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Giorgio Mantica · Ruedi Stoop  
Sebastiano Stramaglia  
Editors

# Emergent Complexity from Nonlinearity, in Physics, Engineering and the Life Sciences

Proceedings of the XXIII International  
Conference on Nonlinear Dynamics  
of Electronic Systems, Como, Italy,  
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*To the memory of Joseph Ford, on the  
twentieth anniversary of his passing*

# Preface

*NDES2015* is the twenty-third Conference of the series *Nonlinear Dynamics in Electronic Systems*, which began in 1993 in Dresden (Germany) and whose 22nd edition took place in Albena, Bulgaria, in 2014. The conference was held in the magnificent ambiance of the Cloister of the Abbey of Sant'Abbondio, in Como, from September 7 to 11, 2015. It gathered about ninety participants from sixteen countries and five continents. Overall, there were sixteen invited and forty-six contributed talks.

Traditionally, the main theme of the conference has been the study of nonlinear oscillations in electronic circuits, with its many potential applications, but in recent years, these gatherings have covered much wider topics, from theoretical questions in pure dynamics to phenomena in complex networks: Here, synchronization has assumed an ever-increasing importance, not only in man-made, but also in biological systems, the human brain being perhaps the most tantalizing example. In *NDES2015*, the interdisciplinary aspect emerged clearly, as can be seen below and in the booklet of abstracts, available online at [www.dfm.uninsubria.it/mantica/ndes15](http://www.dfm.uninsubria.it/mantica/ndes15).

Como, Italy  
Zurich, Switzerland  
Bari, Italy

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Ruedi Stoop  
Sebastiano Stramaglia

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The conference was organized as an activity of the *Center for Nonlinear and Complex Systems* of the Dipartimento di Scienza ed Alta Tecnologia, Università dell'Insubria, Como.

The Camera di Commercio di Como and the Alessandro Volta foundation, thanks to the Scientific Secretary Professor Giulio Casati, who also participated in the organization, provided financial support and secretarial services; Mariagiovanna Falasconi headed the administrative team.

All seminars were hosted in the Cloister of the Abbey of Sant'Abbondio in Como, courtesy of the Università dell'Insubria—thanks to the prorettore vicario professor Giuseppe Colangelo and to the Dipartimento di Diritto, Economia e Culture, direttore professoressa Laura Castelvetti. Logistic help on-site was provided skillfully by Sabrina Meroni and Pietro Catalano.

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h.o.-COMPUTER Software GmbH, Amsterdamer Str. 91, Cologne, Germany, gracefully provided financial support: special thanks to Edmund Preiss and Harald Odendahl, who attended the conference.

The Istituto Nazionale di Fisica Nucleare, INFN, sezione di Milano, provided partial support for travel expenses, thanks to the Director Professor Alberto Santambrogio.

Upon application, the conference was awarded the label *EPS Sponsored* from the European Physical Association, which also funded the prize *best contribution from a young participant*, awarded by a committee composed of invited speakers to Tom Lorimer (University of Zürich and ETH Zürich, Switzerland).

The conference was also recommended by the Italian Associazione Caos e Complessità, thanks to the Director Professor Mario di Bernardo.

Florian Gomez and Tom Lorimer, at University of Zürich and ETHZ, helped with the organization and prepared the booklet of abstracts that was released before the conference.

Abirami Purushothaman at Springer was of great help in the final setup of this volume; it must be fully credited to Sabine Lehr, associate editor, if it appears in the series “Springer Proceedings in Physics.”

Last but not least, Andrea Spiriti, professor of history of art at the Università dell’Insubria, Varese, guided all participants in a scholarly commented visit to the Basilica of Sant’Abbondio, its cloister and the neighboring church of Saints Cosma and Damiano.



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# Introduction

After the conference, the editors solicited contributions to the proceedings and had them peer-reviewed. Out of these, seventeen papers were accepted and are collected herein: A brief description of their content is the best way to present the interdisciplinary, yet strongly coherent matter of this volume.

Part I, *Classical and Quantum Dynamics*, contains the most theoretically oriented investigations. On the classical side, this comprises three papers which describe, in order, new ways to identify chaotic attractors of ODE's, the study of complex bifurcations of delayed maps, and the comparison of fine details in the dynamics of Rulkov maps with those of biological examples. In the quantum domain, a new class of physical systems has surged to widespread attention: Bose condensates in optical lattices. Although physically different from electronic circuits, these systems share some of their mathematical characteristics and are promising of revolutionary applications. Moreover, they also permit to address the problem of the relation between classical and quantum dynamics. Two papers in this part investigate these deep questions.

Part II, *Chaotic Oscillations*, continues in the traditional mainstream of the conference with three papers on electronic circuits. They focus on applications boldly moving forward the state of the art: robust numerical simulations of TaO memristor nano-devices, ultrawide-band microwave chaotic generators implemented as SiGe-integrated circuits, and the cryptanalysis of random number generators based on chaotic circuits.

Part III, *Networks*, starts with yet another analysis of electronic circuits, now interconnected so to form a network. Here, collective behavior arises and is termed *emerging dynamics*, as in the title of this volume. The first paper presents theory and experiments on a configurable network of Chua's circuits, in which coupling strengths and configurations can be dynamically changed, thereby observing the onset of different synchronization patterns. The second paper studies a model of adaptive network, whose connection structure evolves in interaction with node dynamics, which in turn is influenced by the former, as in the usual framework.

Clearly, this model is intended to be a paradigm of neuronal cultures. Neuronal dynamics is also the focus of the third paper of this part, but starting point and aims are here reversed: A synthetic neural network is constructed with the goal of clustering groups of similar data in high-dimensional spaces. The paper describes a novel implementation of Hebbian learning, with potential application to bioinformatics.

Part IV, *Biological Dynamics*, is the most extended of the volume: It contains six papers. Indeed, biologically motivated research also permeated many papers in the previous parts, a fact which testifies both the increasing interest in biological applications and the undisputable superiority of the techniques of dynamics in tackling such problems. The first paper in this part is the lengthiest of this volume: It is an introduction to the concept of network physiology, in which organs and systems—albeit with vastly different characteristics and signal outputs—interact so to produce physiologic states and functions. A new technique, termed time-delay stability, is used to study the bursting activity of brain waves in different frequency domains, which reflects coordinated network interactions among organ systems that are essential to maintain health. The same theme is continued in the second paper, which studies the temporal excitation patterns that follow the passage of a depolarization wave on the cerebral cortex—that is associated with a drastic failure of brain homeostasis. A fascinating problem is addressed in the third paper: the stable internal representation of external spacial locations in the brain of mammals. By combining deep results in algebraic topology with a model of transient hippocampal network (in which the neural structure is subject to physiological reorganization), it is demonstrated that the large-scale spatial representation of the environment encoded by this network can remain stable. In the fourth paper, an undirected network is constructed from brain MRI scans, each node representing a macroscopic cortical location: This network is used to discriminate automatically patients with Alzheimer's disease and mild cognitive impairment. Yet another class of biological network is studied in the fifth paper of this part: It is defined by different gene expressions. The paper presents an algorithm for partitioning the network into different communities and for identifying the DRD2 gene coding for the D2 dopamine receptor. The sixth paper of the part presents a theoretical explanation of the experimental observation of the power-law distribution of time intervals between spikes in cultures of hippocampal neurons: It is demonstrated that it is due to the limited availability of resources that are being exhausted by the culture.

In closing this Introduction, we would like to quote a passage from Joseph Ford, who foresaw the far-reaching implications of dynamics, which are now blossoming and are well displayed in this volume dedicated to his memory:

Over the centuries chaos has been blamed for every disaster visited on man from riots in the street to the heat death of the universe. Of course, not all of these accusations are false, for uncontrolled chaos can most assuredly be a devastating thing. Yet when controlled, the villainous chaos becomes gentle, useful, even enchanting. And why should it not be so; for in truth, chaos is merely dynamics freed from the shackles of order and predictability. Dynamical systems released to randomly explore their every possibility. Chaos can, therefore, provide us with a virtuoso display of exciting variety, a richness of choice,



a cornucopia of opportunity. Dare we hope that humans can harvest the richness without reaping the devastation? (in *Directions in Chaos*, Vol. 1, edited by Hao Bai-lin, World Scientific 1987).

Como, Italy  
Zurich, Switzerland  
Bari, Italy  
August 2016

Giorgio Mantica  
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# List of Talks from NDES2015

## Invited Talks

Stefano Boccaletti (ISC CNR Firenze, Italy) *Explosive synchronization of networked oscillators*

Leonid Bunimovich (Georgia Institute of Technology, Atlanta, USA) *On global stability of delayed and non-delayed networks*

Silvana Cardoso (Dept. of Chem. Eng. and Biotechnology, Cambridge University, UK) *Dynamics of buoyancy-driven flows in the Earth's subsurface and in the ocean*

Thomas L. Carroll (US Naval Res. Labs, Washington DC, USA) *Nonlinear systems characterization using phase space density*

Julyan Cartwright (CSIC Granada, Spain) *Chemobrionics: Nonlinear dynamics, electronic systems, and the origin of life*

Ned Corron (U.S. Army Redstone Arsenal, AL, USA) *Chaos in optimal communication waveforms*

Egidio D'Angelo (Dip. Scienze del sistema nervoso, Università di Pavia, Italy) *Spatiotemporal dynamics of neuron activity in brain microcircuits*

Lucilla de Arcangelis (Dip. Fisica, Seconda Università di Napoli, Italy) *Correlations in the brain*

Hans J. Herrmann (Computational Physics, ETH Zürich, Switzerland) *Rolling and synchronization in dense packings of spheres*

Plamen Ch. Ivanov (Physics Department, Boston University and Division of Sleep Medicine, Harvard Medical School, USA) *Network physiology: How complex physiologic organ systems dynamically interact*

Gregor Jotzu (Institute for Quantum Electronics, ETH Zürich, Switzerland) *Exploring topological and magnetic order with ultracold fermions in optical lattices*

Andrey R. Kolovsky (L.V. Kirensky Institute of Physics, Siberian Branch of Russian Academy of Sciences, Russia) *Treating many-body quantum systems by means of classical mechanics*

Pietro Lio' (Dept. of Computer Science, Cambridge University, UK) *Hierarchical block matrices as looking glasses for multi-scale biology*

Daniele Marinazzo (Gent University, Belgium) *Conserved Ising model on the human connectome*

Lou Pecora (US Naval Res. Labs, Washington DC, USA) *Symmetries, cluster synchronization, and isolated desynchronization in complex networks*

Norbert Stoop (Department of Mathematics, MIT, Cambridge MA, USA) *Rayleigh-Benard instability in curved elastic bilayer systems: Wrinkles, dimples, and the early universe*

### Special Seminar

Andrea Spiriti (Università dell'Insubria, Varese, Italy) *The Abbey and the Cloister of Sant'Abbondio and the Church of the Saints Cosma and Damiano*

### Contributed Talks

(delivered by the first author mentioned)

Carlo Albert (Eawag, Swiss Federal Institute of Aquatic Science and Technology, Switzerland) *Bayesian parameter inference for stochastic differential equation models*

Yuri V. Andreyev et al. (Moscow Institute of Physics and Technology, State University, Russia) *Ultrawideband chaotic transmitter panel*

Alon Ascoli et al. (Technische Universität Dresden, Dresden, Germany) *Continuous and differentiable approximation of a TaO memristor model for robust numerical simulations*

Sergey Belyakin et al. (State University of Moscow, Russia) *Stabilization of hyperbolic Plykin attractor by the Pyragas method*

Damian Berger et al. (University of Zürich and ETH Zürich, Switzerland) *Power laws as the result of exponentially decaying spiking frequency during synchronized activity*

Fausto Borgonovi (Università Cattolica, Brescia, Italy) *Quantum transport in light-harvesting systems*

Zeynep Çağıl et al. (Sakarya University, Turkey) *Chaos synchronization between finance and Rikitake systems by active control with unknown parameters*

Barış Cevher et al. (Sakarya University, Turkey) *Synchronization of chaotic three time scales brushless DC motor system by means of one state passive controller*

Shunda Chen et al. (Center for Nonlinear and Complex Systems, Università dell'Insubria, Como Italy) *Thermal conduction and thermoelectricity in one-dimensional nonlinear systems*

Yuri Dabaghian (Rice University and Duncan Neurological Research Institute, Houston, USA) *Robust spatial memory maps in flickering neuronal networks: a topological model*

Massimiliano de Magistris et al. (Università di Napoli, Italy) *Experiments on clustering and synchronous patterns in a configurable network of chaotic oscillators*

Roberto R. Deza et al. (IFIMAR, UNMdP-CONICET, Mar del Plata, Argentina) *Controlling the range of a Schmitt trigger's switching oscillations by means of external noise and nonlinear feedback*

Federica Di Michele et al. (Università dell'Aquila, Italy) *A simplified mathematical model for nano-bio interface*

Elena V. Efremova, A.S. Dimitrev (Moscow Institute of Physics and Technology, State University, Russia) *Ultrawideband microwave 3–7 GHz chaotic oscillator implemented as SiGe integrated circuit*

Salih Ergün (ERARGE - Ergunler Co., Ltd. R&D Center, Turkey) *Cryptanalysis of a random number generator based on a chaotic oscillator*

Stefan Glüge et al. (Zürich University of Applied Sciences, Switzerland) *Detecting influences—a network analysis of the European bond market based on partial mutual information*

Florian Gomez et al. (University of Zürich and ETH Zürich, Switzerland) *Frequency-sharpening and scale-invariance in a system of forcing-coupled Hopf oscillators*

Jenny Held et al. (University of Zürich and ETH Zürich, Switzerland) *Hebbian learning clustering using networks of Rulkov neurons*

Karlis Kandars et al. (University of Zürich and ETH Zürich, Switzerland) *Simulating neural oscillations with map-based neurons*

A.S. Karavaev et al. (Saratov Branch of the Institute of Radio Engineering and Electronics of Russian Academy of Sciences, Russia) *Phase and frequency locking in complex model of blood pressure dynamics*

Uğur Erkin Kocamaz et al. (Uludağ University, Turkey) *Non-identical chaos anti-synchronization via passive control*

Danil Kulminskiy et al. (Saratov Branch of the Institute of Radio Engineering and Electronics of Russian Academy of Sciences, Russia) *Chimera states in ensembles of time-delayed feedback oscillators with the mean field*

Hiroyuki Kusano et al. (Hosei University, Tokyo, Japan) *Analysis of digital maps based on simple feature quantities*

Marianna La Rocca et al. (Università di Bari, Italy) *Multiplex network based features for early Alzheimer characterization*

Tom Lorimer et al. (University of Zürich and ETH Zürich, Switzerland) *Saturation effect produces deviations from power law statistics in real-world networks*

Volodymyr Maistrenko et al. (National Scientific Centre for Medical and Biotechnical Research, Kyiv, Ukraine) *Cloning of 3D chimera states*

Ludovico Minati et al. (Istituto Neurologico Carlo Besta, Milano and Center for Mind/Brain Sciences, Università di Trento, Italy) *Nonlinear dynamics and low-frequency fluctuations in network hubs: tentative analogy between the resting human brain and coupled single-transistor chaotic oscillators*

Anna Monda et al. (Università di Bari, Italy) *Complex network for DRD2 gene community identification in schizophrenia*

Yasuo Murata et al. (Hosei University, Tokyo, Japan) *Hyperchaos and synchronization in paralleled power converters*

Daiki Ogusu, Tetsuro Endo (Meiji University, Kawasaki, Japan) *Complex bifurcations of Arnol'd tongues generated in three-coupled delayed logistic maps*

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