UNIVERSITÀ DI PISA

DIPARTIMENTO DI INGEGNERIA DELL'INFORMAZIONE

Dottorato di Ricerca in Ingegneria dell'Informazione

Doctoral Course

Multivariate signal processing and complexity analysis in time-varying networks

Prof. Paolo Paradisi

Istituto di Scienza e Tecnologie dell'Informazione "A. Faedo" (ISTI – CNR)
Via G. Moruzzi 1, Pisa - Italy

Short Abstract:

Smart sensors are ubiquitous in nowdays society and will become more and more important in the next future, their applications ranging over many aspects of daily life, such as: (i) healthcare: wearable devices for monitoring of physiological parameters in both hospitals or home (e.g., elderly); (ii) monitoring of athlete's perfomance; (iii) continuous monitoring of industrial plaforms for automatic diagnosis (self-monitoring) or optimization in the production line (Industry 4.0); (iv) human-computer interfaces; (v) automotive. These sensors often give a continuous time monitoring and, thus, a large dataset of complex signals that need to be processed, both in real time or offline, depending on the specific application. Many monitoring systems are developed as a wireless sensor network, i.e., a network with a complex topology of the links, where each link is a communication channel between sensors.
Thus, a proper processing of these large datasets of time signals is crucial, not only regarding computational efficiency, but also for the extraction of informative parameters (information retrieval).

This course will cover the basic concepts and techniques used in the processing of complex time signals, also including feature extraction in multivariate signals with particular attention to connectivity features of time-varying networks.

In the first part, we will give an overview of the main results of classical signal processing. Some practical examples will be given during the lectures, in order to make the students more confident with signal processing tools.
In the second part, we will focus on connectivity measures defined on time-varying networks. We will discuss some specific applications, mainly in health applications and physiological monitoring.
Finally, in the third part, we will give a few insights on recent developments in the processing of signals with complex intermittency, showing some applications in the field of neurophysiology.

Course Contents in brief:

- Statistical signal processing
- Multivariate signals
- Time-varying networks
- Network connectivity and connectomics
- Complex systems
- Signals with complex intermittency

Total # of hours of lecture: 20

References:

[1] S.H. Mneney, An Introduction to Digital Signal Processing: A Focus on Implementation, River Publishers, Aalborg (2008), ISBN: 978-87-92329-12-7.

[2] Boccaletti et al., Complex networks: Structure and dynamics, Physics Reports **424**(4-5), 175-308 (2006).

[3] Zanin et al., Combining complex networks and data mining: Why and how, Physics Reports **635**, 1-44 (2016).

[4] P. Paradisi and P. Allegrini (2017) Intermittency-Driven Complexity in Signal Processing. In: Barbieri R., Scilingo E., Valenza G. (eds.) Complexity and Nonlinearity in Cardiovascular Signals. Springer, Cham, p. 161-195. ISBN: 978-3-319-58709-7.

[5] P. Allegrini, P. Paradisi, D. Menicucci, M. Laurino, A. Piarulli, A. Gemignani: Self-organized dynamical complexity in human wakefulness and sleep: Different critical brain-activity feedback for conscious and unconscious states, Physical Review E **92**(3), 032808 (2015).

[6] P. Paradisi, P. Allegrini: Scaling law of diffusivity generated by a noisy telegraph signal with fractal intermittency, Chaos, Solitons and Fractals **81(B)**, 451-462 (2015).

[7] P. Allegrini, D. Menicucci, R. Bedini, A. Gemignani, P. Paradisi: Complex intermittency blurred by noise: Theory and application to neural dynamics, Physical Review E **82**, 015103 (2010).

[8] P. Allegrini, P. Paradisi, D. Menicucci, A. Gemignani: Fractal complexity in spontaneous EEG metastable-state transitions: new vistas on integrated neural dynamics, Frontiers in Physiology **1**, 128 (2010).

CV of the Teacher

Paolo Paradisi is a researcher at ISTI-CNR (Pisa) since 2010, he is a Physicist with a PhD in Technical Physics. He is an expert in probability theory and statistics; signal processing: development of models and methods, applications to real data; stochastic processes, diffusion and transport processes.

<u>Main research field and activity</u>: complex systems; estimation of complexity in time-varying networks. Applications in neurophysiology (biomedical signal processing and complexity analysis) and in the stochastic modeling of biological systems. Development of models and algorithms of signal processing for time series with complex intermittency.

Editorial and organizing activity: reviewer of many international peer-reviewed ISI/Scopus journals, Associate Editor of the Elsevier Q1 journal Chaos, Solitons and Fractals (CSF). Organizer of 3 international workshops, Guest Editor of a special issue on CSF and member in the technical or scientific committees of several international conferences.

Collaborations and visiting: visiting researcher in many international research institute/universities. In particular, 2004-2008: permanent collaborator of the Center for Nonlinear Sciences (University of North Texas, USA). He is now collaborating with University of Pisa, Dept. of Physics and Dept. of Traslational Research. Since 2014: permanent collaboration with the Severo Ochoa center of excellence BCAM – Basque Center of Applied Mathematics (Bilbao, Spain), of which it is an External Scientific Member.

Teaching and tutoring: he has been assistant teacher for software laboratory, co-supervisor of 5 undergraduate "laurea" theses. He gave seminar lectures for undergraduate students at Pisa University on topics of complexity analysis and signal processing.

Publications: he participated in more than 30 conferences and gave several talks, some of which by invitation. He is principal author or co-author of more than 70 publications (57 Scopus publications, 54 ISI publications) and about 20 technical/project reports.

H-index: 20 (Google), 18 (Scopus), 17 (ISI-WOS)

Room: *From remote by using Microsoft Teams.*

Schedule:

PART 1: **Introduction to signal processing**

Day 1:

Introduction to random signals. Continuous time and discrete time. The role of noise. Stationarity and ergodicity. Main statistical indices in the time domain.

Statistical analysis in the frequency domain 1: the four Fourier transform for periodic/aperiodic signals in continuous/discrete time. The Fast Fourier Transform.

Day 2

Statistical analysis in the frequency domain 2: Parseval's theorem and power spectra; Wiener-Kintchine's theorem.

Sampling of a time-continuous signal, digital signal processing and Shannon-Nyquist's theorem. The aliasing problem and its relevance in the processing of digital (discrete time) signals.

PART 2: **Multivariate signals and Time-varying networks**

Day 3:

Examples of multivariate data from electrophysiology and neuroimaging. Electroencephalograms as time-varying networks. Main definitions in networks analysis.

Classical analyses for source identification and noise reduction: PCA, CCA, ICA.

Connectivity measures in time-varying networks. Directed and undirected links. Phase synchronization in a time-varying network. Granger causality. Information measures.

Day 4 (2 hours):

Other network measures: degree distribution; clustering measures; integration vs. segregation.

Examples: small-world topology; Barabasi-Albert networks.

PART 3: **Signals with complex intermittency**

Day 4 (2 hours):

The example of neural dynamics and neural networks. Bursting and spike trains. Complexity as emergence of self-organization in multi-component cooperative systems. Critical dynamics: avalanches and emergence of intermittent synchronization.

Day 5:

Complex intermittency: definitions, stochastic models, data analysis tools. Complexity indices as a measure of self-organization. The problem of noise in the estimation of complexity. Modeling of noise in intermittent time series. The method of Diffusion Scaling.

The example of electrophysiological signals (EEG, ECG).