Representation and Display of Digital Images of Cultural Heritage: A Semantic Enrichment Approach

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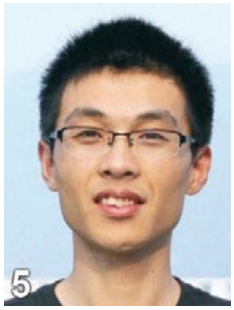

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Abstract: Digital images of cultural heritage (CH) contain rich semantic information. However, today's semantic representations of CH images fail to fully reveal the content entities and context within these vital surrogates. This paper draws on the fields of image research and digital humanities to propose a systematic methodology and a technical route for semantic enrichment of CH digital images. This new methodology systematically applies a series of procedures including: semantic annotation, entity-based enrichment, establishing internal relations, event-centric enrichment, defining hierarchy relations between properties text annotation, and finally, named entity recognition in order to ultimately provide fine-grained contextual semantic content disclosure. The feasibility and advantages of the proposed semantic enrichment methods for semantic representation are demonstrated via a visual display platform for digital images of CH built to represent the *Wutai Mountain Map,* a typical Dunhuang mural. This study proves that semantic enrichment offers a promising new model for exposing content at a fine-grained level, and establishing a rich semantic network centered on the content of digital images of CH.

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1.0 Introduction

Cultural heritage (CH) has been defined as an expression of ways of living, handed down to future generations by every culture and the whole of humankind (ICCROM 2005). CH reflects inheritance, and current concerns about the past (Harrison 2013). Digital images constitute an important medium for recording and preserving CH. Images of CH include not only paintings and images appearing on historical sites or antiquities, but also photographs of architecture, and facsimiles of manuscript illuminations, etc. (Wang et al. 2017). In recent years, advances in digitization initiatives have spawned a myriad of digital image resources of CH. Digital images of CH often contain profound cultural connotations, extensive spatio-temporal scenes, abstract ideological meanings, and can convey complex information difficult to express in the text. Digital images of CH are essential not only for art appreciation, but also for humanities studies. How to optimally protect and utilize these resources has become a topic of great concern in Libraries, Archives and Museums (LAMs) and their related fields. As a result, the fields of Digital Humanities (DH) and Linked Open Data (LOD) have emerged to meet this need.

The process of digitizing CH only maps the visual from physical materials to the digital world. The rich contextual knowledge regarding people, places, events, and objects contained within these images have thus far eluded capture (Chen et al. 2019), resulting in the limited use of these valuable resources. To fully utilize the role of digital media, and convert images into valuable data, there is a need to organize the image into semantic information units. Semantics, as a basic description carrier of knowledge information, can transform visual content into an intuitive, understandable, and text-like language expression. The emergence of smart data has meant digital images of CH require fine-grained semantic disclosure, extensive knowledge association with external resources (Hyvönen et al. 2012; Zeng 2017) and improved presentation methods to better meet user needs (Xie et al. 2018).

The above requirements have still not been satisfied by existing models. Firstly, although advances in the fields of image retrieval, semantic annotation, and semantic description have gradually deepened and optimized the disclosure of digital images, identification of an image's internal objects, its "ofness", is often ignored or lacks sufficient granularity. This results in an insufficient depth of image semantic processing. This is especially true for digital images of CH with complex semantic content. Often the content objects presented in these rich images, such as events, times, places, and people, are not adequately exposed via metadata or simple subject description alone. In many cases, such as in understanding a narrative image, the specific objects are also of great significance. Secondly, an increasingly open semantic web environment has led to CH institutions turning their specialized, siloed image collections into open data sets whose digital images have been successfully linked based on similar styles, creators, and eras. Unfortunately, content contained in these images continue to evade adequate semantic disclosure and connection (Stork et al. 2019, 1). Digital images of CH constitute not only a rich and vital source of information about art, but also about the history of people and places, cultures, traditions, social life, and customs (Klenczon and Rygiel 2014). Coupling digital images of CH with contextual knowledge help to reveal the value of such works. Consequently, content level resource associations between images are required. The last problem is the neglect of non-expert and novice users' needs during the process of developing and using CH digital images. Recent digital CH projects have been designed and developed in non-user-centered and non-descriptive manners (Rahaman 2018). However, user experiments have proved that context is essential to the user's ability to effectively navigate CH image sets in digital environments. Some positive factors to consider when facilitating knowledge discovery in users' viewing of digital images of CH include: more description about the background and interpretation (Hu et al. 2017), exploratory models enabling switching between overviews and detailed exploration (Hall et al. 2012), and an immersive feeling (Galani and Kidd 2019). Unfortunately, these positive factors known to optimize dissemination and utilization of CH image resources, have yet to be widely implemented. Instead, existing digital platforms of CH images focus more on resource aggregation and management, often describing images with simple metadata designed for internal purposes rather than effective public access and appreciation (Fortier and Ménard 2017). However, the need for more innovative and effective ways to turn image content into readable, understandable data (capable of articulating the relationships and background within), is even more urgent in the wake of LOD and DH developments.

This study seeks to provide this called for innovation. Taking the comprehensive image of a Dunhuang mural named the *Wutai Mountain Map* as an example, this study relates a systematic methodology and a technical route for the semantic enrichment of CH digital images. The goal of this study is to disclose the content objects in the image and establish extensive knowledge association, in order to foster deeper comprehension and dissemination of digital images of CH.

2.0 Related work

CH digital images often contain rich semantic connotations. Accordingly, the semantic revelation and description of such images present numerous difficulties. On the one hand, the internal objects in digital images of CH can be complex. For example, a painting may contain multiple people, events, and things, all of which may have discrete histor-

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ical and cultural significance. Therefore, deconstructing the of-ness of the image needs to be more specific and in-depth. Often, it is not enough to reveal CH images on a solely visual level. Contextual information regarding the creation, background, and cultural meanings, must also be expressed in order to foster meaningful knowledge interaction between the viewer and the image. As Risatti (1987) pointed out, seeing a work in the context of contemporary society will greatly enlarge work's possible meanings.

Semantic description of images has been studied for many years, and it has become a multidisciplinary topic, involving image subject analysis, image indexing, image retrieval, image semantic annotation, and other research fields. Among the numerous studies, the following theories and models are of far-reaching significance. Panofsky (1955) determined three levels of meaning in works of art: pre-iconography, iconography, iconology. This model has been widely used in image information organization and semantic annotation. Shatford (1994) proposed that the attributes of images could be divided into four categories: biographical attributes, subject attributes, exemplified attributes, and relationship attributes. Among them, the subject attributes are most closely related to the content and meaning of the image, and its core lies in revealing the ofness and aboutness (Shatford 1986). Eakins (1996), claimed according to the requirements of image retrieval, that image semantic content could be divided into primitive features, logical features, and abstract attributes. Jörgensen (1998), pointed out that images could be described from different facets, arguing multiple entry points should be provided for images in image retrieval. Enser and Sandom (2003) used perceptual, generic-interpretive, specific-interpretive, and abstract levels to describe images.

Due to the advent of semantic web technologies, semantic enrichment has become an ideal method for revealing the data contents and enriching data context in LAMs. In order to improve data quality and discoverability, semantic enrichment tries to add new information at the semantic level. Traditional semantic enrichment uses methods such as tagging, annotating, and categorizing (Clarke and Harley 2014). As semantic technologies and Linked Data advance, semantic enrichment has taken on a wider dimension (Simou et al. 2017). Its meaning is embodied in the holistic process of linking original data with external knowledge resources, such as LOD sets and domain vocabularies. Integration between ontologies, Linked Data, and other methods are often required (Padmavathi and Krishnamurthy 2017). Through these methods and techniques, semantic enrichment can add different types of information and value to data, reflecting the shift from document-centric to entity-centric knowledge modeling. CH information resources constitute one of the most active area in the Semantic Web, and consequently, semantic enrichment has already led to several avant-garde applications. The typical representative is the Europeana project (Manguinhas 2016). The Europeana Data Model (EDM) has already been widely reused in international linked CH and linked archives projects (Mitchell 2013; Southwick 2015; Chen 2019a), as an integration medium for collecting, connecting, and enriching CH data (Doerr et al. 2010).

As for the digital images of CH, their value and potential are often hidden behind complex and unstructured expressions. The meanings and inner connections within CH digital images need to be adequately revealed through semantic-based analysis, extraction, and annotation. Accordingly, the semantic enrichment of images is essentially a process of information discovery and rediscovery (Zeng 2019). At present, work has been done on using ontology and Linked Data technologies to publish and link CH digital image collections. For example, Szekely et al. (2013) published works from the Smithsonian American Art Museum as Linked Data and then linked the artists to external resources. Dragoni et al. (2016) proposed an ontology for a small artwork collection and then enhanced it by linking its metadata about technique, author, and location to external resources. Gracy (2018) paid attention to archival moving images and explored how to map image metadata records to external data sets, in order to enrich images. These researchers all focused on the enhancement of image metadata representing basic features such as: technique, subject, and provenance. Therefore, even within these CH LOD sets, content entities and contexts within images continue to lack disclosure and association. One project related to our research is Stork et al. (2019, 12). Stork proposed a semantic annotation method for field books and then link the content with external datasets to disclose the named entities within. Their research, targeting field books, mainly serves the professional research requirements in the biology domain, and can't cover the resource characteristics and general appreciation needs of DH and CH field.

By combining the experiences and requirements of LAMs , this paper attempts to use the method of semantic enrichment to fill in the existing gap of enhancing the content of CH digital images, in order to finally reveal their content and context, and establish associations with external resources.

3.0 Semantic representation and the enrichment of digital images of cultural heritage

Dunhuang Mogao Grottoes is one of four famous grottoes in China, and a celebrated UNESCO World Heritage site. The caves, murals, and painted sculptures preserved at the site span dozens of dynasties, and offer immeasurable historical, cultural, artistic, and religious value. The *Wutai Mountain Map* (Figure 1), is located on the west wall of the main chamber of cave 61 of the *Dunhuang Mogao Grottoes*. Painted during the period of the Five Dynasties, it is an expansive mural, 13.45 meters long and 3.42 meters wide. The

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Wutai Mountain Map possess a wealth of rich semantic connotations and integrates the characteristics of multiple images of CH in a single composition. The mural is a rare ancient panoramic map that depicts in detail magnificent mountain and river scenery covering thousands of meters, replete with detailed drawings of historical temples, pagodas, and geographic locations. The *Wutai Mountain Map* also includes a number of myths told through figurative imagery. These continuous narratives retell Buddhist allegories and reflect the narrative nature of Buddhist story painting. Finally, the *Wutai Mountain Map* is one of the largest figural paintings in the *Dunhuang Grottoes*, depicting hundreds of believers, travelers, and envoys, who were attracted by Manjusri Bodhisattva to make pilgrimages to Wutai. Therefore, this mural is not only a typical CH image rich in semantics, but also a comprehensive embodiment of digital images of CH. Thus, this study selected the *Wutai Mountain Map* as an example to explore a set of semantic enrichment methods for CH digital images.

To achieve the stated research objective, this paper is organized in detail as follows (Figure 2):

Figure 1. The west wall of the main chamber in cave 61. Inside the red box is *Wutai Mountain Map*.

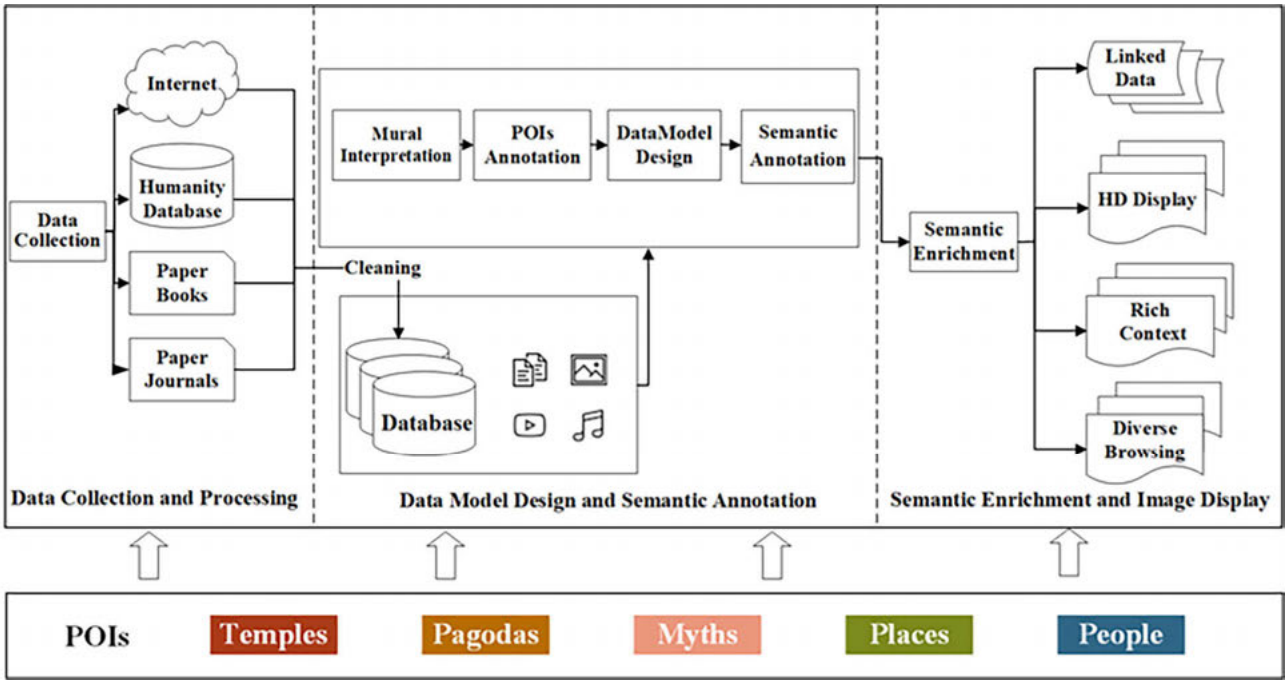

Figure 2. Flow of the semantic enrichment approach.

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1) All authoritative digital resources and paper documents related to the *Wutai Mountain Map* were collected, cleaned, and preprocessed before being stored in the local database.
2) This study interpreted and deconstructed the content of the mural from the facets of people, events, times, places, and things. 185 semantic units were labeled as POIs (Points of Interest).
3) Related ontologies and semantic vocabularies were reused to design the core data model for POIs of the image.
4) Through semantic annotations, all POIs were added with metadata.
5) Using semantic technologies, metadata of the semantic layer was enhanced with external knowledge resources, to realize the enrichment of semantics.
6) A display platform was built from the perspective of users. This platform integrated all the semantic information and contextual knowledge associated with POIs, and provided HD mural presentation, diverse browsing, and other knowledge services.

3.1 Data collection and processing

Acquiring background knowledge related to images of CH could provide knowledge resource support for deconstructing images. Images of CH have rich semantic connotations, and the background and interpretation materials related to this work were widely distributed in paper documents and digital resources. The *Wutai Mountain Map* is complex and domain-oriented in content. To improve the quality of data collection, we collected all related knowledge resources for researching this image on CNKI (the largest academic paper retrieval website in China), Dunhuang Academic Resources Database, Wikipedia, as well as Wuhan University Library. We subsequently completed information resource deduplication, data cleaning, and format conversion manually. Finally, 14 paper books, 97 journal articles, 223 digital images, 6 videos, and 22 audios files useful for researching or interpreting the *Wutai Mountain Map* were collected and stored in the database.

3.2 Mural interpretation and POI annotation

The content entities in the image constitute the basic semantics of the image. To enhance the semantic content in the mural, it was necessary to first excavate the fine-grained content entities in it through interpretation. People, events, time, places, and things were the main components of information resources of CH (Xia 2016), and important facets for describing image content (Shatford 1994). As such, these five dimensions were selected to analyze the image in this study. The choice of parsing granularity was another important decision. This study attempted to analyze each individual content object as a whole, such as an individual temple or a bodhisattva, rather than discrete drawing details or techniques within a single figure. For example, a figure's dress pattern or a temple's roof style were not analyzed independently because object details contained less context, and too detailed deconstruction was not conducive to the comparison and correlation between resources. Thus, to avoid the redundancy of description, it was reasonable and appropriate to take people, events, times, places, and things as the minimum granularity by which to divide the image units, and further subdivision was not required.

Next, through quantitative analysis based on Dunhuang literature (and excluding the unrecognizable parts of the mural due to damage), 185 semantic units were extracted from the *Wutai Mountain Map*. According to the content subjects, they were divided into 88 temples, 13 pagodas, 9 groups of people, 47 myths, and 28 places. To improve accuracy, the extraction and identification of these content objects was completed manually. While simple subject headings could not fully reflect the semantic complexity of their content, the 185 semantic units contained not only mythical elements, such as Buddhist fairy tales, but also secular historical elements, such as temples and pagodas that once existed and might even still exist. The spatio-temporal information hidden in each semantic unit was also different. The buildings in the mural were built at different times and were scattered in different provinces. In addition, the historical and cultural information embodied in semantic units also had extensive relations with texts, principally imitation, reproducibility and intertextuality.

To clearly represent the location of these semantic units in the digital image of the mural for further explanation, Point of Interests (POI) in Geographic Information System (GIS) were used as a representation in this study. POI is usually used to represent geographic entities. From a broader perspective, a POI is a semantically diverse spatio-temporally evolving entity, containing geographical, temporal, and thematic relations. In a sense, a POI is similar to the semantic units in the mural. Accordingly, the 185 semantic units were labeled as POIs by the self-developed image annotation software demonstrated in Figure 3. The International Image Interoperability Framework (IIIF) is a universal standard framework for digital collections that has been widely used by LAM institutions. Our POI annotation adopted IIIF's Image API. Each POI was given a unique standardized URI that could specify its region, size, rotation, and quality characteristics.

3.3 The basic data model definition

To express the semantic content and context of the five kinds of POI in the image as fully as possible, a data model for digital images of CH was defined. The first thing to

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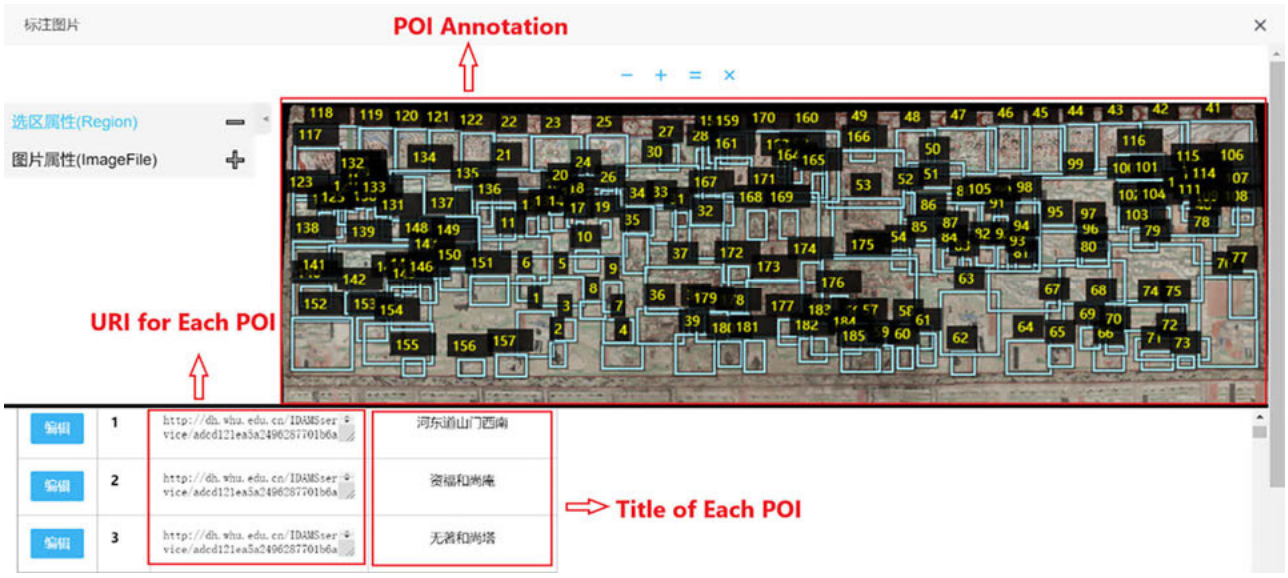

Figure 3. The POI annotation.

make clear was that image, digital image, and image content, are all related to each other despite belonging to different objects. Comprehensive descriptions of the digital image should include the description of the image itself and the description of the content reflected in the image (Wang et al. 2014). The data model was supposed to meet the following functional requirements with reference to Shatford's image semantic model (Shatford, 1986) and combining specific description requirements:

1) Represent the basic features and subject information of the mural semantic unit and its corresponding digital image.
2) Represent the content objects depicted in the semantic units, indicating their names, types, and basic description.
3) Enhance and extend the semantic level by providing interpretation context and background knowledge.

The five dimensions described above helped to identify and categorize content objects in the image, further, this data model helped to describe each content object from image and semantic levels.

To improve interoperability, the defined model reused properties from other ontologies as a best practice whenever possible. Commonly used ontologies and semantic vocabularies were examined and compared in order to ascertain their applicability to our study. EDM, widely used in the field of CH, defines "things" common in CH materials. For each class of CH things EDM provides a series of properties, most of which were reused from other vocabularies. EDM was selected based on its extensibility and reusability. To meet description objectives, we defined three core classes: edm: providedCHO, edm: webResources, dh: ContentObejct, respectively representing the mural object, the digital image of this mural object (IIIF image with supplied URI) and depicted content objects within the mural. The first two classes were reused from EDM, and dh: ContentObject was defined by this study. Context belonged to the semantic category and could provide background information such as: environmental setting, time, sequence, and social background (Huang et al. 2015). To represent context information for content objects in detail, five contextual classes were defined. The contextual classes included edm: Agent, edm: Event, edm: Place, edm: TimeSpan, skos: Concept, all reused from EDM to represent relevant entities and concepts.

In order to define the boundary between reality and fiction, the model was divided into image layer and semantic layer. The mural itself, as well as the digital image of the mural, belonged to the former, because they were both the expression carrier in the objective knowledge world. The mural content belonged to the latter, as it could be both a real-world entity and a fictional idea. The general structure of the model is as follows (Figure 4):

The model contained a total of 40 properties, of which 36 were reused from EDM, DC, DCTERMS, SKOS, OWL, FOAF, RdaGr2, CRM, RDF and RDFS (Figure 5). The model supplied a rich expressivity for describing CH content and provided the basis of our semantic enhancement efforts.

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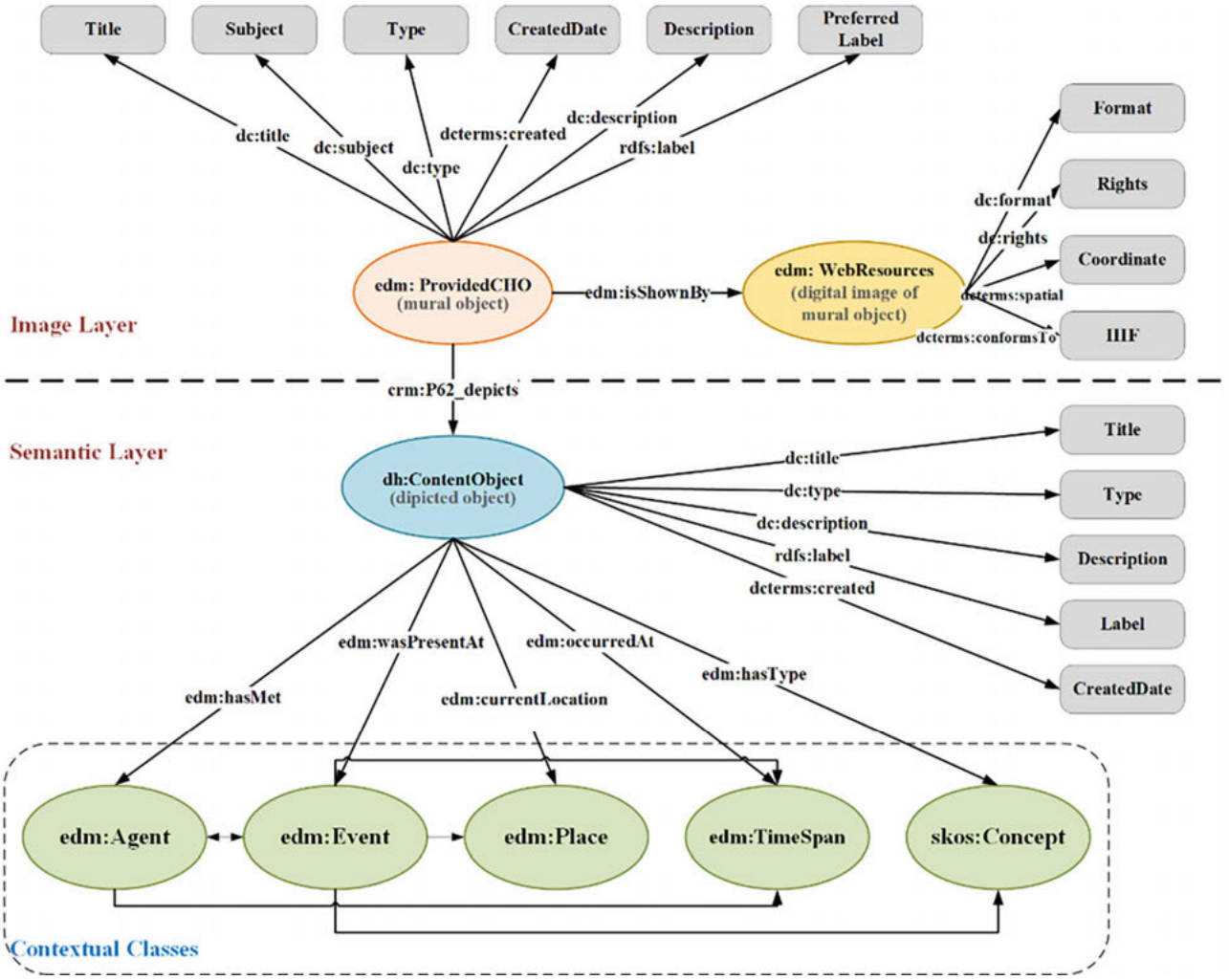

Figure 4. Basic data model.

3.4 Semantic annotation

The semantic units represented by POIs were still image resources, in which various semantic information fragments about people, places, and events, could be blocked in unstructured fields. Thus, to establish a connection between images and external knowledge resources, adding appropriate access points in the image was needed. We chose to annotate metadata for semantic units, since these metadata fields could provide potential access points for linking.

The above data model was defined in a relatively general scope, and slight adjustment was required to accommodate specific data structures during semantic annotation. For the semantic layer of the *Wutai Mountain Map*, the context information was complex, involving different kinds of people, places, and times. This information was difficult to standardize with uniform elements with enumerable scope. For example, agents associated with temples had a variety of characters such as creator, rebuilder, destroyer, practitioner, or bodhisattva. Annotating them all would create a lot of work and result in information redundancy. Furthermore, most of the context information in our local database was recorded as events in short text form. As a result, when describing the mural context, we chose to primarily annotate Current Location, which was important information and could be clearly represented; and Background Event, a rich structure with other context entities involved in it (such as: agents and places), that could be completed and enriched in the semantic enrichment step. Finally, a metadata framework was formed (Table 1), and then semantic annotation was applied for POIs.

3.5 Semantic enrichment

After semantic annotation, the mural image was combined with a metadata set describing the 185 units. This annotation data acted as a mediator between the image and the target data for enhancement. Next, referring to the criteria for

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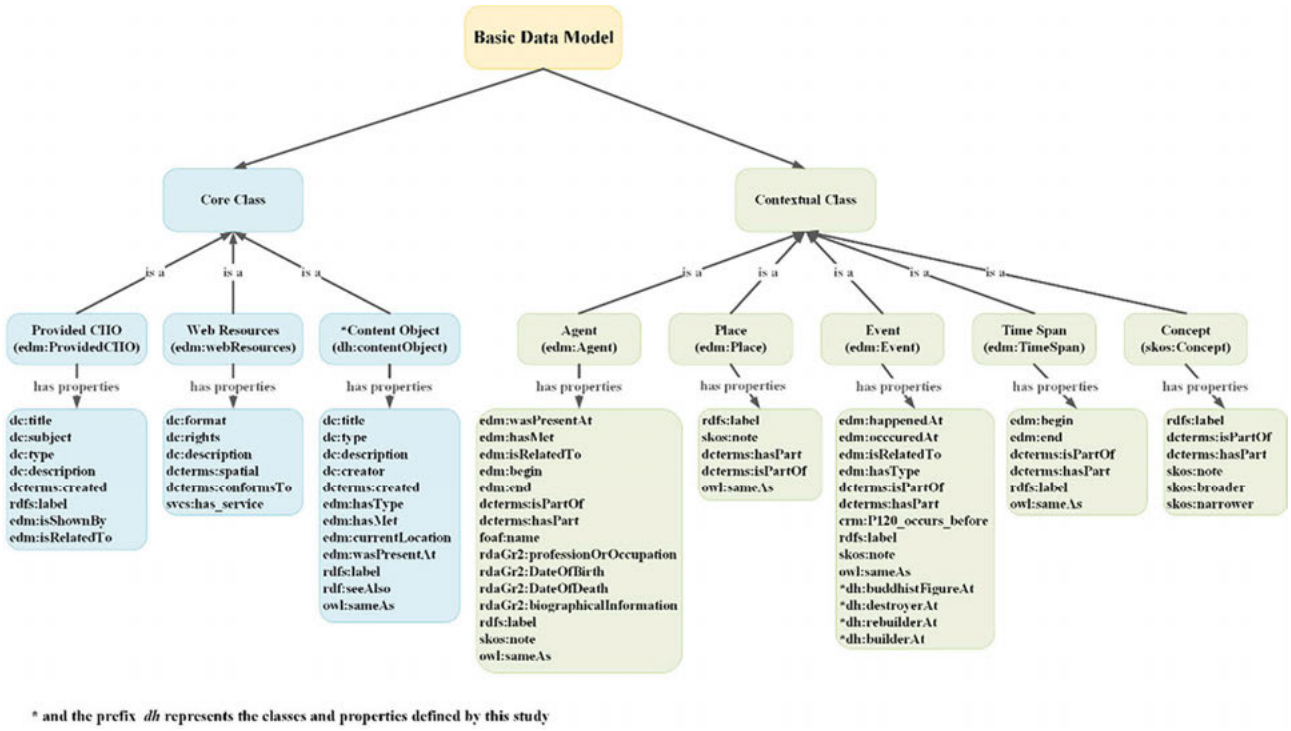

Figure 5. Classes and properties of the data model.

selecting target external data sets proposed by Isaac et al. (2015), five external data resources were selected (Figure 6). Specifically, Dunhuang Mural Thesaurus (DMT), and Wikidata, were used to correlate the content objects; Art & Architecture Thesaurus (AAT) was used to correlate concepts; Virtual International Authority File (VIAF) was used to correlate people; Getty Thesaurus of Geographic Names (TGN) was used to correlate places or locations. The other four resources are well-known, and DMT was constructed by Wuhan University as a domain vocabulary specific to knowledge of Dunhuang murals. It contained 3,896 terms and was the vocabulary most closely associated with the *Wutai Mountain Map*.

3.5.1 Entity-based enrichment by linking to external resources

Entity-based enrichment is a process by which the original data was endowed with supplementary knowledge via linking to external resources (Chen 2019b). This study mainly linked the local data to external resources in two ways: (1) directly reusing external vocabularies and (2) creating identity links. When describing the content object and its context, the values of some properties would be domain terms (well-known places, or people). These values were usually included in domain vocabularies or thesauri. Consequently, for these kinds of properties, this study chose to directly reuse the external controlled vocabularies instead of creating a new URI in accordance with best practices for linked data (W3C 2014). To accomplish this the study employed OpenRefine to automatically map strings used in the POI metadata fields, to the values in the selected vocabulary, and then replace the local values with URI resources in the vocabulary. For instance, when describing the content objects of Foguang Temple, for the property dc:type, "Temple" in AAT was applied as new value; for the property edm:currentLocation, "Wutai" in TGN was likewise applied (Figure 7).

After creating URIs for the local content entity, there were cases where URIs from external resources (such as Wikidata and DMT) pointed to the same entity. In order to provide diverse statements and perspectives for describing objects, we reconciled our data with selected resources, and then created identity links between them. This would help to reduce the cost of discovery and understanding and increase the value of data through broad knowledge links (Sanderson 2016). For establishing identity links, the OWL property owl: sameAs was reused to create equivalence relationships between two resources, indicating that the entities linked up pointed to the same thing (Figure 8).

3.5.2 Establishing internal relations between POIs

There was a variety of semantic units which were represented as POIs in the *Wutai Mountain Map*, reflecting the complexity of semantics. What is more, we found there were also associations between these POIs. Firstly, this mural had

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Element	Value
Digital Image of Mural	
Format (dc: format)	JPEG image
Right (dc: rights)	Dunhuang Academy
Coordinate (dcterms: spatial)	(6828,1576,681,429)
Mural	
Title (dc: title)	Big Foguang Temple
Label (dc: label)	大佛光之寺@ZH
Subject (dc: subject)	Temple
Type (dc: type)	Mural Paintings/Narrative Cycles
Created Date (dcterms: created)	A.D. 947-951
Description (dc: description)	The Big Foguang Temple is painted below the north of Wutai Mountain and is a square courtyard with cloister. It has two floors of double-eaves…
Mural Content	
Title (dc: title)	Foguang Temple
Label (dc: label)	佛光寺@ZH
Type (dc: type)	Temple
Description (dc: description)	Foguang Temple is a Buddhist temple located five kilometres from Doucun, Wutai County, Shanxi Province of China. The major hall of the temple is the Great East Hall, built in 857, during the Tang Dynasty…
Created Date (dcterms: created)	A.D. 471-499
Current Location (edm: currentLocation)	Wutai County
Background Event (edm: wasPresentAt)	Foguang temple was survived in Great Anti-Buddhist Persecution for remote location.
	Famous Chinese architect Liang sicheng discovered and then studied Foguang temple.

Table 1. Semantic annotation framework.

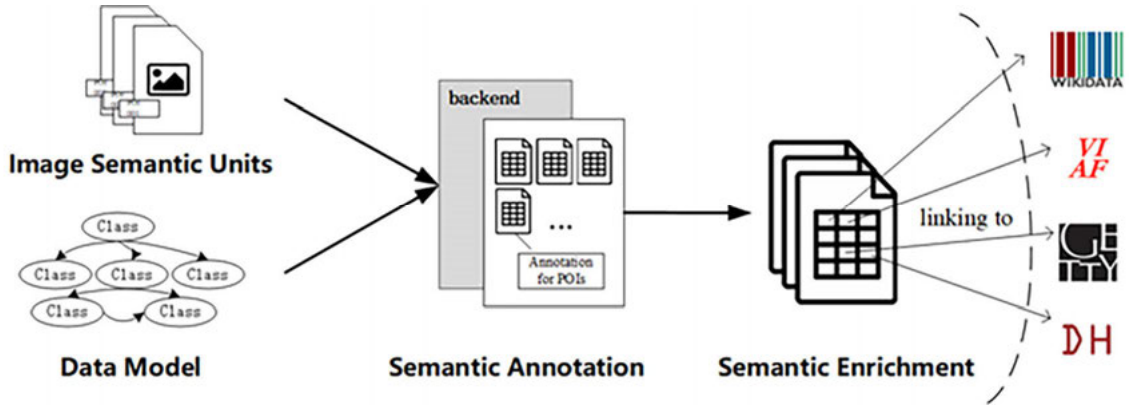

Figure 6. The process of enrichment

sym metry in composition, so there would be two POIs depicting the same content object. To express this relationship, edm:isRelatedTo was used to connect the POIs, and their values of crm:P62_depicts pointed to the same content object (Figure 9). Secondly, the *Wutai Mountain Map* had narrative characteristics. Therefore, two or more POIs distributed in the image might together tell a story, and there would be a chronological sequence between the POIs.

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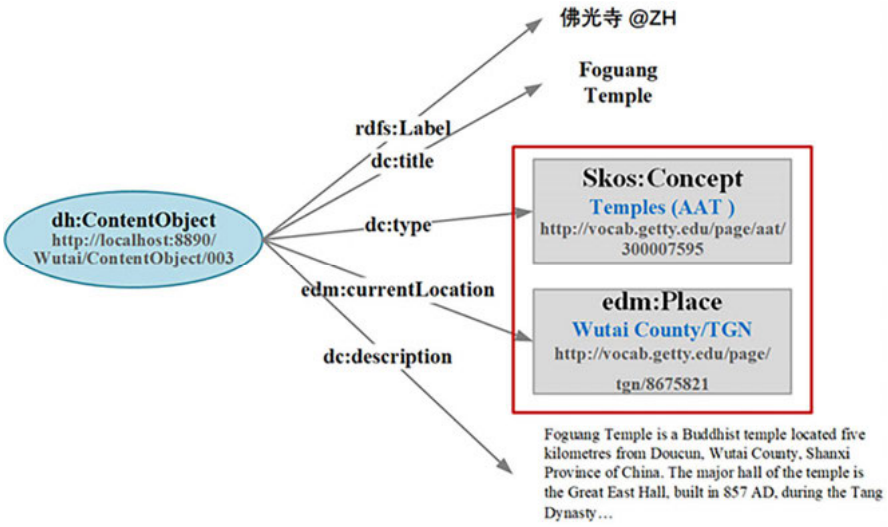

Figure 7. Reusing external vocabularies

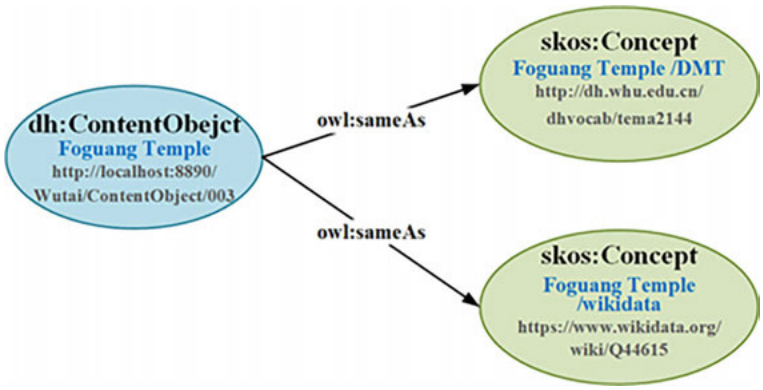

Figure 8. Entity linking by creating identity links.

Under the circumstances, edm:isNextInSequence was selected to link the POIs and express their order of occurrence.

3.5.3 Enhancing the contextual information by event-centric approach

Events are significant in the contextualization of objects. By providing background description about the objects, in terms of people, places, and times involved in such events (Meghini et al. 2019), the object becomes contextualized. When annotating metadata, this study represented each piece of context information as an event, which could be further associated with other historical figures, well-known events, dynasties, and places, both real and mythical. Therefore, the event-centric approach was used in this study, with the goal of enhancing the contextual information of content objects. Specifically, the local event entity was first created as an event class, and subsequently this event class acted as a mediator to associate relevant people, events, places, and concept entities. Next, these related entities were further described or associated with other external resources, in order to support extensive knowledge discovery. For example, the local event entity "Liang Sicheng discovered Foguang temple" was created as a contextual class (Figure 10), and through edm:wasPresentAt, the event was linked with the content entity Foguang temple. Furthermore, the record of Liang Sicheng in the VIAF was reused, and through edm:wasPresentAt, Liang Sicheng was linked to the event as main agent and subject. Finally, more details were ascribed to Liang Sicheng, the famous architect in China.

This study also established inclusion relations, and sequence relations between contextual events. To this end, dcterms:hasPart and dcterms:isPartOf were used to represent inclusion links, and crm:P120_occurs_before was used for representing sequence of events. For instance, "Foguang temple has survived great Anti-Buddhist Persecution for a remote location" was a sub-event of "Great Anti-Buddhist

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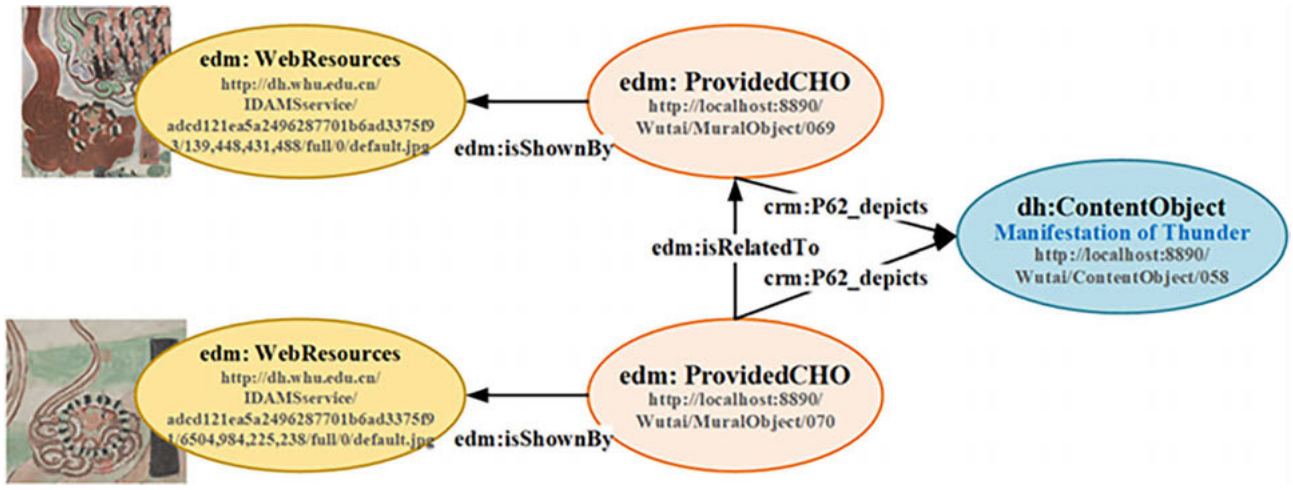

Figure 9. Establishing relations between POIs depicting the same object.

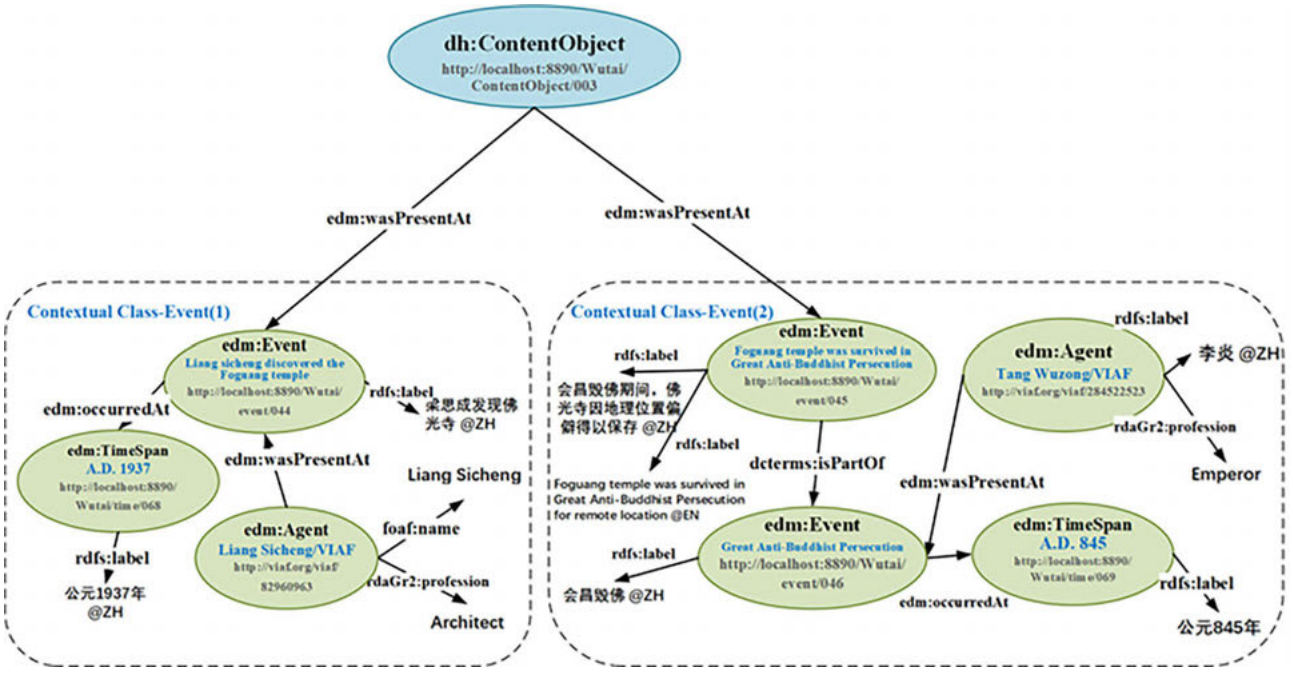

Figure 10. Event-centric enrichment.

Persecution". Under this circumstances, dcterms:hasPart and dcterms:isPartOf could be both used to link the two events. Through these connections, a complete historical background network was constructed.

3.5.4 Defining hierarchical relations between specific and general properties

In the data model, the four properties, dh:builder, dh:rebuilderAt, dh:destroyerAt, dh:buddhistFigureAt, were defined by this study to describe more precisely the role of the agent in the event. The reason for defining these properties ourselves was that required terms to express these relationships could not be found in the existing widely used semantic vocabularies. The key to improve the semantic interoperability of self-defined schema is mappings. RDFS and OWL provided properties to define relations between different properties. Hence, we primarily mapped the self-defined properties to related properties in the EDM and defined the hierarchical relations between them. Specifically, dh:builder, dh:rebuilderAt, dh:destroyerAt and dh:buddhistFigureAt all represented the role of the agent in the event. This meant edm:wasPresentAt was inherently their super-property. Then, with the RDFS property rdfs:sub-

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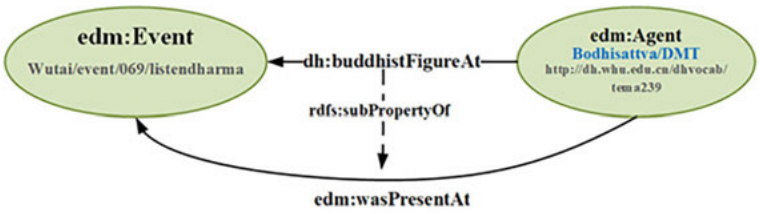

Figure 11. Defining relationships between properties.

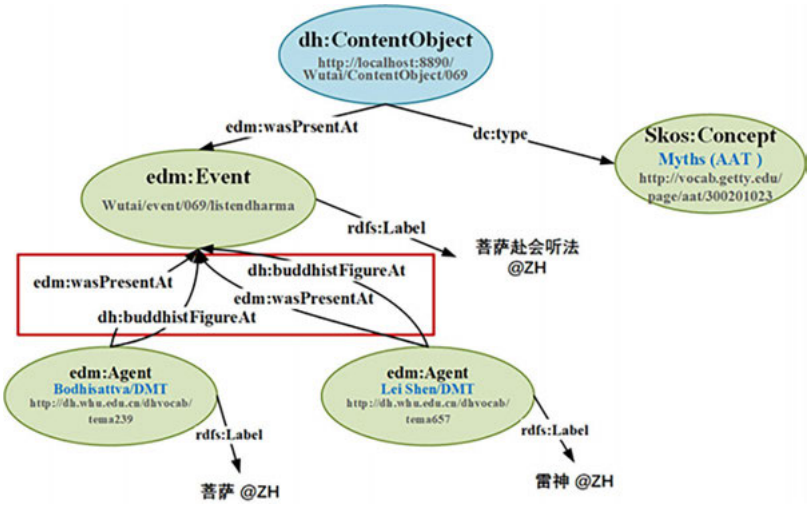

Figure 12. The coexistence of general properties and specific properties.

PropertyOf, the relations between properties could be stated as follows in Figure 11.

General properties and specific properties coexisted in this study (Figure 12). This coexistence of general and specific properties made it possible for users to search objects using general terms and also to present information from a more granular perspective where appropriate (Isaac et al. 2013).

3.5.5 Text annotation and named entity recognition

Text can explain and expand upon image content via the following three types of expansion: (1) elaborations: what can be seen in this image, (2) extensions: what this image could mean, and (3) enhancements: the context needed to fully understand the image (Martinec and Salway 2005). In our study above, metadata and its linking information, as well as the description of the context, was used to interpret POIs. This usage may be regarded as the application of elaboration and enhancement. Since much of this information goes beyond what could be seen in the digital images of CH, it was also necessary to provide extensions for the image, such as interpretation of meaning. This was especially evident in the case of mysterious myths and complicated Buddhist meanings depicted in the *Wutai Mountain Map* which required further detailed explanation. Because the front-end metadata display was less readable to users, it failed to fully capture the user's interest. To remedy this, this study provided texts related to the image details and background information to promote the user's participation. These texts were able to provide a comparison between the depiction of historical events, and the people in the images and literature. For example, the image associated with the POI named "envoys from Silla to worship the Bodhisattva" depicted envoys from the Korean peninsula coming to Wutai Mountain to offer tributes during the Five Dynasties, an event which had not been recorded in the literature. Therefore, it might provide new and important historical materials for the study of the development of Buddhism during the Tang and Five Dynasties, as well as the relationship between China and the Korean peninsula.

Hence, the texts related to the allegorical interpretation, image details and background information of the image recorded in the authoritative research literature (e.g., research papers and monographs on Dunhuang study, historical record) were sorted out. Original academic texts were uniformly rewritten into more readable, story-telling essays. Through annotation, these texts were added to each POI.

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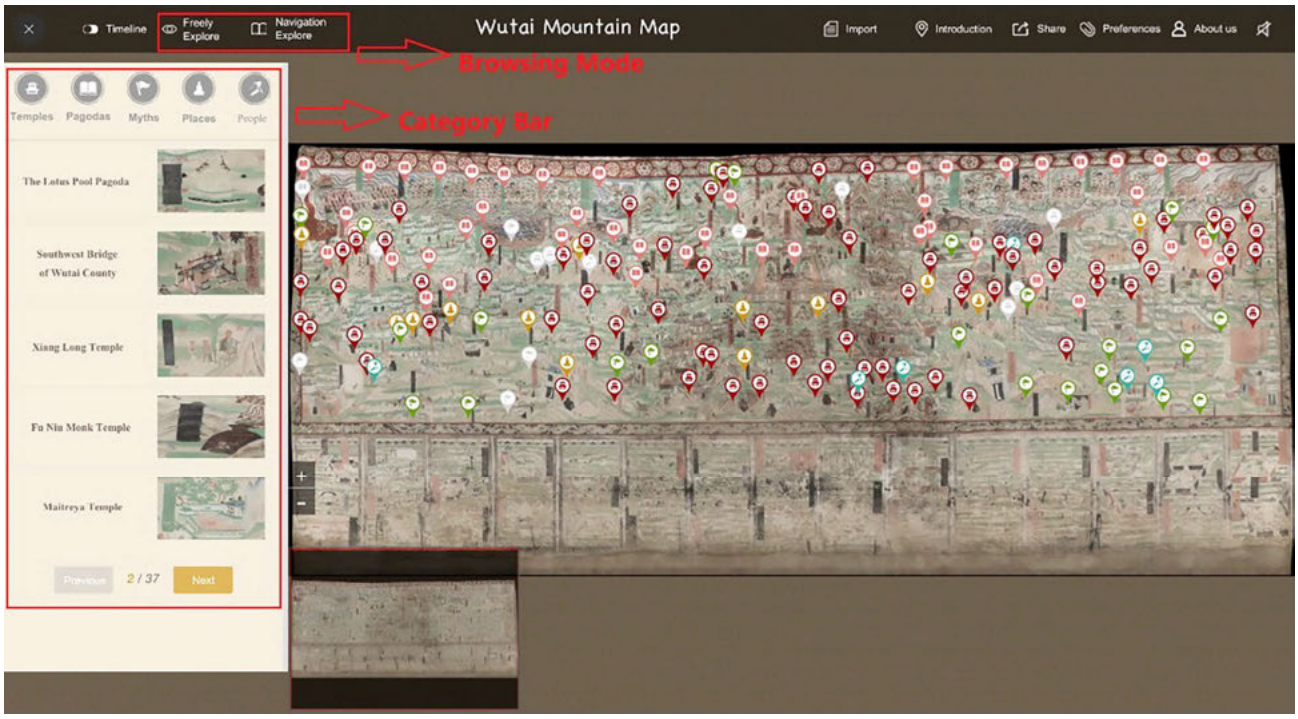

Figure 13. The main page of the platform.

These texts extracted from the literature usually contained important people, places, or Buddhist concepts. To highlight and further illustrate these terms, we extracted these nouns by means of named entity recognition and then connected them with Dunhuang Mural Thesaurus and Wikipedia to provide more interpretation and further reading.

4.0 Display of digital images of cultural heritage

CH data is for discovery and inspiration, not just management. Thus, after converting the image semantic data into RDF and publishing it as Linked Data, a display platform for digital images of CH was built (with IIIF Image API adopted) in order to provide better knowledge services to users.

The platform displays the HD digital image of the *Wutai Mountain Map* provided by Dunhuang Research at a resolution of 38656×16594. It allows users to clearly view the details of each part and smoothly zoom in and out of the whole in a manner that fosters a positive viewing experience for any use. On the platform, the five categories of POIs discussed previously are represented by icons of different colors and styles (Figure 13). For example, the red temple icon represents Temple; the blue portrait icon represents People; the green flag icon represents Place. To the left of the platform, is a category bar displaying the POIs arranged by topic. Also, multiple browsing modes, including Freely Explore, Navigation Explore or Category Explore, are provided for users. These browsing modes allow users to select the right search experience to accommodate their different knowledge backgrounds and exploring needs. For example, in Navigation Explore mode, users may select one of three themes (temple, myth, and place) to explore further. Once a user selects one of these three themes, the platform will automatically lead the user through all the key marked POIs of their chosen theme. For each POI, a user can click the Image Interpretation button on the right side of the page, where they may select two information pages about the POI, Metadata and Detailed Interpretation. The Metadata page displays metadata and linked information for each POI. When choosing Detailed Interpretation, t users can view multimodal information regarding the POI's image details, historical background, and Buddhist significance, and containing: text, image, audio etc. (Figure 14). Audio files are also added as background sounds based on the content characteristics of each POI in order to create a more immersive browsing experience. For example, when the user is browsing the temple POI, he will hear the sound of chanting or beating Muyu (wooden fish) in the temple. Temporal information of POIs and Chinese historical dynasties have been mapped. Through the Timeline depicted in Figure 13, users may also choose to view POIs in chronological order.

5.0 Discussion

Images of CH are precious not only because they embody the exquisite techniques and ingenious ideas of predecessors, but also because they are faithful narrators of history

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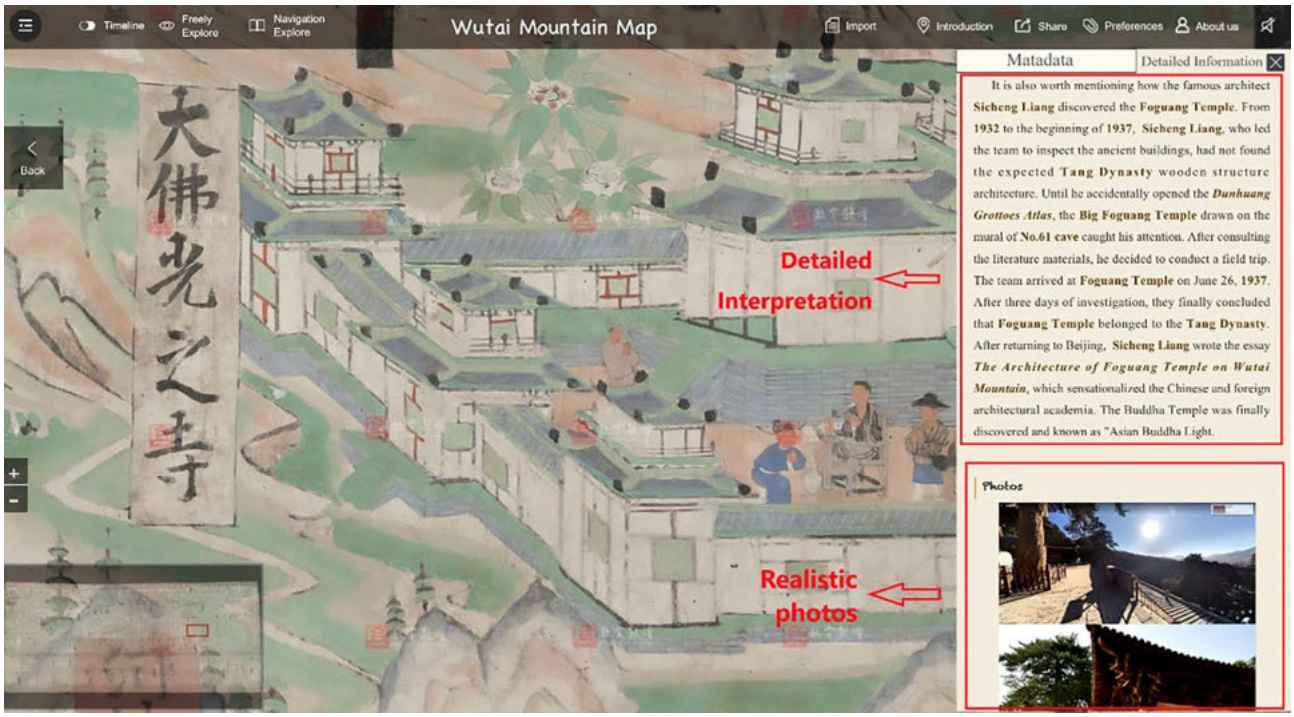

Figure 14. Detailed information of the POI Big Foguang Temple.

and culture. Excavating the social scenes, traditional customs, and historical stories recorded in CH images is critical to revealing their value and potential. By combining the perspective of image research with DH, this study presents a semantic model for CH digital images as well as a method to enrich their content and context in order to disclose the content entities of digital images of CH. The model and method proposed can effectively reveal an image's content and create semantic relation between image and the external knowledge resources as demonstrated by the study's semantic enrichment of the *Wutai Mountain Map*. The semantic enrichment method is conducive to improving users' in-depth understanding as well as to promoting the dissemination and utilization of digital images of CH. To further illustrate our research, the key thoughts and implications of this study are as follows:

1) Whether a method has wide applicability is an important factor affecting its significance. This study selected the *Wutai Mountain Map* as an example because it is a visual resource of CH that exemplified landscape painting, religious story painting, narrative structures, and historical maps. Its depiction pattern is common to different types of images of CH, whether Eastern or Western, classical or modern. The semantic enrichment method capable of revealing as complex and expansive a work as the *Wutai Mountain Map* is clearly applicable to other less complex exhaustive images of CH. It should however be noted that the model and method proposed, are more suitable for CH with documentary, figurative, or narrativity features, because they contain clear semantic units related to other knowledge entities. Images without these features (such as abstract paintings), may not be suitable for this method of analyzing content.
2) Presenting as accurately and extensively as possible the events involved in CH objects is important for understanding history and culture (Ruotsalo and Hyvönen 2007). EDM has provided an object-centric approach, and an event-centric approach for aggregating metadata of CH. However, the event-centric approach is rarely used by aggregators or the linked data CH projects (Dorobăț and Posea 2019).This paper adopts this event-centric approach for semantic enrichment, in order to enhance the context around the content. Our research shows that this approach can improve the richness of digital representations of CH. Therefore, we suggest the application of this underutilized event-centric method be further explored and promoted by the Linked Data field. However, there are also difficulties in applying this method. Events related to CH, whether they are about the lifecycle of works (e.g., creation, circulation, exhibition) or inherent content, are usually recorded in historical documents, which are almost all written in natural language for interpersonal communication. This makes it difficult for the machine to capture event information from these documents, as machine cannot understand complex unstructured text (Almeida et al. 2011). For this reason, we extract and annotate events manually. On a

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small scale, the time and labor costs are acceptable. However, in order to scale this approach to vast CH digital image collections, semi-automatic or man-machine collaborations need to be explored.

3) In the context of LOD, semantic enrichment and linked data have become two closely related concepts. To some extent, the semantic enrichment approach is embodied by the process of publishing linked data. With further development of linked data and semantic technologies, semantic enrichment methods will necessarily be constantly updated and developed.

6.0 Conclusion

This paper analyzes the essential shortcomings of existing CH image information organization methods and identified three major weaknesses: (1) the lack of representation of the content, (2) the lack of association between the content and external knowledge resources, and (3) the neglect of the needs of ordinary users. To address the issues raised, this paper proposes a systematic methodology and a technical route for the semantic enrichment of CH digital images. The feasibility and advantage of this method are attested by their successful application to the semantic representation of a digital image of one of the most complex Dunhuang wall murals.

This final platform demonstrates that semantic enrichment provides a new model for exposing content at a fine-grained level, and providing meaningful contextualization of digital images of CH. By using semantic enrichment methods, such as reusing external vocabularies, event-centric enrichment, entity linking, defining relations between properties, as well as text annotation and named entity recognition, a rich semantic network centered on the content of digital images of CH can be formed. Our work seeks to promote the application of semantic enrichment for image resources and provide a methodological reference for image representation and presentation in LAM institutions. In future work, we plan to construct an evaluation framework to conduct user experiments in order to ascertain how best the semantic enrichment of this study can help researchers and ordinary users understand the semantic content of CH images to enhance their interest, research and appreciation. User experimentation and evaluation will undoubtedly help us optimize our methods and platform in the future.

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