Optimization of Digital Library Knowledge Discovery Services Based on Multi-Feature Coupling (Postprint)

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Abstract

[Purpose/Significance] In the big data environment, users' knowledge needs are shifting from fragmented to correlated. Leveraging multi-feature coupling can assist knowledge discovery services in identifying diverse relationships among resources, thereby optimizing knowledge discovery services. [Method/Process] By analyzing the internal and external attribute features of literature, the concept of multi-feature coupling is defined. From a functional perspective, the relationship between multi-feature coupling and digital library knowledge services is analyzed. Integrated with existing knowledge discovery systems, a multi-feature coupling architecture is constructed, and a methodology for enhancing the supply side of knowledge discovery services is proposed based on a three-tier framework of data layer-coupling layer-service layer. [Results/Conclusion] The data layer ensures data quality, with data sources transitioning from single to hybrid; the coupling layer enhances coupling analysis effectiveness, with analysis units shifting from coarse to fine, emphasizing semantic associations between fine-grained units; the service layer prioritizes user interaction experience, developing multi-dimensional visualization functionalities.

Full Text

Preamble

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Research on Knowledge Discovery Service Optimization of Digital Libraries Based on Multi-feature Coupling

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Abstract

[**Purpose/Significance**] In the big data environment, users' knowledge needs are shifting from fragmentation to correlation. Utilizing multi-feature coupling can assist knowledge discovery services in identifying various relationships among resources, thereby optimizing knowledge discovery services. [**Method/Process**] This paper defines the concept of multi-feature coupling by analyzing the internal and external attribute characteristics of literature. From a functional perspective, it examines the relationship between multi-feature coupling and digital library knowledge services. Combining existing knowledge discovery systems, it constructs a multi-feature coupling architecture and proposes methods to enhance the supply side of knowledge discovery services based on three layers: data layer, coupling layer, and service layer. [**Result/Conclusion**] The data layer ensures data quality, with data sources transitioning from single to mixed. The coupling layer improves coupling analysis effectiveness, with analysis units shifting from coarse-grained to fine-grained, emphasizing semantic associations between fine-grained units. The service layer prioritizes user interactive experience and develops multi-dimensional visualization functions.

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In the "big data" era characterized by informatization, networking, and omnimedia, digital library knowledge discovery services employ the latest network tools, theories, and technologies to integrate concepts of association and collaboration. These services enable users to observe information, locate resources, discover knowledge, and match knowledge with users, thereby providing intelligent services related to knowledge [1]. The data-driven wave of big data has prompted user demands to become more fragmented, personalized, precise, and knowledge-oriented. Users no longer wish to waste time and energy screening and interpreting information from massive resources but instead hope to directly obtain fine-grained knowledge in specific domains or refined knowledge systems under particular themes. Moreover, users no longer construct cognition through traditional disciplinary approaches but based on their required knowledge, which involves causal relationships between knowledge output and input throughout its production process. This input-output relationship between knowledge forms the foundation of coupling.

Coupling is a common phenomenon of mutual influence among information resource entities, referring to potential relationships formed between two or more different subjects based on the same object. These potential connections are constituted through common feature items between two entities, with the quantification of feature items reflecting the degree of association between them [4]. Coupling invisibly clusters resource subjects according to their feature units, forming correlation-based knowledge networks centered on specific themes. It

creates interesting connections among knowledge points, lines, and surfaces to reveal implicit knowledge and rules, helping users not only find required knowledge but also discover embedded associations and implications, and excavate valuable intelligence through potential clues to assist in intelligent activities based on knowledge points and their relationships [2]. Therefore, when using digital libraries for retrieval and browsing, users hope to find not only a document but also its position and importance within the entire knowledge system. If we consider a document as a knowledge point, users want to locate not only this point but also the line it belongs to and the surface where that line resides. Meanwhile, big data has transformed traditional data analysis models from hypothesis-testing sample data analysis to real-time discovery of correlations from massive data to determine relationships between entities.

2. Multi-feature Coupling and Digital Library Knowledge Discovery

2.1 Definition of Multi-feature Coupling

The concept of coupling originated from European R.M. Fano [5] and gained widespread attention in the field of informetrics in 1963 when MIT professor M. Kessler proposed "bibliographic coupling." Kessler [6] stated that coupling relationships are established between two or more documents through commonly cited references, with coupling strength determined by the number of shared references. Higher coupling strength indicates closer connections between documents and higher thematic relevance. E. Bassetcoularde et al. [7] further noted that bibliographic coupling not only indicates thematic similarity between documents but also shows research topic similarity among authors. Wang Xun [8] first introduced the concept of bibliographic coupling to China in 1981. Subsequently, Qiu Junping [9] extended Kessler's bibliographic coupling concept to authors, journals, languages, institutions, and disciplines. Zhang Yuwei [10] also argued that although bibliographic coupling originally used documents as coupling units, documents are published by authors in professional journals within their research fields, and each journal has its themes and categories. Therefore, documents, authors, journals, themes, and categories are merely hierarchical differences and can all serve as basic units for bibliographic coupling.

With the development of coupling research, we can utilize coupling relationships to reveal correlations among various feature units such as authors, keywords, full text, journals, and institutions. In informetrics, coupling analysis is essentially a cross-co-occurrence relationship [11], achieving analysis of different feature associations through co-occurrence relationships of identical features in literature. This involves establishing relationships among internal features of these feature items from different dimensions. Each document consists of several feature items, including authors, citations, keywords, journals, etc., which through reasonable combination constitute the main characteristics distinguishing it from other resources [12], with feature items varying according to their attributes.

Therefore, multi-feature coupling proposed in this paper refers to integrating internal and external features of literature to construct coupling relationships with different feature items as subjects (primarily documents themselves and their creators) and using different feature items as objects to measure coupling strength among objects (mainly quantitative analysis of keywords, full text, references, journals, etc.), thereby constructing multi-angle, deep-level coupling relationships to reveal comprehensive knowledge content for users.

External features of literature are mainly reflected in general descriptive metadata that does not involve content, while internal features analyze literature content from citation and knowledge utilization perspectives, focusing on content analysis. The classification is shown in Table 1 .

Table 1 Classification of Internal and External Literature Features

External Features	Internal Features
General descriptive metadata	Content utilization and citation
Knowledge creators	Literature citation relationships
Document carriers (journals, conferences, etc.)	

2.2 Relationship Between Multi-feature Coupling and Digital Library Knowledge Discovery Services

In the big data environment, digital library knowledge discovery services rely on existing system platforms to conduct ubiquitous, semantic, associative, visual, and intelligent hierarchical research on structured, semi-structured, and unstructured data. They deconstruct and mine potential semantic associations among knowledge units and provide services such as knowledge graph presentation, personalized customization, and intelligent evidence-based retrieval decision-making [13]. Peng Jia [14] noted that current knowledge discovery systems are attempting to integrate resources with common features through linked data and semantic technologies, achieving resource organization and aggregation at the semantic level to help users accurately judge internal connections among multi-type resources and achieve intelligent knowledge discovery. Zeng Jianxun [15] formed an "institution-person-research output" relationship graph after normalizing metadata and revealing semantic relationships in scientific literature, fully exposing implicit research and institutional cooperation relationships and enabling semantic-based research literature recommendation and knowledge discovery.

Evidently, knowledge discovery services are developing toward intelligence, semanticization, and association through semantic association and citation coupling of knowledge. Multi-feature coupling reconnects seemingly unrelated subjects through similar features of objects, displaying complex relationships among subjects for users, helping them clarify internal associations among various types of subjects, excavating hidden knowledge, and guiding users to discover new

knowledge structures and patterns. Multi-feature coupling provides knowledge discovery services with multi-perspective analysis of literature resource relationships and deep mining and reorganization of these relationships, offering services such as subject-specific retrieval, personalized knowledge recommendation, exploration of disciplinary knowledge structure and evolution patterns, and knowledge frontier analysis and prediction. Specific functions of multi-feature coupling are shown in Table 2 .

Table 2 Functions of Multi-feature Coupling Analysis

Coupling Type	Function
Document-Reference Coupling	Reveals development patterns and organizational structures of disciplines, providing new approaches for literature retrieval
Document-Publication Time	Explores research directions within fields, reflecting evolution and historical relationships of research directions
Author-Classification Number	Reveals disciplinary categories of literature from professional perspectives, reflecting similarity in authors' professional fields
Author-Journal	Reveals domain knowledge structure, discovers domain themes, and mines common academic communities
Author-Conference	Measures author similarity, discovers potential cooperation relationships, identifies possible research groups, and shows research topic distribution
Author-Citation	Reveals intellectual structure of disciplines, discovers active groups under current research themes, and mines authors' trajectories in disciplinary development

Coupling Type	Function
Document-Citation	Explores knowledge foundations, reveals disciplinary development status, and identifies research frontier hotspots
Content Feature Words	Discovers literature research themes and identifies core documents
Knowledge Unit-Knowledge Unit	Mines intrinsic knowledge structure characteristics of domains

On one hand, multi-feature coupling analysis starts from different utilization situations of literature content. Through quantitative analysis of commonly utilized knowledge units in literature, it measures coupling strength among knowledge units and clusters literature with content similarity based on coupling strength. This enables discovery services to combine literature into small batches of related clusters according to citation situations, providing users with retrieval pathways from the perspective of literature utilization and guiding them to understand relevant literature and expand their reading scope. Coupling based on citation relationships reflects static relationships between documents. Once published, citation frequency is fixed and does not change over time. Measuring similarity among currently published documents through coupling frequency can provide personalized knowledge recommendations for users. When viewing a newly published paper, the discovery system recommends the most relevant and latest papers to users, helping them discover the latest academic information, particularly for users needing cutting-edge information in specific fields. Simultaneously, discovery services can reveal currently active research frontiers in various disciplines through coupling of highly cited literature. Comparing frontier information across different periods can show peaks and troughs of each research frontier, facilitating researchers to select research entry points during the incubation and early rising periods of various fields, helping them choose suitable research directions, enabling users to intuitively grasp development trajectories of research frontiers, understand focal points of professional domain research frontiers, and detect potential and brand-new frontier information.

On the other hand, multi-feature coupling constructs coupling relationships through similarity elements among subjects from the perspective of literature external features. Authors are direct reflections of knowledge resource innovation, and their common academic behaviors reflect connections among their research interests, gathering relevant authors based on the same research theme. Through author groups under the same theme, discovery services reveal disciplinary knowledge structures to users from specific sub-fields, thereby deriving

a bird's-eye view of the intellectual structure of academic communities in these sub-fields. Moreover, author groups formed through high-intensity coupling can be used to search for all relevant literature published by peers in a specific field starting from author names in the coupling author group, and can also provide users with fixed-topic retrieval services for disciplinary research topics. Author coupling is a dynamic structure that changes over time. Discovery services reveal changes in disciplinary hotspots and future development trends from dynamic coupling relationships among authors. When searching for materials, the system can help users discover the most recent and frequently cited literature.

3. Multi-feature Coupling Architecture for Digital Library Knowledge Discovery Services

Currently, digital library knowledge discovery services rely on certain system platforms such as Baidu Academic Search, Chaoxing Discovery System, CNKI KND Knowledge Discovery Network System, VIP Smart Cube Discovery System, and Wanfang "Taozhi" Discovery System. These systems have gradually achieved judgment of macro academic trends, interdisciplinary intersections and impacts, and knowledge regeneration directions, and possess multi-dimensional comparative analysis and research capabilities for academic achievements in specific years, fields, individuals, and institutions. Therefore, combining the definition of multi-feature coupling and its relationship with knowledge discovery services, this paper constructs a multi-feature coupling architecture for knowledge discovery services based on existing knowledge discovery systems. The framework is divided into three layers from bottom to top: data layer, coupling layer, and service layer, running through the entire process from initial data collection and processing to meeting user needs in knowledge discovery systems. See Figure 1 [Figure 1: see original paper].

Figure 1 Multi-feature Coupling Architecture for Digital Library Knowledge Discovery Services

(1) Data Layer: Primarily responsible for data collection and processing. It collects data from different sources to obtain resources such as journal papers, degree theses, and conference papers. During data collection, inconsistencies in data field formats and field names pose difficulties for coupling analysis. The data layer consists of two main steps: First, data preprocessing removes noisy data to obtain knowledge-containing data, which is the prerequisite and foundation for knowledge discovery systems to provide good knowledge services. Second, it establishes standardized, professional knowledge bases from extracted data for later coupling analysis. The data layer first eliminates invalid, missing, erroneous, and duplicate data, uses data auditing to detect data quality, transforms data types, sizes, and units to facilitate conversion and standardization, and integrates target data through reduction, sorting, and sampling to ultimately generate high-quality citation databases, keyword databases, thesaurus databases, author databases, author institution databases, and other professional knowledge bases for accurate identification of resource feature items in

the coupling layer.

(2) Coupling Layer: Primarily responsible for generating multi-feature coupling relationships and associative clustering. Multi-feature coupling relationships are constructed through similarity elements between two subjects and obtained through correlation degrees between objects, with correlation size measured by coupling strength. Greater coupling strength indicates higher similarity and better clustering effects in coupling networks. First, using established knowledge bases, the coupling layer analyzes different feature items of resources through bibliometric methods such as co-word analysis, co-document analysis, and citation analysis to identify similarity elements among subjects and construct coupling paths between different subject resources and object features. For example, it builds document-citation, document-keyword, or author-citation, author-keyword coupling paths from different literature content utilization situations, obtains subject similarity by measuring object coupling strength, integrates strongly associated nodes to construct closely connected knowledge chains, and uses centrality analysis, cohesive subgroup analysis, core-periphery analysis, and temporal analysis to construct coupling knowledge networks [16]. Node distances and densities in networks reflect closeness of connections, thereby identifying core authors and their academic influence, potential academic group cohesion scales, degrees of interdisciplinary theme relationships, histories and trends of disciplinary development, and knowledge exchange and flow. This layer mainly establishes coupling relationships for selected coupling units to form tightly associated coupling networks and uses visualization technology for static and dynamic graphical representation of coupling networks, presenting knowledge domains with visual expression for target retrieval, interpretation, and prediction.

(3) Service Layer: Primarily responsible for connecting users with knowledge discovery systems, serving as the link between user query input and system result output. Currently, knowledge discovery systems can visually display analysis results through graphical representations based on user retrieval strategies and behaviors, providing users with word spectrum diagrams, knowledge point association diagrams, author association diagrams, institution association diagrams, multi-subject comparisons, and citation relationship diagrams. These achieve three-dimensional associations of subject terms, keywords, knowledge points, authors, and author institutions, mine and trace domain research themes, analyze growth directions of academic research across multiple fields, themes, and disciplines, and predict academic development status and future trends, providing auxiliary approaches for users to interpret knowledge contexts, analyze multi-dimensional knowledge, and make intelligent decisions. Simultaneously, through clustering of high-coupling-strength resources, it provides resource recommendations and knowledge services to users based on clustering results, guiding user needs and assisting in personalized services. In this layer, data cleaning and updating in digital library knowledge discovery systems, improvement of relevant databases, comprehensive coupling relationship analysis, and dynamic upgrading of knowledge association graphs all affect service quality

and effectiveness.

4. Optimization of Digital Library Knowledge Discovery Service Multi-feature Coupling

The previous framework for digital library knowledge discovery service multi-feature coupling shows that current knowledge discovery systems possess massive amounts of various resource types and professional, standardized knowledge bases. Through vertical and horizontal mining and analysis of collection resources that reaches deep into intrinsic knowledge relationships, they reveal complex cross-relationships among knowledge and conduct large-scale, multi-dimensional comparative analysis and research on academic achievements in specific fields, years, authors, and institutions, displaying results through visualization. Although these systems can already assist users in intelligent retrieval, personalized recommendation, and academic research assistance, as the information environment changes, user needs have also changed, with higher expectations for knowledge discovery services. In the big data environment, users' knowledge acquisition needs are shifting from coarse to fine and from fragmented to integrated, with obvious characteristics of targeted and refined demands. Users increasingly prefer high value-added services such as in-depth and broad analysis of resources, competitive analysis of knowledge services, prediction of knowledge innovation, and development trends of review services [17]. Meanwhile, users hope that digital libraries provide an interactively friendly, collaboratively associative discovery platform that guides and supports them in discovering unknown knowledge structures and patterns. Therefore, facing continuously evolving user needs, digital library knowledge discovery services should firmly grasp the concept of "environment changes needs, needs reform services," enhance supply-side capabilities, and achieve more effective resource association through optimization of the data layer-coupling layer-service layer architecture to promote discovery and reuse of important resources, helping users create new knowledge and solve new problems.

4.1 Data Layer: Emphasizing Transition from Single to Mixed Data Sources

Reasonable selection of coupling unit sources is the starting point of multi-feature coupling analysis and the foundation for ensuring coupling analysis quality, enabling discovery of truly needed information and providing targeted discovery services. The first step in coupling analysis is quality control of resources in the data layer, particularly addressing author name ambiguity issues in various resource types. Once processed incorrectly, authors and their corresponding information cannot be fully matched, lacking sufficient information to locate and identify authors, causing users to often retrieve irrelevant literature by 同名 authors in other fields. If such data serves as objects for coupling analysis, the obtained data volume will increase, creating additional burdens for later coupling analysis. Therefore, the data layer should emphasize effective data dis-

ambiguation processing to prepare reliable data for coupling analysis and realize its value throughout the analysis workflow. Knowledge discovery systems should conduct standardized control of author names from the data source, primarily adopting methods such as annotating authors' full names, jointly indexing author and institution information, and contact information to identify different author identities [18], helping users accurately locate data. There are also auxiliary measures for confirming author identity from the source, such as using emerging technologies like ResearchID, ThuRID, and fingerprint recognition to objectively assist in author disambiguation.

In the big data environment, digital libraries include not only traditional digital resources such as books, journals, newspapers, and degree theses, but also semi-new resources like free online resources, document-type electronic resources, scientific data, and associative annotation resources, as well as large amounts of new resources such as user behavior data, comment data, log data, and geographic location data. Therefore, coupling analysis for knowledge discovery services should transition from single data sources to mixed data sources, not limited to published journal and conference papers but also comprehensively utilizing data such as science and technology planning texts, research project proposals, academic records, hot topic reports, and user comments that contain recent and forward-looking research ideas as the foundation for building coupling analysis databases. Coupling analysis based on single data sources is one-sided and difficult to meet users' comprehensive information needs, especially for weak information needs with vague questions and unclear knowledge. Using mixed data sources for coupling analysis can establish coupling relationships through multiple resource types, mining connections among various resources to form multi-level coupling networks that reveal associations among homogeneous layer nodes and connections among heterogeneous layer nodes across different resource types [19]. The more network layers, the deeper the associations, enabling clearer identification of knowledge points and structures in problem domains, accurate identification of problems and their relationships, and revealing rich implicit knowledge to meet users' multi-dimensional information needs.

4.2 Coupling Layer: Emphasizing Transition from Coarse-grained Text Analysis to Fine-grained Semantic Association Analysis

In the big data environment, since the cost of publishing data has become low and publishing channels more diverse, users face massive fragmented resources both inside and outside digital libraries, making it difficult to completely obtain and read all relevant resources in their needed domains. This drives users to prefer more refined, semantic, and associative resource acquisition. Current knowledge discovery systems establish coupling relationships based on common points in literature but rarely achieve association at the semantic level, while semantic-level association can overcome semantic heterogeneity among resources and achieve broad association and deep aggregation of resources. Therefore, knowledge discovery systems should select coupling units that delve from

coarse-grained knowledge units to fine-grained knowledge units. In literature, the control unit of coupling shifts from coarse to fine, where large amounts of fine-grained knowledge units and their potential semantic structures in documents will generate knowledge value-added and promote creation of new knowledge. The smaller the granularity of mined knowledge units, the more precise the knowledge represented. Coupling analysis through semantically associated fine-grained knowledge units can excavate potential associations among knowledge units. Knowledge units appear in different positions in literature with varying expressive capabilities for themes. Fine-grained mining and division should comprehensively consider context, including condensed sections expressing themes such as titles, abstracts, keywords, and supplementary keywords, frontier, discussion, and conclusion sections of full texts, as well as positions of paragraphs, sentences within paragraphs, and words within sentences [20]. This can also draw on CNKI Knowledge Element Search, which further mines fine-grained knowledge units such as statistical information, tables, figures, data facts, and innovation points in literature [21]. Using semantic analysis technology to achieve fine-grained mining of resources and vertical-horizontal association based on semantics reveals structural details of research domains for users, providing detailed interpretation of domain content. This transforms digital library knowledge discovery services from traditional user demand-driven to strategic planning and decision-making services, enhancing the precision of digital library decision support.

4.3 Service Layer: Emphasizing Multi-dimensional Visualization Interaction Development

Discovery system services are developed based on multi-source data fusion, fine-grained knowledge unit semantic analysis, and broad association. The presentation of their results affects service effectiveness and places higher demands on visualization performance. In the big data environment, users hope to analyze massive data through benign visualization interaction perception to acquire knowledge, internalize it into wisdom, and make decisions [22]. Therefore, digital library knowledge discovery services should draw on data visualization technologies (integrating computer graphics, image processing, human-computer interaction, etc.) to integrate and analyze massive, heterogeneous, multi-source data. Using graphical elements to represent each data item in multi-source databases, it should generate visualization schemes in a timely manner through graphics, symbols, colors, textures, etc., represent various attribute values of data in multi-dimensional forms, and conduct slicing, blocking, rotation, and other actions for analysis. From multi-dimensional and all-around observation of data, it should extract information, mine potential patterns, analyze meaningful knowledge models, help users discover new knowledge, and transmit knowledge to users in story form for inspiration beyond information acquisition. Meanwhile, to further reflect the distribution, exchange, and cooperation degree of literature, authors, disciplines, and other affiliations across countries and regions, and to vividly demonstrate research levels and focuses of different coun-

tries and regions to more scientific researchers, discovery systems can utilize geospatial analysis methods by embedding Google Maps or Yahoo! geocoding [23] to create visual graphs with geographic location information, enhancing the scientific nature of visualization analysis and prediction. By improving visualization performance, it provides users with good interactive contexts, guides them to obtain valuable knowledge, and assists them in disciplinary tracing, frontier mastery, and core knowledge identification.

In the big data environment, users no longer use digital libraries to obtain more resources through cause-effect knowledge seeking but pay more attention to correlations and relationships among knowledge, making discovery of resource content and their relationships increasingly important for digital libraries. Providing knowledge discovery, knowledge association graphs, personalized recommendations, specialized retrieval, and research decision assistance services has become increasingly urgent. This paper defines multi-feature coupling to construct connections among knowledge points, lines, and surfaces, analyzes the relationship between multi-feature coupling and digital library knowledge discovery services based on its functions, establishes a multi-feature coupling architecture on the foundation of existing knowledge discovery systems, and proposes corresponding optimization suggestions from the data layer, coupling layer, and service layer facing the evolution of user knowledge needs in the big data environment to enhance the effectiveness of digital library knowledge discovery services.

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Author Contributions

Zhang Han: Proposed research ideas and wrote the paper;
Bi Qiang: Proposed the paper framework and refined research ideas;
Ding Mengxiao: Wrote English abstract and revised the paper;

Li Jie: Refined research ideas and revised the paper;
Mu Dongmei: Refined research ideas and revised the paper.

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