, rather than treating them as separate activities as is currently the case. The different control intervention options available to an agent are assessed not only on whether they maintain safe separation between aircraft, but also whether the aircraft will meet certain time requirements along their trajectories. Our simulations showed that the approach is generally feasible, provided certain parameters (such as operator workload and traffic complexity) are kept within certain bounds. The simulations also revealed areas where the concept will need refinement. The investigation involved a detailed study of actual controller interventions and development of realistic scenarios on which to evaluate the approach.

Recent outputs

Lindsay, P., 'Evaluation of a simple timing-based intervention heuristic for trajectory-based Air Traffic Management', *5th EUROCONTROL Innovative Research Workshop Proceedings*, 2006.

Air Traffic Control workload

Project Leader: Andrew Neal
Researchers: Peter Lindsay, Penelope Sanderson, Ariel Liebman, Gerard Champion, Graham Halford, Mike Humphreys, Martijn Mooij, Scott Bolland, Shayne Loft**.**

The aim of this 3-year project is to develop a computational model that can measure the flow of traffic through an air sector, and predict the level of workload that an air traffic controller will experience, as well as the overall risk of breakdowns in separation between aircraft. The purpose is to develop a tool that can be used for risk analysis and scenario planning. This is a multidisciplinary project, integrating recent models of human memory and reasoning, with formal methods for the analysis of human-computer systems. The project is funded jointly by an ARC Linkage grant and Airservices Australia and administered through UQ's Key Centre for Human Factors and Applied Cognitive Psychology.

In 2006, a large amount of useful ATC operations room data was collected and analysed for 18 sectors covering much of Australia's busiest upper airspace traffic areas. This data included controller subjective workload ratings, flight plans and flight track data. The data was used to develop and evaluate an improved regression model which correlates the traffic patterns with workload ratings and was then incorporated into a prototype workload prediction tool. Agent-based models were developed to emulate the key aspects of the controller's behaviour, including accepting aircraft into the sector and issuing flight level clearances for climbing and descent, followed by hand-off to the next sector. Finally, a problem-solving algorithm has been developed and coded into intelligent agents in order to simulate conflict detection and resolution by the controller. Additionally, a review of air traffic control workload studies was completed and accepted for publication in Human Factors, one of the most prestigious journals in the field.

Recent outputs

Boag, C., Neal, A., Loft, S., Halford, G., 'An analysis of relational complexity in air traffic control conflict detection task', *Ergonomics*, Vol. 49, No. 14, 2006, 1508-1526.

Bolland, S., Fothergill, S., Humphreys, M., Neal, A., 'Modelling the human air traffic controller, Part II: Emulating controller intervention', *Proceedings of the 14th International Symposium on Aviation Psychology*, 2007.

Loft, S., Sanderson, P., Neal, A., Mooij, M., 'Modelling and predicting mental workload in en route air traffic control: Critical review and broader implications', *Human Factors*, 2007.

Loft, S., Bolland, S., Humphreys, M., 'Modelling the human air traffic controller. Expert-Trainee differences in conflict detection.', *Proceedings of the 14th International Symposium on Aviation Psychology*, 2007.

Loft, S., Neal, A., Humphreys, M., 'The development of a general associative learning account of skill acquisition in a conflict detection task', *Journal of Experimental Psychology: Human Perception and Performance*, 2006.

Neal, A., Mooij, M., Bolland, S., Xiao, T., Lindsay, P., Boag, C., 'Using multi-level analysis to model the sources of variability in workload within and between sectors', *Proceedings of the 14th International Symposium on Aviation Psychology*, 2007.

Sanderson, P., Mooij, M., Neal, A., 'Investigating sources of mental workload using a high-fidelity ATC simulator', *Proceedings of the 14th International Symposium on Aviation Psychology*, 2007.

Swarm intelligence for conflict detection and resolution in free flight environments

Project Leader: Hussein Abbass
Researchers: Peter Lindsay, Sameer Alam, Michael Barlow

Free flight is a revolutionary concept that will enable greater traffic volume and operational flexibility by distributing some of the functionality, including conflict detection and resolution, to airborne systems and pilots. Swarm intelligence is the study of computations in social insects (such as ants, termites and some types of bees and wasps). It is a new branch of distributed artificial intelligence, where computations are carried out by a group of agents working cooperatively to achieve a task. Ant colony optimisation (ACO) is an optimisation technique inspired by the behaviour of real ants. In this project, we are developing safe conflict detection and resolution (CDR) algorithms for free flight inspired by natural computations and navigations in colonies of ants. The advantages of such algorithms include being adaptive in a dynamic environment, and being fully distributed.

In 2006, we continued our investigation into developing a methodology for safe manoeuvre. The investigation focused on generating safe trajectories for flights to avoid weather hazards. We developed a method that generates multiple trajectories for the pilot order according to weights that may vary from one situation to another (for example, if the pilot wishes to reach a destination quickly or is happy to have a delay to achieve maximum comfort for passengers). The method guarantees to provide pilots with solutions that are safe according to aviation standards.

Recent outputs

Alam, S., Bui, L., Abbass, H., Barlow, M., 'Pareto meta-heuristics for generating safe flight trajectories under weather hazards', *6th International Conference on Simulated Evolution and Learning*, 2006; *LNCS*, Vol. 4247, 829-836.

Safety assessment of ATC human-computer interaction

Project Leaders: Andrew Neal, Jacqueline Wicks
Researchers: Peter Lindsay, Jingru Dai, Junhua Wang, Simon Connelly

This project is developing a new approach to human reliability assessment and evaluation of human-computer interaction design options by application to air traffic control. The approach is based on modelling the activities (cognitive processes and interactions) involved in en-route control as stochastic processes. The effect of a proposed design intervention can then be investigated by hypothesising its effect on individual activities and conducting simulations to gauge performance over a range of scenarios. The project is a close collaboration between computer scientists from the School of Information Technology and Electrical Engineering and psychologists from the Key Centre for Human Factors and Applied Cognitive Psychology. We are conducting experiments in which human subjects make judgements about, and attempt to manage, air traffic control scenarios presented to them on a computer display. These experiments are being conducted with two related goals in mind: the first is to gain a greater understanding of the decision-making processes of air traffic control operators; and the second is to model their behaviour more realistically in the simulations. The work is also a collaboration with Peter Kwantes from Defence Research and Development, Canada.

In 2006, Operator Choice Models (OCM) were developed for conflict detection and resolution tasks using experimental data collected from simulator trials with student subjects. By measuring conflict recognition in different settings, the experiments and models showed that operator performance depends critically on the nature of the overall task they are undertaking.
The formal models were further used to explore the effect on performance of different computer-based tools. A parameter sweep was conducted, using the Nimrod tool, to compare predicted operator performance for four different design options on a range of different traffic patterns. Staff from the ACCS's Monash node helped develop means for visualising and interpreting the results. Further to this, a paper was prepared on the use of model checking to assist in the formal categorisation and analysis of patterns of behaviour that lead to task failure.

Development of robust ATC simulation code base

Project Leader: Ariel Liebman
Researchers: Peter Lindsay, Colin Ramsay

This project aims to produce a robust code base for a toolkit which can be used to simulate the motion of aircraft in a 3D airspace. The toolkit consists of a core 3D + Time simulator and interface modules which enable the use of standard flight plan data and airspace specifications. The airspace specification uses standard air traffic management approach (e.g. nautical miles (NM) for distance). Aircraft motion is represented to the user graphically with position and altitude being displayed in NM and 100s of feet. The toolkit will also contain support for agents (air traffic controllers, pilots, and so on).

In 2006, the main activities have been the development of the toolkit to support active agents representing, for example, pilots and controllers, and the creation of the code base needed for supporting agent interventions to resolve conflicts and to manipulate aircraft timings.

General ATC Publications

Chen, K., Dam, H., Lindsay, P., Abbass, H., 'Biasing XCS with domain knowledge for planning flight trajectories in a moving sector free flight environment', *Proceedings of the 1st IEEE Symposium on Artificial Life*, 2007.

ACCS in the Media

Making the pace in a hot new year

Centre Chief Investigator David Green's research featured prominently in an article by Beverley Head that appeared in The Age, 31 January 2006. The article highlighted David's campaign to demystify complex systems techniques and to apply them to a wide range of real-world problems.

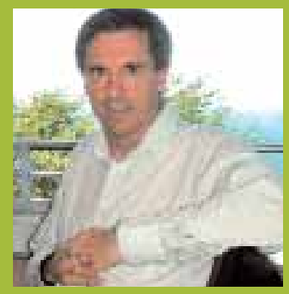
Some of David's recent achievements include

- analysis of social networks to identify how social interaction affects social order;
- development of computer models to demonstrate the ecological effect of breaking up rainforests or clearing land for agriculture; and
- exploration of complexity and stability in food webs.

The article is at
http://www.theage.com.au/news/technology/making-the-pace-in-a-hot-new year/2006/01/30/1138469633668.html

Planning for climate change: From urban design to complex systems

John Quiggin's public talk on 'Complexity, climate change and the precautionary principle' at Brisbane City Hall on 18 September was discussed on ABC Radio. See page 39 for further details. John's views were also repeated in an article in the Australian Financial Review on 23 November.



David Green

Evolutionary Economic Systems

Program Leader: John Foster

We are applying complex systems and network theory in economics and business to understand how evolutionary change occurs. There are strong connections with earlier approaches taken in evolutionary economics and in dealing with the economics of innovation. Consistent with other programs in the Centre, multi-agent modelling and associated simulation and calibration techniques are core components of the methodology that we are using. With regard to the economic statistics available to us, we are developing new ways of testing for complex patterns in high frequency data. For example, we have been studying trade-by trade data in stock markets and in electricity markets and seeking 'pattern matches' in artificially generated data. We are also developing new ways of dealing with spatial complexity in several contexts. Visualisation techniques, rarely used in economics, are being applied in a range of data-rich contexts to better understand the architecture and complex dynamics of systems. Although a key goal in this program is to make fundamental theoretical and empirical advances, care has been taken to work within several applied areas: induction is viewed as very important in the development of new theories, particularly in emergent research fields. In this regard, we feel that it is essential that theories are 'historically friendly' in complex adaptive system settings. This has necessitated the development of new methodological perspectives not previously used in economic research.

Nonlinear econometric modelling: A complex systems perspective

Project Leader: John Foster
Researchers: Melvin J Hinich, Phillip Wild

Complexity in real world systems is intrinsically generated by nonlinear interactions amongst system components that generate unanticipated emergent behaviour commonly associated with complex systems. In this project we have developed statistical techniques that can identify underlying emergent complexity in time series data. This involves applying a battery of nonlinear tests to both confirm the existence and identification of nonlinear interactions. This has been principally based on using relative power of different nonlinearity tests to identify and categorise different types of nonlinear generating mechanisms and confirming complexity through rejections of tests of time reversibility.

Recent outputs

Hinich, M., Foster, J., Wild, P., 'A statistical uncertainty principle for estimating the time of a discrete shift in the mean of a continuous time random process', *Computational Statistics and Data Analysis*, 2007.

Hinich, M., Foster, J., Wild, P., 'Structural change in macroeconomic time series: a complex systems perspective', *Journal of Macroeconomics*, Vol. 28, No. 1, 2006, 136-150.

Complex networks and the world trade web

Project Leader: John Steen
Researchers: John Foster, Jason Potts, Peter Liesch, Tim Kastelle

The study of complex networks is a growing part of the complexity literature that is characterised by the use of statistical mechanics to examine the network properties of a variety of biological, technological, social and economic systems (see Newman 2002 for detailed review). While some work has been done showing that complex network properties exist in directorship networks (Davis 2003), banking investment syndicates (Baum et al. 2004) and inter-firm alliances (Verspagen and Duysters 2004), little has been done in terms of understanding what these properties actually mean for the functioning of these systems. To this extent, the study of world trade networks is still at an embryonic stage that is ripe for theory building and empirical testing.

Essentially, we will be using network parameters as independent variables that affect other performance-related variables such as system robustness, information flow and economic growth.

In 2006, the world trade web project achieved significant milestones. Analytically, we have advanced our understanding of the statistical mechanics of the world trade web while simultaneously achieving publication and conference outcomes in both academic and industry forums. The project has achieved exposure through the foreign affairs magazine 'The Diplomat' and an invited presentation on Globalization and Business Strategy to the annual Certified Practising Accountants Congress. A number of papers have been submitted to prestigious journals. An invited chapter on international trade networks and terrorism is being written for a Sage handbook on international management in conjunction with two leading US researchers in the field, who have previously advised US Congress committees on the impact of terrorism upon international trade.

Recent outputs

Kastelle, T., 'Trading places: globalisation myths', *The Diplomat*, Vol. 41, August 2006.

Kastelle, T., Potts, J., 'The economic evolution of the world trade network', *11th International Schumpeter Society Conference*, June 2006.

Kastelle, T., Steen, J.T., Liesch, P.W., 'Measuring globalisation: An evolutionary economic approach to tracking the evolution of international trade', *DRUID Summer Conference*, June 2006.

Kastelle, T., Steen, J.T., Liesch, P.W., 'The evolution of international trade: a network approach to measuring globalisation', *Academy of International Business Annual Meeting*, June 2006.

Kastelle, T., Steen, J.T., Liesch, P.W., 'Globalisation and connectedness: A network approach to international business', *Academy of International Business Annual Meeting*, June 2006.

Steen, J.T., Liesch, P.W., Knight, G., Czinkota, M., 'The contagion of international terrorism and its effects on the firm in an interconnected world', *Public Money and Management*, Vol. 26, No. 5, November 2006, 305-312.

Complex behaviour in financial markets

Project Leader: Jason Potts
Researchers: John Foster, Mark Bowden, Stuart McDonald

This project studies financial markets using complexity based tools. Two sub-projects are currently completed: real bubbles theory, which looked at the connection between stock market bubbles and evolutionary economic growth; and a network based simulation model of decentralised trading over four asset classes. We are also working on models of fourth-order complexity in financial markets, which involves modelling expectation formation and interaction.

Recent outputs

Earl, P., Peng, T., Potts, J., 'Can speculative decision-rule cascades explain asset price inflation?', *Journal of Economics and Psychology*, 2007.

Potts, J., Morrison, K., 'Meso comes to markets', *Journal of Economic Behavior and Organization*, 2007.

Potts, J., 'Exchange and evolution', *Review of Austrian Economics*, 2007.

Potts, J., 'Can a better theory of rules make for a better theory of institutions?', *Journal of Economics Issues*, 2007.

Eutrophication of the Great Barrier Reef marine ecosystem

Project Leader: Rodney Beard
Researchers: John Foster, James Patterson, Leighton Brough, Liam Wagner, Stuart McDonald

The Great Barrier Reef stretches along the continental shelf of the north-east coast of Australia forming a shallow lagoon between the reef and the coast. Human activity along the coast appears to have led to an accumulation of sediments, fertiliser, pesticides and herbicides in the marine environment with unforeseen consequences. The primary driving force behind this has been economic in nature. Integrated socio-economic and environmental modelling is needed to address scientific and community concern about the possible impact of the coastal agriculture on the eutrophication of the Great Barrier Reef lagoon. Complex systems methodology such as non-linear dynamics and self-organised criticality and network modelling is likely to prove useful in analysing possible impacts of human economic activity on a complex marine ecosystem.

Achievements in 2006 included joint research with Thilak Mallawaraachchi (ABARE and Risk and Sustainable Management Group, UQ) on non-point source pollution from agriculture. We developed a model of how information concerning pollution measures impacts on political behaviour. Other work included the presentation of a paper on using DIAS to model non-point source pollution from agriculture at the 2006 Australian Agricultural and Resource Economics Society Conference at Manly, NSW.

Recent outputs

Beard, R., McDonald, S., 'Time consistent fair water sharing agreements', *Annals of the International Society for Dynamic Games*, Vol. 9, March 2007.

Brough, L., Beard, R., 'A multi-agent simulation model of the impact of eutrophication on the Great Barrier Reef Lagoon using the dynamic information architecture system DIAS', *Australian Agricultural and Resource Economics Society (AARES) 50th Annual Conference*, 2006.

Wagner, L., Ross, J., Possingham, H., 'Catastrophe management and inter-reserve distance for marine reserve networks', *Ecological Modelling*, Vol. 201, No. 1, February 2007, 82-88.

Vehicle-2-Grid

Project Leader: Ariel Liebman
Researchers: Geoff Walker, Zhao Yang Dong, Rizah Memisevic, Tapan Saha

This project aims to determine the feasibility of the use of hybrid wheeled vehicles (car) connected to electricity grid. These are also known as plug-in-hybrid technologies to enable introduction of large-scale renewable energy and at the same time produce significant improvements in the performance of power systems and markets in a changing global energy environment with a special focus on enabling the growth of renewable generation. Specifically the concept involves the modelling of the effects of the use of batteries installed in electric powered or hybrid cars to supply the grid or offset the local demand. Proof of concept connections of hybrid car (Toyota Prius) already exist (http://www.acpropulsion.com/white_papers.htm). The motivating aspect of the use of these technologies is the potential benefit of having a large amount of distributed energy storage on the grid at all times in order to be able to respond to various short-term events on the system. In particular events, such as a sudden increase or drop in supply or demand on a timescale of minutes, the possible benefits are economic, environmental and physical.

In 2006, the foundational aspects of the Vehicle-2-Grid technology benefits have been studied. These include a simulation of the ability of the battery technology and the associated power electronics to contribute to system stability control, and the economic impact on the power system and electricity prices. The stability and control aspect was modelled using Matlab and Simulink and demonstrated that even a relatively modest presence of hybrid vehicles on the grid (the equivalent of 5000-10000 Toyota Prius's) would provide benefits to the control of stability. Additionally, an initial study of market impacts over a 10-year horizon was performed using projection of hybrid vehicle penetration based on available information on manufacturers' plans and current vehicles' sales information. This, in essence, assumed all of Toyota's cars, but none of the other car manufacturers' cars, would be grid-connected by 2015. The early results suggest that, at least for our assumptions, the impacts on prices and transmission congestion costs are marginal. However, the assumptions were very conservative and, globally, there is significant momentum for research and development of the plug-in-hybrid vehicle technology. Hence, to complete the study, scenarios with significantly higher penetration of plug-in-hybrid vehicles need to be performed.

Water usage modelling for the Murray-Darling Basin

Project Leader: John Quiggin

The object of the modelling project is to build a multicatchment model of land and water use in the Murray-Darling Basin, incorporating flexible producer responses to uncertain availability of water for agricultural production. The aim is to provide insights on the implications of alternative specifications for irrigation water rights, environmental flow regimes and other policy. The basic building blocks of the model are catchment-specific farm level models, based on activity analysis, with parameters derived from published gross margin models.

Murray-Darling work has responded to developments in the public debate with an increased focus on urban-rural water trade and problems associated with climate change and drought. The model has been extended to encompass these issues, and results will be presented at the Australian Agricultural and Resource Economics Society Conference in February 2007.

In addition to the modelling work described above, several articles on water policy have been completed (including joint work with Professor John Freebairn) and several have been accepted for publication in the Australian Journal of Agricultural and Resource Economics. Substantial contributions have been made to public debate in a variety of forums, including public inquires and media. There has been particular interest in a proposal for repurchase of renewal rights for irrigation water.

Recent outputs

Adamson, D., Mallawaarachchi, T., Quiggin, J., 'State-contingent modelling of the Murray-Darling Basin: implications for the design of property rights', *50th Annual Conference of the Australian Agricultural and Resource Economics Society*, February 2006.

Freebairn, J., Quiggin, J., 'Water rights for variable supplies', *Australian Journal of Agricultural and Resource Economics*, Vol. 50, No. 3, 2006, 295-312.

Quiggin, J., 'Repurchase of renewal rights: a policy option for the National Water Initiative', *Australian Journal of Agricultural and Resource Economics*, Vol. 50, No. 3, 2006, 425-435.

Quiggin, J., 'Urban water supply in Australia: the option of diverting water from irrigation', *Public Policy*, Vol. 1, No. 1, 2006, 14-22.

Quiggin, J., Chambers, R., 'The state-contingent approach to production under uncertainty', *Australian Journal of Agricultural and Resource Economics*, Vol. 50, No. 2, 2006, 153-169.

Quiggin, J., 'Urban water supply in Australia', *Issues*, Vol. 76, 2006, 41-44.

Quiggin, J., 'Averting an era of water wars', *Presentation to the Australian Davos Connection's Australian Leadership Retreat*, August 2006.

Quiggin, J., 'The uncertain future of water policy', *Keynote address to the 35th Australian Conference of Economists*, September 2006.

Venn, T., Quiggin, J., 'Accommodating indigenous cultural heritage values in resource assessment: Cape York Peninsula and the Murray-Darling Basin, Australia', *Ecological Economics*, 2006.

Venn, T., Quiggin, J., 'Accommodating indigenous cultural values in resource assessment: Cape York Peninsula and the Murray-Darling Basin', *50th Annual Conference of the Australian Agricultural and Resource Economics Society*, February 2006.

Simulation studies of social networks

Project Leader: David Green
Researchers: Alex Tee Neng Heng, Suzanne Sadedin, Tania Leishman

Links between people form networks by which ideas, opinions and attitudes can disseminate throughout societies. This project uses simulation models of social networks to investigate questions such as the formation of social groups, the role of peer influence in marketing, and the effects of economic and resource issues on social behaviour.

In 2006, our simulations have shown that both prescription and peer pressure are needed to achieve cooperation and social order in large societies. Our results show that, in the absence of law enforcement in social networks, peer pressure acts either to maintain law-abiding behaviour, or to flip the entire society into law-breaking (e.g. speeding on the roads). However, if a social network is well-connected, then even a small incidence of punishment suffices to ensure conformity. In general, law-breaking increases as social interactions decrease.

Recent outputs

Green, D., Sadedin, S., Leishman, T.G., 'The emergence of social consensus in simulation studies with Boolean networks', *Proceedings of the First World Conference on Social Simulation 2006*, 2006.

Computational game theory

Project Leader: Stuart McDonald
Researchers: John Foster, John Hawkins, Liam Wagner, Rodney Beard

This project examines the potential for applying global optimisation techniques, based on directed search and machine-learning algorithms, for use in computing the equilibria of both static and dynamic non-cooperative games. The focus of this project is on using these algorithms to increase the likelihood of game theory being used as a modelling tool for large, complicated multi-agent systems.

During 2006, we continued our modelling work applying the haystack game to fishery fleet dynamics and the Byzantine game to network security. Research student Gillian Salerno completed her master's thesis examining rent seeking in the dynamic lake game problem. A paper by honours student Luke Boosey submitted for Australian Economics Honours Student Symposium examined the implementation of binary public goods via population surveys. Based on this work, Luke was offered a PhD fellowship at Caltech.

Recent outputs

Hawkins, J., Beard, R., McDonald, S., 'A multi-agent simulation model of fishery fleet dynamics for the Queensland coral reef line fishery', *AARES* 2006, 2006.

Wagner, L., McDonald, S., 'Finding traitors in secure networks using Byzantine agreements', *International Journal of Network Security*, 2007.

Temporal complexity

Project Leader: Penelope Sanderson
Researcher: Rizah Memisevic

In this project we investigated temporal complexity in the hydropower system and air traffic control domains. Temporal complexity refers to the emergence of stability or instability in a complex system as a result of the timely coordination of different elements of the system. The goal of the research was to develop visualisations of complex system performance that will promote activity within effective temporal contexts.

During 2006, we developed further our theoretical and methodological thinking about temporal complexity, drawing from hydropower system control, air traffic control, and healthcare. Using general principles drawn from Cognitive Work Analysis, we proposed innovative visualisations of hydropower system information that convey temporal properties and promote better human management and control of the system in light of temporal properties. Our analysis revealed some shortcomings in Cognitive Work Analysis for arriving at effective support of human activity in temporal context, which will be the subject of future research. Research is being written up for journal publication.

Recent outputs

Li, X., Sanderson, P., Wong, W., Memisevic, R., Choudhury, S., 'Evaluating functional displays for hydropower system: Model-based guidance of scenario design', *Cognition, Technology, and Work*, Vol. 8, No. 4, 2006, 269-282.

Memisevic, R., Sanderson, P., Wong, W., Choudhury, S., Li, X., 'Investigating human-system interaction with an integrated hydropower', *IEEE Transactions on Power Systems*, 2007.

Complexities of homelessness

Project Leader: John Quiggin
Researcher: Rhea Coleman

Since the mid-1970s, homelessness has grown to become an issue affecting, according to the Australian Bureau of Statistics, roughly 100,000 people in Australia. Government policy to address this issue has focused primarily on the individual and their 'deficits'. The increasing trend towards homeless families, women and young people - a shift from the traditional stereotypical 'core' population of older, homeless men with substance abuse issues - suggests that individual 'deficits' are not the only factors affecting vulnerability to homelessness and, in turn, that a broader policy focus needs to be adopted to address this social pathology. This project will look at the complex interaction between macroeconomic conditions, including housing market conditions, and individual characteristics, which create vulnerability to homelessness, by examining varying rates of homelessness across Australia. Understanding the

broader forces at work upon homeless individuals will aid the better formulation of policy, at both a Federal and State level, accounting for the factors which have been largely ignored to date. (2005/06 summer project)

Electricity networks and energy markets

Project Leader: Zhao Yang Dong
Researchers: Ariel Liebman, Anisah Nizar, Jennie Miao Lu, Mark Bowden, Rizah Memisevic, John Zhe Lu

With the introduction of deregulation, the national electricity network emerged as an excellent example of a complex system in need of an inter-disciplinary approach to modelling and design. This project is investigating how to integrate technical and market aspects of power system dynamics and price dynamics in order to provide key insights into planning expansion of the power transmission network. This project aims to apply modern computational modelling techniques to the interface between the physical properties of the electricity system and its economic considerations. A particular focus is placed on the impacts of the transmission network and power station operation on electricity price behaviour and its influence on infrastructure investment decisions. It also looks into the importance of customer load impact on system and market operations.

In 2006, the project brought together several researchers and postgraduate students to develop methodologies for three different aspects of the power system: the investment and expansion of the electricity system; the management of an electricity trading portfolio; and the behaviour of electricity demand. The work on the electricity system expansion has produced several new approaches for determining the value of flexibility in the expansion process. The electricity trading work has produced some novel methodologies for pricing hedging contracts and the demand-related work has produced new methodologies for detecting fraud and other non-financial losses of an electricity utility.

Recent outputs

Lu, M., Lu, Z., Saha, T., Dong, Z., 'A novel approach to evaluate congestion for composite power system planning in a competitive electricity market', *Proceedings of IEEE PES General Meeting 2006*, 2006.

Lu, M., Dong, Z., Saha, T., 'A hybrid probabilistic criterion for market-based transmission expansion planning', *Proceedings of IEEE PES General Meeting 2006,* 2006.

Lu, Z., Lu, M., Dong, Z., Ngan, H., 'A real options based method for power system planning', *Proceedings of IET International Conference Advances in Power Systems Control, Operation and Management*, 2006.

Lu, Z., Lu, M., Dong, Z., Ngan, H., 'Energy derivative market and derivative pricing via simulation', *Proceedings of IET International Conference Advances in Power Systems Control, Operation and Management*, 2006.

Lu, Z., Liebman, A., Dong, Z., 'Power generation investment opportunities evaluation: A comparison between net present value and real options approach', *Proceedings of IEEE PES General Meeting 2006*, 2006.

Nizar, A., Dong, Z., Liebman, A., 'Customer information systems for deregulated ASEAN countries', *Institution of Engineers Singapore (IES) Journal*, 2006.

Nizar, A., Zhao, J., Dong, Z., 'Customer information system data pre-processing with feature selection techniques for non-technical losses prediction in an electricity market', *Proceedings of 2006 International Conference on Power System Technology*, 2006.

Nizar, A., Dong, Z., Jalaluddin, M., Raffles, M., 'Load profiling method in detecting non-technical loss activities in a power utility', *Proceedings of the First International Power and Energy Conference*, 2006.

Wong, K., Dong, Z., 'Differential evolution, an alternative approach to evolutionary algorithm', *Modern Heuristic Optimization Techniques: Theory and Applications to Power Systems,* Wiley, 2007.

General EES Publications

Chambers, R., Quiggin, J., 'Dual approaches to the analysis of risk aversion', *Economica*, 2006.

Foster, J., 'Why is economics not a complex systems science?', *Journal of Economics Issues*, 2006.

Foster, J., 'Time', *The Elgar Companion to Alfred Marshall,* Edward Elgar, 2006.

Foster, J., 'Macro-econometrics', *The Elgar Companion to Neo Schumpeterian Economics,* Edward Elgar, 2006.

Foster, J., Potts, J., 'Complexity, evolution and the structure of demand', *Flexibility and Stability in the Innovating Economy,* Oxford University Press, April, 2006.

Foster, J., Potts, J., 'A micro-meso-macro perspective on the methodology of evolutionary economics: integrating history, simulation and econometrics', *2006 International Schumpeter Society Conference*, 2007.

Foster, J., Raine A., Potts, J., 'The new entropy law and the economic process', *Ecological Complexity*, 2007.

Metcalfe, J., Foster, J., Ramlogan, R., 'Adaptive economic growth', *Cambridge Journal of Economics*, Vol. 30, No. 1, 2006, 7-32.

Neal, M., 'Estimating complex production function: the importance of starting values', *51st Australian Agricultural and Resource Economics Society Conference*, February 2007.

Quiggin, J., 'Risk and uncertainty in agricultural economics and agricultural policy', *Symposium No. 3 at the 26th Conference of the International Association of Agricultural Economists*, August 2006.

Dependable Computer-Based Systems

Program Leaders: Geoff Dromey, Ian Hayes

The rapid pace of advances in Information and Communications Technology (ICT) has led to networked computer systems of ever increasing complexity and sophistication. Many of these systems - in areas such as transport, health and finance - need to be safe, reliable and generally dependable. There is a constant need for new methods and tools to enable engineers to ensure that such systems meet society's demands for dependability. This program is concerned with the development of modelling and analysis tools to try to ensure that dependability is designed into complex computer-based systems.

Building dependability into complex computer-based systems

Project Leader: Geoff Dromey
Researchers: Ian Hayes, Peter Lindsay, Diana Kirk, John Seagrott, Kirsten Winter, Lars Grunske, Lian Wen, Maria Aneiros, Nisansala Yatapanage, Robert Colvin, Saad Zafar, Toby Myers, Xuelin Zheng

Large-scale, complex, software-intensive systems can be made more dependable by constructing comprehensive formal graphical models of their behaviour. These models need to clearly show how individual functional requirements interact with one another. They also need to show how safety, security, reliability and other types of dependability requirements are manifested as supporting behaviour that coherently integrates with the functional requirements. Ultimately, all the functional and dependability requirements must integrate to preserve the overall behavioural integrity of a system. Adopting the underlying constructive development strategy of building a system out of its requirements offers a promising approach for dealing with large-scale systems, building in dependability and assuring dependability while, at the same time, coping with change, requirements defects and the complexity of such systems. The Behavior Tree notation and supporting design and analysis methodology enables the investigation of constructive development and the creation of integrated views of requirements. Using this approach, the project explored practical ways of engineering in, and systematically assuring the dependability of, large-scale and complex systems. (2005/06 summer project)

In 2006, we have focused on scaling-up the Behavior-Tree methodology to handle industry-scale systems with very large numbers of natural language requirements. As part of this work, we have conducted successful trials in using the method with a number of industrial partners. We have also made an important advance that allows us to build a security policy into a design and then verify that the design satisfies the policy. With the increased usage of wireless LANs, security is a significant issue. The latest WLAN security protocol, the IEEE 802.11i assures rigorous security for wireless networks with its protocol for authentication, authorisation and key distribution. We have developed a Behavior Tree model for the IEEE 802.11i Robust Security Mechanism and used the SAL model checker to formally verify the protocol.

Recent outputs

Dromey, R.G., 'Formalizing the transition from requirements to design', *Mathematical Frameworks for Component Software - Models for Analysis and Synthesis, World Scientific Series on Component-Based Development*, World Scientific Publishers, 2006, 156-187.

Dromey, R.G., 'Scaleable formalization of imperfect knowledge', *1st International Workshop - Asian Working Conference on Verified Software (AWCVS'06)*, Oct 2006, 21-33.

Dromey, R.G., 'Keynote Address - Guiding principles for engineering quality software', *2nd Malaysian Software Engineering Conference (MySEC'06)*, 2006.

Zafar, S., Winter, K., Colvin, R., Dromey, R.G., 'Verification of an integrated role-based access control model', *1st International Workshop - Asian Working Conference on Verified Software (AWCVS'06)*, Oct 2006, 230-240.

Model-based development of safety-critical systems

Project Leader: Peter Lindsay
Researcher: Lars Grunske

The use of model-driven software engineering is steadily growing. In this paradigm engineers work directly with models, and computer programs are generated automatically from the models. However, the evidence required for system safety assurance currently still has to be derived by hand. This project aims to develop new methods for automated evaluation of safety properties from models. Specifically the project is developing encapsulated models for computer-based systems. The project is funded by the Boeing Postdoctoral Research Fellowship Award to the University of Queensland.

In 2006, this project has successfully applied the theoretical concepts of failure propagation models to an embedded control application in the automotive domain. This application was a computer-assisted braking system designed within the component-based development framework SaveCCM. Additionally, progress was made in using model-driven safety evaluation techniques in the optimisation of architecture specifications.

Recent outputs

Grunske, L., 'Identifying "good" architectural design alternatives with multi-objective optimization strategies', *Proceedings of the International Conference on Software Engineering (ICSE), Emerging Results*, 2006, 849-852.

Grunske, L., 'Towards an integration of standard component-based safety evaluation techniques with SaveCCM', *Quality of Software Architectures,* 2006; *Lecture Notes in Computer Science*, Vol. 4214, 199–213.

Grunske, L., 'Evolutionary algorithms for safety-costs trade-off in control system design', *Proceedings of INCOM 2006*, 2006, 249-254.

Validation and rapid prototyping for Behavior Trees

Project Leader: Geoff Dromey
Researchers: Sameer Alam, Diana Kirk, Lian Wen, Robert Colvin, Toby Myers

Simulation and animation are techniques for quickly obtaining a dynamic, visual view of a system from a high-level specification. This may be useful for receiving feedback from a client early in the software life-cycle (validation), or for demonstrating the behaviour of a model which is difficult to observe statically (in particular, emergent behaviour). This project is developing simulation and animation tools for the Behavior Tree framework.

In 2006, a Behaviour Tree editing tool was developed, incorporating several different tools and allowing them to exchange information. The tool also has a collaborative mode where users can work on the same tree in real-time. The simulation tool was integrated with the editing tool Integrare, giving a graphical interface to the simulation. A Behavior Tree Framework for Implementation utilising code generation began development in 2006. The Behavior Tree framework can generate code in either Java or C++ using automated code generation from an XML specification of a Behavior Tree.

Change management: Formalising the impact of requirements change on design

Project Leader: Geoff Dromey
Researchers: Lian Wen, Toby Myers

This project involves using Behavior Trees to model requirements change. One aspect is the investigation of a formal process to map the changes from the functional requirements into the software design, which includes the component architecture, the component behaviours and the component interfaces. The other aspect is the investigation of the impact of change of functional requirements on the component architecture, and how this impact may be reduced or prevented, thereby making the software system more stable and easier to maintain.

In 2006, the theoretical work previously carried out on changing the architecture of a system has been extended to include a new target architecture without changing the behaviour or the set of functional requirements the system satisfies. The results of this work have been published in a journal article. We have also extended the theoretical work undertaken on systematically mapping requirements changes to traceable changes in design work products. This has involved versioning the different sets of changes, resulting in a model where the changes in each version can be traced and recovered. The results have been written up and are to be submitted to a journal. Lian Wen has also submitted his PhD thesis on the work completed in this area.

Recent outputs

Wen, L., Dromey, R.G., 'Architecture normalization for component-based systems', *Electronic Notes in Theoretical Computer Science*, Vol. 160, 2006, 335-348.

Foundations of Behavior Trees

Project Leaders: Geoff Dromey, Ian Hayes
Researcher: Robert Colvin

Behavior Trees are a new framework which allows the functional behaviour of a system to be constructed out of its requirements. Behavior Tree notation is easy to learn and use, and can be used to model a wide range of complex systems, including large software systems and biological and chemical processes. This project is developing a formal semantics for the Behavior Tree framework, which will help to precisely define and compare systems, and allow automated tool support for the development of software in the framework. The project will also extend the Behavior Tree language and semantics to handle real-time and stochastic specifications.

In 2006, the operational semantics was extended to include more powerful constructs such as generalised nondeterministic choice and parallel choice from a set of components or values, and parameterised message passing. The notation was extended to handle real-time constraints, based on the work of Timed Automata. A prototype tool for translating Behaviour Trees to timed automata, suitable for input to the model checker, UPPAAL, was developed. This work is to be published in ASWEC 2007.

Recent outputs

Grunske, L., Winter, K., Colvin, R., 'Timed Behavior Trees and their application to verifying real-time systems', *Proceedings of 18th Australian Conference on Software Engineering (ASWEC 2007)*, April 2007.

Collaborative software engineering based on Behavior Trees

Project Leader: Geoff Dromey
Researchers: David Chen, Kevin Lin

A Real-time Collaborative Genetic Software Engineering system (CoGSE) allows a group of users to view and edit the same Behavior Tree representation at the same time from different sites. To develop CoGSE, we have been investigating constraint maintenance in collaborative systems. Constraint maintenance is an important issue in single-user CAD and CASE tools. In collaborative systems, constraint maintenance becomes even more complicated due to the generation and execution of various combinations of concurrent and dependent operations. In CoGSE, constraint maintenance is required to maintain Behavior Tree structure and to resolve conflicts. Tasks include multi-user editing of Behavior Trees, visualisation methods and collaborative computing methods.

In 2006, research has concentrated on the issues of constraint maintenance in collaborative environments. In particular, how to maintain multi-way dataflow constraints, which are widely applied in various interactive single-user systems, in collaborative systems. A constraint maintenance algorithm has been developed which produces a constraint propagation effect that is consistent with the underlying syntax level execution effect. Furthermore, constraint propagations are performed only when no user operation is waiting for execution which, in turn, improves system-responsiveness. This method has been presented in a conference paper. The other major development this year has been the incorporation of the collaborative editing facility for Behavior Trees into the new Integrare Collaborative Tool Environment.

Recent outputs

Lin, K., Chen, D., Sun, C., Dromey, R.G., 'Multi-way dataflow constraint propagation in real-time collaborative systems', *Proceedings of the 2nd International Conference on Collaborative Computing: Networking, Applications and Worksharing (CollaborateCom 2006)*, 2006.

AutoGuard: An interactive development environment for relative debugging of programs

Project Leader: David Abramson
Researchers: Aaron Searle, Clement Chu

The project was originally rolled in as an ARC Discovery project, and was completed in 2006. Relative Debugging is a paradigm that assists users to locate errors by comparing the contents of key data structures within two executing programs. In particular, the contents of key data structures in a development version are compared with the contents of the corresponding data structures in an existing version as the two programs execute. If the values of two corresponding data structures differ at points where they shouldn't, an error may exist and the developer is notified.

During 2006, the outcome of this research is the discovery of techniques that empower Relative Debugging users to become more productive and allow the Relative Debugging paradigm to be significantly enhanced. Specifically, the research has resulted in the following three contributions: 1. Formalisation of the Relative Debugging Methodology; 2. Data Flow Browsing for Relative Debugging; and 3. Automatic Relative Debugging. These contributions have enhanced the Relative Debugging paradigm and allow errors to be localised with little or no human interaction. Minimising the user's involvement reduces the cost of debugging programs that have undergone software evolution. Automating the Relative Debugging paradigm reduces the need for users to have a detailed knowledge of the programs under consideration, thereby improving productivity and has a significant impact on current debugging practices.

Verification of lock-free algorithms

Project Leader: Robert Colvin
Researchers: Ian Hayes, Brijesh Dongol

Computer systems are increasingly being used to tackle problems involving interactions between hundreds of independent processes, all competing for access to some central data store. The algorithms underlying such complex computer systems can be implemented using a new technique, called a 'lock-free' approach, which provides significant improvements in efficiency over existing implementation techniques. However the benefits come at the cost of increased complexity of the algorithms involved. This project will investigate effective strategies for verifying lock-free algorithms, building on earlier work using I/O Automata and simulation techniques.

In 2006, several nonblocking algorithms were formally verified, including a scalable lock-free stack and a lazy wait-free queue. A theory for proving lock-freedom was developed, and this theory was encoded in the PVS theorem prover and applied to two examples.

Recent outputs

Colvin, R., Groves, L., Luchangco, V., Moir, M., 'Formal verification of a lazy concurrent list-based SetAlgorithm', *CAV*, 2006, 475-488.

Dongol, B., 'Formalising progress properties of non-blocking algorithms', *8th International Conference on Formal Engineering Methods,* 2006; *LNCS*, Vol. 4260, 284-303.

General DCS Publications

Dromey, R.G., 'Climbing over the 'no silver bullet' brick wall', *IEEE Software, Vol. 23, No. 2, March 2006*, 118-120.

Dromey, R.G., 'Making real progress with the requirements defect problem', *Measuring Quality Requirements in Information Systems, Idea Group Inc, 2006*, 87-108.

Sithirasenan, E., Zafar, S., Muthukkumarasamy, V., 'Formal verification of the IEEE 802.11i WLAN security protocol', *Australian Software Engineering Conference (ASWEC '06)*, 2006, 181-190.

Smith, G., Winter, K., 'Simulation machines for checking action system refinements', *REFINE 2006 - International refinement workshop*, 2006; *Electronic Notes in Theoretical Computer Science*.

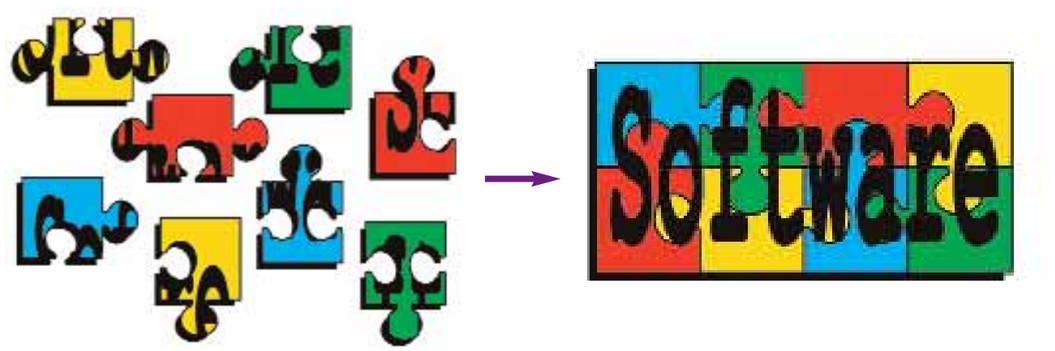
Taming the Complexity of Large-Scale Software-Intensive Systems

Information and communications technology now underpins all modern infrastructure. What accompanies this is an insatiable demand to build software-intensive systems of unprecedented scale. Conventional software and systems engineering are struggling to cope with the complexity that accompanies this unprecedented scale.

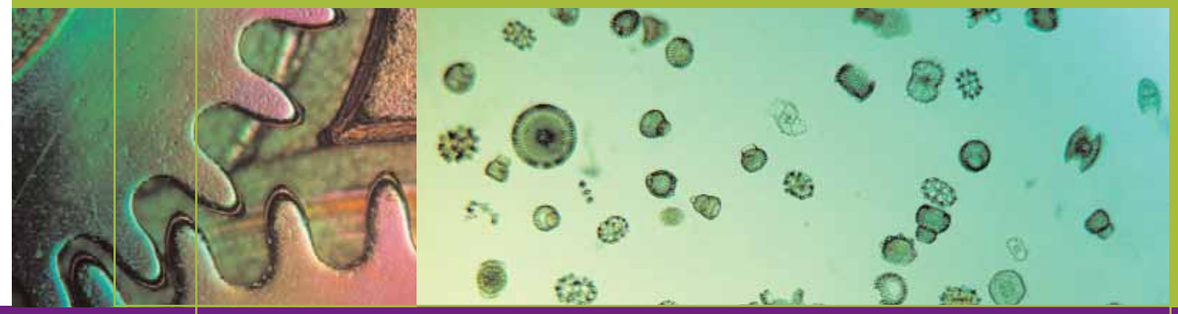
The major problem is the hundreds and thousands of pieces of information that specify the requirements used to design such systems; more often than not, they contain many inconsistencies and other defects simply because no individual has the memory capacity to see the system as a whole or comprehend all the potential interactions and problems among the requirements. As a consequence, many defects end up being built into large-scale systems reducing their dependability and causing very high development and maintenance costs.

Work in the Centre's Dependable Systems Program over the last three years has focused squarely on developing and trialling with industry a very different way of handling requirements complexity and systematically finding and removing defects from the requirements for these very large systems. The Behavior Trees method uses what might be best described as a jigsaw puzzle metaphor. System developers initially focus on formalising the localised and manageable detail in individual requirements, turning them into composable jigsaw puzzle pieces. They then put the pieces together in a manner similar to the way a jigsaw puzzle is put together. Just as for a jigsaw puzzle, creating this integrated picture of the requirements shows where there are pieces missing and where other pieces do not fit; these correspond to defects in the requirements.

In the last year, we have conducted three major trials with industry which have confirmed the effectiveness of this very different approach to modelling very large-scale systems. Current work is focused on building powerful technology to support and enhance this advance in development methodology.



The picture only emerges when the pieces of the puzzle are put together – whether it is a jigsaw puzzle or a software requirements specification



Complex Systems Theory and Applications

In addition to the research programs described above, the ACCS includes a number of projects addressing key problems for complex systems. The projects are concerned with the application of theory to solve issues in the design and operation of complex socio-technological systems, and with the development of new analysis techniques for complex systems. Some of these projects were rolled into the ACCS when Centre operation commenced in 2004.

Application of Grid computing to complex systems modelling

Project Leader: David Abramson
Researchers: Colin Enticott, Slavisa Garic, Tom Peachey, Blair Bethwaite

Over the last several years, combinations of super-computers, or Grids, have been developed which couple geographically distributed resources such as high-performance computers, workstations, clusters of computers, and scientific instruments. Grids such as the US-based TeraGrid have begun to provide the infrastructure to support global collaboration in science and engineering in ways that were not previously possible. Many complex systems models have enormous resource requirements. In this project we investigate the application of Grid computing to these complex systems models, and illustrate the utility of this approach. In particular, we shall apply and further develop a number of Grid-specific methodologies and tools.

During 2006, we ran a training course for ACCS members on using Grid computing, in particular, our Nimrod tools for supporting complex systems research. This opened up opportunities in a number of projects in areas of economics simulation and optimisation, air traffic control, ecology and genetic regulatory networks.

Adaptive network-centric multi-agent architecture for land combat

Project Leader: Hussein Abbass
Researchers: Ang Yang, Ruhul Sarker

Land combat is a complex adaptive system. The aim of this project is to develop a multi-agent system for land combat to understand the dynamics of this complex system and potentially map lessons learnt in the defence domain to other projects such as those related to game theory in economics. ACCS provided partial funding for this project in the form of financial assistance for training a student, with the main source of funding coming from UNSW.

In 2006, Ang Yang submitted his PhD on the topic. The WISDOM system developed in his PhD thesis was used by a number of DSTO colleagues. We developed methodologies for fitness landscape analysis of combat games (see IEEE SMC-B paper). We also collaborated with Dr KC Tan and used some of our models in studying civil violence using a game theory. Last, but not least, we continued our collaboration with DSTO on optimising fleet mixes.

Recent outputs

Abbass, H., Baker, S., Bender, A., Sarker, R., 'Identifying the fleet mix in a military setting', *The Second International Intelligent Logistics Systems Conference*, 2006.

Quek H., Tan, K., Goh C., Abbass, H., 'Modeling civil violence: An evolutionary multi-agent, game theoretic approach', *IEEE Congress on Evolutionary Computation*, 2006, 1624-1631.

Yang, A., Abbass, H., Sarker, R., 'Characterizing warfare in red teaming', *IEEE Transactions on Systems, Man and Cybernetics - Part B, Cybernetics*, Vol. 36, No. 2, 2006, 268-285.

Yang, A., Abbass, H., Sarker, R., 'Land combat scenario planning: A multiobjective approach', *6th International Conference on Simulated Evolution and Learning*, 2006; *LNCS*, Vol. 4247, 837-844.

Adaptive network mining for security and safety

Project Leader: Hussein Abbass
Researchers: Daryl Essam, Michael Barlow, Yubin Yang

Network mining is a novel and new concept in data mining. Traditionally, data mining stood shorthanded when faced with a small dataset. Moreover, there have been many assumptions which were necessary to build the theory of data mining techniques, but unfortunately these assumptions were impractical. Take, for example, the assumption of independency, where the values a field in a database table can take are independent of each other, and the records are also independent. Consider two fields in a database table: the name of employees and their telephone numbers. Let us assume two employees, John and Mark. Traditionally, these two values are considered entirely independent of each other. However, if both employees have the same telephone number, this assumption deems quickly to be invalid. It also implies that the two database records are somehow dependent. As such, assuming independency of data records and values within fields makes theoretical proofs easier, but certainly increases the demand for more data, and traditional data mining techniques will certainly overlook and miss many interesting patterns. In this project, we are developing a software infrastructure for network mining that can potentially be used for security and safety applications such as analysing flight accidents.

In 2006, we continued and expanded our work in the security domain. One of the interesting studies we undertook was in collaboration with Dr. Eleni Petraki from the University of Canberra on understanding counterfeiting and developing strategies to mitigate the risk arising from counterfeiting crimes and its impact on security.

Recent outputs

Petraki, E., Bo, Z., Abbass, H., 'Mitigating the threat of counterfeiting to international security through public awareness', *The Security Technology Conference, the 5th Homeland Security Summit*, 2006, 190-207.

Modelling fear conditioning in rats

Project Leader: Robert Colvin
Researcher: Geoff Dromey

Fear conditioning involves the pairing of a neutral stimulus (e.g. a tone) with an aversive stimulus (e.g. a footshock). After a number of pairings, the neutral stimulus elicits the behavioural and physiological responses normally seen after exposure to the aversive stimulus. The neural pathways involved in the formation of these fear memories have been studied extensively. However, by providing a detailed computer model of the neural networks underlying fear conditioning, the current proposal will provide a rapid and powerful way of testing hypotheses and direct further experiments into fear conditioning being performed at the Queensland Brain Institute.

In 2006, two Behaviour Tree models were developed, one giving the high-level, observable behaviour of a rat under a fear conditioning experiment, and the other giving a more detailed description of the neurological processes involved.

Software architecture and scale-free networks

Project Leader: Geoff Dromey
Researcher: Lian Wen

This project studies the evolution and topological structure of large software systems and their relationships with scale-free networks. We have found that the component architecture of all the tested Java packages is scale-free, and that a close relationship exists between optimised sorting algorithms and scale-free networks. This will lead to practical methods by which to control and manage the architecture of large software systems, as well as encouraging further research into their evolution.

In 2006, we have drafted two papers on our earlier work on the study of scale-free properties of sorting algorithms and scale-free properties of large software libraries. Results of this work were presented at a Workshop on Complex Systems held at the Warren Centre in Sydney in April 2006. Part of this work has also been written up in Lian Wen's PhD thesis which was submitted for examination in late 2006.

Multi-objective optimisation

Project Leader: Hussein Abbass
Researchers: David Green, Lam Bui

When solving many real life problems, one is usually faced with two or more objectives that are in conflict, requiring the need for a compromise between the conflicting objectives. Multi-objective optimisation is about solving problems with conflicting objectives. In this project, we develop robust multi-objective optimisation techniques for decomposing and solving complex problems with many constraints and variables in the existence of noise.

In 2006, our work on multi-objective optimisation continued to be very successful with new efficient methods for handling large-scale complicated multiobjective black-box optimisation problems. Most of the work is submitted for journal publications, hence the small number of papers appearing in 2006. We anticipate in 2007 to have published most of this work and advanced the research in this area further.

Recent outputs

Bui, L., Deb, K., Abbass, H., Essam, D., 'Dual guidance in evolutionary multi-objective optimization by localization', *6th International Conference on Simulated Evolution and Learning*, 2006; *LNCS*, Vol. 4247, 384-391.

Emerging applications of advanced computational methods and discrete mathematics

Project Leader: Peter Adams
Researchers: Barbara Maenhaut, Darryn Bryant

Combinatorial computing plays an important role in visualising, modelling and solving a variety of important practical problems, particularly in the field of complex systems. In this project, we are investigating approaches such as grid computing, evolutionary algorithms and refined theoretical approaches in order to enhance combinatorial searches. These are being used in a variety of problems, ranging from searches for combinatorial designs to applications in bioinformatics. Future developments in combinatorial computing techniques may have broader applications including understanding network-based systems in biology, engineering and economics.

In 2006, research has continued into the development of effective computational tools which can be applied in graph decomposition problems and to various bioinformatics projects. There were two journal articles accepted for publication during 2006, representing advances in the knowledge of small-order combinatorial graphs. There was also a book chapter that appeared, representing innovations in DNA sequencing technologies.

Recent outputs

Adams, P., Eggleton, R., MacDougall, J., 'Taxonomy of graphs of Order 10', *Congressus Numerantium*, 2007.

Adams, P., Eggleton, R., MacDougall, J., 'Graphs with a given degree sequence', *Congressus Numerantium*, 2006.

Cochran, D., Lala, G., Keith, J., Adams, P., Bryant, D., Mitchelson, K., 'Sequencing by aligning mutated DNA fragments', *The Frontiers of Biochip Technologies,* Springer Verlag, 2006, 231-245.

Computational group theory

Project Leader: George Havas
Researcher: Colin Ramsay

Group theory is a fundamental part of pure mathematics with diverse applications. Computational group theory addresses many problems. In this project, we study computationally-based proofs in groups given by presentations. As an integral part of the research we will design, implement, test, analyse and apply new algorithms for groups. We will also develop metrics for evaluating the quality of proofs, with a view to addressing Hilbert's '24th' problem which is finding criteria for determining simplest proofs.

During 2006, Havas presented nine invited lectures at overseas conferences and universities. In July, he was a London Mathematical Society-supported visitor to four Universities in the UK. Two papers on computational group theory appeared in refereed journals in 2006 and two papers appeared in refereed conference proceedings. These papers solved questions about efficient presentations for groups, distinguished groups associated with geometries, and resolved a long-standing conjecture about an infinite family of groups related to trivalent graphs.

Recent outputs

Campbell, C.M., Havas, G., Ramsay, C., Robertson, E.F., 'On the efficiency of the simple groups with order less than a million', *Experimental Mathematics*, 2007.

Conder, M., Havas, G., Ramsay, C., 'Efficient presentations for the Mathieu simple group M22 and its cover', *Proceedings of the Conference Finite Geometries, Groups, and Computation*, 2006, 33-42.

Havas, G., Ramsay, C., 'On proofs in finitely presented groups', *Groups St Andrews 2005,* 2007; *London Mathematical Society Lecture Note Series*, Vol. 340, 457-474.

Havas, G., Vaughan-Lee, M.R., 'Computing with 4-Engel groups', *Groups St Andrews 2005,* 2007; *London Mathematical Society Lecture Note Series*, Vol. 340, 475-485.

Havas, G., Leedham-Green, C., O'Brien, E., Slattery, M., 'Certain Roman and flock generalized quadrangles have nonisomorphic elation groups', *Advances in Geometry*, Vol. 6, No. 3, 2006, 389-395.

Havas, G., Robertson, E.F., Sutherland, D., 'The Fa,b,c conjecture is true, II', *Journal of Algebra*, Vol. 300, 2006, 57-72.

Havas, G., Leedham-Green, C., O'Brien, E., Slattery, M., 'Computing with elation groups', *Proceeding of the conference Finite Geometries, Groups, and Computation, September 4-9, 2004, Pingree Park, Colorado, USA*, 2006, 95-102.

Efficient marking schedules for the short-response paper of the Queensland Core Skills Test

Project Leader: Anne Street
Researchers: Colin Ramsay, Ken Gray, Karen Harris

Each year, approximately 35,000 Queensland students in the final year of high school, from all over the State, take a Core Skills Test, one paper of which is in short-response format. The schedule and resources are such that it is impossible to take samples of the students' scripts and to train the 650 markers well ahead of time, so that real data on how long each question will take to mark is available before the marking starts. Training markers is expensive, so we want to keep it to a minimum, as well as to produce an optimal match of markers to questions, and to ensure a common finishing time for all markers. A successful technique has been developed which supports dynamic assignments of resources, using a network to ensure that the loads are optimally balanced. This technique, due to Ken Gray, is also being developed for use in other problems, including some that arise in connection with testing.

In 2006, a study of the designs relevant to the construction of marking schedules was undertaken.
The project studied how to compare two designs, and to identify how and where they differ. It also made progress on how much of an individual design is needed in order to identify it uniquely.

Recent outputs

Gray, K., Street, A., 'On defining sets of full designs and of designs related to them', *Journal of Combinatorial Mathematics and Combinatorial Computing*, Vol. 60, 2007.

Gray, K., Street, A., 'Defining sets', *Handbook of Combinatorial Designs*, 2, Chapman & Hall/CRC, Taylor & Francis Group, 2007, 382-385.

Automatic problem decomposition

Project Leader: Hussein Abbass
Researchers: David Goldberg, Kumara Sastry, Robert McKay

Solving many real life problems is a complex task. The number of elements and factors in each problem is enormous and the only way to solve these problems reliably, quickly and accurately is by decomposing them into smaller sub-problems. Unfortunately, when we are faced with a new problem, we do not usually know the correct decomposition. This project is about automatically decomposing a problem on the fly while solving it.

In 2006, our focus was placed on automatic decomposition of classification problems. Dr Minh Ha Nguyen completed her PhD and was awarded her PhD with a recommendation from one of her examiners that the thesis deserves a prize. Some of this work has not appeared in publication yet, with a paper accepted for publication in IEEE SMC part C to appear in 2007. Other publications related to this area were an invited review chapter on probabilistic model-building genetic programming and projects starting in the area of supply chain management.

Recent outputs

Nguyen, M., Abbass, H., McKay, R., 'A novel mixture of experts model based on cooperative coevolution', *Neurocomputing*, 2006, 155-163.

Sarker, R., Freeman, G., Kara, S., Kayis, B., Ray, T., Abbass, H., 'A multi-agent approach for analyzing material flow in a manufacturing supply chain', *The Second International Intelligent Logistics Systems Conference*, 2006.

Shan, Y., McKay, R., Essam, D., Abbass, H., 'A survey of probabilistic model building genetic programming', *Scalable Optimization via Probabilistic Modeling From Algorithms to Applications, Studies in Computational Intelligence*, Vol. 33, 1, Springer Verlag, 2006.

General CSTA Publications

Abbass, H., 'Learning regularities and patterns using probabilistic finite state machines', *Complexity International*, 2007.

Abbass, H., 'An economical cognitive approach for bi-objective optimization using bliss points and interaction', *Soft Computing*, Vol. 10, No. 8, 2006, 687-698.

Bodén, M., Yuan, Z., Bailey, T.L., 'Prediction of protein continuum secondary structure with probabilistic models based on NMR solved structures', *BMC Bioinformatics*, Vol. 7, No. 68, 2006.

Connor, J., Symons, M., Feeney, G., Young, R.M., Wiles, J., 'The application of machine learning techniques as an adjunct to clinical decision making in alcohol dependence treatment: A preliminary study.', *Journal of Substance Use and Abuse*, 2006.

Dorr, G., Noller, B., Woods, N., Hewitt, A., Hanan, J., Adkins, S., Ricci, P., 'Development of a decision-making tool to minimise environmental and public health risk of pesticide application', *Rational Environmental Management of Agrochemicals: Risk Assessment, Monitoring and Remedial Action, ACM International Conference Proceeding Series,* Oxford University Press, 2006.

Dorr, G., Hanan, J., Woods, N., Kleinmeulmann, P., Adkins, S., Noller, B., 'Simulating spray deposition on plant canopies within a wind tunnel', *International Advances in Pesticide Application Conference 2006,* January 2006; *Aspects of Applied Biology*, Vol. 77, 395-403.

Dorr, G., Noller, B., Hewitt, A., Hanan, J., Adkins, S., 'A decision-making tool to minimise environmental and public health risk of pesticide application', *Proceedings 6th Annual Health and Medical Research Conference of Queensland*, 2006.

Green, D., Klomp, N., Rimmington, G.R., Sadedin, S., *Complexity in Landscape Ecology, Landscape Series*, Vol. 4, Springer, 2006.

Green, D., Bransden, T., 'Complexity Theory', *The McGraw-Hill Encyclopedia of Science & Technology*, McGraw-Hill, 2006, 507-511.

Kanagarajah, A.K., Lindsay, P., Miller, A., Parker, D., 'An exploration into the uses of agent-based modeling to improve quality of health care', *International Conference on Complex Systems*, July 2006.

Kirley, M., Abbass, H., McKay, R., 'Diversity mechanisms in Pitt-style evolutionary classifier systems', *Data Mining and Discovery Approaches Based on Rule Induction Techniques, Massive Computing series*, Vol. 6, Springer Verlag, 2006, 433-458.

Mathon, R., Street, A., Gamble, G., 'Classification of partitions of the set of all triples on ten points into copies of Fano and affine planes', *Discrete Mathematics*, 2007.

Research Students

Research by postgraduate research students under the supervision of Centre staff contributes significantly to the Centre's longer-term research goals. By providing high quality training environments, the Centre actively aims to retain Australia's best young complex systems researchers within the country. Scholarship or top-up funding was awarded to 14 students at UQ, four at Griffith, and three at UNSW@ADFA in 2006. Centre funding also enables students to attend conferences and workshops, to present their work and to gain a wider perspective on research and technical innovation.

To provide awareness of opportunities for postgraduate study with ACCS, the Centre sponsored a barbeque in August for University of Queensland undergraduates from Information Technology & Electrical Engineering, Economics, Mathematics and Biology. The Centre also participated in the Innovation Expo held by the School of Information Technology & Electrical Engineering in October. Other outreach activities are described later in this Report.

Research Degrees Awarded

Rodney Beard (UQ) – PhD
'Ito stochastic control theory, stochastic differential games and the economic theory of mobile pastoralism'
Advisors: Colin Brown & John Mott

Nicholas Geard (UQ) – PhD
'Artificial ontogenies: a computational model of the control and evolution of development'
Advisor: Janet Wiles

Minh Ha Nguyen (UNSW@ADFA) – PhD
'Cooperative coevolutionary mixture of experts: A neuro ensemble approach for automatic decomposition of classification problems'
Advisors: Hussein Abbass & Robert I. McKay

Lesley Seebeck (UQ) – PhD
'The co-evolution of information technologies and their host systems'
Advisor: Simon Kaplan

James Watson (UQ) – PhD
'From genotypes to phenotypes and back again: Modeling the interaction between individual behaviour and evolution'
Advisors: Janet Wiles, Jim Hanan & Mikael Bodén

Kai Willadsen (UQ) – PhD
'Robustness in Boolean models of genetic regulatory systems'
Advisor: Janet Wiles

PhD Students

Sameer Alam (UNSW@ADFA)
'A complex system approach to free-flight air traffic management'
Advisors: Hussein Abbass, Michael Barlow & Peter Lindsay

Shane Arnott (UQ)
'Use of modelling and simulation in support of strategic organisational decision making'
Advisors: Peter Lindsay & Richard Davis

Jennifer Badham (UNSW@ADFA)
'The effect of social network structure on the spread and control of epidemics'
Advisor: Hussein Abbass & Rob Stocker

Mark Bowden (UQ)
'Can the interaction of heterogeneous agents explain price fluctuations in financial markets?'
Advisors: Jason Potts, Stuart McDonald & John Foster

Lam Bui (UNSW@ADFA)
'Distributed multi-objective optimisation'
Advisors: Hussein Abbass, Daryl Essam, David Green & Kalyanmoy Deb

Brett Campbell (UQ)
'Designing to maintain human agency in context-aware systems'
Advisors: Margot Brereton & Ted McFadden

Tim Cederman-Haysom (UQ)
'Participatory design of ubiquitous computing'
Advisors: Margot Brereton & Peter Sutton

Kuang Yuan Steven Chen (UQ)
'A methodology for training teams of agents'
Advisors: Peter Lindsay & Hussein Abbass

Mikolaj Cieslak (UQ)
'Modelling carbon allocation in kiwifruit vine'
Advisors: Jim Hanan, Christine Beveridge & Alla Seleznyova

Simon Connelly (UQ)
'Use of agent-based modelling to investigate shared situation awareness'
Advisors: Peter Lindsay & Marcus Gallagher

Brijesh Dongol (UQ)
'Formal reasoning about progress in concurrent programs'
Advisors: Ian Hayes & Robert Colvin

Jared Donovan (UQ)
'Participatory design of gestural interfaces in complex multi-modal work environments'
Advisors: Margot Brereton & Stephen Viller

Elizabeth Dun (UQ)
'Computational analysis of branching and flowering in pea plants'
Advisors: Christine Beveridge & Jim Hanan

Liqi Han (UQ)
'Multi-scale modelling of legume nodulation'
Advisors: Jim Hanan & Peter Gresshoff

John Hawkins (UQ)
'Machine learning architectures for biological sequence analysis'
Advisors: Mikael Bodén & Janet Wiles

Geoffrey Jones (UQ)
'Institutions, information mediating competencies, service exporting sectors and economic growth in Vietnam and other developing countries'
Advisors: John Foster, Tom Mandeville & Jason Potts

Ashok Kanagarajah (UQ)
'Characteristics and improvement strategies for health sector supply chains'
Advisors: Peter Lindsay, David Parker & Anne Miller

Tim Kastelle (UQ)
'Towards an evolutionary economic theory of firm internationalisation'
Advisors: Peter Liesch, John Steen & Jason Potts

Donny Kurniawan (Monash)
'Integrated software development environments for the Grid'
Advisor: David Abramson

Xilin Li (UQ)
'Visualisation and coordination with complex systems'
Advisors: Penelope Sanderson & Zhao Dong

Kai Lin (Griffith)
'Maintaining constraints in real-time collaborative systems'
Advisors: David Chen & Geoff Dromey

Jennie Miao Lu (UQ)
'Probabilistic transmission expansion planning in competitive electricity market'
Advisor: Zhao Dong

John Zhe Lu (UQ)
'Electricity market planning and management'
Advisors: Zhao Dong & Penelope Sanderson

Stefan Maetschke (UQ)
'Advanced machine learning approaches to sequence characterisation in bioinformatics'
Advisors: Marcus Gallagher, Geoff McLachlan & Mikael Bodén

Michelle McPartland (UQ)
'Evolving non-player character behaviour in games'
Advisors: Peta Wyeth & Janet Wiles

Kate Morrison (UQ)
'The value of markets'
Advisors: Peter Earl & John Foster

Toby Myers (Griffith)
'Fuzzy Behavior Trees: combining fuzzy logic with Behavior Trees'
Advisors: Geoff Dromey & Vladimir Estivill-Castro

Anisah Nizar (UQ)
'Advanced techniques for framework analysis of customer behaviour due to non-technical losses for electricity supply industry'
Advisors: ZhaoYang Dong & Penny Sanderson

Andrew Rae (UQ)
'A behaviour-based methodology for fault tree generation'
Advisor: Peter Lindsay

Alan Raine (UQ)
'On growth, property and energy transformation'
Advisors: John Foster, Jason Potts & Tom Mandeville

Ella Reeks (Rohen) (UQ)
'Agent coordination in emerging markets'
Advisors: Tom Mandeville, John Foster & Peter Earl

Blaize Rhodes (UQ)
'Presence, awareness and a process trellis'
Advisor: Simon Kaplan

John Seagrott (Griffith)
'Investigating potential productivity improvements through a systematically constructive requirements engineering approach'
Advisor: Geoff Dromey

Aaron Searle (QUT)
'Automatic relative debugging'
Advisors: John Gough & David Abramson

Kamran Shafi (UNSW@ADFA)
'Learning classifier systems for network intrusion detection'
Advisors: Hussein Abbass & Weiping Zhu

Morgan Smith (UQ)
'Modelling air traffic control systems using learner agents'
Advisor: Ariel Liebman

Philip Valencia (UQ)
'Can practical distributed robotic solutions be automatically generated for real world applications'
Advisors: Peter Corke & Peter Lindsay

Lian Wen (Griffith)
'Mapping requirements changes to design changes'
Advisor: Geoff Dromey

Ang Yang (UNSW@ADFA)
'A networked multi-agent combat model: Emergence explained'
Advisors: Hussein Abbass & Ruhul Sarker

Yu-Hei Flora Yeh (UQ)
'Model selection in machine learning using computational statistics'
Advisors: Marcus Gallagher, Hussein Abbass & Janet Wiles

Saad Zafar (Griffith)
'Integrating safety and security requirements into the design of large systems'
Advisor: Geoff Dromey

Xuelin Zheng (Griffith)
'A framework for early detection of requirements defects'
Advisor: Geoff Dromey

Masters

Andriy Kvyatkovskyy (UQ)
'Evolutionary computation in combinatorial graph theory'
Advisors: Peter Adams & Marcus Gallagher

Gillian Salerno (UQ)
'The political economy of lake eutrophication'
Advisor: Stuart McDonald

Honours

Lynne Davis (UQ)
'Predicting localisation of proteins to the nucleolus'
Advisor: Mikael Bodén

David Hendry (UQ)
'Modelling photosynthesis'
Advisors: Christine Beveridge & Jim Hanan

Cameron Smith (UQ)
'Visualising models of complex ecosystems'
Advisor: Jim Hanan

Mark Wakabayashi (UQ)
'Computational plausibility of stretch receptors as the basis for motor control in C. elegans'
Advisor: Janet Wiles

Summer Student Projects

To encourage students to pursue research careers, the Centre funded the following summer student projects at the Brisbane node of the Centre. The 2005/06 summer student projects were reported in the 2005 Annual Report.

2006/2007 Projects

Lynne Davis (UQ)
'The diffusion kernel and its application to predict gene networks from expression data'
Supervisor: Mikael Bodén

Nathan Kachel (UQ)
'Benchmarking complex optimisers'
Supervisor: Marcus Gallagher

Jared Moore (UQ)
'Development of a reusable scientific software library'
Supervisors: James Watson & Janet Wiles

Andres Sanin (UQ)
'Modelling the role of cellular interactions in morphology'
Supervisors: James Watson & Janet Wiles

Tran Thu Trang (UQ)
'Impacts of climate change in the Murray Darling Basin for irrigators'
Supervisors: John Quiggin & David Adamson

Mark Wakabayashi (UQ)
'Modelling self-organising properties of multicelled organisms'
Supervisor: Janet Wiles

Behavior Trees Go Mobile

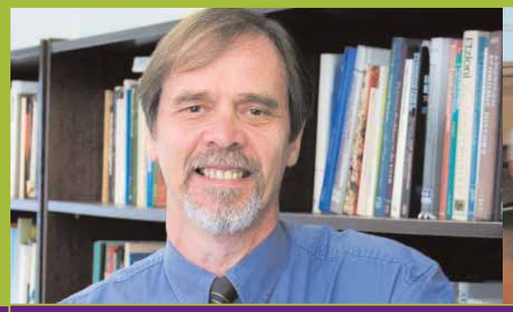
A Behavior Tree Framework for Implementation has helped get Behavior Trees off the whiteboard and going mobile on a Khepera Mobile Robot (pictured below). During a visit to University of Technology Malaysia, graduate student Toby Myers demonstrated the potential of Behavior Trees by using them to control a Khepera Robot to perform obstacle avoidance whilst moving towards a predefined target.

The controller was designed using an extension of Behavior Trees which can model Fuzzy Sets and allows Fuzzy Controllers to be designed using the standard Behavior Tree Process. The majority of the code for the system was automatically generated in C++ using a code generation tool based on the Behavior Tree Framework for Implementation.

Being able to model Fuzzy Controllers with Behavior Trees opens up a range of future possibilities: rapid prototyping using automated code generation; ensuring safety of fuzzy controlled robotic systems with failure mode and effects analysis (FMEA); and the design of complex systems consisting of many interacting fuzzy controllers.

In addition to this project, two other projects have been implemented using the Behavior Tree Framework: an Ambulatory Infusion Pump and a Traffic Light Controller for an Intersection. The implementation of the Traffic Light Controller contained 2750 lines of generated code and required only 250 lines of handwritten code.

Photo courtesy of K-Team Corporation, Switzerland



Outreach, Links and Service to Community

Keynote and Invited Addresses at International Conferences

Hussein Abbass, Keynote Speaker, 2006 International Seminar Series, Intelligent Robot Research Centre, Advanced Institute of Science and Technology (KAIST), Korea, November, 'Recent advances on artificial life and adaptive robotics'.

Geoff Dromey, Keynote Speaker, 2006 Malaysian Software Engineering Conference.

George Havas, Invited Speaker, Oberwoldach Computational Group Theory Workshop, Mathematisches Forschungsinstitut Oberwolfach, Germany, (www.mfo.de), 2-8 July, 'Experiences with the Knuth-Bendix procedure'.

George Havas, Invited Speaker, SAGE Days 2006, University of California at San Diego, USA, 4-5 February, 'Proofs in finitely presented groups'.

Ian Hayes, Invited Panellist, British Computer Society-FACS/FME Evening Seminar , London, 30 January, 'Formal methods in the last 25 years'.

Ian Hayes, Invited Speaker, Unified Theories of Programming Symposium (UTP 2006), Darlington, UK, February, 'Termination of real-time programs: definitely, definitely not, or maybe'.

Peter Lindsay, Keynote Speaker, 4th IEEE International Conference on Computer Sciences: Research Innovation & Vision for the Future (RIVF 2006), Ho Chi Minh City, Vietnam, 12-16 February, 'Engineering of complex systems'.

Peter Lindsay, Keynote Speaker, Formal Methods Conference, Hamilton, Ontario, Canada, August, 'Distributed control in network-based systems: a complex systems approach'.

Peter Lindsay, Invited Speaker, Airservices Australia Asia Pacific Air Navigation Service Providers Conference, Australia, 16-18 August., 'Impact of complex systems technologies on safety'.

Serving the Research Community

The Centre is taking a leading role in organising the **8th Asia-Pacific Complex Systems Conference (Complex'07),** which is to be held at Surfers Paradise in July 2007. See page 33 for further details.

Hussein Abbass was Associate Editor of the International Journal of Applied Systemic Studies (IJASS) - Inderscience Publishers, a member of the Editorial Review Board of the 'Advances in Data Warehousing and Mining' Book Series published by IGI Press, Inc (USA), Chair of the IEEE-NN-EC Task Force on Artificial Life and Complex Adaptive Systems, Sub-Committee Chair for Conference Liaison, the Australian Computer Society Artificial Intelligence Committee, member of the IEEE System, Man Cybernetics Society Technical Committee on Soft Computing, Technical Co-Chair of SEAL 06, China, of SPIE'06, Adelaide, IEEE-ALife'07, Hawaii, and of the IEEE Congress on Evolutionary Computation 2007, Singapore. He was a Program Committee member of European Conference on Genetic Programming (EuroGP'06), 29th Australasian Computer Science Conference (ACSC'06), Computational Intelligence in Security, Australasian Data Mining Conference (AusDM06), 19th Australian Joint Conference of Artificial Intelligence 2006 (AI 2006), IEEE Congress on Evolutionary Computation (CEC'06), and Genetic and Evolutionary Computation Conference (GECCO'06).

David Abramson and **John Foster** were both appointed to the ARC College of Experts.

Geoff Dromey was invited to be the Australian representative on the Technical Committee for the 1st Asian Working Conference on Verified Software.

David Green was Editor of Complexity International, a member of the Editorial Advisory Board, of the journals Ecological Informatics and the Journal of Economic Interaction and Coordination (JEIC), and an Australian Research Council reader.

Lars Grunske was Technical Program Chair for the Australian Systems Engineering, Test & Evaluation Conference (SETE 2006).

Jim Hanan was Coordinator and Chair of the 'Systems Biology and Modelling in Plants' session for the International Society for Plant Molecular Biology 2006, held in Adelaide in August.

Ian Hayes is on the Steering Committee for the Formal Methods Symposia Series, the Editorial Board of the BCS/Springer journal 'Formal Aspects of Computing', the Program Committees for the 5th Workshop on Quantitative Aspects of Programming Languages (QAPL 2007), the International Conference on Engineering Complex Computing Systems (ICECCS'07), and the International Colloquium on Theoretical Aspects of Computing (ICTAC 2007), and was on the Program Committees for the 4th Workshop on Quantitative Aspects of Programming Languages (QAPL 2006), the 8th International Conference on Mathematics of Program Construction (MPC 2006), and Formal Methods (FM 2006).

Ariel Liebman is on the Organising Committee for the Australian Mathematical Sciences Institute (AMSI) Industry Workshop & ICE-EM Short Course on 'The mathematics of electricity supply and pricing' in 2007.

Peter Lindsay was on the Program Committee for the 2nd International Conference on Research in Air Transportation (ICRAT 2006), the Australian Systems Engineering, Test & Evaluation Conference (SETE 2006), the 1st International Workshop on Formal Methods for Interactive Systems, the Uninhabited Airborne Systems special stream of Information, Decision and Control (IDC 2007), the Complexity and Nonlinear Dynamics Conference held as part of the 2006 International Society for Optical Engineering's international colloquium (SPIE 2006); he is on the Program Committee for the 12th IEEE International Conference on Engineering of Complex Computing Systems (ICECCS'07), and for the 'Organic Computing - An Approach to Controlled Emergence' special session of the IEEE Congress on Evolutionary Computation (CEC 2007).

International Conference on Complex Systems

The Centre is taking a leading role in organising the **8th Asia-Pacific Complex Systems Conference (Complex'07)** which is to be held at the Surfers Paradise Marriott Resort, Gold Coast, Queensland from 2-5 July 2007. Peter Lindsay is Conference General Chair, Janet Wiles is Program Co-Chair (with COSNet's Bob Dewar), Peter Adams is Local Organisation Chair and Carol Stirk is Sponsor and Exhibits Coordinator.

Complex'07 will be the key complex systems event in Australia and the Asia-Pacific region for the year, seeking to bring together those in the region who are actively involved in complex systems research and practice. It also aims to provide an introduction to specialised topics for people seeking to know more about the theoretical and practical aspects of research in complex systems, and will be similar in format to those in the International Conference on Complex Systems (ICCS) series.

The Conference will feature a day of workshops/tutorials, followed by three days of keynote presentations, panel discussions, contributed papers and poster sessions.

Registrations open on 30 March 2007, with an early bird registration deadline of 31 May 2007.

For further details visit the Conference website at www.complex07.org

COMPLEX 07

Visitors to the Centre

The Centre conducts an international visitor program and other networking activities that engage allied researchers who might not be formally associated with the Centre.

Prof Don Campbell
Monash Institute of Health Services, Australia
November

Prof Keith Clark
Dept of Computing, Imperial College, London, UK
July

Prof Sean Cleary
City College, City University of New York, USA
April-May

Prof Roger Eggleton
Dept of Mathematics, Illinois State University, Illinois, USA
July

Prof Robert Glass
Indiana University, USA
January-December

Prof Garrison W. Greenwood
Portland State University, USA
August-December

Mariangela Guidolin
Dipartimento di Scienze Economiche, Marco Fanno
Università degli Studi di Padova, Padova, Italy
July-October

Prof David Hill
Research School of Information Sciences and Engineering, Australian National University
July

Prof Melvin Hinich
University of Texas at Austin, USA
July, December

Prof Barbara Kitchenham
University of Durham, UK
November

Prof Andrew Lewis
Griffith University, Australia
June

Prof Franco Malerba
CESPRI, Bocconi University, Milan, Italy
February-April

Prof Dr Hartmut Schmeck
Institute AIFB, University of Karlsruhe, Germany
March

Ravi Sing
Indian Institute of Information Technology and Management, Gwalior, India
January-March

Prof Katherine St. John
Lehman College, City University of New York, USA
April-May

Daniel Bradley, Carlos Espinosa, and Janet Wiles

Visits to International Institutions

Visits by Centre participants to leading international laboratories aim to develop relationships and build networks to help achieve global competitiveness and recognition for Australian complex systems research.

Of these visits, six are of particular note because of the high standing of the laboratories visited in the complex systems field:

Mark Bowden was invited to visit Prof Thomas Lux's group in the Department of Economics at the University of Kiel, Germany.

Lam Bui undertook an extended research visit to the Indian Institute of Technology, Delhi, India, and spent time collaborating with our Partner Investigator Prof Kalyanmoy Deb there.

Helen Dam and Kamran Shafi visited the Illinois Genetic Algorithms Laboratory at the University of Illinois, Urbana-Champaign, USA and the University of Birmingham, UK.

Geoff Dromey was Visiting Professor at UTM, Malaysia during December.

George Havas undertook a number of research trips in 2006. The first included visits to the University of St Andrews, UK, the City University of New York, and the University of California at San Diego, USA. During the second research visit, George visited the Mathematisches Forschungsinstitut Oberwolfach, Germany, and the Universities of St. Andrews, Newcastle, Leicester and Warwick in the UK. On the third research trip, George again visited the University of St Andrews, UK as well as the City University of New York.

Ian Hayes was a Senior Visiting Research Fellow at the Interdisciplinary Research Collaboration in Dependability (DIRC) in Newcastle, UK as part of their Senior Visiting Fellows program.

Peter Lindsay visited the Eurocontrol Experimental Centre at Bretigny-sur-Orge, France, and the Boeing Research and Technology Europe Centre, Madrid, Spain. He was also invited to visit the Canadian Defence Research and Development organisation in Toronto, Canada.

Stuart McDonald spent a month at Social & Information Sciences Laboratory at CalTech, Pasadena, California, USA. He has subsequently taken up a postdoctoral fellowship there.

Anne Street visited Auburn University, Alabama, USA.

Seminars

Centre seminars are held by videoconference at 11.00am most Thursdays, organised by Ariel Liebman. Details of past and future seminars in this series are available on the ACCS website (www.accs.edu.au). Anyone is welcome to join the ACCS emailing lists to receive regular announcements of seminars and other Centre activities. Simply email the Director with your request and your preferred email address.

Seminars presented by Centre visitors in 2006 included:

2 March
Gary Eves –Queensland Parallel Supercomputer Foundation, Todd Churchward – SGI
'High performance computing infrastructure'

13 March
L. Andrew Coward – Australian National University
'A systems architecture approach to the brain: From neurons to consciousness'

23 March
Hartmut Schmeck – University of Karlsruhe, Germany
'Organic computing - visions and challenges'

26 April
Katherine St. John – Lehman College, City University of New York, USA
'Computational methods for analysing phylogenetic trees'

11 May
Luis R. Izqierdo – The Macaulay Institute, Aberdeen, UK
'Is your model susceptible to floating-point errors?'

25 May
Bernard Degnan – Integrative Biology School, UQ
'Reconstruction of the ancestral metazoan genome: structural and functional aspects of the sponge genome'

24 July
Michael Ward – Queensland Health
'Complex systems challenges in healthcare'

31 July
Jennifer Stow – Institute for Molecular Bioscience, UQ
'Sticking together - the only way to eat your lunch and prevent cancer'

24 August
Rodolfo Baggio – Bocconi University, Milan, Italy
'The Web Graph of a complex tourism system'

7 September
Carlos Espinosa – National Autonomous University of Mexico
'From gene networks to flowers: Results from dynamic models'

12 October
Joseph Winsen – University of Newcastle, NSW
'An overview of the effects of the SWIS Market on Generators'

8 November
Garrison W. Greenwood – Portland State University, USA
'Mimicking army ant swarm raids to search large continuous spaces for global optima'

22 November
Jérôme Buhl – University of Sydney
'From disorder to order in animal collective motion'

23 November
Audrey Dussutour – University of Sydney
'Moving in the crowd: Ants hold the key to traffic chaos'

7 December
Paul Simshauser – Babcock & Brown Power
'The dynamic efficiency gains from introducing capacity payments in the National Electricity Market'

Hussein Abbass and ACCS Canberra node participants joining in a weekly Centre seminar by videoconference

Professional Courses

Centre participants benefited from participation in a range of professional courses:

Nimrod
A three-day course was held at UQ in June. Ten ACCS personnel participated. See page 39 for details.

Complex Adaptive Systems Winter School
Dr Rizah Memisevic and PhD students Michelle McPartland and Flora Yeh participated in the UNSW@ADFA Winter School in June. See details on this page.

Software Licensing Models
David Israel from UniQuest presented a course on different forms of software licensing in August. Choosing the right form of licensing is important for ensuring successful commercialisation of the Centre's intellectual property.

Electricity Market Simulation Tool
Dr Glenn Drayton from Energy Exemplar presented a course at UQ in June on the use of Plexos electricity market simulation software. Glenn spent two days training 15 people from the Centre and the power systems engineering group at ITEE.

Machine Learning Summer School
Flora Yeh PhD student participated in the Machine Learning Summer School (MLSS 2006) held in Taiwan in July/August.

Complex Adaptive Systems Winter School at UNSW@ADFA

This year's Winter School was organised by the Canberra node of the Centre on 26-30 June, at the University of New South Wales at the Australian Defence Force Academy (UNSW@ADFA). The workshop was attended by 40 participants including academics, scientists and research students from around Australia.

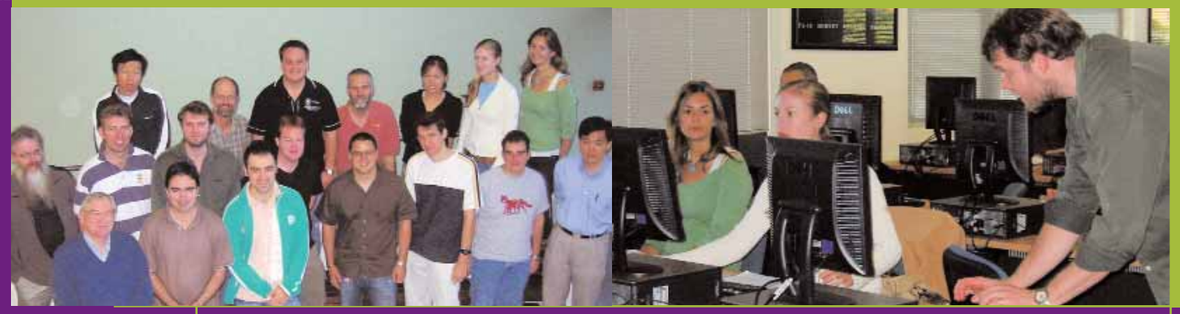
Complex Adaptive Systems (CAS) is a relatively new interdisciplinary field focusing on studying the interaction and dynamics in systems with many interconnected components. Normally, these systems can be seen as a network, where the nodes represent the components and the links represent the interaction. Examples include the brain, crowd behaviour, economies, environments, genes, governments, societies, swarm of robots, and many others. The use of CAS as a lens to look at these systems is changing our views on how to design and/or control these systems, opening many new challenges.

The Winter School took the audience into the world of CAS, covering basic principles, tools, methodologies, and applications to real-life situations. The ACCS provided travel/accommodation scholarships to eight students from universities in Queensland, New South Wales, Victoria and Tasmania.

The relevance of complexity research to real-world applications was an underlying theme for the presentations, and the Winter School culminated in presentations that identified and explained research in areas such as air traffic control, free flight, Australian defence and security, communication networks, classifier systems, supply-chain management, diversity and change, and epidemic spread.

Presenters at UNSW@ADFA Winter School

Participants at UNSW@ADFA Winter School



Participants at Nimrod training course

Workshops

Centre participants organised a number of workshops to enhance education and training, collaboration, and excellence in research:

Complex Adaptive Systems Winter School
See details on page 36.

Nimrod Training Course
In June, Tom Peachy, Slavisa Garic and Colin Enticott from the Monash node, and Andrew Lewis from the Griffith node, presented a three-day training course at UQ on Nimrod to 15 participants from the ACCS, CSIRO, UQ and Griffith University. Modelling and simulation are key techniques for understanding complex systems. But the process of developing, calibrating and validating models can be extremely time consuming and prone to errors. Nimrod was developed by researchers at the Monash node of the ACCS to simplify the process of handling large sets of parameter values. A number of ACCS projects have since used the tool extensively in their research.

Personal Software Engineering Discussion Group
Daniel Bradley organised a weekly informal seminar series that ran for much of 2006. The aim was to provide a forum for software developers working in the complex systems modelling area to share experience in solving software engineering issues.

Mastering System Complexity
Geoff Dromey presented three one-day and three introductory workshops on the Behavior Tree method to CSIRO ICT Division personnel in Sydney, Canberra and Brisbane. More than 40 scientists in each of the centres attended the introductory sessions, and more than 20 in each centre attended the one-day sessions. CSIRO is expecting to trial the method on a future large-scale project that will require significant systems engineering.

Workshop on Intelligent Systems for Bioinformatics
The Centre co-sponsored this workshop, which was held in conjunction with the Australian Joint Conference on Artificial Intelligence in Hobart in December. Mikael Bodén and Timothy Bailey were the organisers. The workshop attracted 20 participants and featured reports from several of the Centre's Genetic Regulatory Network program projects. The proceedings were published as volume 73 of the Australian Computer Society's CRPIT series (crpit.com/Vol73.html).

Software Engineering Process Group (SEPG) Conference
Geoff Dromey presented a half-day workshop at this conference in Melbourne in September.

Energy Market Modelling & Risk Management Workshops
Ariel Liebman presented a workshop entitled 'The next generation power market: Uncovering the key drivers' at the Tasmanian Power 2006 Conference in Hobart in November and a workshop titled 'Cutting edge practical risk management' at the Energy Market Risk Conference in Sydney in June.

Other Workshops

Complexity in ICT Systems Workshop
Geoff Dromey and Peter Lindsay presented at this workshop, held as part of the Australian Software Engineering Conference (ASWEC 2006) in Sydney in April.

COSNet Forum
Hussein Abbass, David Green, Peter Lindsay and Janet Wiles participated in the Complex Open Systems Research Network (COSNet) Forum in Canberra in November.

CSIRO Complex Systems Science in Focus
Janet Wiles gave a Keynote talk on 'Challenges in biocomplexity from molecules to minds' at this workshop in Sydney in August.

Government, Industry and Business Briefings

The briefings listed are illustrative of how the Centre feeds ideas, discoveries and techniques to government and industry to improve their current practices and seed innovation. A number of Centre personnel have been invited to join advisory or expert panels, recognising their expertise in the relevant areas.

Geoff Dromey was invited by Maritime Services Division of the Department of Defence to provide advice on the design of a new information architecture for the divisional web-based systems; and also to conduct a trial of methodology by Griffith University Information Services; Geoff has conducted an ongoing trial in the use of requirements modelling methodology for a large system with over 1000 requirements for Ansaldo, a large international transportation company; and conducted an ongoing trial of requirement modelling methodology with the Department of Defence for a very large system for implementing battlespace communications. Geoff is also having ongoing discussions with Hatch Mining, a major multi-national company, about systems integration, reliability and failure mode modelling for a large mining/industrial project.

Geoff Dromey and **Griffith** researchers have been consulted by Raytheon, a major multi-national company, who wish to undertake a major trial of requirements modelling methodology.

Ariel Liebman was an Invited Speaker at the Terrapinn Energy and Trading Risk Management Conference in Sydney in October, and gave a presentation jointly with Geoff James from CSIRO ICT titled 'Risk management in an intelligent grid: Agent based demand side management'. He was an invited speaker and Conference Chair on the first day of the Tasmanian Power 2006 Conference in Hobart in November, and was also a Panel Member invited to discuss 'Energy Trading and Risk Management' at the Queensland Power Conference in Brisbane in October.

Peter Lindsay and **Geoff Dromey** were invited by the Defence Materiel Organisation (DMO) to join an expert advisory panel to the Director, Electronic Systems Division, on systems and software engineering. Peter also joined Boeing Australia's Systems Engineering Process Council as an observer. Peter and Geoff also presented at the Complexity in ICT Systems and Projects Workshop, held as part of the Australian Software Engineering Conference (ASWEC 2006), in Sydney in November.

Peter Lindsay was an Invited Speaker at the Airservices Australia Asia Pacific Air Navigation Service Provider Conference on the Gold Coast in August; and participated in the 2006 Eurocontrol Air Traffic Management Innovative Research Workshop in France in December. He visited Boeing's Air Traffic Management research group in Madrid, Spain in December for discussions on research collaboration on trajectory management. He gave a presentation on the Centre's research at the Canadian Defence Research and Development organisation in Toronto, Canada in August.

Andrew Neal and researchers from the ATC Workload project briefed senior managers from Airservices Australia on workload prediction measures for the proposed ADSB roll-out.

John Steen briefed members of CPA Australia (formerly known as the Australian Society of Certified Practising Accountants) at their Congress held in Brisbane on 25 October. John's presentation was entitled 'Globalisation and its impact on organisational strategy'.

The Centre also conducted workshops with organisations including Boeing Australia, Airservices Australia, the University of Sydney's Warren Centre and Education Queensland.

Industry Visitors

Visits by the following industry representatives served to strengthen ties with the Centre and promote communication of discoveries and techniques.

Dr Holger Becht, System Safety Manager, Boeing Australia

Dr Glenn Drayton, Managing Director, Energy Exemplar

Chris James, John Phillips and Peter Seebacher, The Warren Centre, The University of Sydney

Dr Bill Lyons, Phantom Works, Boeing USA

Greg McDonald, Future Direction Group, Airservices Australia

Francisco Navarro and Dr Miguel Vilaplana, Boeing Research & Technology Europe Centre, Madrid, Spain

Dr Kelvin Ross, K.J. Ross & Associates

Dean Sedgmen, Director, School Technologies, Dept of Education and the Arts, Queensland Government

Paul Simshauser, CEO, Babcock & Brown Power

Dr Terry Stevenson, Chief Technology Officer, Raytheon Australia

Barry Sutherland, Business Development Manager, Network-enabled Systems Division, Boeing Australia

Dean Webb and Joel Gray, International Business Development, Boeing USA

Technology Transfer and Commercialisation Activities

Our technology transfer and commercialisation activities are aimed at encouraging end users to adopt Centre ideas, methods and tools to enable them to better understand, design and manage complex systems.

One of the measures of our success is the degree to which our methods and tools are taken up and used by others. There is broad interest in the work we are doing. Amongst others, we have collaborations with:

- CSIRO Livestock Industries (see page 9, 'Applying complex systems models to muscle-specific gene').
- Centre of Excellence in Integrative Legume Research (CILR) and ARC Centre in Bioinformatics (see page 9, 'Modelling regulatory networks at cell, tissue and organism level').
- Key Centre for Human Factors and Applied Cognitive Psychology (see page 14, 'Safety assessment of ATC human-computer interaction').
- Airservices Australia (see page 13, 'Air traffic control workload').
- US-based 'TeraGrid' (see page 25 'Application of Grid computing to complex systems modelling').
- Defence Science and Technology Organisation (DSTO) (see page 25 'Adaptive network-centric multi-agent architecture for land combat').
- Queensland Brain Institute (see page 26 'Modelling fear conditioning in rats').
- Queensland Health (see page 30 Ashok Kanagarajah's PhD project entitled 'Characteristics and improvement strategies for health sector supply chains').

The Centre has developed an Intellectual Property (IP) Register to assist with management of the identification, protection and commercialisation of Centre IP and to help ensure compliance with restrictions on third-party Background IP introduced into the Centre. The IP Register consists of a database of IP information cross-linked with project information, with a web-based user interface accessible to Centre participants. UniQuest, the commercialisation arm of The University of Queensland, has identified commercial potential for the IP Register and is proposing to develop the tool into a commercial product.

Discussions have also been held with a view to patenting two of the Centre's innovations.

There is increasing industry interest in the Behavior Trees method (see page 24 'Taming the Complexity of Large-Scale Software-Intensive Systems').

Public Awareness Programs

Through Public Awareness Programs and Industry Workshops, the Centre aims to raise awareness of complex systems in Australia, and its importance in innovation and international competitiveness.

The Centre maintains a website (www.accs.edu.au) and mailing list to assist in its task of raising public awareness of complex systems.

The Centre has supported the development of Monash University's Artificial Life Virtual Lab (VLAB). VLAB presents online simulations and demonstrations of models to help people understand how complex organisation and behaviour emerges in living systems. Further details are on page 40.

The Centre presented and jointly sponsored a lecture during The University of Queensland's Research Week to raise public awareness of the Centre's research. Further details are on this page.

Planning for Climate Change: The Environment as a Complex System

Staged as part of The University of Queensland's Research Week, a public lecture organised by the Centre and BrisScience attracted nearly 300 people at the Brisbane Town Hall on 18 September. The level of audience interest was high and we received a lot of positive feedback.

Centre Chief Investigator Professor John Quiggin spoke on 'Complexity, climate change and the precautionary principle' and Professor Ed Blakely from the University of Sydney spoke on 'Climate change: Planning for it and not just worrying about it'. Brief details of John Quiggin's presentation follow.

Complexity, Climate Change and the Precautionary Principle

John Quiggin

The problem of climate change involves interactions between current and future human energy and land use, driven by a world economy and society embracing billions of people, and global atmospheric, oceanic and biospheric systems operating at scales ranging from microscopic to planetary.

In debating policy decisions about such complex systems, it is common to appeal to the precautionary principle. One popular version states: 'When an activity raises threats of harm to human health or the environment, precautionary measures should be taken, even if some cause-and-effect relationships are not fully established scientifically'.

However, this principle itself creates difficulties in a situation where any activity we undertake has the potential to cause harm. Some have therefore suggested that the precautionary principle should be discarded.
In this lecture, it will be argued that the precautionary principle can be given a rigorous formulation that provides useful guidance in dealing with complex systems.

Monash University's Artificial Life Virtual Laboratory (VLAB)

Artificial Life (ALife) is an area of theoretical research that uses simulations to understand how organisation and behaviour emerges in living systems. The increasing prominence of computers has led to a new way of looking at the world. This view sees nature as a form of computation. That is, we treat objects as simple computers, each obeying its own set of laws. VLAB is an online virtual laboratory within which users can experiment with models of complex systems.

VLAB provides online resources for researchers, who are able to experiment with models described in our recent research. It is also an educational resource. For the public at large, it helps to raise awareness of complexity issues. For students, the hands-on approach is an effective way of learning to understand key concepts in complexity.

Recent usage statistics indicate that the majority of the site's users are from .edu domains.

The main online facilities provided by VLAB are interactive simulation models, which are implemented as Java applets for users to download and run. Each applet contains a simulation to demonstrate a basic concept or a recent research result. VLAB also provides related tutorials, references and web links that cover key ideas and processes in complexity theory.

The demonstrations cover technical matters such as asynchrony, feedback, and the onset of chaos. They also show complexity at work in many real systems. These include biological examples such as epidemics, forest mosaics, evolution, insect swarms and starfish outbreaks. They also include examples of human and artificial systems such as the influence of media on social opinion, and cascading failures in power grids.

VLAB can be found online at
http://www.complexity.org.au/vlab/

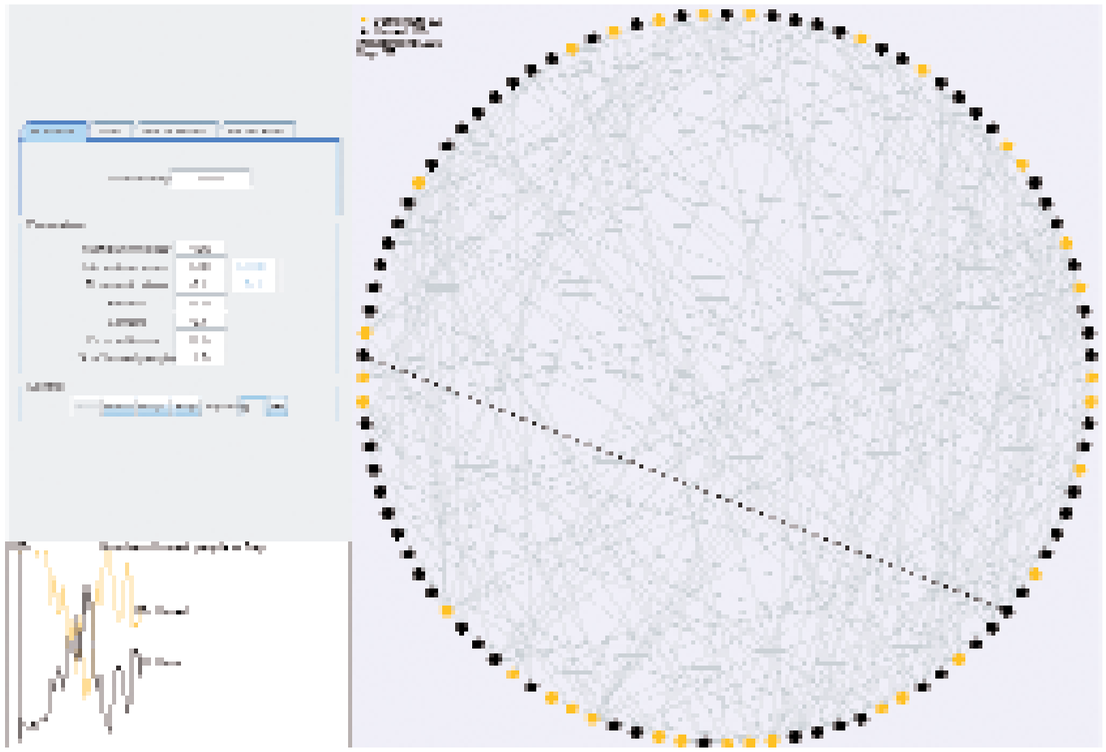


Image from VLAB showing a simulation of the spread of dishonest behaviour through a social network.

Centre personnel presented at the following conferences:

2nd International Conference on Computational Finance and its Applications (Computational Finance 2006)

3rd International Conference on Legume Genomics and Genetics 2006 (ICLGG 2006)

6th International Conference on Complex Systems (ICCS 2006)

10th International Conference on the Simulation and Synthesis of Living Systems (Alife X)

12th International Conference on Computing in Economics and Finance (CEF 2006)

14th Annual International Conference on Intelligent Systems for Molecular Biology (ISMB 2006)

31st Australasian Conference on Combinatorial Mathematics and Combinatorial Computing

48th Academy of International Business Annual Meeting

Australian Agricultural and Resource Economics Society 50th Annual Conference (AARES 2006)

Australian Software Engineering Conference (ASWEC 2006)

Australian Workshop on Combinatorial Algorithms (AWOCA 2006)

ComBio2006

Danish Research Unit for Industrial Dynamics (DRUID) Summer Conference 2006

Formal Methods (FM'06)

Functional-Structural Plant Modelling in Crop Production Workshop

IEEE Congress on Evolutionary Computation (CEC 2006)

International Conference on Formal Engineering Methods (ICFEM 2006)

The International Society for Plant Molecular Biology 2006 Conference (ISPMB 2006)

Undergraduate & Postgraduate Courses

The following course was developed and delivered by Centre participants.

Introduction to Complex Systems
(UQ COMP4006/7011)
Coordinator: Janet Wiles (with lectures from ACCS personnel Mikael Bodén and Andre Leier).
Level: Undergraduate/Postgraduate

In addition, Centre participants presented aspects of complex systems science and engineering in the following undergraduate and postgraduate courses:

Advanced Algorithms and Data Structures
(UQ COMP4500/COMP7500)
Coordinator: Ian Hayes
Level: Undergraduate/Postgraduate

Functional Plant Biology
(UQ BOTN2002)
Presenter: Guest lectures by Jim Hanan on modelling of regulatory networks
Level: Undergraduate

Mathematical Biology
(UQ MATH3104)
Presenter: Guest lectures by Jim Hanan on computational modelling of biological systems
Level: Undergraduate

Scientific Computing: Advanced Techniques and Applications
(UQ MATH3201)
Coordinator: Bernard Pailthorpe
Level: Undergraduate

System Safety Engineering
(UQ ENGG7020)
Presenters: Peter Lindsay, Lars Grunske, Simon Connelly
Level: Postgraduate, also offered as a public course to industry.
Included dependability analysis for complex engineered systems

Systems Engineering
(UQ ENGG4000/7000)
Coordinator: Peter Lindsay (with lectures from ACCS researcher Lars Grunske)
Level: Undergraduate/Postgraduate

Publications 2006

Papers published in journals that the University of Queensland considers Tier 1, the top ten percent in their field, are starred❖.

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Performance Indicators Report

P1. Research findings

Description	2006 Actual	Details	2006 Target
Quality of publications	18	See Publications, pages 42 to 43	At least eight in the top 10% of journals and conferences in relevant areas
Invitations to address and participate in international conferences	9	See Keynote and Invited Addresses, page 32	5-6
Invitations to visit leading international laboratories	6	See Visits to International Institutions, page 34	3
Number and nature of commentaries about the Centre's achievements	3	See ACCS in the Media, page 15	3

P2. Research training and professional education

Description	2006 Actual	Details	2006 Target
Number of postgraduates recruited - with Centre financial support - affiliated with the Centre	 2 (22 total to date) 12 (34 total to date)	See Research Students, page 29	14 over the life of the Centre
Number of postgraduate completions	6 (9 total to date)	See Research Students, page 29	14 over the life of the Centre
Number of honours students	4 (15 total to date)	See Research Students, Honours, page 31	30 over the life of the Centre
Number of professional courses/workshops	9	See Workshops, page 37	1
Participation in professional courses	5	See Professional Courses, page 36	2
Number and level of undergraduate and high school courses in the complex systems area	primary contributor: 3 other contributor: 2	See Undergraduate & Postgraduate Courses, page 41	Primary contributors to 2-3 undergraduate courses per annum, and contributions (e.g. guest lectures) to other courses; contribution to high school awareness events

P3. International, national and regional links and networks

Description	2006 Actual	Details	2006 Target
Number of international visitors	12 (4 of these had significant Centre financial support)	See Visitors to the Centre, page 34	4
Number of national and international workshops	6	See Workshops, page 37	2
Number of visits to overseas laboratories	14	See Visits to International Institutions, page 34	5
Examples of relevant Social Science & Humanities research supported by the Centre	3 publications	See Evolutionary Economic Systems publications, pages 16 to 20	1 publication

P4. End-user links

See the Director's Report, page 2, and Technology Transfer and Commercialisation Activities, pages 38 and 39, for details of end-user links

P5. Organisational support

See the Financial Statement, page 48, for details of organisational support

P6. Governance

See the Management section, page 6, for details of governance of the Centre

P7. National benefit

See the Director's Report, page 2, for details of national benefit

Financial Statement

Statement of income and expenditure year ended 31 December 2006

INCOME	
ARC Centre grant	960,035
Collaborating institutions' cash contribution	325,000
Other UQ funds	34,401
NHMRC	33,625
Industry cash contribution	52,800
Funds carried forward from 2005	604,282
TOTAL INCOME	**2,010,143**

EXPENDITURE	
Maintenance	165,181
Travel	105,469
Equipment	12,543
Salary	1,160,702
Scholarships	172,272
TOTAL EXPENDITURE	**1,616,166**

Funds carried forward to 2007	**393,977**

Activity Plan for 2007

Having brought together a world-class group of researchers and established the infrastructure and mechanisms to enable them to interact in a cross-disciplinary manner, the Centre's focus in 2007 will be on demonstrating quality and achieving uptake of the Centre's research.

More specifically, the following new initiatives are planned:

- Organise the 8th Asia-Pacific Complex Systems Conference (Complex'07), to be held on the Gold Coast in July.
- Continue to improve Centre researchers' skills in development and validation of models. A training needs exercise will be conducted in March.
- Hold a postgraduate workshop at which research students can present their projects and get feedback from experts.
- Hold workshops for Centre Project Leaders on research project management, technology transfer and commercialisation.

Ongoing activities include:

- Foster cross-disciplinary research across the Centre by undertaking projects to explore domain-independent notations and modelling techniques.
- Work with end-user organisations to develop collaborative projects, to trial and evaluate the Centre's research.
- Identify opportunities for the transfer of ACCS methods and tools to industry.
- Invite key international researchers to visit the Centre for discussions with Centre participants.

Australian Government
Australian Research Council

The ARC Centre for Complex Systems is a partnership of:

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