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Editorial

Complex Systems: an Interdisciplinary Approach

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Two main peculiarities characterize complex systems: the nonlinearity and the noisy environmental interaction. The comprehension of noise role in the dynamics of nonlinear systems plays a key aspect in the efforts devoted to understand and model so-called complex systems.

Understanding of physical, chemical, biological, ecological, engineering and social systems indeed may be enhanced by analysis of their complex nature. One approach to understanding the complexity is to start with a conceptually simple view of the system and add details that introduce new levels of complexity. In general the effects of small perturbations and noise, which is ubiquitous in real systems, can be quite difficult to predict and often yield counterintuitive behavior. Even low-dimensional systems exhibit a huge variety of noise-driven phenomena, ranging from a less ordered to a more ordered system dynamics.

The nonlinear dynamics of complex systems is one of the most exciting and fastest growing branches of modern sciences. This research area is at the forefront in interdisciplinary research and it has an increasingly important impact on a variety of applied subjects ranging from the study of turbulence and the behavior of the weather, through the investigation of electrical and mechanical oscillations in condensed matter systems, to the physics of nano-structures and nano-devices, and to the analysis of biological and economic phenomena. Transport in ion-channels, synchronization, coherence in biological extended systems, virus propagation, forecasting protocols are just a few examples that illustrate the subtle beneficial synergy between noise and nonlinearity. Complex systems may have extremely rich coherent dynamics due to the environmental noise and, in specific points of their phase space, are extremely sensitive to external perturbations.

The performance of any complex system depends on a correct information exchange between its components. In most natural systems a signal carrying information is often mixed with noise. Usually the contamination by the noise makes it difficult to detect signals, but in some cases noise induced effects known as *stochastic resonance, resonant activation and noise enhanced stability* improve conditions for signal detection when noise and system parameters become "optimal" [1-3]. The combined action of external deterministic or random driving forces and the environmental noise has given rise to new phenomena with a rich scenario of far-from equilibrium effects. To describe complex systems, it is in fact fundamental to understand the interplay between noise, periodic and random driving forces and the intrinsic nonlinearity of the system itself.

Frequently, noise effects have been assumed to be only a source of disorder. Now researchers are gaining a better understanding of population dynamics by bringing noise into nonlinear models, both for marine and for terrestrial animals [4,5]. The noise through its interaction with the nonlinearity of the living systems can give rise to new, counterintuitive phenomena like noise-enhanced transport, noise-sustained synchronization, noise-induced transitions, noise-enhanced stability, stochastic resonance, noise delayed extinction, temporal oscillations and spatial patterns. In addition, the analysis of experimental data of population dynamics frequently needs to consider spatial heterogeneity. Characterizing the resulting spatiotemporal patterns and the spatial organization is, perhaps, the major challenge for ecological time series analysis and for dynamics modeling [6-9].

The study of complex systems concerns the emergence of collective properties in systems with large numbers of components interacting nonlinearly with each other. These elements can be atoms or bacteria in a physical or biological context, or people, businesses or financial market prices in an economic context.

The science of complexity tries to discover the emergent behavior of complex systems, focusing on the structure of interconnections and general architecture of the systems, rather than their individual components.

The development of the science of complexity is not reduced to a single theoretical or technological innovation, but implies a new scientific approach that has enormous potential to deeply influence the scientific, social, economic and technological activities.

This special issue contains the collection of papers of the presented contributions at the "Seminar of Complex Systems: Understanding the Complexity", held at the Physics Department of Palermo University from 5 March to 28 May 2009. These papers received a peer-review process from the Editorial board of the Journal "Quaderni di Ricerca in Didattica (Scienze)".

About 200 undergraduate students in engineering, biology and physics have attended the interdisciplinary Seminar on Complex Systems. Twelve speakers, young researchers in physics and engineering, have presented their recent research results in complex systems. The subject of the lectures given at the Seminar covered different areas of complex systems, ranging from physics to biology, ecology, and medicine. The lectures in physics were: (i) Generation of terahertz radiation in nonlinear waveguides, (ii) Josephson Junction Devices: An Introduction, (iii) An approach to statistical mechanics through the Boltzmann factor, (iv) A brief introduction to quantum mechanics, (v) Interference in Quantum Mechanics, (vi) The physics of ultracold atoms: principles and applications. The lectures in biophysics and ecosystems were: (i) Remote Sensing and Stochastic Dynamics of fish populations in the Strait of Sicily, (ii) Anomalous diffusion and biological processes in ecosystems, (iii) Stochastic resonance in the recognition and courtship of species Nezar viridula. Finally the lectures in physics applied to medicine were: (i) ESR dosimetry for applications in medicine and industry, (ii) Role of noise in the 'middle temporal lobe epilepsy.

This special issue is dedicated to the memory of Prof. Filippo Spagnolo, recently deceased, and Editor in Chief of the Journal till his death on 2 March 2011. His untimely death leaves a great void in the area of interdisciplinary research of educational research, mathematics education and fundamentals of mathematics, physics, chemistry and natural sciences, but at the same time a high cultural heritage along with a high human depth that only a true master can transmit. On the trace of the work initiated by prof. F. Spagnolo is this special issue dedicated to him.

Prof. F. Spagnolo, founder of this scientific journal since 1990 and its section in Natural Sciences in 2010, with the collaboration of Professor. C. Fazio, has contributed to fill a cultural void, but above all to create an international interdisciplinary forum on foundations, educational research in mathematics and natural sciences [10-12]

References

[1] L. Gammaitoni, P. Hanggi, P. Jung and F. Marchesoni, "*Stochastic resonance*", Rev. Mod. Phys. **70**, 223–287 (1998).

[2] W. Ebeling and B. Spagnolo, *"Noise in Condensed Matter and Complex Systems"*, Fluctuation and Noise Letters, **5** (2), L159-L161 (2005).

[3] B. Spagnolo, A. A. Dubkov, A. L. Pankratov, E. V. Pankratova, A. Fiasconaro and A. Ochab-Marcinek, “*Lifetime of metastable states and suppression of noise in interdisciplinary physical models*”, Acta Physica Polonica B **38**, 1925–1950 (2007).
[4] B. Spagnolo and A. A. Dubkov, “*Editorial of Critical Phenomena and Diffusion in Complex Systems*”, International Journal of Bifurcation and Chaos **18** (9), 2643 - 2647 (2008).
[5] Quang-Xing Liu, Zhen Jin and Bai-Lian Li, “*Resonance and frequency-locking phenomena in spatially extended phytoplankton–zooplankton system with additive noise and periodic forces*”, J. Stat. Mech. **5**, P0511 (2008).
[6] H. Levine, E. Ben Jacob, “*Physical schemata underlying biological pattern formation-examples,issues and strategies*”, Physical Biology **1**, 14 (2004).
[7] E. Ben-Jacob, “*Social behavior of bacteria: from physics to complex organization*”, Eur. Phys. J. B **65**, 315-322 (2008).
[8] A. Provata, I. Sokolov and B. Spagnolo, “*Editorial: Ecological Complex Systems*”, Eur. Phys. J. B **65**, 307 -314 (2008).
[9] M. De Laat and V. Lally, “*It's not so easy: researching the complexity of Emergent Participant Roles and Awareness in Asynchronous Networked Learning Discussions*”, Journal of Computer Assisted Learning **20**(3), 165-171 (2010).
[10] Quaderni di Ricerca in Didattica, (Mathematics) n.1, 1990.
[11] Quaderni di Ricerca in Didattica, (Mathematics) n.19, 2009.
[12] Quaderni di Ricerca in Didattica, (Science) n. 1, 2010.