The Bio-Inspired and Social Evolution of Node and Data in a Multilayer Network

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Abstract: Following a bio-inspired approach, applied to multilayer social networks, the idea is to build a novel paradigm aimed to improve methodologies and analysis in the Information and Communication Technologies. The social network and the multilayer structure allow to carry out an analysis of the complex patterns, in terms of the dynamics involving the main entities, nodes and data. The nodes represent the basic kernel from which generating ties, interactions, flow of information, influences and action strategies that affect the communities. The data, gathered from multiple sources, after their integration, will become complex objects, enclosing different kinds of information. The proposed approach introduces a level of abstraction that originates from the evolution of nodes and data transformed in "social objects". This new paradigm consists of a multilayer social network, divided into three layers, generating an increasing awareness, from "things" to "knowledge", extracting as much "knowledge" as possible. This paradigm allows to redesign the ICT in a bio-networks driven approach.

1 INTRODUCTION

The new ICT paradigm is expected to contribute to the process of improvement in the realization of a knowledge-based networking, characterized by innovation, making the networks sustainable with processes based on a strategic bio-inspired approach, considering also the social, human and cognitive aspects. The future network needs to meet some requirements, such as ubiquity, mobility, dynamicity, reliability. The ubiquitous nature leads to a logical fusion and integration of different aspects of real and online social network platforms. The network nodes acquire a common representation through identity features. These features, following a bio-inspired approach, enclose genotypic and phenotypic traits. In addition to these traits, it is important to consider also context-aware capabilities, self-organization, self-protection, perception, decision-making processes and cognitive behavior. Considering these features, the nodes interact through social networks and they are able to self-organize dynamically in communities and groups, based on aggregation metrics. We think that the node is an abstraction, an object which collects bio-inspired features as well as human and social capabilities. Similarly, data shared inside the network are a complex object, like a box, which travels across the network through interactions between nodes. Data and nodes represent the objects that trigger influence, interaction, contagion and decision criteria. These two entities enclose many different social aspects. In the future of ICT we will expect to be able to obtain context-aware services, which stem from a bio-inspired approach able to drive methodologies for analyzing social complex networks. We propose in this paper an evolutionary perspective of nodes and data, an innovative multilayer perspective. To solve the heterogeneity issue of these entities, we propose a social object oriented approach, following the bio-inspired principles in a multilayer social network. The paper is organized as follows: the second section is about background; in the third section we will explain the social object oriented evolution of networks and the novel bio-multilayer network schema; in the fourth

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section, we will focus on future directions challenges and strategies of this work and finally we conclude with some considerations.

2 BACKGROUND

2.1 Social Networks Analysis

The social network analysis is an analytical tool used to understand how highly connected systems and entities, which form social links and networks, operate (Aggarwal, 2011). It considers social relationships in terms of network theory, with nodes, representing the individual actors within the network, and ties (referred also as edges, links, or connections), which are the relationships between the individuals. The resulting structures are complex graphs connecting social contacts, and the graph theory, from a structural point of view, is able to describe these relationships using metrics, such as betweenness, centrality, degree, closeness, clustering coefficient, etc. The power of social network analysis is that it produces a different view, where the attributes of individuals are less important than their relationships and ties with other actors within the network. Furthermore, the behavioral dimension means that the individual's actions have to be evaluated not in isolation, but considering the connections with the other players, who can use different strategies (Easley and Kleinberg, 2010). All these structural and behavioral aspects have to cope with the network dynamics, so that connections and behaviors between nodes change over the time, increasing the complexity of the analysis. Since a significantly larger amount of data is available for the case of online social networks, these networks have made much more robust, in terms of statistical significance, the verification of some structural properties, such as the small world phenomenon, preferential attachment, and other structural dynamics. The community detection is one of the most well-known structural problems in the context of social networks (Fortunato, 2009); it is closely related to the problem of finding structurally related groups in the network, called communities. In order to understand the complex dynamics of social networks, in this work we suggest to change the perspective of analysis, and evolving the concepts of "node" and "data", the bio-inspired social object, which includes the social perspective and the bio-inspired approach. Considering a data-centric perspective, the social network analysis helps to transform a context-aware object in a data "social" object, while in a node-centric perspective, by analyzing communities and their evolution in social networks, we can introduce cognitive features in the nodes, obtaining a node "social" object.

2.2 Multilayer Networks

Almost all real and virtual systems are inherently composed of multiple layers (or subsystems), which contribute to the wholeness of their functionality but can also be considered as systems in their own right. Network science has been largely successful in abstracting meaning from single-layer subsystems (Newman et al., 2009) and it is only recently that multilayer networks (Kivelä et al., 2010) have become a popular paradigm for the modeling of interrelated subsystems and entire systems. This is largely due to the capability of multilayer models for understanding the bigger entity more realistically. In fact, most real world entities are connected each other in more than one way, from transportation systems to social relationships.

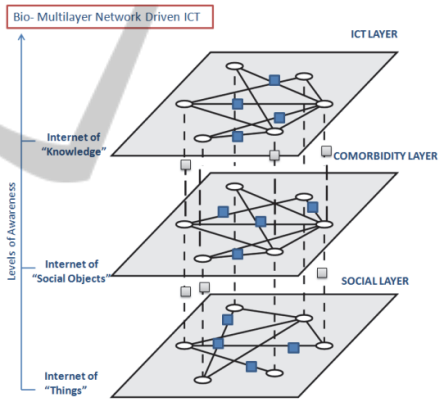

Figure 1: Bio-Inspired Multilayer Network for ICT. (See Text).

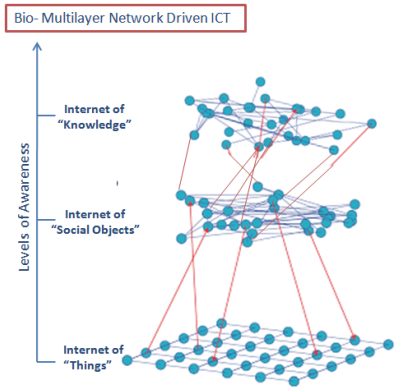

Figure 2: Dynamic Complex Patterns of the Multilayer Structure. (See Text).

This multiplexity, or the complexity caused by the existence of more than one link between entities, has been observed across multiple fields. In social networks for instance, different and not mutually exclusive relationships can be considered between the same two people (e.g. friends, relatives, colleagues, etc). Although social relationships are difficult to measure and such rich information about all the ties are rarely available, modeling social ties considering only one dimension does not capture the realistic human social dynamics. Networks, where occur multi-edges of different types between the same nodes, are referred as multiplex networks, or more generally multilayer networks, since each type of edge can be abstracted to either an independent or interdependent layer (Kivelä et al., 2010). The real potential of multilayer networks, in terms of applications and value, has not been exploited yet. One of the goals of the present work is to build and interpret a multilayer network model able to detect and separate the different layers and dimensions of analysis of a bio-inspired network-oriented ICT model.

3 A MULTILAYER APPROACH SOCIAL OBJECT ORIENTED

The proposed paradigm in this paper is the result of a biologically-inspired approach applied to complex social networks. Exploiting a multilayer architecture, it consists of an evolution process that involves both nodes and data. This approach starts from the consideration that all techniques and models related to information and communication have to be based on what governs the network dynamics. These processes in a social-based context are determined from nodes and data. This requires an evolution of these entities inside a multilayer network which shows the patterns of the different relationships and interactions among nodes and communities, through the sharing of data. The main goal is to solve all the issues related to heterogeneity, which can be an obstacle to more complex and deep analysis of networks. The network is characterized by a multitude of nodes of different nature, and by a multi-channel data collection. The aim is to obtain an evolution of the networks considering bio-inspired social objects. This evolution will become useful to enable the ICT procedures to be in line with the bio-inspired processes that rule the complex social network. The future ICT will be driven from these objects creating strategies and applications with an innovative and dynamic approach. The Fig.1 illustrates a multilayer social network, divided in three different layers. The three layers show the same topology but actually it could be different across layers. The first layer is the social layer, characterized by interactions between nodes through the sharing of data. In the second layer we introduce the comorbidity perspective, which is a medical concept referring to the co-existing of different diseases in the same subject, it creates other different relationships between nodes, that represent patients/individuals who share the same diseases or morbidities. In the third layer we consider the ICT in terms of interventions which involves the single entities and the system as a whole. In this perspective, the multilayer organization enables us to analyze the complex patterns of analysis. Starting from a simple node which interacts with other nodes, we can obtain an evolution and a growing awareness. The Fig. 2 shows the dynamic patterns as the result of the coupling effect of interdependent layers. Only by studying the inter-layer interactions between nodes, it is possible to detect the emergent behaviors and focus on the key features related to data and nodes, from which these patterns are generated. One perturbation in one layer could drive changes in the other layers through interactions. The evolution process from node and data to “social objects”, is indicated in Fig. 3. The “social objects” pave the way to the higher level of awareness, referred as “knowledge”, the abstraction of the outcome of the flow of information and social objects. The social objects merge together all the different cognitive, social and human aspects and the various contexts. The node, in the proposed paradigm, becomes an abstract object which contains any kind of presence and/or participation in the social networks. This can encompass simple network nodes, both hardware and software, IoT sensors, human nodes, etc. The node’s presence is defined as a set of bio-inspired features, such as genotype and phenotype. The genotype is represented by the immutable traits of that object. The phenotype is a combination of observable features, behavioral manifestations of genotype, and the result of interactions between genes, environment, and random factors. The multitude of heterogeneous nodes, with capabilities of self-organization, through mechanisms of aggregation and clustering techniques, becomes an organized structure of communities and groups. Enabling context-awareness and cognitive capabilities, the nodes become smart, able to decide their strategies inside and outside the communities. Adding abilities

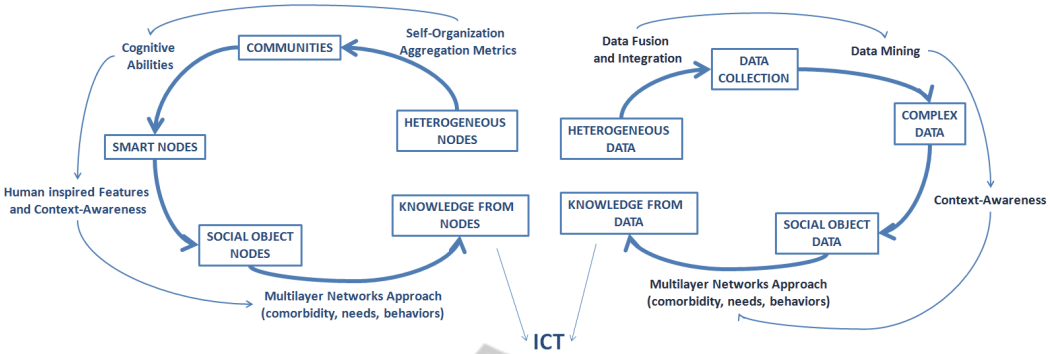

Figure 2 3: Evolution of Node and Data. The evolution, involving data and nodes, is a process which starts from disaggregated and heterogeneous things, and gets the social objects and finally, the knowledge for the ICT.

extracted from complex social networks analysis, in terms of emerging behaviors, we will obtain the abstraction, which is the social object node. The data, the other entity of the network, are any kind of collected information, useful to network analysis. The data could consist of statistical data, data gathered from sensors, social data, derived from online and real social network platforms. Collecting data may be relatively easy, but the complexity arises in combining and integrating datasets from multiple sources and different contexts, in order to extract the real knowledge about networks. This is the reason why, as we will explain in the next section, we need a complex mining, able to fuse and integrate in a unique structure these heterogeneous data, collected from different sources and of different nature. Furthermore, we have to integrate data considering the different contexts and environmental conditions in which these data are generated, considering who created them and for what purpose, so we have to consider a context-aware data mining, related to how attributes should be interpreted according to the different contexts.

4 FUTURE STRATEGIES AND APPLICATIONS

4.1 Knowledge Mining for Health

Public Health and Clinical Interventions Management is one of the future targets of the ICT and networking. The aim is to improve the efficiency of some processes related with this context, optimizing methodologies and procedures, providing technological support systems. Social network phenomena appear to be relevant in the health context, in particular in the biological and behavioral traits linked to diseases. Some diseases appear to spread through social ties (Christakis and Fowler, 2007), so the importance of considering the structure of social ties and the social contagion process for a better understanding of the subtle and deep processes underlying these social phenomena. These issues imply an increasingly better evaluation of the methodologies of analysis of the social networks. In fact, a future changing in relationships can affect the extraction techniques in the node behaviors, relating them to the diseases that arise and, subsequently, evaluate the relationships between them, and the co-occurrence in the same individual, that will be defined and treated in the next section. Therefore, this complex analysis involves multiple levels of awareness, from the nature of nodes, in terms of behavior and biological traits (genotype and phenotype), to their behavior when organized in communities. In this scenario, nodes and data become the entities to focus on, looking for both the extraction of behavioral rules and the data mining processes. The level of abstraction proposed in this paper allows to treat the network entities as social objects and then, the use of appropriate techniques for the collection, integration and analysis of data, would make possible the realization of a higher level of mining (Scatà, Di Stefano and La Corte, 2014). The weights assigned to these interactions and the social dynamics, such as the social contagion related to diseases in this scenario, could be crucial for extracting more knowledge related to the probability that some individuals, for example the ones who are more at risk than others, are going to contract certain diseases. This deeper analysis would be unthinkable using the traditional methods. The diagnostics is driven by a complex system of analysis that gathers and integrates the traits that characterize the nodes and data.

4.2 Comorbidity and Social Behaviors

Comorbidity means the co-occurrence of one or more different diseases in the same patient. Comorbidity represents an extremely complex field of research, and the complexity arises because of the complex relationships between conditions, disorders or diseases, all related to a single individual/patient. These conditions are often independent each other, in fact there could be no pathological association among them, but sometimes the relation is very strong and it is due to direct or indirect causal relationships and the shared risk factors among diseases (Tong et al., 2007), more than a chance alone. The complexity is also due to the uncertainty that depends on the number of associated morbidities (Capobianco E. and Liò P., 2013). Following the definition provided by the US National Library of Medicine, comorbidity is considered to be a secondary diagnosis, detected simultaneously or one after another in the same patient. Comorbidity is associated with multiple different symptoms, decreased length and quality of life and increased healthcare management (Islam M. et al., 2014). The study of comorbidity relationships between diseases could be exploited to build a model for predicting the diseases an individual may develop in the future, so the idea would be to prevent or at least inhibit the future occurrence. The analysis of comorbidity has to consider different dimensions morbidities (Capobianco E. and Liò P., 2013): the clinical dimension, related to diagnosis and treatment; the therapeutic dimension, which seeks to restore the steady state but can add complexity based on the reaction to drugs or interventions; the genetic dimension, which looks for the molecular causes, the levels of gene expression, susceptibility and risk factors; the omics dimension, which highlights the common causes behind comorbidity and it consists also of a functional analysis based on gene sets. It is necessary to consider the computational aspects, as inferential approaches may help to identify the direction of causality, for example, using evidence synthesis. In the future work, we want to add another dimension, the social one, in fact we will evaluate how social behaviors can influence the evolution of patients in terms of comorbidity. One of the ideas underlying this paper, in terms of comorbidity, is to highlight also the psycho-cognitive aspects of the individual (node) that will influence his behavior against illness, empowering patients in the healthcare decision process (Gorini A. and Pravettoni G., 2011). The way to conduct this social interaction analysis could be using theoretical and analytical tools, such as decision-making and game-theoretic approach, that we will introduce in the next subsection.

4.3 Decision-Making and Game-Theoretic Strategies

The decision's criteria depend both on individual knowledge and social context, intrinsically linked and dependent each other. Thanks to its individual knowledge, the node, acquiring awareness of the context and the environment to which it belongs, is able to analyze the information received by its neighbors, evaluating their actual behaviors and predicting the future ones. The node, once established its objective, compares all the alternatives using its set of decision's criteria, among them it is also possible to establish a hierarchy, giving a different weight to each single criterion and creating a scale of preferences. Then, the node can choose the best alternative trying to improve its individual utility and also the one of the community. The evaluation could be conducted also using simple heuristics (Bagnoli, Guazzini and Liò, 2007). Another future challenge in the multilayer structure is to model interactions between nodes in a comorbidity scenario. Game theory and the game-theoretic approach could represent an analytical tool that helps us in studying these interactions, considering for instance a multi-player game, where each player is an individual/patient who has simultaneously multiple co-occurrent diseases or morbidities which are in competition each other. The competition depends on the fact that the selection of a treatment or procedure could influence another morbidity because of the side-effects of drugs.

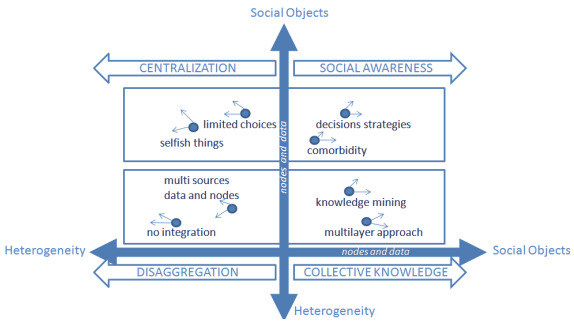

Figure 4: Future directions of social-object oriented paradigm.

In this competing scenario, at each time step the patient has to choose his strategy, considering simultaneously different decision parameters, related

not only to himself but also to his community, as explained before, so there is no a strategy that is absolutely better than the other ones.

5 CONCLUSIONS

The evolution process, that involves nodes and data, enables us to give a new definition, which tries, first of all, to solve the issue related to the management of heterogeneous data and different nodes. In Fig. 4 we show the future directions of social-object oriented paradigm. The social multilayer network allowed us to analyze the complex dynamic patterns involving these entities, shedding light on the different types of interactions at various layers. The multiplex structure, consisting of three layers, the social layer, the comorbidity layer and the ICT layer, allows to consider, respectively, the social interactions and the social contagion between nodes through the sharing of data, the comorbidity relations between diseases, and the ICT interventions as a result of the analysis of the complex patterns involving entities, the context and the system as a whole. The multilayer social network paradigm describes the evolution of data and nodes, considering an increasing level of awareness, from things to knowledge between social objects nodes through the social objects data. This evolution process leads to a bio-inspired network-driven ICT, redesigning the ICT communication paradigm. Future works will be focused on a complex analysis which accounts for the different aspects and data to get a knowledge-based mining, supported by datasets collected related to this context. The topic, which we are going to develop, is linked to health and also other applications and we will focus on studying and modeling the decision-making processes using a game-theoretic approach, in order to analyze from this new social perspective the issue of comorbidity and the influence of social behaviors.

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