COMPLEXITY SCIENCE

Imperial College London

Complexity Science

In the Faculty of Natural Sciences

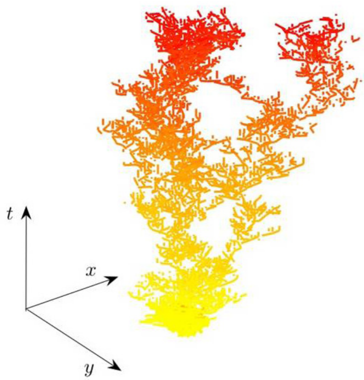
Complexity Science is transdisciplinary. The aim is to improve our understanding of how complex systems consisting of large numbers of interacting components work. We do this through collaborative studies of concrete examples within specific fields. Complexity Science is currently undergoing a rapid growth worldwide caused by the challenge to understand problems in, e.g., neuroscience, communication and transport networks, engineering, biology and sociology. Despite the diverse nature of such systems it is being discovered that commonalities do indeed exist. For example the interactions among the constituents often give rise to emergent hierarchical network structures that undergo intermittent evolution in time.

When interaction matters

At Imperial, quantitative modelling using methods from a wide range of mathematics, statistical mechanics and network theory is applied in collaborative efforts within projects in neuroscience, evolutionary biology, medicine, engineering and sociology producing new insights of fundamental importance and of immediate relevance to applications.

The coherent combination of applied science will, when performed in collaboration with research in fundamental aspects of complex systems theory, provide the ideal forum to move complexity science beyond the confines of idealised modelling. Simple laboratory experiments are typically too idealised to be able to address the most interesting research questions in complexity science. Researchers therefore have to resort to data obtained from real systems. Hence theoretical investigations in complexity science should be carried out in close collaboration with researchers investigating a variety of real systems to make it possible to identify commonalities of theoretical practical importance.

The Complexity and Networks programme is situated in the Institute for Mathematical Sciences and brings together researchers from across the college and from other universities in UK and abroad.



A population spreading as a fractal through two space dimensions plus one time dimension.
Figure courtesy to Alastair Windus.

Imperial College London
Photo: FJ Gaylor

The simplest way to characterise Complexity Science at Imperial is as quantitative modelling of emergent phenomena at a macroscopic level caused by the many interactions taking place at a microscopic level. We want to contribute to the development of a framework within which it is possible to encapsulate the myriad of degrees of freedom of a system at a microscopic level, into just a few degrees of freedom at a macroscopic level. For this we use various types of statistical mechanics.

In its current form statistical mechanics does not hold all the answers for all complex systems, however, we think that broadly speaking it is the best methodology available to obtain a quantitative description of complex systems. By systematically applying it to fields outside its traditional range of application in physics, statistical mechanics can be developed further, and at the same time contribute to the understanding of those fields. The importance of this feedback loop cannot be overestimated. It can also provide a starting point for the possible development of new mathematical techniques and approaches. This is at the moment happening within the theory of large networks, as e.g. encountered in neuroscience, engineering and social science.

Research sponsored by: EPSRC Engineering and Physical Sciences Research Council

COMPLEXITY SCIENCE

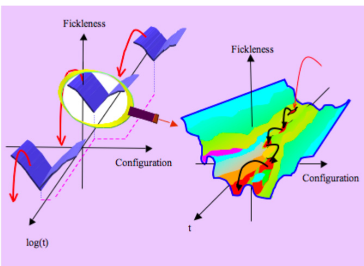
Imperial College London

Dynamics of Complex Systems

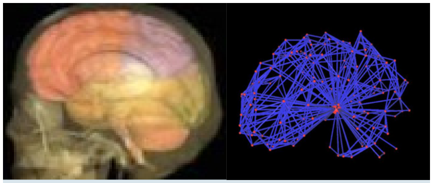
Dynamics is essential. Everything changes with time and when dealing with complex systems the changes can be dramatic. Often a stationary state doesn't exist for relevant time scales. Typically the overall state and properties may change abruptly through abrupt events separated by long periods of quiescence. We have found that the same statistics and slow decrease in activity is present in seemingly very different situations.

The Tangled Nature model of evolution was inspired by observations suggesting intermittent bursts of extinction and creation events in the fossil record. The model reproduces these observations and describes the statistics of the events in terms of record statistics. It is found that the same statistics and observed slowing down applies to a range of seemingly unrelated systems. We found for example in model studies of superconductors that the magnetic field relaxes in the same way. This behaviour is also seen in the type of magnetic materials call spin glasses and in polymer glasses. Most surprisingly our collaborators at Bristol University have found in their experiments on ant colonies that the times at which ants leave the nest exhibit the same statistical behaviour. This leads to the anticipation that slow, directed dynamics, during which the system's properties change significantly, is fundamental to complex systems.

The microscopic mechanisms underlying this type of dynamics is related to a slow, decelerating but spasmodic release of an intrinsic strain or tension. The strain arises from local frustration. As the strain is released through "quakes," some system variable undergoes record statistics with accompanying log-Poisson statistics for the quake event times. It is interesting to note that to check this scenario, one just need a time series of an appropriate observable to check if the statistics of the abrupt changes has the properties of a Poisson process as function of logarithmic time. A better understanding of this very general behaviour might help us to improve our understanding of catastrophic events such as systems failure or financial crashes.



Motion through a high-dimensional landscape indicating the slow smooth relaxation interrupted by abrupt dramatic major upheavals.

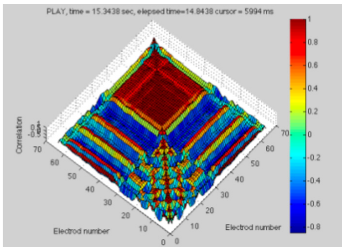


Brain scan and extracted functional network.
Figures courtesy of F. Turkheimer, P. Piccini and R Wise.

Emergence in neuroscience

Analysis of fMRI data is used to extract the nature of the time-averaged correlations across the entire brain. Further analysis is applied to investigate causality relations between different parts of the brain. One very remarkable finding is that the time averaged correlation structure is scale free and hence entirely different from what one would anticipate from standard functional imaging.

In a related research effort, EEG data sampling is used to assess the working of the brain during music making and the degree of creativity involved. Since a measure of creativity doesn't exist, the performer and musical judges evaluate the rendition; their classification is then compared with the EEG analysis. The hope is in particular to elucidate what happens when creative leaps and ingenuity occur during play. There are indications that during particular creative play, the right hemisphere becomes strongly correlated internally while the remaining part of the brain briefly de-correlates.



Instances of excess correlations covering the entire right hemisphere seen as red level of correlations between electrodes within that brain region. Figure courtesy of S. Rahman.

For more information contact

Professor Henrik Jeldtoft Jensen, Programme Leader
Professor Kim Christensen

Institute for Mathematical Sciences
53 Prince's Gate
Imperial College London
South Kensington campus
London SW7 2PG

Email: h.jensen@imperial.ac.uk
k. christensen@imperial.ac.uk

Telephone: +44 (0)20 7594 0990
Website: www.imperial.ac.uk/mathsinstitute
www.imperial.ac.uk/naturalsciences

Edited and designed by the Faculty of Natural Sciences, Imperial College London. February 2010.