Research on the Construction of a Knowledge Graph for Qing Dynasty Sacrificial Ritual Vessels Based on Archival Documents (Postprint)

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Abstract

[Purpose/Significance] China's sacrificial culture boasts a long history traceable to the pre-Qin era, wherein sacrificial ritual vessels embody the beliefs of worshippers. This study constructs a knowledge graph of Qing Dynasty sacrificial ritual vessels based on the "Imperially Endorsed Illustrated Collected Statutes of the Great Qing" and "Illustrated Regulations for the Ritual Paraphernalia of the Imperial Court," thereby accelerating the digital development of Qing Dynasty archival documents and addressing the challenges posed by the scattered distribution and underutilization of sacrificial-related archival materials from the Qing period.

[Method/Process] This study employs knowledge graph methodologies to construct an ontology model for Qing Dynasty sacrificial ritual vessels through knowledge modeling. It utilizes knowledge acquisition to systematically organize and extract entities, attributes, and relations from the "Imperially Endorsed Illustrated Collected Statutes of the Great Qing" and "Illustrated Regulations for the Ritual Paraphernalia of the Imperial Court." The knowledge of Qing Dynasty sacrificial ritual vessels is represented using RDF triples, followed by knowledge fusion of multi-source data, and subsequently stored via the RDF data model to build the knowledge graph, enabling knowledge discovery through graph querying.

[Results/Conclusion] The research reveals that knowledge graph visualization can clearly present the knowledge associations among Qing Dynasty sacrificial ritual vessels. SPARQL queries further demonstrate that the colors of these vessels carry specific meanings and exhibit indirect connections with sacrificial locations.

Full Text

Preamble

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Abstract:
[**Purpose/Significance**] China's sacrificial culture has a long history, traceable to the pre-Qin era. Sacrificial vessels carry the beliefs of worshippers. This study constructs a knowledge graph of Qing Dynasty sacrificial vessels based on *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty*, which can accelerate the digital development process of Qing archival documents and address the challenges of dispersion and difficult utilization of Qing sacrificial archives. [**Method/Process**] This research employs knowledge graph methodologies to construct an ontology model for Qing sacrificial vessels through knowledge modeling. Knowledge acquisition was used to organize and extract entities, attributes, and relationships from *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty*. Qing sacrificial vessel knowledge was represented using RDF triples, followed by knowledge fusion of sacrificial vessel knowledge from different sources. Finally, Qing sacrificial vessel knowledge was stored using an RDF data model to build the knowledge graph, enabling knowledge discovery through retrieval. [**Result/Conclusion**] The study found that knowledge graph visualization can clearly present knowledge associations among Qing sacrificial vessels. SPARQL queries revealed that colors of Qing sacrificial vessels have specific meanings and are indirectly linked to sacrificial locations.

Keywords: Qing Dynasty; sacrificial vessels; knowledge graph; archival documents
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Sacrificial vessels were objects used by ancient nobility in ceremonial activities, symbolizing the power and status of users and carrying worshippers' devotion to celestial gods, earthly deities, and ancestors. They became primary carriers for ancient people to entrust their beliefs, thus their shape, size, decoration, and materials all needed to conform to the harmony of heaven, earth, and humanity. Sacrificial vessels underwent tremendous changes from their emergence in primitive society through slave society to feudal society. During the Shang and Zhou dynasties, jade and bronze ware dominated, but after the Qin and

Han dynasties, bronze gradually exited the historical stage. By the Qing Dynasty, the final feudal dynasty in Chinese history, sacrificial vessels developed to primarily include jade, porcelain, wood, and copper. The Qing Dynasty left behind numerous relatively complete archival documents related to sacrificial vessels, which hold profound significance for reflecting Qing sacrificial culture and even social institutions.

In the era of rapid information technology development, archival resource development increasingly relies on computer technology. Humanities scholars have introduced digital humanities technologies such as linked data, knowledge graphs, geographic information systems, and the International Image Interoperability Framework (IIIF) into library, information, and archival science, achieving fruitful results. This study takes Qing archival resources including *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty* as research objects and employs knowledge graph technologies to develop Qing sacrificial vessel knowledge.

1 Literature Review

1.1 Ontology and Knowledge Graph Research in Document-Based Knowledge Development

With the continuous development of semantic technologies, theoretical and applied research on semantic ontologies and knowledge graphs has matured. Knowledge development based on documents has become a focus in library, information, and archival studies. Leveraging the strong semantic expression, knowledge reasoning, and data association capabilities of ontologies and knowledge graphs can promote domain knowledge integration, implicit knowledge development, and cross-domain resource sharing.

(1) Knowledge Graph Theory Research: Scholars such as Chen Tao et al. distinguished concepts among knowledge maps, knowledge graphs, and graph databases, arguing that literature 计量-based knowledge maps cannot be called knowledge graphs. Semantic knowledge graphs based on linked data are true knowledge graphs, while graph database-based knowledge graphs are broad knowledge graphs [1]. Cao Qian elaborated on the implementation process, key technologies, and application progress of knowledge graph technology [2]. Yuan Man integrated domestic and international metadata and ontology standards, proposing a five-layer standard system for knowledge graph construction to avoid “knowledge silos” [3].

(2) Ontology Research: Zhu Yanxin et al. built an evidence-based medical literature ontology based on FAIR principles using protégé modeling tools, facilitating better organization, utilization, and presentation of internal document characteristics and promoting the development of relevant databases and semantic webs [4]. He Lin et al. explored ontology construction methods for pre-Qin classics using natural language processing technology, proposing an automatic ontology instance acquisition method verified with *Zuo Zhuan* [5]. Li Yueyan et al. used semantic web technology to construct a historical event ontology model based on historical event texts and designed a retrieval system [6], improving historical text utilization efficiency.

(3) Knowledge Graph Application Research: Ouyang Jian constructed a classical knowledge graph from model, demand, and application layers, comprehensively and systematically describing bibliographic information of major Chinese classical works [7]. Zhou Lina et al. built the KnowPoetry Tang Poetry knowledge service platform based on a Tang poetry knowledge graph, achieving functions such as knowledge exploration, semantic retrieval, and spatiotemporal trajectory [8]. Y.T. Wei et al. manually constructed classification vocabularies based on Tang poetry texts, combined them with modern Chinese descriptions and annotations, built a Chinese classical poetry knowledge graph, and applied it to reasoning and analysis [9]. Ding Heng et al. designed and implemented a standard literature knowledge service system based on knowledge graphs and ontological retrieval, improving standard literature information service quality [10]. S. Liu et al. constructed a knowledge graph of ancient Chinese history and culture using knowledge extraction, fusion, and visualization technologies based on structured, semi-structured, and unstructured historical text data [11].

(4) Image Resource Domain: Scholars introduced the International Image Interoperability Framework (IIIF) and associated it with knowledge graphs, enabling new breakthroughs in semantic retrieval and resource sharing. For example, Chen Tao and Zhang Yongjuan et al. proposed a semantic framework for image resources [12], combining semantic knowledge graphs with IIIF to achieve image resource integration, sharing, and semantic retrieval based on image features [13], promoting openness and association of image resources in libraries, archives, and museums, and providing new ideas for linking Qing sacrificial vessel image resources in this study.

Drawing on the above research, this study follows the knowledge graph construction process of knowledge modeling, acquisition, representation, fusion, and storage. It uses Uniform Resource Identifiers and Resource Description Framework (RDF) to build a semantic knowledge graph based on linked data and simulates knowledge graph visualization and retrieval applications through front-end frameworks and back-end query endpoints.

1.2 Research on Qing Dynasty Sacrificial Vessels

Research on Qing Dynasty sacrificial vessels is concentrated domestically, with few directly related studies. More scholars focus on indirectly related topics such as "ritual vessels" and "sacrifice." Zhang Ke explored social concepts embedded in Qing musical instruments from a ritual-music perspective [14]. Yang Liuyue analyzed design concepts of Qing porcelain ritual vessels from perspectives of shape, glaze color, object combinations, and Confucian culture, exploring their significance for modern porcelain design [15]. Gao Jiyang thoroughly discussed the evolution trajectory and influencing factors of ancient vessel shapes, constructing a series of genealogical diagrams [16]. Fang Qiushi investigated Qing sacrificial ritual norms from the perspectives of *Da Qing Tong Li* and *Da Qing Lu Li* [17]. X.L. Jiang analyzed the textual context of *Imperially Commissioned Manchu Sacrificial Rituals to Heaven*, examining Manchu sacrificial ceremonies recorded in different document versions and exploring Qing rulers' attitudes toward Shamanic rituals [18].

The above studies show that Qing sacrificial vessel research adopts humanities perspectives, with relatively weak digital and knowledge-based research. Whether exploring Qing sacrificial laws, vessel shapes, or social concepts, most use qualitative research methods, making comprehensive and fine-grained studies of sacrificial vessels difficult. The introduction of digital humanities technologies breaks the limitations of traditional research methods affected by information quantity and precision. Therefore, this study integrates different types of Qing sacrificial vessel knowledge from *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty*, applies knowledge graph technologies, addresses the dispersion and difficult utilization of Qing sacrificial vessel archives, and provides convenience for users to understand Qing sacrificial vessels and utilize related archives.

2 Data Sources and Research Design

2.1 Data Sources

This study primarily uses content recorded in *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty. Da Qing Hui Dian* (Collected Statutes of the Qing Dynasty) has five editions compiled at different times. This study references the fifth compilation of *Imperial Assembly Graph of Qing Dynasty*, completed in the 25th year of the Guangxu reign and compiled by Kun Gang and others under imperial order. It records sacrificial ceremonies, vessels, court assemblies, banquets, musical regulations, instruments, and dances, serving as illustrated explanations of related content in *Da Qing Hui Dian*. The complete work comprises 40 cases and 270 volumes, with 22 volumes missing. This study mainly uses volumes 21-25 on sacrificial vessels. *Ritual Vessel Schema of the Imperial Dynasty* was compiled by Qing Dynasty officials including Yun Lu and Jiang Pu, recording sacrificial vessels, instruments, crowns and clothing, musical instruments, ceremonial insignia, and military equipment, with both text and illustrations in 18 volumes. This study references volumes 1 and 2 on sacrificial vessels. To ensure completeness and accuracy of the Qing sacrificial vessel knowledge graph, this study also references *Imperial Assembly of Qing Dynasty* (Siku Quanshu edition), volumes 36-50 on auspicious rituals, and other related archival documents.

2.2 Research Design

Based on *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty*, this study constructs a knowledge graph of Qing sacrificial vessels using knowledge graph theories and technologies. The research framework is shown in Figure 1 [Figure 1: see original paper]. Logically, the Qing sacrificial vessel knowledge graph can be divided into a conceptual layer and a data layer. The conceptual layer forms the foundation of the knowledge graph, expressing and storing the conceptual layer through knowledge modeling to build the Qing sacrificial vessel ontology. The data layer is the instantiation of the conceptual layer, constructed through knowledge acquisition, representation, fusion, and storage.

First, knowledge acquisition integrates sacrificial vessel-related textual content from *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty*, extracts sacrificial vessel knowledge, and represents it as structured data, including entity extraction, attribute extraction, and relationship extraction of Qing sacrificial vessels.

Next, the extracted entities, attributes, and relationships of Qing sacrificial vessels are represented in a computer-understandable and learnable form through RDF for fine-grained expression of Qing sacrificial vessel knowledge.

Then, knowledge contained in and related to *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty* is fused.

Finally, the Qing sacrificial vessel knowledge graph is stored in an RDF database. The application layer visualizes the knowledge graph, sets up server query endpoints, designs and simulates retrieval functions for the knowledge graph, and enables knowledge discovery.

2.3 Research Tools

In the knowledge modeling phase, this study uses TopBraid Composer for ontology modeling to construct classes, properties, and relationships of the Qing sacrificial vessel ontology, add instances, and conduct entity association. Compared with other tools like protégé, TopBraid Composer supports both ontology description language and conceptual-level modeling, has a broader audience, and features more concise and standardized underlying data storage that better complies with W3C Semantic Web standards.

Both retrieval and visualization of the Qing sacrificial vessel knowledge graph are based on the Apache Jena Fuseki server. Fuseki is a server provided by Jena that supports SPARQL query language for knowledge graphs, usable for knowledge graph storage, management, and retrieval. This study sets up a knowledge graph query endpoint (SPARQL Endpoint) through the Fuseki server. On one hand, it simulates retrieval functions for the Qing sacrificial vessel knowledge graph; on the other hand, it uses Python tools to interconnect front-end and back-end data, combined with Web front-end technology to achieve knowledge graph visualization.

3 Construction of Qing Dynasty Sacrificial Vessel Knowledge Graph

3.1 Knowledge Modeling

Knowledge modeling is the process of constructing the conceptual layer of the Qing sacrificial vessel knowledge graph—that is, building the Qing sacrificial vessel ontology model—which forms the foundation for knowledge graph construction and application. This ontology is built based on *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty*. Attribute data such as vessel shape and color come from their records, ensuring reliability of the knowledge graph. It serves both users with utilization needs for Qing sacrificial vessels and those needing related archival content. To ensure ontology model accuracy, this study combines manual modeling with the "seven-step method" to construct the Qing sacrificial vessel ontology model.

(1) Determine the scope of the Qing sacrificial vessel knowledge graph ontology. Taking *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty* as primary references, the study focuses on vessels used in Qing sacrificial activities.

(2) Search for reusable ontologies. Reuse involves referencing classes or properties in an ontology through URIs provided by ontology builders. This study searched for relevant classes and properties through ontology service centers. Results showed reusable concepts in FOAF (Friend of a Friend), Time Ontology, and Shanghai Library's Genealogy Ontology, including reusable classes such as "Organization," "Person," "TemporalEntity," "Interval," "Instant," and reusable properties including "firstName," "lastName," "courtesyName," and "inXSDDate." Reusing existing ontology concepts reduces repetitive definition, avoids conceptual divergence, improves Qing sacrificial vessel ontology quality, and promotes semantic association with external ontologies, advancing knowledge sharing.

(3) Enumerate important elements of the Qing sacrificial vessel ontology. Based on *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty*, Qing sacrificial vessels can be summarized as having important data attributes such as color, shape, size, material, and decoration, as well as object properties including sacrificial location, sacrificial object, and usage in sacrifices.

(4) Define the Qing sacrificial vessel ontology classification system. Classify the enumerated elements to determine classes and parent-child relationships involved in Qing sacrificial vessels. Establishing class hierarchies generally includes top-down and bottom-up approaches; this study adopts a top-down method, starting from top-level concepts of Qing sacrificial vessels and gradually refining to form a systematic classification system. Under the default "owl:Thing" class, seven classes are established: "Sacrificial Vessel," "Place," "Archival Document," "Sacrifice," "Person," "Organization," and "Temporal

Entity." Among them, "Sacrificial Vessel" is divided by material into seven categories including "Jade Ware" and "Woodware"; "Sacrifice" is divided according to *Imperial Assembly of Qing Dynasty* into "Grand Sacrifice," "Medium Sacrifice," and "Group Sacrifice"; "Person" is divided based on historical existence; "Organization" is subdivided by establishment time; and "Temporal Entity" reuses "Interval" and "Instant" from the Time ontology (see Table 1). Through constructing this two-level classification system, real-world things are abstracted into concepts, enabling the Qing sacrificial vessel ontology to better reflect reality through symbols.

(5) Define Qing sacrificial vessel ontology properties and relationships. Based on defined vessel classes, data properties (DatatypeProperty) and object properties (ObjectProperty) are defined. Data properties enrich feature descriptions of instances, helping users understand characteristics of knowledge graph instances and assisting semantic retrieval. Object properties establish connections between instances to support associated retrieval, knowledge recommendation, and knowledge discovery. This study primarily defines properties for classes such as sacrificial vessels and archival documents. Data properties include name, image, shape, material, decoration, color, and size. Object properties include placedAt, savedAt, heldIn, referTo, and subConceptOf.

(6) Define Qing sacrificial vessel ontology constraints. Constraints limit property domains and ranges—that is, subjects and objects. Data property constraints are shown in Table 2 , where "name," "otherName," "image," and "description" serve as universal data properties with domain set to "owl:Thing," usable by all classes to avoid repetitive definition of identical properties. Other subjects are relevant classes, with ranges generally being string types. For large texts and attributes unsuitable for text representation (such as images), the range is set to URI for resource location, facilitating multimedia resource storage, reducing storage requirements for the knowledge graph, and promoting interconnection and sharing of data from different sources. Temporal entity-related properties are set to corresponding temporal data types. Object property constraints are shown in Table 3 , where "subConceptOf," "equalTo," "reference," and "time" have domain set to "owl:Thing" (subjects can be any class), "subConceptOf" and "equalTo" have object set to "owl:Thing" (objects can be any class), while other object properties limit specific classes as subjects and objects. Constraining domains and ranges of data and object properties reduces arbitrary property addition, ensures the knowledge graph is clear and readable, facilitates ontology reuse and rewriting, and enables the knowledge graph to more accurately reflect the real world.

(7) Establish the Qing sacrificial vessel ontology. Based on defined classes and properties, the study uses TopBraid Composer ontology modeling tool to create relevant classes and properties based on RDF, RDFS, and OWL data models, stored in human-readable and machine-readable Turtle format. The ontology structure is shown in Figure 2 [Figure 2: see original paper], where dark-background properties and nodes are reused external properties and classes, lighter-background ones are custom properties and classes, and the "Thing" node is the top-level class node.

3.2 Knowledge Acquisition

Most referenced archival documents are in digitized image format. Figure 3 [Figure 3: see original paper] shows images of sacrificial vessel "Jade Cang Bi" from *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty*. Comparison reveals that the two compilations adopt different classification methods: the former classifies by sacrificial vessel type, with descriptions of the same vessel type varying by location or sacrifice, while the latter uses a "location-vessel" classification standard, explaining vessel names, shapes, meanings, and some historical evolution according to relevant classics. *Imperial Assembly Graph of Qing Dynasty* records sacrificial vessels more comprehensively, while *Ritual Vessel Schema of the Imperial Dynasty* provides more detailed descriptions of specific vessels.

Digitized archival document images are unstructured data with irregular structure and no predefined metadata, making data processing difficult. Therefore, this study transcribes images into text format and extracts entities, attributes, and relationships from text data according to classes and properties defined in the Qing sacrificial vessel ontology model. Although scholars have proposed knowledge extraction technologies for unstructured text using machine learning and natural language processing [19], *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty* were compiled in the Qing Dynasty with semantics and syntax differing from modern texts, containing rare characters and lacking annotated text. Existing knowledge extraction methods perform poorly, and the text volume is relatively small. To ensure data accuracy and accumulate training and test data for future Qing archival knowledge extraction research, this study adopts manual knowledge extraction, storing it in two-dimensional table format for RDF mapping. Knowledge acquisition forms the foundation for data layer construction, and its quality determines the quality of knowledge representation, fusion, and storage. Taking the archival document images shown in Figure 3 as an example, entities such as Jade Cang Bi, Temple of Heaven Main Position, and Prayer for Grain Altar Main Position can be extracted along with their relationships and attributes like color and size (detailed information shown in Figure 4 [Figure 4: see original paper]). This study extracted 415 sacrificial vessel entities, 95 location entities, and 40 archival document entities from *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty*, supplementing sacrifice, person, organization, and temporal entities according to relationships—for example, supplementing author "Zuo Qiuming" based on *Zuo Zhuan*, and supplementing sacrificial object "Haotian Shangdi" (Supreme Deity of Heaven) based on "Temple of Heaven Main Position."

3.3 Knowledge Representation

The Qing sacrificial vessel knowledge graph uses the RDF data model to represent knowledge as <entity, attribute, value> or <subject, predicate, object> triples for machine understanding. Each entity corresponds to a node, and predicates correspond to directed edges. Multiple triples integrate to form a directed graph of nodes and edges. Using the knowledge extraction results shown in Figure 4 as an example, according to classification standards of the two source documents, vessels with the same name used at different locations are treated as different vessels. Therefore, only "Jade Cang Bi" used at "Temple of Heaven Main Position" is used as an example, with results shown in Figure 5 [Figure 5: see original paper]. "Entity-entity" associations can be represented as <Jade Cang Bi_{01}, placedAt, Temple of Heaven Main Position> and <Jade Cang Bi_{01}, referTo, Imperial Assembly Graph of Qing Dynasty>, while "entity-attribute" relationships are represented as <Jade Cang Bi_{01}, shape, round> and <Jade Cang Bi_{01}, color, cang (dark blue)>.

3.4 Knowledge Fusion

Fusing multi-source heterogeneous Qing sacrificial vessel knowledge requires identifying and integrating conceptual equivalence, hierarchical, and progressive relationships through knowledge fusion at both conceptual and data layers. Conceptual layer fusion is cross-ontology alignment or matching, integrating equivalent classes, subclasses, or properties between this study's ontology model and other ontology models. This can determine similarity between this study's ontology and other published ontologies to discover more similar knowledge. Data layer fusion includes linking Qing sacrificial vessel knowledge graph entities with external knowledge graphs and disambiguating internal entities within the knowledge graph. The former uses logical terms like "owl:sameAs" for association, while the latter eliminates entity diversity and ambiguity. For example, "Jade Cang Bi" is called "Jade Cang Bi" in *Imperial Assembly Graph of Qing Dynasty*, "Cang Bi" in *Ritual Vessel Schema of the Imperial Dynasty*, and "Jade Bi" in reality. Meanwhile, "Jade Cang Bi" can be used in multiple contexts. Therefore, unique identifiers are assigned to sacrificial vessels, with "name" and "otherName" properties assisting identification for entity disambiguation. The concept "Temple of Heaven" includes "Circular Mound Altar" and "Prayer for Grain Altar," with directional concepts like "main position," "accompanying position," and "subordinate position." Thus, the "subConceptOf" property associates "Temple of Heaven" with its sub-concepts. Entity linking achieves association of multi-source heterogeneous data, while entity disambiguation enables more accurate and comprehensive semantic retrieval.

3.5 Knowledge Storage

This study adopts RDF storage based on Linked Open Data (LOD) to store the Qing sacrificial vessel knowledge graph, offering standardization and lightweight advantages. It does not depend on specific software—only a query endpoint is needed to use SPARQL query statements for retrieval, making queries convenient. Through open query endpoints, cross-domain queries of the knowledge graph can be achieved, offering advantages in data association and knowledge sharing. Using the knowledge represented in Figure 5 as an example, specific storage content is shown in Figure 6 [Figure 6: see original paper]. To distinguish vessels with the same name used at different locations, entities are stored with unique identifiers (IDs). Combined with URI prefixes, they form unique URIs locating each entity. The "name" and "otherName" properties assist identification and query. For example, the Jade Cang Bi used at Temple of Heaven Main Position has ID "Jade Cang Bi_{01}," name "Jade Cang Bi," and other names "Cang Bi" and "Jade Bi." This storage method ensures entity URI uniqueness, avoids node relationship confusion, and facilitates subsequent retrieval applications.

4 Application of Qing Dynasty Sacrificial Vessel Knowledge Graph

4.1 Graph Visualization

Visualization is a fundamental application of the Qing sacrificial vessel knowledge graph. Using directed graphs, it clearly displays inter-node relationships and overall graph characteristics, such as parent-child, equivalence, and sibling relationships among entities of the same class, and associations between different entity classes. By following relationships between nodes, adjacent nodes can be found sequentially to discover associated information. For example, from "Jade Cang Bi_{01}," adjacent location node "Temple of Heaven Main Position" can be discovered, and from there, all sacrificial vessels used at that location can be found. Alternatively, from "Temple of Heaven Main Position," the parent node "Temple of Heaven" can be found to explore all sibling nodes of "Temple of Heaven Main Position" and their associated sacrificial vessels, thereby discovering all vessels used in sacrifices at the Temple of Heaven.

Knowledge graph visualization methods are diverse, including graph databases, Web frontends, knowledge graph visualization software, and social network analysis tools, each with advantages and disadvantages. This study adopts a Web frontend approach using force-directed layout for visualization (see Figure 7 [Figure 7: see original paper]). The graph contains mostly sacrificial vessel, archival document, location, and person nodes: 415 sacrificial vessel nodes, 40 archival document nodes, 95 location nodes, and 11 person nodes. The overall network centers on "Imperial Assembly Graph of Qing Dynasty," with all sacrificial vessels directly associated with it. Location nodes are mostly directly associated with sacrificial vessels. Thus, 415 sacrificial vessel nodes are distributed in the inner layer around "Imperial Assembly Graph of Qing Dynasty," with 105 vessels directly referencing *Ritual Vessel Schema of the Imperial Dynasty*, which in turn references other documents like *Mencius*, *San Li Tu*, and *Zuo Zhuan*, resulting in small clusters of sacrificial vessel and archival document nodes around the "Ritual Vessel Schema of the Imperial Dynasty" node. Location nodes are distributed around sacrificial vessels.

Through knowledge graph visualization, the knowledge structure of Qing sacrificial vessels and their associations with background documents are clearly presented. For sacrificial vessel users, it enables quick understanding of knowledge associations among Qing sacrificial vessels and facilitates finding data on dimensions and shapes for deeper understanding. For archival users, it enables rapid access to overall document content and quick location of specific knowledge points. When users have no clear browsing purpose, the Qing sacrificial vessel knowledge network can provide inspiration and unexpected information. Compared with other visualization methods, Web frontend is easier for secondary development. Subjects, predicates, and objects in the Qing sacrificial vessel knowledge graph are mostly URI-based, and the Web is a common way to access URIs, offering data interconnection advantages. Thus, Web frontend-based visualization facilitates future utilization and research, while the Web's rapid dissemination, wide reach, and convenience can promote dissemination of research results and improve utilization efficiency of Qing archival documents.

4.2 Graph Retrieval

Retrieval is another application of the Qing sacrificial vessel knowledge graph. Retrieval methods vary by storage method—for example, SQL for relational databases and Cypher for Neo4j graph databases. This study uses RDF storage, thus adopting SPARQL query language.

Compared with visualization, retrieval enables more accurate and faster location of required nodes, attributes, and relationships. For example, given node "Jade Cang Bi_{01}," to find its placement location and all vessels at that location, the query statement shown in Figure 8 [Figure 8: see original paper] can be used at the query endpoint. Retrieval results are shown in Figure 9 [Figure 9: see original paper], with ten results including Jade Cang Bi. The results show that this vessel is placed at Temple of Heaven Main Position, along with vessels such as bamboo baskets and gourd wine vessels, clearly displayed in two-dimensional table format.

4.3 Knowledge Discovery

Using the above retrieval functions, not only can associated nodes be quickly retrieved, but implicit information under knowledge associations can also be discovered. This study explores the association between sacrificial vessel color attributes and usage locations.

4.3.1 Retrieval Design Knowledge discovery first designs generic retrieval statements based on different locations. In the Qing sacrificial vessel knowledge graph, the Temple of Heaven has multiple concept hierarchy levels. Therefore, a generic retrieval statement is designed using the Temple of Heaven as an example. The Temple of Heaven comprises the Circular Mound Altar and Prayer for Grain Altar. *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty* do not clearly distinguish between the Circular Mound Altar, Prayer for Grain Altar, and Temple of Heaven. For example, *Imperial Assembly Graph of Qing Dynasty* records "Jade Cang Bi" placement locations as both "Temple of Heaven Main Position" and "Prayer for Grain Altar Main Position," with overlapping concepts but identical vessel attributes. Therefore, this study does not discuss conceptual distinctions in detail, recognizing that the Temple of Heaven has sub-concepts like "Circular Mound Altar," "Prayer for Grain Altar," "Temple of Heaven Main Position," "Temple of Heaven Subordinate Position," etc., while "Temple of Heaven Subordinate Position," "Circular Mound Altar," and "Prayer for Grain Altar" also have numerous sub-concepts. Thus, the generic retrieval statement is designed to retrieve three-level concepts: "concept → sub-concept → sub-sub-concept" to ensure retrieval recall. The retrieval statement is shown in Figure 10 [Figure 10: see original paper].

4.3.2 Discussion of Retrieval Results Using the generic retrieval statement to query the Temple of Heaven, Altar of the Sun, Altar of the Moon, and Altar of Earth and Grain, results show that most sacrificial vessels at the same location share the same color: cyan for the Temple of Heaven, red for the Altar of the Sun, white for the Altar of the Moon, and yellow for the Altar of Earth and Grain. This indicates some direct or indirect association between sacrificial vessel colors and locations.

Taking the Temple of Heaven as an example, Table 4 shows retrieval results. Among sacrificial vessels with color descriptions in the two source documents, most vessels placed at the Temple of Heaven are cyan or dark blue, except for "Fengxian Silk" and "Lishen Silk." Location alone cannot associate sacrificial vessels with colors, so associated classes—Sacrifice and Person—must be examined. From the associated classes, sacrifices at the Temple of Heaven are mostly grand sacrifices to heaven, primarily worshipping "Haotian Shangdi." Zheng Xuan and Jia Gongyan annotated in *Zhou Li Zhu Shu*: "For ritual objects, they must resemble their class… Heaven uses dark color because both dark and black are celestial colors, thus using dark color" [20]. Rituals for "Heaven" should follow Heaven's color—cyan. Similarly, the Altar of the Sun worships the Sun God "Great Brightness Deity," using red; the Altar of the Moon worships the Moon and stars, using white; the Altar of Earth and Grain worships the Earth God and Grain God, using yellow.

Among Temple of Heaven sacrificial vessels, "Fengxian Silk" is placed at accompanying positions, which generally worship imperial ancestors. In ancient Chinese concepts, white represents solemnity for revering the deceased, thus "Fengxian Silk" uses white. Similarly, "Lishen Silk" is placed at subordinate positions to worship various deities, such as the Sun God, Moon God, Big Dipper, Five Planets, 28 constellations, all stars, and weather deities. Meanwhile, the five colors "cyan, red, yellow, white, black" also symbolize yin-yang and the five elements [21], with the five elements' mutual generation considered auspicious, thus using all five colors to worship celestial deities. Therefore, SPARQL retrieval discovered that sacrificial vessel color attributes have indirect associations with placement locations. Combined with sacrifices and sacrificial objects, different colors represent different meanings, connecting originally unrelated knowledge and achieving the knowledge discovery function of the Qing sacrificial vessel knowledge graph.

Conclusion

Knowledge graphs, as a research hotspot in digital humanities, have semantic and knowledge-based characteristics. This study organized knowledge related to sacrificial vessels from *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty*, constructed a Qing sacrificial vessel knowledge graph through knowledge modeling, acquisition, representation, fusion, and storage, and visualized it using Web frontend technology. The knowledge network of Qing sacrificial vessels and their associated background documents is clearly presented. At the same time, a knowledge graph query endpoint was created, SPARQL query language was used for retrieval, generic retrieval statements were designed to analyze associations between sacrificial vessel colors and locations, cultural meanings behind colors were analyzed, and implicit knowledge associations among Qing sacrificial vessels were explored.

Linked data-based knowledge graphs have good scalability. The Qing sacrificial vessel knowledge graph constructed in this study has vertical and horizontal applicability and inclusiveness. Vertically, sacrificial vessels recorded in documents from different dynasties or different ruling periods of the same dynasty can reuse this ontology for temporal association to form a larger-scale knowledge graph. Horizontally, the ontology's classes, properties, and relationships can be expanded to apply to other rituals recorded in documents (military rituals, guest rituals, etc.) or other objects (musical instruments, weapons, etc.). For example, "Hui" (conductor's baton) used in Qing Zhonghe Shaoyue music can reuse decoration, size, and function properties, while "Bells" can add "inscription" properties.

The constructed Qing sacrificial vessel knowledge graph has limitations in instance quantity and construction technology. The sacrificial-related content recorded in *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty* is limited, focusing mainly on sacrificial vessels and locations, with relatively few descriptions of persons, sacrifices, etc., resulting in a lack of related entities. Knowledge modeling and acquisition methods mostly adopt manual approaches, offering high accuracy but low development efficiency. Future work will optimize the knowledge graph construction process, expand content vertically and horizontally, and truly achieve cross-domain knowledge association.

Overall, this study constructed a Qing sacrificial vessel knowledge graph based on Qing archival documents, proposing an ontology model expandable to different dynasties and objects, providing a foundation for subsequent construction of complete sacrificial vessel or Qing ritual object knowledge graphs. Through the knowledge graph, it provides convenience for scholars exploring Qing sacrificial vessels, thereby supporting digital scholarship. It also achieves aggregation of various document resources to some extent through Qing sacrificial vessels as intermediaries, reduces utilization difficulty of specialized documents, expands user groups, lowers barriers for interdisciplinary scholars, and enriches digital development outcomes of Qing archival resources.

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Author Contributions

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Research on the Construction of Knowledge Graph of Sacrificial Vessels in Qing Dynasty Based on Archival Documents

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Abstract:
[**Purpose/Significance**] Chinese sacrificial culture has a long history, traceable to the pre-Qin era. Sacrificial vessels carry the beliefs of worshippers. This study constructs a knowledge graph of Qing Dynasty sacrificial vessels based on *Imperial Assembly Graph of Qing Dynasty* and *Ritual Vessel Schema of the Imperial Dynasty*, which can accelerate the digital development process of Qing archival documents and solve the problems of dispersion and difficult utilization of Qing sacrificial archives. [**Method/Process**] This research adopts knowledge graph methods, constructing an ontology model for Qing sacrificial vessels through knowledge modeling, extracting entities, attributes, and relationships from the two source documents through knowledge acquisition, representing Qing sacrificial vessel knowledge using RDF triples, performing knowledge fusion of multi-source knowledge, and finally storing the knowledge using RDF data model. Knowledge discovery is achieved through graph retrieval. [**Result/Conclusion**] The study finds that knowledge graph visualization can clearly present knowledge associations among Qing sacrificial vessels. SPARQL queries reveal that colors of Qing sacrificial vessels have specific meanings that are indirectly related to sacrificial locations.

Keywords: Qing Dynasty; sacrificial vessels; knowledge graph; archival documents