THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

ARC Centre for Complex Systems

2003 annual report

Australian Government
Australian Research Council

UNSW

Griffith UNIVERSITY

MONASH University

School of Information Technology and Electrical Engineering

ARC Centre for Complex Systems

2003 Annual Report

This report summarises the goals of the new ARC Centre for Complex Systems and the activities undertaken in 2003 towards achieving those goals.

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Director's Report

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 new *ARC Centre for Complex Systems (ACCS)* will conduct world-class basic and applied research on questions fundamental to understanding and managing complex systems. The goal is 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 will provide a focus for complex systems science research in Australia, and will develop strong engineering infrastructure for modelling and analysis of network-based systems, including high-performance computing and visualisation facilities, to enable the science to be applied to real-world problems. The result will be methods and tools that can be used to understand, manage and control complex systems.

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

ARC funding was confirmed late in 2003 and the year was spent in planning projects and setting up collaborations between Centre participants and with other research centres, industry and government. Full operation will commence in 2004. This first "annual report" outlines the vision for the Centre and its operations.

Professor Peter Lindsay

Director, ACCS

Motivation for the Centre's Research

The Increasingly Interconnected Modern World

Complex systems pervade the modern world. Individuals, societies, economies, and environments are highly interconnected by intricate, dynamically changing networks. Actions in one part of the network can have unexpected consequences in other parts.

Consider some examples:

Case 1. The Australian National Electricity Market's network of transmission lines is influenced both by physical-engineering constraints and market-control mechanisms. On a hot day in early 2001, a transmission line failed, causing a widespread cascade of blackouts and a separation of the energy supply in Victoria and NSW. Because operators lacked understanding of the complex relationships between the constraints and controls, they applied corrective measures that served only to increase the difficulty of restoring the network to full operation. They lacked the tools needed to visualise and control this dynamic network.

Case 2. Until recently, genomic research has focussed primarily on single genes that yield single products. However, many organic processes (for example, growth and development) involve large networks of interacting cells and genes. With maps of several genomes now available, biotechnologists have to understand these interactions and learn how to control them. The first countries to achieve these goals will reap a huge competitive advantage.

Case 3. During 2002, the National Trust declared the entire Murray River to be Australia's most endangered heritage site. Many factors motivated the decision, including water quality, salinity, threatened ecosystems and species, and environmental degradation. Major problems have arisen because numerous agents, including farmers, councils, and government agencies, have acted to address local problems without understanding their system-wide impact.

The Network View of Complex Systems

Of course, many different factors are at play in such systems. If we are to understand and manage large systems, we need to deepen our understanding of the fundamental phenomena in play and to build tools that can help us to plan and influence the complex behaviours that emerge. The Centre's research program is based around the observation that many complex systems, including the examples above, share the following important characteristics:

Networks of interacting agents: Although people, genes, and power stations are very different types of systems, they can all be viewed as networks, where each node in the network is a semi-autonomous agent that follows local rules of behaviour.

Emergent properties: Understanding network structures and how individual agents operate is insufficient: the whole exceeds the sum of its parts. The challenge is to understand emergent, large-scale system features and behaviour, such as self-organisation and cascading failures.

Adaptation: Each system changes continually and organically in response to environmental pressures, interactions among its nodes, and variations within and among its nodes.

Because deep similarities exist between so many different systems, we contend that most complex systems phenomena can be addressed using a common approach. Therefore,

The theme of the Centre's core research is computation in and by networks of agents.

How the Centre will Tackle the Problem

The ACCS brings together a strong, interdisciplinary team across four major Australian universities, equipped with some of Australia's best high-performance computing and visualisation facilities. The Centre will explore both the science and the engineering of complex systems.

In the *science stream* of its research program, the Centre aims to develop a coherent set of theories, computational techniques and modelling tools for network-based systems, drawing inspiration from nature. The focus will be on how complex system behaviours arise from (relatively) simple agent behaviours and connections between agents. The aim is to capture how natural systems self-organise and adapt, and then apply those insights to other areas.

Computer modelling and simulation of complex systems are important for testing the validity of existing theories and developing new theories. The *engineering stream* of the Centre's research program will be concerned with providing a modelling framework, theory, toolset, and infrastructure to enable complex-systems researchers to build powerful models and simulations economically and reliably. It will also facilitate application of the theories to real-world systems, and develop principles for managing (planning and controlling) complex systems.

Chief Investigators

UNIVERSITY OF QUEENSLAND

Professor Peter Lindsay (Director)
- Boeing Professor of Systems Engineering,
  School of Information Technology & Electrical Engineering

Dr Peter Adams
- School of Physical Sciences

Professor Kevin Burrage (Federation Fellow)
- Professor of Computational Mathematics,
  and co-Director, Advanced Computational Modelling Centre

Professor John Foster
- School of Economics

Professor Ian Hayes
- School of Information Technology & Electrical Engineering

Professor Simon Kaplan
- School of Information Technology & Electrical Engineering

Professor Geoff McLachlan
- Professor of Statistics, School of Physical Sciences

Professor Bernard Pailthorpe
- Professor of Computational Science,
  and Director, Queensland Parallel Supercomputer Facility

Professor John Quiggin (Federation Fellow)
- School of Economics,
  and School of Political Science & International Studies

Professor Penelope Sanderson
- Key Centre for Human Factors

MONASH UNIVERSITY

Professor David Green
- School of Computer Science & Software Engineering

Professor David Abramson
- School of Computer Science & Software Engineering

GRIFFITH UNIVERSITY

Professor Geoff Dromey
- Director, Software Quality Institute

AUSTRALIAN DEFENCE FORCE ACADEMY (UNIVERSITY OF NEW SOUTH WALES)

Dr Hussein Abbass
- School of Information Technology & Electrical Engineering

Partner Investigators

INDIAN INSTITUTE OF TECHNOLOGY – KANPUR, INDIA

Professor Kalyanmoy Deb

- Professor of Mechanical Engineering, Director of the Kanpur Genetic Algorithms Laboratory

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE, FRANCE

Dr Guy Theraulaz

- Centre de Recherches sur la Cognition Animale

BOEING AUSTRALIA

Dr Rick Neilson

- Chief Engineer, Boeing Australia Limited

The Core Research Program

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

Free flight air-traffic control

Air traffic control is one of the major bottlenecks preventing increased use of airspace and reduction in travel times. Free flight involves a fundamental shift from centralised control mechanisms (such as en-route air-traffic control) to localised control (whereby pilots take over primary responsibility for maintaining separation between aircraft). Major issues arise with respect to assuring safety and providing aviation services. We will apply complex systems science to the problem by modelling of airspace as networks of aircraft, and developing new approaches to assurance of system-level properties including safety, and the interplay between centralised control mechanisms (such as airport approach sequencing) and local control. This work builds on the group's existing work in human factors and human-computer interaction in air-traffic control.

Genetic regulatory networks

We will tackle fundamental questions about growth and form in cellular biology. Traditional reaction-diffusion models take a top-down view that examines the control of growth patterns by biochemical gradients. These models need to be integrated with models that capture local organisations and interactions. In particular, we will study how ontogeny based on realistic phenotypic descriptions such as L-systems can be derived from genetic regulatory models. We shall seek deeper understanding of the network structuring and control mechanisms that underlie genetic regulation in cell-level development of organisms. The vision is to be able to take insights arising from how DNA regulates the growth of organisms, extract general principles, and then transfer them to other domains, such as air traffic control and economics.

Evolution of economic systems

We will develop collaborative projects to apply our core research to fundamental questions concerning the evolution of economic systems. The key to this will be establishing a new kind of value theory that can translate the connective geometry of economic systems into aggregated value measures. Two ARC Federation Fellows will participate in this program: Kevin Burrage (nonlinear dynamic equations) and John Quiggin (economy of the Murray Darling Basin).

Research Training & Professional Education

Each year, ACCS will support approximately eight postdoctoral and eight postgraduate researchers to work on our research program. The Centre will provide the projects, supervisors and facilities to attract the most-able postdoctoral and postgraduate researchers. Scholarships will be available for undertaking postgraduate research degrees.

The Centre plans to develop a world-leading coursework masters program in complex systems. To the best of our knowledge, it will be the only institution in the world to offer a Masters of Engineering in Complex Systems degree.

The Centre will put in place a professional education program to disseminate its findings widely. This program is expected to include a winter or summer school, short courses, masters-level coursework, an annual conference, industry workshops and public lectures.

The Centre will run an active visitors program, to bring internationally renowned researchers to participate in the Centre's research and outreach programs.

Public Seminar Series

In 2003 an *Introduction to Complex Systems* course and seminar series was inaugurated, with guest lectures that typically attracted audiences of 60-100 people. The list of topics and speakers (which included five Federation Fellows) demonstrates the breadth and depth of interest in complex systems research in the ACCS and its collaborations:

- Dr Janet Wiles (ITEE), *Introduction to Complex Systems I: Network structure, dynamics and computation*
- Dr Jennifer Hallinan (IMB), *Introduction to Complex Systems II: Agents, emergence and self-organization*
- Prof John Mattick (Director, Institute for Molecular Bioscience), *Programming the autopoietic development of complex organisms: the hidden layer of non-coding RNA*
- Prof Kevin Burrage (ACCS), *The dynamics of complex systems*
- Prof David Green (ACCS, Monash), *Interactions matter: complexity in landscapes and ecosystems*
- Prof Hugh Possingham (Director, The Ecology Centre), *Marine-reserve system design: algorithms, problems and models*
- Prof Max Lu (Director, ARC Centre for Functional Nanomaterials), *Fuel cell technology and the role of nanomaterials*
- Prof John Quiggin (ACCS), *Economies as complex systems*
- Prof Gerard Milburn (Centre for Quantum Computer Technology), *Quantum complex systems*
- Dr Lindsay Hood (Hewlett-Packard, Canberra), *Agent-based modelling in the social sciences*
- Prof Bernard Pailthorpe (ACCS), *Grid computing: planetary scale simulations, data and user interfaces*
- Prof Perry Bartlett (Director, Queensland Brain Institute), *The plastic brain*
- Prof Simon Kaplan (ACCS), *Socio-technical systems*
- Prof Peter Lindsay (ACCS), *Free flight air traffic control*
- Prof John Foster (ACCS), *Complexity, self-organization, networks and constrained optimization in economic systems*

National Benefit

ACCS will foster the emerging discipline of complex systems within Australia by creating a critical mass of researchers. It will address leading-edge issues to place Australia at the forefront of international research. ACCS will also serve to promote the impact of Australian research on complex systems. It will reduce fragmentation by providing avenues for national and international networking and collaboration, as well as by providing essential infrastructure. It will actively aim to retain Australia's best young complex systems researchers within the country.

Through joint applied projects with collaborators, ACCS will contribute to solving major national problems arising from complexity. It will feed ideas, discoveries, and techniques to Australian government and industry to improve their current practices and seed innovation in particular. It will also seek to collaborate to develop commercial applications of its research.

Examples of software tools that could be developed within the Centre include those that allow:

- Tools for visualisation and control of complex network-based technological systems in areas such as power distribution, air-traffic control, telecommunications and the Internet, manufacturing, and defence.
- Bioinformatics tools for modelling genetic regulatory networks and organism development.
- Tools for modelling the effect of government policies (e.g., new regulatory mechanisms or infrastructure) on complex socio-technical systems in areas such as health, transport, economics, irrigation, and ecology.
- Tools for modelling and predicting the possible effect of interventions on complex environmental and biological systems (such as the Murray River basin and the Great Barrier Reef), the growth and development of organisms, and the spread of disease.

End-User Links

Further industry collaborations and funding will be established over the life of the program in order to apply the Centre's research.

ACCS will focus primarily on fundamental research. Nonetheless, we will sustain strong links to application and commercialisation activities. For instance, we already have strong links with Boeing. Boeing anticipates that ACCS's fundamental research will help them solve problems associated with large-scale systems integration. We also have established links with Airservices Australia, the Civil Aviation Safety Authority, Qantas Airlines, Boeing ATM and the ASTRA cross-industry aviation group, and CSIRO's Centre for Complex Systems Science.

The Centre will actively pursue links with key organisations nationally and internationally, including for example the National Centre of Excellence for Aviation Operations Research (NEXTOR) and the Santa Fe Institute in the US, and the Dependability Interdisciplinary Research Centre in the UK.

Another important group of end-users of Centre-developed methods and tools are other researchers, such as biologists and agronomists. Research centres with which the ACCS developed collaborations in 2003 include:

- The Institute for Molecular Bioscience
- The ARC Centre for Bioinformatics
- The ARC Key Centre for Human Factors & Applied Cognitive Psychology
- The ARC Centre of Excellence for Integrative Legume Research

Governance & Centre Administration

The ACCS is headquartered in the School of Information Technology and Electrical Engineering in the Engineering, Physical Sciences & Architecture Faculty of the University of Queensland.

A full-time *Director* (Prof Peter Lindsay) will lead and be responsible for all aspects of the Centre's operations.

The Centre will have an *Advisory Board* that will advise on Centre management, strategic directions, and commercialisation of Centre research. The Centre Advisory Board will include university academic expertise and senior university staff, industry & end-user representation, senior staff of the ACCS, and expert international representation.

The Director will be responsible for preparing and updating the Centre's research program, in consultation with the *Research Advisory Committee*. This Committee will comprise the Chair of the Centre Advisory Board, the Director, the Chief Investigators, representatives of the collaborating organisations, and – where possible – visiting international fellows.

A *Centre Manager* will be responsible for the financial, marketing, and administrative activities of ACCS. The position will be a joint appointment with the School of Information Technology and Electrical Engineering at UQ.

A *Centre Education Officer* will be responsible for coordination of research training and the professional education programs and will support the Centre Manager in marketing activities.

Financial Statement

ARC funds received in December 2003 $250,000

Commitments carried forward to 2004:

University of Queensland	$250,000
Monash University	$25,000
Griffith University	$25,000
University of NSW (ADFA)	$25,000

Total funds carried forward to 2004: $575,000

The ARC has indicated funding of $901,659 per annum for 2004-2007, and the university nodes have committed $325,000 per annum for this period.

For More Information

For more information on any aspect of the ACCS, or to discuss possible collaboration, please contact the Centre's Director:

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