Preface

Modern life in fully developed countries relies on the coordinated functioning of several infrastructures such as Electric System, Aqueducts, Communication Assets, Fresh food distribution chains, Gas-ducts, Oil Pipelines, Transports, Financial networks, etc. Several of such infrastructures have been regarded as critical since they provide vital services to sustain the modern technological society and its development.

During the last decades, the level of awareness about the importance of protecting our *Critical Infrastructures* (CIs) has been steadily growing. In this respect, US has been the first country to take an official financial commitment by means of the celebrated American Presidential Directive PDD-63 of May 1998 under the Clinton administration. After ten years also the European Community made a similar commitment through the EUDIR Council Directive 2008/114/EC (dated December the 8-th, 2008), that has been afterwards implemented by the EU member states. It has to be noticed that, while the US directive is very broad in its scope, the EU directive is presently limited to the energetic, transport and financial sectors.

The functioning of Critical Infrastructures requires both physical components and human actors. It is therefore important not only to employ reliable components, but also to understand human behaviour at both individual and collective levels. Moreover, each infrastructure resorts to other CIs (typically, but not limited to, energy and ICT) to accomplish its goals: in other words, CIs are *inter-dependent*. Identifying, understanding and analysing critical infrastructure interdependencies is therefore a crucial task to be pursued by the scientific community at both the academic and applied levels [1].

In the development of CIs, the ICT sector has played a crucial role in several respects. ICT pervades any complex activity of modern societies based on communications and represents a fundamental part for the governance of any complex infrastructure. The quality and quantity of information-based services provided to our modern society has been steadily increasing during last 30 years (Web, e-mail, e-commerce, social networking, e-banking, e-health, Web-based entertainment, SCADA systems, etc). In order to improve their performance and to enhance their reliability, the infrastructures have been endowed with increasingly complex connection networks and computerized systems, thus allowing their governance optimization and reducing the humans allocated to that purpose. Nowadays, our society is on the verge of a new revolution in which the infrastructures are required to become *smart* and to integrate into a *smart* technological environment. Driving the advent of a *smart* society on a painless and secure path represents one of the most difficult challenges for all the technologically advanced countries.

Most of the infrastructures exhibit a network structure. In the last decade, stemming from the availability of large data and based on the statistical physicist perspective of the graph theory, a new paradigm to describe large networks has blossomed: the Network Science [2, 3].

Network Science has revealed a powerful and unifying tool that enables to treat on the same footing widely different networked systems, ranging from biology to sociology to power grids to the Internet and the World Wide Web. In fact, despite their intrinsic differences, all such networks are large systems consisting of simple elementary units (the nodes) interacting via basic mechanisms (represented by the links). Statistical Physics teaches us that this is the case where to expect the occurrence of *emergent behaviours*, i.e., of collective (systemic) effects. In fact, while each component may be perfectly working, the system as a whole can be in a failure state: as an example, think about a big traffic jam, where all the cars, lights, indications, navigators and roads are perfectly functioning and yet everybody is stuck.

Financial networks' analysis represented the forerunner to assess the concept of systemic risk in real infrastructures. Nowadays, several financial institutions consider and employ the global metrics developed by EU network scientists [4] to assess their risk level and robustness consistently with the Basel III Stress Testing [5].

Applying the Network Science paradigm to Inter-dependent Critical Infrastructures has lead to the development of the concept of "Networks of Networks": the *NetONets*. While from the graph-theory point of view a network of networks is just a larger (inhomogeneous) network, in real life infrastructural networks are governed and operated separately and interactions are only allowed at well-defined boundaries. Assessing properties on NetONets instead of that on single networks is like deciding to consider males and females instead of human beings as a single community: depending on the question to answer, either approach may be the most fruitful.

The first applications of the *NetONets* approach to understand critical infrastructures has been related to the propagation of failures in inter-dependent infrastructures modelled as either trees or planar lattices [6, 7]. However, the upheaval of the interest in *NetONets* has followed the publication of a Nature paper on a percolation model of cascade failures in coupled ICT/power networks [8]. Another important step towards real applications has been the analysis of the North America inter-connected electric systems [9] aiming to reduce the global vulnerability of the system.

In general, numerous efforts are nowadays devoted to develope the mathematics of *NetONets*. While most of the current models have a percolative flavour [10–13], some new directions in understanding the dynamics on *NetONets* are being explored [14–16] resorting to the spectral properties of networks. The European efforts on the subject have recently concentrated in the "MULTIPLEX" project [17] combining top scientists in Complexity and Algorithmic. While the complexity approach allows to concentrate on systemic effects and emergent behavior, other routes have to be considered to perform the analyses of the systems needed for several tasks including management, planning the development, enhancing the security, defining coordinated national and EU/US contingency plans, and assessing the policies at the state and the regional levels. To such an aim, several techniques such as I/O models, federated simulations, agent-based models, time-series analysis are employed. Each of the previous approaches provides a partial perspective of the system behaviour; however to manage and understand the complexity of our society, all of them are required. Our book aims to foster a meta-community able to share and integrate all such perspectives.

This volume is structured along three main sections: part I covers the theoretical approaches, part II provides some applications and part III is devoted to phenomenological modelling. The former taxonomy has been mainly introduced for the sake of presentation. However, due to their inter-disciplinarity, it is difficult to ascribe each contribution to a specific topic only. To improve legibility, each part of the book is endowed with a brief overview of its contents.

We have spent our best efforts to provide the reader with as different contributions as possible; most of the authors have been actively involved in the *NetONets* and related conference series. However, by no means our book can be regarded as exhaustive. Probably, the I/O models [18] represent the most significant lack in our book. Some of the most important topics, such as the systemic risk analysis [19] or time series analysis, would have deserved a more extended treatment. We hope to be able to cover such topics in a nearby future.

Furthermore, there are important topics that are crucial to develop in the nearby future. In particular, the human behaviour, both at the management and at the end user levels, must be accounted for improving the analysis, modelling and simulation of inter-dependent infrastructures. Regarding the complexity approach, it is crucial to build up methodological tools for the statistical analysis of 'small' systems. In fact, while most of the current techniques are aimed to understand the behaviour of the system in the infinite-size limit, almost all infrastructural networks exhibit a relatively small size.

We have tried hard to produce a book that could be regarded as an updated reference for the *NetONets* state-of-the-art. To the same purpose of providing updated information, we have also built a website (netonets.org) wherein to gather and advertise all the initiatives in the field.

One of the main barriers to overcome is the lack of a common language. It is therefore crucial to foster the up-growing *NetONets* community providing a common ground for knowledge sharing. We hope that our efforts will contribute to such a direction.

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