Evaluation of Semantic Web Ontologies for Modelling Art Collections

Danfeng Liu, Antonis Bikakis, Andreas Vlachidis

Department of Information Studies, University College London
{danfeng.liu.15, a.bikakis, a.vlachidis}@ucl.ac.uk

Abstract. The need for organising, sharing and digitally processing Cultural Heritage (CH) information has led to the development of formal knowledge representation models (ontologies) for the CH domain. Based on RDF and OWL, the standard data model and ontology language of the Semantic Web, ontologies such as CIDOC-CRM, the Europeana Data Model and VRA, offer enhanced representation capabilities, but also support for inference, querying and interlinking through the Web. This paper presents the results of a small-scale evaluation of the three most commonly used CH ontologies, with respect to their capacity to fulfil the data modelling requirements of art collections.

Keywords. Ontology Evaluation, Digital Humanities, Art Collections, CIDOC-CRM, VRA Core, EDM.

1. Introduction

The voluminous, diverse and heterogeneous Cultural Heritage (CH) information that is available in museums, art galleries and other CH institutions, has recently led many of them to adapt advanced metadata models to better organise their data and enable the development of enhanced data services to the visitors of their physical collections and their digital counterparts. Amongst the several available metadata models developed for such purposes, Semantic Web ontologies are the most widely used, mainly because of their enhanced expressiveness, allowing to represent complex semantic relationships among CH entities, but also due to several other properties they enjoy such as extensibility, generality and inference support.

In the case of art collections, the data modelling challenges are even greater than other fields of CH. Artworks are available in multiple formats (images, texts, etc.), they are multi-topical (art, science, etc.), multi-cultural and multi-targeted (different recipients [1]. It is therefore even more difficult to develop a data model that can efficiently capture all these different diversities and heterogeneities but in the same time remain simple in its use.

Motivated by the above observation, this paper attempts to address the following research questions:

Do the current CH ontologies meet the data modelling requirements of art collections and especially with respect to the following needs of art galleries:

(a) cataloguing (collection & conservation management);
(b) display and publication of metadata (presentation of data);
(c) portals and system management.

Our study is focused on three CH ontologies, which are commonly used for modelling art collections metadata: the CIDOC Conceptual Reference Model (CIDOC-CRM), the Europeana Data Model (EDM) and VRA Core. Our methodology consists of selecting a characteristic sample of artworks and modelling its associated metadata using the three different ontologies, and then, based on the outcome of the first task, evaluating the three ontologies using a set of criteria associated to the data modelling needs and requirements outlined by the research questions.

The rest of the paper is structured as follows: Section 2 provides the necessary background information on the three ontologies. Section 3 describes our methodology in detail. Section 4 presents the results of the evaluation and Section 5 concludes.

2. Background

The CH domain was one of the first ones to adopt Semantic Web data models, methods and tools for modelling CH collections and publishing them online [2]. In this domain, SW technologies are mainly used for two purposes: the development of inner curation systems and the establishment of open collection databases. Ontologies and data models such as CIDOC-CRM, EDM and VRA Core are used to standardise the vocabularies for describing the relevant CH entities and their relationships, and in this way to enable interoperability among different CH institutions. Below, we provide some background information on these three models.

CIDOC Conceptual Reference Model (CIDOC-CRM). CIDOC-CRM is a formal structure developed by the International Committee for Documentation (CIDOC) of the International Council for Museums (ICOM) for describing the implicit and explicit concepts and relationships used in CH documentation [3]. Its event centric mechanism, which employs a vocabulary consisting of 82 classes and 262 properties and following the RDF semantics, enables the interrelation between people, things, places and time-spans through common events. In 2016, CIDOC-CRM became an ISO standard (ISO 21127:2006) for the interchange of cultural heritage information.

Europeana Data Model (EDM). EDM was developed in the context of the Europeana project as a Semantic Web-based framework for representing cross-domain collection metadata in museums, libraries and archives [4]. It is aligned to CIDOC-CRM in its definition of an event-centric model. To enhance interoperability, it reuses elements from other Semantic Web vocabularies, such as RDF, the Open Archives Initiative Object Reuse and Exchange (OAI-ORE) framework, the Simple Knowledge Organization System (SKOS) namespace, Dublin Core and the W3C Data Catalog Vocabulary (DCAT) [5]. It also introduces 11 new classes and 30 properties.

The Visual Resource Association Core Categories (VRA Core). VRA Core was developed for describing works of visual culture, collections, as well as images that document them [6]. It, therefore, represents three broad groups of entities, which are works, images, and collections. Having a much narrower scope than CIDOC-CRM and EDM, it consists of 19 elements including *Title*, *Record Type*, *Material*, *Creator*, *Measurements*, *Technique*, *Subject*, *Relation*, and *Rights*. It was originally developed as an XML Schema, but has recently become available as an RDFs ontology, enabling its use in Semantic Web environments.

3. Methodology

The sample we used for the evaluation consists of the four artworks presented in Table 1. The descriptions of the four artworks contain multiple kinds of information, meeting our aims for assessing the representation capabilities of the three ontologies. In the case of the paintings, the descriptions include their technical description, provenance, exhibition history, relevant bibliography, but also information about X-radiographs of the paintings. What is more interesting in the case of the two sculptures is their relationship: SA is the original work, and SB is the plaster cast of SA. SB is, however, considered, an artwork itself, created with certain art techniques.

Table 1: The sample of artworks used in our evaluation

id	Artwork	Artist	Institution
PA	Self-Portrait (1659)[1]	Rembrandt	National Gallery of Art, Washington
PB	Queen Elizabeth I (1879)[2]	Unknown	National Portrait Gallery, London
SA	David (1501-1504)[3]	Michelangelo	Galleria dell' Accademia, Florence
SB	David (casted 1857)[4]	Unknown	V&A, London

The criteria and measures we used to evaluate the ontologies, presented in Table 2, were selected from the relevant literature on ontology evaluation. Specifically, the criteria were adopted from the application-based evaluation methodology proposed by Brank et al. [7]. According to this study, each of the criteria has a specific evaluation research purpose: C1-C2 are associated to the cataloguing needs of a CH institution, C3 is related to portal & system management, while C4-C6 are related to the presentation and publication of metadata. The measures, which correspond to the different criteria, were adopted from the Ontology Quality Evaluation Framework presented in [8] and the evaluation methodology proposed in [9].

Table 2: Ontology evaluation criteria and measures

Criterion	Measure	Definition
Lexical, Vocabulary & Concept (**C1**)	**Accuracy**	Whether the ontology captures and represents correctly aspects of the real world.
	Clarity	The effectiveness of the ontology in communicating the defined terms and their intended meaning.
	Completeness/Competency	Whether the ontology covers all essential and relevant concepts in the domain of interest.

[1] http://www.nga.gov/content/ngaweb/Collection/art-object-page.79.html
[2] http://www.npg.org.uk/collections/search/portrait/mw02082
[3] http://www.accademia.org/explore-museum/artworks/michelangelos-david/facts-about-david/
[4] http://collections.vam.ac.uk/item/O39861/david-plaster-cast-michelangelo/

Hierarchy &Taxonomy(**C2**)	**Conciseness**	Whether the ontology includes any irrelevant or redundant axioms.
Computational-Efficiency (**C3**)	**Interoperability**	Whether the ontology interacts or reuses axioms from other data models.
User Experience (**C4**)	**Ease of Use**	Whether it is easy to operate the ontology and there is appropriate guidance.
	Learnability	How easy it is to find the information needed to use, and whether there is any relevant documentation.
Semantic Relations (**C5**)	**Indexing and Linking**	Whether the defined classes can act as indices to retrieve the requested information.
	Inferencing	Whether the ontology can make implicit knowledge explicit through reasoning.
Functional Adequacy (**C6**)	**Consistent Research and Query**	Whether the ontology can achieve better querying and searching methods.

4. Evaluation

4.1 Modelling the four artworks

The task of creating ontology-based descriptions of the four artworks using the three different ontologies consisted of two steps: The first step was to create the data model for each artwork using elements of each ontology. Examples of such data models are depicted in Figures 1-3 (EDM). Figure 1 depicts the description of the creation of PB through three different production events, using terms from CIDOC-CRM. Figure 2 demonstrates the use of aggregation in EDM for representing various web resources related to SA. Figure 3 illustrates the use of EDM to describe the relationship between SA and its plaster copy, SB. In the second step, we implemented the data models in Protégé[5] by adding appropriate individuals and property assertions with respect to the three ontologies. The second step aimed at verifying the data models, and also at examining the ontological inferences that could be made based on the semantics of each ontology. Figure 4 depicts the OWL/XML statements that describe different image resources related to PB, using terms from VRA Core.

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

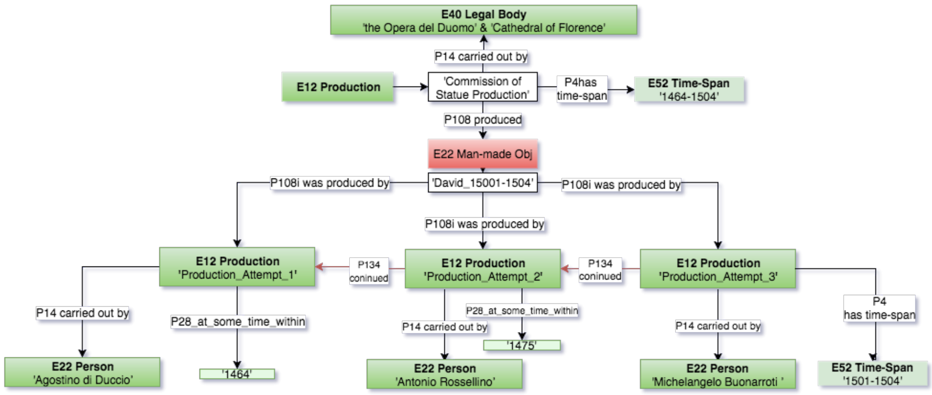

Figure 1: The data model of PB using CIDOC-CRM

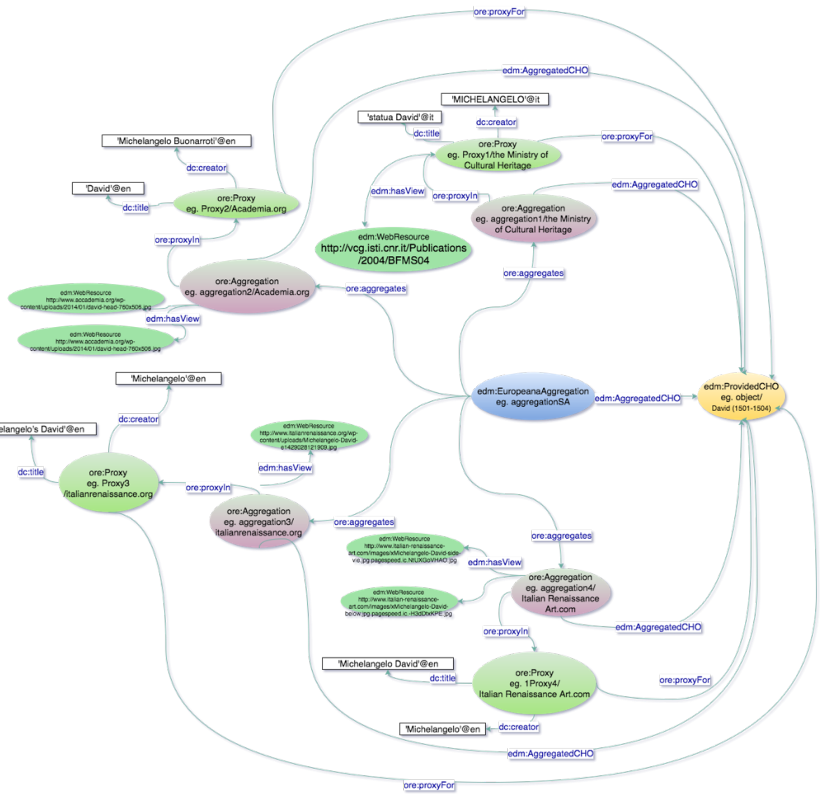

Figure 2: Using EDM to aggregate different online resources

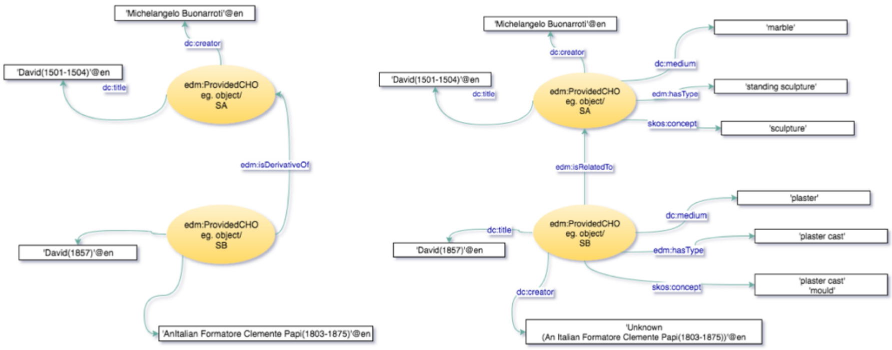

Figure 3: Using EDM to model the relationship between SA and SB

```
rdf:RDF
<!-- http://www.vraweb.org/vracore/vracore3.owl#PaintingA-Image1 -->
<owl:NamedIndividual rdf:about="http://www.vraweb.org/vracore/vracore3.owl#PaintingA-Image1">
    <rdf:type rdf:resource="http://www.vraweb.org/vracore/vracore3.owl#Image"/>
    <recordType rdf:resource="http://www.vraweb.org/vracore/vracore3.owl#image"/>
    <type rdf:resource="http://www.vraweb.org/vracore/vracore3.owl#digital_image"/>
    <description>the digital photo of Self_Portrait 1659 Rembrandt, coloured.</description>
    <idNumber.currentRepository>Self-Portrait(1659)byRembrandt.jpeg</idNumber.currentRepository>
    <rights>The National Gallery of Art, Washington, DC</rights>
    <creator.corporateName>National Gallery of Art, Washington DC</creator.corporateName>
    <creator.role>national gallery</creator.role>
    <measurements.format>JPEG</measurements.format>
    <measurements.resolution>3088 X 4000 px</measurements.resolution>
    <technique>Scanning</technique>
</owl:NamedIndividual>

<!-- http://www.vraweb.org/vracore/vracore3.owl#PaintingA-Image2 -->
<owl:NamedIndividual rdf:about="http://www.vraweb.org/vracore/vracore3.owl#PaintingA-Image2">
    <rdf:type rdf:resource="http://www.vraweb.org/vracore/vracore3.owl#Image"/>
    <recordType rdf:resource="http://www.vraweb.org/vracore/vracore3.owl#image"/>
    <type rdf:resource="http://www.vraweb.org/vracore/vracore3.owl#X-radiography"/>
    <description xml:lang="en">the x-radiograph plate of the head of Self_Portrait 1659 Rembrandt, BW</description>
    <idNumber.currentRepository>Self-Portrait(1659)byRembrandt2.jpeg</idNumber.currentRepository>
    <rights>The National Gallery of Art, Washington, DC</rights>
    <creator.corporateName>National Gallery of Art, Washington DC</creator.corporateName>
    <creator.role>national gallery</creator.role>
    <measurements.format>JPEG</measurements.format>
    <technique>X-Radiography</technique>
</owl:NamedIndividual>
```

Figure 4: Using VRA Core to model images of PB

4.2 Criteria-based Evaluation

Based on the data modelling tasks described in 4.1, we assessed the three different ontologies using the measures we present in Table 1. The results of the evaluation are summarised in Table 3, where '✗'denotes that the ontology doesn't exhibit good performance with respect to the corresponding criterion, '✓' denotes that the ontology performs well, and '✭' that the ontology has excellent performance. Sections 4.2.1-4.2.3 discuss in more detail the performance of each ontology.

CIDOC-CRM is efficient in representing information related to custody and acquisition. Its expressivity sometimes, does not easily lend to as straightforward implementation of metadata for describing visual resources, e.g. information describing an image of the artwork, such as its dimension, time of creation, format, resolution and technique.

Table 3: Summary of the evaluation of the three ontologies

Measure	CRM	EDM	VRA
Accuracy	✓	★	★
Clarity	★	✗	★
Completeness/Competency	✓	✗	✓
Conciseness	★	★	★
Interoperability	★	✓	✓
Ease of Use	✓	✗	★
Learnability	★	✗	★
Indexing and Linking	✓	★	✓
Inferencing	★	✗	✓
Consistent Research and Query	★	★	✓

4.2.1 CIDOC-CRM

CIDOC-CRM demonstrated its expressive power as a comprehensive ontology model for modelling cultural heritage information. It contains terms for capturing all aspects of the descriptions of the four artworks, structuring them in an event-centric way. For the specific scope of this experiment, there are, however, quite a lot of non-relevant to the task classes, which we did not use. Of course, the range of concepts it captures makes it applicable to a broad range of domains and applications and enhances its interoperability.

One problem we experienced with CIDOC-CRM was that it was not always clear which class was more appropriate for modelling a specific entity, as some of its classes very similar meaning. For example, it was difficult to decide which of *E22 Man-made_Object* and *E19 Physical_Man_Made_Thing* is more appropriate for modelling each of the four artworks.

On the other hand, concepts in CIDOC-CRM are very systemically linked and designed. Once the user gets familiar with the logic and structure of the model, it is very smooth in its use, either for research or indexing. Being based on RDFS, this model also exhibits all the inference capabilities offered by the semantics of the language.

It is hard to judge the indexing ability of the ontology. On the one hand, it enabled us to represent nearly all data related to the four artworks. It allows, however, users to follow different data modelling approaches, making the implementation of an indexing scheme for artwork difficult. For example, 'oil on canvas' (for PA) can be modelled in several different ways; i) as one individual, instance of *E55 Type*, linked to PA through the *P2 has type* property, ii) using two separate instances of *E55 Type,* 'oil painting' and 'canvas', linked to PA through the *P2 has type* propert. and ii) PA can be modelled as a composition (though *P46 composed of*) of two different instances of *E22 Man-made Object*, the first one referring to an artwork with type 'oil painting', and the second to the frame with type 'canvas'.

4.2.2 EDM

EDM is a metadata schema especially designed for Europeana.org so that its classes and properties are all appropriate for supporting the specific tasks of the project. However, it exhibits a poorly designed concept definition for its entities, which makes its use rather confusing. One example is the definitions of *edm:PhysicalThing* and *edm:*ProvidedCHO; edm*:PhysicalThing* refers to the persistent physical item that *edm:ProvidedCHO* represents. Therefore, the role of *edm:PhysicalThing* in data modelling is not clear and may confuse the users of EDM.

EDM is generic, including classes capturing high-level concepts related to artwork, but does not contain enough specialised classes for representing more specific metadata of CH artefacts. For example, we were only able to describe the location of the artworks at the granularity of country. It also lacks terms for modelling other relevant CH information, such as production process, acquisition, or technical reports. It is designed to focus on web resource aggregation and hence only collects the most basic information related to CH artefacts. Another important point is that EDM is only able to capture web resources. For example, for the case of the two sculptures (SA and SB), there was no way to describe their 'physical' characteristics in EDM.

The EDM vocabulary is rather difficult to understand and use, as its definition and guidelines to its users are quite unclear. It does not also provide sufficient guidelines about the use of terms it imports from external vocabularies.

On the other hand, EDM is a simple and general model for the description of cultural heritage information, making it appropriate for supporting indexing and research queries. It can be used to extract exhibition records easily in a simple and clear representation. And its ability to model aggregated information (through *ore:Aggregation*, as shown in Figure 3*)* is very and useful, especially for the information management needs of a CH portal.

4.2.3 VRA Core

VRA Core was designed to enable object-centred descriptions of artwork with clear relationships between original work and its images. It smoothly models, for example, the numerous and complicated visual resources related to PB. It contains all essential terms to represent useful information about both the artwork and its images in an accurate, simple and concise way. For example, it uses *vra:stylePeriod.style* to describe the art style of the work, which is particularly useful for artwork. Moreover, it provides specific terms to describe provenance or acquisition data, such as *vra:location.formerRepository* and *vra: location.formerSite*.

With respect to the representation of dimensions, it is the most efficient among the three ontologies; it uses *vra:measurements.dimension, vra:measurements.format* and *vra:measurements.resolution*, which capture the different aspects of dimension for both physical objects and images.

Note that VRA Core does not provide an element to link a Work to its corresponding Image(s). This is described in [10] as a 'local implementation issue'. and may lead to problems when aggregating data from different resources. The solution is rather partly solved by introducing a generic property called *vra:relation*, which is used to describe relations between works and images with domain and range *vra:VisualResource* (a superclass of *vra:Work* and *vra:Image*). However, *vra:Work* and *vra:Image* are not disjoint classes, as some image might also be a work of art, such as photography. In our modelling task, it was very difficult to decide whether to define SB as an image, object or work in this context, while we also faced the same problem when attempting to represent any copied artwork of SB.

4.2.4 Evaluation Summary

In table 4, we summarize the results of the evaluation with respect to the different research purposes that the ontologies can be used for.

Table 4 Summary of the evaluation of the three ontologies

Research Purpose	Criteria/Metric	CRM	EDM	VRA
Institutional Usage for Cataloguing	Lexical, Vocabulary, Concept	✓	✗	★
	Hierarchy, Taxonomy			
Portals & System Management	Computational Efficiency	★	✓	✓
Presentation of Metadata	User Experience	★	✗	★
	Semantic Relations			
	Functional Adequacy			

It is obvious that VRA Core and CIDOC-CRM better meet the cataloguing needs of CH institutions. We evaluate VRA Core as the best among the three ontologies for metadata presentation due to its efficient data modelling capabilities. EDM, on the other hand, appeared to be less strong for specialized cataloguing and data presentation. However, its support for modelling aggregation makes it very useful for the development and management of CH portals and information systems.

5. Conclusion

This paper evaluates the three popular Cultural Heritage ontologies with respect to their abilities to represent works of art. Our evaluation methodology consisted of selecting four characteristic examples of artwork, for which rich descriptions are available, creating descriptions of the four artworks using the three ontologies, and (based on the data modelling tasks) assessing the three ontologies using a set of evaluation criteria related to different uses of CH ontologies.

The main challenge of this evaluation was that, especially in the case of CIDOC-CRM and EDM, there were no detailed guidelines on how to use them to create the descriptions. Although, admittedly, the sample we used is rather small to generalize our conclusions, our experiment clearly identifies the main strengths and limitations of each ontology, and its results can be helpful for anyone who wants to semantically model similar CH information to support different kinds of applications. Our findings can be summarized as follows: CIDOC-CRM is a very general and ontology, able to capture a great range of concepts related to the CH domain and in multiple different ways, according to the needs of the underlying application. EDM is more appropriate for creating and aggregating simpler semantic descriptions. VRA Core is the most appropriate among the three models for cataloguing purposes and for describing the relationships between different visual resources.

We plan to extend this work by considering more samples from a greater range of artwork types. Our endmost goal is to provide guidelines on how to best combine elements from the three (or other) ontologies in order to satisfy the set of criteria related to the design purposes of the CH ontologies in the best possible way.

Acknowledgements

This work was partially supported by CrossCult: "Empowering reuse of digital cultural heritage in context-aware crosscuts of European history", funded by the European Union's Horizon 2020 research and innovation program, Grant#693150.

References

[1] Mantegari, G. (2009). Cultural Heritage on the Semantic Web: From representation to fruition. Ph.D. dissertation, Universita degli Studi di Milano Bicocca. Available online at: https://boa.unimib.it/handle/10281/9184

[2] Hyvönen, E. (2012). Publishing and Using Cultural Heritage Linked Data on the Semantic Web. United States: Morgan & Claypool.

[3] Doerr, M. (2003). The CIDOC Conceptual Reference Module: An Ontological Approach to Semantic Interoperability of Metadata. *AI Magazine*, vol. 24, no. 3, pp. 75–92.

[4] Doerr M., Meghini C., Isaac A., Hennicke S. and Gradmann S. (2010). The Europeana Data Model (EDM). In World Library and Information Congress. 76th IFLA General Conference and Assembly, Gothenburg, Sweden, 10-15 August 2010.

[5] Europeana (2016). EDM Mapping Guidelines V2.3. Available online at: http://pro.europeana.eu/page/edm-documentation

[6] The Library of Congress (2007) VRA Core 4.0 Schemas and Documentation. Available online at: https://www.loc.gov/standards/vracore/schemas.html

[7] Brank J, Grobelnik, M. and Mladenić, D (2005). A Survey of Ontology Evaluation Techniques. In Proceedings of the Conference on Data Mining and Data Warehouses (SiKDD 2005).

[8] Duque-Ramos, A., Fernández-Breis, J.T., Stevens, R., Aussenac-Gilles, N. (2011). OQuaRE: A SQuaRE-based Approach for Evaluating the Quality of Ontologies. *Journal of Research and Practice in Information Technology*, 43(2), 41–58.

[9] Vrandečić, D. (2009). Ontology Evaluation. In: Staab, S. and Studer, R. (eds), Handbook on ontologies, Berlin: Springer, pp. 293–314.

[10] Van Assem, M. (2005). RDF/OWL Representation of VRA. Available online at: https://www.w3.org/2001/sw/BestPractices/MM/vra-conversion.html