Book Chapters and Books

Valeri M. Mladenov
Plamen Ch. Ivanov (Eds.)

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Nonlinear Dynamics of Electronic Systems

22nd International Conference, NDES 2014
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Proceedings

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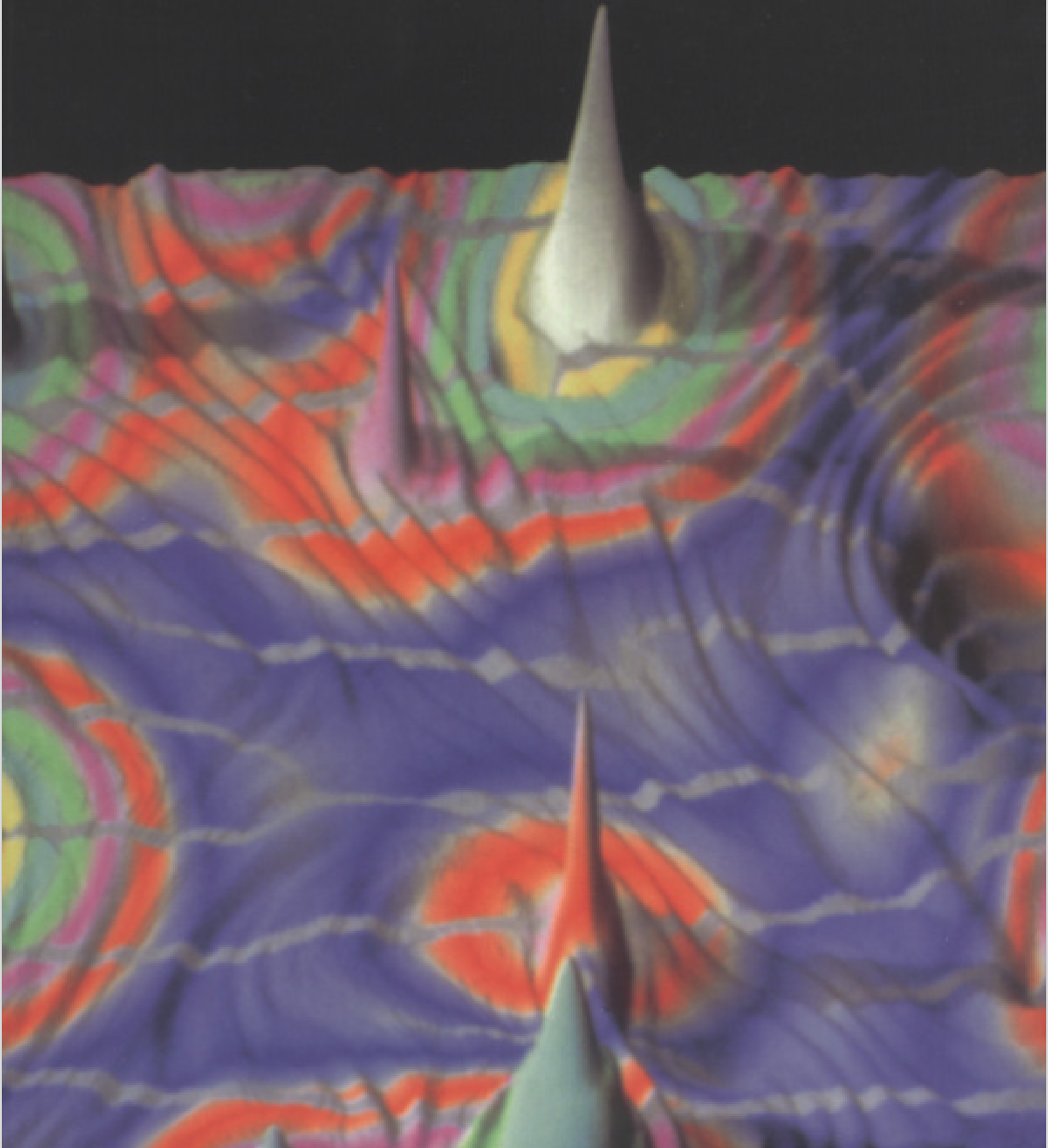
Preface

These proceedings comprise papers presented during the International Conference on Nonlinear Dynamics of Electronic Systems (NDES) 2014. The unique feature of the conference is to bring together theoretical aspects of nonlinear science in electrical engineering, physics, and mathematics, as well as related applications. Nonlinear oscillations, synchronization, chaotic behavior, neural networks, and complex systems together with power electronics, biomedical systems and neurocomputing, networks of infrastructure and social interactions are a few topical examples of the need for expertise in the wide field of nonlinear science.

The NDES conference series was founded in 1993, and through the years has been established as one of the most prominent series of conferences in the field of nonlinear science and its applications. NDES conferences took places in Dresden (1993), Krakow (1994), Dublin (1995), Seville (1996), Moscow (1997), Budapest (1998), Rønne (1999), Catania (2000), Delft (2001), Izmir (2002), Scuol (2003), Vora (2004), Potsdam (2005), Dijon (2006), Tokushima (2007), Nizhniy Novgorod (2008), Rapperswil (2009), Dresden (2010), Kolkata (2011), Wolfenbüttel (2012) and Bari (2013). The organizer of this 22nd issue of NDES was the Technical University of Sofia, Bulgaria. The conference was held during July 4–6, 2014, in Albena, one of the preeminent resorts in Europe located on the Bulgarian Black Sea coast.

During NDES 2014 seven plenary talks were given by some of the most famous researchers in the world of nonlinear science: Vadim Anishchenko from Saratov State University, Russia; Alain Arneodo from Ecole Normale Superiore, Lyon, France; Shlomo Havlin from Bar-Ilan University, Ramat-Gan, Israel; Juergen Kurths from Humboldt-Universität Berlin, Germany; Ruedi Stoop from the University and ETH of Zürich, Switzerland; Wolfgang Mathis from Institut für Theoretische Elektrotechnik, Hannover, Germany; and Ronald Tetzlaff from Technische Universität Dresden, Germany.

In total 65 manuscripts were submitted to NDES 2014. All manuscripts passed a multistep review process before the final decisions. After a thorough peer-review process, the program co-chairs selected 47 papers. The quality of all manuscripts received was high, and it was not possible to include all good papers in the final conference program. The selected papers were divided by subject into the following main topics: nonlinear oscillators, circuits and electronic systems; networks and nonlinear dynamics; and nonlinear phenomena in biological and physiological systems. In parallel to NDES 2014, a satellite workshop on "Electro-physiological Signals in Living Beings: Data and Methods of Nonlinear Analysis" was organized by Prof. Plamen Ch. Ivanov from Boston University, Harvard Medical School, and Bulgarian Academy of Sciences and by Prof. Antonio Scala from the London Institute for Mathematical Sciences and Institute for



Wavelets in Physics

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Wavelets in medicine and physiology

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Abstract

We present a combined wavelet and analytic signal approach to study biological and physiological nonstationary time series. The method enables one to reduce the effects of nonstationarity and to identify dynamical features on different time scales. Such an approach can test for the existence of universal scaling properties in the underlying complex dynamics. We applied the technique to human cardiac dynamics and find a universal scaling form for the heartbeat variability in healthy subjects. A breakdown of this scaling is associated with pathological conditions.

10.1 Introduction

The central task of statistical physics is to study macroscopic phenomena that result from microscopic interactions among many individual components. This problem is akin to many investigations undertaken in biology. In particular, physiological systems under neuroautonomic regulation, such as heart rate regulation, are good candidates for such an approach, since: (i) the systems often include multiple components, thus leading to very large numbers of degrees of freedom, and (ii) the systems usually are driven by competing forces. Therefore, it seems reasonable to consider the possibility that dynamical systems under neural regulation may exhibit temporal structures which are similar, under certain conditions, to those found in physical systems. Indeed, concepts and techniques originating in statistical physics are showing promise as useful tools for quantitative analysis of complicated physiological systems.

A. Bunde · J. Kropp · H. J. Schellnhuber (Eds.)

The Science of Disasters

Climate Disruptions, Heart Attacks, and Market Crashes

Springer

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7. Fractal and Multifractal Approaches in Physiology

Plamen Ch. Ivanov, Ary L. Goldberger, and H. Eugene Stanley

We explore the degree to which concepts developed in statistical physics can be usefully applied to physiological signals. We first review recent progress using two analysis methods: (i) detrended fluctuation analysis to quantify homogeneous structures, termed monofractals, which are characterized with the same scaling properties throughout the entire signal, and (ii) wavelet-based multifractal analysis to quantify signals of higher complexity, termed multifractals, which require many exponents to characterize their scaling properties. We next illustrate the problems related to physiological signal analysis with representative examples of heartbeat dynamics under healthy and pathological conditions. We discuss the findings of fractal and multifractal properties in the human heartbeat and how they change with disease.

7.1 Introduction

Even under healthy, basal conditions, physiological systems show erratic fluctuations resembling those found in dynamical systems driven away from a single equilibrium state. Do such 'nonequilibrium' fluctuations simply reflect the fact that physiological systems are being constantly perturbed by external and intrinsic noise? Or, do these fluctuations actually contain useful, 'hidden' information about the underlying nonequilibrium control mechanisms? We report some recent attempts to understand the dynamics of complex physiological

◀ **Fig. 7.0.** Leonardo da Vinci's hand drawing of the human heart with panels on the background illustrating how the local Hurst exponent (vertical color bars) changes in time (horizontal axis). Healthy heart records (shorter panels, bottom) appear polychromatic indicating multifractality, while heart failure records (longer panels) are more monochromatic (blue color predominantly) indicating loss of multifractality. Courtesy of Z.R. Struzik (CWI, Amsterdam, The Netherlands) and Anna Ludwicka (Artgraph, Warszawa, Poland)

Modelling Biomedical Signals

Editors

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STOCHASTIC APPROACHES TO MODELING OF PHYSIOLOGICAL RHYTHMS

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The scientific question we address is how physiological rhythms spontaneously self-regulate. It is fairly widely believed, nowadays, deterministic mechanisms, including perhaps chaos, offer a promising avenue to pursue in answering this question. Complementary to these deterministic foundations, we propose an approach which treats physiologiocal rhythms as fundamentally governed by several random processes, each of which biases the rhythm in different ways. We call this approach stochastic feedback, since it leads naturally to feedback mechanisms that are based on randomness. To illustrate our approach, we treat in some detail the regulation of heart rhythms and sleep-wake transitions during sleep — two classic "unsolved" problems in physiology. We present coherent, physiologically based models and show that a generic process based on the concepts of biased random walk and stochastic feedback can account for a combination of independent scaling characteristics observed in data.

1 Modeling scaling features in heartbeat dynamics

1.1 Introduction

The fundamental principle of homeostasis asserts that physiological systems seek to maintain a constant output after perturbation [1,2,3,4]. Recent evidence, however, indicates that healthy systems even at rest display highly irregular dynamics [5,6,7,8,9,10]. Here, we address the question of how to reconcile homeostatic control and complex variability. We propose a general approach based on the concept of "stochastic feedback" and illustrate this approach by considering the neuroautonomic regulation of the heart rate. Our results suggest that in healthy systems the control mechanisms operate to drive the system away from extreme values while not allowing it to settle down to a constant (homeostatic) output. The model generates complex dynamics and

LECTURE NOTES IN PHYSICS

G. Rangarajan
M. Ding
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Processes with Long-Range Correlations

Theory and Applications

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Long-Range Dependence in Heartbeat Dynamics

Plamen Ch. Ivanov

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1 Introduction

Physiologic signals are generated by complex self-regulating systems that process inputs with a broad range of characteristics [1,2,3]. Many physiological time series are extremely inhomogeneous and nonstationary, fluctuating in an irregular and complex manner. An important question is whether the "heterogeneous" structure of physiologic time series arises trivially from external and intrinsic perturbations which push the system away from a homeostatic set point. An alternative hypothesis is that the fluctuations are, at least in part, due to the underlying dynamics of the system. The key problem is how to decompose subtle fluctuations (due to intrinsic physiologic control) from other nonstationary trends associated with external stimuli. Till recently, the analysis of the fractal properties of such fluctuations has been restricted to second moment linear characteristics such as the power spectrum and the two-point autocorrelation function. These analyses reveal that the *fractal* behavior of healthy, free-running physiological systems is often characterized by $1/f$-like scaling of the power spectra over a wide range of time scales [4,5,6,7,8]. A signal which exhibits such power-law long-range dependence and is homogeneous (i.e. different parts of the signal have different statistical properties) is called a monofractal signal. Many physiologic time series, however, are inhomogeneous with different parts of the signal characterized by different statistical properties. In addition, there is evidence that physiologic dynamics exhibits nonlinear properties [9,10,11,12,13,14,15]. Such features are often associated with multifractal behavior, i.e., presence of long-range power-law dependence in the higher moments which is a nonlinear function of the scaling of the second moment [16]. Up to now, robust demonstration of multifractality for nonstationary time series has been hampered by problems related to a drastic bias in the estimate of the singularity spectrum due to diverging negative moments. Moreover, the classical approaches based on the box-counting technique and structure function formalism fail when a fractal function is composed of a multifractal singular part embedded in regular polynomial behavior [17]. By means of a wavelet-based multifractal formalism, we show that healthy human heartbeat dynamics exhibits even higher complexity (than previously expected from the finding of monofractal 1/f scaling) which is characterized by a broad *multifractal* spectrum [18].

In recent years the study of the statistical properties of heartbeat interval sequences has attracted the attention of researchers from different fields [19,20,21,22,23].

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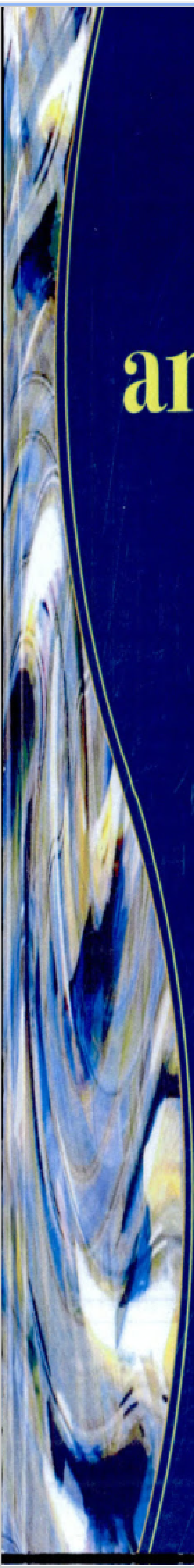

Advances in Condensed Matter and Statistical Physics

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Random walks in physiologic dynamic

Plamen Ch. Ivanov

Abstract

The scientific question we address is how physiological rhythms spontaneously self-regulate. It is fairly widely believed, nowadays, deterministic mechanisms, including perhaps chaos, offer a promising avenue to pursue in answering this question. Complementary to these deterministic foundations, we propose an approach which treats physiologiocal rhythms as fundamentally governed by several random processes, each of which biases the rhythm in different ways. We call this approach stochastic feedback, since it leads naturally to feedback mechanisms that are based on randomness. To illustrate our approach, we treat in some detail the regulation of heart rhythms and sleep-wake transitions during sleep — two classic "unsolved" problems in physiology. We present coherent, physiologically based models and show that a generic process based on the concepts of biased random walk and stochastic feedback can account for a combination of independent scaling characteristics observed in data.

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1.2 Random walks and feedback mechanisms

The concept of dynamic equilibrium or "homeostasis" [1, 2, 3] led to the proposal that physiological variables, such as the cardiac interbeat interval $\tau(n)$, where n is the beat number, maintain an approximately constant value in spite of continual perturbations. Thus one can write in general

$$\tau(n) = \tau_0 + \eta\,, \tag{1}$$