Introductory remarks to 'Symposium on complexity and 21st century challenges '(Ralph Dum, London 25-03-2004)

Three years ago we organised a first brainstorming on the possibility to finance 'complex system research' in the European Commission. Back then, it was organised, here at London School of Economics, as a side-event to the business meeting of Santa Fe Institute. We went a long way from there! This symposium is a joint venture between SFI, LSE, EC and the network of excellence EXYSTENCE that covers complex system research in Europe. The Future and Emerging Technologies Unit of the EC is funding research projects in complex system in a diverse range of areas, other parts of EC and national programmes are joining efforts to fund complex system research considered as one of the most promising attempts to tackle challenges ahead of us.

What are the driving forces behind this recent surge of interest in complex system studies? Why do scientists, engineers, policy makers, business managers (as confirmed by their high attendance to this symposium as audience as well as speakers), management consultants, or funding agencies, like the EC or the EPSRC in UK, show this high interest in complex systems just now? And what are complex systems anyway? The answer to the last question I will leave to the following speakers. A partial answer to the first can be found in the spectacular increase of capabilities of information technologies and the deep and radical changes IT is causing in science, engineering, business, and society. Let me give two examples to support this statement: The increase in empirical data on various types of systems and the penetration of IT into business and society.

Information technologies allow us to acquire and to store extraordinary amounts of data. We are currently creating a wealth of empirical data on living and on social systems that was simply not available only 10 years ago. For example, new methods of data acquisition in molecular biology - micro array technologies to study gene expression networks - have catapulted many laboratories from studying the expression of one or two genes in a month to studying tens of thousands of genes in a single afternoon. Together with stunning progress in computation this opens radically new avenues for life sciences. Exploiting this wealth of information could advance our understanding of living systems, as well as our ability to design effective therapeutics, to entirely new levels.

In business, IT had an equally profound impact. The encounter - or some might say clash - of new communication technologies with businesses resulted in entirely new business architectures like e-commerce or C2C business (see EBay). We have to understand the impact of these new architectures to business and to society. While often exciting new opportunities arise due to interactions not possible without communication technologies, there is also a risk involved: highly connected systems are exposed to the risks of cascading failures, like in the recent breakdown of electric power grids in Italy and NY, like in the South Asian banking crisis which was a blow to the belief in the 'supra-conductivity of capital' or like in the uncontrolled consequences of delocalised business processes.

Finally, IT itself is now at the edge of a complexity barrier which will need new approaches to system design and control of large scale systems if we are to continue progress at the same pace as in the past. In the future, scientists will have to understand, engineers will have to create and businesses and society will have to cope with systems acting at a level of complexity which was simply not possible before the IT revolution. Such 'complex systems' are highly interconnected and heterogeneous, they are open to exchanges with their environment, they are highly dynamic and rarely in equilibrium. Modelling and understanding such complex systems is therefore -for many decades to come - a profound challenge to science - driven by societal needs as much as by scientific opportunities.

How does research in complex systems enter the picture? Non-equilibrium and non-linearity are hallmarks of complex systems studied by physicists like I. Prigogine or biologists like Lord May. Heterogeneity and adaptation characterise 'complex adaptive systems' that were promoted by the founders of SFI. One intriguing characteristics of such systems is the existence of multiple attractors of system dynamics (the 'adjacent possible' of Stuart Kauffman). We experience a shift from studies exemplified by equilibrium models with a single well-determined point of equilibrium to studies of highly dynamic processes with points of equilibrium which depend on the history of the system dynamics. In biology this complex system approach can model self-organising or autocatalytic processes, in economy for instance the increasing return economy first analysed by Brian Arthur. In his presentation, Brian Arthur will take a look at technology as a CAS driven by nonlinear dynamics of innovation processes. Geoffrey West, in turn, will present research in the FET funded project ISCOM where he extends fascinating work on use of scaling theory to understand metabolic networks in living organisms to networks in urban and cooperate systems.

Let me cite Lord May in an article published in Nature in early 80es*:* **'**Not only in research but also in the everyday world of politics and economics we would all be better off if more people realised that simple non-linear systems do not necessarily possess simple dynamical properties'

I will briefly digress on the nature of multidisciplinarity in complex system research. There are in essence two types of multidisciplinary research: In the first type the object of study is intrinsically multidisciplinary – bioinformatics or NBIC are very recent examples: various disciplines need to contribute for a complete view. The second type of multidisciplinary research attempts to draw intrinsic -perhaps even universal - concepts from studies of a wide range of objects from various disciplines.

An example of this type is the emerging 'science of networks'. Due to progress in IT we can now study networks on a scale far larger than previously possible: instead of a few hundreds we now study millions of network nodes and analyse their large - scale statistical properties. Inspired by empirical studies of networks ranging from networks in biology over communications networks to social networks, researchers have in recent years tried to uncover properties intrinsic to all of these diverse networks. Intrinsic properties of networks studied include robustness of networks to disturbances, or the influence of the topology of the underlying networks in spread of epidemics or in the flow of information. Lord May will give an account on recent progress in our understanding of spread of the small-box virus and how research can be extended to spread of information in society,

One intriguing consequence of the penetration of IT into society is that IT and society are starting to co-evolve and increasingly, results from social sciences are making their way into IT. A good example is the Internet, the most elaborate computational artefact ever created by mankind. The internet is unique among all IT systems in that it is operated and used by a multitude of economic interests -service and content providers - engaged in a varying relationship of collaboration and competition: the internet is not a product of top-down deliberate design, but the emerging product of competing individual interests. This suggests that tools for understanding and managing the Internet may come from game theory, computational markets for resource allocation or auction theory. In his presentation, Scott Kirkpatrick will outline the potential consequences of the sheer size of the Internet for the future of computation and present research funded in the FET project EVERGROW.

Due to this co-evolution - not restricted to the Internet but happening in all areas of deployment of IT to society - we will not be able to progress further without basic research that elucidates the role of 'Society as information processing', that is a 'information society science'. For example, how well and how are institutions storing, distributing and processing information? Can we quantify the flow of information in societal structures and extend the concepts of entropy and energy from systems dominated by scarcity of resources (energy or even bandwidth) to systems dominated by intangible resources like knowledge.

Luc Steels will present basic research into emergence of language in societies of agents (for instance robots), research done in the FET-funded project ECAGENTS. While this is research fascinating in itself it also holds the promise for a new approach to managing distributed information systems- semantic interoperability. Humans have the capacity to invent representations 'on the fly' much in contrast to artificial systems. In the future, Societies of agents that reach some form of agreement (like mutual trust or shared conventions) could replace centralised structures like the Semantic web or centralised management used in C2C business structures.

Agent-based modelling - another IT-facilitated development in the social sciences –holds the promise to systematically study the micro-macro link between individual incentives of agents and characteristics of group behaviour and the role of information exchange in the creation of social structures. This could open unprecedented opportunities to study social systems and might even give rise to hope to use these methods to ameliorate civil conflict through studies of such models. Chris Barrett will present work where he pushed agent-based simulations for spreads of epidemics and urban transport to entirely new levels in terms of number of agents and in terms of use of empirical data and in terms of mathematical understanding of the foundations. A possible pitfall of the increase in computational power is that also the mathematical illiterate can do experiments in silico. Emergence of novel properties is then synonymous to 'I have no glue as to what is going on'. In such large-scale simulation, only mathematical literacy can help generate understanding in large-scale simulations.

The symposium is rich in examples of basic research which is creating *generative understanding*, that is understanding which generates novel and inherently non-predictable pathways for technology and novel responses to societal challenges. This is the ultimate motivation for choice of topics of this symposium: the conviction that addressing the major challenges of the 21st century is where multidisciplinary complex system research will make a difference.