Postprint: Integration and Knowledge Discovery of Seal Resources Based on IIIF and Semantic Knowledge Graphs

Authors: Zhang Yongjuan, Liu Wei, Yu Jianrong, Chen Tao

Date: 2023-04-01T16:15:52+00:00

Abstract

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Full Text

Research on Seal Resource Integration and Knowledge Discovery Based on IIIF and Semantic Knowledge Graph

Zhang Yongjuan[1],[2], Liu Wei[3], Yu Jianrong[2], Chen Tao[3],[4]

[1]Department of Library, Information and Archives, Shanghai University, Shanghai 200444
[2]Shanghai Institute of Nutrition and Health, Chinese Academy of Sciences / Shanghai Information Center for Life Sciences, Shanghai 200031

[3]Shanghai Library / Shanghai Institute of Scientific and Technological Information, Shanghai 200031
[4]School of Information Management, Nanjing University, Nanjing 210023

Abstract: [Purpose/Significance] Image resources in digital humanities research contain substantial information yet remain severely underutilized, as they cannot be effectively shared or reused across heterogeneous databases and applications. The International Image Interoperability Framework (IIIF) breaks down barriers to image resource exchange and sharing. [Method/Process] This study combines IIIF with semantic knowledge graphs (linked data technology) to integrate, share, and discover knowledge from image resources, revealing relationships between resources and enabling knowledge reasoning. Additionally, it implements semantic retrieval based on image features to assist knowledge discovery through feature extraction and recognition using CNNs algorithms. [Result/Conclusion] The paper proposes a comprehensive solution for digital humanities image resource integration and knowledge discovery, and constructs a "Seal Knowledge Center" using seal image resources as an application case to empirically test the feasibility and practicality of the proposed solution.

Keywords: digital humanities; image resource integration; IIIF; linked data; knowledge graph; knowledge discovery
Classification Number: G203
DOI: 10.13266/j.issn.0252-3116.2020.07.015

Digital humanities is an emerging interdisciplinary research field formed by applying modern information technology to traditional humanities research, which has gained widespread attention and sparked a research and application boom both domestically and internationally in recent years. As a non-textual visual medium for conveying information, knowledge, and ideas in digital humanities, images take diverse forms including paintings, photographs, sketches, manuscripts, seals, etc., containing profound cultural connotations, complex spatiotemporal contexts, and relatively abstract conceptual meanings. While domain-specific image annotation models currently facilitate user understanding of images, barriers still exist in sharing, reusing, integrating, and discovering knowledge across different image resources. Images remain trapped within databases, unable to be shared or reused. The International Image Interoperability Framework (IIIF) is still in the exploratory stage domestically, with limited application of international interoperability standards, linked data, knowledge graphs, and related technologies for image resources. The sharing, reuse, integration, and knowledge discovery of images have become important issues urgently needing resolution in China's digital humanities field.

2 Research Status

2.1 IIIF Research Progress in Image Resource Semantic Interoperability

In terms of image data interoperability, foreign research and practical applications are relatively mature. Established in 2015 by 29 non-profit image resource institutions including European and American libraries, IIIF provides unified display and sharing of online resources such as books, maps, scrolls, manuscripts, musical scores, and archives carried by images. Major international cultural heritage research institutions have adopted IIIF for image management and sharing. IIIF addresses issues of discoverability, reinterpretation, reuse, citation, exchange, and comparative analysis of digitized cultural resource images, providing an international universal standard to ensure global image storage interoperability and accessibility.

In data annotation, mature international standards also exist. Open Annotation Collaboration (OAC) was among the earliest international standards proposed to promote standardized annotation, sharing, and reuse. W3C's Open Annotation Data Model (OADM) builds upon OAC by introducing linked data technology, serving as an international interoperability framework for data annotation. Through crowdsourcing, it enables online semantic annotation, allowing digital humanities scholars to add more associations to enrich content, and creates links between resources and annotations based on linked data methods that open data to the internet, enabling platform-wide resource and annotation sharing and openness.

Scholar Zeng Lei has repeatedly proposed at relevant conferences the use of open collaborative annotation and IIIF for deep semantic indexing of images, playing a guiding and promoting role in the domestic application of these international standards. Shanghai Library, Wuhan University, Peking University, Fudan University, and Shanghai Huiyou Cultural Communication Co., Ltd. are actively exploring IIIF-based image management and sharing solutions. While large-scale application reports based on IIIF and linked data for image resources have not yet emerged, technological breakthroughs may soon lead to an explosion of IIIF applications in digital humanities image resources.

2.2 Semantic Knowledge Graphs (Linked Data) in Image Resource Integration and Knowledge Discovery

Knowledge graphs are a technology that uses computers to store, manage, and present concepts and their relationships, which can be divided into semantic knowledge graphs based on RDF storage (i.e., linked data) and generalized knowledge graphs based on graph databases. Semantic knowledge graphs (linked data) focus on knowledge publishing and linking, while generalized knowledge graphs emphasize knowledge mining and computation. Linked data represents the continuation and development of Google's Knowledge Graph, and the combination of rich graph operations in generalized knowledge graph re-

search with linked data will usher in a new era for digital humanities research. In library and information science and digital humanities, semantic knowledge graphs (linked data) are more frequently discussed.

Semantic knowledge graphs (linked data) and IIIF complement each other, playing important roles in image resource integration and sharing. Resources such as Voltaire's letters and Leonardo da Vinci's manuscripts use linked data and IIIF for semantic organization and publishing of their image resources. LinkedCanvas provides an image semantic annotation sharing solution that serves as an important supplement to Synaptica's Open Annotation Semantic Indexing System (OASIS). It uses linked data technology, vocabularies, and IIIF to enrich image content with ontologies, establishing an organization, association, and sharing framework for non-textual data and annotation data in the global cultural heritage community based on linked data platforms (LDP), W3C's OADM data model, and IIIF semantic interoperability framework. This enables annotations to be shared across different hardware and software platforms.

Advances in machine learning/neural network algorithms and other artificial intelligence (AI) technologies are also driving the development of semantic knowledge graphs (linked data), IIIF, and image semantic retrieval in digital humanities. The "Venice Time Machine" project by EPFL's Digital Humanities Laboratory uses machine learning algorithms to dynamically digitize Venice's centuries of history, recreating the city's glorious republican era and revealing the social networks, trade, and intellectual development across Europe at that time.

Domestic research on linked data includes numerous reports and papers in professional journals, with practical applications mainly concentrated on textual data. Shanghai Library has launched a series of linked data application platforms including a genealogy knowledge base, ancient books evidence-based platform, and celebrity manuscript knowledge base. Zeng Ziming applied linked data technology to the linked display of Dunhuang visual resources. Hou Xilong et al. used linked data for intangible cultural heritage knowledge management research. These studies can also be viewed as knowledge graph applications, though most systems use linked data technology for metadata-level knowledge organization and publishing, rarely employing knowledge graph concepts to reveal relationships between resources and enable knowledge reasoning. The China Biographical Database Project (CBDB) uses knowledge graph concepts to display rich kinship and social relationships between individuals, forming a unique social network that can reveal implicit relationships through inference rules. However, practical cases of using IIIF, semantic knowledge graphs (linked data), etc., to achieve image resource integration, sharing, and reuse are still rare.

Overall, foreign mature practice cases that simultaneously apply linked data, IIIF, and AI technologies such as machine learning algorithms for text and image resource integration and knowledge discovery have gained peer recognition and represent an important future direction for digital humanities research. Do-

mestic research primarily focuses on using linked data technology to describe and study textual metadata, with limited application research on IIIF and semantic knowledge graph (linked data) based image resource integration and knowledge discovery in digital humanities, presenting technical challenges and significant obstacles. Therefore, this study attempts to apply IIIF, semantic knowledge graphs (linked data), and other semantic technologies to overcome technical difficulties and establish feasible solutions for image resource integration, implicit relationship revelation, and knowledge discovery.

3 Solution for Image Resource Integration and Knowledge Discovery

Through investigation and analysis of successful foreign practices, this study proposes a solution for image resource integration and knowledge discovery. Using seal image resources as application objects, we constructed a "Seal Knowledge Center" to verify the feasibility and practicality of the solution, achieving integration of seal image resources with other resources and knowledge discovery through semantic knowledge graphs.

This solution primarily involves IIIF-based image metadata description and semantic knowledge graph (linked data) based knowledge discovery. The IIIF-based image metadata description includes Image API, Presentation API, and image annotation. The semantic knowledge graph (linked data) based knowledge discovery includes KOS/ontology construction, linked data publishing services, semantic indexing, and semantic annotation, while also leveraging deep learning methods for image retrieval to ultimately achieve resource integration, knowledge graph presentation, and knowledge discovery services. The solution architecture is shown in Figure 1 [Figure 1: see original paper].

3.1 Image Metadata Description Based on IIIF and OADM

The International Image Interoperability Framework (IIIF) defines a set of common API specifications that support interoperability between image repositories. At the most fundamental system level, it resolves incompatibility issues between hardware and operating systems. IIIF currently has four standard APIs that can be used for image metadata specification, image presentation, semantic annotation and sharing, and semantic retrieval, with the ability to extend new APIs as needed.

The "Image API" can be used as part of the image cataloging process, specifying the source, region, size, rotation, quality, and format of requested images through URIs. The "Presentation API" specifies a web service that returns JSON-LD structured documents describing the structure and layout of digital objects, enabling comparison of multiple images and online user annotation with provenance and controlled sharing. Its structure includes: collection, manifest, sequence of all pages, canvas, annotation, and digital content, allowing each image annotation to be assigned a unique HTTP URI for online access and an-

notation. This enables image delivery and provenance-based sharing on existing systems, ultimately allowing recombination of numerous resources for multiple reuses.

The "Search API" supports searching annotation content within a single IIIF resource. The "Authentication API" describes a set of workflows for guiding users through existing access control systems.

Annotation is the act of establishing associations between different pieces of information. W3C's OADM Open Annotation Data Model provides an extensible, interoperable framework for expressing annotations, enabling easy sharing across platforms to meet even the most complex requirements in the simplest way. OADM defines namespaces for its classes and properties, which remain constant even if the ontology changes. All versions of the ontology remain accessible from version-specific URLs, and the namespace URI provides access to the latest version.

The combination of OADM and IIIF Search API enables structural organization and reuse of images (see Figure 2 [Figure 2: see original paper]). Open annotation data content is annotated on the IIIF Presentation API canvas, allowing annotation of entire canvases or partial regions with arbitrary shape selection. Annotations support online collaboration by individuals or groups and can be opened to users in crowdsourcing form. The canvas, as a new interactive layer linked on the Web with a unique URI, allows anyone to annotate anything anywhere—whether web pages, e-books, videos, images, audio streams, or data in raw or visualized forms—enabling linking and sharing of annotation content across different services while maintaining traceability to their origins for search and discovery.

The use of international open standards such as IIIF and OADM lays the foundation for implementing image semantic retrieval and knowledge graph construction. Our team has conducted meaningful trials and explorations using IIIF Image APIs and OADM annotation in the image resource integration and knowledge discovery solution and the "Seal Knowledge Center," achieving deep zoom and online invocation of seal images through URIs specifying source, region, size, rotation, quality, and format. Using the IIIF Presentation API to describe seal resource structure and layout enables comparison of multiple seal images and online user annotation with provenance-based controlled sharing. OADM open annotation data content is annotated on canvases, currently using whole-canvas annotation. Future work can adopt crowdsourced multi-user online collaboration for deeper regional annotation or character-based annotation using OCR; implement IIIF Search API for image retrieval, annotation retrieval, and text retrieval of seal images; and extend the Authentication API if needed for access control (see Figure 3 [Figure 3: see original paper]).

3.2 Knowledge Organization of Image Description Content and Linked Data Publishing

(1) Knowledge Organization of Image Description Content. This solution uses ontologies for knowledge organization of image description content. During ontology design, existing ontology classes and properties are reused whenever possible. Following this principle, the seal ontology reuses classes and properties defined under namespaces such as shl and foaf (see Table 1). Additionally, the seal platform extends "owner" to link seal platform resources with Shanghai Library's name authority database, while using sameAs and owner to connect with other datasets.

(2) Linked Data Publishing of Image Description Content. This model uses the SinoPedia Linked Data Publishing Platform (SinoPedia Platform, LDSP) [14] to publish image content as five-star linked data (see Figure 4 [Figure 4: see original paper]). LDSP is our team's prior research achievement that can function both as an independent knowledge base for resource retrieval and as a Linked Data Hub to publish multi-source linked datasets, providing content negotiation services for related resources.

LDSP's linked data transformation service (LDTS) converts unstructured, semi-structured, and structured data into linked data stored in a triplestore (OpenLink Virtuoso). The linked data query service (LDQS) provides SPARQL endpoints for different datasets, supporting SPARQL federated queries. The linked data publishing service (LDPS) supports single LODVIEW platform access to multiple SPARQL endpoints, displaying resources from different sites on SinoPedia and providing linked data content negotiation services (primarily RDF/XML, JSON-LD, NT, TTL). LODVIEW is a Spring and Jena-based web application that can publish RDF data according to linked data publishing standards together with SPARQL endpoints, publishing image metadata according to the five-star data model standards. The linked data knowledge service (LDKS) integrates the LODLIVE module to achieve knowledge integration and knowledge graph visualization of linked multi-source datasets [16].

The five-star linked data knowledge base constructed through this model supports development of various applications and data calls. This semantic (concept) and linked data knowledge base-based retrieval method enhances semantic content associated with image resources.

Integration and fusion of different dataset resources primarily uses OWL properties such as sameAs and seeAlso, with sameAs being widely used to connect entities that are the same across ontologies. The LDKS service extracts sameAs relationships from major datasets into a central pool (a graph storing sameAs relationships) as network infrastructure for a central "mapping" layer, uniformly and dynamically harvesting sameAs properties and establishing bidirectional links between related datasets. When other external datasets establish links with any dataset in the central repository, they automatically acquire sameAs relationships with related datasets.

Persons are the core element of the seal platform. When constructing the seal knowledge graph, we primarily use seal owners as the core association object for linking and fusing information between different data sources. External linked data knowledge bases include datasets from the Linked Open Data Cloud (LOD) such as LOC, VIAF, and DBpedia, as well as Shanghai Library's open name authority files, ancient books knowledge base, SinoPedia, and CBDB.

(3) Image Resource Integration, Knowledge Graphs, and Knowledge Discovery. Semantic knowledge graphs (linked data) are essentially semantic networks formed by interconnected knowledge points that support knowledge discovery, indexing, and visualization by search engines. This study uses the LDKS provided by the LDSP platform (see Figure 4) to implement knowledge graph and knowledge discovery applications. The knowledge graph and visualization technologies provided by LDKS can integrate multi-source datasets from different knowledge bases (including linked datasets in LOD and those published by Shanghai Library). The published linked data knowledge base can associate and fuse with external linked data knowledge bases, which provide richer associations and semantic enhancement for image descriptions and offer knowledge sources for knowledge graph visualization, ultimately enabling knowledge discovery across datasets and helping users mine and analyze implicit knowledge from linked data to provide multi-dimensional knowledge services (see Figure 5 [Figure 5: see original paper]).

(4) Image Retrieval and Knowledge Discovery Based on Machine Learning. OCR recognition of non-textual image content is difficult, and seal images often contain traditional and ancient characters, adding to OCR challenges. This study attempts to use deep learning methods for image feature recognition and extraction to ultimately achieve image retrieval, using AI to assist knowledge discovery.

Convolutional Neural Networks (CNNs) are a deep supervised machine learning model with strong adaptability, excelling at mining local data features, extracting global training features, and classification. Its weight-sharing network structure makes it more similar to biological neural networks, achieving excellent results across pattern recognition fields. Compared with image classification methods based on SIFT, HOG, and other features, CNN-based methods have stronger high-level semantic abstraction capabilities, along with natural translation invariance and trained scale invariance within certain ranges—essential characteristics for image classification.

This model adopts the deep CNN model VGG16 proposed by Oxford University's VGG group for image feature extraction. It improves upon AlexNet's larger convolution kernels by using consecutive small kernels instead, as stacked small kernels outperform large ones because multiple non-linear layers increase network depth to learn more complex patterns at lower cost (fewer parameters), achieving good results in image classification tasks (see Figure 6 [Figure 6: see original paper]).

By using the VGG16 model to extract features from seal images, a seal image feature library is formed. On the user end, images used for retrieval also undergo feature extraction using the VGG16 model, which are then compared and retrieved against the seal image feature library to complete image-based retrieval. Users can select images from relevant retrieval results based on deviation scores. Each image integrates cross-repository related resources. Clicking presents relationships between different resources through knowledge graphs, and further clicking enables visual queries through knowledge graphs for knowledge discovery, as shown in the example in Figure 7 [Figure 7: see original paper].

4 Application Case Analysis of the Image Resource Integration and Knowledge Discovery Solution

Seals represent a distinctive and research-significant image category. Beyond standalone seal images, they widely exist in large scroll paintings and can be annotated and marked as parts of scrolls. Seal images contain much information beyond seal script, including holder biographical information, historical context of seal usage, and seal evolution. These deep-level contents can greatly enrich seal information through semantic annotation, facilitating image resource integration and knowledge discovery. To verify the solution with sample data, we constructed the "Seal Knowledge Center," which currently includes 15,053 seals from figures including Aisin-Gioro Hongli, Zhang Daqian, Dong Qichang, etc., achieving integration and linking between the seal knowledge base and Shanghai Library's name authority database, ancient books knowledge base, and CBDB [17].

This section uses 160 seals related to Dong Qichang in the "Seal Knowledge Center" as an application case to analyze and validate the model's usability and effectiveness. Users can log in to the "Seal Knowledge Center" to access more data and knowledge discoveries about other figures. Dong Qichang (1555-1636), styled Xuanzai, was a prominent official and famous calligrapher/painter in the late Ming Dynasty. The "Seal Knowledge Center" contains 160 seals related to Dong Qichang, currently including seal script and owner information. Before age 50, Dong Qichang used name seals including "Dong Qichang" (16 seals), "Dong Qichang Yin" (43 seals), and "Dong Shi Xuanzai" (20 seals). Between ages 50-59, he added "Qi Chang Zhi Yin" (1 seal) and "Dong Xuanzai" (12 seals). Between ages 60-69, he added "Qi Chang" and "Xuanzai" (21 seals) and "Si Bai." Starting at age 69, he used the "Chang" character seal, and after age 80 used the "Si Weng" seal (2 seals).

The Seal Knowledge Center can discover implicit relationships and underlying knowledge across linked knowledge bases through SPARQL federated queries. As shown in Figure 8 [Figure 8: see original paper], through SPARQL federated queries and the extended "owner" property, the seal platform links with Shanghai Library's name authority database, which through a sameAs graph links with the CBDB knowledge base, thereby discovering the implicit knowledge

that “Dong Qichang’s wife was Cheng Xiu of the Ming Dynasty.”

The SPARQL federated query statement implementing the reasoning process in Figure 7 is as follows:

```
SERVICE <http://cbdb.library.sh.cn/sparql>{
PREFIX owl:<http://www.w3.org/2002/07/owl#>
PREFIX shl:<http://www.library.sh.cn/ontology/>
PREFIX rdfs:<http://www.w3.org/2000/01/rdf-schema#>
PREFIX foaf:<http://xmlns.com/foaf/0.1/>
SELECT ?name ?dynasty WHERE{
SERVICE <http://data.library.sh.cn:8890/sparql>{
?seal a shl:Seal;
shl:sealCharacters"董 氏 玄 宰 7"@cht;
shl:owner ?owner.
?owner owl:sameAs ?uri.
?rel a shl:Relationship;
shl:relationLabel'妻 子';
shl:relationSubject ?uri;
shl:relationObject ?obj.
?obj foaf:name ?name;
shl:temporal/shl:dynasty ?dynasty.
FILTER(lang(?name) ='cht')
FILTER(lang(?dynasty) ='cht')
```

In addition to supporting SPARQL federated queries, the seal platform supports visual semantic queries based on knowledge graphs, enabling federated queries across different knowledge bases by clicking different nodes on the knowledge graph. As shown in Figure 9 [Figure 9: see original paper], clicking different nodes can query Shanghai Library’s name authority database and CBDB knowledge base, visually revealing on the knowledge graph that “Dong Qichang’s wife was Cheng Xiu of the Ming Dynasty.” Clicking different nodes can also query Shanghai Library’s ancient books knowledge base to discover two ancient books related to Dong Qichang: *Huang Ting Jing* and *Bai Hua Ting* Ming manuscript copies.

The discoveries that “Dong Qichang’s wife was Cheng Xiu of the Ming Dynasty” and the two related ancient books *Huang Ting Jing* and *Bai Hua Ting* Ming manuscript copies obtained through the seal platform cannot be achieved by traditional databases, further validating the usability and effectiveness of the image knowledge organization model for image semantic enhancement.

5 Summary and Outlook

This paper conducts in-depth research and exploration on the application of IIIF, linked data, and knowledge graph technologies in digital humanities image resource integration and knowledge discovery. Centering on image data characteristics, it proposes a comprehensive solution for image resource integra-

tion and knowledge discovery. Starting from underlying data construction using linked data open standards, the solution supports reuse of domestic and international open linked datasets, combines IIIF and OADM international standards to achieve interoperability of image resources between the "Seal Knowledge Center" and other collection institutions, and enables controlled sharing and reuse with provenance.

Compared with the internationally renowned LinkedCanvas image semantic annotation sharing solution, this solution focuses on IIIF and knowledge graph (linked data) based image resource integration and knowledge discovery. In terms of image content semantic annotation, it implements whole-image annotation based on the OADM data model, successfully exploring an IIIF and OADM-based solution for image resource annotation, association, and sharing. Future research can apply this to online multi-user collaborative partial image annotation and sharing for deeper knowledge discovery, providing researchers with more convenient online collaborative academic research environments.

This solution can be applied to digital humanities image resource integration, sharing, and knowledge discovery including seals and paintings, as well as digital humanities research platform and environment construction, holding significant meaning for promoting semantic construction of library collections, special collections, and ancient book image resources.

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Author Contributions:
Zhang Yongjuan: Framework design and paper writing;
Liu Wei: System planning and guidance, revision suggestions;
Yu Jianrong: Framework guidance, revision suggestions;
Chen Tao: Algorithm guidance, system implementation.

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