Semantic Union Catalog: A Postprint on the Construction of Union Catalogs Based on BIBFRAME 2.0

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Abstract

[Purpose/Significance] As semantic bibliographic models represented by BIBFRAME continue to mature, bibliographic data is undergoing a transformation from MARC to semantic bibliographic formats. This paper explores construction models for union catalogs based on semantic bibliographic data. [Method/Process] First, we analyze the construction models of traditional union catalogs, concluding that traditional union catalog construction methods offer certain reference value in the Semantic Web environment. Second, based on an analysis of the bibliographic information representation format of BIBFRAME 2.0, we propose three models for constructing semantic union catalogs: centralized semantic union catalog, distributed semantic union catalog, and a hybrid semantic union catalog combining centralized and distributed approaches. Finally, we build an experimental platform using Jena Fuseki and Apache HTTP Server to test the interoperability models of semantic union catalogs. [Results/Conclusion] Experimental results demonstrate that the three semantic union catalog construction methods proposed in this study are feasible in practice and can provide valuable references for the implementation of semantic bibliographic data interoperability and cross-database retrieval systems in library and information science departments.

Full Text

Semantic Union Catalog: Construction of Union Catalogs Based on BIBFRAME 2.0

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Abstract

[**Purpose/Significance**] With the continuous improvement of semantic bibliographic models such as BIBFRAME, bibliographic data are undergoing a transition from MARC to semantic bibliographic formats. This paper explores the construction model of semantic union catalogs based on semantic bibliographic data. [**Method/Process**] The study first analyzes the construction model of traditional union catalogs, arguing that while traditional approaches offer valuable insights, they cannot be directly applied in the Semantic Web environment. Based on an analysis of BIBFRAME 2.0's bibliographic information representation, the paper proposes three construction models for semantic union catalogs: centralized semantic union catalogs, distributed semantic union catalogs, and a hybrid model combining both approaches. Finally, an experimental platform was built using Jena Fuseki and Apache HTTP Server to test the interoperability patterns of semantic union catalogs. [**Result/Conclusion**] Experimental results demonstrate that the three proposed construction methods are feasible in practice and can provide valuable references for semantic bibliographic data interoperability and cross-database retrieval systems in library and information departments.

Keywords: union catalogs; BIBFRAME; Semantic Web; linked data

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Since the Library of Congress established MARC standards in 1966, MARC has become the mainstream exchange format for bibliographic data and the cornerstone of current union catalog construction. Despite its widespread application in library and information science, MARC has long faced academic criticism. L. Andresen argued that MARC lacks flexibility, creating barriers for resource description in local and online systems [1]. G. Alemu et al. noted that MARC was designed for documents, making it difficult to describe relationships between non-document entities [2]. R. Tennant, in his influential article "MARC Must Die," pointed out that MARC is confined to the library domain and its data is too flat to express hierarchical relationships between entities [3].

Over the past two decades, organizations such as the Library of Congress and OCLC have made numerous improvements to MARC, developing formats like MARC21 and MARCXML. After the release of RDA, the library community quickly supplemented and modified relevant fields in MARC21 to align with RDA. However, MARC's document-centric design philosophy has become a constraint on its development, and simply mapping MARC fields to XML cannot fully reveal the entities and relationships involved in bibliographic resources. To address MARC's limitations, the library community began exploring the use of linked data for bibliographic metadata description, aiming to establish a more open, scalable bibliographic data exchange standard that can integrate into the Semantic Web environment. The BIBFRAME (Bibliographic Framework) semantic bibliographic model represents a significant step forward in replacing MARC. Although BIBFRAME is still evolving, its influence from the Library of Congress will inevitably impact future union catalog construction models.

1 BIBFRAME and Its Research Overview

BIBFRAME (Bibliographic Framework) is a bibliographic data model jointly developed by the Library of Congress and Zepheira, a data services company specializing in Semantic Web technologies. It aims to describe bibliographic data using linked data to replace MARC. The Library of Congress released the BIBFRAME draft in late 2012 and published the official version in 2014. Following feedback from BIBFRAME applications, the Library of Congress released the revised BIBFRAME 2.0 model and vocabulary in April 2016.

The BIBFRAME 1.0 model included 53 classes and 289 properties (including subclasses and subproperties) [4], with four core classes: Work, Instance, Authority, and Annotation. The Work class reflects the conceptual essence of a work; the Instance class reflects the physical manifestation of a work, where one work can have multiple instances but each instance corresponds to only one work; the Authority class implements authority control for persons, organizations, events, and subjects related to works and instances; and the Annotation class provides descriptive information about works and instances (such as covers, descriptions, reviews, holdings, etc.).

BIBFRAME 2.0 optimized the architecture of BIBFRAME 1.0, comprising 140 classes and 165 properties (including subclasses and subproperties) [5]. The increase in classes and decrease in properties primarily stems from BIBFRAME 1.0's use of multiple properties to represent different types of resources. For example, different identifier types used separate properties like bf:isbn, bf:issn, and bf:lccn. In BIBFRAME 2.0, all identifiers are represented using the bf:identifiedBy property, with identifier types reflected through multiple classes such as bf:Isbn, bf:Issn, and bf:Lccn.

Another significant change in BIBFRAME 2.0 was reducing the four core classes to three: Work, Instance, and Item. The Work and Instance classes maintain the same meaning as in version 1.0, while the Item class represents a holding copy of an instance (either physical or electronic) and reflects information such as location, barcode, and call number. Its concept is similar to the HeldItem subclass of the Annotation class in BIBFRAME 1.0. [Figure 1: see original paper] shows a BIBFRAME 2.0 bibliographic data fragment formalized in RDF/Turtle format. This data includes a work (bf:Work), an instance of the work (bf:Instance), and an item of that instance (bf:Item), defining properties such as title (bf:title), contributor (bf:contributor), ISBN (bf:Isbn), holding library (bf:heldBy), and barcode (bf:Barcode).

Following BIBFRAME's emergence, several foreign institutions and scholars conducted relevant experiments and research. As of April 2016, seven institutions (Library of Congress, British Library, German National Library, Princeton University Library, George Washington University Library, U.S. National Library of Medicine, and OCLC) had released bibliographic test datasets on the

BIBFRAME project platform [6]. Researchers from the Europeana project explored mapping relationships between the Europeana Data Model (EDM) and BIBFRAME [7]. The Linked Data for Libraries (LD4L) collaboration among Cornell University Library, Harvard University Library, and Stanford University Library attempted to create a semantic information storage model for academic resources by integrating linked datasets including BIBFRAME, VIVO, VIAF, and ISNI [8].

Chinese library science research on BIBFRAME began in 2014. Liu Wei and Xia Cuijuan were the first to discuss BIBFRAME's architecture, characteristics, and application fields [9]. A search of Chinese databases revealed that as of April 2016, there were 11 academic papers on BIBFRAME in China, focusing on three aspects: (1) BIBFRAME's architecture and application fields; (2) conversion paths from MARC (CNMARC, MARC21) to BIBFRAME; and (3) comparative studies between BIBFRAME and related models and standards such as FRBR, RDA, and Schema.org. However, application research on BIBFRAME remains limited in China. Xia Cuijuan et al.'s "Design of Genealogy Ontology Based on Bibliographic Framework (BIBFRAME)" is the only study addressing BIBFRAME's application in a specific domain [10], and no research has yet explored union catalog construction models based on the BIBFRAME model.

```
@prefix bf: <http://id.loc.gov/ontologies/bibframe/>.
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#>.
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>.
<http://library.org/resources/work/9406476> a bf:Text, bf:Work;
    bf:title [ a bf:WorkTitle; rdfs:label "Across the river and into the trees" ];
    bf:contributor<http://viaf.org/viaf/97006051>.
<http://library.org/resources/instance/5866658> a bf:Instance;
    bf:instanceOf<http://library.org/resources/work/94064763>;
    bf:identifiedBy [ a bf:Isbn; rdf:value "9780743565172" ].
<http://library.org/resources/item/72616221> a bf:Item;
    bf:itemOf<http://library.org/resources/instance/5866658>;
    bf:heldBy<http://library.org/organization/sample-lib>;
    bf:identifiedBy [ a bf:Barcode;rdf:value "001937362" ].
```

Figure 1 BIBFRAME 2.0 bibliographic data example

2 Analysis of Traditional Union Catalog Construction Models

Union catalogs play a crucial role in interlibrary resource sharing activities such as federated searching, cooperative cataloging, and interlibrary loan. The earliest union catalog dates back to 1898 when ten Prussian university libraries compiled the *Berlin Printed Catalog*. Subsequently, driven by institutions like the Library of Congress, various forms emerged including card catalogs, microfilm catalogs, CD-ROM catalogs, and online catalogs, with online catalogs currently being the mainstream form. From an architectural perspective, traditional online catalogs can be divided into two types: centralized online union catalogs and distributed online union catalogs.

2.1 Centralized Online Union Catalogs

The typical characteristic of centralized online union catalogs is the existence of a central bibliographic database that synchronizes with member libraries' data through specific mechanisms. The key to implementing centralized union catalogs lies in the data synchronization mechanism between the central database and member libraries. Current practices primarily rely on two forms: manual batch synchronization and metadata harvesting. Taiwan's "National Bibliographic Information Network" (NBINet) exemplifies the former. According to NBINet's "Cooperative Cataloging Guidelines," member libraries must periodically or irregularly submit CMARK, USMARK, or MARK21 format files to the Taiwan "National Central Library," which then imports the MARC data into the NBINet database [12].

The CALIS Union Catalog Database also employs a centralized database structure, establishing eight union catalog databases at management and regional centers. These databases maintain quasi-synchronization through "incremental replication" technology (mutual "mirroring") [11].

Metadata harvesting-based online catalogs typically adopt the OAI-PMH protocol, which defines two roles: data provider and service provider. Data providers publish one or more bibliographic data repositories using the OAI protocol, while service providers regularly harvest OAI repositories using OAI-PMH-compatible clients. Currently, openarchives.org lists 3,014 registered data providers [13]. In China, both the CALIS Dissertation Database and the Chinese Academy of Sciences' Institutional Repository Consortium have adopted a model where member libraries build separate databases and the central library harvests them centrally using OAI-PMH [14].

2.2 Distributed Online Union Catalogs

Distributed online union catalogs consist of separate bibliographic databases maintained by different institutions. Search requests are broadcast to multiple institutions through federated search, and returned results are aggregated. Current mainstream distributed online catalogs are primarily based on the Z39.50 protocol, where search clients convert requests into Z39.50 Application Protocol Data Units (APDUs) and broadcast them to multiple Z39.50-compatible servers. Servers decode the APDUs, convert them into their own system search requests, execute queries, and return results using the same method. The Hong Kong University of Science and Technology's "Hong Kong University Libraries Union Catalog" uses Z39.50 to enable distributed searching across eight Hong Kong universities and sixteen foreign institutions [15].

3 Semantic Construction of Union Catalogs

The Semantic Web, proposed by T. Berners-Lee in 1998, aims to add machine-understandable semantics to web documents. In 2006, Berners-Lee introduced the term "linked data" to interconnect RDF data on the Web, ultimately creating a Web of Data. Following these concepts, the library community has continuously explored strategies for bibliographic data semanticization. Current efforts focus on two areas: (1) semanticization of vocabularies and classification schemes, such as the Library of Congress's semantic description (based on SKOS) and linked data publication of the Library of Congress Subject Headings, and the Taiwan "National Central Library's" SKOSification of subject headings and semantic conversion of Chinese book classification for use in its cataloging system [16]; and (2) semanticization of bibliographic datasets, such as the British Library's conversion of the British National Bibliography (BNB) from MARC21 to linked data RDF/XML format with web-based dataset downloads, and German researchers' publication of the DBLP computer science bibliography as linked data using D2R servers [17].

In recent years, as linked data applications have deepened in library and information science, some institutions have begun attempting semantic construction of union catalogs. The Swedish National Library was the first to publish a union catalog as linked data, releasing the Swedish Union Catalogue as linked data in 2008 [18]. OCLC's WorldCat, the world's largest online catalog, has described widely-held works using Schema.org vocabulary and published them as linked data since 2012, with 197 million bibliographic records currently released [19].

Current semantic union catalog construction practices primarily convert existing MARC data, semantically describe bibliographic records using institution-specific ontologies, and publish them in RDF formalizations such as Turtle, RDF/XML, or RDFa. These approaches have limitations: they cannot achieve native semantic union catalog construction; lack semantic data interoperability between union catalogs and member libraries, causing delays in semantic bibliographic data synchronization; and lack standardized semantic bibliographic formats like BIBFRAME for union catalog construction. Therefore, building union catalogs with BIBFRAME as the standard bibliographic data carrier that enables native semantic interoperability is an urgent issue in bibliographic data semanticization.

4 Architecture of Semantic Union Catalogs Based on BIBFRAME 2.0

As discussed, traditional online catalogs can adopt centralized or distributed construction strategies. While these methods offer reference value in the Semantic Web environment, they cannot be simply replicated. Constructing semantic union catalogs based on BIBFRAME 2.0 should leverage BIBFRAME's openness and cross-domain linking capabilities, drawing on traditional online catalogs' OAI harvesting mechanisms and Z39.50-based broadcast query mechanisms. Three construction models can be employed: centralized, distributed, and hybrid approaches.

4.1 Centralized Semantic Union Catalogs

Centralized semantic union catalogs feature a central semantic data repository. As shown in [Figure 2: see original paper], the central repository contains multiple datasets storing BIBFRAME 2.0 triples for works, instances, and items, as well as URI naming authority data for member libraries, collections, and authors. All datasets expose data to member libraries through access-controlled SPARQL endpoints. Each member library also maintains a local BIBFRAME data repository, similarly exposing data via SPARQL endpoints to the central repository.

The key to implementing centralized semantic union catalogs lies in synchronization mechanisms between central and local datasets. Two synchronization forms are possible:

(1) **Batch synchronization**: The central system periodically polls member libraries' SPARQL endpoints to harvest local bibliographic repository data into the central repository. This approach serves as a Semantic Web alternative to OAI-PMH harvesting.

(2) **Incremental synchronization**: This approach integrates semantic union catalog construction with online cataloging. When a member library acquires new holdings, it first queries its local repository for corresponding work, instance, and item information. If none exists, it sends a SPARQL query via HTTP POST to the central repository's SPARQL endpoint. If the central repository contains the resource data, the member library copies it to its local repository; otherwise, it performs original cataloging and synchronizes data to both local and central repositories. To prevent inconsistencies after data updates, a Pingback mechanism can be established between central and local systems, notifying member libraries when central repository data changes. Incremental synchronization effectively prevents duplicate metadata creation, making it particularly suitable for works and instances with strong commonality.

4.2 Distributed Semantic Union Catalogs

Distributed semantic union catalogs eliminate central semantic data repositories, instead storing BIBFRAME data across different institutions. Each institution maintains data for all works, instances, and items in its collection, exposing BIBFRAME data through SPARQL endpoints to external users. When the union catalog receives user search requests, it can send SPARQL queries to each member library and merge result sets, or use SPARQL's federated query mechanism to simultaneously query designated institutions' bibliographic data, deduplicate results, and present them to users. [Figure 3: see original paper] shows a SPARQL query example that uses federated search to retrieve holding copy quantities for a book with a specified ISBN from two libraries.

Distributed semantic union catalogs require minimal architectural adjustments from member libraries and no dedicated synchronization software, making them suitable for resource integration among loosely-coupled library consortia. However, the lack of coordination mechanisms may lead to duplicate construction of work and instance data, creating data deduplication challenges.

```
SELECT ?lib (COUNT(*) as ?itemNum) WHERE {
    SERVICE <http://library1.org/sparql> {
        ?instance bf:identifiedBy ?isbn.
        ?isbnrdf:value "9780743565172".
        ?item bf:itemOf ?instance.
        ?item bf:heldBy ?lib.
    }
} UNION {
    SERVICE <http://library2.org/sparql> {
        ?instance bf:identifiedBy ?isbn.
        ?isbnrdf:value "9780743565172".
        ?item bf:itemOf ?instance.
        ?item bf:heldBy ?lib.
    }
}
GROUP BY ?lib
```

Figure 3 Distributed bibliographic retrieval based on federated query

4.3 Hybrid Centralized-Distributed Semantic Union Catalogs

The hybrid model combines characteristics of both approaches. In this model, common data with strong universality such as works, instances, and naming authorities are managed centrally, while individualized data such as holdings are managed in a distributed manner (see [Figure 4: see original paper]). This approach reduces duplicate resource construction through centralized management of work and instance data while maximizing retrieval coverage across member libraries through distributed collection of holdings data.

5 Experimental Evaluation

To validate the effectiveness of the proposed semantic union catalog construction methods, the author built an experimental platform using Jena Fuseki and Apache HTTP Server for testing. Fuseki is a SPARQL server in the Apache Foundation's open-source Semantic Web framework Jena, featuring a built-in TDB triplestore and providing HTTP REST architecture-based SPARQL endpoint services.

Fuseki includes an Apache Shiro framework-based access control mechanism

[20]. However, testing revealed that its access control primarily targets triple-store management systems rather than SPARQL endpoint services, leaving endpoints exposed and creating data security risks. To address this, the author used Apache HTTP Server's reverse proxy mechanism to construct a reverse proxy pointing to Fuseki server URLs, applying AuthType Basic restrictions to the reverse proxy and thereby covering SPARQL endpoints within the authentication scope.

To test interlibrary interoperability in centralized semantic union catalogs, the author deployed two servers with Fuseki and Apache HTTP Server on a local area network, simulating central and local repositories. A "center" dataset was created on the central repository server and a "local" dataset on the local repository server. Both datasets contained three named graphs—work, instance, and item—to store BIBFRAME 2.0 RDF test data.

Jena ARQ is Jena's SPARQL query engine, providing APIs for basic SPARQL queries, federated queries, and SPARQL updates. The author used Jena ARQ APIs to implement querying and modification of remote semantic bibliographic repositories, enabling operations such as bulk data download and record copying. [Figure 5: see original paper] shows key code for bibliographic data read/write operations (where "admin" and "pw" are authentication credentials, and http://192.168.1.2/center/sparql and http://192.168.1.2/center/update are the query and update SPARQL endpoints wrapped by reverse proxy).

```
/* Data Query */
String queryString = "select * where { graph <http://192.168.1.2/center/work> { <http://lib.
Query query = QueryFactory.create(queryString);
HttpAuthenticator auth = new SimpleAuthenticator("admin","pw".toCharArray());
QueryExecution qexec = QueryExecutionFactory.sparqlService("http://192.168.1.2/center/sparql
ResultSet results = qexec.execSelect();
while (results.hasNext()) { ... }  // Iterate through result set

/* Data Modification */
SimpleAuthenticator("admin","pw".toCharArray());
String updateString = "prefix bf: <http://id.loc.gov/ontologies/bibframe/>" +
                      "insert data { graph <http://192.168.1.2/center/work>" +
                      "{ <http://lib.org/work/98767> a bf:Work. } }"; // Add work data
UpdateRequest update = UpdateFactory.create(updateString);
UpdateProcessRemote updateProcess = (UpdateProcessRemote) UpdateExecutionFactory.createRemot
updateProcess.setAuthenticator(auth);
updateProcess.execute();
```

Figure 5 Bibliographic data read/write operations based on Jena ARQ API

To verify the reliability of distributed semantic union catalog interoperability, the author automatically generated 1,000 BIBFRAME work test records, with 10 instances for each work and 10 items for each instance, totaling 100,000 holdings records. These were distributed across three computers in a wide area network (two on Chinanet, one on Cernet). Another host on Chinanet served as the union catalog server, performing SPARQL queries on the three computers using federated search to retrieve all holdings information for specific works. Experimental results showed that 10 queries for different works all returned correct results with an average response time of 1.2 seconds. However, the experiment also revealed a "barrel effect" in SPARQL federated queries: if one node experiences excessive connection delay or disconnects, the union catalog query times out. Therefore, distributed semantic union catalogs based on federated search are primarily suitable for scenarios with low network latency and few member library nodes. For applications with uncertain network latency or requiring large-scale distributed queries, querying member library SPARQL endpoints separately using Jena ARQ APIs and then merging results would be more appropriate.

6 Summary and Outlook

Compared with traditional union catalogs, semantic union catalogs based on BIBFRAME 2.0 offer two main advantages: (1) They separate bibliographic content revelation from holdings data. In the BIBFRAME model, work data represents abstract content, while instance and item data represent physical manifestations, described separately. In semantic union catalogs, work, instance, and item triples can be stored in different datasets, maintained by different institutions or departments, and integrated during user retrieval. (2) They enhance bibliographic data openness and linking. In the Semantic Web, HTTP URIs serve as entity identifiers. In BIBFRAME bibliographic data, any entity related to books (authors, publishers, libraries, regions) can be identified using URIs, helping break down barriers between traditional library closed systems and the World Wide Web and facilitating mashups with other open datasets.

In response to bibliographic data semanticization following BIBFRAME 2.0's emergence, this study proposes three semantic union catalog construction models—centralized, distributed, and hybrid—based on analysis of traditional union catalog construction mechanisms. These models enable federated querying of semantic bibliographic data across libraries, providing a foundation for BIBFRAME-based cooperative cataloging and interlibrary loan. Experimental validation using BIBFRAME and semantic repositories demonstrates the feasibility of the proposed methods.

This study primarily used automatically generated bibliographic data for testing, without converting large volumes of MARC data or testing with numerous member library nodes across regional networks. Future research will explore CNMARC-to-BIBFRAME 2.0 conversion mechanisms and investigate semantic union catalog applications in cross-regional, multi-node environments.

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