A Framework for Improved Access to Museum Databases in the Semantic Web

Dana Dannélls
Department of Swedish Language
University of Gothenburg
SE-405 30 Gothenburg, Sweden
dana.dannells@svenska.gu.se

Mariana Damova
Ontotext
Sofia 1784, Bulgaria
mariana.damova@ontotext.com

Ramona Enache
Department of Computer Science and Engineering
GU and Chalmers University of Technology
SE-412 96 Gothenburg, Sweden
ramona.enache@chalmers.se

Milen Chechev
Ontotext
Sofia 1784, Bulgaria
milen.chechev@ontotext.com

Abstract

Digital museum databases have extremely heterogeneous data structures which require advanced mapping and vocabulary integration for them to benefit from the interoperability enabled by semantic technologies. In addition to establishing ways of extracting and manipulating digitally encoded cultural material, there exists a need to make this material available and accessible to human users in different forms and languages that are available to them. In this paper we describe a method to manage and access museum data by integrating it within a series of interlinked ontological models. The method allows querying and generation of query results in natural language. We report on the results of applying this method from experiments we have been pursuing.

1 Introduction

During the past few years several projects have been undertaken to digitize cultural heritage materials (Clough et al., 2008; Dekkers et al., 2009) through the use of Semantic Technologies such as RDF (Brickley and Guha, 2004) and OWL (Berners-Lee, 2004). Today there exist large number of digital collections and applications providing direct access to cultural heritage content.[1]

However, digitization is a labour intensive process and is long from being complete. Because of the heterogeneous data structures different museums have, digitally encoded cultural material stored in internal museum databases requires advanced mapping and vocabulary integration for it to be accessible for Semantic Web applications. In addition to establishing ways for managing various vocabularies, and for exploiting semantic alignments across them automatically (van der Meij et al., 2010), computer engineers also need to investigate automatic methods to make this information available to computer users in different forms and languages that are available to them.

Our work is a step towards this direction. It is about an automatic workflow of sharing data infrastructures that is explicitly targeted towards the Semantic Web. We have developed a method to manage and access museum data by integrating it within a series of interlinked ontological models. The method allows querying and generation of query results in natural language using the Grammatical Framework (GF). We have been experimenting with data collections from the Gothenburg City Museum that we made available for querying in the Museum Reason-able View loaded in the triple store OWLIM.

In the remainder of this paper we present the ontologies that were merged including CIDOC-CRM,[2] PROTON,[3], the Painting ontology and the data that we have been experimenting with (Section 2). We describe the creation of the Museum Reason-able View with structured query examples (Section 3). In Section 4, we introduce the Grammatical Framework and demonstrate the mechanisms of interfacing between the structured data and natural language. We provide an overview of related work (Section 5) and end with conclusions.

[1] http://www.europeana.eu/portal/

[2] The Conceptual Reference Model (CRM): http://cidoc.ics.forth.gr/

[3] http://proton.semanticweb.org/

Proceedings of Language Technologies for Digital Humanities and Cultural Heritage Workshop, pages 3–10,
Hissar, Bulgaria, 16 September 2011.

2 The Ontologies and Museum Data

2.1 The CIDOC-CRM

The International Committee for Documentation Conceptual Reference Model (CIDOC CRM) that was accepted by ISO in 2006 as ISO21127 (Crofts et al., 2008), is one of a widely used standards that has been developed to facilitate the integration, mediation and interchange of heterogeneous cultural heritage information.

The CIDOC CRM, independent of any specific application, is primarily defined as an interchange model for integrating information in the cultural heritage sector. Although it declares rich common semantics of metadata elements, many of the concepts that are utilized for describing objects are not directly available in this model. To arrive at the point where information that is available in museum databases about paintings could be recorded using this model, we developed the painting ontology that integrates the CIDOC-CRM with more specific schemata.

2.2 The Swedish Open Cultural Heritage (SOCH)

The Swedish Open Cultural Heritage (SOCH) is a web service used to search and fetch data from any organization that holds information related to the Swedish cultural heritage.[4]

The idea behind SOCH is to harvest any data format and structure that is used in the museum sector in Sweden and map it into SOCH's categorization structure. The data model used by SOCH is an uniform data representation which is available in an RDF compatible form.

The schema provided by SOCH helps to intermediate data between museums in Sweden and the Europeana portal. More than 20 museums in Sweden have already made their collections available through this service. By integrating the SOCH data schema in the ontological framework we gain automatic access to these collections in a semantically interoperable way.

2.3 The Painting Ontology

The painting ontology is a domain specific ontology. It is designed to support integration and interoperability of the CIDOC-CRM ontology with other schemata. The main reference model of the painting ontology is the OWL 2 implementation of the CRM.[5] The additional models that are correctly integrated in the ontology are: SOCH, Time Ontology,[6] SUMO and Mid-Level-Ontology.[7] The painting ontology was constructed manually using the Protégé editing tool.[8]

Integration of the ontology concepts are accomplished by using the OWL construct: *intersectionOf* as specified below:

```
<owl:Class rdf:about="&painting;Painting">
 <owl:equivalentClass>
  <owl:Class>
    <owl:intersectionOf rdf:parseType="Collection">
      <rdf:Description rdf:about="&ksasok;item"/>
      <rdf:Description rdf:about="&milo;PaintedPicture"/>
     </owl:intersectionOf>
   </owl:Class>
  </owl:equivalentClass>
 <rdfs:subClassOf rdf:resource="&core;E22_Man-Made_Object"/>
</owl:Class>
```

The schemata that are stated in the above example are denoted with the following prefixes: painting ontology (&painting), SOCH (&ksamsok), Mid-Level-Ontology (&milo) and CIDOC-CRM ontology (&core). In this example, the class *Painting* is defined in the painting ontology as a subclass of *E22_Man-Made_Object* class from the CIDOC-CRM ontology and is an intersection of two classes, i.e. *item* from the SOCH schema and *PaintedPicture* from the Mid-Level Ontology.

The painting ontology contains 184 classes and 92 properties of which 24 classes are equivalent to classes from CIDOC-CRM and 17 properties are sub-properties of CIDOC-CRM properties.

2.4 Proton

PROTON (Terziev et al., 2005) is a light weight upper level ontology, which was originally built with a basic subsumption hierarchy comprising about 250 classes and 100 properties providing coverage of most of the upper-level concepts necessary for semantic annotation, indexing, and retrieval. Its modular architecture allows for great flexibility of usage, extension, integration and remodeling. It is domain independent and complies with the most popular metadata standards like DOLCE,[9] Cyc,[10] Dublin Core.[11]

PROTON is encoded in OWL Lite, and contains a minimal set of custom entailment rules (axioms). It is interlinked with CIDOC CRM, and is used in

[4] http://www.ksamsok.se/in-english/

[5] http://purl.org/NET/cidoc-crm/core

[6] http://www.w3.org/TR/owl-time/

[7] http://www.ontologyportal.org/

[8] http://protege.stanford.edu/

[9] http://www.loa-cnr.it/DOLCE.html

[10] http://www.ontotext.com/downloads/cycmdb

[11] http://www.cs.umd.edu/projects/plus/SHOE/onts/dublin.html

the data integration model to provide access to the Linked Open Data (LOD) for Cultural Heritage (Damova and Dannélls, 2011).

2.5 The Gothenburg City Museum Database

The Gothenburg City Museum (GCM) preserves 8900 museum objects described in two of the museum database tables. These two tables correspond to two of the museum collections, i.e. GSM and GIM. Each of these tables contains 39 properties for describing museum objects. Table 1 shows 20 of these properties, including the object type, its material, measurements, location, etc. All properties and object values stored in the database are given in Swedish.

Field name	Value
Field nr.	4063
Prefix	GIM
Object nr.	8364
Search word	painting
Class 1	353532
Class 2	Gothenburg portrait
Amount	1
Producer	E.Glud
Produced year	1984
Length cm	106
Width cm	78
Description	oilpainting represents a studio indoors
History	Up to 1986 belonged to Datema AB, Flöjelbergsg 8, Gbg
Material	oil colour
Current keeper	2
Location	Polstjärnegatan 4
Package nr.	299
Registration date	19930831
Signature	BI
Search field	BO:BU Bilder:TAVLOR PICT:GIM

Table 1: A painting object representation in the GCM database.

The Gothenburg City Museum's data that is used as our experimental data follows the structure of the CIDOC-CRM but it contains many concepts that are not available in CIDOC-CRM. So, in order to be able to fully integrate the Gothenburg City Museum data into a semantic view it was necessary to make use of concepts and relationships from the remaining ontologies.

Figure 1 shows how elements from the Goethenburg city museum are represented with elements from different schemata, e.g. CIDOC-CRM, PROTON, SOCH and the Painting ontology.

2.6 DBpedia

DBpedia (Auer et al., 2007) is the RDF-ized version of Wikipedia, comprising the information from Wikipedia infoboxes, designed and developed to provide as full as possible coverage of the factual knowledge that can be extracted from Wikipedia with a high level of precision. DBpedia describes more than 3.5 million things and covers 97 languages. 1.67 million of DBpedia things are classified in a consistent ontology, including 364,000 persons, 462,000 places, and 99,000 music albums. The DBpedia knowledge base has over 672 million RDF triples out of which 286 million extracted from the English edition of Wikipedia and 386 million extracted from other language editions.

DBpedia is used as an additional source of data, which can enrich the information about the Gothenburg museum data. For example, their location identified with the DBpedia resource referring to the city of Gothenburg.

3 Integrating and Accessing Museum Data

3.1 Integration for flexible computing

Integrating datasets into linked data in RDF usually takes place by indicating that two instances from two datasets are the same by using the built in OWL predicate: `owl:sameAs`.[12] However, recent research (Damova, 2011; Damova et al., 2011; Jain et al., 2011) has shown that interlinking the models according to which the datasets are described is a more powerful mechanism of dealing with large amounts of data in RDF, as it exploits inference and class assignment.

We have adopted this approach when creating the infrastructure for the museum linked data, including several layers of upper-level ontologies. They provide a connection to different sets of linked data, for example PROTON for the LOD cloud. They also provide an extended pool of concepts that can be referred to in museum linked data that do not directly pertain to the expert descriptions of the museum objects, and the strictly expert museum knowledge is left to CIDOC-CRM. This model of interlinked ontologies offers a flexible access to the data with different conceptual access points. This approach is implemented as a Reason-able View of the web of data (Kiryakov et al., 2009).

3.2 The Museum Reason-able View

Using linked data techniques (Berners-Lee, 2006) for data management is considered to have great potential in view of the transformation of the web of data into a giant global graph. Still there are challenges related to them that have to be handled

[12] `http://www.w3.org/TR/owl-ref/`

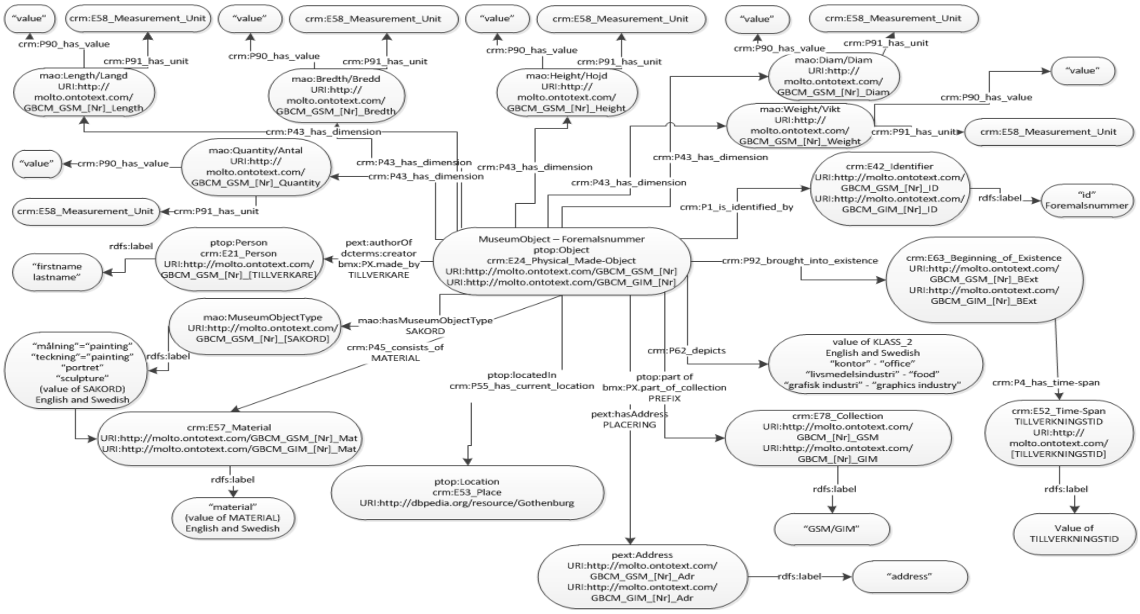

Figure 1: Dataset interconnectedness in the Museum Reason-able View.

to make this possible. Kiryakov et al. (2009) discuss these challenges and present an approach for reasoning with and management of linked data. In summary, a Reason-able View is an assembly of independent datasets, which can be used as a single body of knowledge with respect to reasoning and query evaluation. Each Reason-able View is aiming at lowering the cost and the risks of using specific linked datasets for specific purposes. We followed this approach when constructing the Museum Reason-able View with the data from the Gothenburg City Museum, DBpedia, Geonames and the ontologies listed in Section 2.[13]

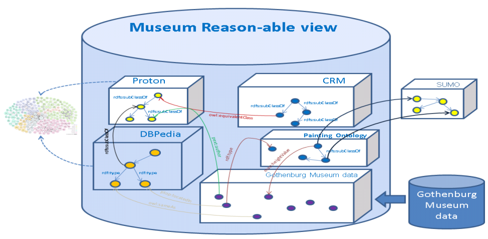

Figure 2: Integration of Gothenburg city museum data into the Museum Reason-able View.

The process of Gothenburg city museum data integration into the Museum Reason-able View consists in transforming the information from the museum database into RDF triples on the ontologies described in the previous section. Figure 2 shows the architecture of the Museum Reason-able View, which includes interconnected schemata and links to external to the Gothenburg museum data, such as DBpedia. The knowledge base contains close to 10K museum artifacts from the Gothenburg city museum, and the entire DBpedia.

3.3 Accessing Museum Linked Data

The Museum Reason-able View is loaded in OWLIM (Bishop et al., 2011) and its data are accessible via a SPARQL (Eric and Andy, 2008) end point and keywords.[14] The queries can be formulated by combining predicates from different datasets and ontologies in a single SPARQL query, retrieving results from all different datasets that are part of the Reason-able View.

A query example about the location, address, description and time of paintings by Carl Larsson is given below.

```
PREFIX crm: <http://purl.org/NET/cidoc-crm/core#>
PREFIX ptop: <http://proton.semanticweb.org/protontop#>
PREFIX painting:<http://spraakbanken.gu.se/rdf/owl/painting#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX pext: <http://proton.semanticweb.org/protonext#>

select * where
{
?museumObject crm:P55_has_current_location  ?location .
?museumObject painting:hasCategory [rdfs:label "teckning"@sv].
?museumObject pext:authorOf  [rdfs:label "Carl Larsson"@sv].
?museumObject  crm:P55_has_current_location ?location .
OPTIONAL {
 ?museumObject pext:hasAddress [rdfs:label ?address].}
?museumObject  crm:P62_depicts  ?description .
?museumObject crm:P92_brought_into_existence
[ crm:P4_has_time-span [  rdfs:label  ?time ] ].
}
```

[13]Geonames website: http://www.geonames.org/

[14]The data is available at: http://museum.ontotext.com

SPARQL Query
Results for PREFIX crm: <http://purl....

Download in JSON | SPARQL Results in XML | SPARQL Results in JSON

museumObject	location	collection	address	description	time
http://molto.ontotex...	http://dbpedia.org/r...	GIM@sv		glasindustri@sv	
http://molto.ontotex...	Göteborg@en	GIM@sv		glasindustri@sv	
http://molto.ontotex...	http://dbpedia.org/r...	GSM@sv	Huvudmagasinet Gårda@sv	1 göteborgsporträtt@sv	1889
http://molto.ontotex...	Göteborg@en	GSM@sv	Huvudmagasinet Gårda@sv	1 göteborgsporträtt@sv	1889
http://molto.ontotex...	http://dbpedia.org/r...	GSM@sv	Huvudmagasinet Gårda@sv	1 göteborgsporträtt@sv	1889
http://molto.ontotex...	Göteborg@en	GSM@sv	Huvudmagasinet Gårda@sv	1 göteborgsporträtt@sv	1889
http://molto.ontotex...	http://dbpedia.org/r...	GIM@sv		glasindustri@sv	
http://molto.ontotex...	Göteborg@en	GIM@sv		glasindustri@sv	
http://molto.ontotex...	http://dbpedia.org/r...	GSM@sv	Huvudmagasinet Gårda@sv	1 göteborgsporträtt@sv	1889

Figure 3: The results from a SPARQL query.

The above query returns the results that are depicted in Figure 3. Note that the returned location is the DBpedia resource about the city of Gothenburg. The results also show that museum items from the two collections – GIM and GSM – are harvested, which means that the data from the collections are integrated together and accessible from a single query point.

Other queries can be asked about the types of art work preserved in the museum, their material, or about artwork from a certain period of time, etc. Below follows another query example about the address, the time of paintings and the collection they are coming from.

```
select ?museumObject ?location ?collection
?address ?description ?time where
{
?museumObject crm:P55_has_current_location ?location ;
ptop:partOf [ rdfs:label ?collection ] ;
painting:hasCategory [ rdfs:label "teckning"@sv ] ;
crm:P62_depicts ?description .
OPTIONAL {?museumObject pext:hasAddress
[ rdfs:label ?address ] .}
OPTIONAL {?museumObject crm:P92_brought_into_existence
[ crm:P4_has_time-span [ rdfs:label ?time ] ] .}

}
```

The Reason-able View is accessible with SPARQL queries, which require intimate knowledge of the schemata describing the data, and technical expertise in SPARQL. Moreover, the results from SPARQL are not always easy to understand, in particular if the retrieved information is given in a language other than English. This is why the results are send forward to the NLP component to verbalize the ontology links.

4 Ontologies Verbalization

4.1 The Grammatical Framework (GF)

The Grammatical Framework GF (Ranta, 2004) is a grammar formalism, based on Martin-Löf's type theory (Martin-Löf, 1982). Its key feature is the division of a grammar in the abstract syntax-which acts as a semantic interlingua and the concrete syntaxes-representing verbalizations in various target languages (natural or formal).

GF comes with a resource library (Ranta, 2009), where the abstract syntax describes the most common grammatical constructions allowing text generation, which are further mapped to concrete syntaxes corresponding to 18 languages.[15] The resource library aids the development of new grammars for specific domains by providing the operations for basic grammatical constructions, and thus making it possible for users without linguistic background to generate syntactically correct natural language.

To verbalize the data that is stored in the Museum Reason-able View, we utilize GF. The advantages of using GF for verbalization is three fold: it provides mechanisms for type checking, by validating coercions between the basic class of an instance and the class required by the definition of the relation that uses it; the framework offers support of direct verbalization which makes it easier to generate text from the ontology and so to create natural language applications using it without the aid of external tools; GF has a resource library that cover the syntax for 18 languages.

4.2 Translation of the Museum Reason-able View to GF

The capabilities of GF as a host-language for ontologies were already investigated in Enache and Angelov (2010), where SUMO, the largest open-source ontology was translated to GF. It was shown that the type system provides a robust

[15] `www.grammaticalframework.com`

framework for encoding classes, instances and relations. The same basic implementation design that was used for encoding SUMO in GF is applied in this work for representing the Museum Reasonable View.

The classes form a hierarchy modelled by an inheritance relation, which is the reflexive-transitive closure of the subclass relation `rdfs:subClassOf` from the ontology, are encoded as functions in the GF grammar. Other information stated in the ontology, is encoded in GF as axioms, external to the grammar. These are used for verbalization as in the following example from the OWL entry corresponding to the painting *Big Garden*:

```
<owl:NamedIndividual
  rdf:about="&painting; BigGardenObj">
 <rdf:type
  rdf:resource="&painting;Painting"/>
 <isPaintedOn
  rdf:resource="&painting;Canvas"/>
 <createdBy
  rdf:resource="&painting;CarlLarsson"/>
 <hasCreationDate rdf:resource=
                 "&painting;Year1937"/>
</owl:NamedIndividual>
```

A representation of the instance *BigGardenObj* is defined as follows:

```
fun BigGardenObj : Ind Painting ;
```

Where the *Painting* was defined previously as a class. The remaining information about *Big Garden* from the ontology is encoded as a set of axioms with the following syntax:

```
isPaintedOn (el BigGradenObj) (el Canvas)
createdBy (el BigGardenObj)(el CarlLarsson)
hasCreationDate (el BigGardenObj) (el (year 1937))
```

A couple of clarifying remarks about the GF encoding are needed in order to understand better the representation of the ontology: the dependent type `Ind` is used to encode class information of instances, and the wrapper function `el` is used to make the above-mentioned coercion, where the two types, along with the inheritance object that represents the proof that the coercion is valid are not visible here, since GF features implicit arguments.

In GF, the natural language generation is based on composeable templates. We obtain the verbalization of classes and templates automatically, mainly based on their Camel-Case representation. For the relations, more work is needed, since a grammatically correct verbalization is not possible based only on the ontology information.

Below follow a few English sentence examples that we are able to generate:

- *B*ig Garden is a painting
- *B*ig Garden is painted on canvas
- *B*ig Garden is painted by Carl Larsson
- *B*ig Garden was created in 1937

Below we provide examples for ontology relations in the shape of *O1 is painted by O2* and feed these to the GF parser which will build an abstract syntax tree, from which we abstract over the placeholders *O1* and *O2*, replacing them with function arguments.

For example, the relation `hasCurrentLocation` and `hasCreationDate` have the following abstract syntax representation:

```
fun hasCurrentLocation : El Painting
 -> El Place -> Formula ;

fun  Painting_hasCreationDate :
 El Painting_Artwork
 -> El Painting_TimePeriod -> Formula ;
```

Their English representation in the concrete syntax is:

```
lin hasCurrentLocation o1 o2 =
 mkPolSent (mkCl o1
 (mkVP (passiveVP locate_V2)
      (mkAdv at_Prep o2))) ;

lin  Painting_hasCreationDate o1 o2 =
 mkPolSentPast (S.mkCl o1 (S.mkVP
   (S.passiveVP create_V2)
   (S.mkAdv in_Prep o2))) ;
```

Since the parser uses the resource library grammars, the result sentence will be syntactically correct, regardless of the arguments we use it with. Also, one does not need extensive knowledge of the GF library or GF programming in order to build verbalization. This might not make a difference for English, which is morphologically simple, but future work involves building such a representation for French, German, Finnish and Swedish, where it would be more difficult to achieve correct agreement, without grammatical tools.

Below follows an example of how the construct *owl:intersectionOf* is represented in the GF abstract syntax:

```
Equiv_TimePeriod =  Equivalent TimePeriod
 (both E52_TimeSpan Sumo.YearDuration) ;
```

Equivalent Class Class is a dependent type that encodes type equivalence.

5 Related Work

Museum Data Integration with semantic technologies as proposed in this paper is intended to enable efficient sharing of museum and cultural heritage information. Initiatives for developing such sharing museum data infrastructures have emerged in the recent years. Only a few of them rely on semantic technologies.

The Museum Data Exchange 2010 project has developed a metadata publishing tool to extract data in XML.[16] Brugman et al. (2008) have developed an Annotation Meta Model providing a way of defining annotation values and anchors in an annotation for multimedia resources. The difference between these approaches and our approach is that we chose to reuse many of the concepts and the relationships that are already defined in the standard model CIDOC-CRM.

Other related initiatives in the Web of structured data is the Amsterdam Museum Linked Open Data project,[17] aiming at producing Linked Data within the Europeana data model (Dekkers et al., 2009; Haslhofer and Isaac, 2011), and the National Database Project of Norwegian University Museums (Ore, 2001) who developed a unified interface for digitalizing cultural material.[18]

In Sweden, as well as other countries, semantic technologies enter the cultural heritage field increasingly and there have been some suggestions describing the tools and techniques that should be applied to digitalize the Swedish Union Catalogue (Malmsten, 2008). Following these ideas and experiences from experimenting with museum data (Bryne, 2009) who have shown that conversion of museum databases is best approached through integration of existing models, we decided to invest in a manual design step to built a framework that captures specific characteristics of museum databases.

[16] http://www.oclc.org/research/activities/museumdata/default.htm

[17] http://www.europeana.eu/portal/thoughtlab_linkedopendata.html

[18] http://www.muspro.uio.no/engelsk-omM.shtml

To our knowledge, we made the first attempt of using CIDOC-CRM to produce museum linked data with connections to external sources like DBpedia. Our attempt to generate natural language sentences from ontologies, and more precisely from the structured results of SPARQL queries are the novelty of the work presented in this paper.

6 Conclusions

We presented a framework for integrating and accessing museum linked data, and a method to present this data using natural language generation technology.

A series of upper-level and domain specific ontologies have been used to transform Gothenburg museum data from a relational database into RDF and build a Museum Reason-able View. We showed how federated results to SPARQL queries using predicates from multiple ontologies can be obtained. Consequently, we demonstrated how templates are automatically obtained in GF to generate the query results in natural language.

Future work includes extending the museum data in the Museum Reason-able View, running several queries, and increasing the coverage of the GF grammar. We intend to have a grammatical coverage for at least five languages. Other directions for future work, also include fluent discourse generation from the ontology axioms, as well as paraphrasing of the existing patterns for verbalization.

Acknowledgments

This work is supported by MOLTO European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement FP7-ICT-247914.

References

Sören Auer, Christian Bizer, Georgi Kobilarov, Jens Lehmann, Richard Cyganiak, and Zachary Ives. 2007. DBpedia: A nucleus for a web of open data. In *Lecture Notes in Computer Science (LNCS)*, volume 4825, pages 722–735.

Tim Berners-Lee. 2004. OWL Web Ontology Language reference, February. W3C Recommendation.

T. Berners-Lee. 2006. Design issues: Linked data. Retrieved from http://www.w3.org/DesignIssues/LinkedData.html.

B. Bishop, A. Kiryakov, D. Ognyanoff, I. Peikov, Z. Tashev, and R. Velkov. 2011. OWLIM: A family of scalable semantic repositories. *Semantic Web Journal, Special Issue: Real-World Applications of OWL*.

Dan Brickley and R.V. Guha, 2004. *RDF Vocabulary Description Language 1.0: RDF Schema*. W3C. `http://www.w3.org/TR/rdf-schema/`.

Hennie Brugman, Véronique Malaisé, and Laura Hollink. 2008. A common multimedia annotation framework for cross linking cultural heritage digital collections. In *International Conference on Language Resources and Evaluation (LREC)*.

Kate Bryne. 2009. Putting hybrid cultural data on the semantic web. *Journal of Digital Information (JoDI)*, 10(6). Eds. Martha Larson, Kate Fernie, John Oomen.

Paul Clough, Jennifer Marlow, and Neil Ireson. 2008. Enabling semantic access to cultural heritage: A case study of tate online. In *Proceedings of the ECDL. Workshop on Information Access to Cultural Heritage*, ISBN 978-90-813489-1-1, Aarhus, Denmark, September.

Nick Crofts, Martin Doerr, Tony Gill, Stephen Stead, and Matthew Stiff, 2008. *Definition of the CIDOC Conceptual Reference Model*.

Mariana Damova and Dana Dannélls. 2011. Reasonable view of linked data for cultural heritage. In *Proceedings of the third International Conference on Software, Services and Semantic Technologies (S3T)*.

Mariana Damova, Atanas Kiryakov, Maurice Grinberg, Michael K. Bergman, Frederik Giasson, and Kiril Simov. 2011. Creation and integration of reference ontologies for efficient lod management. In *Semi-Automatic Ontology Development: Processes and Resources, IGI Global*, Hershey PA, USA.

Mariana Damova, 2011. *Data Models and Alignment*, May. Deliverable 4.2. MOLTO FP7-ICT-247914.

Makx Dekkers, Stefan Gradmann, and Carlo Meghini, 2009. *Europeana Outline Functional Specification For development of an operational European Digital Library*. Europeana Thematic Network Deliverable 2.5.

Ramona Enache and Krasimir Angelov. 2010. Typeful ontologies with direct multilingual verbalization. *Workshop on Controlled Natural Languages (CNL) 2010*.

Prud'hommeaux Eric and Seaborne Andy. 2008. SPARQL. the query language for RDF, January. W3C Recommendation.

Bernhard Haslhofer and Antoine Isaac. 2011. data.europeana.eu the europeana linked open data pilot. In *Proceedings of the Intl. Conf. on Dublin Core and Metadata Applications*.

Prateek Jain, Peter Z. Yeh, Kunal Verma, Reymonrod G., Mariana Damova, Vasquez Pascal Hitzler, and Amit P. Sheth. 2011. Contextual ontology alignment of lod with an upper ontology: A case study with proton. In *Proceedings of 8th ESWC, Extended Semantic Web Conference*, Heraklion, Greece, May.

A. Kiryakov, D. Ognyanoff, R. Velkov, Z. Tashev, and I. Peikov. 2009. LDSR: Materialized reason-able view to the web of linked data. In *Proceedings of OWL: Experiences and Directions (OWLED) 2009*, Chantilly, USA.

Martin Malmsten. 2008. Making a library catalogue part of the semantic web. In *Proceedings of the Intl. Conf. on Dublin Core and Metadata Applications*, Berlin, German.

Per Martin-Löf. 1982. Constructive mathematics and computer programming. In Cohen, Los, Pfeiffer, and Podewski, editors, *Logic, Methodology and Philosophy of Science VI*, pages 153–175. North-Holland, Amsterdam.

Christian-Emil Smith Ore. 2001. The norwegian museum project, access to and interconnection between various resources of cultural and natural history. In *European Conference on Research and Advanced Technology for Digital Libraries ECDL*.

Aarne Ranta. 2004. Grammatical framework, a type-theoretical grammar formalism. *Journal of Functional Programming*, 14(2):145–189.

Aarne Ranta. 2009. The GF resource grammar library. *Linguistic Issues in Language Technology*, 2(2).

I. Terziev, A. Kiryakov, , and D. Manov, 2005. *D.1.8.1 Base upper-level ontology (BULO) Guidance*. Deliverable of EU-IST Project IST.

Lourens van der Meij, Antoine Isaac, and Claus Zinn. 2010. A web-based repository service for vocabularies and alignments in the cultural heritage domain. In *Proceedings of the 7th Extended Semantic Web Conference, (ESWC 2010)*.