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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 fundamental to understanding, designing and managing complex systems. The goal was to develop 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 has developed strong infrastructure for modelling and analysing network-based systems, enabling the science to be applied to real-world problems. The resulting methods and tools are being used to understand, manage and control complex systems in domains including electricity networks, bioscience, high-tech systems acquisition, and air traffic control.

The Centre has its headquarters 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 campus at the Australian Defence Force Academy in Canberra. The Centre’s research programs emphasise cross-disciplinary research, involving leading researchers from a range of disciplines including: systems and software engineering, economics, visualisation, human factors, computational mathematics and statistics, and relevant application domains, including aerospace, economics, energy and biology. Funding was provided by the Australian Research Council (ARC) and the universities involved. Industry collaborations and further funding has been established to continue 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.

I write this section of the Annual Report with a mixture
of sadness and pride. Sadness, because the 2008
Annual Report will be the last annual report produced
by the ACCS. And pride, because of the significant
achievements and accomplishments of the Centre and its
participants.

As will be evident from the rest of this Annual Report,
in 2008 the Centre continued to build on its earlier
successes, consolidating collaborations across different
disciplines and sites, and establishing new collaborations
with industry and overseas institutions. We had a bumper
crop of PhD completions, and another fine year of high-
quality publications. According to recently released
ARC figures, the ACCS performed in the top 20% of
its cohort of 16 centres created in the 2003 Centres of
Excellence round of funding on 9 of the 14 per dollar-
funding performance indicators measured in 2007, and
we anticipate that we will score similarly well in the 2008
measures.

The rest of this Annual Report gives details of many of
the achievements of the research teams and individuals
who contributed to the Centre’s success in 2008.

Sadly, with the termination of Australian Research Council
funding in 2008, it has not proved viable to continue to
conduct our research programs beyond 2009 as a cross-
disciplinary, multi-institutional research centre in complex
systems science and engineering. But the good news is
that the results achieved by the ACCS over the five years
of its existence, including theory, methods and tools,
have laid the foundations for significant follow-on applied
research projects in collaboration with industry.

In particular, the Centre’s three core research programs
in 2008 – air traffic management, electricity networks
and energy markets, and dependable computer-based
systems – have all secured follow-on funding to apply
their research outcomes in industry collaborations. These
programs all grew out of the Centre’s cross-disciplinary
approach, and would probably not have arisen without
ARC Centre of Excellence funding.

Likewise, the nexus between the computational and
biological research that was started in the Centre’s
Genetic Regulatory Networks (GRN) program has
underpinned the Thinking Systems Project, led by
Professor Janet Wiles. Many of the network structures
and feedback loops of genetic systems that were studied
in the GRN program have counterparts in the neural
systems underlying navigation and spatial awareness.
The Thinking Systems Project is an ARC Special
Research Initiative jointly funded by the Australian
Research Council and the National Health and Medical
Research Council, and developed to a large degree
through the ACCS collaboration between ACCS Chief
Investigators Janet Wiles and Kevin Burrage.

We are grateful to the Australian Research Council and
the collaborating universities for their support of the
ACCS from 2004 to 2008.

The ACCS will wind down its operations in 2009. For
the most part this will involve consolidating on advances
made in 2008 and writing up results for publication.

I thank Peter Adams, Janet Wiles and John Foster for
standing in as Acting Director while I was on special
studies program in the second half of the year. I am
also very grateful for the continuing support provided
by Centre Manager Virginia Garton, whose diligence
has been a core strength of the Centre. Finally, I would
like to thank everyone who helped in putting this Annual
Report together, but especially Centre Outreach Officer
Leanne Brandis, who managed the project and collated
the material.

I wish all Centre participants continuing success in their
future endeavours.

Peter Lindsay
Director, ACCS
April 2009
Recognition of Centre personnel

Centre Chief Investigators received many noteworthy appointments during 2008:

- **Hussein Abbass** was made a Fellow of the Australian Computer Society (FACS) and an Associate Fellow of the Australian Institute of Management (AFAIM).
- **Peter Adams** was elected secretary of the Federation of Australian Scientific and Technological Societies. Peter was also appointed Associate Dean–Academic for the Faculty of Science at The University of Queensland.
- **John Foster** was elected President of the International J.A. Schumpeter Society, the world’s premier association of economists researching economic evolution, complex systems and innovation.
- **Ian Hayes** became a Fellow of the British Computer Society (FBCS).
- Centre researcher **Anne Street** was reappointed as an Honorary Professor at The University of Queensland for three years.

The quality of the research of two Centre Chief Investigators **Geoff Dromey** and **John Quiggin** was acknowledged by the inclusion of their research in the ARC’s publication *Outcomes. Results of Research in the Real World*, which was produced to celebrate the ARC’s inaugural Graeme Clark Research Outcomes Forum. This highlighted the “outstanding real-world results” achieved by Professors Dromey and Quiggin.

Centre collaborator **John Steen** received an ALTC Citation for Outstanding Contributions to Student Learning—For excellence in business strategy case study teaching and coaching, resulting in exceptional performance by the University of Queensland in the Australasian BCG strategy competition.

Centre Chief Investigator **Ian Hayes** and Staff member **Rob Colvin** received the best paper award for their paper “CSP with hierarchical state”, for the *Integrated Formal Methods: 7th International Conference* in Dusseldorf, Germany.

Centre PhD students received numerous awards in 2008, attesting to the quality of their research:

- **Sameer Alam** was awarded the Victorian Fresh Scientist Prize for 2008 for his work on ATOMS. Sameer was awarded his PhD from UNSW@ADFA in 2008 with his thesis “Evolving complexity towards risk: A massive scenario generation approach for evaluating advanced air traffic management concepts.”
- **Ardiaty Arief**, a current Centre PhD student at The University of Queensland, was awarded the Maude Walker Scholarship which is awarded to provide a top-up scholarship to a student for the purpose of postgraduate research in electrical engineering.
- A paper by **Paul Bell** on his research “Adaptive interactive profit expectations and small world networks” was awarded The University of Queensland’s BEL Faculty Research Conference 2008 Best Paper by a PhD Student.
- Centre staff member **Helen Dam** was awarded the Ria de Groot Prize as the best female postgraduate for 2008 at UNSW@ADFA. Helen was awarded her PhD in 2008 with her thesis “A scalable evolutionary learning classifier system for knowledge discovery in stream data mining.”
- **Jason Ke Meng**, a current Centre PhD student at The University of Queensland, was awarded the Richard Jago Memorial Prize which is a travel grant used for the purpose of furthering research by a visit to another institution, attendance at a conference or any other approved activity requiring a period of absence from Brisbane.
- **Kamran Shafi**’s thesis “An online and adaptive signature learning approach for intrusion detection using learning classifier systems” was awarded Best Thesis in IT at UNSW@ADFA for 2008.

Two Centre Chief Investigators, **John Foster** and **John Quiggin** participated in the 2020 Summit held on the 19th and 20th April at Parliament House in Canberra. The summit, designed to ‘help shape a long term strategy for the nation’s future’ consisted of 1002 delegates considering 10 critical areas. John Foster was a member of the ‘The future of the Australian economy’ working group and John Quiggin of the ‘Population, sustainability, climate change and water’ group.

Images courtesy of the Australian Government, Department of the Prime Minister and Cabinet.
Centre Personnel

The ACCS fostered the emerging discipline of complex systems within Australia by creating a critical mass of researchers. In 2008, the Centre brought together a strong, interdisciplinary team across four major Australian universities.

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<tr>
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<th>School/Unit</th>
<th>Institution</th>
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<tr>
<td>Prof Peter Lindsay</td>
<td>Information Technology &amp; Electrical Engineering</td>
<td>The University of Queensland</td>
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<tr>
<td>Prof John Foster</td>
<td>Economics</td>
<td>The University of Queensland</td>
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| Chief Investigators | |
|---------------------|---------------- |----------------|
| 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 & Communication Technology | Griffith University |
| Prof David Green | Computer Science & Software Engineering | Monash University |
| Prof Ian Hayes | Information Technology & Electrical Engineering | The University of Queensland |
| Prof Bernard Paitthorpe | 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 Kalyannoy Deb | Mechanical Engineering | Indian Institute of Technology, Delhi, India |
| Mr Wayne Needs | Support Systems in Australia | Boeing Australia Limited |
| 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 |
| Mr Daniel Bradley | Webmaster | The University of Queensland |
| Ms Leanne Brandis | Education Officer | The University of Queensland |
| Mr Leighton Brough | Tools Coordinator | The University of Queensland |

| Collaborators | |
|---------------|---------------- |----------------|
| Dr Michael Barlow | Information Technology & Electrical Engineering | UNSW@ADFA |
| Prof Gilbert Baumslag | Center for Algorithms & Interactive Scientific Software | City College, City University of New York, USA |
| Dr Rodney Beard | Business | University of Alberta, Canada |
| Dr Christine Beveridge | ARC Centre of Excellence for Integrative Legume Research | The University of Queensland |
| Dr Mikael Boden | Information Technology & Electrical Engineering | The University of Queensland |
| Mr Jim Boston | Senior Project Manager | Raytheon Australia |
| Dr Mark Bowden | Business and Law | Victoria University |
| Dr Darryn Bryant | Mathematics | The University of Queensland |
| Dr Lam Bui | Information Technology & Electrical Engineering | UNSW@ADFA |
| Prof Alan Burns | Computer Science | University of York, UK |
| Dr Colin Campbell | Mathematics & Statistics | University of St Andrews, Scotland |
| Dr David Chen | Information & Communication Technology | Griffith University |
| Prof Keith Clark | Computing | Imperial College, UK |
| Prof Marston Conder | Mathematics | University of Auckland, NZ |
| Dr David Cornforth | CSIRO Energy Technology | CSIRO |
| Assoc Prof Zhao Yang Dong | Information Technology & Electrical Engineering | The University of Queensland |
| Assoc Prof Diane Donovan | Mathematics | The University of Queensland |
| Assoc Prof Peter Earl | Economics | The University of Queensland |
| Mr Colin Enright | Computer Science & Software Engineering | Monash University |
| Dr Daryl Essam | Information Technology & Electrical Engineering | UNSW@ADFA |
| Prof Peter Fritzson | Computer and Information Science | Linköping University, Sweden |
| Dr Marcus Gallagher | Information Technology & Electrical Engineering | The University of Queensland |
| Mr Slavica Garic | Computer Science & Software Engineering | Monash University |
| Dr Nicholas Geard | Electronics & Computer Science | The University of Southampton, UK |
| Dr Anne-Marie Grisogono | Land Operations | Defence Science and Technology Organisation |
| Prof Peter Gressho | ARC Centre of Excellence for Integrative Legume Research | The University of Queensland |
| Assoc Prof Lindsay Groves | Mathematics, Statistics & Computer Science | Victoria University of Wellington, NZ |
| Dr Lars Grunskie | Information Technology & Electrical Engineering | Swinburne University of Technology |
| Dr Jim Hanan | Computational science for Plants, Animals, and their Interactions | The University of Queensland |
| Prof David Hill | Research School of Information Sciences & Engineering | Australian National University |
| Prof Melvin Hinich | Department of Government | The University of Texas at Austin, USA |
| Dr Geoff James | Information & Communication Technologies (ICT) | CSIRO |
| Prof Cliff Jones | Computing Science | Newcastle University, UK |
| Dr Tim Kastele | UQ Business School | The University of Queensland |
| Dr Kung-Kiu Lau | Computer Science | University of Manchester, UK |
| Prof Peter Liesch | UQ Business School | The University of Queensland |
| Ms Tania Leishman | Computer Science & Software Engineering | Monash University |
| Dr Xue Li | Information Technology & Electrical Engineering | The University of Queensland |
| Dr Chris Lokan | Information Technology & Electrical Engineering | UNSW@ADFA |
| Dr Victor Luchangco | Scalable Synchronization Group | Sun Microsystems Laboratories, USA |
### Collaborators

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<th>Collaborator</th>
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<th>Institution</th>
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<tr>
<td>Prof Jin Ma</td>
<td>Electric Power Engineering</td>
<td>North China Electric Power University, China</td>
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<tr>
<td>Dr Tom Mandeville</td>
<td>Economics</td>
<td>The University of Queensland</td>
</tr>
<tr>
<td>Mr Greg McDonald</td>
<td>Future Directions Group</td>
<td>Airservices Australia</td>
</tr>
<tr>
<td>Dr Stuart McDonald</td>
<td>Social &amp; Information Sciences Lab</td>
<td>California Institute of Technology, USA</td>
</tr>
<tr>
<td>Prof Robert McKay</td>
<td>Computer Science &amp; Engineering</td>
<td>Seoul National University, South Korea</td>
</tr>
<tr>
<td>Prof Chuck Miller</td>
<td>Mathematics &amp; Statistics</td>
<td>University of Melbourne</td>
</tr>
<tr>
<td>Dr Mark Moir</td>
<td>Scalable Synchronization Research Group</td>
<td>Sun Microsystems Laboratories, USA</td>
</tr>
<tr>
<td>Dr Marks Nester</td>
<td>Principal Forestry Systems Analyst</td>
<td>Queensland Forestry Research Institute, Gympie</td>
</tr>
<tr>
<td>Prof Mike Newman</td>
<td>Mathematical Sciences Institute</td>
<td>Australian National University</td>
</tr>
<tr>
<td>Prof Eamonn O’Brien</td>
<td>Mathematics</td>
<td>University of Auckland, NZ</td>
</tr>
<tr>
<td>Dr Jason Potts</td>
<td>Economics/ARC Centre for Creative Industries</td>
<td>UQ/Queensland University of Technology</td>
</tr>
<tr>
<td>Dr Mikhail Prokopenko</td>
<td>Information &amp; Communication Technologies (ICT)</td>
<td>CSIRO</td>
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<tr>
<td>Prof Edmund Robertson</td>
<td>Mathematics &amp; Statistics</td>
<td>University of St Andrews, Scotland</td>
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<tr>
<td>Dr Peter Robinson</td>
<td>Information Technology &amp; Electrical Engineering</td>
<td>The University of Queensland</td>
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<tr>
<td>Dr Suzanne Sadedin</td>
<td>Information Technology</td>
<td>Monash University</td>
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<tr>
<td>Prof Tapan Saha</td>
<td>Information Technology &amp; Electrical Engineering</td>
<td>The University of Queensland</td>
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<tr>
<td>Dr Jonathan Searle</td>
<td>Engineering Systems &amp; Management</td>
<td>Defence Academy, UK</td>
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<tr>
<td>Dr Alla Seleznyova</td>
<td>Palmeirton North Research Centre.</td>
<td>Horticulture &amp; Food Research Institute of NZ</td>
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<tr>
<td>Assoc Prof Libao Shi</td>
<td>National Key Laboratory of Power Systems in Shenzhen</td>
<td>Tsinghua University, China</td>
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<tr>
<td>Dr Lukas Skoufa</td>
<td>UQ Business School</td>
<td>The University of Queensland</td>
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<tr>
<td>Dr John Steen</td>
<td>UQ Business School</td>
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<td>Dr Rob Stocker</td>
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<td>Dr Rodney Strachan</td>
<td>Economics</td>
<td>The University of Queensland</td>
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<tr>
<td>Prof Anne Street</td>
<td>Centre for Discrete Mathematics &amp; Computing</td>
<td>Raytheon Australia</td>
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<tr>
<td>Dr Terry Stevenson</td>
<td>Chief Technology Officer</td>
<td>Boeing Research &amp; Technology, Europe, Spain</td>
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<tr>
<td>Prof Paul Strooper</td>
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<td>The University of Queensland</td>
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<tr>
<td>Prof Chengzheng Sun</td>
<td>Computer Engineering</td>
<td>Nanoyang Technological University, Singapore</td>
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<tr>
<td>Prof Doug Troeger</td>
<td>Center for Algorithms &amp; Interactive Scientific Software</td>
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<td>Prof Michael Vaughan-Lee</td>
<td>Mathematical Institute</td>
<td>University of Oxford, UK</td>
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<tr>
<td>Dr Miguel Vitapiana</td>
<td>ATM Advanced Trajectory Technologies</td>
<td>The University of Queensland</td>
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<tr>
<td>Dr Liam Wagner</td>
<td>Economics</td>
<td>La Trobe University</td>
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<tr>
<td>Prof Dianhui Wang</td>
<td>Computer Science &amp; Computer Engineering</td>
<td>University of Leeds, UK</td>
</tr>
<tr>
<td>Dr James Watson</td>
<td>Computing</td>
<td>South China University of Technology, China</td>
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<tr>
<td>Prof Fushuan Wen</td>
<td>Electrical Engineering</td>
<td>Johann Wolfgang Goethe University, Germany</td>
</tr>
<tr>
<td>Dr Kai Willadsen</td>
<td>Frankfurt Institute for Advanced Studies</td>
<td>Hong Kong Polytechnic University, Hong Kong</td>
</tr>
<tr>
<td>Prof Kit Po Wong</td>
<td>Electrical Engineering</td>
<td>Technical University of Denmark</td>
</tr>
<tr>
<td>Assoc Prof Zhao Xu</td>
<td>Centre for Electrical Technology</td>
<td>State Power Grid Company, China</td>
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<tr>
<td>Prof Yusheng Xue</td>
<td>Nanjing Automation Research Institute (NARI)</td>
<td>Electric Power Research Institute (EPRI), USA</td>
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<tr>
<td>Dr Pei Zhang</td>
<td>Grid Operation &amp; Planning</td>
<td>Electric Power Research Institute (EPRI), USA</td>
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### Research Staff

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<th>Research Staff</th>
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<tr>
<td>Dr Sameer Alam</td>
<td>UNSW@ADFA</td>
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<td>Mr Blair Bethwaite</td>
<td>Monash University</td>
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<tr>
<td>Mr Daniel Bradley</td>
<td>The University of Queensland</td>
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<td>Dr Melinda Buchanan</td>
<td>The University of Queensland</td>
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<td>Mr Kan Man Clement Chu</td>
<td>Monash University</td>
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<td>Dr Robert Colvin</td>
<td>The University of Queensland</td>
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<td>Dr Hai Hong Helen Dam</td>
<td>UNSW@ADFA</td>
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<tr>
<td>Mr Ngoc Minh Dinh</td>
<td>Griffith University</td>
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<td>Miss Sheree Driver</td>
<td>Monash University</td>
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<td>Mr Adrian Dumsa</td>
<td>The University of Queensland</td>
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<td>Dr Ken Gray</td>
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<td>Assoc Prof George Havas</td>
<td>The University of Queensland</td>
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<td>Dr John Hawkins</td>
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<td>Dr Daniel Horsley</td>
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<td>Mr Gary Leishman</td>
<td>Monash University</td>
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<td>Dr Ariel Liebman</td>
<td>The University of Queensland</td>
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<tr>
<td>Dr Minh Ha Nguyen</td>
<td>UNSW@ADFA</td>
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<td>Mr Tom Peachey</td>
<td>Monash University</td>
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<td>Dr Daniel Powell</td>
<td>Griffith University</td>
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<td>Dr Colin Ramsay</td>
<td>The University of Queensland</td>
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<td>Mr Evgeny Shilov</td>
<td>The University of Queensland</td>
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<tr>
<td>Mr Martyn Symons</td>
<td>UNSW@ADFA</td>
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<td>Mr Jiangjun Tang</td>
<td>Griffith University</td>
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<td>Dr Philip Wild</td>
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<td>Dr Kirsten Winter</td>
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<td>Ms Nisansala Yatapanage</td>
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<td>Mr Junhua Zhao</td>
<td>The University of Queensland</td>
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<tr>
<td>Mr Xun Zhou</td>
<td>The University of Queensland</td>
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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 to review the Centre's research and research plans.

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. Membership of the Centre’s Advisory Board was expanded in 2008 to strengthen representation of industry and government organisations that are key end-users of the Centre’s research. The following people were members of the Advisory Board in 2008:

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
Head, National Security Science & Technology Unit, Department of Prime Minister & Cabinet, Canberra, ACT

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

Professor Peter Fritzson
Department of Computer and Information Science, Linköping University, Linköping, Sweden

Professor Ian Hayes
School of Information Technology & Electrical Engineering, The University of Queensland, St Lucia, Qld

Mr Terry Jones
Director, Centre for Distributed Energy and Power, Energy Transformed Flagship, CSIRO Energy Technology, Newcastle, NSW

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

Mr Wayne Needs
Vice President—Operations, Boeing Australia, Brisbane, Qld

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

Dr Terry Stevenson
Chief Technology Officer, Raytheon Australia, Brisbane, Qld

Mr Bob Peake
Strategic Coordination Unit, Airservices Australia, Canberra, ACT

Professor Stephen Walker
Executive Dean, Faculty of Engineering, Physical Sciences & Architecture, The University of Queensland, St Lucia, Qld
Recognition for computer scientists as a piece of Monash history returns home

Centre Chief Investigator David Abramson, was recently honoured by an exhibition in the Monash Museum of Computing History (see www.infotech.monash.edu.au/about/projects/museum/exhibition.html).

In the mid-1980s, David Abramson and fellow Monash academic John Rosenberg developed a new computer. As detailed in the stories referenced below, the PC was, at the time, at the leading edge of computer science research, and “many of the ideas generated during the research have been adopted by the software industry such as 64-bit architecture, security architectures, and distributed virtual memory”. One of the few MONADs PCs was recently returned to Monash after spending the last 23 years at the University of Ulm in Germany supporting operating system research.

See also:
Climate change research

Climate change is an example of a complex system in that it arises from local interactions between many human and environmental factors. Emergence is evident in the way behaviours appear that could not be anticipated from an understanding of the factors alone; and self-organisation means these behaviours appear spontaneously rather than being externally controlled or engineered. In this way, each person’s behaviour in the area of waste, water, and energy usage can lead to environmental and climate changes at the global level.

Complex systems science is being applied to tackle the problem, and a number of the Centre’s researchers are acknowledged as experts in aspects of Climate Change including:

- economic modelling,
- electricity market design,
- emissions trading,
- energy/power generation,
- greenhouse gas emission reduction,
- infrastructure and service provision, and
- environmental and resource management.

The University of Queensland’s commercialisation company UniQuest, has prepared a directory of their Climate Change Research Group (see www.uniquest.com.au/uploads/UQ%20Climate%20Change%20Directory.pdf). Centre researchers John Foster, John Quiggin, Zhao Yang Dong, Ariel Liebman, Tapan Saha, Lucas Skoufa and Liam Wagner are included in the directory.

Some of their research in the areas of implications for the Murray-Darling basin, emissions trading benefits, and new issues facing the Australian national electricity market is presented as case studies within the report.

Details of other Centre research and publications in aspects of Climate Change are included in the general description of the Centre’s research program and projects on the following pages.

Research Program

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

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

In the science stream of its research program, the Centre has developed a coherent set of theories, computational techniques and modelling tools for network-based systems. This has led to new insights and new approaches to studying how natural systems self-organise and adapt.

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 both economically and reliably. The results have helped to facilitate the application of complex systems theories to real-world systems, and to develop principles for managing, planning and controlling complex systems.

The Centre’s core ARC-funded program was based around a number of application areas:

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

External funding is used to apply Centre results to government and industry problems.
Air Traffic Control

Program Leader: Peter Lindsay

As more vehicles take to the air, air traffic control is a constraining factor on the number of aircraft that can be accommodated, and on the trajectories that they fly. Europe, the USA and Australia are all considering fundamentally new ways of managing air traffic, to improve efficiency without compromising safety. We applied complex systems science to the problem by developing and using air traffic simulators to study new concepts and tools for air traffic management, and developing new approaches to assurance of system-level properties including safety and efficiency.

Evaluation of future air traffic management concepts

Project Leader: Peter Lindsay

Researchers: Ariel Liebman, Greg McDonald, Colin Ramsay, Miguel Vilaplana

This project is using modelling and simulation to explore new operational concepts for air traffic management (ATM) using the ATC simulation toolkit developed by the Centre. The 2007 Australian ATM Strategic Plan proposed a notion of User Preferred Trajectories, whereby airspace users have more direct influence over the 4-D trajectory that they fly. This in turn is expected to lead to large 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 2008 the project’s focus was on analysing and writing up the result of the timing intervention study that was begun in 2007. The study modelled the effect of increased traffic volumes on delays, caused by ATC flow and separation interventions in feeder sectors. A non-linear increase was observed, together with large jumps in system metrics such as workload when certain thresholds were reached. A decision support tool concept was modelled and found to significantly reduce delays, but to have little or no effect on the thresholds observed. Work also began on a study of idle-throttle Continuous Descent Approaches, in collaboration with Boeing RTE in Madrid, using Boeing trajectory simulation tools to study the robustness of such trajectories against late changes to Required Time of Arrival. This fundamental scientific research is expected to inform the redevelopment of airspace design to enable optimally efficient, quieter trajectories as aircraft approach airports.

Recent outputs


Propagation of uncertainty in trajectory computations

Project Leaders: Peter Lindsay, Miguel Vilaplana

Researchers: Ariel Liebman, Colin Ramsay

The ability to accurately predict the 4-D trajectory that an aircraft intends to follow is important for a wide range of ATM applications, including conflict detection, traffic planning and air/ground coordination. Boeing Research and Technology Europe (BRTE) commissioned the ACCS to develop a theoretical framework for modelling uncertainties associated with the trajectory prediction process. The work began in 2007 with a preliminary review of the literature.

In 2008 the literature on aircraft trajectory-prediction methods was extensively reviewed and the results were synthesised into a theoretical framework that separated out the different types of uncertainty. Important factors included: environmental conditions such as wind, aircraft performance characteristics; operational decisions such
as the pilot procedure invoked and the precise time at which it is invoked; the prediction process itself, and the data and algorithms on which it is based. A series of experiments were undertaken using BRTE’s trajectory description language and toolset to demonstrate how different uncertainty factors can be separated out and their effects studied independently and in conjunction.

Recent outputs


Using network simulation and visualisation tools for air traffic management research
Project Leader: Ariel Liebman
Researcher: Daniel Bradley

The aim of this project was to model air traffic management using existing network simulation software developed to model gene regulatory networks. This project aimed to provide a network simulation approach to understanding air traffic management and air traffic congestion; and to increase understanding of appropriate abstraction levels suitable for a unified simulation approach for complex systems.

In 2008 we developed a discrete, spatial, hexagonal network model and simulation system, that utilised an ant-trail inspired network generator to generate possible flight-paths through the network.

Distributed conflict resolution for a free flight environment
Project Leader: Peter Robinson
Researcher: Keith Clark

This project investigated the use of agents to cooperatively resolve conflicts while trying to optimise overall system efficiency. The idea behind this is that plane agents would propose conflict resolution plans together with the cost of carrying out the plans to the planes they are in conflict with. Through negotiation the plane agents would decide on a collection of plans to resolve the conflicts.

In 2008 we developed an agent-based system where the agents cooperate in conflict resolution. The system is currently being evaluated and a paper being written.

Modelling interdependency in airport operations
Project Leader: Hussein Abbass
Researcher: Jiangjun Tang

This aim of this project was to understand interdependency in airport operations. For example, the way in which airport security can affect customs operations. Understanding the information flow is key to measuring the impact of interdependency on air traffic.

In 2008 we were very successful in capturing interdependency in network operations. We captured key types of information flow, and also produced a service oriented diagram.

Recent outputs

General ATC publications


Evolutionary Economic Systems

Program Leader: John Foster

We applied 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 were using. With regard to the economic statistics available to us, we aimed to develop new ways of testing for complex patterns in high frequency data. For example, we studied trade-by-trade data in stock markets and in electricity markets and sought ‘pattern matches’ in artificially generated agent-based modelling data. We also aimed to develop new ways of dealing with spatial complexity. Visualisation techniques, rarely used in economics, were 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 was to make fundamental theoretical and empirical advances, care was 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 felt it to be essential that theories be ‘historically friendly’ in complex adaptive system settings. This 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 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 developed statistical techniques that can identify underlying emergent complexity in time series data. This involved applying a battery of nonlinear tests to both confirm the existence and identification of nonlinear interactions. This was principally based on using the 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


Complex networks and the world trade web

Project Leader: John Steen

Researchers: John Foster, Tim Kastelle, Peter Liesch, Sam MacAulay, Jason Potts

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, Rowley and Shapilov 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 was still at an embryonic stage ripe for theory building and empirical testing. Essentially, we used network parameters as independent variables that affect other performance-related variables such as system robustness, information flow and economic growth.

In 2008 the research team made further progress in the study of complex networks. Tim Kastelle completed his PhD ‘Analysing the evolution of international trade: A complex networks approach’. There are currently five papers from this work under editorial review. The research team is using the analytical techniques developed in this project to analyse innovation networks within project-based firms. Data collection for this project with industry partners Rio Tinto Coal Australia and Hatch Engineering commenced at the end of 2008.

Recent outputs


Water usage modelling for the Murray-Darling Basin

Project Leader: John Quiggin

Researcher: Liam Wagner

The object of the modelling project was 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 was 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 were catchment-specific farm level models, based on activity analysis, with parameters derived from published gross margin models.
In 2008 we were commissioned by the Garnaut Climate Change Review to forecast the outcomes of climate change on the Murray-Darling Basin. In view of continuing uncertainty about the way in which the climate will be affected, forecasting the outcomes of climate change is a complex task. The model is solved by linear programming within each catchment. The two major outputs from this process were data to be used by Queensland Treasury on behalf of the Garnaut Review, and the report itself: 'The implications for irrigation in the Murray–Darling Basin.'

Recent outputs

Simulation studies of social networks
Project Leader: David Green
Researchers: Sheree Driver, Gary Leishman, Suzanne Sadedin

Links between people form networks by which ideas, opinions and attitudes can disseminate throughout societies. This project used 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.

Boolean network models (BN) represent a society as a network in which individuals are the nodes (with two states, e.g. agree/disagree) and social relationships are the edges. In BN models, the behaviour that emerges from peer interactions differs in subtle, but important ways from equivalent mathematical models (e.g. Markov, dynamic systems). Despite their simplicity, BN models provide potentially important insights into many social issues. Work in 2008 focused on the evolution of network structure in response to social processes by which individuals forge new relationships and by which existing relationships are broken. The results revealed that selection on the basis of a single issue tends to fragment a society into cliques whereas a selection based on overall similarity leads to long, branching chains of association (Leishman and Green 2008). We showed that dual phase evolution (DPE) plays an important role in mediating the emergence of these structures.

Recent outputs

General EES publications


The primary avenue for sharing knowledge within Rio Tinto is through community of practice groups. These groups are formed around common interests within the firm – some groups are oriented towards specific process issues (e.g., dragline operations), while others are more general (e.g., safety). They use several different methods to encourage knowledge-sharing including regular face-to-face meetings, teleconferencing, and a collaborative message forum. The ACCS team is analysing the knowledge-sharing networks across several of these teams using complex network analysis. Sam’s PhD research is trying to understand how people search through the network for knowledge that they need.

Hatch and GroundProbe have fewer formal processes for knowledge sharing, in part because they are both smaller than RTCA. In these firms, the research team is measuring the network structure of several project teams as they evolve through time. This is one of the first longitudinal network studies undertaken within project-based firms.

See ‘Rio’s Knowledge is Power. Stories from the coalface are proving to be handy training tools for a global miner,’ Blair Price, Australian Mining Monthly, February 2009, 6–10.
Electricity Networks and Energy Markets

**Program Leaders:** Zhao Yang Dong, John Foster & Ariel Liebman

With the introduction of deregulation, the national electricity network has emerged as an excellent example of a complex system in need of an inter-disciplinary approach to modelling and design. This program investigated ways of integrating technical and market aspects of power system with price dynamics to provide key insights into planning expansion of the power transmission network. It also aimed to apply modern computational modelling techniques to the interface between the physical properties of the electricity system and its economic considerations. A particular focus was 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 looked into the importance of customer-load impact on system and market operations.

**Optimal allocation of embedded renewable electricity sources throughout the distribution network**

**Project Leader:** Ariel Liebman  
**Researchers:** David Abramson, Zhao Yang Dong, John Foster, Liam Wagner, Phillip Wild

This study required the simulation of the Australian electricity network down to the level of the distribution sub-station where we assumed that generation resources are connected at the sub-station and the total amount of generation is less than 30MW (the minimum level currently required for registration with the National Electricity Market). The study was formulated as a combinatorial optimisation problem where the total generation at each substation was composed of several (N) units of renewable and low emission generation resources selected from the following set of generation technologies: wind turbines, solar photovoltaic, solar thermal, biomass, micro-turbine (gas-fired), and geo-thermal. Each of these different types of generating technologies have different capital costs, fixed maintenance costs, and variable operation costs. Additionally, the rate at which the capital costs decrease over a long term horizon is different for each technology, with each rate being uncertain and having different degrees of uncertainty. Additional uncertainties exist in the long term forecasts for demand growth and fuel costs (e.g. coal, gas, distillates and bio-fuels such as biodiesel).

This two part project reached two major milestones in 2008. In the technical part of the project, the Nimrod high-performance computing scheduling software was migrated to the Windows platform to enable integration with the Plexos market simulation software (www.energyexemplar.com), a commercial energy market software tool used in 30 countries around the world. In the economics component of the project, a model of a 30 node micro-grid connected to a main grid was implemented in Plexos to model a test system where the forecast growth in electricity demand cannot be met using the grid’s existing network infrastructure. Once integrated with Nimrod, the user will be able to determine the economically optimal deployment of renewable generation sources inside this grid to meet demand.

**Electricity market price analysis and risk management with advanced data mining techniques**

**Project Leader:** Zhao Yang Dong  
**Researchers:** Jason Ke Meng, Dianhui Wang, Kit Po Wong, Xia Donna Yin, Junhua Zhao, Joe Xun Zhou

This project aimed to develop methodologies and tools for market analysis and system security assessment from a complex system’s point of view using data-mining based methods. The electricity network as a complex system exhibits economical as well as physical characteristics. This research will look into two of the most important aspects of an electricity network in a market environment, namely market price and system security. Specifically, the objectives of this project were to investigate the complex and highly volatile price spikes in an electricity market, and to develop advanced tools to correctly model and predict the price spike.

At the same time, the power system behind the electricity market must maintain a secure state at all times to ensure the functionality of the market. System security/stability is the utmost responsibility of the system operator (usually also the market manager). This project also investigated the features of an electricity network with respect to its stability/security. The aim was to identify the major factors that contribute to possible system failure, and to predict instability events which may lead to system blackouts.

2008 achievements included a general methodology for electricity market price modelling and risk management methods particularly for generation company investment/planning. A comprehensive price modelling tool was developed. This tool can handle price series, intervals of electricity price, and price spikes so as to provide useful information for risk management in an electricity market. Methodologies for risk management target various risk factors in the market related to operations and planning, such as emissions trading impacts, uncertainties of generation new entry with respect to transmission planning, and uncertainties in demand forecasting. Publications in this area in 2008 included IEEE Transactions, top conferences and refereed book chapters. A number of PhD students involved with this project also successfully completed their theses.

**Recent outputs**  


Impacts and risk of emissions trading on electricity generation companies and projects

**Project Leader:** John Foster  
**Researchers:** Matteo Beltrami, Lukas Skoufa

This project aims to develop and apply a stochastic model to the assessment of the impacts of a CO₂ emissions trading scheme on Australian and international power generation entities. These entities could be new investments in power generation plant, or existing power generation companies, or utilities. Particular focus will be placed on the statistical nature of key economic factors affecting the profitability of a power generation entity. These include input fuel costs and electricity outputs. Careful attention will be paid to the correlations between the input costs (particularly coal or gas market prices), the emission permit prices, which need to be postulated since no such scheme exists in Australia, and electricity market prices. The quantities analysed to assess risks and opportunities to the generation entities are the Profit and Loss probability distributions.

This project commenced in October 2008. In the first three months, we began constructing the input-output econometric model that will be used to assess the impact of carbon trading on different industries and product groups. This is still continuing and involves the collection of relevant data, the econometric estimation of structural equations and linkage calibration of the I/O data with estimated econometric equations. New data was collected concerning electricity generation and distribution systems and high frequency data for the wholesale electricity market was also collected in preparation for simulations of carbon trading impacts, both on existing fossil fuel generators and emerging renewable energy generators. Some preliminary work was also completed in implementing both the PLEXOS and agent-based modelling platforms that will be used to simulate networked behavioural change, as carbon pricing raises average electricity prices.

Agent based modelling for electricity price simulation  
**Project Leader:** Ariel Liebman  
**Researchers:** Mark Bowden, Zhao Yang Dong, John Foster

Electricity markets have developed around the world over the past 15 years. However, these markets are mostly still in a maturing phase and data is not reliable or at best not representative of the full range of outcomes.
Electricity network expansion planning in a market environment

Project Leader: Zhao Yang Dong
Researchers: David Hill, Ariel Liebman, Jennie Miao Lu, John Zhe Lu, Jason Ke Meng, Yateendra Mishra, Anisah Nizar, GuangYa Yang, Xia Donna Yin, Joe Xun Zhou

This project investigated the integration of technical and market aspects of power system dynamics and price dynamics to provide key insights into planning the expansion of the power transmission network. This project aimed to apply modern computational modelling techniques to the interface between the physical properties of the electricity system and its economic considerations. A particular focus was 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 looked into the importance of customer load impact on system and market operations.

Electricity (transmission) network expansion planning requires holistic consideration of transmission, generation and, because of the incremental penetration of distributed generation, distribution as well. In 2008, in addition to the least-cost based planning methodology, a flexible planning framework was developed to cope with the increasing uncertainties in the planning environment. It included system security assessment methodology, protection system planning (especially out of step relay setting), load modelling impact, generation new entry, (long term) demand forecast, and special generation system modelling (such as hydro system modelling and wind modelling). The research team studied the impact of the emissions trading scheme on the Australian National Electricity Market operations and pricing in detail.

Recent outputs


General NEM publications


Dependable Computer-Based Systems

Program Leaders: Geoff Dromey, Ian Hayes, Peter Lindsay

The rapid pace of advances in Information and Communications Technology (ICT) has led to technological 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 was concerned with the development of modelling and analysis tools to ensure that dependability is designed into complex computer-based systems.

Analysing the requirements for large-scale software-integrated systems

Project Leaders: Danny Powell, Terry Stevenson
Researchers: Jim Boston, Geoff Dromey

This project was designed to assess the effectiveness of using the analysis method we have developed using Behavior Trees and Composition Trees for modelling and finding major defects in acquisition and functional performance requirements documentation for large-scale industry projects. The requirements documentation for six large projects were analysed, each involving approximately 1000 requirements. In each case the analysis was carried out after normal reviews and inspections had been conducted and after the defects found by these methods had been corrected. The project was largely funded by Raytheon Australia.

Recent outputs


Quantitative modelling and analysis of critical systems

Project Leader: Peter Lindsay, Kirsten Winter
Researcher: Robert Colvin, Lars Grunske

Complex systems often exhibit real-time and stochastic behaviour. To analyse the requirements of such systems a modelling notation is needed to capture timing and probabilistic constraints. This also needs to be supported by tools for automated analysis.

In 2008 the project conducted further studies using stochastic analysis tools. We investigated the combined use of the simulator Modelica and the stochastic analysis tool PRISM in the context of safety analysis, in particular in the process of Failure Modes and Effects Analysis (FMEA). This study resulted in a new methodology for hazard identification and tool supported quantitative FMEA. Moreover, the insight into the techniques supported by the PRISM tool led to a translation scheme from probabilistic Behavior Trees to the PRISM input notation. This translation scheme will be implemented to provide automated support for analysing probabilistic Behavior Trees.

Recent outputs


Large-scale systems consist of a complex integration of software components that determine the behaviour of the system and hardware components which interact with the system’s environment to produce the behaviour. The software/hardware integration problem occurs early in development when it is often necessary to make poorly-informed decisions about how software and hardware components integrate. If later in development it is discovered these decisions are wrong, it can be costly and time consuming to make the necessary changes to how the software and hardware components integrate.

Consider, for example, an Automated Train Protection system that controls the braking of a train if a driver fails to respond appropriately to a dangerous situation. A natural language requirement for the system could specify that “in certain conditions if the train’s speed is not observed to be decreasing the brakes are activated”. However this requirement does not specify the information necessary to design how the software and hardware components integrate—it needs to be specified that a speedometer hardware component must make measurements of the train’s speed and provide them to a software component that determines changes in the train’s speed. But the requirement does not specify how often the speedometer needs to report the speed of the train and with what degree of accuracy, nor does it specify how much the train’s speed needs to be decreasing for the brakes to remain deactivated.

Answering questions like these require a detailed knowledge of the environment, and of the hardware and software components that will form the system. They are normally investigated by building prototype systems to examine the problem. Centre PhD Student Toby Myers, together with Centre Chief Investigator Geoff Dromey and Centre collaborator Prof Peter Fritzson of Linköping University of Sweden have developed an alternate approach called, co-modelling, which investigates software/hardware interactions earlier in development.

Co-modelling uses the Behavior Engineering method to perform requirements analysis and model software components, and Modelica to model the hardware components and the environment. The Behavior Engineering model and the Modelica model are integrated to form a co-model that can simulate numerous scenarios to determine the consequences of decisions about how software and hardware integrate. This allows system engineers to systematically investigate how software and hardware should be integrated to satisfy a system’s requirements.

Change management: Formalising the impact of requirements change on design

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

This project used Behavior Trees to model requirements change. One aspect was 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 was 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.

Recent outputs

Myers, T., Dromey, R.G., “From requirements to embedded software—Formalising the key steps”, Australian Software Engineering Conference (ASWEC), 2009.


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 aimed to develop 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 also extended the Behavior Tree language and semantics to handle real-time and stochastic specifications.

In 2008 the semantics for Behavior Trees were redefined as an extension of the well-known process algebra CSP. This is a more mature version of the semantics which opens up the possibility of reusing analysis tools developed for CSP, and the potential for collaboration with other groups. This work won the Best Paper award at the 2009 Integrated Formal Methods Conference. The semantics were also extended to capture relational behaviour, which is a fundamental behavioural type commonly used in requirement documents.

Recent outputs


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 investigated 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.

Verification of lock-free algorithms

Project Leader: Robert Colvin
Researchers: Brijesh Dongoi, Lindsay Groves, Ian Hayes, Victor Luchangco, Mark Moir

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 investigated effective strategies for verifying lock-free algorithms, building on earlier work using I/O Automata and simulation techniques.

In 2008 a new technique for proving lock-freedom was developed. It is simpler and more general than earlier
techniques. The technique was successfully applied to more complex algorithms.

Recent outputs


General DCS publications


ACCS in the media
Sustainable electricity think-tank established
A number of Centre personnel were involved in the Inaugural Symposium on Electrical Energy Evolution in China and Australia (www.eeevolution.org), in Queensland in July. Centre Chief Investigator Zhao Yang Dong was Technical Chair, and Centre PhD student Donna Yin was responsible for China liaison. The formation of a 22-member Working Group of electricity energy experts was announced at the conclusion of the symposium. This has since been reported widely, for example in Get Farming (www.getfarming.com.au) PACE.—Australia’s Process and Control Engineering website (www.pacetoday.com.au) and Fast Thinking (www.fastthinking.com.au). Membership of the working party consists of representatives from Australian industry and Australian and Chinese universities. According to the Chair of the group and ACCS collaborator, CSIRO’s Geoff James, the group will work together to develop better ways to utilise and distribute energy.

Cyberinfrastructure expert spells out cooperation Between US and Australia
Centre Chief Investigator David Abramson and his Monash University Message Lab team collaborate with researchers at the University of California at San Diego (UCSD). The collaboration covers both middleware and applications of grid systems, both of which have been at the centre of his ACCS research. The considerable sharing of software tools that forms the basis of much of the collaboration has resulted in “…a family of tools that helps you do ‘what if’ analysis with computational models, so you can do really heavy computational experiments, like ‘What if the universe evolved under these parameters?’ or ‘What would happen if I chopped down all of these trees?’ or ‘What if we switched all cars over from gasoline to ethanol?’” Further details of these collaborations are reported by Tiffany Fox at www.calit2.net/newsroom/article.php?id=483 ‘Cyberinfrastructure expert spells out cooperation Between US and Australia,’ 5 March 2009.

Software can help you avoid those awkward confrontations
In a Special Report on Project Management, Christopher Jay writes in The Australian Financial Review of other (i.e. other than Behavior Trees) aspects of Geoff Dromey’s work. He reports on how programs that profile personalities in a group can help avert the risk of misunderstanding and failure. 9 October 2008, p6, ‘Software can help you avoid those awkward confrontations’)

How to run a million jobs
Featured in International Science Grid This Week (iSGTW) is a discussion arising from an informal session at Supercomputing 2008 (SC08) on solutions for handling and avoiding ‘megajobs’. Centre Chief Investigator David Abramson was a presenter and panel member. 3 December 2008, iSGTW Feature, www.isgtw.org/?pid=1001531
Complex Systems Theory and Applications

In addition to the research programs described above, the ACCS included a number of projects addressing key problems for complex systems. The projects were 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.

Modelling fear conditioning in rats

**Project Leader:** Robert Colvin  
**Researchers:** Geoff Dromey, Martyn Symons

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, this project aimed to provide a rapid and powerful way of testing hypotheses and direct further experiments into fear conditioning being performed at the Queensland Brain Institute (QBI).

In 2008 a $35,000 UQ Early Career Researcher grant was obtained for this project. Martyn Symons was employed, and created four models of fear conditioning using Behavior Trees. In collaboration with researchers at the QBI, these models were simulated and analysed. Preliminary work began on creating more detailed models using neural networks.

Application of Grid computing to complex systems modelling

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

Over the last several years, combinations of supercomputers, 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 investigated the application of Grid computing to these complex systems models, and illustrated the utility of this approach. In particular, we applied and further developed a number of Grid specific methodologies and tools.

In 2008 we built infrastructure that would allow us to perform sensitivity studies on the Australian electricity distribution network. This required integration of the Plexos modelling system with the Nimrod parameter sweep tool. Because Plexos only runs on Windows, we ported the Nimrod to Windows, which required modifying the Nimrod ‘Agent’ code to allow it to run under the Cygwin environment. We tested the system on a small study, but were not able to launch any large scale experiments due to lack of licenses for Plexos. This latter restriction is currently being investigated by the vendor.

High performance complex systems simulation project

**Project Leader:** David Abramson  
**Researchers:** Colin Enticott, Tom Peachey

In-silico experimentation is increasingly being used to understand the behaviour of complex systems when
it is not possible to perform real world experiments. For example, a computer simulation of an electrical distribution grid, a genetic regulatory network, an air traffic control system or a healthcare system, might model the behaviour of that system under particular conditions that cannot be tested in the real. Running this model might show what happens when certain input conditions are present. However, to fully understand the dynamics of the system, it is necessary to explore what happens when many inputs change. Moreover, to get results that are statistically significant, it might be necessary to run the model many times with different initial conditions. This can require enormous amounts of computing time. Recently, combinations of super-computers, or Grids, have been developed which couple geographically distributed resources such as high-performance computers, workstations, clusters of computers, yielding potentially very large distributed supercomputers. In previous research we developed a methodology (parametric modelling) and software environment (Nimrod) for performing very large in-silico experiments using Grids. In this project we aimed to apply parametric modelling to a range of ACCS supported complex systems modelling experiment; and augment Nimrod with new capabilities for exploring complex systems.

In 2008 we further developed the Nimrod/E tool chain, building components that generate designs, and display parameter sensitivity using a variety of statistical graphing techniques. We tested the system on some bioengineering models of the heart, and demonstrated the effectiveness of the system for complex systems design.

Recent outputs


Experimental design

**Project Leader:** Anne Street

**Researchers:** Diane Donovan, Ken Gray, George Havas, Marks Nester, Colin Ramsay

Experimental designs can be thought of as arrangements of elements of a set into subsets with predetermined properties desirable for particular applications in particular situations. Such arrangements are characterised and described by various factors, including: their current and potential fields of application, such as in cryptographic protocols, in planning sample surveys, clinical experiments or marking schemes for tests, and so on; their properties; their size and complexity; and their origins, possibly from algebraic structures, from finite geometries, from computer search, or from some combination of these. Each such factor is a potential subject of interest in its own right, but the research in this project aimed to identify and address problems and complexities that arise when several, if not all, of these factors are in play. These arrangements are often conveniently represented by graphs, requiring the application of graph theory for many examples and applications.

In 2008 we extended our earlier work in most of these areas, as well as considering applications of balanced sequential arrays in forestry. This related to designing layouts for experimental forests.

**Recent outputs**


**Multi-objective optimisation**

**Project Leader:** Hussein Abbass

**Researchers:** Lam Bui, David Green

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 developed robust multi-objective optimisation techniques for decomposing and solving complex problems with many constraints and variables in the existence of noise.

In 2008 we finalised our work on localisation. Our innovative proposed method to solve multi-objective problems through the use of local models and applying dynamic forces to control the movements of the models, proved to be an efficient way for solving these problems in environments with high noise.

**Recent outputs**

Emerging applications of advanced computational methods and discrete mathematics

Project Leader: Peter Adams
Researchers: Darryn Bryant, Melinda Buchanan

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 investigated approaches such as grid computing, evolutionary algorithms and refined theoretical approaches 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.

This project concluded in 2008, with the final work being a comprehensive survey of known existence results of G-designs for a range of graphs G, including some new results for missing small-order graphs.

Recent outputs

Computational group theory

Project Leader: George Havas
Researchers: Gilbert Baumslag, Colin Campbell, Marston Conder, Chuck Miller, Mike Newman, Eamonn O’Brien, Colin Ramsay, Edmund Robertson, Doug Troeger, Michael Vaughan-Lee

Group theory is a fundamental part of pure mathematics with diverse applications. Computational group theory addresses many problems. In this project, we studied computationally-based proofs in groups given by presentations. As an integral part of the research we aimed to design, implement, test, analyse and apply new algorithms for groups. We also aimed to 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 2008 work focused on: the solution of problems related to the efficiency of finite simple groups; aspects of the Hughes’ conjecture about the index of certain subgroups; and the Andrews-Curtis conjecture. New efficient presentations were found for large simple groups not previously known to be efficient. Relatively small counter examples to the Hughes’ conjecture were found and explicitly constructed.

Recent outputs


Automatic problem decomposition

Project Leader: Hussein Abbass
Researchers: Daryl Essam, Chris Lokan, 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 subproblems. Unfortunately, when we are faced with a new problem, we do not usually know the correct decomposition. This project involved automatically decomposing a problem on the fly while solving it.

In 2008 we introduced a number of ways to automatically decompose machine learning problems and our work on this problem from previous years started to appear in high quality journals. For example, the work with Nguyen on cooperative co-evolution and mixture of experts appeared in IEEE Trans on SMC-C, while the work with Dam and Pornthep was accepted (to appear in 2009) at the IEEE Transactions on Neural Networks.

Recent outputs
Genetic Regulatory Networks

Although the Centre’s Genetic Regulatory Networks (GRN) program was essentially completed in 2007, one project was finalised in 2008, and publications continue to appear.

Machine learning architectures for biological sequence analysis

Project Leader: Mikael Boden
Researchers: John Hawkins, Janet Wiles

This project contributed a software technique, and concrete implementation to allow the exploration of the nuclear portion of the proteome, and hence another avenue for exploring gene regulation. The project aimed to develop a nascent piece of IP developed within the Centre and see it through to commercial reality.

General GRN publications


Research Students

Research by postgraduate research students under the supervision of Centre staff contributed significantly to the Centre’s longer-term research goals. By providing high quality training environments, the Centre actively aimed to retain Australia’s best young complex systems researchers within the country. In 2008, scholarship or top-up funding was awarded to nine students at The University of Queensland and 2 at Griffith. Centre funding also enabled students to attend conferences and workshops, to present their work and to gain a wider perspective on research and technical innovation.

Research Degrees Awarded

Sameer Alam (UNSW@ADFA) – PhD
‘Evolutionary scenario planning for evaluating advanced air traffic management concepts’
Advisors: Hussein Abbass, Michael Barlow & Peter Lindsay

Jennifer Badham (UNSW@ADFA) – PhD
‘The role of social network properties on the impact of direct contact epidemics’
Advisor: Hussein Abbass & Robert Stocker

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

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

John Hawkins (UQ) – PhD
‘Machine architectures for biological sequence classification’
Advisors: Mikael Boden & Janet Wiles

Tim Kastelle (UQ) – PhD
‘Analysing the evolution of international trade: A complex networks approach—measuring globalisation in the international trade network from 1938–2003’
Advisors: Peter Liesch, John Steen & Jason Potts

Xilin Li (UQ) – PhD
‘Visualisation and adaptation in complex systems: hydropower system case study’
Advisors: Penelope Sanderson & Zhao Yang Dong

Anisah Nizar (UQ) – PhD
‘Data Mining techniques and technologies in customer information billing system to predict, forecast and estimate the customer behaviour in electricity market’
Advisors: Zhao Yang Dong & Penny Sanderson

Kamran Shafi (UNSW@ADFA) – PhD
‘Multi agent based early warning system for Internet threats’
Advisors: Hussein Abbass & Weibing Zhou

Larry Lin Feng Weng (UQ) – PhD
‘Advanced techniques for engine optimisation and control’
Advisors: Zhao Yang Dong

Lian Wen (Griffith) – PhD
‘Mapping requirements changes to design changes’
Advisor: Geoff Dromey

Guang Ya Yang (UQ) – PhD
‘Electricity market management and planning’
Advisors: Zhao Yang Dong & David Hill

Xuelin Zheng (Griffith) – PhD
‘A model for characterising requirements and design defects’
Advisor: Geoff Dromey

PhD Students

Mohsin Ali (UQ)
‘Efficient grid based algorithms for power system data analysis’
Advisors: Xue Li & Zhao Yang Dong
Jennie Miao Lu (UQ)
‘Probabilistic transmission expansion planning in competitive electricity market’
Advisor: Zhao Yang Dong

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

Sam MacAulay (UQ)
‘The division of labour and innovation in communities of practise: Insights from an analysis of problem solving networks’
Advisors: Lars Håkanson (Copenhagen Business School) John Steen & Tim Kastelle

Alisdair MacDiarmid (UQ)
‘Adaptive requirements elicitation in distributed complex systems’
Advisor: Peter Lindsay & Anne-Marie Grisogono

Michelle McPartland (UQ)
‘Evolutionary techniques in complex environments’
Advisors: Marcus Gallagher & Janet Wiles

Jason Ke Meng (UQ)
‘Intelligent fault diagnosis approach to high voltage transmission line’
Advisors: Zhao Yang Dong & David Hill

Yateendra Mishra (UQ)
‘Stability studies in a deregulated power system’
Advisors: Zhao Yang Dong & Pei Zhang (EPRI)

Toby Myers (Griffith)
‘Model driven engineering using the Behavior Engineering methodology’
Advisors: Geoff Dromey & Vladimir Estivill-Castro

Greg Paperin (Monash)
‘The role of extrinsic disturbances and phase changes in the evolution of natural and artificial complex systems’
Advisor: David Green

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

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

Morgan Smith (UQ)
‘Learning agents to model air traffic control systems’
Advisor: Ariel Liebman & Peter Robinson

Philip Valencia (UQ)
‘Can practical distributed robotic solutions be automatically generated for real world applications’
Advisors: Peter Lindsay & Mikhail Prokopenko

Nisansala Yatapanage (Griffith)
‘Formal verification of system designs’
Advisor: Geoff Dromey

Yu-Hei Flora Yeh (UQ)
‘Model selection in machine learning using computational statistics’
Advisors: Marcus Gallagher, Hussein Abbass & Janet Wiles
Donna Xia Yin (UQ)  
‘Artificial intelligence and data mining techniques in electricity market forecasting’  
Advisors: Tapan Saha & Zhao Yang Dong

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

Joe Xun Zhou (UQ)  
‘Investigation of distributed generation and its impact on power grid as a complex system’  
Advisor: Ariel Liebman & Geoff James

Rui Zhang (UQ)  
‘Date mining methods for power system data analysis’  
Advisor: Zhao Yang Dong

Linan Zhao (UQ)  
‘Power system dynamic stability assessment’  
Advisor: Zhao Yang Dong

Summer Student Projects
To encourage students to pursue research careers, the Centre funded the following summer student projects at the Brisbane node. The 2007/08 summer student projects were reported in the 2007 Annual Report.

2008 Projects
Joseph Mullins (UQ)  
‘Economic analysis of bidding strategy specific to electricity markets’  
Supervisor: Peter Adams  
(See page 24, ‘Emerging applications of advanced computational methods and discrete mathematics’)

Miriam Hochwald (UQ)  
‘Tool support for model checking probabilistic Behavior Tree models’  
Supervisors: Kirsten Winter, Robert Colvin  
(See page 18, ‘Quantitative modelling and analysis of critical systems’)

Student Linkages
Guo Chen worked with Prof David Hill at ANU (from August onwards) on complex network theory for power system security assessment.

Stephen Kong visited and conducted research with CSIRO working on renewable energy stability, control and design.

Jason Ke Meng won the Richard Jago Memorial Prize, a travel scholarship, and will visit Hong Kong to conduct research on power system stability and computation.

Yateendra Mishra won a UQ travel grant to visit and conduct research in the USA with Electric Power Research Institute and University of Tennessee on power system stability and control.

Masters Students
Vic Ter Chin (UQ) – MPhil  
‘Emergency control for power systems separation’  
Advisor: Zhao Yang Dong & Tapan Saha

Dadang Azis (UQ) – ME  
‘Data mining methods for power generator faulty detection and analysis’  
Advisor: Zhao Yang Dong

Ho Eng (UQ) – ME  
‘Power system stability analysis’  
Advisor: Zhao Yang Dong

Muhammad Imaduddin (UQ) – ME  
‘Status and deregulation perspective of the Indonesian power industry’  
Advisor: Zhao Yang Dong

D. Liang (UQ) – ME  
‘Emissions trading impact on the Australian NEM’  
Advisor: Zhao Yang Dong

J.H. Xu (UQ) – ME  
‘Power system planning’  
Advisor: Zhao Yang Dong

Honours Students
Khee Hui Ann (UQ)  
‘Electricity market and economic impacts of plug-in electric vehicles : Impacts on transmission system’  
Advisor: Ariel Liebman

David Bell (UQ)  
‘Investigating how delays and disruptions flow through air traffic control systems’  
Advisor: Ariel Liebman

Ci-Yang Gee (UQ)  
‘Electricity market and economic impacts of plug-in electric vehicles: The impacts of different battery technologies’  
Advisor: Ariel Liebman

Ei Hua Ling (UQ)  
‘Impact of implementing emissions trading and distributed generation in the NEM’  
Advisor: Zhao Yang Dong

Steve Ng (UQ)  
‘Electricity market and economic impacts of plug-in electric vehicles: V2G in support of renewable energy generation’  
Advisor: Ariel Liebman
Let scientists focus on the science

Centre Chief Investigator David Abramson explains how Nimrod and other middleware tools can relieve scientists of some of the angst associated with processing, enabling them to focus on the science.

When scientists find the complexity of dealing with high performance computers too high, they miss out on the advantages it has to offer. An understandable view — their expertise is science, not coercing a computer into doing what they want. Over the years, our group has helped many scientists and engineers, in disciplines ranging from quantum chemistry to public health policy, to embrace new computing technologies that will advance their research.

This started about 5 years ago. We suggested to a group of physicist colleagues that they run their code in parallel on a cluster. Their problem separated in a straightforward manner into independent, parallel tracks, and appeared a perfect match for software tools (called Nimrod) that we were developing. They declined, saying they didn’t have the time and expertise to convert their codes. We offered to adapt their code, and in a very short time it was able to deliver new results with profound conclusions for their experimental science — a dramatic result.

This pattern has continued. Recently, for example, we helped climate science colleagues answer a complex question for which an actual experiment is effectively impossible: “If you burn the savannah in northern Australia, can this affect the weather?” Using Nimrod, we helped them simulate the weather while varying four key parameters — the fire intensity, the area burned, the timing and the regrowth period. The combinations generated 90 independent simulations that ran on distributed supercomputers continuously for six months. The experiment shipped some 1.6 TB of data across national and international networks for analysis by collaborators. The team was able to conclude that under the right circumstances the onset of the monsoon can be varied.

“Nimrod was a great boon to us, because it allowed us to focus on our scientific questions without worrying about clusters, networks and international partnerships”, said Monash Professor Amanda Lynch.

Unlike many other parallel computing environments Nimrod focuses on the science — how to help researchers express their problem in the simplest possible way. While it only solves a narrow range of parallel programming problems (so called “embarrassingly” or “pleasingly” parallel), it does this using a very simple declarative language, supported by a Web interface. Users can easily explore what happens when input parameters change and can access a range of search methods from complete enumeration to algorithms that provide optimization functions.

The powerful, automatic optimisation features of Nimrod’s search capability help scientists “tune” their models to better match reality, and save time and computing power by avoiding fruitless parameter combinations. For example, Professor Andrew McCulloch’s bioengineering lab at the University of California, San Diego used Nimrod to run complex cardiac simulations, and to tune the model parameters to minimize the difference between simulated output and experimental data.

David Abramson contributed this Feature article to iSGTW, 8 April 2009, see www.isgtw.org/?pid=1001740. The iSGTW weekly e-newsletter (International Science Grid This Week) is emailed free to subscribers.
Outreach, Links and Service to Community

Keynote and Invited Addresses at International Conferences


**Hussein Abbass**, Plenary Speaker: 12th Asia Pacific Symposium on Intelligent and Evolutionary Systems, 7–8 December 2008, Melbourne, Australia, ‘The future of intelligent systems is non-dominance’.


**John Quiggin**, Invited Speaker: 53rd AARES Conference, Cairns, 10–13 February 2009 ‘Climate change: Can the Great Barrier Reef be saved?’


Serving the Research Community

Centre participants served on many conference program committees and editorial boards. A selection of these are reported below.

**Hussein Abbass** was on the Program Committee for the 21st Australian Joint Conference of Artificial Intelligence (AI 2008), 1–5 December, Auckland, New Zealand; the 2008 Winter Workshop on Economics with Heterogeneous Interacting Agents (WEHIA/ESHIA), 5–7 December, Taiwan; the 2008 World Congress on Computational Intelligence (WCCI), Hong Kong; the 2008 Genetic and Evolutionary Computation Conference (GECCO), USA; the 2008 Simulation of Adaptive Behavior (SAB), Osaka, Japan, on 7–12 July; and the 12th European Conference on Genetic Programming (EuroGP2008).

Hussein Abbass was on the editorial boards of the *International Journal of Applied Systemic Studies (IJASS)*,
Zhao Yang Dong was also Program Committee member for Advanced Data Mining and Application conference (ADMA), 17–19 August 2009, Beijing, China; the 13th Pacific-Asia Conference on Knowledge Discovery and Data Mining (PAKDD-09), 27–30 April 2009, Bangkok, Thailand;

Zhao Yang Dong is Vice Chair of the Queensland section of the IEEE, and Associate Editor, Austrasia, International Journal of Renewable Energy, UK, He was a member of the IEEE PES CAMS Task Force on Understanding, Prediction, Mitigation and Restoration of Cascading Failures.

Geoff Dromey was a reviewer for IEEE Software. He was on the Programme Committee for the 2nd IEEE International Symposium on Theoretical Aspects of Software Engineering (TASE), 7–9 June 2008 Nanjing, China; and on the Steering Committee for 6th IEEE Conference on Software Engineering & Formal Methods (SEFM’08).

John Foster (with J.S. Metcalfe) was guest editor of Economics of Innovation and New Technologies, special issue on ‘Knowledge, innovation and evolutionary economic modelling: some complex systems perspectives’. He was also on the editorial boards of the Journal of Evolutionary Economics, Review of Political Economy, and Journal of Institutional Economics.

David Green was on the programme committee for the Seventh International Conference on Simulated Evolution And Learning (SEAL’08), Melbourne, December, and Co-chair of the 12th Asia-Pacific Symposium on Intelligent and Evolutionary Systems (IES08), Melbourne, December.

David Green was also Editor of Complexity International, a member of the Editorial Advisory Board for the journal Ecological Informatics, and for the Journal of Economic Interaction and Coordination (JEIC).
Jim Hanan was guest editor of the special issue of Functional Plant Biology on ‘Functional-structural plant Modelling’ (Issue 35).


Ian Hayes is on the steering committee for the Formal Methods (FM) Symposia and is on the editorial board of the BCS/Springer journal Formal Aspects of Computing.

Tim Kastelle was Associate Editor, Innovation: Management, Policy and Practice.

Peter Lindsay was a member of the program committee for the 3rd International Conference on Research in Air Transportation (ICRAT 2008); 13th IEEE International Conference on Engineering of Complex Computer-based Systems (ICECCS‘08); 6th IEEE Conference on Software Engineering & Formal Methods (SEFM’08); 2nd IFIP Conference on Biologically Inspired Collaborative Computing (BICC 2008); 6th International Conference on Autonomic and Trusted Computing (ATC-09). Peter was also on the editorial board of the Science of Computer Programming journal and was a reviewer for Formal Aspects of Computing. He also reviewed grant applications for the UK Engineering and Physical Sciences Research Council and the Royal Society of New Zealand.

Professor Quiggin is on the editorial boards of numerous Australian and international journals, including Journal of Risk and Uncertainty; Australian Journal of Agricultural and Resource Economics; Economic and Labour Relations Review; and Journal of Economic and Social Policy.


Anne Street was on the editorial board for Ars Combinatoria and Bulletin of the Institute of Combinatorics and its Applications. Anne was referee for Oxford University Press, Prentice-Hall Inc., Cambridge University Press, and Springer Verlag; and referee for the following journals: Aequationes Mathematicae; Bulletin of the Australian Mathematical Society; Combinatorica; Congressus Numerantium; Designs, Codes and Cryptography; Discrete Mathematics; Journal of Combinatorial Mathematics and Combinatorial Computing; Journal of the Australian Mathematical Society; Linear Algebra and its Applications; Utilitas Mathematica; Zeitschrift fur Krystallographie.

Kirsten Winter was an anonymous reviewer for the International Conferences: Integrated Formal Methods and Mathematics of Program Construction

Visitors to the Centre

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

Dr Rodolfo Baggio

Dept of Institutional Analysis and Public Management
Bocconi University, Italy
January
Prof Keith Clark
Dept of Computing, Imperial College, London, UK
April & September

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

Prof Peter Fritzson
Dept of Computer and Information Science, Linköping University, Sweden
July 2007–May 2008

Dr Jennifer Hallinan
School of Computing Science, Newcastle University, UK
January

Prof Melvin Hinich
Dept of Government, University of Texas at Austin, USA, December

Prof Moshe Rosenfeld
Institute of Technology, Washington University, USA
February–March

Prof Anil Wipat
School of Computing Science, Newcastle University, UK
January

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

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

Darryn Bryant undertook a research visit to Ryerson University in Toronto Canada in June/July.

George Havas visited the Centre for Mathematics and its Applications, ANU, Canberra, in January; Mathematical Institute, University of St Andrews, UK in March; Center for Algorithms and Interactive Scientific Software, the City College of the City University of New York, USA, in March; and the Workshop on Groups and Computation, Ohio State University, USA, in March.

Ian Hayes had a Visiting Professorship at the University of Newcastle upon Tyne, UK for the second half of 2008, and also visited the University of York, UK.

Peter Lindsay spent the second half of 2008 in Europe on Special Studies Program. His host organisation for the most part of his visit was the UK EPSRC’s Large-Scale Complex IT Systems (LSCITS) initiative, at the Universities of Bristol and York. He gave talks on the ACCS’s research at LSCITS, the Bristol Centre for Complexity Sciences, and the University of York’s Centre for Complex Systems Analysis. In the UK he also visited the Universities of Oxford, St Andrews and Newcastle, and the Defence Academy’s Simulation &
Professional Courses
Centre participants benefited from participation in a range of professional courses and special training seminars.

Project Management for Research
As outlined in the Centre’s 2008 Activity Plan, a course aimed at providing Centre personnel with research project leadership training was presented at UQ Business School Downtown on 13–15 February. The course consisted of three sessions: ‘HR management for research teams’, ‘Writing grant applications, business cases and plans’, and ‘Keeping the customer happy’. Ten Centre personnel participated in the course.

Research Commercialisation
Centre participants were treated to some of Centre Chief Investigator Geoff Dromey’s wisdom and experience when he presented a session for them on 29 August on ‘Research commercialisation: Lessons from a personal winding road.’

Introduction to Object-Oriented Modelling and Simulation with Modelica.
Tutorials with hands-on exercises presented by Peter Fritzson, Centre visitor from Linköping University in Sweden were conducted again in 2008. The tutorials provided a basic introduction to the concepts of modelling and simulation, as well as the basics of object-oriented component-based modelling.

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

Geoff Dromey and Daniel Powell presented a one-day tutorial, ‘Engineering large-scale software-integrated systems: Using composition trees and Behavior Trees’, at the 6th Annual SEPG Australia Conference, 18–21 August, Melbourne.

Daniel Powell presented a one-day tutorial, ‘Engineering and analysing requirements using Behavior Trees’, at the Software & Systems Quality Conference Australia, Canberra, 29–31 October.

Other Workshops
Centre researcher, Phillip Wild, was invited to present ‘The potential impact of carbon abatement on the electricity industry and Australian economy: Scheme proposals, ‘innovative pathways’ and modelling frameworks’ at the Energy Economics Workshop, Milan Polytechnical University, 10–18 October 2008.

Centre researcher, Jim Hanan, presented a three-day workshop on ‘Functional structural plant modelling’ at the Institute of Agricultural Resources and Environment Sciences, Jiangsu Academy of Agricultural Sciences, Nanjing, China.
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.

Centre Chief Investigator Hussein Abbass and researchers Sameer Alam and Ariel Liebman presented to government and industry at Smart Decision Making for Clean Skies (Modern Air Traffic Management and the Environment) 2–3 July at UNSW@ADFA, Canberra.

Peter Lindsay gave a talk on the ACCS’s air traffic management research at CGH Technologies in Washington DC, USA. He also visited Boeing Research & Technology Europe in Madrid, Spain as part of ongoing research collaboration.

Daniel Powell presented to the International Centre for Complex Project Management. This not-for-profit company provides global leadership aimed at improving the international community’s ability to successfully deliver very complex projects and manage complexity across all industry and government sectors. Government support comes from Australia, UK, US, Canada and Singapore and the list of global corporate partners includes BAE Systems, Boeing, Lockheed, Martin, Mallesons Stephen Jaques, Raytheon and Thales and continues to grow.

Ariel presented a one-day post-conference masterclass, ‘The shape of the electricity markets under growth in clean energy sources’, as part of Clean Energy Australia 2008, in Sydney in June.

Kirsten Winter was invited to visit National ICT Australia (NICTA) in Sydney to present on work done in the Centre project: Quantitative modelling and analysis with Behavior Trees. Kirsten’s presentation was ‘Probabilistic failure mode and effect analysis.’

A number of Centre personnel were invited to join advisory or expert panels, recognising their expertise in the relevant areas.

- Centre Chief Investigator’s John Foster and John Quiggin were members of the Australian Government’s 2020 Summit working groups.

Industry Visitors
Meetings between Centre personnel and the following industry representatives served to strengthen ties with the Centre and promote communication of discoveries and techniques.

- Mr Matt Ashford, Defence Materiel Organisation
- Dr Holger Becht, System Safety Manager, Boeing Australia Limited
- Mr Jim Boston, Raytheon Australia
- Dr Al Bryant, Director, Boeing Phantom Works Australia
- Mr Walter Dollman, Qantas Airways Ltd
- Dr Bill Lyons, Boeing USA
- Mr Greg McDonald, Future Directions Group, Airservices Australia
- Mr Gary Morris, Boeing Australia Limited
- Mr Paul Parks, Boeing Phantom Works – Networked Systems Technology, USA
- Mr Adrian Pitman, Defence Materiel Organisation, Australia
- Dr Robert Porteous, Manager, Strategic Planning, Airservices Australia
- Dr Terry Stevenson, Chief Technology Officer, Raytheon Australia
- Captain Murray Warfield, General Manager Regulatory & Industry Affairs, Qantas Airways Ltd
- Mr Dean Webb, International Business Development, Boeing USA
- Dr Virginia Wheway, Phantom Works Australia
- Mr Brendan Williams, Boeing Australia Limited
Technology Transfer and Commercialisation Activities

Our technology transfer and commercialisation activities were 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 was broad interest in Centre research. Amongst others, we had collaborations with:

- AGL Energy (see page 15, ‘Agent based modelling for electricity price simulation’)
- Airservices Australia (see page 9, ‘Evaluation of future air traffic management concepts’; and page 26, Sameer Alam’s PhD research ‘Evolutionary scenario planning for evaluating advanced air traffic management concepts’)
- Babcock & Brown Power (see page 15, ‘Agent based modelling for electricity price simulation’)
- Boeing (see page 9, ‘Evaluation of future air traffic management concepts’; and page 9, ‘Propagation of uncertainty in trajectory computations’)
- CSIRO (see page 14–17, Electricity Networks and Energy Markets program and page 39, CSIRO Flagship Funding)
- Electric Power Research Institute (EPRI), USA (see page 28, Yateendra Mishra’s PhD research ‘Stability studies in a deregulated power system’)
- Queensland Brain Institute (see page 22, ‘Modelling fear conditioning in rats’)
- Queensland Department of Primary Industries and Fisheries & HortResearch, NZ (see page 27, Mikolaj Cieslak’s PhD research ‘Modelling carbon allocation in kiwifruit vine’)
- Queensland Forestry Research Institute, Gympie (see page 23, ‘Experimental design’)
- Raytheon (see pages 18–21, ‘Dependable computer-based systems’ program)
- Rio Tinto Coal Australia, Hatch Engineering, GroundProbe and Vestas (see page 11, ‘Complex networks and the world trade web’ and see pages 13 & 27, Sam MacAulay’s PhD research ‘The division of labour and innovation in communities of practise: Insights from an analysis of problem solving networks’)
- Sun Microsystems Laboratories (see page 20, ‘Verification of lock-free algorithms’)
- TeraGrid (see page 22, ‘Application of Grid computing to complex systems modelling’)

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. The commercial potential of the IP register continues to be investigated by the Centre’s Tools Coordinator and Webmaster.

Public Awareness Programs

Through Public Awareness Programs 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.uq.edu.au) and mailing list to assist in its task of raising public awareness of complex systems.

With COSNet funding the team at Monash continued to develop VLAB, the Complexity Virtual Lab, http://vlab.infotech.monash.edu.au/. VLAB is a web-based resource for research and education about complex systems. Its goals are to stimulate interest in complex systems and artificial life and to provide demonstrations, both for key ideas and for recent research findings.

VLAB presents simulations (mostly java applets), together with related tutorials, references and web links to help people understand how complex organisation and behaviour emerges in living systems. The site currently attracts over 3000 users per month.

VLAB demonstrations include cellular automata, swarms, evolution, networks and non-linear dynamic systems. A plied examples include forest ecology, fire spread, epidemics, starfish outbreaks, spread of computer viruses and cascading power failures.

Geoff Dromey and the Dependable Computer-Based Systems research team maintain the Behavior Engineering website at www.behaviorengineering.org. It provides details of their revolutionary new approach to engineering complex systems. The team has prepared half, one, two, five and ten day versions of a course suitable for presentation in a range of industry and public forums.

Centre personnel presented at the following conferences:

1st Istanbul Conference on Design Theory and Combinatorics
2nd International Workshop on Equation-Based Object-Oriented Languages and Tools
3rd International Nonlinear Science Conference
4th Conference on Artificial Intelligence and Interactive...
Centre participants presented aspects of complex systems science and engineering in the following undergraduate and postgraduate courses:

**Advanced Algorithms & Data Structures**  
(UQ COMP4500)  
Coordinator: Brijesh Dongol  
Level: Undergraduate

**Behavioural and Evolutionary Economics**  
(UQ ECON2060)  
Coordinator: A/Prof P. Earl  
Lecturer: John Foster (some lectures on Complex Economic Systems)  
Level: Undergraduate

**Innovation Leadership**  
(UQ TIM7811) – UQ Business School MBA  
Addresses the issues relating to managing innovation within an evolving complex economy.  
Coordinator: Tim Kastelle, John Steen  
Level: Postgraduate

**Power System Operations and Security**  
(UQ ELEC7309)  
Coordinator: Zhao Yang Dong  
Level: Postgraduate

**Programming in the Large / Advanced Software Engineering**  
(UQ CSSE2002/7023)  
Coordinator: Graeme Smith  
Presenters: Paul Strooper, Kirsten Winter  
Level: Undergraduate/Postgraduate

**Software Engineering**  
(Griffith 2509ICT)  
Presenter: Geoff Dromey  
Level: Undergraduate

**Systems Engineering**  
(UQ ENGG4000/7000)  
Coordinators: Peter Lindsay  
Level: Undergraduate/Postgraduate

**System Safety Engineering**  
(UQ ENGG7020)  
Presenters: Peter Lindsay (Coordinator), Mark Bofinger (Savive Pty Ltd), Graeme Smith, Ariel Liebman  
Level: Postgraduate, also offered as a public course to industry. Included dependability analysis for complex engineered systems.
A number of Centre Chief Investigators and collaborators have been successful in obtaining considerable follow-on funding from the ARC.


**Linkage Grants**

**A new approach to air traffic management to deliver significantly reduced environmental impact and system wide efficiencies**

Prof PA Lindsay; Prof RG Dromey; Dr RK Porteous; Dr VL Wheway, (The University of Queensland, Griffith University, Airservices Australia, The Boeing Company Phantom Works, Qantas Airways Limited)  
This project is a direct follow-on from the ACCS Air Traffic Control program. Aviation is often cited as a major contributor to harmful emissions in the upper atmosphere. The primary outcome of this project will be the development of a model for air traffic management that will enable aviation industry stakeholders to optimise the deployment of 4-D User Preferred Trajectories across Australian airspace. It is expected that this will result in significant environmental benefit, through reductions in fuel burn for each flight, and system-wide efficiency increases. The project will enable improved use of airspace and airport facilities, whilst at the same time allowing the aviation industry to continue to contribute to Australia’s sustainable economic growth.

**A high throughput Grid based environment for real time bio-medical imaging**

Researchers: Prof DA Abramson; Dr M Lackmann; Dr M Haase; Dr IS Harper; Dr S Scheck (Monash University, Leica Microsystems)  
This project is a follow-on from the ACCS project ‘Application of Grid computing to complex systems’. Since the first microscope, the development and sophistication of imaging technologies have set the pace in life-sciences. The ability to ‘distinguish’ smaller and smaller structures continues to define the foundation for biological and bio-medical research. Over the next five to ten years we expect the resolution of microscopes will challenge the computational and storage capacity of current stand alone instruments. This project will develop a software architecture that integrates image capturing hardware and data analysis and storage software into a Grid of high performance computers and storage devices. Together with Leica, we will build a virtual microscope facility that will provide substantial functionality not currently available in Australia. The resulting system will provide a powerful scalable solution for future developments. Importantly, our proposal consolidates a critical mass of expertise connecting biomedical with computer science, thereby addressing a well recognised constraint that to date has limited their national and international impact.

**Reducing the risks associated with developing large scale, critical software-integrated systems**

Prof RG Dromey; Prof PA Lindsay; Prof IJ Hayes; Prof P Fritzson, (Griffith University, The University of Queensland, Raytheon Australia, K.J. Ross & Associates Pty. Ltd)  
This project is a direct follow-on from the ACCS Dependable Complex Systems program. Industry, government and defence increasingly rely on large-scale, critical software-integrated systems. The scale and complexity of these systems means current methods of analysing, designing and assuring their dependability are struggling to provide the constructive support and assurance that is demanded. Consequently, there are significant risks of cost and schedule overruns and of system problems and failures. This project builds on results from our current collaboration—a new method for modelling, analysis and defect detection for the requirements of large-scale systems. We will develop and scale-up to industry strength, simpler, more powerful, strategies for analysing, designing and providing the high level of assurance required.

**Assessing the impacts of proposed carbon trading and tax schemes on the electricity industry and the overall economy**

Prof J Foster; Prof JC Quiggin; Dr PE Simshauser; Mr CJ Nalder, (The University of Queensland, Babcock & Brown Power Pty Ltd)  
This project is a direct follow-on from the ACCS Electricity Networks & Energy Markets program. Currently, policy makers require a much clearer understanding of the impacts of different carbon abatement policies. Mounting evidence on global warming is making this an increasingly urgent priority. The proposed project is specifically concerned with using state of the art economic modelling approaches to give the best advice possible to policy makers in crafting an environmentally sustainable set of economic policy instruments that can maintain our enviable standard of living well into the future. The findings of the project will be available before the new Kyoto negotiation round commences.

**A scalable debugging framework for petascale computers**

Prof DA Abramson; Dr L DeRose; Mr R Moench (Monash University, Cray Inc)  
Supercomputing underpins a wide range of areas of importance to the Australian economy: mining, agriculture, engineering, medical research and pharmaceutical development to name a few. It is of critical importance that software solutions in these areas behave correctly and do not generate erroneous results. This project concerns a new approach to debugging and will develop software tools and techniques that make it possible to detect and locate errors as software is converted from smaller systems to run on the next generation of ‘petascale’ supercomputers. The outcomes will be a range of new debugging mechanisms for use on national high performance computing facilities, as well as a commercial quality implementation that can be exploited by our industry partner.
Software quality improvement through static analysis and annotation

Prof IJ Hayes; Dr CN Cifuentes (The University of Queensland, Sun Microsystems Australia)
Software forms the basis of critical infrastructure that supports industries such as electronic commerce. Flaws in the software can lead to failure of the overall system, or allow the security mechanisms of the software to be bypassed. This project is developing methods to improve the quality of software by finding common flaws that lead to security vulnerabilities or runtime failures. Within Australia, it is estimated that there are approximately 75,000 software developers who make substantial use of C/C++ and who could benefit from the availability of better automatic static analysis tools to improve both the quality of the code they produce and their productivity.

Discovery Grants

Dual phase evolution in networks

Prof DG Green; Prof HA Abbass (Monash University, UNSW@ADFA)
This project is a direct follow-on from the ACCS Complex Systems Theory & Applications program. A grand challenge for modern society is the sheer complexity of vast networks arising from organisations and infrastructures. Unexpected, sometimes catastrophic, behaviour often emerges from interactions within such systems. As a result, the Internet, financial markets, power grids and other vital infrastructures are susceptible to costly problems such as cascading failures, inefficiency, and unpredictability. High-tech industries, such as biotechnology and information networking, face problems in coordinating networks of interacting agents. This project will expand the horizon of complex systems by deriving the design principles underpinning stable and resilient network structures and validate these principles on real world networks.

Combining time bands and teleo reactive programs for advanced dependable real time systems

Prof IJ Hayes; Prof CB Jones; Prof A. Burns; Prof KL Clark (The University of Queensland)
Some of the ideas for this project emerged from discussions during a visit to Australia by Keith Clark which was co-funded by the ACCS. It builds upon work done in the ACCS project ‘Building dependability into complex computer-based systems.’ Society is becoming increasingly reliant on sophisticated real-time computer systems in applications ranging from car stability control to critical infrastructure, such as railway signalling systems. Further, there is a demand for ever greater automation and sophistication in the software controlling these systems. The research challenge in this project is to provide robust implementations of these systems in a way that allows one assess their dependability.

Innovation and dynamic networks in project based firms

Dr JT Steen; Mr TH Kastelle; Prof MJ Dodgson (The University of Queensland)
Seed funding for this project was provided under the ACCS’s ‘Complex networks and the world trade web’ project. Innovation is central to Australia’s future prosperity but many commentators have bemoaned national performance in ‘obvious’ indicators of innovation such as R&D spending and patents. We argue that a lot of innovation in Australia is actually hidden in the business of projects. To compete in the international economy it is vital to know how to manage innovation in this context. The proposed research will use new methods in network analysis to show how firms can be better structured to encourage innovation (See page 13).

Talking with robots: Evolving grounded language for embodied agents

Dr GF Wyeth; Prof J Wiles (The University of Queensland)
The coming personal robot revolution will be built on robots that have real-world intelligence, with an ability to understand and communicate about the world in the way we humans do. This project extends a previous ARC project, which developed robot-friendly languages for naming places in the world. This new project will develop the robots’ abilities and language to understand a comprehensive range of real world objects, places, actions, attributes and relationships. This project represents a major advance for Australia in the new and fast growing personal robot industry.

CSIRO Flagship Funding

CSIRO have created a series of National Research Flagships to tackle national priorities. The Intelligent Grid Cluster is a 3-year collaborative research project that will contribute to the CSIRO Energy Transformed Flagship’s research goal of halving greenhouse gas emissions and doubling the efficiency of the nation’s new energy generation, supply and end use technologies. Centre participants (including Tapan Saha, John Foster, Zhao Yang Dong, Ari Liebman, Lukas Skoufa, Liam Wagner, and Philip Wild) are undertaking two projects in the Intelligent Grid Cluster.

Market and economic modelling of the impacts of distributed generation and local cooperating agent based demand side management

Project Leader: Prof J Foster (School of Economics, The University of Queensland)
This project anticipates that more and varied sources of power will be introduced to the grid and investigates their potential impacts. It also seeks to develop technology and software packages to manage the introduction of smaller and less constant sources of electricity into the network. Further details are at http://igrid.net.au/node/4

Control methodologies of distributed generation for enhanced network stability and control

Project Leader: Prof T.K. Saha (School of IT&EE, The University of Queensland)
This project will provide a comprehensive understanding of the impacts of distributed energy in the Australian electricity system. This will include the economic benefits due to deferral of network infrastructure as well as the enablement of new investment in various aspects of the electricity and energy system. Further details are at http://igrid.net.au/node/11
Publications

2008

Papers published in publications that The University of Queensland considers to be the top ten percent of journals in their field, are starred ✴.

Books


Chapters in books


Journal papers (published)


Conference papers


Technical & other reports


Accepted for Publication in 2009

Books

Chapters in books

Journal papers

Conference papers
Myers, T., Dromey, R.G., “From requirements to embedded software—Formalising the key steps”, *Australian Software Engineering Conference (ASWEC)*, 2009.
## Performance Indicators Report

### P1. Research findings

<table>
<thead>
<tr>
<th>Description</th>
<th>2008 Actual</th>
<th>Details</th>
<th>2008 Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of publications</td>
<td>20</td>
<td>See Publications, page 40</td>
<td>At least eight in the top 10% of journals &amp; conferences in relevant areas</td>
</tr>
<tr>
<td>Invitations to address and participate in international conferences</td>
<td>12</td>
<td>See Keynote &amp; Invited Addresses, page 30</td>
<td>5–6</td>
</tr>
<tr>
<td>Invitations to visit leading international laboratories</td>
<td>3</td>
<td>See Visits to International Institutions, page 33</td>
<td>3</td>
</tr>
<tr>
<td>Number and nature of commentaries about the Centre’s achievements</td>
<td>10</td>
<td>See ACCS in the Media, page 21 and columns on pages 7, 13, 29 and 33</td>
<td>3</td>
</tr>
<tr>
<td>Additional competitive grant income</td>
<td>$300,278*</td>
<td></td>
<td>$180,000 in 2008</td>
</tr>
</tbody>
</table>

*Not included in the Centre’s financial report as it will be administered by the individual universities.

### P2. Research training and professional education

<table>
<thead>
<tr>
<th>Description</th>
<th>2008 Actual</th>
<th>Details</th>
<th>2008 Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of postgraduates recruited — with Centre financial support — affiliated with the Centre</td>
<td>0 (26 total to date)</td>
<td>See Research Students, page 26</td>
<td>18 over the life of the Centre</td>
</tr>
<tr>
<td>Number of postgraduate completions</td>
<td>11 (64 total to date)</td>
<td>See Research Students, page 26</td>
<td>18 over the life of the Centre</td>
</tr>
<tr>
<td>Number of honours students</td>
<td>13 (28 total to date)</td>
<td>See Research Students, Honours, page 28</td>
<td>36 over the life of the Centre</td>
</tr>
<tr>
<td>Number of professional courses/workshops</td>
<td>7 (35 total to date)</td>
<td>See Workshops, page 34</td>
<td>1</td>
</tr>
<tr>
<td>Participation in professional courses</td>
<td>2</td>
<td>See Professional Courses, page 34</td>
<td>2</td>
</tr>
<tr>
<td>Number and level of undergraduate and high school courses in the complex systems area</td>
<td>2</td>
<td>See Undergraduate &amp; Postgraduate Courses, page 37</td>
<td>Primary contributors to 2–3 undergraduate courses, and contributions to other courses &amp; high school awareness events</td>
</tr>
</tbody>
</table>

### P3. International, national and regional links and networks

<table>
<thead>
<tr>
<th>Description</th>
<th>2008 Actual</th>
<th>Details</th>
<th>2008 Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of papers published with international co-authors/reports for international bodies</td>
<td>25</td>
<td>See Publications, page 40</td>
<td>8</td>
</tr>
<tr>
<td>Number of international visitors</td>
<td>8 (of these, 4 had significant Centre financial support)</td>
<td>See Visitors to the Centre, page 32</td>
<td>4</td>
</tr>
<tr>
<td>Number of collaborative national and international workshops and exchanges</td>
<td>3</td>
<td>See Workshops, page 34</td>
<td>2</td>
</tr>
<tr>
<td>Number of visits to overseas laboratories</td>
<td>14</td>
<td>See Visits to International Institutions, page 33</td>
<td>5</td>
</tr>
<tr>
<td>Research projects with international partners</td>
<td>10</td>
<td>See Technology Transfer and Commercialisation, page 36</td>
<td>1</td>
</tr>
<tr>
<td>Examples of relevant Social Science &amp; Humanities research supported by the Centre</td>
<td>5 publications</td>
<td>See Evolutionary Economic Systems publications, pages 11–12</td>
<td>1 publication</td>
</tr>
</tbody>
</table>

### P4. End-user links

See Technology Transfer and Commercialisation Activities, page 36, for details of end-user links

### P5. Organisational support

See the Financial Statement, page 44 for details of organisational support

### P6. Governance

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

Statement of operating income and expenditure for the year ended 31 December 2008.

<table>
<thead>
<tr>
<th>INCOME</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ARC Centre grant</td>
<td>728,458</td>
</tr>
<tr>
<td>Collaborating institutions’ cash contribution</td>
<td>350,000</td>
</tr>
<tr>
<td>NHMRC</td>
<td>8,719</td>
</tr>
<tr>
<td>Industry cash contribution</td>
<td>33,834</td>
</tr>
<tr>
<td>Other funds</td>
<td>35,000</td>
</tr>
<tr>
<td>Funds carried forward from 2007</td>
<td>337,346</td>
</tr>
<tr>
<td><strong>TOTAL INCOME</strong></td>
<td><strong>1,493,357</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>EXPENDITURE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance</td>
<td>49,968</td>
</tr>
<tr>
<td>Travel</td>
<td>55,909</td>
</tr>
<tr>
<td>Equipment</td>
<td>11,800</td>
</tr>
<tr>
<td>Salaries</td>
<td>955,379</td>
</tr>
<tr>
<td>Scholarships</td>
<td>58,769</td>
</tr>
<tr>
<td><strong>TOTAL EXPENDITURE</strong></td>
<td><strong>1,131,825</strong></td>
</tr>
</tbody>
</table>

Funds carried forward to 2009 361,533