The Grand Challenge in Non-classical Computation.
International Workshop 18-19th April 2005, University of York and Microsoft Research

Position Paper

Non-classical Computation and the Science of Complex Systems

Jeffrey Johnson
ONCE-CS: Open Network for Connecting Excellence in Complex Systems
IST FET Coordination Action 2005 – 2008
AHRB/EPSRC Designing for the 21st Century Cluster: Embracing Complexity in Design
Department of Design and Innovation
The Open University
j.h.johnson@open.ac.uk
23rd March 2005

We are on the crest of a massive paradigm shift in science that will have profound effects on every aspect of human life in the next five to twenty years. Apart from underlying major changes in computational and communication technologies, the emerging science of complex systems will enable new ways of designing, planning and managing human systems. As a consequence the information systems of the future will embody the new science, through its concepts and their applications. Organisations that recognise and adapt to the huge change this implies will thrive, while those that do not have this vision will die. We can expect large corporate failures, and the birth of major new businesses. Public administration will be characterised by new efficiencies and achievement in some area, matched by unacceptably poor performance from authorities that do not adapt in a timely way. Although these successes and failures will reflect the ability to understand the impact of the new science on human and socio-technical systems, they will be underpinned by huge advances in the design and implementation of information systems.

Increasingly it is being found that many systems exhibit behaviour that cannot be understood from the perspective of conventional science, and these systems are often considered to be complex. Although there is no satisfactory definition of complexity, there is a number well-defined characteristics that often apply to what we consider complex systems. These include the computational irreducibility of chaos, path dependence and discrete multilevel dynamics. They also include large incomplete and inconsistent data sets, with new science being enabled by mass storage technology and intense computation. The science addresses systems in which relatively autonomous agents interact with others within their environment to self-organise without top-down control mechanisms, adapting to change. Perhaps more than anything, the science is characterised by emergence. This is notably so in the science of artificial systems – systems designed to produce desirable emergence and suppress undesirable emergence – including the information systems that underpin modern civilisation.

Most scientific domains exhibit complexity, from physics, chemistry and biology through to economics, geography, psychology, sociology and political science. Consider a matrix in which these traditional domain names are listed along the top, with the characteristics issues of complex systems listed down the side. These include the problem of reconstructing systems from observation, representing multilevel dynamic systems inside computers, simulation, and so on. Many scientists take a domain-centred approach, in which they are interested in primarily in one domain and research it in great depth. For example, some biologists spend their life researching biological systems, with no professional interest in, say, economics or computer science. Similarly, some sociologists spend their life investigating social systems, with no professional interest in, say, physics or chemistry. In contrast to this vertical approach, a complex systems scientist takes a horizontal approach, cutting across the boundaries of conventional science. For example, chaos occurs in many domains, from the weather to road traffic; systems from many domains can be modelled as cellular automata, from viral infection to markets; network properties found in the Internet can also be observed in anthropology; and so on. The two extremes are inevitable. One can spend a lifetime researching a small part of particular domain in great depth, or one can research in greater breadth across the disciplines. Science needs both approaches. In a single lifetime, no-one can master all domains. No agent knows everything. Complex systems scientists tend to be expert in one or two domains, complemented by a less deep knowledge of many domains. Complex systems scientists are interested in *fundamental questions* that cut across domain boundaries.

Paradoxically, the context of the new computer-enabled science of complex systems is deep dissatisfaction with the way computer systems are designed, implemented, and maintained. More positively, computer scientists see great opportunities for new kinds of computation through the science of complex systems.

Computer systems are artificial systems and their science involves not just what they are, but what they *ought* to be. Like many designed systems, they can (i) be inherently complex, (ii) involve complex processes in their manufacture, (iii) co-evolve with a complex external social and economic environment, and (iv) involve complex human interactions during the design and implementation process. Thus (i) computation systems are inherently complex, from novel computation hardware at micro and meso levels, to emergent network phenomena at macro levels, (ii) the processes of manufacturing computation systems can be complex, from conventional chip fabrication to new chemical and biological approaches, (iii) new computation systems will evolve in the complex socio-politico-economic context of the market and regulation, and (iv) the human systems of people who design and implement new computation systems are complex, and the success of new technologies will depend on how well these human systems are managed. Currently a cluster of researchers is investigating the issue of embracing complexity in design, as part of the AHRB/EPSRC Designing for the 21st Century initiative launched in 2004. This cluster is researching complexity across the design disciplines, including the design of computational hardware and software systems.

Although computer science can be viewed from a technical perspective, the application of new technologies will underpin the economic success, social wellbeing and political stability of societies in the future. Large complex systems like health services, financial institutions, food, transport, the military, and government will all be based on new generations of computational platforms integrating new scientific knowledge of social dynamics. The added-value in information technology will be fantastic, as will be the added-cost for those not at the forefront of the technology. For this reason the European Commission launched its Information Societies Technologies initiative in Framework VI, including the Future Emerging Technology initiative: “FET is the IST programme nursery of novel and emerging scientific ideas. Its mission is to promote research that is of a long-term nature or involves particularly high risks, compensated by the potential of a significant societal or industrial impact”. FET is supporting research in complex systems through Exystence (complEX sYStems Network of exCEllence, 2002 – 2005), ONCE-CS (Open Network Connecting Excellence in Complex Systems, 2005-2008), and four Integrated Projects (2004-2008): PACE (Programmable Artificial Cell Evolution), EC Agents (Embodied and Communicating AGENTS), DELIS (Dynamically Evolving, Large Scale Information Systems), and EVERGROW (EVER-GROWing global scale-free networks, their provisioning, repair and unique functions).

In this context and the aims of this workshop, there is potential for intense interdisciplinary approaches to developing future novel computational architectures, involving the design and complex systems communities. FET is already engaged in future generations of novel computational building blocks, and is supporting research into complex self-organising systems as future computational architectures. Thus it is explicitly engaged in the grand challenge in non-classical computation, and supporting researchers in this field.