Formalizing enrichment mechanisms for bibliographic ontologies in the Semantic Web

Helena Simões Patrício[1,2 [0000-0002-4261-126X]], Maria Inês Cordeiro[1[0000-0002-6897-961X]] and Pedro Nogueira Ramos[2,3[0000-0003-0231-4356]]

[1] Biblioteca Nacional de Portugal, Lisboa, Portugal,
[2] Information Sciences, Technologies and Architecture Research Center (ISTAR-IUL)
[3]University Institute of Lisbon (ISCTE-IUL), Portugal
{icordeiro, hpatricio}@bnportugal.pt, pedro.ramos@iscte-iul.pt

Abstract. This paper presents an analysis of current limitations to the reuse of bibliographic data in the Semantic Web and a research proposal towards solutions to overcome them. The limitations identified derive from the insufficient convergence between existing bibliographic ontologies and the principles and techniques of linked open data (LOD); lack of a common conceptual framework for a diversity of standards often used together; reduced use of links to external vocabularies and absence of Semantic Web mechanisms to formalize relationships between vocabularies, as well as limitations of Semantic Web languages for the requirements of bibliographic data interoperability. A proposal is advanced to investigate the hypothesis of creating a reference model and specifying a superontology to overcome the misalignments found, as well as the use of SHACL (Shapes Constraint Language) to solve current limitations of RDF languages.

Keywords: Linked Open Data, Bibliographic data, Semantic Web, SHACL, LOD validation, Ontologies, Reference model, Bibliographic standards

Acknowledgments: This project was partially funded by the Fundação para a Ciência e Tecnologia (ISTAR UID/Multi/4466/2016).

1 Introduction

The principles of the Semantic Web and the new data structures emerging from RDF languages have raised the need for new models of bibliographic description. On this matter Godby, Wang & Mixter [1] acknowledge that there is already a critical mass of bibliographic data available as linked data, yet no corresponding evolution of the underlying standards did occur, thus calling for a reflection on the modeling of bibliographic data in the context of the Semantic Web.

From the most recent literature on the subject it is possible to identify a set of limitations to a full convergence of the bibliographic ontologies with the principles and techniques of the Semantic Web. Moreover, the RDF language does not provide means for the needs of validation, quality and consistency control of ontologies.

In the following sections the limitations and inadequacies of bibliographic ontologies and RDF languages are analyzed and the possibilities to overcome them through solutions based on semantic enrichment and validation of their vocabularies are explored.

2 Limitations at the conceptual level

Taking into account that modelling languages are built with a particular paradigm in mind, which constrains its applicability [2] and the profound impact of the new Semantic Web paradigm, it is important to understand to what extent the conceptual models created in recent years for bibliographic information translate such new paradigm and ensure the subsequent alignment. At this level, we refer to two types of limitations: first, the inadequacy for the Semantic Web of both the FRBR (Functional Requirements for Bibliographic Records) model[1] and its representations in RDF; and second, the absence of a framing reference model.

2.1 Shortcomings of the FRBR model

Despite being the first conceptual model explicitly defined for bibliographic data and resulting from the emergence of Internet and World Wide Web technologies, FRBR is not aligned with the Semantic Web paradigm. In fact, one of the criticisms about FRBR is that its elements have derived from standards of a paradigm prior to the Semantic Web. For Willer & Dunsire [3], this reinforces the need to rethink the more abstract models, rather than just define a new framework for old data elements. In the same line, Murray [4] identifies several issues from the fact that the model is based on requirements defined for functions and data structures characteristic of legacy systems such as card catalogues or MARC (Machine Readable Cataloging) formats, resulting in the creation of entities, attributes and relationships derived from pre-existing standards. Besides, the FRBR model does not provide context for its elements that allow them to be understood in wider environments, whether bibliographic or other domains. This makes it difficult for FRBR descriptions to co-exist with descriptions produced by different organizations and make FRBR entities to be seen as purely theoretical and not as data structures designed to be connected [4].

As for FRBR representations in Semantic Web languages, such as FRBRer[2], FRBR Core[3] and FRBRoo[4] ontologies, some authors [5, 6, e.g.] point out that generally these models are not well aligned with the principles and techniques of linked data because they do not allow for class hierarchy, thus not enabling transitivity and basic mechanisms of inference. Consequently, the entities below the WEMI (Work, Expression, Manifestation, Item) sequence are unable to use the attributes of the higher entities. For Coyle [6], this intransitivity derives from the ER (Entity-Relationship) model, which does not support hierarchies.

---

[1] https://www.ifla.org/publications/functional-requirements-for-bibliographic-records

[2] http://iflastandards.info/ns/fr/frbr/frbrer/

[3] http://vocab.org/frbr/core.rdf

[4] https://www.ifla.org/files/assets/cataloguing/FRBRoo/frbroo_v_2.4.pdf

Zapounidou, Sfakakis & Papatheodorou [7] claim that there is no hierarchy in WEMI entities because they have been modelled as disjoint classes and implemented with cardinality constraints that do not determine the transitivity of a hierarchy, but rather a sequence of WEMI entities' instantiations. In fact, the WEMI class disjunction prevents the sharing of properties or relationships and the connection to similar data [8] and determines that each instance can only belong to one of the WEMI classes, while in the actual world resources can be instances of more than one class [9].

Clearly, divergences most evident between FRBR and the Semantic Web result from ER model being natural to the "closed world" of databases [8], which may explain the fact that in many cases the representation of FRBR for the Semantic Web have been a mere "syntactic transcription" in RDF [3]. Baker, Coyle & Petiya [9] point out that the application of ER in FRBR has determined that WEMI entities have certain attributes (domain and range constraints) and are linked together by dependency relationships (cardinality restrictions). Therefore, according to the ER model, it should be possible to validate data against these constraints. It happens, however, that these ER concepts do not fit the Semantic Web, since neither the RDF domain constraints nor the cardinality of OWL (Ontology Web Language)[5] axioms can validate data. In both cases, they are constraints that just allow to infer new information, which may be wrong. This is a problem of Semantic Web languages, to be discussed later, that also translates in the superficial nature of FRBR publications in RDFS (Resource Description Framework Schema)[6]/ OWL. For example, in the FRBRer ontology a cardinality constraint has been specified which determines that an *expression* can only be an execution of one single *work*. In this case, if an *expression* is related to more than one *work*, semantic reasoners will not mark these statements as error; instead, they will infer that both works are the same with different URIs and this new inferred information may not be correct [9].

As a "multi-entity" model, FRBR has changed the focus from the record as a whole to its disaggregated data components where elements and attributes are not seen as parts of a record but become linked to specific entities [9]. This model is perfectly suited to the rules underlying linked data, because data being freed from the record unit can more easily be linked to other information, allowing the expression of multiple points of view about a given resource [1]. In this respect, Murray and Tillet [10] even argue that each FRBR entity is not properly an autonomous entity, but rather a point of view about a resource which in a multi-entity perspective can be expressed in bibliographic data graphs that bring together multiple statements or points of view on a given resource. Therefore, it can be concluded that the objective of having a single bibliographic model, as in the creation of FRBR in the 1990s, is outdated, since RDF is prepared to optimize the fusion of data from multiple sources through graph structures which group together multiple descriptions or points of view [9, 11].

The criticism about FRBR arises precisely from the fact that the model neither establishes the creation of a "super-entity" that could group WEMI entities nor assigns them properties to allow them to be treated as a whole. On the other hand, FRBR does

[5] https://www.w3.org/TR/owl2-primer/
[6] https://www.w3.org/TR/rdf-schema/

not appear as the model most appropriate to the perspective of entities as points of view because it makes a strict demarcation of WEMI entities and specifies with little clarity the relations between them. For these reasons, some authors refer to the need of rethinking FRBR [9, 11] and consider the possibility of creating a multi-entity model different from FRBR, as the distinction between WEMI entities cannot be so rigid because such distinction is not universal and varies culturally [10].

In August 2017, a new model, named IFLA Library Reference Model (IFLA-LRM) was approved [12], envisaging not only the editorial consolidation of the various models of the FRBR family, but also the construction of a single and coherent model capable of structuring the bibliographic data more clearly and better adapted to the Semantic Web [13] and of combining the different analysis' standpoints of the various FRBR models by using a common model and terminology [14]. IFLA-LRM maintains the ER framework, therefore the above-mentioned criticisms in this respect still apply. As for the remaining issues inherent to FRBR, with the new model all seems to be overcome [13]. However, as we are not aware of initiatives to represent IFLA-LRM in RDFS or OWL and previous FRBR representations are still valid, it seems relevant to ask whether convergence with the Semantic Web has improved with the new model and to analyze the transformation initiatives that, meanwhile, will appear.

2.2 Absence of a conceptual framework for bibliographic standards

The scattered nature of existing bibliographic standards has been replicated in the respective representations in RDF languages, with no guarantee of the consistency and quality of their inter-relationship. The need for a common conceptual model is revealed, first and foremost, in the relationship between standards because the multiplicity of them in the bibliographic field can easily lead to contradiction and difficulties in their combined application [15]. Sprochi [16] points out the need for a reference model to frame the different levels of bibliographic standards, such as FRBR, RDA and BIBFRAME, because they are closely related and strongly dependent on one another for implementation.

In what concerns ISBD (International Standard Bibliographic Description), the main criticisms of its representation as LOD are the lack of a model based on entities and relationships, as it is typical of the Semantic Web, in contrast with its underlying flat model of the bibliographic record as a text [17], with some authors suggesting that ISBD should be replaced by another language of description more adequate to the new paradigms [3].

RDA (Resource Description and Access), in turn, is a standard already born in the generation of FRBR that is, according to most authors [6, 18, e.g], completely compatible with the Semantic Web because it implements FRBR as a multi-entity conceptual model and, in its RDF representation[7], is connected to DCMI Metadata Terms[8] by subclass relationships with its elements, which facilitates understanding the more than

[7] http://www.rdaregistry.info/

[8] http://dublincore.org/documents/dcmi-terms/

900 RDA elements and prevents them to get stuck in bibliographic data silos [6]. However, some authors [14, e.g.] point out significant differences between the FRBR model and RDA which may justify a deeper analysis of this bibliographic standard.

At the level of data coding standards, the introduction of conceptual models based on graphs and tree models, such as FRBR, made MARC formats unsuitable because of their "record model" structure of "flat" files originally thought to be sequentially accessed. This not only implies a considerable duplication of metadata but also relies on textual data (textual values) instead of Uniform Resource Identifiers (URI). Although having representations in RDF, MARC formats have structural limitations to adapt to the Web environment because they are based on coding standards older than 40 years and originally designed to automate the creation and printing of catalogue cards [18].

These limitations motivated, in 2008, the beginning of a transition process towards a new bibliographic format aligned with the Semantic Web, BIBFRAME [9]. BIBFRAME appears among the ontologies most compatible with the open Web because, unlike FRBR, it uses the class hierarchy and does not define disjunctions between classes [6].

With regard to local initiatives for the publication of LOD datasets by libraries, the lack of a comprehensive bibliographic standard results in the proliferation of ontologies developed locally as "proving ground" for the experimentation of models of data transformation [19]. The absence of a common conceptual framework is evident from the combined application of standards with different levels of abstraction and developed upon very different conceptual models. Suominen & Hyvonen [20] argue that libraries are risking to abandon "silos" of MARC data to adopt "silos" of linked data, since the models being adopted may be incompatible.

3 Limitations in semantic interoperability

RDF is a data language that relies on the use of triples to declare facts about resources. In the Semantic Web, aggregation of data from multiple sources is achieved through URIs that identify the component parts (classes and properties) of RDF triples and allow pointing to vocabularies or ontologies that contain the definitions of such classes and properties. Ontologies are, thus, fundamental to the Semantic Web, as vocabularies of elements that provide the correct interpretation of the linked data, making them self-descriptive [21].

An ontology is the explicit and shared formal representation of a conceptualization, defining a set of representation primitives for modeling a domain of knowledge or discourse [22]. In the context of the Semantic Web, ontologies are used to specify conceptual vocabularies for information sharing between systems, providing services that facilitate interoperability between multiple and diverse systems [22].

In this context, it is important to analyze the level of semantic interoperability of bibliographic ontologies. From the main bibliography and a first analysis of biblio-

[9] https://www.loc.gov/bibframe/

graphic ontologies, the most frequent and transversal aspects are highlighted: underuse of semantic mechanisms; reduced number of links to other vocabularies; and point-to-point mappings.

3.1 Underuse of the semantic mechanisms of classification and hierarchy

Not making use in bibliographic vocabularies of basic mechanisms of the Semantic Web, such as class hierarchy or other class-level relationships, prevents the bibliographic domain from taking advantage of all the potentialities of linked data technologies. For example, not using classification, which relates all instances of a given class to the instances of another class, prevents inference inherent to classification, with relationships having to be at the individual level, i.e., at the level of data and not at that of vocabulary.

Another example is the non-use of hierarchies or relationships between classes: the addition of a new class obliges to define relationships at the instance level because it is not possible to infer new relationships from already established relationships with any superclass to which the new class would belong. In fact, the implementation of RDA in RDF makes little use of class hierarchy and shows few relationships between terms, which is probably a remnant of its origins as a list of terms [6].

Another aspect is data constraints which, most often, in bibliographic standards are not formalized with inference languages, rather consisting of textual notes only.

3.2 Reduced linking to other vocabularies

Linking to URIs of elements from external ontologies is an essential component of the linked data technique. However, in the development of bibliographic ontologies a cherry-picking methodology [19] has been followed, meaning the use of elements from external vocabularies without a semantic link to elements of the ontology that instantiates external elements, not allowing these to benefit from the advantages of the semantic integration of vocabularies, also called LOV - Linked Open Vocabularies.

For example, if a particular element of a local ontology would be linked to a subclass of an ontology element such as schema.org, any instance of the local class would be, by the semantic mechanism of inheritance, an instance of the superclass of schema.org, thus making it possible to be directly "consumed" by search engines of a general scope. That is, domain-specific vocabularies, such as those of the bibliographic domain, would become visible to general search engines [19].

In fact, a preliminary analysis of bibliographic standards published in the linked data cloud shows that, in general, there are few links to data elements of other ontologies or little use of elements from external vocabularies. For example, FRBRer, representing the FRBR conceptual model, makes use of elements from two external ontologies only: FOAF (Friend of a Friend) and DCMES, applying them just to identify administrative data about the ontology itself, such as the FRBR *title* and *creator* of the ontology homepage.

On the other hand, despite most standard ontologies being based on the FRBR model, the formal use of elements from FRBR ontologies is not much representative.

According to information on the LOV website, only the ISBD ontology makes use of the official IFLA representation of FRBRer. Often the replication of external vocabulary elements happens because, at the moment the ontology is developed, there is still no RDF representation of such external vocabularies, as it happened, for example, with the creation of FRBR classes in RDA that adopts FRBR as a conceptual model but did not choose to follow any of the vocabularies that express FRBR in RDF, establishing instead its own FRBR classes [6, 9].

As for initiatives of publishing bibliographic datasets as LOD, libraries have preferentially chosen to mix elements from external ontologies with locally developed ontologies of data elements. It happens, however, that local elements are created without any link to standard bibliographic vocabularies (for example, the National Library of Spain data is based on FRBR but created its own representation of elements); other issues are limitations arising from the application of standard ontology elements at the level of data instantiation only, where they appear mixed with the local elements. Finally, the formalization of elements taken from different bibliographic standards is often absent, occurring in a combination of standards with different levels of abstraction and different conceptual models. These issues may be caused by the experimental nature of many bibliographic data transformation initiatives or even, as Godby [19] points out, by the lack of time for discussion and integration of elements of pre-existing ontologies.

3.3 Proliferation of vocabularies

The dispersion of bibliographic standards was replicated in their publication as RDF ontologies, with no guarantee of consistency and quality of their interrelationship. According to Zapounidou, Sfakakis & Papatheodorou [7] the structural heterogeneity of bibliographic standards can lead to incompatibilities between standards of different levels of abstraction. For example, the implementation of FRBRer or FRBRoo in BIBFRAME is impossible, because in BIBFRAME there is a 1:1 relationship between *Work* and *Item* classes, whereas in FRBR ontologies the relation between these classes is 1:* . The same authors also raise other structural problems such as conflicts between the primitives of different models and different modeling solutions for the same entities of the real world. Besides the already mentioned standards, other ontologies and models with bibliographic components will be considered in our research, such as BIBO[10], VIVO[11] and the CERIF model[12].

In the process of transforming bibliographic data into LOD, libraries define the vocabularies or ontologies to be used for publishing datasets. It may happen that this mixture of ontologies and creation of new elements/properties does not fit the data to be modeled [23].

[10] BIBO – The Bibliographic Ontology - http://bibliontology.com

[11] VIVO Ontology for Researcher Discovery - http://purl.bioontology.org/ontology/VIVO

[12] CERIF - The Common European Research Information Format - https://www.eurocris.org/cerif/main-features-cerif

In addition to the fragmentation of standard ontologies used by libraries, each library develops its own ontology, both standard and local ontologies can be based in very different conceptual models. In fact, as Suominen & Hyvonen [20] point out, bibliographic data expressed in different vocabularies can be very difficult to combine and use together; and, although small differences in vocabulary can be solved using mappings, it is not clear if this can suffice to guarantee the interoperability of bibliographic data in the Semantic Web.

The main problems encountered in library LOD transformation initiatives are the proliferation of vocabularies for the same data, coupled with the lack of good practice in vocabulary development and management. This is leading to truly chaotic situations [20, 23, 24, 25]. Thus, it is urgent to find common strategies for the publication, discovery, evaluation and mapping of vocabularies of bibliographic elements [24].

The absence of a common conceptual model and methodology for the creation or mapping of linked data in the library field has led to the proliferation of multiple independent efforts to map and combine data, which makes initiatives difficult to sustain [26]. The excessive number of vocabularies used in the publication of bibliographic data as linked data impairs the reusability of such data. This diversity is well demonstrated in Willer & Dunsire [3] analysis of vocabulary and ontology diversity.

3.4 Point-to-point mappings

As mentioned in section 3.2, links to external vocabularies are rarely used in bibliographic ontologies; it is therefore important to know if there are mappings between elements of different ontologies made by “third party” ontologies. Although there are several alignments and mappings between bibliographic ontologies, we are not aware of any standard ontology created at a higher level to express semantic relations between vocabularies.

Indeed, existing mappings have been developed in a distributed manner, making point-to-point connections between ontology elements. The best-known example are the alignments made by the IFLA ISBD Working Group, relating not only IFLA standards to each other (FRBR, UNIMARC and ISBD), but also ISBD with the external vocabulary RDA. As the alignments are made unidirectionally from ISBD to RDA, it is necessary to have the reverse mapping from RDA to ISBD [27]. This would not be needed if there was a central ontology for representing, at a higher level of abstraction, the semantic connections between these vocabularies.

Current mappings between bibliographic ontologies are being carried out as "crosswalks" or schema-to-schema mappings, characteristic of XML. This type of relationship between elements of different vocabularies ensures a "mapping interoperability" that facilitates the exchange of data between different schemas but does not solve semantic compatibility issues [28]. In fact, this type of mapping works for 1:1 relationships, but does not ensure semantic interoperability in 1:* or *: 1 relationships and does not solve situations of mismatch as well. For these cases, one must consider the use of mechanisms of semantic linking between the elements, attributes, entities and relationships of different ontologies [29].

Regarding technologies feasibility assessment, the Systematic Literature Review of linked data software tools undertaken by Armando Barbosa [30] will be considered in our research.

4 RDF/RDFS/OWL limitations

As already mentioned in previous parts of this paper, there are also issues with the use of Semantic Web languages of the RDF family for the representation of bibliographic data. In this section, they are reviewed and synthesized in two main aspects: i) the missing capability for data structures validation; and ii) the poor adequacy for the purposes and characteristics of bibliographic data, especially given the granularity and atomization of its elements.

In the first aspect, we should remind that FRBR applies the ER model, establishing for each entity its own attributes or properties. However, in RDF the use of a certain property cannot be limited to a certain class, due to the Semantic Web “AAA Principle” that states that *Anyone can say Anything about Anything*. In fact, the use of RDF restrictions such as “range” and “domain” to constrain the use of a property to a certain class allows the inference of new information only, not its validation. The specification of data structures that can be validated against certain constraints is a requirement of multi-entity models such as FRBR, but this will have to be done with languages other than those of the RDF family [9].

The same limitation applies to hierarchy: RDF expresses transitive properties and classes, but for inference only. It is not possible to use RDF to "impose" a given hierarchy. That is, RDF does not solve the historical problems of lack of transitivity of bibliographic data models, since it allows to connect WEMI entities, for example, but not in a hierarchical way. RDF has a graph rather than a hierarchical or tree structure, so it can connect virtually everything in any direction [15].

The specification of many constraints in RDF, which occur in most bibliographic ontologies, is also not very adequate from the point of view of the graph structure itself. In fact, vocabularies in RDF are as more reusable as they have fewer data constraints. Constraints greatly isolate the ontologies and should be expressed in "profiles" for data quality control, independently of the ontologies to which they apply [9].

In the second aspect, the adequacy for the purposes and characteristics of bibliographic data, Yee [15] argues that RDF is not suitable for bibliographic data because of its excessive atomization, reflected in standards such RDA.

5 Exploring new interoperability solutions: a reference model and a SHACL-based superontology

With RDF providing mechanisms to combine multiple data sources in an "open world" where bibliographic description can be an aggregation of multiple viewpoints about a resource, the claim for a single common bibliographic model to overcome the limitations in the interoperability of bibliographic standards and ontologies, suggested by some authors [17, e.g.] is no longer justified [9]. However, as explained in the previous sections, simply translating existing ontologies into RDF is not enough and RDF languages have limitations that make them inadequate for certain interoperability requirements.

In this context, it seems relevant to investigate the possibility of higher abstraction mechanisms to potentiate semantic interoperability, at two levels:

i) the creation of a reference model capable of encompassing the different existing models in the bibliographic and similar domains; and
ii) the specification of a superontology based on the reference model, i.e., a reference ontology of a higher level of abstraction than existing standard and local ontologies, in the sense defined by Brinkley [31], that would be an instrument for relating semantically the elements of standard bibliographic vocabularies and for specifying mechanisms for restricting or constraining bibliographic data.

Despite the multiplicity of points of view of an "open world" for the bibliographic field, the need still remains for a solution to control the quality and consistency of bibliographic data, that is, to “close the world” when necessary through the specification of constraints to validate data structures. As stated above, this would be a requirement of the superontology that RDF languages cannot meet, given its limitations already explained in the previous section of this paper.

The lack of standards to express data constraints led to the creation of Shapes Constraint Language (SHACL)[13], a schema language for RDF that allows the specification of constraints (called " shapes ") for the validation of RDF graphs [32]. SHACL is also more powerful than OWL in the inference mechanisms because it can be used for rule-based inferences [33]. In this sense, it is worth investigating the hypothesis of using SHACL, a high-level vocabulary for the expression of data constraints which is simultaneously a language for ontologies, approved as a W3C Recommendation in July 2017.

Although constraints for validation of bibliographic data should be expressed separately from the vocabularies to which they apply [9], in our research we will not consider the use of application profiles, extension vocabularies or other mechanisms specific to languages of metadata schemas, since they do not have validation effects in the Semantic Web. Indeed, such extension profiles or ontologies need to be formally recognized by the entities that manage the base-ontologies, while AAA and OWA (Open World Assumption) principles allow that inconsistent or non-formally recognized profiles or extensions can exist and be applied. For this reason, we will instead explore the possibility of using SHACL as a language to validate data from the "open world" of the Semantic Web with "closed world" constraints [9].

6 Conclusions

This paper has provided a review of current limitations to the convergence between existing bibliographic ontologies and the Semantic Web that impair the potential of

[13] https://www.w3.org/TR/shacl/

reuse of bibliographic data in that context. The review provides an analysis of the issues deriving from the use of a variety of different bibliographic standards and vocabularies separately conceived and managed, insufficiencies of their expression in Semantic Web languages and limitations of practical experiences in bibliographic LOD data transformation as well.

In order to improve bibliographic data interoperability in the Semantic Web, a research proposal is put forward to investigate new means to enrich and integrate the semantics of ontologies already in use by libraries, through the creation of a reference model and the formalization of a higher level ontology making use of SHACL to overcome limitations identified in the RDF family of languages, especially in what concerns the enabling of constraint mechanisms, capable of ensuring the semantic validity and quality of data.

References

1. Godby, C.J., Wang, S., Mixter, J. K.: Library linked data in the cloud: OCLC's experiments with new models od resource description. Morgan & Claypool, San Rafael, CA (2015). doi: 10.2200/S00620ED1V01Y201412WBE012
2. Cordeiro, M.I.: Information technology frameworks in LIS: exploring IT constructs as sources of conceptual alignment. Thesis submitted for the Degree of Doctor of Philosophy at the University of London (UCL). (2005).
3. Willer, M., Dunsire, G.: Bibliographic information organization in the Semantic Web. Chandos, Oxford (2013).
4. Murray, R.J.: The FRBR-Theoretic library: the role of conceptual data modeling in cultural heritage information system design. In: iPRES 2008: Proceedings of the Fifth International Conference on Preservation of Digital Objects. British Library, London, pp. 163–168. (2008).
5. Peponakis, M.: Conceptualizations of the cataloging object: a critique on current perceptions of FRBR Group 1 entities. Cataloging & Classification Quarterly. 50:5-7, pp. 587-602. (2012).
6. Coyle, K.: FRBR, before and after: a look at our bibliographic models. American Library Association, Chicago (2016).
7. Zapounidou, S., Sfakakis, M., Papatheodorou, C: Representing and integrating bibliographic information into the Semantic Web: a comparison of four conceptual models. Journal of Information Science, pp. 1-29. (2016).
8. Coyle, K.: FRBR, twenty years on. Cataloging and Classification Quarterly, 53 (3-4), pp. 265-285. (2015). doi 10.1080/01639374.2014.943446
9. Baker, T., Coyle, K., Petiya, S.: Multi-entity models of resource description in the Semantic Web: a comparison of FRBR, RDA and BIBFRAME. Library Hi Tech, 32 (4), pp. 562-582. (2014). doi: 10.1108/LHT-08-2014-0081
10. Murray, R.J., Tillett, B.: Cataloging theory in search of graph theory and other ivory towers. Information Technology and Libraries, 30 (4), pp. 170-184. (2011).
11. Martin, K. E.; Mundle, K.: Positioning libraries for a new bibliographic Universe: a review of cataloging and classification literature 2011-12. Library Resources & Technical Service, 58 (4), pp. 233-249. (2014).
12. Riva, P., Le Boeuf, P., Zumer, M.: IFLA Library Reference Model: a conceptual model for bibliographic information. IFLA, Den Haag (2017).
13. Riva, P.: Il nuovo modello concettualle dell' universo bibliografico: FRBR Library Reference Model. AIB Studi, 56 (2), pp. 265-275. (2016).

14. Peponakis, M.: In the name of the name: RDF literals, ER attributes, and the potential to rethink the structures and visualizations of catalogs. Information Technology and Libraries, June, pp. 19-38. (2016).
15. Yee, M. M.: Can bibliographic data be put directly onto the Semantic Web? Information Technology and Libraries. June, pp. 55-80. (2009).
16. Sprochi, A.: Where are we headed? Resource Description and Access, Bibliographic Framework, and the Functional Requirements for Bibliographic Records Library Reference Model. International Information & Library Review, 48 (2), pp. 129-136. (2016). doi: 10.1080/10572317.2016.1176455
17. Svensson, L.G.: Are current bibliographic models suitable for integration with the Web? Information Standards Quarterly, 25 (4), pp. 7-13. (2013).
18. Szeto, K.: Positioning library data for the Semantic Web: recent developments in resource description. Journal of Web Librarianship, 7 (3), pp. 305-321. (2013). doi: 10.1080/19322909.2013.802584
19. Godby, C. J.: A division of labor: the role of Schema.org in a Semantic Web model of library resources. In Seikel, J., Seikel, M. (eds.): Linked Data for the cultural heritage, pp.73-101. ALCTS, Chicago (2016).
20. Suominen, O., Hyvonen, N.: From MARC silos to Linked Data silos? o-bib. Das offene Bibliotheksjournal, 4 (2). (2017).
21. Hawtin, R., et al.: Review of the evidence for the value of the "linked data" approach: final report to JISC. JISC, Curtis+Cartwright (2011).
22. Gruber, T.: Ontology. In Liu, L, Oszu, M. (eds.): Encyclopedia of Database Systems. Springer (2009). doi:10.1007/978-0-387-39940-9_1318
23. Hanneman, J., Kett, J.: Linked data for libraries. In:World Library and Information Congress: 76th IFLA General Conference, Gothenburg, 10-15 August. (2010).
24. Dunsire, G., et al.: Linked data vocabulary management: infrastructure, data integration, and interoperability. Information Standards Quarterly, 24 (2-3), pp. 4-13. (2012).
25. Hallo, M. et al.: Current state of linked data in digital libraries. Journal of Information Science, 42 (2), pp. 117-127. (2016). doi:10.1177/0165551515594729
26. Coyle, K., Silvello, G., Tammaro, A.M.: Comparing methodologies: Linked Open Data and Digital Libraries. In: AIUCD'14 - Proceedings of the Third AIUCD Annual Conference - Humanities and Their Methods in the Digital Ecosystem,article No. 3. ACM Digital Library (2014). doi: 10.1145/2802612.2802615
27. Escolano Rodriguez, E.: RDA and ISBD: history of a relationship. JLIS.it, 7 (2), pp. 49-81. (2016).
28. Howarth, L. C.: FRBR and linked data: connecting FRBR and linked data. Cataloging & Classification Quarterly. 50:5-7, pp. 763-776. (2012). doi: 10.1080/01639374.2012.680835
29. Doerr, M., Riva, P., Zumer, M.: FRBR entities: identity and identification. Cataloging & Classification Quarterly. 50:5-7, pp. 517-541. (2012). doi: 10.1080/01639374.2012.681252
30. Barbosa, A., et al.: The use of software tools in linked data publication and consumption: a Systematic Literature Review. International Journal on Semantic Web and Information Systems. 13 (4), pp. 68-88. (2017).
31. Brinkley, J.F., et al.: A framework for using reference ontologies as a foundation for the semantic web. In: AMYA Symposium Proceedings 2006, pp. 96-100. (2006).
32. Knublauch, H., Kontokostas, D. (eds.): Shapes Constraint Language (SHACL). W3C Recommendation 20 July 2017. W3C (2017).
33. Knublauch, H.: SHACL and OWL compared. spinrdf.org. (2017).