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Personalized Multimedia Integration for the Heterogeneous Museum Systems Using the Ontology Mapping Approach

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ABSTRACT

Presently, many museums have developed their own multimedia information systems to store the artifacts and other objects of scientific, artistic, cultural or historical interest into the digital resources and make them available for public viewing on the Web. However, searching for the multimedia information is still not relevant to the user requirement, and the system does not provide meaningful information. This research work proposes the personalized multimedia integration system for museums based on ontology which is a core component of the Semantic Web technology. The multimedia information for each resource has been expressed in the Web Ontology Language (OWL). The research also resolved the problem of information integration by proposing the ontology mapping technique to cope with the semantic conflicts and structural conflicts via the OWL properties. Then the ontology storing users' interest was designed which matched the museum's ontology so that retrieval of multimedia information is meaningful and direct to the users' needs.

Keywords: Ontology Mapping; Personalized Multimedia Integration; Heterogeneous Museum Systems; Semantic Web

1. Introduction

Nowadays, many museums have developed their own multimedia information systems to store the artifacts and other objects of scientific, artistic, cultural or historical interest into the digital resources and make them available for public viewing on the Web. However, each multimedia information system can be developed or procure independently that differs from place to place. As a result, the systems as a whole have become heterogeneous and dependent on a variety of applications or database management systems. This heterogeneity has led to the following problems: 1) Each museum has its own information storing format or structure. For instance, Museum 1 names its object information table as "Object", whereas Museum 2 names the table as "Resource". Museum 1 stores creator's or object inventor's information in a creator table. Museum 2 stores its creator's information as an attribute in another table, which may make it difficult to find relationships between information sources; 2) Retrieval of information from each source is on the most part of keyword-based. The system still cannot retrieve information meaningfully by applying words that have similar meaning; 3) The system cannot directly retrieve what the user needs if the user does not specify his or her requirement each time he is searching. For example, a user who prefers a video file should specify every time that he wants the video file.

In this paper, we present the ontology-based personalized multimedia integration architecture of a museum system which is a major component of the Semantic Web Technology [1]. The multimedia information structure from each source is extracted into the ontology expressed in Web Ontology Language (OWL) [2]. The local ontology from each source is integrated through the ontology mapping process to form the ontology-based personalized multimedia domain. This research aims to resolve the semantic and structural conflicts occurred during the ontology mapping process. To resolve the semantic conflicts, the research employs the principle of semantic similarity measurement through the WordNet [3] database. The research also employs the OWL properties to resolve the semantic conflicts, as well as the structural conflicts.

In addition, to obtain the results in accordance with the user's interest and requirement, the research transforms the personalized user profile into an ontological model.

The user information stored in the user profile ontology can be used as a criterion to query the museum's information ontology so as to achieve efficient information retrieval that is mostly direct to the user's interests.

2. Literature Reviews

2.1. Semantic Web Technology

The Semantic Web technology enhances the capability of the present day Web technology to enable computer or software agent to understand Web information (machine understandable) which corresponds to human's understanding. Then the information can be further processed and managed by computer efficiently. Development of Semantic Web employs the ontology as an important component. The ontology defines a common vocabulary explicitly without any ambiguity so that both human and computer or software agent can understand and share information in a domain. One may consider to use ontology as an unified knowledge model for knowledge representation and vocabularies [4]. Hence, the semantic conflicts of information can be solved and the computer or software agent is able to search for the synonymous terms with similar meaning. Generally, ontology consists of classes or concepts, which in turn comprise groups of things called instances which have the same properties. Classes and instances can create relationships between classes or between instances. The relationship between classes can be called the subsumption hierarchy, whereby a general class (or superclass) subsumes more specific classes (or subclasses). The subsumption hierarchy is used to store properties at the level of generality and automatically provide them to the lower level of specific concepts through the inheritance mechanism. In addition, there is a general relationship that relies on properties as the connector. The property that links relationships between classes or between instances are called the ObjectProperty, whereas the property that connects classes or instances with literal is called the Data Type Property, which is the property used to describe each instance or class characteristic. Creating machine understandable ontology for computer or software agent requires transformation of ontology structure into a language form such as the Resource Description Framework (RDF/RDF Schema) [5,6] and Web Ontology Language (OWL). OWL has RDF/S as its sublanguage, but adding more advanced constructs to describe semantics of RDF that enables the computer to understand the information meaning more than RDF/S. Moreover, in information search and retrieval from ontology, many more languages have been developed, for example, RQL [7], RDQL [8], SPARQL [9], OWL-QL [10], etc. This research relied on OWL to express the ontology structure and used SPARQL for searching and retrieving information from the ontology.

2.2. DCMI—Dublin Core Metadata Initiative [11]

The DC is the specialized metadata vocabulary defined by the Dublin Core Metadata Initiative (DCMI). The DCMI is an organization dedicated to promoting the widespread adoption of interoperable metadata standards for describing a wide range of networked resources. The DC consists of a set of predefined properties for describing digital resources unambiguously. The DC standard encompasses two levels: *Simple* and *Qualified*. Simple DC [12] (see **Figure 1**) comprises fifteen standard elements, for example: *title*, *creator*, *subject*, *description*, *publisher*, and so on; whereas Qualified DC [13] employs additional qualifiers called "Dublin Core Qualifiers" (DCQ) to further refine the meaning of a resource, for example: an element *abstract* is defined as an alternative qualifier to refine the *description* element. The simple DC usually uses prefix *dc* as "http://purl.org/dc/elements/1.1/" namespace to annotate each standard element, whereas qualified DC usually uses prefix *dcterms* as "http://purl.org/dc/terms/" namespace. For example, the *dc:title* is used as a name given to the resource. Use of Dublin Core metadata enables resource owner to define explicit resource terms without ambiguity and lessen the problem of sharing and exchanging resource data between systems. A complete description for the DC metadata can be found in [11].

2.3. Related Works

Many research studies attempted to solve the problem of information integration from heterogeneous data sources. A number of studies [14-17] aimed at solving problems in multiplicity of information structures both in the databases and Web bases, by using ontology as an assistant mechanism for representing the information structure and mapping information from different systems which have

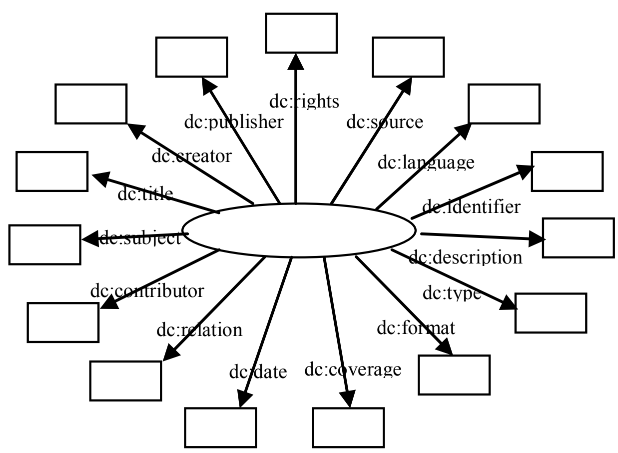

Figure 1. The simple DC standard [11].

structures and names discrepancies. This makes the information meaning understandable, and relationships between the information are correlated. The integration of information from multiple sources has to cope with the problems both in terms of structure and semantic conflicts. A lot of research works, for example [18-21] tried to solve the problem via ontology mapping [22] by applying various tools developed for the mapping or by relying on the WordNet and OWL properties to solve the problems. In the context of ontology personalization, D.-N. Chen, and Y.-C. Chiang [23] integrated ontology and collaborative filtering to design a system to provide information recommendation service. The system collects the information of the users and could learn the preferences of every user and those preferences in common which could be recommended to the users. X. Aimé, F. Furst, P. Kuntz and F. Trichet [24] provided the similarity measure dedicated to the personalization of a Domain Ontology by mainly adapting the content of an ontology to its context of use. An approach aims at talking about several parameters such as culture, educational background and emotional state to reflect the relevance users of ontologies perceive on the subclass hierarchies and to what extent the terms associated to the concepts are representative. Some other research studies [25,26] emphasized on solving the integration of museum information from heterogeneous sources. However, most research works have not specifically solved structural conflicts and information retrieval does not really convey meaning directly according to the individual's interest.

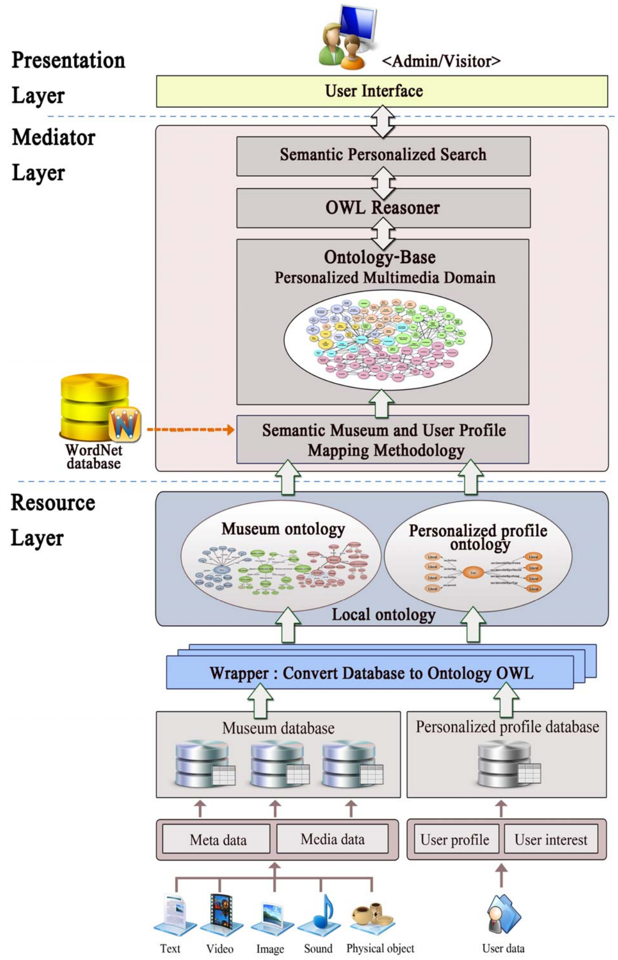

Figure 2. The system architecture design.

3. Research Methodology

3.1. System Architecture Design

This research designed the system architecture consisting of three layers as shown in **Figure 2**, *i.e.*, Resource Layer, Mediator Layer and Presentation Layer. Each layer has been designed with the following details:

3.1.1. Resource Layer

The resource layer is the layer in which each museum stores its multimedia data. This layer consists of the following components:

1) Database—This refers to the museum database for storing the multimedia digital resources and the personalized user profile.

2) Wrapper—The transforming of information stored in the relational database to the ontology expressed in OWL.

3) Local Ontology—Result of information transformation from the Wrapper module. The local ontology extraction consists of the personalized user profile ontology for storing users' interests and museum ontology for storing the multimedia information. The extracted local ontologies are expressed in OWL which enables machine-understandable and semantic retrieval.

3.1.2. Mediator Layer

This layer mediates the information retrieval and integration system. The mediator layer is composed of the following operating components:

1) Semantic Personalized Search receives command from the user interface in the Presentation Layer and retrieves information from the mediator ontology according to user's condition.

2) Ontology-Based Personalized Multimedia Domain is a system's mediator ontology built from mapping of the museum local ontologies. This ontology is used as the main component for retrieving media information of the museum accurate to user's interest.

3) Semantic Museum Ontology Mapping is the module for mapping of the local museum ontologies from multiple museum resources. The semantic conflicts and structural conflicts arise during the ontology mapping process. To solve the semantic conflicts, this module employs Wordnet database to calculate the similarity value be-

tween the concepts pair and the properties pair. The relation is built through OWL properties such as *owl*:*equivalueClass* and *owl*:*equivalentProperty*. To cope with the structural conflict, the solution relies on other properties of OWL such as *owl*:*Restriction*, *owl*:*onProperty*, and *owl*:*someValuesFrom* in bridging the different ontologies with structural conflict. The outcome of ontology conflict solution leads to the Ontology-Based Personalized Multimedia Domain.

4) Word Net database assists in locating semantic similarity of classes or properties between local ontologies which will be integrated to build a mediator ontology of the system.

5) OWL Reasoner is a tool providing various reasoning services for OWL documents, such as OWL species, consistency checking, satisfiability, and entailment test. The research employs the Pellet reasoner [27] for semantic information retrieval of the system's mediator ontology. The reasoner enables the computer to retrieve meaningful information and infer new knowledge stored in the mediator ontology to obtain deep relationship information not visible to general users.

3.1.3. Presentation Layer

This layer provides the user interface to receive registration data of users and record in the personalized profile database. The layer also receives retrieval command and conditions from the user, and then exhibits results of information retrieval from ontology and arrange appropriate format for the user.

3.2. Ontology Design

The museum information resources for research experiment were derived from two museum systems with different database structures. The information from each system's database was extracted into ontology structure via the wrapper module. This research applied the research work [28] and the tools given in [29] for extracting information from database structure into ontology structure expressed in OWL. For this section, example of ontologies built from two sources of museum and a user profile ontology built from the personalized profile database will be shown.

The museum ontology of Museum 1 (see **Figure 3**) is the ontology extracted from the database schema of the Museum 1's system. The ontology structure is depicted as a graph consisting of classes, relationships between classes in the form of subsumption hierarchy, and the properties called the ObjectProperty such as *status*, *period*, and *collection*. These properties have been designed to have an *object* class as a domain, and the superclass properties can be inherited to different child classes.

1) The museum ontology of Museum 2 (see **Figure 4**) is the ontology extracted from the database schema of the Museum 2's system. This ontology employs the Dublin Core Metadata Element Set-DCMES to describe information, such as *dc:title* to describe the resource title, *dc*:*format* to describe the resource format and *dc*:*language* to describe the resource language.

2) The museum ontology of Museum 2 (see **Figure 4**) is the ontology extracted from the database schema of the Museum 2's system. This ontology employs the Dublin Core Metadata Element Set-DCMES to describe information, such as *dc:title* to describe the resource title, *dc*:*format* to describe the resource format and *dc*:*language* to describe the resource language.

3) User Profile Ontology, as shown in **Figure 5**, stores personal information and information about interest of users. This includes period, material, category, and for

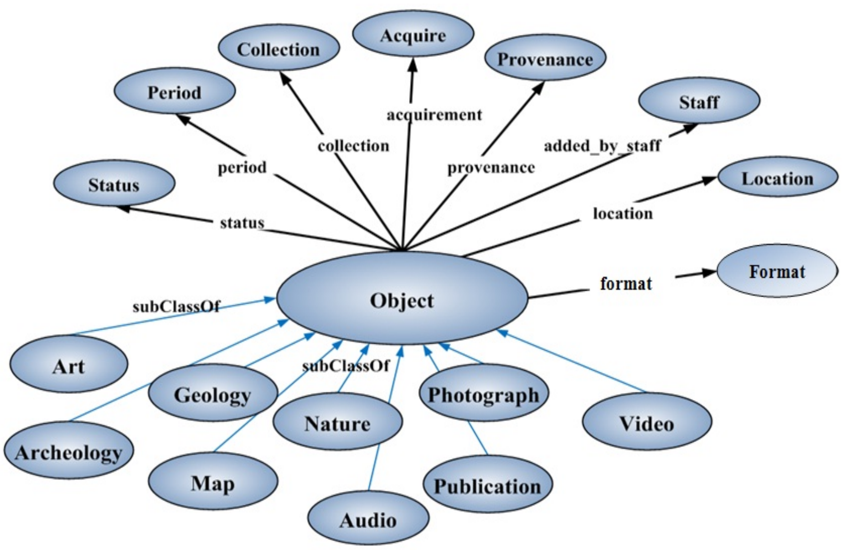

Figure 3. Ontology structure for storing data of Museum 1.

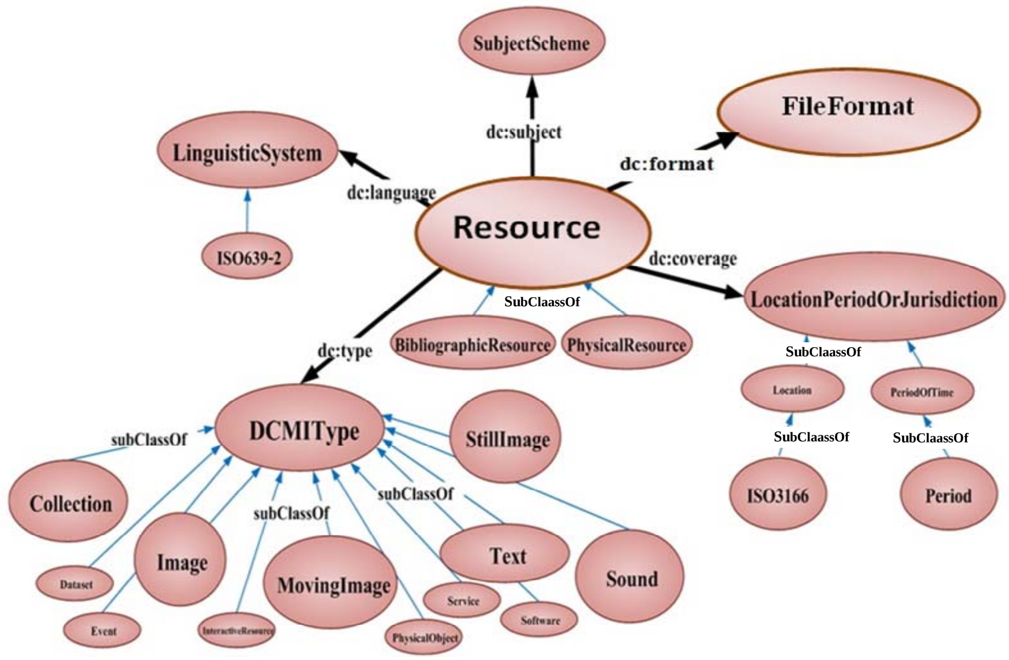

Figure 4. Ontology structure for storing data of Museum 2.

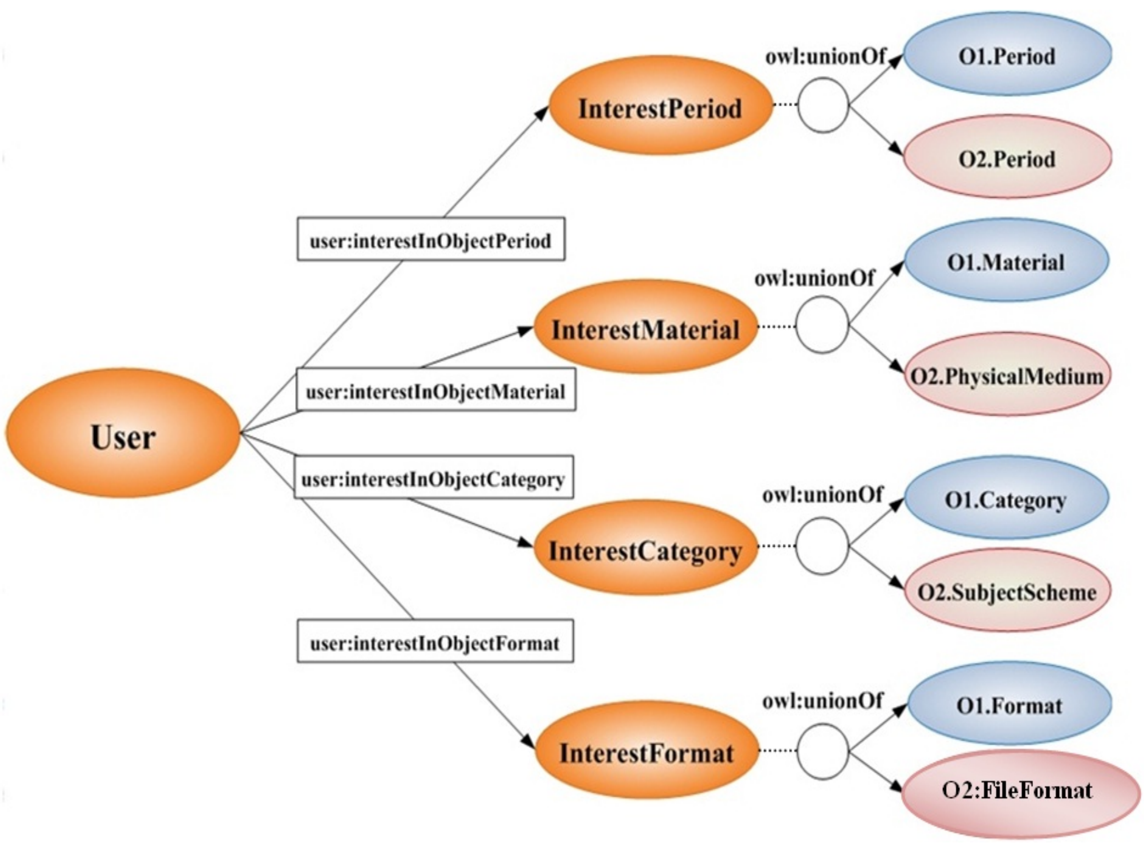

Figure 5. The user profile ontology.

mat of the objects which are stored into the user interest classes. The museum ontology classes associated to the user interest classes are combined through the *owl:union Of* property, such that the instances retrieved from the museum ontology classes are shown for a user to specify his/her interest.

3.3. Ontology Integration

Integration of data from ontologies that is derived from heterogeneous sources requires consideration of the heterogeneity problems. For this paper, we classified the heterogeneity problems into two main levels: the semantic heterogeneity and the structural heterogeneity as follows.

3.3.1. Semantic Heterogeneity

Occurs when there is a disagreement on the meaning, interpretation, or intended use of the same or related data. The semantic heterogeneity can be classified into various types, such as, semantic conflicts, property value conflicts, scaling conflicts, and so on. This paper focuses on semantic conflicts as described below:

Semantic conflicts, are concerned with the semantically equivalent classes or properties defined by different names. To solve the semantic conflicts, the concepts (classes or properties) pair from different ontologies is compared and computed the semantic similarity value based on the similarity value equation. In this research, the equation proposed by Wu and Palmer (wup) [30] was selected because it was designed on the basis of the WordNet to measure semantic similarity. The semantic similarity assessment is achieved by terming the compared words "concepts" as in the following Equation (1).

$$Sim_{wup}(c_1, c_2) = \frac{2 \times depth(lcs(c_1, c_2))}{depth(c_1) + depth(c_2)} \quad (1)$$

where *depth* is the distance from the concept node to the root of the hierarchy, and $lcs(c_1,c_2)$ is the lowest common subsumer of c_1 and c_2.

The similarity score is $0 < Sim_{wup}(c_1, c_2) \leq 1$ and is never zero since the depth of the *lcs* is not 0. And if $Sim_{wup}(c_1, c_2) = 1$, then concepts c_1 and c_2 are in the same synset, *i.e.*, similar meanings ($c_1 \equiv c_2$) although different words are used.

When the similar pair of concepts was obtained, the OWL property was applied to solve the semantic conflict, for example, *owl*:*equivalentClass* or *owl*:*equivalentProperty*, as shown in **Table 1** and **Table 2**, respectively.

3.3.2. Structural Heterogeneity

Occurs when the same concepts of different systems are modeled with different logical structures. The principle of structural conflict consideration was based on the characteristics of data storing. Although, there are various types of structural heterogeneity, this paper focuses on schematic discrepancies as described below:

- *Schematic discrepancies* occur when the logical structure of a set of properties and their values belonging to a concept in one system are organized to form a different structure in another system. For example, Ontology 1 might store or differentiate data in a single class, while Ontology 2 might store the same type of data in Ontology 1 through the property, as shown in the example in **Figure 6**. It can be seen that the *O*1: *Photograph* class is equivalent to the concept *O*2: *Resource* whose property *dc*:*type* has the range as the concept *O*2: *Image*.
- In most cases no direct concept to concept mapping is possible. Solution of structural conflicts in this research was achieved through the use of OWL properties, namely, *owl*:*equivalentClass*, *owl*:*onProperty*, and o*wl*:*someValueFrom*, as shown in **Figure 7**.

Table 1. Result of calculation of similarity score between selected classes.

Ontology 1	Ontology 2	Similarity value	Similarity structure
Object	Resource	0.625	*owl*:*equivalentClass*
Provenance	Provenance Statement	1	*owl*:*equivalentClass*
Location	Location	1	*owl*:*equivalentClass*
Period	PeriodOfTime	1	*owl*:*equivalentClass*
Period	Period	1	*owl*:*equivalentClass*
Category	SubjectScheme	0.75	*owl*:*equivalentClass*

Table 2. Result of calculation of similarity score between selected properties.

Ontology 1	Ontology 2	Similarity value	Similarity structure
Name	*dc*:*title*	0.9333	*owl*:*equivalent Property*
Description	*dc*:*description*	1	*owl*:*equivalent Property*
Format	*dc*:*format*	1	*owl*:*equivalent Property*
Added_Date	*date*	1	*owl*:*equivalent Property*
Category	*dc*:*subject*	0.75	*owl*:*equivalent Property*
Provenance	*Provenance*	1	*owl*:*equivalent Property*

Figure 6. Example of schematic discrepancies.

```
<owl:Class
   rdf:about="http://www.museum1.org/photo#Photograph">
<owl:equivalentClass>
        <owl:Restriction>
           <owl:onProperty
               rdf:about="http://purl.org/dc/elements/1.1/type"/>
           <owl:someValuesFrom
               rdf:about="http://purl.org/dc/dcmitype/Image"/>
        </owl:Restriction>
</owl:equivalentClass>
</owl:Class>
```

Figure 7. Use of OWL properties to solve the structural conflicts.

3.4. Research Experiment

The Ontology-Based Personalized Multimedia Domain derived from ontology mapping of different sources can be used as a core component for semantic data retrieval through the SPARQL as in the following examples:

Example 1 illustrates a query of data from ontology with structural conflicts (as shown in **Figure 6**). The query in **Figure 8** shows a request for the photograph files in the ontology or all instances of the *Photograph* class.

The results executed from SPARQL command in **Figure 8** return all instances of the *Photograph* class of Ontology 1 and instances from the *Resource* class in Ontology 2 which has the *dc*:*type* values as instances in the *Image* class. A portion of query results is illustrated in **Figure 9**.

It can be seen that when the semantic property of OWL is used in the construction and integration of ontologies, semantic retrieval is more efficient. User can use terms defined in one ontology to locate information from one source, but the system is able to retrieve more results from another ontology.

Example 2 illustrates a query of data from ontology according to the users' interest. For this example, **Table 3** illustrates the user's interest stored in the user profile ontology (**Figure 5**) and **Table 4** shows details of object files existing in Ontology 1 and Ontology 2.

The query in **Figure 10** shows a request for the object files in the ontology that have format corresponding to the users' interest.

With the benefits of OWL properties in enabling greater inferencing, the museum ontology 1 can define the *O*1:*format* property to be inversed of the *O*1: *formatOf* via the *owl*:*inverse Of* property, as shown in **Figure 11**.

Once the *O*1:*formatOf* property is defined to be inverseOf the *O*1: *format* property, user can pose a query by using either *O*1:*formatOf* or *O*1 *format* property without creating the instance statement for the *O*1:*formatOf* property.

```
SELECT ?File
WHERE
{?File <http://www.w3.org/1999/02/22-rdf-syntax-ns#type>
<http://www.museum1.org/photo#Photograph> }
```

Figure 8. SPARQL command for retrieving the photograph files.

Query Results (10 answers):
File
O1:photograph_01
O1:photograph_04
O2:ResourceImage001
O2:ResourceImage003
….
….

Figure 9. Instances results retrieved from the photograph class.

```
SELECT   ?Object
WHERE { <http://www.UserProfile.org/user#user_001>
<http://www.UserProfile.org/#interestInObjectFormat> ?Format .
?Format <http://www.museum1.org/#formatOf> ?Object }
```

Figure 10. SPARQL command for retrieving the object files corresponding to the user's interest.

```
<owl:ObjectProperty rdf:ID="formatOf">
        <owl:inverseOf rdf:resource="#format"/>
        <rdfs:domain rdf:resource="#Format"/>
        <rdfs:range rdf:resource="#Object"/>
</owl:ObjectProperty>
```

Figure 11. Using owl:inverseOf property.

Table 3. Example of the user's interest stored in the user profile ontology.

User:user_001	
Class	Instance
InterestPeriod	Renaissance
InterestMaterial	gold
InterestCategory	art
InterestFormat	pdf

Table 4. Example of object file description stored in the museum ontology.

Object	Period	Material	Category	Format
O1:art_001	Rebirth	gold	art	pdf
O1:art_002	Rebirth	wood	video	avi
O2:art_003	Renaissance	gold	art	pdf

The results executed from SPARQL command in **Figure 10** return all instances of the *Object* class of Ontology 1 and instances from the *Resource* class in Ontology 2 which was found in the Renaissance period, made from gold, classified in the art category, and has a pdf format. Hence, the object O2:art_003 and O1:art_001 instances that are most matched with the user's interest are returned to a user view.

3.5. System Evaluation

This research evaluated the results of experiment and assessed the efficiency of information retrieval from integrated ontologies based on the Precision, Recall and F-Measure [31] values. Precision is the ratio of the number of relevant records retrieved to the total number of irrelevant and relevant records retrieved. Recall is the ratio of the number of relevant records retrieved to the total number of relevant records in the ontology. Precision and Recall values are calculated from Equations (2) and (3) as follows:

$$\text{Precision} = \frac{A}{A+B} \times 100\% \tag{2}$$

$$\text{Recall} = \frac{A}{A+C} \times 100\% \tag{3}$$

where A is number of relevant records retrieved. B is number of relevant records not retrieved. C is number of irrelevant records retrieved.

Precision and Recall values can be used to calculate F-measure which is defined as a harmonic mean of precision and recall, as shown in Equation (4) below:

$$F = 2 \times \left(\frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} \right) \tag{4}$$

Evaluation of the retrieving efficiency of information interested by 30 users shows that most objects found corresponded to the interest of users. The object information is retrieved on the criterion of classification, format, material, and period of each object with the Precision value of 1.00 the Recall value of 0.93, and the average of overall efficiency or F-measure was 0.96. These results were in very high levels.

4. Conclusions

This research designed and developed the integration of multimedia information interested by individuals in the museum system based on Semantic Web technology. The multimedia information sources were derived from two museum systems and extraced into ontologies. The researchers developed ontologies with OWL language and integrated the ontologies based on the ontology mapping technique. To solve the semantic heterogeneity, the principle of semantic similarity values via the WordNet is applied to the research. To solve the structural heterogeneity, we employed the OWL properties to be used during the ontology mapping process. In semantic data retrieval, SPARQL language was imperatived for retrieving data in ontologies.

The experiment shows that data retrieving according to 30 users' multiple interests corresponded to their requirements. This was based on the information of each object's period, material, classification, and format, with a Precision value of 1.00, Recall value of 0.93, and an average F-measure of 0.96, indicating high levels of experimental results.

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