Ontology Construction and Evaluation for Chinese Traditional Culture: Towards Digital Humanity

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Abstract: Against the background that the top-level semantic framework of Chinese traditional culture is not comprehensive and unified, this study aims to preserve and disseminate cultural heritage information about Chinese traditional culture through the development of a domain ontology which is constructed from ancient books. A combination of top-down and bottom-up approaches was used to construct the ontology for Chinese traditional culture (CTCO). An investigation of historians' needs, and LDA topic clustering model were conducted, understanding the specific needs of historians, collecting the topic, concepts and relationships. *CIDOC CRM* was reused to construct the basic framework of CTCO. Ontology structure and function were adopted to evaluate the effectiveness of CTCO. Evaluation results show that the ontology meets all the quality criteria of OntoMetrics, and the experts agreed on content representation (average score = 4.30). CTCO contributes to the organization of traditional Chinese culture and the construction of related databases. The study also forms a common path and puts forward proposals for the construction of domain ontology, which has great social relevance.

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1.0 Introduction

As a part of cultural heritage, traditional culture is the record, research and interpretation of the past events and activities of human society. As a major branch of world culture, Chinese traditional culture has high ideological and cultural value. In depth research into Chinese traditional culture is conducive to understanding the development process of national and world history, and promoting cultural exchanges between China and foreign countries. The forms of cultural heritage include not only material cultural heritage such as museum collections, historical buildings and human cultural sites, but also intangible cultural heritage such as folk literature, traditional music and traditional skills. Whether in content or form, ancient books are an important carrier of cultural heritage. They are an important carrier and historical precipitation of Chinese traditional culture, loaded with the traditional factors and basic elements of Chinese culture and thought (Zhou 2015; Gu 2018).

In the field of Chinese traditional culture, the construction of a cultural heritage knowledge base through semantic web technology based on ancient books has become a new hot spot in recent years, with examples such as the China Biographical Database Project (Harvard et al. 2018), the China minzu cultural resources (http://www.minwang.com.cn/) and so on. As a conceptual model and modeling tool, ontology can describe cultural heritage resources at semantic and knowledge levels, and has been widely employed in the field of history. At present, the *CIDOC CRM* ontology, which has been certified by the international ISO standard, is widely reused by cultural resource organizations such as museums and archives. It can effectively realize the knowledge expression of cultural heritage resources and realize the information exchange and integration between heterogeneous cultural knowledge.

However, the knowledge in Chinese traditional culture is huge in scale, diverse in form and wide in source, and there are differences in database construction methods, standards and norms. At present, most of the cultural heritage knowledge bases are based on documents or people, time and place, and lack event centered expressions of traditional cultural knowledge. There is also a lack of a unified expression framework of Chinese traditional cultural knowledge, leading to a clear semantic gap between the low-level features and high-level semantics of Chinese traditional cultural resources (Wang et al. 2014). From the user's point of view, the real value of a cultural resource database is to achieve the rapid, distant and co reading of humanities research (Wang et al. 2020). But there is no ontology for Chinese traditional cultural knowledge. And the definition of concept type and relationship of *CIDOC CRM* has strong pertinence, so it is difficult to fully meet the needs of fine-grained and semantic expression of Chinese traditional cultural knowledge.

This study, therefore, constructs the description framework of Chinese traditional cultural knowledge based on the ancient books, including 24 classes and 142 properties around event, actor, place, time and object; this covers the content involved in Chinese traditional cultural events, and enables the machine to understand the semantics in the form of the ontology. This paper also creates a general pathway for the construction and evaluation of cultural heritage ontology. Differently from the thematic database, we have more comprehensively identified the reorganization and reasoning of cultural heritage resources based on existing research. It will help users to locate Chinese traditional cultural knowledge quickly, accurately, and comprehensively. The specific path is as follows: using a survey of historians' needs, and a LDA topic clustering model to achieve concept clustering from bottom to top, reusing the ontology such as *CIDOC CRM* to build ontology framework from top to bottom, and finally forming the ontology of Chinese traditional culture. In addition, this study evaluates the ontology of traditional Chinese culture by using the indicators of attribute richness, inheritance richness, etc., ontology coverage and task fit from ontology structure and ontology function.

2.0 Related research

2.1 Knowledge expression of Chinese traditional culture

There have been many knowledge expression methods since *Qi Lue* initiated bibliographic organization with literature as the unit in ancient China. In the first half of the 20th century, Harvard-Yenching instituted the sinological index office, introduced western indexing ideas and compiled the unique book style word by word index to ancient books—*Sinology Index Series*, which deepened the description of knowledge from literature to vocabulary. The development of modern information processing technology provides new vitality for the organization and description of Chinese traditional culture. Chinese library and information departments have designed a metadata description scheme for ancient texts, rubbings, epigraphs etc., and constructed a database for different literature resources, such as the Chinese memory database project (http://www.nlc.cn/cmptest/), Chinese genealogy knowledge base (https://jiapu.library.sh.cn/#/), China biographical database project and so on (Zeng et al. 2018; Xia et al. 2016; Xu 2017). With the development of computer technology, users have a more fine-grained and semantic need for traditional cultural knowledge. Ontology, metadata and knowledge mapping technology have also been employed to reveal traditional Chinese culture (Zhou et al. 2017). For example, Shanghai Library has designed an ontology for genealogy resources (Xia et al. 2016), Zhonghua book company presides over the twenty-four histories ontology for the semantic organization of knowledge about persons, places, times, etc., (Dong et al. 2015). The knowledge base of ancient texts of Chinese medicine extracts knowledge elements from ancient texts of Chinese medicine and establishes the relationship between knowledge elements (Yu et al. 2016).

Generally speaking, existing research mainly aims at specific fields or topics of Chinese traditional culture and does not involve building a comprehensive top semantic framework. It is still important to align with international standards, and a range of construction methods have been summarized for specific construction purposes.

2.2 Conceptual models for traditional culture

In the field of cultural heritage, the International Committee for Documentation (CIDOC) developed the object-oriented

concept reference model, CIDOC CRM, in 1996. It is a formal ontology intended to facilitate the integration, mediation and interchange of heterogeneous cultural heritage information. It aims at providing semantic definitions and clarifications of concepts and relationships needed in the work of cultural heritage, so as to achieve a common understanding of cultural heritage (DS/ISO 21127-2014 2014). CIDOC CRM involves the idea of faceted classification, and uses 98 entities and 198 properties to describe the humanities, arts, time, place, person and copyright covered by cultural heritage (Doerr 2003). Many museums, art galleries and libraries in Europe, Asia and Americas have constructed specific ontology models based on CIDOC CRM, thus enabling the mapping, annotation, integration and sharing of cultural resources such as the European archaeological project ARIADNE. The ARIADNE reference model (ARIADNE RM) enables the mapping and integration of archaeological data of artifacts, archives and other tangible cultural heritage with the classes and properties of CIDOC CRM, including the language type, publisher, creator, and the events, times, places to which the artifacts relate (Aloia 2017a; 2017b). The Finnish semantic computing research group has reused the core classes and properties of CIDOC CRM to organize tangible cultural heritage around events of the Second World War, including archival material such as war memoirs, war albums and biographies (Hyvönen 2016). Based on the core classes and properties of CIDOC CRM, Hao (2011) takes the Dragon Boat Festival as an example to construct a traditional festival knowledge ontology, which covers the categories of activities, times, places involved in traditional festivals and the corresponding relationships and properties, in line with the basic characteristics of Chinese intangible cultural heritage.

Besides CIDOC CRM ontologies such as SEM, EDM and FOAF are commonly used in the field of cultural heritage. Van Hage et al. (2011) created a simple event model (SEM) based on reusing word-lists or ontology models, such as DC, FOAF, CIDOC CRM, etc. SEM enables the typological, structural, and relational representation of events and related knowledge of person, times and places etc., with a focus on the types of entity categories appropriate to the fields of history, cultural heritage, geography, etc. Xu et al. (2017) developed a narrative image annotation ontology (NIAO) based on reusing the core classes, properties of SEM and CIDOC CRM, combined with the underlying features of narrative-type images. De Boer et al. (2015) focused on the events and narratives embedded in tangible cultural heritage, revealing the descriptions of objects, person, times and places, developing the digital cultural heritage browsing system (DIVE) and constructing a corresponding ontology based on SEM. Coladangelo (2020) constructed an ontology for contra dance based on CIDOC CRM, FRBR, FRBRoo and LRM, which focused on the agent, event, place, time and work, etc. Table 1 displays representative ontology models in the field of cultural heritage.

In general, the current practical applications related to CIDOC CRM are mostly for specific topics or specific types of cultural resources at specific historical stages. At the same time, CIDOC CRM lacks support for specific community terms such as traditional Chinese cultural events because of the complexity of class and property in CIDOC CRM, and it is unable to provide a fine-grained description of event relationships. Therefore, this paper constructs the CTCO by referring to ontology frameworks such as CIDOC CRM and reusing its core classes and properties, which can reduce the complexity of the ontology and improve the efficiency of integrating and sharing the knowledge of Chinese traditional culture.

3.0 Design and construction of the ontology for Chinese traditional culture

Previous researchers have proposed a variety of ontology construction methods, for example, Tove (Petrie 1992), Methontology (Fernández-López et al. 1999), Method 101 (Noy and McGuinness. 2001), human-centric faceted approach for ontology construction (Ghosh 2020) and so on.. Iqbal et al.

Ontology	Basic framework	Category	Domain
CIDOC CRM	CIDOC CRM	Cultural heritage	General
SEM	SEM	Cultural heritage	General
Ariadne RM	CIDOC CRM	Tangible cultural heritage	Archaeology, Antiquities
WarSampo	CIDOC CRM	Tangible cultural heritage	History, Military
DBF	CIDOC CRM	Intangible cultural heritage	Traditional culture, Festivals
NIAO	CIDOC CRM, SEM, etc.	Cultural heritage	Traditional culture, Narrative images
DIVE	SEM, FOAF, etc.	Tangible cultural heritage	Historiography, Archives

Table 1. Common ontologies in the field of cultural heritage.

(2013) compared these ontology construction methods. In fact, there is no fully mature ontology construction method (Iqbal et al. 2013), nor an ontology construction method suitable for diverse fields and data sources. In order to create the ontology more flexibly, this paper proceeds by determining domain scope, listing important terms in ontology, defining class and hierarchical structure, defining properties, considering reuse ontology and evaluating the ontology according to the needs of the model, source of domain characteristics, and concepts and properties.

3.1 Ontology design ideas

Ontology construction methods are mainly divided into top-down and bottom-up from the perspective of the concept construction sequence (Uschold et al. 1995). The top-down method relies on domain experts and requires an overall grasp of domain knowledge; the bottom-up method relies on data, and obtains the concepts through refinement and induction (Francesconi 2010). The composition and structure of Chinese traditional cultural knowledge are complex, with diverse content structures and logical structures (Zhang et al. 2014). Therefore, this study investigates the knowledge needs of historians, which then becomes the basis for constructing ontology concepts and attributes. Then the LDA topic clustering model is used to realize the conceptual topic clustering of the corpus. We also reuse, inherit and supply CIDOC CRM to achieve the combination of top-down and bottom-up methods. Finally, the CTCO is constructed. Figure 1 shows the specific construction process of the ontology.

3.2 Investigation of the knowledge needs of historians

Research on the knowledge representation of traditional Chinese culture is limited to specific topics or specific time periods because of the present lack of a systematic and standardized knowledge expression framework. To achieve the effective expression of Chinese traditional cultural knowledge, this paper not only refers to foreign traditional cultural knowledge expression methods and standards, but also combines the characteristics of Chinese traditional culture. Historians are at the core of the study of traditional Chinese culture. We should focus on the needs of historians as the basis for building the concepts and attributes of the domain ontology. Thus, this study tries to understand historians' needs for Chinese traditional cultural knowledge through interviews.

3.2.1 Interview objects and methods

This study conducted in-depth interviews with four historians or history enthusiasts in related fields using qualitative research methods in an attempt to understand the needs of historians for knowledge of traditional Chinese culture.

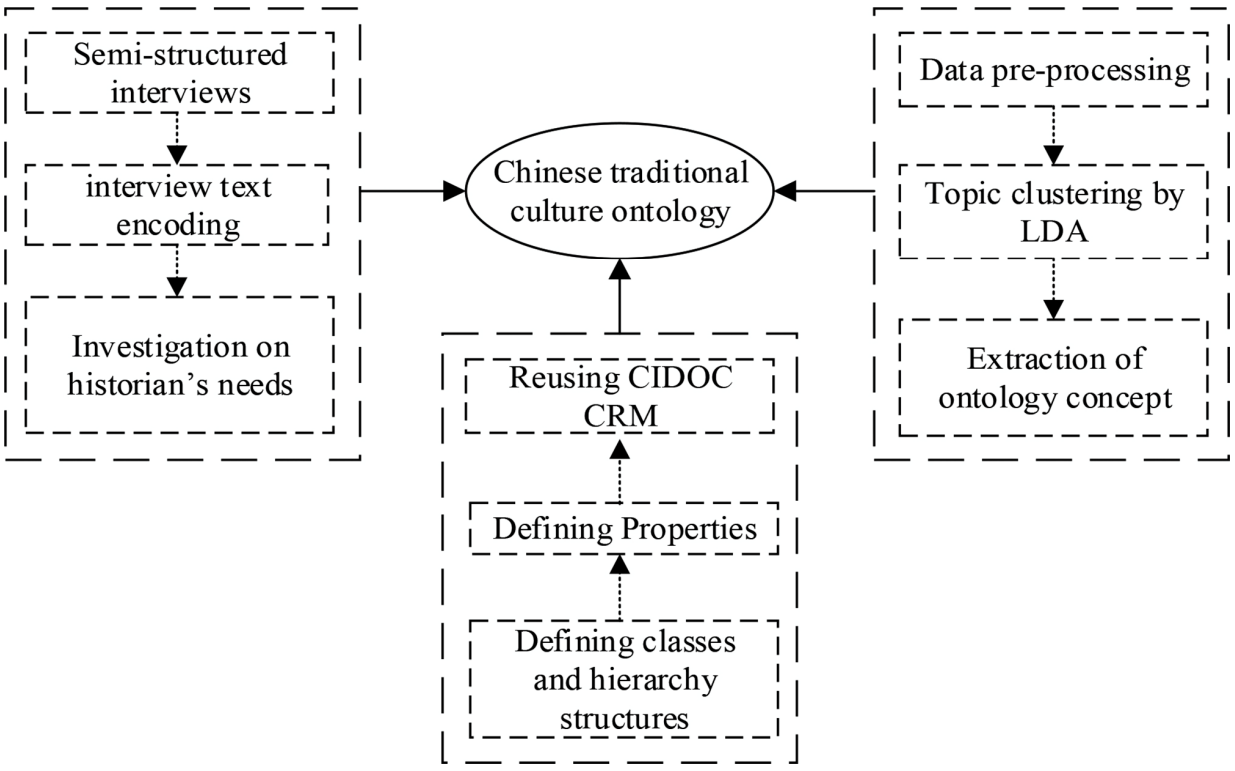


Figure 1. The construction process of the ontology for Chinese traditional culture.

The research interests of the interviewees are mainly in Chinese history and information management, and all have master's or doctoral degrees. To understand the specific needs of historians for the expression of Chinese traditional cultural knowledge, we conduct interview in a semi-structured manner by face-to-face or online exchanges. The results of the interview can be the foundation for the construction of the classes and properties of the CTCO.

3.2.2 Encoding process

This study employed open encoding through abstract extraction, concept formation, category extraction, and then realizes the main axial coding; it further established the main categories through the internal links between the categories (Wang et al. 2017). Specifically, we first extracted the original interview sentences related to the subject of this study, decomposed them into several abstracts, summarized the abstracts and expressed them in words or sentences as short as possible (A1... An); extracted subcategories (B1... Bn) take a certain concept as the centre, and combine other kinds of concepts into concept groups to display the open coding. Secondly, we summarize the main category (C1... Cn) through the internal relationship between subcategories to discover spindle coding. In addition, through the analysis of the original interview data of the interviewers, we found that no new main category relationship was found in the coding process of the fifth interviewer, and the main category still exists in the content composition, topic composition and logical composition. This study finally selected the original corpus of the first four interviewers for the research. We extracted 45 concepts, 15 sub-categories and 3 main categories by transcribing, organizing and analyzing the original interview data from four historians and history enthusiasts, as are shown in Table 2.

3.2.3 Analysis of results

The results of the interviews show that most historians believe that Chinese traditional culture is formed in the course of historical events, and historical events can reveal Chinese traditional culture better. Specifically, historians focus on the content composition, topic composition and logical composition of historical events. At the level of content composition, historians believe that time, place and person are the basic components of historical events and are of great value in the description of historical events. In terms of topic composition, historians focus more on ancient Chinese military, political, economic, technological, social and catastrophic events which have become a prominent focus in the construction of the CTCO. On a logical level, historians are more sensitive to the causes, beginnings, developments, transitions and outcomes of events, which can clarify the historical developing context and the connections between historical elements.

Main categories	Sub-categories	Concepts
C1: Content Composition	B1: Event	A1: Traditional culture is formed through historical events, A2: Historical events reveal traditional culture
	B2: Actor	A3: Countries, A4: Institutions and organizations, A5: Person, A6: Person's births, deaths, native place, careers
	B3: Place	A7: Complete address, A8: Current address, A9: Terrain conditions
	B4: Time	A10: Start time of event, A11: Duration of event, A12: End time of event, A13: turnaround time of time
	B5: Object	A14: War materiels, A15: Weapons, A16: Chariots, A17: Military orders, A18: Institutions and policies
	B6: Primitive value	A19: Where does the data come from? A20: Assisting determination
C2: Topic composition	B7: Politics	A21: Coups, A22: Political prosperity, A23: Dynastic change, A24: Political unrest
	B8: Military	A25: Attack and defense, A26: War, A27: Parade, A28: Organization of forces, A29: Dedication
	B9: Economy	A30: Bumper food harvest, A31: Economic prosperity
	B10: Technology	A32: Science and technology influence the course of history
	B11: Society	A33: Social environment, A34: Prosperity of social life
	B12: Disaster	A35: Natural and man-made disasters, A36: Plague
C3: Logical composition	B13: Consequent	A37: Chronological sequence, A38: Historical process
	B14: Causality	A39: Causal cisgenesis, A40: Causes of events, A41: Consequences of events, A42: Passage of events
	B15: Turning	A43: Historical transform, A44: Turning point, A45: Prosperity to extinction

Table 2. Encoding process.

3.3 Topic clustering of ontological concepts

Domain concepts and properties are the core of the ontology framework. This study tries to achieve the extraction of relevant concepts in the corpus by means of the LDA topic model, and identifies the core classes and properties of the CTCO based on the aforementioned investigation of the needs of historians and history enthusiasts.

3.3.1Data sources and data pre-processing

In this study, we chose *Zuo Zhuan* (Zuo -468)*, Gongyang Zhuan* (Gong -481) and *Guliang Zhuan* (Gu -481) (Hereafter collectively called *Three Commentaries*) as the data sources. *Three Commentaries* are ancient Chinese narrative chronicle texts, which were written in the spring and autumn period, and warring states period. They have strong historical standing, literary value, and exert profound influence on later generations. *Three Commentaries* covers a vast number of historical facts in politics, diplomacy, the military, economics and culture, including the decline of the royal family, lords of the realms, dynastic alliances, natural disasters and other aspects (Wu 2007).

In existing research, *Three Commentaries* have been machine annotated and manually corrected by Chen Xiaohe's digital humanities team at Nanjing Normal University (Chen et al. 2013). We segmented words according to their part of speech and entity types based on this existing research, and then processed the data by removing stop words. The stop words in this study are based on the stop words commonly used in Chinese ancient texts, such as *Han Shu*, *Lun Heng*, *Taiping Jing* and *Shi Ji.* We also followed the aforementioned studies in removing function words with no practical meaning such as adverbs, prepositions, conjunctions, auxiliaries and modal particles as in *Three Biographies* (Cheng 2020; Cui 2008).

We finally obtained a corpus containing 35,951 sentences, which becomes the basis for the topic clustering. In addition, we collected statistics on the data which was pre-processed to obtain the part of speech appearing frequently in *Three Biographies*; the specific results are shown in Table 3.

It can be seen from Table 3 that the most frequent parts of speech in *Three Biographies* are verbs and nouns, which include person, place, time and common nouns, Among them, verbs can reveal the frequency of events in the corpus; common nouns mainly refer to the part of speech, excluding person and place, which can preliminarily reveal the frequency of entities. The data of the corpus after segmentation and stop word removal covers most content of *Three Biographies.* It shows that the pre-processing of data is reasonable and effective. Besides, the rationality of concept extraction can be verified by comparing the parts of speech appearing frequently and the result of concept extraction in the process of the follow-up study.

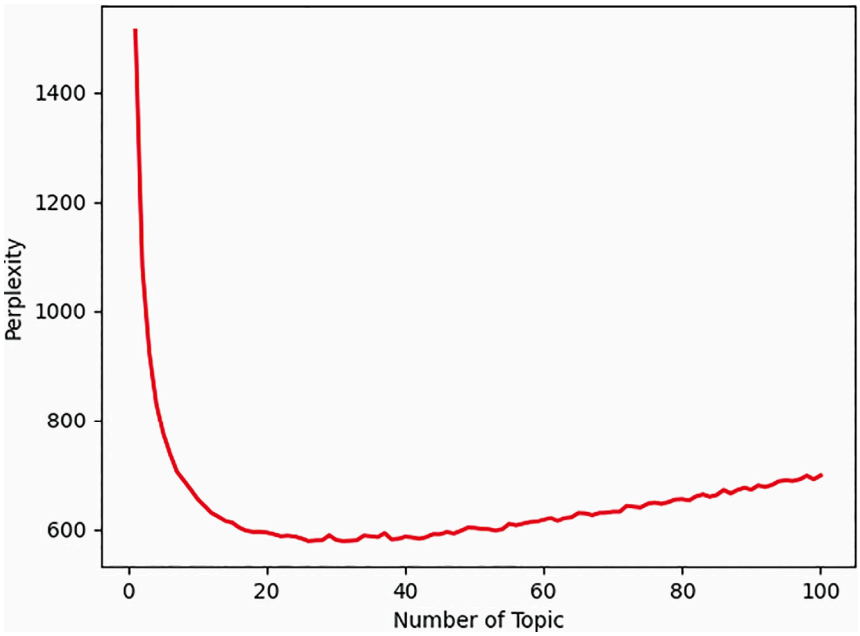
3.3.2 Extraction of ontology concepts

This study uses the Bayesian probability model LDA topic clustering model to process and analyze the information data in *Three Biographies*, in order to get the thematic information and key information in the corpus quickly. Specifically, each pre-processing sentence of *Three Biographies* corresponds to a word vector, i.e., each sentence of the corpus is generated from the words in this bag of words according to certain distributions. Then we applied TF-IDF algorithm to reduce the dimensionality of the corpus, and finally applied the LDA topic model to process the corpus. According to the distribution of perplexity, which is shown in Figure 2, we finally chose 24 topics after cross-referencing the topics and combining with the multiple meanings of the words of ancient texts. The top 10 feature words of each topic are shown in the Table 4.

According to the clustering results of LDA topic model, we obtained 24 topics, including meeting and alliance, sacrifice, divination, war, marriage, and exodus. The results meet the needs of historians and the content characteristics of *Three Biographies*, and finally become the basis for the construction of classes and properties of the CTCO. It also shows that the results of topic clustering conform to the basic characteristics of the corpus, and can expose the knowledge expression of Chinese traditional culture by comparing the parts of speech appearing frequently with the clustering results of *Three Biographies*.

Terms	Quantity	Proportion
Verbs	64248	29.03%
Common nouns	44224	19.98%
Person	18541	8.38%
Place	12555	5.67%
Time	5318	2.40%
Numerals	2002	0.90%

Table 3. The parts of speech appearing frequently in the *Three Biographies*



Parameter setting: α=50/K, β=0.01, Topic=100 (Note: The number of topics "K" can be selected by calculating the perplexity of the model to select the optimal value. The "K" is taken to be 100 in the first experiment. Through several experiments, it is observed that the perplexity is taken as the minimum when "K" is taken as 24, i.e., the optimal number of topics for Three Biographies is taken as 24.)

Figure 2. Distribution of perplexity.

3.4 Reuse and construction of ontology

In previous work, we enabled the topic clustering of *Three Biographies* and obtained 24 topics. But the distribution of topics is chaotic, which cannot form a complete framework of Chinese traditional culture. To form the basic framework of CTCO, we combined the CIDOC CRM and the features of Chinese traditional culture as informed by CIDOC CRM. Then we reused and created the classes and properties at a finer level. Specifically, the ontology reuse and construction norms mainly includes reality, monotonicity, minimality, shortcuts, disjointness and extensions (CIDOC 2014). Reality means that the ontology focuses on explicit knowledge that can be perceived or recorded through the senses, and does not include tacit knowledge at the abstract level; monotonicity means that whether it is an existing or new ontology class or property, its structure and reasoning must be valid; minimality means that the structure of the ontology should be concise and to the point, without repeated concepts or properties; shortcuts mean to ensure that the properties path between the concepts is complete and, as far as possible, not verbose; disjointness means to ensure that the concepts do not intersect more than necessary; extensions mean that the design of the ontology should take into account the future reuse situation, allowing other researchers to reasonably adjust and extend the classes or attributes according to the ontology.

3.4.1 Reusing ontologies

In this section, we briefly describe the concepts and properties of CIDOC CRM and SEM for explicit reuse of CTCO, in order to make the ontology reuse rules in this paper clearer. We use the prefixes CIDOC: and SEM: respectively, and for concepts and properties built by CTCO, we use the prefix CTCO:.

The top layer of CIDOC CRM is CIDOC: CRM Entity, which mainly includes temporal entity (CIDOC: Temporal Entity(x)), persistent item (CIDOC: Persistent Item(x)) and original value (CIDOC: Primitive Value(x)). This hierarchical structure and category system are obviously more suitable for the semantic description of collections of museums and archives, but less for the event-centric CTCO. Therefore, we additionally introduce SEM which is more suitable for events. The top layer of SEM is Sem: core, which mainly includes events (Sem: event(x)), roles (Sem: actor(x)), places (Sem: place(x)) and time (Sem: time(x)). Therefore, this paper reorganizes CIDOC CRM and SEM to form the concept and property of CTCO based on the needs of Chinese traditional culture description. Specifically, CTCO contains the following axioms:

No.	Topic	Features
1	Alliance	Alliance, Qi Hou, Zheng Bo, Jin Hou, Song Gong, Wei Hou, Chen Hou, Find Alliance, Cai Hou, Fete
2	Rituals	Sacrifice, Ritual, Funeral, Lords, Emperor, Minister, Orders, Gives, Secretary, Clothing
3	Death	Death, Sin, Killing, Worry, Adieu, Abandonment, Existence, Content, World, Mountain
4	Relationship	Brother, Mother, Deicide, Inheritance, Near, Woman, Brother, Girls, Marriage
5	Divination	Divination, Killing, Minister, Murder, Propitious, Hunting, Changing, Stealing, Bodies, Foreign
6	Destruction	Destroy, Plot, Go, Meet, Ji Sun, Yu, Ji'S, Admonish, Old, Temple
7	Persons	Zi Chan, Call, Shu Xiang, Zhao Meng, Ji Zi, Say, Xuan Zi, Zi Dashu, Wen Zi, Stay In
8	Natural phenomena	Fire, Flood, Out, Live, Pray for Rain, Run, Control, Death, Fog, Bulid
9	Fortification	All the Vassals, City, Lu State, Crusade, Open Up, Fear, Favour, Garrison, Strength, Defense
10	Leaving	Return, Grasp, Field, Flee, Jin People, Qi People, Border, The Capital, Seeing-Off, Pedestrian
11	Politics	Country, Serve, Order, Obey, The Late Emperor, Project, Abolish, Fete, Our Country (Self-Abasing Terms), Understand and Sympathize With
12	Bribery	Boodle, Request, Money, Exempt, Generate, Accept, Prince, Bribe, Draught Animals, Drum
13	Visit	Arrive, Pay A Formal Visitcall, Run, Hire, Have An Audience With, Drink, Wine, Ju State, Zuo Shi (Minister), Kotow
14	Parade	Watch, Book, Taboo, Huan Gong, Respect, Army, Respect, Xiang Gong, Zhuang Gong, China
15	Relocation	Move, Attcak, Xu State, Zheng State, Alliance, Qi People, Surround, Hostage, Flat, Song People
16	Groups	Chu State, Wu State, Chen State, Cai State, Chu People, Wu Zi, Wu State, Chao State, Huang State, Wu People
17	Power struggles	Jin State, Qin State, Chu State, Rebellion, Invasion, Jin Hou, Battle, Pay Back, Qin Bo, Wen Gong
18	Intangible objects	System, Institution, The Masses, Ethics, Grievances, Official, Government Decree, Desire, Penal Law, Services
19	War	Attack, Zheng State, Lead Troops, Invasion, Chu State, Rescue, Chen State, Surround, Chu Zi, Stagnancy
20	Time	Autumn, The Lunar Month, July, August, March, September, February, First Year, Third Year, Zhao Gong
21	Military	Army, Military Affairs, Defeat, Battle, Capture, Sacrifice, Defend, Archery, Chariot Guards, Chase
22	Marriage	Marriage, Ritual, October, Literal, December, The First Day Of Each Month In The Lunar Calendar, The Spring And Autumn Period, January, December, November
23	Material objects	Food, Rides, Horse, Enter, Soldier, Bull, Wound, Prince, Weapons, Jade
24	Escape	Jin State, Wei State, Qi State, Zheng State, Ju State, Run, Assist, Qi State, Sadness, Attack

Table 4. Distribution of topical features (Topic=24).

CTCO:event(x) → CIDOC:event(x)
CTCO:place(x) → CIDOC:place(x)
CTCO:actor(x) → CIDOC:actor(x)
CTCO:object(x) → CIDOC:thing(x)
CTCO:event(x) → Sem:event(x)

Based on the analysis discussed above, we represent basic elements as binary properties in CTCO, linking events to other elements such as actor, place, etc. More precisely, we have a main hierarchy of CTCO, and map the first-order axioms of *CIDOC CRM* to CTCO, and describe CTCO in the formal language of OWL (see Table5).

In addition, we takes "the people of Chu state failed" as an example to simply test the logical reasoning effect of CTCO. The specific first-order logic is as follows:

CTCO:event(x)∧CTCO:has result event(x,y)∧CTCO:event(y) → CTCO:has casual event(y,p)∧CTCO:event(p)

Using the reasoning engine function of Protégé, the reasoning result of "the people of Chu state are failed" is shown in Figure 3, the yellow bottom area in the figure being the reasoning result. Specifically, by means of the above rules, it can be deduced that the cause and event of "the people of Chu state failed" is "the people of Chu state save Wei state".

3.4.2 Defining classes and hierarchy structures

Ontology classes are the descriptions of domain concepts, such as "physical object" and "nonphysical object", which are included under the predefined class of "Object" in this study. The hierarchy structure of ontology classes is a representation of the relationship between concepts, presenting a structure of superclass-subclass. This study constructs the framework of CTCO from top to bottom based on CIDOC CRM and constructs the classes and properties from bottom to top based on the results of the historians' needs survey and topic clustering. The basic framework of

Core classes	Interpretations	FOL	OWL
CTCO: core	It covers all entities in CTCO including events, place, time, actor and object, and can be applied to applications that include events.	CTCO:core(x)→owl:thing(x)	<owl:Class rdf:about="CTCO#core"> <rdfs:subClassOf rdf:resource="owl#thing"/> </owl:Class>
-E5: Event	An event or phenomenon that occurs within a finite period of time.	CTCO:event(x)→CTCO:core(x)	<owl:Class rdf:about="CTCO#event"> <rdfs:subClassOf rdf:resource="CTCO#core"/> </owl:Class>
--E7: Acticty	All actions performed intentionally.	CTCO:carried out by→CTCO:activity(x)→CTCO:actor(y) CTCO:carried out by(x,y)→had participant(x,y)	<owl:ObjectProperty rdf:about="CTCO#carried_out_by"> <rdfs:subPropertyOf rdf:resource="CTCO#had_participant"/> <rdfs:domain rdf:resource="CTCO#activity"/> <rdfs:range rdf:resource="CTCO#actor"/> </owl:ObjectProperty>
--E63: Beginning of existence	Covers all events that start or give birth to a character or object.	CTCO:brought into existence→CTCO:Beginning of Existence(x)→CTCO:actor(y) CTCO:brought into existence(x,y)→had participant(x,y)	<owl:ObjectProperty rdf:about="CTCO#brought_into_existence"> <rdfs:subPropertyOf rdf:resource="CTCO#had_participant"/> <rdfs:domain rdf:resource="#beginning_of_existence"/> <rdfs:range rdf:resource="#actor"/> </owl:ObjectProperty>
--E64: End of Existence	Covers all events that end or perish a character or object.	CTCO:took out of existence→CTCO:End of Existence(x)→CTCO:actor(y) CTCO:took out of existence(x,y)→had participant(x,y)	<owl:ObjectProperty rdf:about="CTCO#took_out_of_existence"> <rdfs:subPropertyOf rdf:resource="CTCO#had_participant"/> <rdfs:domain rdf:resource="CTCO#end_of_existence"/> <rdfs:range rdf:resource="CTCO#actor"/> </owl:ObjectProperty>
-E39: Actor	A person or group of persons capable of performing an action, without an explicit subject, is also classified as such.	CTCO:had participant→CTCO:event(x)→CTCO:actor(y)	<owl:ObjectProperty rdf:about="CTCO#had_participant"> <rdfs:domain rdf:resource="CTCO#event"/> <rdfs:range rdf:resource="CTCO#actor"/> </owl:ObjectProperty>
-E53: Place	The location involved in an event, including a spatial extent.	CTCO:took place at place→CTCO:event(x)→CTCO:place(y)	<owl:ObjectProperty rdf:about="CTCO#took_place_at_place"> <rdfs:subPropertyOf rdf:resource="topObjectProperty"/> <rdfs:domain rdf:resource="CTCO#event"/> <rdfs:range rdf:resource="CTCO#place"/> </owl:ObjectProperty>

Core classes	Interpretations	FOL	OWL
-sem: Time	It is a symbolic representation of the time of occurrence of an event, an expression of the continuity and sequential nature of material change.	CTCO:happen at time→CTCO:event(x)→CTCO:time(y)	<owl:ObjectProperty rdf:about="CTCO#happen at time"> <rdfs:domain rdf:resource="CTCO#event"/> <rdfs:range rdf:resource="CTCO#time"/> </owl:ObjectProperty>
-E70: Object	It contains everything that exists in the event, either as a physical object or as a outcome of knowledge.	CTCO:was influenced by→CTCO:event(x)→CTCO:object(y)	<owl:ObjectProperty rdf:about="CTCO#was_influenced_by"> <rdfs:domain rdf:resource="CTCO#event"/> <rdfs:range rdf:resource="CTCO#object"/> </owl:ObjectProperty>
E59: Primitive Value	It contains the original values used to represent certain documentary elements.	CTCO: has original value→CTCO:core(x)→CTCO:primitive value t(y)	<owl:ObjectProperty rdf:about="CTCO#has original value"> <rdfs:domain rdf:resource="CTCO#core"/> <rdfs:range rdf:resource="CTCO#primitive value"/> </owl:ObjectProperty>

Annotation:header and namespace
<?xml version="1.0"?>
<rdf:RDF xmlns="http://www.semanticweb.org/administrator/ontologies/2021/0/CTCO#"
xml:base="http://www.semanticweb.org/administrator/ontologies/2021/0/CTCO"
xmlns:owl="http://www.w3.org/2002/07/owl#"
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:xml="http://www.w3.org/XML/1998/namespace"
xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#">
<owl:Ontology rdf:about="http://www.semanticweb.org/administrator/ontologies/2021/0/CTCO"/>

Table 5. Core classes, interpretations and its FOL of CTCO.

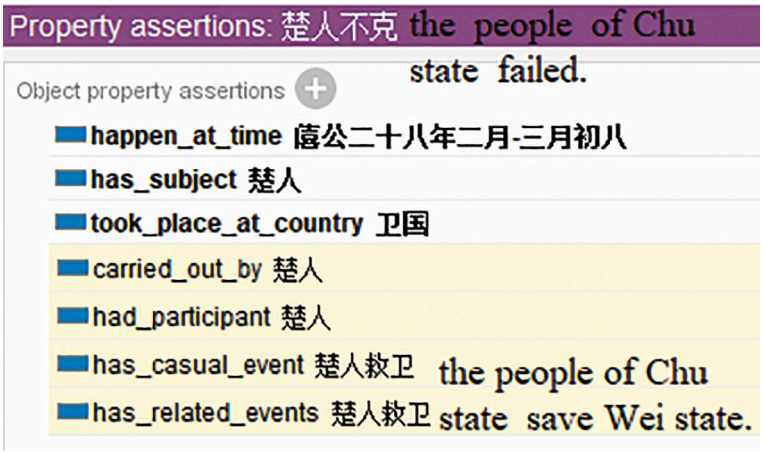


Figure 3. The reasoning result of "the people of Chu state are failed".

the CTCO constructed in this study is shown in Figure 4, and the core classes in the ontology are elaborated in Table 5 (in section 3.4.1), where the classes beginning with "E:" and "Sem:" are reused classes, referring to CIDOC CRM and SEM, and the classes beginning with "A:" are self-built classes.

3.4.2 Defining properties

The CTCO defines 142 properties around the concepts of event, time, place, object and actor by combining the content characteristics of *Three Biographies* and the needs of historians based on CIDOC CRM. The specific definitions and explanations of the core properties are shown in Table 6, where the properties beginning with "P:" and "Sem:" are reused properties, referring to CIDOC CRM and SEM, and the properties beginning with "Q:" are self-built properties. The final constructed core concept model of the CTCO is shown in Figure 5. In addition, this study refers to the China biographical database (Fuller 2020), and combines the research results of Sun (2015) and Chen (2015) to design five data properties, including personal information, time type, object description, place type and natural phenomenon. Specifically, person information includes alias, character, emperor's title, gender, time of birth and time of death, ethnic group, clan, ancestral origin, dynasty, official position, time in office of the person. Time type enables conversion between ancient timekeeping and AD timekeeping; object description includes product type, material, unit of measurement and

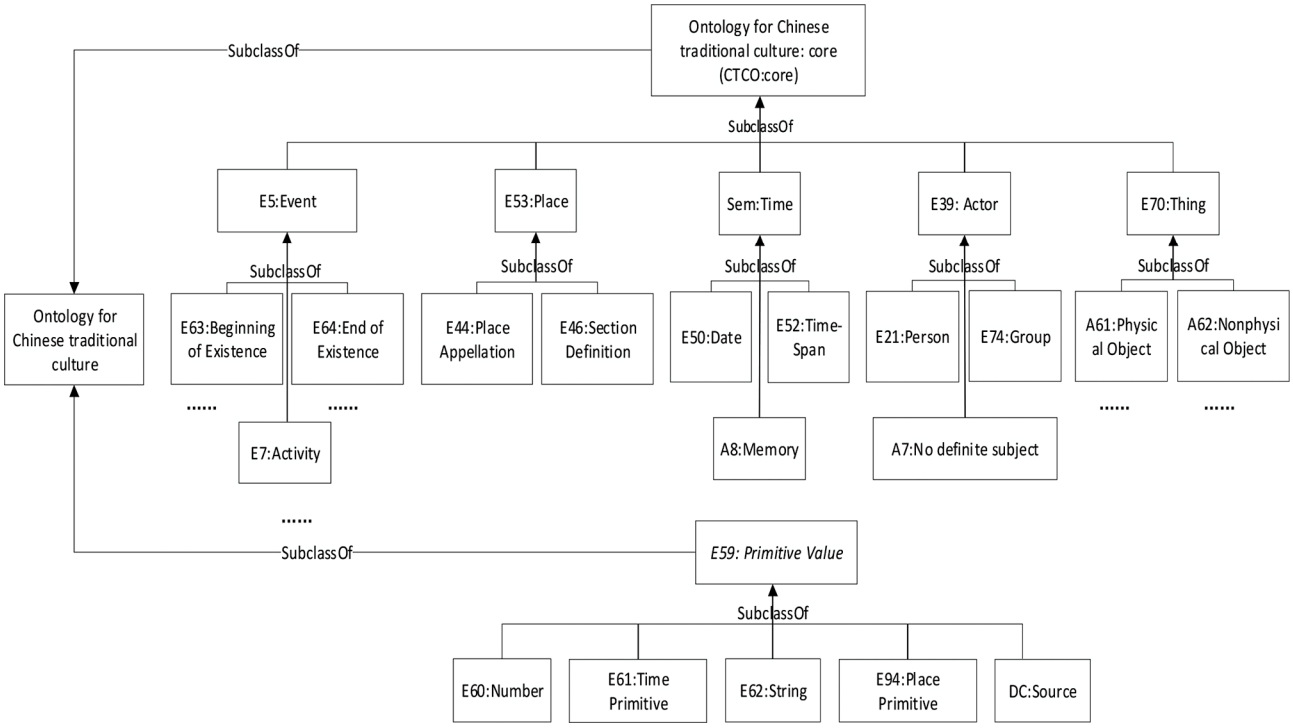


Figure 4. Framework of the ontology for Chinese traditional culture.

Core Properties	Domain	Range
SEM: has time	E5: Event	Sem: Time
P7: took place at	E5: Event	E53: Place
P11: had participant	E5: Event	Sem: Actor
P16: used specific object	E5: Event	E70: Object
Q16: has related event	E5: Event	E5: Event
-P9: consists of	E5: Event	E5: Event
-Q16-1: has subsequent event	E5: Event	E5: Event
-Q16-2: has casual event	E5: Event	E5: Event

Table 6. Core properties of the ontology for Chinese traditional culture.

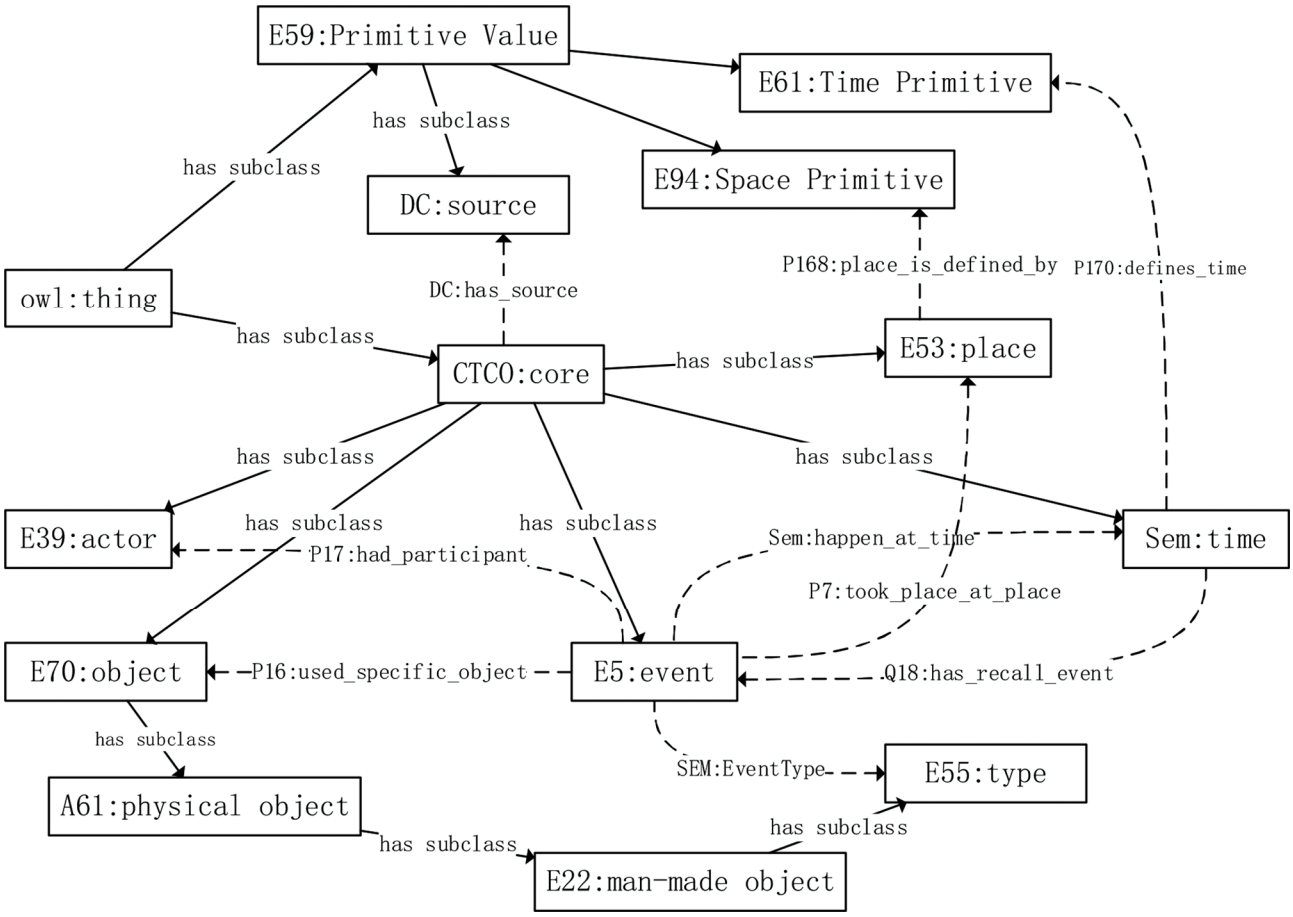


Figure 5. Core concept model of the ontology for Chinese traditional culture.

quantity of scale; place type includes country, regional division and present-day address of the place; and natural phenomenon includes specific types of natural phenomena.

3.5 Creating instances

This study extracts the subject, predicate and object from the corpus of *Three Biographies* to form events in the form of "subject-predicate-object", which constitute all instances of events in the CTCO. We extract the information of time, place, actor and object in the corpus, and this information constitutes the descriptive information of Chinese traditional cultural events. Some of the examples constructed in this study are shown in Figure 6.

4.0 Evaluation of the ontology for Chinese traditional culture

Ontology evaluation is to assess the performance and applicability of ontology in a specific application field or environment. It is an important factor that affects whether ontology can be applied in the semantic web (Gangemi et al. 2006). According to Gangemi et al. (2015; 2014), ontology structure and ontology function are the two most commonly used ontology evaluation methods. The evaluation of ontology structure is to evaluate the concepts and relationships in the ontology from ontology itself, the golden standard (Maedche and Staab 2002), application based (Porzel and Malaka 2004), data-driven (Brewster et al. 2004) and other mainly approaches evaluate ontology structure around lexical, hierarchy, context, syntactic and other semantic relations (Brank et al. 2009). The evaluation of ontology function is to evaluate the performance of the ontology from the function and application of ontology and the application effect of actual tasks (Ren et al. 2019). In order to verify the effectiveness of the CTCO, this study evaluates the ontology from ontology structure and ontology function based on quantitative and qualitative methods, specifically using indicators such as attribute richness, inheritance richness, etc., ontology coverage and task fit.

Figure 6. Selected instances of the ontology for Chinese traditional culture.

Metrics	CTCO	CIDOC CRM
Attribute richness	0.358974	0.158537
Inheritance richness	0.974359	0.963415
Relationship richness	0.651396	0.660944
Class/relation ratio	0.336207	0.351931
Average population	6.266231	Not applicable
Class richness	0.435897	Not applicable

Table 7. The metrics of the ontology for Chinese traditional culture and CIDOC CRM.

4.1 Evaluation of ontology structure

This study uses the ontology online metrics platform OntoMetrics, which enables automatic metrics for ontology features and instances through metrics such as the number of classes and properties in the ontology (Lantow 2016). This study takes CIDOC CRM and other ontologies as a reference, and Table 7 shows the structure metrics and knowledge base metrics related to the clarity and brevity of the ontology.

Attribute richness is the number of data properties owned by each class, which is proportional to the number of the knowledge conveyed by the ontology. Inheritance richness describes the distribution of knowledge in different classes, and reveals the classification, domain coverage and knowledge granularity of the ontology. Average population and class richness are related to the number of instances in the ontology (Tartir et al. 2020; Gangemi et al. 2005). Through the comparison of relevant data in Table 7, it can be seen that the CTCO has better attribute richness, inheritance richness, average population and class richness. It reveals that the granularity of knowledge description in the CTCO is finer. But the score of relationship richness and class/relation ratio is slightly lower than that of CIDOC CRM. Because the construction of the CTCO is based on the characteristics of Chinese traditional culture, historians' needs and topic clustering of Chinese ancient books, so the setting of ontology class and property is more specific, resulting in a stronger expression of Chinese traditional culture. Accordingly, the expression of CTCO to other cultural heritage knowledge is weak by comparing with CIDOC CRM.

4.2 Evaluation of ontology function

The evaluation method of ontology function is based on the specific content of the corpus. It uses ontology in an actual task and evaluates the results of the task, with emphasis on the accuracy of the ontology knowledge expression (Raad et al. 2015). Specifically, we use the indicators of ontology coverage and task fit. Ontology coverage generates a quality score that represents how well a given dataset is "covered" (is relevant to) an ontology. Task fit evaluates the CTCO according to specific application requirements and goals. These approaches require a dataset that reasonably approximates a given domain or problem along with an ontology (Digiuseppe et al. 2014). *The War of Chengpu* has strong narrative rules, including the war background, causes and results, time, place, both sides of the war and other Chinese traditional culture knowledge. Therefore, we chose all

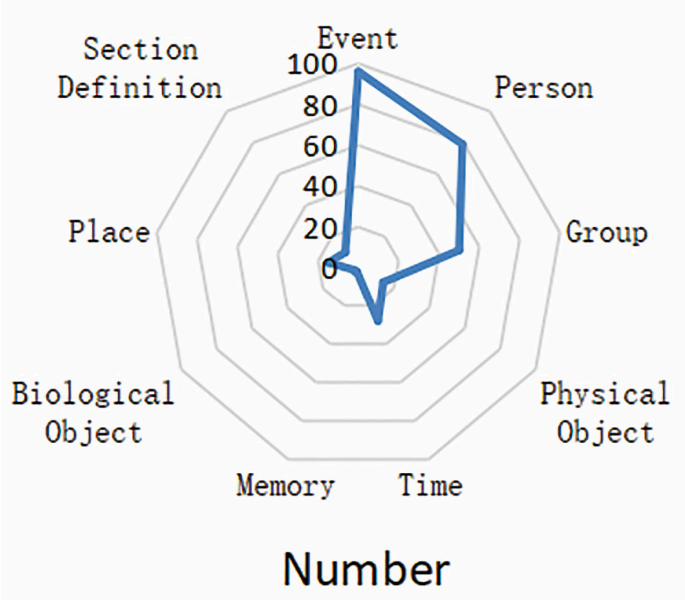


Figure 7. Ontology coverage of Chinese traditional culture.

the sentences describing *the War of Chengpu* in *Zuo Zhuan* as the dataset of the evaluation of ontology function in this part.

4.2.1 Ontology coverage

In order to verify the applicability of the CTCO, this paper calculates the ontology coverage based on the 117 sentences annotated in *Xi Gong 28.3* of *Zuo Zhuan*, and calculates the proportion of the number of sentences containing ontology class in the total number of sentences. The final results are shown in the Figure 7.

The results of Figure 7 show that the CTCO has a good ability to express historical knowledge in the domain of cultural heritage. Meanwhile, it shows that the Chinese traditional culture revealed in the excerpted corpus mainly focuses on events, and expresses knowledge through fine-grained information such as person, object, time and place; this shows that the CTCO has better domain coverage. In addition, this study further annotates the class of event, and the results show that the events of war, travel and killing appear more frequently in the excerpted corpus, which is in line with the contextual characteristics of the corpus, indicating that the description of historical knowledge by the CTCO is basically in line with historical characteristics.

In addition, this study visualizes the sub-events *Xu Chen defends Chen state and Cai state* and *Xu Chen attacks Chen state and Cai state* covered by *the War of Chengpu* based on the CTCO in order to visualize the concepts covered in the ontology; the visualization is shown in Figure 8. The figure mainly depicts the time and place, combatants and results of the battle, and reveals the chronological and causal relationships between the battles, which shows that the CTCO can express the knowledge related to *the War of Chengpu* clearly.

4.2.1 Task fit

This study applies the ontology to a specific task in order to evaluate the quality of the ontology. We score the application results through expert verification in order to verify how well the ontology matches the reality it describes. Specifically, we wrote and ran SPARQL query statements about *the War of Chengpu* to obtain system generated answers. Then, four domain experts scored the degree to which the system generated answers match reality. The scores range from 1 to 5, indicating very non-conforming to very conforming (The specific query statements and expert validation results are shown in Table 8). The results show that the average score of the validation results is 4.30, which indicates that the answers obtained by using SPARQL query basically pass the domain experts' validation and the CTCO has a good expression effect. The lower scores of 3.30 and 3.80 for the antecedent and subsequent events of *War of Chengpu* are mainly due to the dependence on domain knowledge and subjectivity in the process of instance filling. Domain experts suggest that the naming of events should be strictly regulated and the definition of the scope of events should be strengthened in the follow-up research process.

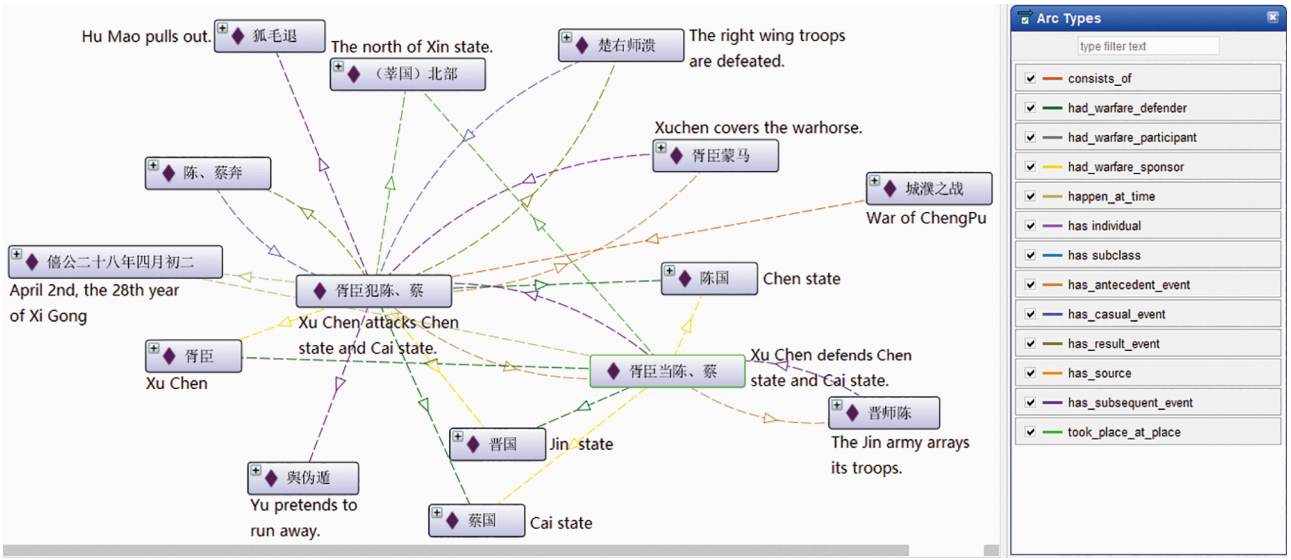


Figure 8. Visualization of the sub-events of the *War of Chengpu*.

No.	Natural language query	SPARQL query	System generated answers (Average score of experts)
1	What are the sub-events in the war of ChengPu?	SELECT? subevent WHERE {CTCO:war of ChengPu CTCO:consists_of ? subevent}	"Jin Wengong, Song Chenggong, Guo Guifu, Cui Yao, Xiaozi Yin stationed at Chengpu.", "Yuan Zhen, Qie Qin attacked the army of Chu state.", "The army of Jin arrayed its troops.", "Chu escaped.", "Hu Mao, Hu Yan attacked Zixi", "Xu Chen Dang defended Cai state."(4.30)
2	When did the war of ChengPu take place?	SELECT? time WHERE {CTCO:war of ChengPu CTCO:happen_at_time ? time}	The 28th year of Xi Gong (4.00)
3	Where did the ChengPu war take place?	SELECT? place WHERE {CTCO:war of ChengPu CTCO:took_place_at_place ? place}	ChengPu (4.50)
4	Who was the initiator of the war of ChengPu?	SELECT? sponsor WHERE {CTCO:war of ChengPu CTCO:had_warfare_sponsor ? sponsor}	Chu state (4.80)
5	Who was the defender in the war of ChengPu?	SELECT? defender WHERE {CTCO:war of ChengPu CTCO:had_warfare_defender ? defender}	Jin State (5.00)
6	What other countries participated in the war of ChengPu?	SELECT? participant WHERE {CTCO:war of ChengPu CTCO:had_warfare_participant ? participant}	"Wei state", "Cao state", "Chen state", "Cai state", "Qin state", "Qi state" (4.00)
7	What was the result of the war of ChengPu?	SELECT? result WHERE {CTCO:war of ChengPu CTCO:has_result_event ? result}	"The army of Chu was defeated.", "The leftwing troops were defeated.", "The rightwing troops were defeated.", "Zi Yu was undefeated." (4.50)
8	What were the following events in the war of ChengPu?	SELECT? subsequent WHERE {CTCO:war of ChengPu CTCO:has_subsequent_event ? subsequent}	"The army of Jin stayed", "Jin Wengong built the palace.", "Alliance between Jin Wengong and Zheng Wengong.", "Jin Wengong contributed to the king." (3.80)
9	What was the prelude to the war of ChengPu?	SELECT? antecedent WHERE {CTCO:war of ChengPu CTCO:has_antecedent_event ? antecedent}	"The army of Jin invaded Cao state.", "The army of Jin attacked Wei state.", "yield and withdraw so as to avoid a conflict." (3.30)
10	What is the source of the war of ChengPu?	SELECT? resource WHERE {CTCO:war of ChengPu CTCO:has_resource ? resource}	“Xi Gong 28.3” of *Zuo Zhuan* (5.00)

Table 8. Query statements and validation results of *the War of Chengpu*.

4.3 Discussion

The evaluation results show that this work has achieved a good level of effectiveness in knowledge expression by constructing the CTCO through the comprehensive use of the methods of the historians' needs survey, topic clustering, and ontology reusing. The following discussions are drawn from the combination of the ontology evaluation results and the review of the process of ontology construction.

(1) The attribute richness and inheritance richness of the CTCO are high, but the scores of relationship richness and Class/relation ratio are low. It indicates that the ontology can clearly express Chinese traditional culture and is more applicable to the domain scope of this study, which accordingly leads to a weaker generality of the ontology to a certain extent. The main reason is that the CIDOC CRM ontology reused in this study is generalized to cultural heritage, and the classes and properties are more abstract and less relevant. In the process of ontology construction, some classes and properties that conform to the characteristics of Chinese traditional culture are added.

(2) The CTCO can cover most historical events and has a high ontology coverage. Because the ontology construction utilises the combination of top-down and bottom-up methods, the reuse of CIDOC CRM can ensure the systematic nature of the ontology; the integrity of the ontology can be ensured through users' needs survey and topic clustering.

(3) The CTCO has a high task fit and a high satisfaction among historians, but the experts give a low score to the search results for event logic structure. This is because the ancient text has the characteristics of multiple meanings of words and concise lines, and the logical relationship of events is more dependent on domain knowledge, which requires manual intervention.

5.0 Conclusion

This study constructed the CTCO according to the norms of ontology construction, and proposed the construction path of ontology in the field of cultural heritage. We constructed the ontology concept from bottom to top through historians' needs survey and LDA topic clustering, and constructed the ontology framework from top to bottom by reusing the ontology CIDOC CRM. Then we verified the effectiveness of the CTCO by attribute richness, inheritance richness, etc., ontology coverage and task fit from ontology structure and ontology function. The results showed that the ontology of Chinese traditional culture can better express the knowledge of time, place, actor and object in historical events, and reorganize the knowledge of time sequence, causality and inclusion among historical events.

This study also puts forward some suggestions on the construction of domain ontology: (1) We need to strictly follow the construction process and specification of ontology, and define the scope and concept of the domain ontology clearly, so that we can avoid the problem that the setting of class and property is not clear. (2) We cannot reuse another ontology completely. It is necessary to reuse, inherit and supplement the ontology according to the actual needs and domain characteristics. Meanwhile, we can also use new methods of digital humanity, such as topic clustering to achieve the acquisition of ontology classes and properties. (3) We should not only have an overall grasp of domain knowledge, but also be good at using mature domain ontology and mature corpora such as dictionaries and catalogs. (4) We also need to use semantic technology to effect the combination of machine technology and manual handling, so that we can avoid the problem of low automation of ontology construction, such as using natural language processing technology to process big data which is difficult to process manually.

In the future research process, the CTCO can be applied to the development of semantic search, virtual reality display, cultural and creative products, mobile applications and other applications to enhance the user experience. The verified ontology content is very important to the development of cultural heritage applications. It provides content for the development of these applications to ensure that users get the correct heritage information. In the future research process, we will continue to optimize the model and fill in data examples, in order to provide reference for the construction, evaluation and application of ontology in the field of cultural heritage.

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