

Modeling and Mining Feature-Rich Networks

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ABSTRACT

In the field of web mining and web science, as well as data science and data mining there has been a lot of interest in the analysis of (social) networks. With the growing complexity of heterogeneous data, feature-rich networks have emerged as a powerful modeling approach: They capture data and knowledge at different scales from multiple heterogeneous data sources, and allow the mining and analysis from different perspectives. The challenge is to devise novel algorithms and tools for the analysis of such networks.

This tutorial provides a unified perspective on feature-rich networks, focusing on different modeling approaches, in particular multiplex and attributed networks. It outlines important principles, methods, tools and future research directions in this emerging field.

CCS CONCEPTS

• **Theory of computation** → **Graph algorithms analysis**; • **Human-centered computing** → *Social networks*; *Social media*; • **Information systems** → *World Wide Web*.

KEYWORDS

social media, social network analysis, social interaction networks, feature-rich networks, mining social networks

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1 INTRODUCTION

In the last years, networks have proven to be a useful tool for modeling structural complexity of a variety of complex systems in different domains including sociology, biology, ethology and computer science. In contrast to simple homogeneous static networks, networks in real world settings are often dynamic, heterogeneous, and both nodes and links can be described by a set of attributes and/or multiple relations. Thus, the mining of such *feature-rich* networks [20] is gaining increasing interest; such networks include, in particular, *node-attributed* and/or *link-attributed* networks, including multiplex networks. This tutorial provides a survey on the latest algorithmic advances for modeling and mining feature-rich networks, including both node and link attributed networks.

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We structure the materials as follows: First, we start with a brief introduction defining the field of feature-rich networks. Then, two main sections are presented: the first on modeling and mining *multiplex networks* and the second on mining *attributed networks*. Then, we present applications of the presented network mining methods, and brief overview on available analysis tools. We conclude with a summary and interesting research directions.

2 MODELING AND MINING MULTIPLEX NETWORKS

The concept of multiplex networks has been introduced with the goal to provide an expressive model for modeling real-world complex networks [11, 23]. A multiplex network is roughly defined as a multi-layer graph where each layer contains the same set of nodes but interconnected by different types of links. Nodes across different layers can also be coupled by special *coupling links*. Different types of coupling links can be defined allowing to model various types of networks including; multi-relational networks, dynamic networks or heterogeneous networks. Analysis of multiplex networks requires redefining most of the basic concepts and metrics usually used for plain complex networks including: nodal degree and neighborhood, paths, as well as different centrality functions. [9, 11, 27]. It also requires providing new algorithms to handle basic complex networks analysis tasks such as community detection [18] and link prediction [36]. We cover all these issues with a special focus on the central problem of community detection.

3 MODELING AND MINING ATTRIBUTED NETWORKS

Attributed networks, where nodes and/or links are labeled with additional information, allow further dimensions for network analysis and mining, e. g., [34, 43, 44]. Then, these enable novel methods and approaches for complex network analysis that directly work on the feature-rich attribute structure. These include approaches, for example, that specifically exploit the descriptive information of the labels assigned to nodes and/or edges of the graph. Nodes denoting actors, for example, can be labeled with properties of the latter for compositional subgroup analysis, which can be implemented using subgroup discovery [1, 2]. Furthermore, explicit descriptions for model building and explication can be provided, e. g., using community detection methods e. g., [25, 33]. This also extends to link prediction [26]. Here, we provide an overview on recent algorithmic advances for modeling and mining attributed networks. We start with an introduction, providing basic definitions and introductory examples. After that, we tackle two specific methods: community detection, e. g., [3, 5, 6, 8, 10, 12, 17, 32, 35, 41, 42] and link prediction, e. g., [16, 21] on attributed networks.

4 APPLICATIONS AND TOOLS

There are different types of applications of the presented approaches for multiplex and attributed network mining. One important area is recommender systems, for which we show two applications: mining multiplex networks and attributed networks for enhancing tag recommendation in folksonomies [19], and mining multiplex networks for enhancing social interactions at social events [38, 39], respectively. Another original application of multiplex network mining includes an ensemble approach for cluster ensemble selection [22]. Furthermore, a summary of the available tools for multiplex and attributed network mining will be made. This includes a brief review of the Muna Library [14] and the VIKAMINE toolkit [4].

5 CONCLUSIONS

Network science is now mature enough to move towards analyzing and mining networks with much richer information than plain complex networks, modeled as *feature-rich complex networks*. Different extensions and future research directions can be identified: These include hybrid combinations of attributed, multiplex, and dynamic networks, e. g., [38], adaptations of Bayesian approaches for modeling and mining feature-rich networks [7, 13], extending and adapting network embedding methods and deep learning approaches for feature-rich networks, c. f., [15, 24, 37, 40] for some initial directions, and also including semantics into feature-rich network modeling and mining e. g., [28–31].

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