Instance Assisted Ontology Alignment for Digital Museums

HONGZHE LIU
Institute of Information Technology
Beijing Union University
BeiSiHuan East Road, Beijing
CHINA

HONG BAO
Institute of Information Technology
Beijing Union University
BeiSiHuan East Road, Beijing
CHINA

JUNKANG FENG
School of Computing
University of Paisley
PA1 2BE, Paisley, Scotland
UK

Abstract: - It is desirable to the distribute data and knowledge of a huge amount of cultural heritage and to make them available readily to people, but the distributed, heterogeneous and autonomous nature of the databases of digital museums gives rise to the challenge of achieving the best retrieval results in cross-system searching. To make this difficult task tractable, we analyze semantic heterogeneities among these data sources and describe an instance based approach to accomplishing soundness and completeness preserving ontology alignment by using the information flow theory.

Key-Words: - Digital museum, information flow, ontology alignment, soundness, completeness

1. Introduction

In the open environment of the Internet and the Web, information resources are heterogeneous and are indexed with different vocabularies and organized according to different schemes. How to achieve the best retrieval results in cross-domain searching has presented a particular challenge to the information profession. In information retrieval, users typically are neither, nor should they need to be, aware of the behind-the-scenes mechanisms for matching their query terms to the vocabularies employed by various systems. The ideal approach would be to provide a "one-stop" seamless searching instead of requiring the user to search individual databases or collections separately. To enable such an approach, it is important to render the different knowledge organization systems interoperable.

Chinese civilization has been around for thousands of years, and as a result a huge amount of cultural heritage and antiques are scattered all over the vast territory of China. All kinds of digital museums have been developed for them. Each of these museums maintains large digital archives of their collections. They represent an extremely valuable cultural heritage resource, and yet access and exploitation of the data is constrained due to the distributed and heterogeneous nature of the resource. Therefore it is highly desirable to find an avenue to integrating these distributed and heterogeneous systems.

The remainder of this paper is organized as follows: Section 2 describes a motivating example in digital museum domain. Section 3 defines the ontology mapping. Section 4 lists the related works. Section 5 proposes our solution. Finally section 6 summarizes our contribution of the work and gives a conclusion.

2. Motivating Example

Given two digital museums 1 and 2 with local ontology alignment as the follows:

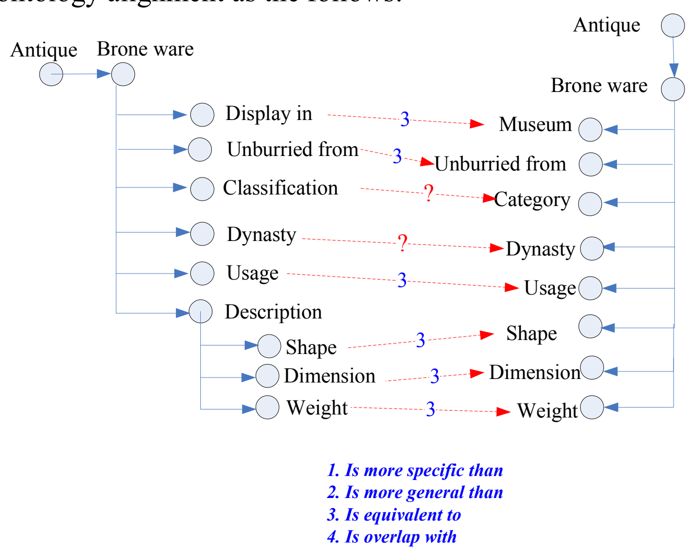

Fig.1 Partial conceptual alignment between two local ontologies

Table 1 Instances of digital museum 1

Bronze Ware	**Dynasty**
NiuShouWenLiNiao Bo 牛首纹立鸟镈	XiaShang 夏商
JuanYunWen Nao 卷云纹铙	XiaShang 夏商
ShenRenWenShuangNiao Gu 神人纹双鸟鼓	XiaShang 夏商
JiaYiBingDing Bo 鎛甲乙丙丁	XiZhou 西周
HuWenZheng Nao 虎纹钲（铙）	XiZhou 西周
YingHouJianZhong 应侯见钟	XiZhou 西周
YunWen Nao 云纹铙	ChunQiuZhanGuo 春秋战国
ZengHouYiBian Zhong 曾侯乙编钟	ChunQiuZhanGuo 春秋战国
HuNiuYu Chun 虎钮錞于	ChunQiuZhanGuo 春秋战国
ZhanGuo Gu 战国鼓	ChunQiuZhanGuo 春秋战国
QuGuanHuLu Sheng 曲管葫芦笙	ChunQiuZhanGuo 春秋战国
QinGong Bo 秦公鎛	ChunQiuZhanGuo 春秋战国
Gong Bo 公鎛	QinHan 秦汉
Gong Zhong 公钟	QinHan 秦汉
TieJinTong Gu 贴金铜鼓	QinHan 秦汉
…	…

Table 2 Instances of digital museum 2

Bronze Ware	**Dynasty**
JuanYunWen Nao 卷云纹铙	Shang 商
BianXingShouMianWen Nao 变形兽面纹铙	ChunQiu 春秋
JinHouMu Zhong 晋侯木钟	XiZhou 西周
WangSunHaoYong Zhong 王孙诰甬钟	Late ChunQiu 春秋晚期
Gong Zhong 公钟	QinHan 秦汉
Xing Zhong 兴钟	XiZhou 西周
NiuShouWenLiNiao Bo 牛首纹立鸟镈	Shang 商
PanSheWenBian Bo 蟠蛇纹编鎛	Late ChunQiu 春秋晚期
Gong Bo 公鎛	Qin 秦
JiaYiBingDing Bo 鎛甲乙丙丁	XiZhou 西周
ShenRenWenShuangNiao Gu 神人纹双鸟鼓	Late Shang 商晚期
WuZhuXianWen Gu 五铢线纹鼓	Late XiHan 西汉晚期
ZhanGuo Gu 战国鼓	ZhanGuo 战国
HuNiuYu Chun 虎钮錞于	ZhanGuo 战国
QuGuanHuLu Sheng 曲管葫芦笙	ZhanGuo 战国
…	…

Two standards for classifying Bronze Ware are as follows:

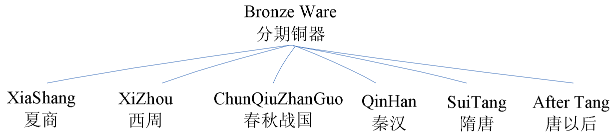

Fig. 2 bronze Ware classifications 1 according to creation time

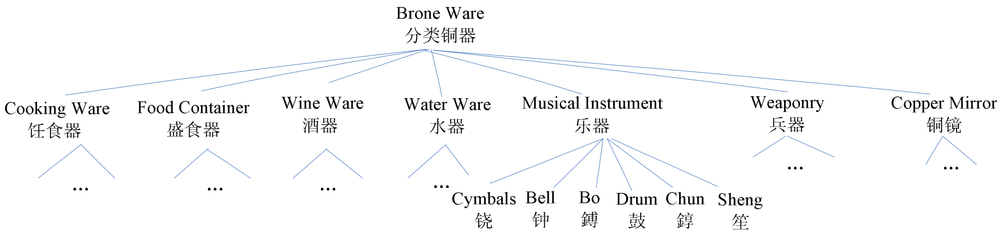

Fig. 3 Bronze Ware classifications 2 according to usage and shape

The category in table 1 is based on the creation time of the Bronze Ware，that is, the dynasty when it was created. The category in table 2 is based on the usages of the Bronze Ware on the first classification level. For example, if it is usually used for cooking food, a piece of Bronze Ware belongs to Cooking Ware. The Musical Instruments are classified further according to their shapes on the second level.

Two local ontology partially maps at conceptual level in figure 1, and they still cannot communicate with each other due to above content based heterogeneity (shown in tables 1 and 2 and fig. 2 and 3).

3 Problem definitions

In order define our problem, we give the following definition:

Definition 1 (Ontology) An *ontology* is a pair ***O*** = **<*C, R*>** where ***C*** is a finite set of *concept* connected by R which is a finite set of *relations*.

Definition 2 (Bridge rule) Given a family ***O*** = *{**O**$_i$}* $i \in I$ of *ontologies*, a *bridge rule* from *i* to *j* is *i : X→ j : Y :*

1. *is more specific than*
2. *is more general than*
3. *is equivalent to*
4. *is overlap with*

Where ***X, Y*** are concept names of ***O**$_i$* and ***O**$_j$* respectively. *Bridge rules* from *i* to *j* represent *conceptual relations* stated from the *j*-th subjective point of view.

Definition 3 (conceptual relation) A *conceptual relation* ***B*** = **<*C, B*>,** consists of a collection of *concepts* ***C****={**C**$_i$} ($i \in I$)* from *ontology* ***O*** = *{**O**$_i$} ($i \in I$)* and a collection of *bridge rules* ***B*** = *{**B**$_{ij}$}* $i \neq j \in I$ between them.

Definition 4 (Ontology Semantics) For each *local ontology* ***O**$_i$*, the *semantics* is a family of *local interpretations* $\{\Delta^{I_i}\}$ $i \in I$, one for each ***O**$_i$*. Each I_i is called a *local interpretation* and consists of a nonempty, possibly *infinite domain* Δ^{I_i} ,and a *valuation function* $.^{I_i}$ which maps every *concept* to a subset of Δ^{I_i} , every *relation* to a subset of $\Delta^{I_i} \times \Delta^{I_j}$. Since *local interpretation domains* Δ^{I_i} can be heterogeneous, the semantic correspondences between them are modeled using *semantic relation*.

Definition 5 (Semantic relation) *A semantic relation* r_{ij} from Δ^{I_i} to Δ^{I_j} is a subset of $\Delta^{I_i} \times \Delta^{I_j}$ that represents a possible way of mapping the elements of Δ^{I_i} into the domain Δ^{I_j} , seen from subjective *j*-th perspective. For instance, if Δ^{I^1} and Δ^{I^2} are the representations of weight in kilogram and in pound, then r_{12} could be the rate of exchange function, or some other approximation relation.

Definition 6 (ontology mapping) *Ontology Mapping* is the process whereby two *ontologies* are *semantically related at conceptual level*, and the source ontology instances are transformed into the target ontology entities according to those *semantic relations.*

As shown with the motivating example in Section 2 when we looked at mappings between local ontologies, normally we cannot identify *conceptual relations* including *bridge rules* between two concepts based entirely on their literal meaning. We observe that the *semantics* of local ontologies and the *semantic relations* help the task. But how to identify them? Information flow theory proposes a principle where the two tiers involved in a *classification*, namely the *types* and the *particulars* both contribute to the flow of information. Drawing on this fundamental idea and that semantic inter-operability is essentially a problem of *information flow*, we propose an instance assisted ontology alignment approach to distributed digital museums.

4 Related Works

A project similar to ours is the SCULPTEUR[1] project, which is an ontological-based solution for navigating, searching and retrieving digital cultural heritage information from multiple distributed digital museums. The nature of the work would seem an ontology based semantic integration for multiple heterogeneous sources such as the work of RDFT: mapping meta-ontology for integration task[2], MAFRA: mapping framework for distributed ontologies[3], OntoMerge: Ontology Translation by merging and reasoning[4], Observer: interoperation across preexisting ontologies[5], OIS: framework for ontology integration system[6], somewhere: querying distributed ontologies[7].

Ontology based integration through can overcome semantic heterogeneities, but there is not a universal ontology mapping method for all solutions especially for some specific domain. For example, the classification heterogeneity, which is a commonplace in Chinese antique classifications, would not seem solvable by currently available ontology based methods. In order to find the internal correspondences between different classifications, we propose an information flow based solution, which classifies as *types* the hierarchy of the classifications and as *tokens* the instances that satisfy the corresponding *types*, and an agreed *classification* with an indexed family of *infomorphisms* act as *core connections* of them. Yannis Kalfoglou and Marco Schorlemmer use a similar idea to resolve the English and French concept conflict in [8].

5 Using Information Flow for the Semantic Heterogeneity

5.1 Information Flow Theory

Information Flow is a rigorous, mathematic theory of knowledge distribution proposed by Barwise and Seligman in 1997[9]. It helps solve problems of how information about one or more components of a distributed system carries information about other components.

Classification. A *classification* is a structure $\boldsymbol{A} = \langle tok(A), typ(A), \models_A \rangle$, where *tok(A)* is a set of objects to be classified, called the *tokens* of ***A*****,** *typ(A)* is a set of objects used to classify the *tokens*, called the *types* of ***A***, and $\models_A$ is a binary relation between *tok(A)* and *typ(A)* that determines which *tokens* are classified by which *types*. If $a \models_A \alpha$ then we say that *a* is of type α in *classification **A***.

Theory. Given a *classification **A***, a *sequent* is a pair *(Γ, Δ)* of sets of *types* of ***A***.

A *token a* of ***A*** is said to satisfy the *sequent (Γ, Δ)* if,

$$(\forall \alpha \in \Gamma)[a \models \alpha] \Rightarrow (\exists \alpha \in \Delta)[a \models \alpha]$$

We say that *Γ entail*s *Δ* in ***A***, written $\Gamma \vdash_A \Delta$, if every *token* of ***A*** satisfies *(Γ, Δ)*.

If $\Gamma \vdash_A \Delta$, then the pair (*Γ, Δ*) is said to be a *constraint* supported by the *classification **A***.

The set of all *constraints* supported by ***A*** is called the *complete theory* of ***A***, denoted by *Th(A)*. The complete *theory* of *A* represents all the regularities supported by the system being modeled by ***A***.

- **Entailment:** a *constraint* of the form $\alpha \vdash \beta$ represent the claim that α *entail*s β.
- **Necessity:** a *constraint* of the form $\vdash \alpha$ represent the claim that the type α is necessarily the case, without any preconditions.
- **Exhaustive:** a *constraint* of the form $\vdash \alpha, \beta$ represent the claim that every *token* is of one of the two *types* α and β, again without any preconditions.
- **Incompatible types:** a *constraint* of the form $\alpha, \beta \vdash$ represents the claim that no *token* is of both *types* α and β.
- **Incoherent types:** a *constraint* of the form $\alpha \vdash$ represents the claim that no *token* is of type α.

Infomorphism. Let $\boldsymbol{A} = \langle tok(A), typ(A), \models_A \rangle$, and $\boldsymbol{C} = < tok(C), typ(C), \models_C >$, be two *classifications*. An *infomorphism* between $\boldsymbol{A}$ and $\boldsymbol{C}$ is a contravariant pair of function $f = (f^{\wedge}, f^{\vee})$ that satisfies the following Fundamental Property of *Infomorphism*:

$$f^{\vee}(c) \models_A \alpha \;\; iff \;\; c \models_c f^{\wedge}(\alpha)$$

For all *tokens* c of C and all *types* α of A. We refer to $f^{\wedge}$ as "f-up" and $f^{\vee}$ as "f-down". We take account of the fact that the functions $f^{\wedge}$ and $f^{\vee}$ act in opposite directions by writing $f: A \rightleftarrows C$.

Local logics A *local logic* $\boldsymbol{L} = <\boldsymbol{A}, \vdash_L, N_L>$ consists of a *classification* $\boldsymbol{A}$, a set $\vdash_L$ of *sequents* (satisfying certain structural rules) involving the *types* of $\boldsymbol{A}$, called the *constraints* of L, and a subset $N_L \subseteq \boldsymbol{A}$, called the *normal tokens* of L, which satisfy all the *constraints* of $\vdash_L$. A *local logic* L is **sound** if every *token* is *normal*; it is **complete** if every *sequent* that holds of all *normal tokens* is in the consequence relation $\vdash_L$. A *logic* is **natural** if it is generated by some *classification*, and a *natural logic* is *sound* and *complete*. Using *infomorphisms*, we can move *local logics* around from one *classification* to another even though this normally preserve neither *soundness* nor *completeness*.

If Γ is a set of *types* of $\boldsymbol{A}$, we denote by Γ^f the set of translations of *types* in Γ. If Γ is a set of *types* of $\boldsymbol{B}$, we denote by Γ^{-f} the set of *types* of $\boldsymbol{A}$ whose translations are in Γ.The following two inference rules allow us to pass from one *classification* to another:

f-Intro: $$\frac{\Gamma^{-f} \vdash_A \Delta^{-f}}{\Gamma \vdash_B \Delta}$$

f-Elim: $$\frac{\Gamma^{f} \vdash_B \Delta^{f}}{\Gamma \vdash_A \Delta}$$

The first rule allows us to go from a *sequent* of $\boldsymbol{A}$ to a *sequent* of $\boldsymbol{B}$; the second rule allows us to go the other way round. It can be proven (which is omitted in this paper and interested user is referred to Barwise and Seligman 1997) that *f*-**Intro** preserves *soundness*, whereas *f*-**Elim** preserves *completeness*. Given an *infomorphism* f: $\boldsymbol{A} \rightleftarrows \boldsymbol{B}$ and a *logic* L on one of these *classifications*, we obtain a *natural logic* on the other. If L is a *logic* on $\boldsymbol{A}$, then $f[L]$ denotes the *logic* on $\boldsymbol{B}$ obtained from L by *f*-**Intro**. If L is a *logic* on $\boldsymbol{B}$, then $f^{-1}[L]$ denotes the *logic* on $\boldsymbol{A}$ obtained from L by *f*-**Elim**.For any binary *channel* $\boldsymbol{C}$ as Fig.4, we define the *local logic* $\text{Log}_C(\boldsymbol{D})$ on $\boldsymbol{D}$ induced by that *channel* as $\text{Log}_C(\boldsymbol{D}) = d^{-1}[p[\text{Log}(\boldsymbol{P})]]$

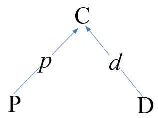

Fig. 4 Binary logic channel C

As we have observed, if Log ($\boldsymbol{P}$) is *sound* and *complete*, and p、d is *token surjective*, then $\text{Log}_C(\boldsymbol{D})$ is *sound* and *complete*.

5.2 Proposed Solution

Followed by above, C connect P and D by means of two pairs of contra-variant functions, it captures an existing duality between concepts and instances: Each pair consists of a map of concepts on the so called *type* level and map of instances on the so called *token* level, and pointing in the opposite direction. We model the two Bronze Ware categories shown in figure 2 and figure 3 as ***P(C)*** ***and D(C)***, and they are connected by an agreed understanding ***C(C)***, the *type*, *token* and generated *theory* details of the *two local logics* are illustrated bellow:

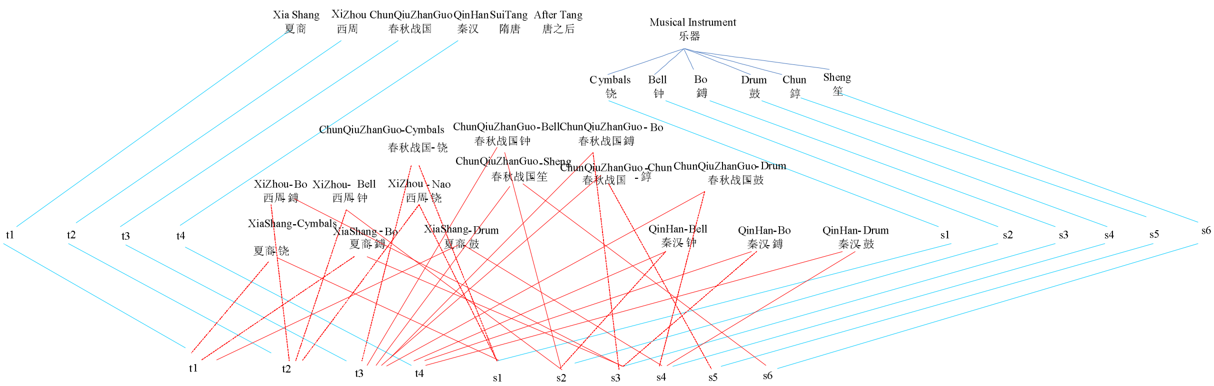

Fig.5 Bronze ware classification alignment

P(C):Type: *XiaShang, XiZhou, ChunQiuZhanGuo, QinHan* **Token:** *t1, t2, t3, t4*
Theory : $\vdash_{P(C)}$*XiaShang, XiZhou, ChunQiuZhanGuo, QinHan ; XiaShang, XiZhou, ChunQiuZhanGuo, QinHan* $\vdash_{P(C)}$

D(C):Type: *Cymbals, Bell, Bo, Drum, Chun, Sheng* **Token:** *s1, s2, s3, s4, s5, s6* **Theory:** $\vdash_{D(C)}$ *Cymbals, Bell, Bo, Drum, Chun, Sheng;Cymbals, Bell, Bo, Drum, Chun, Sheng* $\vdash_{D(C)}$

C(C):Type: *XiaShang-Cymbals, XiaShang-Bo,*

XiaShang-Drum, XiZhou-Cymbals, XiZhou-Bell, XiZhou-Bo, ChunQiuZhanGuo- Cymbals, ChunQiuZhanGuo-Drum, ChunQiuZhanGuo-Bell, ChunQiuZhanGuo-Bo, ChunQiuZhanGuo-Nao, ChunQiuZhanGuo-Chun, QinHan-Cymbals, QinHan -Bell, QinHan –Bo **Token:** *<t1,s1>, <t1,s3>, <t1,s4>, <t2,s1>, <t2,s2>, <t2,s3>, <t3,s1>, <t3,s2>, <t3,s3>, <t3,s4>, <t3,s5>, <t3,s6>, <t4,s2>, <t4,s3>, <t4,s4>*
Theory: $\vdash_{C(C)}$*XiaShang-Cymbals,XiaShang-Bo, XiaShang-Drum, XiZhou-Cymbals, XiZhou-Bell, XiZhou-Bo, ChunQiuZhanGuo- Cymbals, ChunQiuZhanGuo-Drum, ChunQiuZhanGuo-Bell, ChunQiuZhanGuo-Bo, ChunQiuZhanGuo-Nao, ChunQiuZhanGuo-Chun, QinHan-Cymbals, QinHan -Bell, QinHan –Bo;XiaShang-Cymbals, XiaShang-Bo, XiaShang-Drum, XiZhou-Cymbals, XiZhou-Bell, XiZhou-Bo, ChunQiuZhanGuo-Cymbals, ChunQiuZhanGuo-Drum, ChunQiuZhanGuo-Bell, ChunQiuZhanGuo-Bo, ChunQiuZhanGuo-Nao, ChunQiuZhanGuo-Chun, QinHan-Cymbals, QinHan -Bell, QinHan –Bo* $\vdash_{C(C)}$

Fig. 5 shows how both categories base their concepts upon their agreed understanding. For example, the agreed understanding is materialized by two maps that form the alignment. It requires the *classification* of particular instances of both categories according with the agreed understanding, since it is this agreed way of *classification* which will determine how the both categories are going to be related to each other. The following table 3 and 4 shows connections classified into the *types* which determines a *theory* of how these concepts are related.

Table 3 Connections classified according to *types* from one point of view

Instance connection	Xia Shang	Xi Zhou	ChunQiu ZhanGuo	Qin Han	Cymbals	Bell	Bo	Drum	Chun	Sheng
<t1,s1>	1				1					
<t1,s3>	1						1			
<t1,s4>	1							1		
<t2,s1>		1			1					
<t2,s2>		1				1				
<t2,s3>		1					1			
<t3,s1>			1		1					
<t3,s2>			1			1				
<t3,s3>			1				1			
<t3,s4>			1					1		
<t3,s5>			1						1	
<t3,s6>			1							1
<t4,s2>				1		1				
<t4,s3>				1			1			
<t4,s4>				1				1		

We can conclude with the following *constraints* according to above table, which is the *theory* about relations between the two antique categories:
XiaShang $\vdash_{C(C)}$ *Cymbals, Bo, Drum;XiZhou* $\vdash_{C(C)}$ *Cymbals, Bell, Bo;ChunQiuZhanGuo* $\vdash_{C(C)}$ *Cymbals, Bell, Bo, Drum, Chun, Sheng;QinHan* $\vdash_{C(C)}$ *Bell, Bo, Drum*

Table 4 Connections classified according to *types* from another point of view

Instance connection	Cymbals	Bell	Bo	Drum	Chun	Sheng	Xia Shang	Xi Zhou	ChunQiu ZhanGuo	Qin Han
<s1,t1>	1						1			
<s1,t2>	1							1		
<s1,t3>	1								1	
<s2,t2>		1						1		
<s2,t3>		1							1	
<s2,t4>		1								1
<s3,t1>			1				1			
<s3,t2>			1					1		
<s3,t3>			1						1	
<s3,t4>			1							1
<s4,t1>				1			1			
<s4,t3>				1					1	
<s4,t4>				1						1
<s5,t3>					1				1	
<s6,t3>						1			1	

Constraints concluded:
Cymbals $\vdash_{C(C)}$ *XiaShang, XiZhou, ChunQiuZhanGuo;Bell* $\vdash_{C(C)}$ *XiZhou, ChunQiuZhanGuo, QinHan;Bo* $\vdash_{C(C)}$*XiaShang, XiZhou, ChunQiuZhanGuo, QinHan;Drum* $\vdash_{C(C)}$ *XiaShang, ChunQiuZhanGuo, QinHan;Chun* $\vdash_{C(C)}$ *ChunQiuZhanGuo;Sheng* $\vdash_{C(C)}$ *ChunQiuZhanGuo*

Again, we model two 'dynasty' concepts' instance values and their instances classified according to the values as two *classifications*, and their generated *theories* as ***P(D)*** and ***D(D)*** separately, with ***C(C)*** as their *core connection*. The alignment between two 'dynasty' concepts is shown in Fig.6:

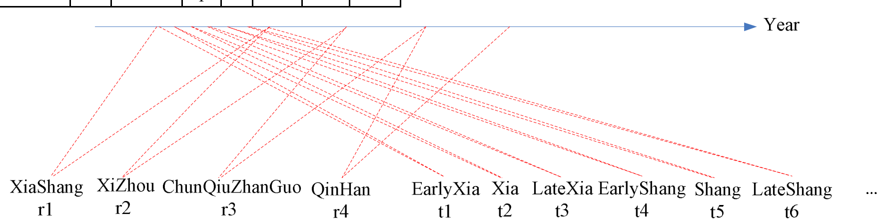

Fig.6 Two 'dynasty' concepts alignment

P(D):Type: *XiaShang XiZhou ChunQiuZhanGuo QinHan***Token:** *r1, r2, r3, r4* **Theory:** $\vdash_{P(D)}$*XiaShang XiZhou ChunQiuZhanGuo QinHan;XiaShang XiZhou ChunQiuZhanGuo QinHan* $\vdash_{P(D)}$
D(D) :Type:*EarlyXia,Xia,LateXia,EarlyShang,Shang,LateShang…***Token:** *t1, t2, t3, t4, t5, t6* **Theory:** $\vdash_{D(D)}$*EarlyXia,Xia,LateXia,EarlyShang,Shang,LateShang…;EarlyXia,Xia,LateXia,EarlyShang,Shang,LateShang…* $\vdash_{D(D)}$
C(D) :Type:*XiaShang-EarlyXia,XiaShang-Xia,XiaShang-LateXia,XiaShang-EarlyShang,XiaShang-Shang,XiaShang-LateShang...***Token:** *<r1, t1><r1,*

t2><r1, t3><r1, t4><r1, t5><r1, t6>…
Theory: *EarlyXia* $\vdash_{C(D)}$ *XiaShang,Xia* $\vdash_{C(D)}$ *XiaShang, LateXia* $\vdash_{C(D)}$ *XiaShang,EarlyShang* $\vdash_{C(D)}$ *XiaShang,Shang* $\vdash_{C(D)}$ *XiaShang,LateShang* $\vdash_{C(D)}$ *XiaShan;…; XiaShang* $\vdash_{C(D)}$ *EarlyXia,Xia,LateXia，Early Shang, Shang, LateShang;…*

The *theories* can be translated into ontology *bridge rules* as following:
XiaShang $\vdash_{C(C)}$ *Cymbals, Bo, Drum* → *XiaShang* ***is overlap with*** *Cymbal, XiaShang* ***is overlap with*** *Bo,XiaShang* ***is overlap with*** *Drum;*
EarlyXia $\vdash_{C(D)}$ *XiaShang* → *EarlyXia* ***is more specific*** *than XiaShang*

The completed two local ontologies' alignment is as following fig. 7:

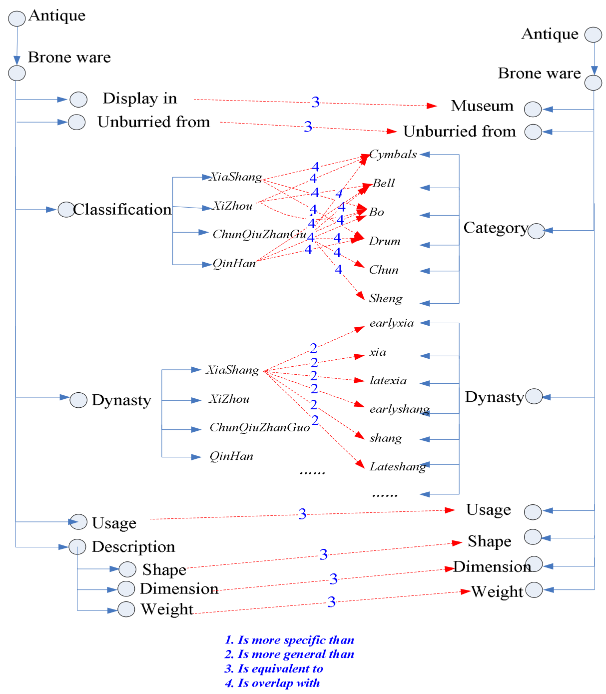

Fig.7 Two local ontologies alignment

6. Conclusion and Contribution

We have constructed a prototype system that involves querying distributed heterogeneous ontologies, the system consists of a collection of peers that maintain local ontologies, including repositories of data instantiating certain concepts of local ontologies. Peers are acquainted with neighbors via mappings, and query processing is defined as a distributed algorithm for query rewriting. Queries are posed to a given peer using its local ontology. The answers that are expected are not only instances of local classes but also instances of classes of foreign peers obtained via specified mappings.

The problem of decentralized querying distributed data through distributed ontologies is that the soundness and completeness of it is hard to measure, the solution we proposed is based on information flow theory, the soundness and completeness of the query result can be achieved.

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