Exploring Citation-Based Methods for Identifying Potential Interdisciplinary Knowledge Combinations: Postprint

Authors: Du Dehui, Liu Chao

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Abstract

[**Purpose/Significance**] In the era of big science, exploring and identifying potential interdisciplinary knowledge combinations facilitates knowledge integration and innovation. [**Method/Process**] This study analyzes identification pathways for potential interdisciplinary knowledge combinations based on direct citation relationships, constructs an evaluation index model for integration potential, and combines it with grey relational analysis. Empirical analysis is conducted using journal articles in library and information science as a case study. [**Results/Conclusions**] Potential interdisciplinary knowledge combinations with high integration potential and novelty for library and information science are identified, providing insights and references for exploring knowledge integration and innovation across different disciplines.

Full Text

An Exploration of a Potential Interdisciplinary Knowledge Combination Identification Method Based on Citation

Du Dehui, Liu Chao
Department of Library, Information and Archives, Shanghai University, Shanghai 200444

Abstract: [Purpose/Significance] In the era of big science, exploring and identifying potential interdisciplinary knowledge combinations is conducive to promoting knowledge integration and innovation. [Method/Process] Based on direct citation relationships, this paper analyzes the identification path for potential interdisciplinary knowledge combinations, constructs evaluation indicator models for integration potential, and combines grey relational analysis to conduct empirical analysis using journal papers from the library and information science discipline as an example. [Result/Conclusion] Potential interdisciplinary knowledge combinations with greater integration possibility and novelty for library and information science are identified, providing ideas and references for exploring knowledge integration and innovation across different disciplines.

Keywords: citation analysis; potential interdisciplinary research; knowledge combination identification; integration potential

Introduction

With the increasing "micro-differentiation"of science and the growing complexity of research problems, knowledge from a single discipline can no longer meet the needs of problem-solving, leading to progressively deeper and faster integration of knowledge across disciplines. Researchers typically need to break through disciplinary boundaries and cross different research fields to promote knowledge innovation through mutual penetration between disciplines [?]. Meanwhile, the rapid development of various disciplines and increasingly sophisticated research tools have prompted scholars to either apply methods from their own discipline to different research fields or apply various methods to a fixed disciplinary domain [?]. In exploring interdisciplinary knowledge exchange, identifying and judging future development trends is essential for providing constructive suggestions for the development and planning of interdisciplinary research [?]. Facing the impact of current emerging technology waves, the construction of new liberal arts requires breaking through traditional disciplinary thinking patterns and emphasizing inheritance, innovation, intersection, and integration in disciplinary development. In the process of constructing the disciplinary system of library and information science, many theories and methods from other disciplines have been absorbed and borrowed [?]. Interdisciplinary knowledge combinations refer to the integration of knowledge from one' s own discipline with knowledge from other disciplines that have high fusion potential—that is, knowledge combinations formed by associating knowledge constituted by topics or keywords from one' s own discipline with knowledge constituted by topics or keywords from other disciplines through certain relationships, which possess research value, novelty, and development potential. Faced with the growing demand for knowledge integration between different disciplines, there is an urgent need to mine potential interdisciplinary knowledge combinations from the vast number of scientific and technological documents. By identifying potential interdisciplinary knowledge combinations, we can purposefully grasp knowledge points from other disciplines that can be combined with the target discipline, thereby serving problem research in the target discipline.

Literature Review

In 1926, Professor R. S. Woodworth from Columbia University first proposed the concept of "interdisciplinarity" at the annual meeting of the Social Science Research Council, emphasizing that interdisciplinarity involves the intersection, penetration, and integration of different basic disciplines [?]. Regarding interdisciplinary knowledge research, scholars have mainly explored three aspects: the role of interdisciplinary knowledge, the development patterns and evolution of interdisciplinary fields, and the structural characteristics of interdisciplinary topics and interdisciplinary knowledge identification.

The Role of Interdisciplinary Knowledge

Exploring the role of domain knowledge in the transfer process between different disciplines from an interdisciplinary perspective helps clarify the influence of interdisciplinary knowledge in promoting research output and disciplinary knowledge development. E. Yan et al. [?] combined knowledge trade theory with citation networks to explore the trade influence of disciplinary knowledge by calculating trade surplus amounts between disciplinary topic categories. H. Eto [?] utilized the input and output forces of interdisciplinary information to measure the output behavior of nanotechnology project results. K. Karunan et al. [?] constructed a quantitative method model based on citation networks to evaluate the intensity, dominant patterns, and mutual contribution rates of knowledge interactions between different disciplines. Ke Qing et al. [?] revealed the main knowledge sources and knowledge contribution promotion effects of library and information science by analyzing the overall situation and temporal evolution of interdisciplinary citations in the discipline. Xu Lu et al. [?] analyzed the output intensity, timeliness, and interdisciplinarity dimensions to conclude that interdisciplinary citations help broaden the disciplinary scope of knowledge output. The above studies primarily conducted quantitative analyses of the influence intensity and knowledge contribution characteristics of interdisciplinary knowledge from the perspective of knowledge transfer, laying a foundation for subsequent interdisciplinary research. However, they lacked analysis of the formation and evolutionary characteristics of interdisciplinary fields, while exploring the development and evolution of interdisciplinary fields helps deepen understanding of the dynamic relationship changes in interactions between various disciplines.

Development Patterns and Evolution of Interdisciplinary Fields

Knowledge from various fields plays different roles at different stages of interdisciplinary development, making it necessary to explore the development patterns and evolution processes of interdisciplinary fields. Interdisciplinary research typically undergoes three stages: incubation, germination, and maturity. Different research fields play different roles such as knowledge source, knowledge receiver, knowledge responder, and interdisciplinary participant in different periods [?]. T. Chakraborty [?] proposed the citing literature diversity index and summarized the development pattern of interdisciplinary knowledge as "absorption—internalization—output" by combining it with the referenced literature diversity index. Lü Dongqing et al. [?] identified four interdisciplinary patterns in domestic humanities and social sciences through cluster analysis: cohesive, convergent, balanced, and open types, as well as four evolution trends: low-stable, high-stable, sharply fluctuating, and balanced fluctuating. Yue Zenghui et al. [?] described the quantitative characteristics of disciplinary knowledge diffusion from the perspectives of central tendency, dispersion degree, and distribution pattern, and used social network analysis to explore the intermediary characteristics and broker role characteristics of disciplinary knowledge diffusion. Liang Zhentao et al. [?] analyzed the development patterns of interdisciplinary fields using citation relationship networks, examined the relationship structures and role evolution of various disciplines in interdisciplinary fields at different stages, and revealed the evolutionary paths of interdisciplinary fields from a micro-level perspective based on literature citation relationships. The above studies mainly used citation analysis methods to explore the formation processes and development patterns of interdisciplinary fields by constructing measurement indicator models or citation relationship networks, and studied the dynamic evolution and development paths of interdisciplinary fields from a micro-level perspective.

Structural Characteristics of Interdisciplinary Topics and Interdisciplinary Knowledge Identification

With the deepening of interdisciplinary research, focusing solely on the development patterns and evolution processes of interdisciplinary fields can no longer achieve fine-grained mining and exploration of interdisciplinary knowledge itself. Therefore, a series of scholars have begun to study the structure and characteristics of interdisciplinary topics and explore methods for discovering interdisciplinary-related knowledge. L. Li et al. [?] proposed a topic correlation analysis method to extract common and unique topic latent features from multiple disciplines. S. Lafia et al. [?] constructed models and designed science maps based on publications and research projects from the Earth Research Institute at UC Santa Barbara to reveal the potential topic structure of interdisciplinary research at the institute. Li Changling et al. [?] identified cross-research topics by analyzing the core-periphery model of co-word matrices between intelligence science and computer science for mutually cited papers. Yue Zenghui et al. [?] used high-frequency word co-occurrence and high-frequency word-discipline co-occurrence networks to identify hot research topics and cross-research topics in intelligence science and computer science interdisciplinary applications from the perspectives of interdisciplinary field foundations and interdisciplinary correlation foundations. Wu Lei et al. [?] used an improved topic correlation analysis method to extract common and independent topics from agricultural reproductive biology and veterinary medicine, and quantified the correlation between independent topics of the two disciplines using correlation measurement methods. Li Changling and Liu Xiaohui et al. [?, ?] respectively used closed and open non-related knowledge discovery methods, defining discipline A as the target discipline, and obtained interdisciplinary-related knowledge with high integration potential for the target discipline through citation relationships between documents from different disciplines. They defined the interdisciplinary cooperation potential index of topic nodes in target discipline documents and mined potential interdisciplinary cooperation topics. Additionally, some scholars have explored the identification of interdisciplinary-related knowledge based on citation analysis. Zhang Rui et al. [?] measured knowledge flow between disciplines from the perspective of literature citation, extracted interdisciplinary academic terms, and judged their development trends. Du Dehui et al. [?] constructed a discipline-related novelty index based on citation keywords and explored methods for identifying interdisciplinary-related knowledge using library and information science as an example. Pai Yanxin et al. [?] constructed a weak citation association network for interdisciplinary knowledge using target discipline source documents, interdisciplinary references, and interdisciplinary citing documents to identify interdisciplinary-related knowledge combinations. Furthermore, Li Changling et al. [?] identified optimal interdisciplinary-related knowledge pairs by constructing a weak relationship network between target discipline knowledge nodes and interdisciplinary-related knowledge based on friend relationships in scholar blogs.

In summary, mining interdisciplinary research topics and related knowledge can provide ideas and references for further exploring the application of interdisciplinary knowledge and leveraging the potential utilization value of interdisciplinary research. Current studies mainly use topic correlation analysis, co-occurrence analysis, non-related knowledge discovery theory, and citation analysis to mine interdisciplinary research topics and related knowledge. However, few scholars have used direct citation relationships between documents to identify potential interdisciplinary knowledge combinations across different disciplines. Therefore, this study uses citation analysis to explore the identification method of potential interdisciplinary knowledge combinations from the perspective of direct citation relationships, and mines potential interdisciplinary knowledge combinations with greater integration possibility to enrich related methods and approaches for interdisciplinary knowledge discovery.

Identification Path Analysis of Potential Interdisciplinary Knowledge Combinations Based on Citation Relationships

Citations are carriers of knowledge flow between academic achievements. Knowledge discovery methods based on citation relationships can generate more types of associated entities and maintain local consistency [?]. Keywords are important knowledge units that identify document content and are the condensation and extraction of core article content. By analyzing the citation paths of keywords in interdisciplinary references, we can reveal the citation status of interdisciplinary knowledge in target discipline documents [?]. Let the target discipline node document set be S (S={S1,S2,S3,···,SN}), and within the references of S, there exists an interdisciplinary reference set IR (IR={IR1,IR2,IR3,···,IRN}). Let the set of keywords constituting node documents be GK, which contains keywords Kp (p=1,2,···,x), and let the set of keywords constituting interdisciplinary references be GI, which contains keywords Iq (q=1,2,···,y). For the node document set S, GI belongs to the knowledge input side, so interdisciplinary knowledge with high utilization value for the target discipline can be identified from it. [Figure 1: see original paper] shows the identification path for potential interdisciplinary knowledge combinations under citation relationships.

As shown in Figure 1, the interdisciplinary reference keyword set GI contains interdisciplinary knowledge that is relatively novel for the target discipline. Here, the IDN index from the authors' previous research [?] is used to identify related knowledge belonging to other disciplines that has been rarely or not yet applied to the target discipline from this citation relationship. The IDN index is calculated as the product of the citation count of interdisciplinary reference keyword Iq in node document set S and the number of node documents it appears in, divided by the number of documents published in the target discipline with Kp as the theme. IDN index calculation can effectively identify interdisciplinary knowledge with strong relevance and high novelty to the target discipline. Based on the citation relationship between node documents containing Kp and interdisciplinary references containing Iq, Iq representing such interdisciplinary knowledge can be paired with corresponding Kp representing the target discipline knowledge to obtain initial interdisciplinary keyword groups, which are then screened through integration potential indicators and grey relational analysis to obtain potential interdisciplinary knowledge combinations with greater integration potential.

Construction of Integration Potential Evaluation Indicators

As described above, this paper uses the IDN index to obtain interdisciplinary knowledge with strong relevance and high novelty to the target discipline, and matches them through citation relationships to obtain initial interdisciplinary keyword groups. To mine potential interdisciplinary knowledge combinations with higher integration possibility and stronger novelty for the target discipline, we measure the integration potential of initial interdisciplinary keyword groups from three aspects: the citation association between target discipline node document keyword Kp and interdisciplinary reference keyword Iq, the academic research value of Kp, and the potential integration novelty of Kp and Iq, thereby laying the foundation for subsequent identification and screening of potential interdisciplinary knowledge combinations.

(1) Citation Association

In direct citation relationships, the strength of association between Kp and Iq is reflected in the total frequency M of Kp-containing node documents citing Iq-containing interdisciplinary references (hereinafter referred to as Kp citing Iq). The larger the M value, the stronger the citation intensity of Kp citing Iq, and the stronger the association of Iq for Kp, indicating higher possibility of their integration.

(2) Academic Research Value

Many non-targeted interdisciplinary knowledge combinations are generated in citation relationships. Therefore, it is necessary to screen target discipline knowledge with higher academic research value to match with interdisciplinary-related knowledge. The higher the academic research value of target discipline node document keyword Kp in its discipline, the more targeted the potential interdisciplinary knowledge combination formed with corresponding interdisciplinary keywords. This study measures the academic research value of Kp from two aspects: academic influence and academic research activity.

Professor Yu Liping's time factor [?] assigns different weights to indicator objects based on publication time, correcting the impact of citation lag caused by the age of papers on evaluation results. This indicator is referenced to measure the academic influence of node document keyword Kp in the target discipline within a 5-year time window (TIF5), with the calculation formula as follows:

$$\text{TIF5} = \frac{\sum_{d=1}^{5}(C_{t-d} \times d)}{\sum_{d=1}^{5}(E_{t-d} \times d)}$$

In Formula (1), the time window r=5 years, the statistical year is t, C_{t-d} (d=1,2,3,4,5) represents the citation frequency in statistical year t of documents containing node document keyword Kp published d years before statistical year t within the 5-year time range, and E_{t-d} (d=1,2,3,4,5) represents the number of documents containing node document keyword Kp published d years before statistical year t within the 5-year time range. Additionally, to ensure the formula remains meaningful when the number of documents containing Kp in a given year is 0, 1 is added to E_{t-d} in the denominator. In Formula (1), the newer the publication time of documents containing the keyword, the greater the weight.

The number of documents in the target discipline with a theme word is a direct reflection of the research activity of that theme word. Therefore, this paper uses the average annual document volume V_a with node document keyword Kp as the theme within the time window r to represent the overall level of research activity of Kp in the target discipline. Since the time window in this paper is limited to 5 years, the calculation formula is as follows:

$$V_a = \frac{\sum_{d=1}^{5} E_{t-d}}{5}$$

Let W_1 represent the weight of academic influence TIF5, and W_2 represent the weight of academic research activity V_a. Then the calculation formula for the academic research value (ARV) of node document keyword Kp in the target discipline is:

$$\text{ARV} = W_1 \times \text{TIF5} + W_2 \times V_a$$

(3) Potential Integration Novelty

Under direct citation relationships, target discipline node document keyword Kp and interdisciplinary reference keyword Iq may have already integrated, which is reflected in documents as a co-occurrence relationship between the two. Based on this, the stronger the co-occurrence relationship between Kp and Iq in the target discipline, the lower the novelty of the knowledge combination they form, which is less conducive to innovative integration of interdisciplinary knowledge. Let U represent the number of documents in the target discipline with both Kp and Iq as themes. The smaller the U value, the higher the integration novelty of the two. Therefore, the calculation formula for the potential integration novelty (PIN) of Kp and Iq in the target discipline is:

$$\mathrm{PIN} = \frac{1}{U+1}$$

Grey relational analysis is one of the commonly used methods in comprehensive quantitative evaluation research, with advantages such as simple calculation, strong reliability, and low sample size requirements. Therefore, this paper uses grey relational analysis to comprehensively evaluate the three indicators of ARV index, M value, and PIN index, thereby screening potential interdisciplinary knowledge combinations with higher integration possibility.

Data Source and Preprocessing

This paper takes library and information science as the target discipline and selects CSSCI as the source database for node document sets and reference sets, obtaining bibliographic information and reference title information from 9 high-quality journals in library and information science ("Journal of the China Society for Scientific and Technical Information," "Information and Documentation Services,""Information Studies: Theory & Application,""Journal of Intelligence,""Library and Information Service," "Library and Information Knowledge," "Information Science," "Library and Information," and "Modern Information") in 2018. After removing non-academic articles such as "conference notifications" and "topic guidelines"from the journal publications, 2,168 valid node documents in library and information science and 52,401 references were finally obtained. Next, "reference-reference keyword" data that could be obtained in batches were downloaded from VIP, incomplete reference keyword data were supplemented using the CNKI database, and relational data of "node document set-reference document set-reference keyword set" were matched using the relational database MySQL.

Initial Interdisciplinary Keyword Group Matching

This paper uses the journal-discipline classification system of the "Chinese Science and Technology Journal Citation Reports (Expanded Edition)" and

VBA programs to classify references by discipline. After removing library, information, and archive categories, 8,954 Chinese journal references from other disciplinary categories were obtained, and relational data of "node document set S-node document keyword set GK-interdisciplinary reference set IR-interdisciplinary reference keyword set GI" were matched.

Knowledge exchanged between different disciplines mainly includes scientific research methods, processes, thinking modes, and technologies [?]. Therefore, for library and information science, theories, methods, models, algorithms, etc., from other disciplinary fields are knowledge with greater potential utilization value that can often promote interdisciplinary intersection and mutual penetration. Accordingly, this paper uses self-developed programs combined with manual judgment to extract interdisciplinary node document keywords belonging to categories such as "theory," "method," "model," "algorithm," and their synonyms or near-synonyms from the interdisciplinary reference keyword set GI. Using interdisciplinary reference keywords with discipline-related novelty index values greater than or equal to 2 as samples, initial interdisciplinary keyword groups were extracted with them. Statistics revealed that many initial interdisciplinary keyword groups had Kp citing Iq frequency of only 1 (M=1), indicating very weak association and minimal integration potential, so such data were filtered out. After the above processing, some initial interdisciplinary keyword groups are shown in .

Identification of Potential Interdisciplinary Knowledge Combinations

The total frequency M of Kp-containing node documents citing Iq-containing interdisciplinary references was counted, with results shown in column 3 of . Using CNKI' s professional retrieval platform, with 20 source journals in library and information science from CSSCI as the retrieval scope, time window r=5 years, the document volume E_{t-d} (d=1,2,3,4,5) containing Kp in the theme of documents from d years before t=2019 was counted, with results shown in columns 4-8 of ; the citation frequency C_{t-d} of E_{t-d} in statistical year t was counted, with results shown in columns 9-13 of . The data from columns 4-13 of were substituted into Formula (1) and Formula (2) to calculate the academic influence TIF5 and overall research activity level V_a of node document keyword Kp in the target discipline, with results shown in columns 14 and 15 of respectively. The entropy weight method was used to assign weights to TIF5 and V_a, obtaining $W_1 = 19.66\%$ and $W_2 = 80.34\%$. The total ARV index score of Kp in the target discipline was calculated using Formula (3) and SPSSAU analysis software, with results shown in column 16 of . The document volume U with both Kp and Iq as themes in the 20 source journals of library and information science from CSSCI in 2019 was counted, as shown in column 17 of . The U values were substituted into Formula (4) to calculate the PIN index of Kp and Iq in the target discipline, as shown in the last column of , with calculation results rounded to two decimal places.

Observing columns 1-2 of , it can be found that "digital humanities—ACP method," "big data—ACP method," and "intelligence system—ACP method" all correspond to the interdisciplinary knowledge "ACP method." Therefore, this paper uses grey relational analysis to comprehensively evaluate the three indicators of ARV index, M value, and PIN index for initial interdisciplinary keyword groups to obtain interdisciplinary knowledge combinations with higher integration potential. The calculation process is as follows:

(1) Based on the M value, ARV index, and PIN index of initial interdisciplinary keyword groups, the original indicator matrix was constructed, and the maximum values of these three indicators in the sample data were selected to form the reference indicator sequence: $A_0 = (7, 0.86, 1)$.

(2) The standardized sequence matrix of the three indicators was obtained from each indicator data and the reference indicator sequence, with partial results shown in columns 2-4 of .

(3) The absolute differences between corresponding elements of each indicator sequence and the reference indicator sequence were calculated to form the difference sequence $\Delta_{0i}(j)$ of i sample objects and j indicators, as shown in columns 2-4 of . From the difference sequence $\Delta_{0i}(j)$, the maximum difference (the maximum value of all indicator values for sample objects in the difference sequence) and the minimum difference (the minimum value of all indicator values for sample objects in the difference sequence) were obtained. Let the resolution coefficient $\rho = 0.5$, and substitute the values from columns 2-4 of into Formula (5) to obtain the correlation coefficients between indicator sequences and the reference sequence. Among them, the correlation coefficient of indicator M is ζ_1, that of ARV index is ζ_2, and that of PIN index is ζ_3, with partial calculation results shown in columns 5-7 of .

$$\zeta_i(j) = \frac{\min\min\{\Delta_{0i}(j)\} + \rho \times \max\max\{\Delta_{0i}(j)\}}{\Delta_{0i}(j) + \rho \times \max\max\{\Delta_{0i}(j)\}}$$

(5) The entropy weight method was used to assign weights to M value, ARV index, and PIN index, obtaining weights of 73.16%, 22.16%, and 4.68% respectively. The indicator weights and the correlation coefficients of each indicator from columns 5-7 of were substituted into Formula (6) to calculate the relational grade R_i of each initial interdisciplinary keyword group, with calculation results rounded to 4 decimal places.

$$R_i = \sum_{j=1}^{3} w_j \times \zeta_i(j)$$

Based on the magnitude of the relational grade, the initial interdisciplinary keyword group with the largest relational grade was selected from each group with the same interdisciplinary reference keyword as the interdisciplinary knowledge combination with the highest integration potential in that group. Partial results are shown in column 2 of , with their corresponding relational grade R_i values shown in column 3 of .

As shown in , the interdisciplinary knowledge combination with the highest integration potential obtained from the sample dataset is "factor analysis—multi-criteria compromise solution ranking method (VIKOR)." Factor analysis is a quantitative analysis method for objective evaluation that is widely applied in scientific and technological evaluation fields such as universities [?], scholars [?], and journals [?, ?, ?]. However, factor analysis only selects common factors with eigenvalues greater than 1 for evaluation, leading to information loss. The principle of the multi-criteria compromise solution ranking method is to determine positive and negative ideal solutions and prioritize them according to the proximity between evaluation objects and ideal solutions [?]. The multi-criteria compromise solution ranking method can simultaneously consider the maximization of the overall sample and the minimization of individual differences, making evaluation results more reasonable [?]. Therefore, factor analysis can be combined with the multi-criteria compromise solution ranking method to obtain more authentic and reasonable evaluation results while fully utilizing overall sample data.

Additionally, the integration potential of "citation analysis—technology trajectory" is also relatively high. Technology trajectory, also known as technology path, refers to the natural track of technology development. It is the technical evolution path based on explicit choices about technology change directions implied in technology paradigms, or a set of possible technology development directions [?, ?, ?]. In the field of library and information science, technology trajectory theory can be combined with SPC (search path count) and SPLC (search path link count) algorithms in citation main path analysis to explore the formation and evolution of technology themes in knowledge exchange, knowledge evolution, and knowledge mutation processes by leveraging the continuity, finiteness, systematicity, diversity, and exclusivity characteristics of technology trajectories.

Conclusion

With the development of science and technology and the continuous deepening of scientific research, interdisciplinarity has become one of the ways to break free from fixed thinking patterns in single disciplines, injecting fresh blood into solving scientific research problems. This study analyzes the identification path of potential interdisciplinary knowledge combinations based on citation relationships and constructs evaluation indicators for integration potential. In terms of empirical analysis, relational datasets were constructed using publications, references, and citing documents from 9 high-quality journals in library and information science, initial interdisciplinary keyword groups were matched, and grey relational analysis and the entropy weight method were used to identify interdisciplinary knowledge combinations with higher integration possibility in the dataset. However, as an exploratory study of potential interdisciplinary knowledge, this paper only conducts empirical analysis using library and information science as an example, and the application of this method in other disciplines remains to be improved.

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Author Contributions

Du Dehui: Conceptualization, methodology design, data processing, writing and revision.
Liu Chao: Revision and proofreading.

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