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## Analysis of Structural Characteristics and Differences of Triadic Relationship Groups in Author Collaboration Networks (Postprint)

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### Abstract

[Purpose/Significance] This study takes the publishing authors and their publication quantities from Wuhan University and Nanjing University in the field of library and information science as research subjects, identifies the structural characteristics and differences of internal collaboration networks within the two institutions, explores collaboration potential, provides references for enhancing cooperative exchanges among authors, with the aim of facilitating better development in this field. [Method/Process] Establishes a directed collaboration network between secondary authors and first authors, statistically analyzes the collaboration composition of the two institutions, visualizes the collaboration network relationships through social network analysis software Pajek, and simultaneously conducts characteristic analysis of triadic relationships. [Results/Conclusion] Through analysis, it is found that Wuhan University tends to favor dual-author collaborations, where secondary authors primarily collaborate with high-productivity authors, the network exhibits a convergent tendency, and lacks collaboration among secondary authors; scholars in this field at Nanjing University tend to publish independently, with more authors joining the collaboration network as first authors, causing the network to expand outward, while lacking collaboration among first authors.

### Full Text

#### Preamble

#### Triad Census Analysis on Structural Characteristics and Differences of Author Cooperative Networks

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## Abstract

**[Purpose/Significance]** This study examines published authors and their output quantities in library and information science research from Wuhan University and Nanjing University to identify structural characteristics and differences in their internal collaboration networks, explore collaboration potential, and provide insights for enhancing cooperation and communication among authors to facilitate better development in this field. **[Method/Process]** Directed cooperative networks were established between sub-authors and first authors, and the collaboration composition of both institutions was statistically analyzed. The cooperative network relationships were visualized using the social network analysis software Pajek, while simultaneously conducting characteristic analysis of triad relationships. **[Result/Conclusion]** The analysis reveals that Wuhan University tends toward two-person collaborative publications, where sub-authors frequently collaborate with high-productivity authors, showing a convergent network tendency and lacking collaboration among sub-authors. In contrast, scholars in this field at Nanjing University prefer independent publication, with more authors joining the cooperative network as first authors, causing the network to expand outward, while lacking collaboration among first authors.

**Keywords:** author cooperation network; triad census analysis; library and information science; Wuhan University; Nanjing University

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## Introduction

Global integration and the Internet of Everything have become undeniable realities. Scientific collaboration among researchers has significantly propelled technological development, rendering cooperation networks increasingly dense. Collaborative research has garnered widespread attention for its advantages in reducing research costs, alleviating the difficulty of research topics, enhancing scientific output capacity, and expanding academic influence. The rise and development of social network analysis and bibliometric analysis have brought benefits for unraveling the mysteries of cooperative networks.

Historically, numerous studies have analyzed the structural characteristics of scientist collaboration networks. In 1997, W. Glanzel et al. [?] proposed a model for measuring and analyzing the degree of multilateral co-authorship links. This model established a “outer, middle, inner” three-tier cooperation system with the core of multilateral cross-type cooperation patterns, bilateral interactive cooperation patterns, and supplementary cooperation patterns. Cooperation patterns vary diversely depending on time, discipline type, and other factors. Currently, most analyses of author cooperation networks adopt perspectives from the subgraph level, multi-relational structures, or overall network structure, with articles identifying network structures from more micro-level perspectives

being extremely rare.

At the ternary micro-level, V. Batagelj et al. [?] proposed the Triad Census algorithm in 2001 to discover and calculate triadic relationships in social networks, thereby revealing structural characteristics of large-scale sparse networks. Foreign research commonly focuses on algorithmic improvements for triadic relationships and social media network relationships [?]. In 2009, Fu Chunhua [?] studied clique structures in social networks and quasi-social networks, proposing a new statistical measure—K-groups (including dyads and triads)—and applied a series of extended methods to link a new indicator, multilateral cooperation index degree ( $\delta$ ), with international collaborative papers ( $f$ ) to analyze international cooperation patterns. In 2002, E. Otte and R. Rousseau [?] proposed applying social network analysis methods such as network density, degree centrality, closeness centrality, betweenness centrality, and cliques to author cooperation relationship analysis and network structure interpretation. In 2013, Qiu Junping and Dong Ke [?] applied social network analysis and hierarchical clustering analysis to divide cooperation networks into author collaboration, author co-citation, author bibliographic coupling, word-author coupling, and journal-author coupling. In 2016, Hou Jianhua and Wang Zhongyu [?] proposed a multilateral cross-type cooperation pattern with “outer, middle, inner” three-tier cooperation systems at its core.

This study refines the author cooperation problem to the level of first authors and sub-authors (with all non-first authors collectively referred to as sub-authors), arguing that different authors of the same paper contribute differently to its completion. Different weights are assigned to authors based on their positions in the author list. Taking published authors in library and information science research from Wuhan University and Nanjing University as examples, directed author cooperation networks were constructed for social network analysis using triad census analysis. Based on the fundamental behaviors of triads, this study attempts to identify structural differences in cooperation networks across different institutions, thereby discerning variations in information transmission and knowledge sharing characteristics, and providing a foundation for further scientific research collaboration.

## Theoretical Methods and Data Sources

### 2.1 Triads in Social Network Analysis

In social network analysis, relationships among three individuals are called triads. Triad types can be categorized into balanced, clusterable, hierarchical clusterable, transitive, hierarchical clusterable networks, and forbidden models. This classification applies to social hierarchy sequence analysis in social networks but differs from the distribution characteristics of author cooperation networks. This study applies triad concepts to author cooperation networks, decomposing cooperation relationships among multiple authors into several three-person cooperation relationships.

Social network analysis can be divided into narrow and broad senses [?]. Narrow social network analysis mainly includes ego-centric network analysis and complete network analysis. Simultaneously, social network analysis can be divided into five levels reflecting different network properties: individual-level analysis, dyadic analysis, triad analysis, subgraph-level and multi-relational structure analysis, and overall network analysis [?].

Triad analysis in social network analysis is based on fundamental triad types, analyzing various possible connection relationships among three actors, such as relationship and information transmission and sharing. Through triad census calculation (where all nodes in the network are matched with all other nodes to form triads and conduct model statistics), the properties of the entire network can be explained [?]. According to J.A. Davis et al. [?], triad types adopt an M-A-N three-digit coding system, with an additional letter appended at the end (D for downward, U for upward, C for cyclic, T for transitive) to indicate the direction of selection relationships. There are 16 possible triad types, as shown in Figure 1 [Figure 1: see original paper] [?].

## 2.2 Triads in Author Cooperation Network Analysis

Figure 1 illustrates 16 triad types, sorted according to the “symmetric-asymmetric-null” relationship model. For example, 021 indicates 0 symmetric relationships, 2 asymmetric relationships, and 1 null relationship. When the occurrence frequency of a particular triad in a network is significantly higher than its expected random occurrence frequency, it can be considered that the relevant model may guide or influence the distribution of relationships in the network. Different structural triad models have characteristics such as transmission and circulation, and their application to author cooperation networks helps determine the overall structural features of cooperation networks.

Since the analysis objects differ, author cooperation networks divide triads into open and closed types based on author cooperation networks, as shown in Figure 2 [Figure 2: see original paper].

Figure 2 involves 16 triad types, where open triads have partially missing cooperation among three individuals with relatively loose collaboration, while closed triads form cooperation loops with denser cooperation patterns. Additionally, closed triads can be regarded as the next developmental stage of open triads. The cooperation characteristics of each model are shown in Table 1. Different triads have distinct features and cooperation trends, which are analyzed through specific examples below.

## 2.3 Visualization and Analysis

The visualization process helps clearly display the distribution of author cooperation networks. Nodes and node sizes represent authors and their publication quantities in 18 core library and information science journals (including publications as first and sub-authors, with non-first authors collectively referred to

as sub-authors). In-degree and out-degree centrality are distinguished by different colors, with arrows pointing to first authors. The connection weight  $W_i$  represents author cooperation weight, calculated as  $W_i = n_i \times N_i$  (Formula 1), where  $n_i$  indicates the number of collaborative publications between sub-authors and first authors, and  $N_i$  indicates the sub-author's position in the author list. Thicker connections indicate greater cooperation weight between two authors. Visualization was performed using Pajek software, with specific settings shown in Figure 3 [Figure 3: see original paper].

Table 2 displays the number of various triads found in the network (data obtained from Pajek software statistics), arranged according to open and closed triads. This distribution of triads is called a triad census.

The triad census includes: first column showing triad types; second column showing actual triad counts; third column showing expected random counts; fourth column showing relative differences calculated to compare actual versus expected quantities; fifth column showing  $(n_i - e_i)/e_i$ .

Note: “Expected random count ( $e_i$ )” is calculated from random networks of the same size (with identical nodes and connections) according to random principles.

## 2.4 Data Sources

Literature data for analysis and visualization were obtained from the CNKI database. Based on the 18 core journals in the “Catalogue of Chinese Core Journals” (2017 edition) under G25 Library and Information Services (see Table 3), institutional fuzzy searches were conducted for Wuhan University and Nanjing University with a time span of 2016-2016 (search date: September 23, 2017), yielding 298 and 166 literature records respectively.

The data were statistically processed and organized, and cooperative networks were generated and visualized using Pajek software. Cooperation was defined as direct collaboration between sub-authors and first authors, without considering cooperation among sub-authors. Additionally, given the broad nature of paper collaboration, authors from other institutions who have cooperated with target institutions also possess potential for cooperation with target institution authors. All authors from articles containing signatures from both institutions (including authors from other institutions) were considered to form a large cooperative network for analysis.

## Empirical Research

### 3.1 Analysis of Author Cooperation in Library and Information Science at Wuhan University

The following sections analyze the composition of author cooperation and the triads in the cooperation network to identify network structural characteristics of different institutions.

**3.1.1 Cooperation Composition Analysis** Statistics were compiled on cooperation between first authors and sub-authors with different numbering positions. The results were imported into Pajek software to generate the author cooperation network in library and information science at Wuhan University, as shown in Figure 4 [Figure 4: see original paper].

Figure 4 arranges subnetworks from top to bottom and left to right in descending order of author count. Specific cooperation composition is shown in Table 4 .

Overall, the cooperation network includes 71 small subnetworks, including single-author publications. Two-person subnetworks account for the largest proportion at 35%, while subnetworks with five or more authors total 18, with the largest cooperation network comprising 35 authors. More articles have dual authorship, with single-author publications accounting for only 14%, and cooperation among five or more authors being rare. Regarding author status, half of the scholars have served as second authors, followed by first authors.

**3.1.2 Triad Analysis** Table 5 displays the triad census for this network. Statistical analysis shows that models with large differences between the Wuhan University author cooperation network and random networks are mainly distributed in open models. Among these, the model with the largest numerical and proportional difference is 7-111D (ratio 37.78), followed by model 3-102 (ratio 23.48). Although model 11-201 shows huge relative differences, its absolute value is only 3 more than the random value. Models 8-111U and 9-030T also show large differences from random values (ratios 23.24 and 15.16 respectively). Thus, the Wuhan University cooperation network can be viewed as open-model dominated, with 7-111D as the representative cooperation network.

To more clearly analyze internal network structure, the cooperation network centered on the most productive author, Huang Ruhua, is analyzed below, as shown in Figure 5 [Figure 5: see original paper].

This subnetwork contains 30 nodes, with Huang Ruhua as the core first author for cooperation. Within the search timeframe, Huang Ruhua published 19 papers, 17 as first author, ranking first. She formed direct cooperative relationships with 11 authors but lacked bidirectional cooperation. The greatest cooperation weight was with Li Nan, with 4 co-authored papers (Huang Ruhua as first author, Li Nan as second author). Xiao Ximing formed an indirect cooperative relationship with Huang Ruhua through Li Baiyang, indicating potential for direct cooperation. The author with the most direct cooperation with Xiao Ximing was Wanyan Dengdeng, with 5 co-authored papers (Xiao Ximing as first author, Wanyan Dengdeng as second author), also lacking bidirectional cooperation.

The cooperation triad census for this subnetwork is shown in Table 6 . This subnetwork formed no closed triads. The model with the largest difference from the random network is the open model 5-021U (42 instances, ratio 1.96), illustrated in Figure 6 [Figure 6: see original paper].

Figure 6 shows Huang Ruhua as the first author, with Li Nan and Wang Chunying both forming multiple unidirectional cooperations with her, with Li Nan cooperating more closely. This model demonstrates that Huang Ruhua lacks bidirectional cooperation with the two sub-authors, and communication between Li Nan and Wang Chunying is minimal. The model centers on the middle node (Huang Ruhua) with a convergent tendency, where more sub-authors assist a few authors in becoming first authors.

The second largest relative difference is model 8-111U (3 instances, ratio 1.77), shown in Figure 7 [Figure 7: see original paper].

Zhou Lihong and Han Yingying have each served as first authors in cooperative publications with each other, while Zhou Lihong also had unidirectional cooperation with Wang Pu as a sub-author. Cooperation between Zhou Lihong and Han Yingying is closer. This model centers on Zhou Lihong, with Wang Pu and Han Yingying lacking communication but showing strong collaboration potential.

### 3.2 Analysis of Author Cooperation in Library and Information Science at Nanjing University

**3.2.1 Cooperation Composition Analysis** Using the same method, Nanjing University's 2016 publications in this field were statistically analyzed and visualized using Pajek, generating the network shown in Figure 8 [Figure 8: see original paper].

Figure 8 displays the entire author cooperation network in library and information science at Nanjing University. Specific cooperation statistics are shown in Table 7 .

The Nanjing University author cooperation network includes 39 cooperative subnetworks, including single-author publications. Single-author subnetworks account for the largest proportion at 36%, while subnetworks with five or more authors total 6, with the largest subnetwork comprising 34 authors. Among published papers, dual-author cooperation is most common but accounts for less than half, with over 30% of scholars choosing three-author cooperation. Regarding author status, the number of authors who have served as first authors is highest at 46%, with more than half having served as first authors.

**3.2.2 Triad Analysis** Table 8 shows the triad census for this cooperation network. Statistical analysis reveals that models with large differences between the Nanjing University author cooperation network and random networks are distributed in both open and closed triads. Model 8-111U shows the most significant numerical and proportional difference (ratio 47.55). Model 13-120U, which did not appear in random networks, emerged 9 times (ratio 4658.26). Although models 11-201 and 12-120D show huge relative differences, their absolute values are only 2 and 3 more than random values respectively. Thus, the Nanjing

University cooperation network can be viewed as open-model dominated with a closed tendency, with 8-111U as the representative cooperation network.

To more clearly analyze internal network structure, the cooperation network centered on the most productive author, Zheng Jianming, is analyzed below, as shown in Figure 9 [Figure 9: see original paper].

Zheng Jianming cooperates as the core author. Within the search timeframe, Zheng Jianming published 19 papers, forming direct cooperative relationships with 8 authors. He had one co-authored paper with Jing Yuan, where Zheng Jianming was first author and Jing Yuan was sub-author. Zheng Jianming and Jing Yuan each served as first authors in two co-authored papers, forming a mutual cooperation relationship. The author with the greatest cooperation weight with Zheng Jianming was Sun Honglei, with 4 co-authored papers. Chen Ya connects to Zheng Jianming through Zhu Jie, Jing Yuan, and Wang Meng, indicating huge potential for future cooperation development.

The triad census for this subnetwork is shown in Table 9. The model with the largest difference from the random network is the open model 8-111U (8 instances, ratio 6.23), illustrated in Figure 10 [Figure 10: see original paper].

Zheng Jianming and Jing Yuan each served as first authors in cooperative publications with each other, while Zheng Jianming also had unidirectional cooperation with Sun Honglei as a sub-author. This shows closer cooperation between Zheng Jianming and Jing Yuan. The model centers on Zheng Jianming, with both Jing Yuan and Sun Honglei having strong publication capabilities but lacking cooperation between them.

The second largest relative difference is model 4-021D (35 instances, ratio 2.66), shown in Figure 11 [Figure 11: see original paper].

Chen Ya cooperated with Wang Meng and Jing Yuan as a sub-author, cooperating more closely with Jing Yuan. This model not only lacks bidirectional cooperation between the two but also shows that cooperation between Wang Meng and Jing Yuan needs strengthening. The model has a divergent tendency, with sub-authors assisting more authors in becoming first authors.

## Comparative Analysis of Author Cooperation Between the Two Universities

### 4.1 Comparative Analysis of Cooperation Composition

The above sections have described the cooperation composition of both institutions separately. The following comparison reveals institutional differences between the two universities' cooperative networks, as shown in Figure 12 [Figure 12: see original paper].

Wuhan University tends toward individual cooperation between two persons and large-scale collaborative groups of five or more persons. Half of all authors

have served as second authors, accounting for 50% (125% of total), with over half of articles being dual-author publications. Nanjing University tends toward independent publication and two-person cooperation. The proportion of authors who have served as first authors is highest at 60% (123% of total), with two-author cooperation being most common but accounting for less than half, and over 30% of scholars choosing three-author cooperation.

## 4.2 Comparative Analysis of Triad Types

Both institutions' triad compositions are distributed across open and closed models. Analysis from the previous sections shows differences in model quantity and type between the two institutions. A comparative analysis of triad type differences between the two institutions is now conducted to identify similarities and differences, as shown in Table 10 .

Overall, Wuhan University shows greater differences from random values in open triad distribution, while Nanjing University shows more significant differences in closed triads (major differences are highlighted in bold italics). Wuhan University frequently exhibits triads 7-111D, 3-102, and 5-021U, while Nanjing University shows larger gaps from random quantities in triads 8-111U and 4-021D. The triad type comparison is shown in Figure 13 [Figure 13: see original paper].

Wuhan University frequently exhibits model 5-021U (461 instances, ratio 2.66), where larger numbers of sub-authors assist a few first authors, with fewer sub-author collaborations. Model 7-111D (24 instances, ratio 37.78) shows two authors cooperating closely, both having served as first authors in cooperative publications with each other, while the third author joins as a sub-author. Both models exhibit convergent tendencies. Model 3-102 (3087 instances, ratio 23.48) indicates close cooperation between two authors, corresponding to the largest proportion of two-author cooperative publications in the composition analysis. These models make the cooperation network more cohesive.

Conversely, Nanjing University exhibits model 8-111U (37 instances, ratio 47.55), where all three authors have served as first authors, featuring two closely cooperating authors, one of whom serves as a sub-author cooperating with another author. Model 4-021D (200 instances, ratio 1.66) features two first authors lacking cooperation between them. Both models exhibit divergent tendencies, causing the cooperation network to expand outward.

In closed models, Wuhan University has more 9-030T models, while Nanjing University exhibits model 13-120U, which did not appear in random networks, as shown in Figure 14 [Figure 14: see original paper].

In model 9-030T (10 instances, ratio 15.16), one author (upper node) served twice as first author cooperating with two other authors; one author (lower-left node) assisted the other two in cooperative publications; and one author (lower-right node) served as both first author cooperating with one author and as

sub-author assisting the upper node. This model forms a relatively tight closed-loop cooperation pattern with convergent, divergent, and transitive tendencies, representing a relatively mature composite model, but lacking bidirectional cooperation between each pair.

Model 13-120U (9 instances, random value 0) adds a cooperation relationship between first author and sub-author based on the 9-030T model, transforming the original sub-author into a first author. This not only enables authors in this model to achieve higher cooperation levels but also increases the number of first authors in the network, giving it stronger network expansion tendencies than the 9-030T model.

## Conclusion

This study applies triad census analysis from social network analysis to author cooperation networks, analyzing author cooperation structures from the triadic relationship level to reveal different cooperation patterns and characteristics across institutions, explore collaboration potential, and provide references for enhancing cooperation among authors. Through triad census analysis of author cooperation network structures in library and information science research at Wuhan University and Nanjing University, the following findings emerge:

In terms of cooperation composition, Wuhan University tends toward two-person cooperative publication, with a smaller proportion of all publishing authors having served as first authors. It has more large-scale cooperative subnetworks centered on core publishing authors. Nanjing University has more independent authors, with more scholars having served as first authors.

Regarding triad analysis, the two institutions show significant differences in open and closed triad distributions. Comparing open triad models reveals that Wuhan University features larger numbers of sub-authors assisting a few first authors, with the third author typically joining as a sub-author while consolidating cooperation between two authors, lacking sub-author communication, and showing a convergent tendency toward high-productivity authors that makes the network more cohesive. Conversely, Nanjing University features a few sub-authors assisting more first authors, with the third author typically joining as a first author, lacking communication among first authors, and gradually expanding the first-author group to expand the cooperation network outward.

Comparing closed triads shows that both institutions possess relatively mature cooperation patterns with convergent, divergent, and information transmission functions. Comparatively, Wuhan University more severely lacks bidirectional cooperation between each pair, while Nanjing University's larger number of sub-authors enhances network expandability.

Many factors contribute to different author cooperation characteristics across institutions, including institutional development models, education and training methods, teacher-student cooperation, researcher career age composition,

number of authoritative researchers, academic atmosphere, and individual differences. How different cooperation patterns affect research output and quality, and whether these findings differ across disciplines, remain questions for future research.

This study conducted exploratory research on author cooperation networks in library and information science using triad theory with limited data. In fact, the statistical characteristics of triad theory are particularly suitable for large-scale sparse network research. The findings possess certain generalizability but require further empirical investigation.

Applying triad analysis to author cooperation research and identifying cooperation patterns and structures across institutions from author list positions can help target institutions maximize internal talent resources, identify internal cooperation deficiencies, and transform cooperation models. For external researchers, it can help identify primary authors of institutional academic papers and their cooperation patterns, thereby facilitating targeted collaboration and promoting better cooperation and development in relevant research fields.

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## Author Contributions

**Wang Jiabin:** Conceived the research idea and was the primary author of the paper.

**Hou Haiyan:** Provided guidance on research direction and paper revision.

**Huang Fu:** Provided guidance on paper revision and technical direction.

**Hu Zhigang:** Proposed writing ideas, suggestions, and revision comments.

*Note: Figure translations are in progress. See original paper for figures.*

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