Complexity and Self-organization: Data Analysis and Models

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To my wife Theresa.

Abstract

The understanding of the emergent behaviour of *complex systems* is probably one of the most intriguing challenges in modern theoretical physics. In the present Thesis we use novel data analysis techniques and numerical simulations in order to shed some light on the fundamental mechanisms involved in their dynamics. We divide the main core of the research into three parts, each of which address a specific, and formally well defined, issue.

In the first part, we study the processes of self-organization and herding in the evolution of the stock market. The data analysis, carried out over the fluctuations of several international indices, shows an avalanche-like dynamics characterized by power laws and indicative of a critical state. Further evidence of criticality relates to the behaviour of the price index itself. In this case we observe a power law decline with superimposed embedded log-periodic oscillations which are possibly due to an intrinsic discrete scale invariance. A stochastic cellular automata, instead, is used to mimic an open stock market and reproduce the herding behaviour responsible for the large fluctuations observed in the price. The results underline the importance of the largest clusters of traders which, alone, can induce a large displacement between demand and supply and lead to a crash.

The second part of the Thesis focuses on the role played by the complex network of interactions that is created among the elementary parts of the system itself. We consider, in particular, the influence of the so-called "scale-free" networks, where the distribution of connectivity follows a power law, on the antiferromagnetic Ising model and on a model of stochastic opinion formation. Novel features, not encountered on regular lattices, have been pointed out. In the former case a spin glass transition at low temperatures is present while, in the latter, the turbulent-like behaviour emerging from the model is found to be particularly robust against the indecision of the agents.

The last part is left for a numerical investigation of an extremal dynamical model for evolution/extinction of species. We demonstrate how the mutual cooperation between them comes to play a fundamental role in the survival probability: a healthy environment can support even less fitted species.

Statement of Originality

This work contains no material which has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

I give consent to this copy of my thesis, when deposited in the University Library, being available for loan and photocopying.

Marco Bartolozzi

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