



# A fuzzy social network centrality analysis model for interpersonal spatial relations



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## ABSTRACT

Interpersonal nodes in the social networking sites reflect the para-virtual and para-real relationships, and form a complex social network. To reveal the properties of the interpersonal nodes and their inter-relations effectively, this paper develops an evaluation index system, which contains fuzzy comentropy, fuzzy node degree, fuzzy condensation degree, fuzzy cluster coefficient and fuzzy geographic concentration, and particularly proposes a fuzzy social network centrality analysis (FSNCA) model, which combines "node distribution", "node connection strength" and "node condensation and cluster", based on the fuzzy graph-theory. The FSNCA model has been successfully applied to study the interpersonal nodes' spatial relations in three social networking services (SNS) cases, in which three progressive layers, "nodes", "node connections" and "differences between node connections", are analyzed respectively. In the first case, the "friend group nodes" are studied to evaluate the equilibrium of node distribution in the network space by use of the fuzzy comentropy index. In the second case, the "connections between BBS group regional nodes" are studied to evaluate the centrality status and types of nodes in the network space by use of the fuzzy node degree index. The third case analyzes the "node connections of two kinds of chance relation groups" to evaluate the differences of centrality status in different networks by use of the fuzzy condensation degree, fuzzy cluster coefficient and fuzzy geographic concentration indexes. The systematic cognition of the interpersonal node spatial relations in the SNS community proves that the proposed method can effectively reveal the essence of fuzzy centralities. It sheds some light on the para-virtual and para-real geographical research, which is of significance to enrich the para-virtual and para-real geographical spatial relation theory, and it can also directly support the management and development of social networks of online services.

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## 1. Introduction

With the advent of interactive media in social networks, the information audience not only receives information, but also participates in more diverse ways of information creating, transmitting and sharing ("recommending"). This situation diversifies the information processing methods, and makes social networks more dynamic, large scale, diverse and complex. This also provides new research opportunities to social network researchers – not only to study the relationships among individuals, groups or organizations, but also to face integrative problem expression and impacts in the large scale, interdisciplinary, multi-levels of interrelation environments. In social network research, the network char-

acteristics have been represented by using graph-theory since the early 21st century. The fuzzy structural properties of social networks then received in-depth studies, which became one of the main research methods. This study aims to propose a fuzzy social network centrality analysis (FSNCA) model for social networks based on the spatial relationships between the interpersonal social network nodes, and apply the FSNCA model in analyzing three case studies.

Fuzzy graph-theory, which takes fuzzy graph as the research object, is a branch of fuzzy mathematics. Fuzzy graph of fuzzy graph-theory consists of several nodes and links which connect with different nodes. This fuzzy graph is usually used to describe fuzzy relations in different objects. Nodes represent the objects and the connecting lines represent the fuzzy relations between the two objects. The method of fuzzy graph is an important means in analyzing fuzzy social network structure, which fuzzy quantifies the interaction between different nodes to explain the form of the

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geographic elements of fuzzy social network in geographical space and their spatial relations. Fuzzy graph-theory is used to analyze the spatial structure of SNS community, and to explain the propagation characteristics of information in different networks and the centrality of the node in its network [1]. Nair and Saeasamma (2007) [2] first pointed out the fuzzy attributes of social networks, and proposed that fuzzy social networks were composed of actors and their relations, which were expressed by fuzzy graphs. They used the nodes and edges in fuzzy graphs to represent actors and their relations in social networks respectively. The relations between actors were uncertain, and the varieties of possible relations were calculated by the probability. Ignjatovic, et al., (2010) [3] further indicated that all social networks were fuzzy social networks, which brought fuzzy social networks' research to a new level—using the fuzzy mathematics method to express the fuzzy relations among nodes, links and boundaries in fuzzy social networks. After years of research, fuzzy social networks have formed a preliminary system and scholars have summarized some basic features which are the same as those of real communities [4]. Based on the previous research, the basic feature of fuzzy SNS communities is the fuzzy procedure of the processing and merging information. The fuzziness of the connections between nodes and the network degree of a node, which is the core of the group, are determined by the times of node connections.

Based on the fuzzy attributes of social networks, the main research methods are social network analysis (SNA) and fuzzy social network analysis (F-SNA), which is combined with fuzzy mathematics [3]. In SNA, scholars focus on modeling the complicated relations as a certain network configuration and conducting quantitative analysis on the simplified network configuration and its change with the aid of some mathematical models. Abbasi, et al., (2011) [5] developed an evaluation model which combined graph theory, matrix method, social metric method and algebraic method to express relationships in a network organization and describe the network structure visually. In F-SNA, scholars have studied the fuzzy structural characteristics and attributes of social networks and their applications in business relationships, organization structures and so on from the perspective of sociology and economics. Hu, et al., (2013) [6] gave basic concepts and calculation formulas of fuzzy social networks, such as structure holes, density and location attributes.

In recent years, the research on fuzzy social networks has focused on structural properties, such as fuzzy node degree, structure equivalence and structural holes. Nair and Sarasamma (2007) [2] constructed a fuzzy operator  $a \circ b = a + b - ab$  based on the fuzzy graph, and discussed the fuzzy attributes of social networks through data mining technology. Fan, et al., (2007, 2008) [7,8] introduced the concepts of regular similarity and generalized regular equivalence into the fuzzy social network research. They defined fuzzy regular equivalence and general fuzzy regular equivalence by fuzzy relation equations. The calculation method and examples were given. In addition, there are still some other applications in the study of structural properties, such as calculating the connection and the similarity in locations of two nodes in the network [9,10].

These scholars deeply discussed fuzzy structural attributes of fuzzy social networks, which provided the foundation of the fuzzy social network structural relationship analysis [11]. However, the fuzzy spatial position analysis has not been carefully discussed and the empirical analysis of fuzzy social network applications and relations has not been carried out. So there are two challenges for the further development of social network analysis methods. One is whether the method can be used in the study of para-virtual and para-real social networks or not. The other is whether the method can be used in a specific field of interpersonal nodes' spatial relations or not. It is necessary to take spatial relations of interper-

sonal nodes in SNS community as the objective of research and set up an index system from the aspects of structural properties. This study proposes a FSNCA model of SNS community and applies the model to analyze spatial position and relations in fuzzy social networks. It is of great significance to expand the theory of para-virtual and para-real geography spatial relations and deepen the geography research on SNS community structures. The findings may also directly support online social network service development and management.

This paper concentrates on the node centrality, and studies the membership degree, node inequality, the gradualism in connection strength, the structural holes, incomplete networks brought from the condensation, and cluster coefficients from the aspect of the methodology.

In order to give a more comprehensive description of the application of the fuzzy social network model, this study chooses friend groups from the Kaixin Website (<http://www.kaixin001.com/>), tourism groups from Tianya BBS (<http://www.tianya.cn/bbs/index.shtml>), and two relation groups from the Renren Net (<http://www.renren.com/>). In this paper, we still use the data of the three cases which were published in the journal of *Economic Geography* [12]. From the content of the research, friend groups, BBS groups and relation groups are three types of social networks which are layer-layer progressive, and related to the problems of equilibrium of node distribution in the network space, centrality characteristics of contact nodes, and different centralities in different contact nodes respectively. The case of the friend network focuses on nodes. With the friends' distribution as the basic information, it explains fuzzy comentropy index, reveals centrality characteristics of interpersonal nodes' spatial distribution in the SNS community, and gets the conclusion of the concentrated and unbalanced degree. The case study of the BBS network focuses on node connections. With the regional plate as the information construction, it sets up a relation network of "fine articles" in regional sections and posts, repliers position relations. The emphasis of the case study is the comprehension of contact relations and the explanations of the index of the fuzzy node degree, in-degree and out-degree, with the aim of getting the conclusion of a node's centrality status and type. The case of relation network focuses on type comparison, with two basic types – learn-related type and interest-related type, and tries to explain the index of fuzzy condensation degree, fuzzy cluster coefficient and fuzzy geographic concentration. We try to get different centrality of different relation networks from the perspective of difference in connection nodes. The findings are as follows: (1) there is a significant centrality of interpersonal nodes' spatial distribution in SNS communities and it presents a significant local concentration characteristic. (2) Different interpersonal nodes have significant different centrality statuses; the whole network presents multiple centrality features that are centrality of attractiveness and activeness. (3) Centralization characteristic of the node spatial distribution takes on a significant difference among different chance groups, and the centralization characteristic of the interest margin relation groups is weaker than that of the learning relation groups.

The main contributions of this paper include: (1) the fuzzy social network analysis method is introduced in the study of SNS community, and the concept of fuzzy SNS community is proposed; (2) the structure chart of fuzzy social networks is established by using the spatial position of graph theory; (3) a fuzzy analysis model based on fuzzy graph theory is proposed to solve the centrality characteristics of interpersonal node space relations in SNS community; (4) the proposed FSNDA model is successfully applied in three cases in SNS community to analyze network structure characteristics and interpersonal nodes' distribution features of SNS community.

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