Network Science in Computer Engineering and Information Technology

Habilitation Thesis

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Abstract

Since the beginning of the new Millennia, we have witnessed the emergence of the New Science of Complex Networks; this new field encompasses multiple elements from physics, mathematics, and computer science. Specifically, Complex Networks describe the structure and behavior of complex systems that can be modelled as graphs, namely mathematical structures consisting of objects, nodes, or vertices, which are connected with lines, links, or edges. As opposed to conventional graph theory, complex networks have a large number of nodes (up to several millions) and complex irregular interconnection topology.

Although the field of Complex Networks is implicitly multidisciplinary, it is particularly related to physics, namely to statistical physics and complex systems. Also, complex networks bridge the gap between complexity and algorithmic models, which in turn pave the way for a lot of innovative computer applications in fields such as biology, medicine, economy, social sciences, or physics. Moreover, in the case of computers, the circle is becomes complete, as the theory of complex networks can be used back, in order to solve complicated computer and electrical engineering problems.

By taking into consideration the field of application, the vast domain of Complex Networks can be divided in: biological networks (such as disease networks, food networks in given environments, gene networks, pathway networks, metabolic networks, protein interaction networks, drug interaction networks, etc.), technological networks (computer networks, the world wide web, road and transportation networks, power distribution networks, electronic components network, computer software class networks, etc.), social networks (online social networks, political networks, economic networks, friendship networks, collaboration networks), semantic networks (LISP semantic network, natural language word networks).

The overarching field of Information Technology includes various approaches where computer algorithms and applications are used for the advancement of biology, medicine, pharmacology, or social physics. Indeed, the last decade has witnessed significant progress in personalized or precision medicine, based on big data techniques and computer technologies such as Complex Network Analysis, Machine Learning (including Deep Learning). Moreover, the advance in social system physics has gain a lot of momentum since the global dissemination of Online Social Networks.

Our approach to using complex networks in information technology is twofold. First, we propose new computer-based models for simulating the dynamics of opinion is social networks. Further, we validate our tolerance-based opinion diffusion model against social behavior detected in real-

world data from Twitter, Facebook and Yelp. We also analyze and confirm our hypotheses by providing a comprehensive probabilistic interpretation of our tolerance-based computational model. Our research in the field of computational social network analysis is reported in 3 ISI journals (including the prestigious Computer Communications and PeerJ Computer Science), as well as in 9 ISI Proceedings papers. As recognition for our contributions to the field of complex networks, we received the Best Paper Award for our paper at the 2nd European Network Intelligence Conference, ENIC 2015, at Karlskrona in Sweden, for our work titled ”FMNet: Physical Trait Patterns in the Fashion World”.

Second, we apply a dual complex network clustering, which relies on both modularity classes and force directed network layouts, in order to advance the fields of network medicine and network pharmacology. In the case of network medicine, we cluster networks of OSAS (Obstructive Sleep Apnea Syndrome) patients, in order to generate patient phenotypes that can be effectively used for managing patients according to precision medicine principles. In the case of network pharmacology, we use our dual clustering methodology in order to extract pharmaceutical properties for available drugs, only from information on drug-drug interactions. To this end, we build a drug-drug interaction network and process it, by algorithmically defining functional drug communities; analyzing the generated drug communities leads to recovering previous drug repositioning examples, as well as to proposing new important repositionings. As a result of our research activity in the fields of network medicine and computational drug repositioning, we published 2 ISI Journal papers (including Nature’s Scientific Reports), as well as 4 conference papers.

Our future research will focus on applying complex networks in computer engineering and big data analysis. As such, we provide an extensive overview on how network analysis can be used to optimize multi-core communication in Network-on-Chip (NoC) systems. Indeed, our initial assessment proves that – from a conceptual standpoint – fractal topologies can provide a low-power, reliable and performant communication infrastructure for NoCs.

We also propose as future development for our research activity, the use of IoT technologies for gathering physiological signals, in order to manage and attain early diagnosis for respiratory diseases such as OSAS and COPD (Chronic Obstructive Pulmonary Disease). In this context, IoT technologies are used to gather big data, which will be processed using multi-fractal spectra analysis, in order to derive the patient compatibility network which will be further analyzed with complex network tools. These future research efforts will be supported by research grant PNCDI III P2, 31PED/2017 entitled “Internet of Things meets Complex Networks or early prediction and management of Chronic Obstructive Pulmonary Disease”.