# Towards a Semantic Web Enabled Representation of DL Foundational Models: The Quality Domain Example

Nicola Ferro(✉) and Gianmaria Silvello

Department of Information Engineering, University of Padua, Padua, Italy
{ferro,silvello}@dei.unipd.it

**Abstract.** The convergence of Libraries, Archives and Museums (LAM) has been a topic of much discussion in the *Digital Library (DL)* research field, but their similarities and common points are not yet fully exploited in existing formal models for DL such as the *Streams*, *Structures*, *Spaces*, *Scenarios*, *Societies (5S)* model or the DELOS Reference Model.

On the other hand, Semantic Web and Linked Data technology are nowadays mostly used for interoperability at the data level but they would represent a viable option for building a semantic representation and interoperability at the level of different DL models of themselves.

To this end, we discuss a quite ambitious goal that should be part of the DL agenda that is expressing foundational models of DL by means of ontologies which leverage Semantic Web and Linked Data technologies and which link them to the ontologies currently used for publishing cultural heritage data. This would pave the way for a deeper interoperability among DL systems and lower the barriers between LAMs.

In this paper we exemplify this proposal by focusing on the quality domain which is a fundamental aspect in the DL universe and we show how this part of the DELOS Reference model can be expressed via a *Resource Description Framework (RDF)* model ready to be used in a Semantic Web environment for interoperability at the DL model level and not only at the data level.

## 1 Motivation

Over the past two decades, digital libraries have been steadily evolving and shaping the way people and institutions access and interact with our cultural heritage, study and learn [6,7,11–13,22,23,36]. Nowadays, the reach of digital libraries goes far beyond the realm of traditional libraries and also encompasses other kinds of cultural heritage institutions, such as archives and museums.

In the context of *Libraries, Archives, and Museums (LAM)* unifying a variety of organizational settings and providing more integrated access to their contents is an aspect of utmost importance. Indeed, LAM collect, manage and share digital contents; although the type of materials may differ and professional practices vary, LAM share an overlapping set of functions. Fulfilling these functions


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in "collaboration rather than isolation creates a win-win for users and institutions" [37]. Although the convergence between libraries, archives and museums has been a topic of much discussion in the digital library community, the emerging similarities between these three types of cultural heritage institutions are not yet evident in the proposed formal models, developed systems, and education of professionals [29,30].

Two main approaches are viable to bridge the gap among different cultural heritage and memory institutions and to provide comprehensive DL able to embrace the full spectrum of LAMs and interoperate together: one is somewhat "top-down" and consists in the development of full (formal) models of what DL are, as in the case of the 5S model [17] or the DELOS Reference Model [8]; the other is somehow "bottom-up" and concerns the exploitation of semantic Web technologies and linked (open) data [19,20] in order to represent and describe common entities, such as actor ontologies – e.g. *Friend of a Friend* (*FOAF*)[1] or BIO[2]; place ontologies – e.g. GeoNames[3]; time ontologies – e.g. the time period encoding scheme[4] in the Dublin Core Metadata Terms; event ontologies – e.g. the Event Ontology[5] or *Linking Open Descriptions of Events* (*LODE*)[6]; and many others.

However, there is a notable gap between these two approaches: the above mentioned ontologies are used to describe entities and resources which need to be managed by DL but they are not used to represent the concepts themselves which constitute a (formal) DL model. Therefore, they allow for semantic interoperability and integration at the data level, i.e. among the resources which are managed by different DL but they do not allow for semantic representation and interoperability at the level of different models of DL as the 5S and the DELOS Reference model are.

As an example, we could use the class `Agent` in FOAF to represent the notion of user of a DL in order to allow two systems to exchange user profiles. Nevetheless, the `Agent` class is neither related to the concept of *society* in the 5S model nor to the concept of *actor* in the DELOS Reference model, which are both concerned with the notion of users of a DL. Therefore, to exchange user profiles, two different DL systems, one built using the 5S model and the other built using the DELOS Reference model, would need, at the best, a set of (hard-coded) rules instructing them to translate their internal notion of *society*/*actor* into the `Agent` class. This situation somehow hampers a more profound kind of interoperability among DL systems, an interoperability which stems from a commonly shared semantic view of what a DL is rather than a lower level one, deriving from the possibility of sharing data and resources with a common semantics.

Therefore, we think that a quite ambitious goal should be part of the DL agenda, namely expressing foundational models of DL by means of ontologies

1 http://www.foaf-project.org/.
2 http://vocab.org/bio/0.1/.html.
3 http://geonames.org/.
4 http://dublincore.org/documents/dcmi-period/.
5 http://motools.sourceforge.net/event/event.html.
6 http://linkedevents.org/ontology/.

which leverage semantic Web and linked data technologies and which link them to the ontologies currently used for publishing cultural heritage data. As discussed above, this would pave the way for a deeper interoperability among DL systems and lower the barriers between LAMs. Moreover, it would open up also more advanced possibilities for the automatic processing of resources since, for example, DL systems could automatically exploit the link between the models they are build upon in order to interoperate and exchange resources. This latter aspect was also part of the original 5S model vision, which aimed at automatically instantiating and deploying a DL system from a catalog of components corresponding to the notions introduced in the model [15]; unfortunately, this vision has not been fully embodied yet, especially in wide settings, but the last decade of efforts geared towards interoperability and the today pervasiveness of semantic Web technologies may offer the opportunity of performing the next step in this direction.

The paper is organized as follows: Sect. 2 briefly summarizes the main DL models, as the 5S and DELOS Reference model are; Sect. 3 describes the details of a relevant sub-domain of those models, i.e. the quality domain; Sect. 4 provides an example of the approach discussed above in the case of the quality domain; Sect. 5 draws some final remarks.

## 2 Models for Digital Libraries

### 2.1 5S Model

The 5S [12,16,17] is a formal model which draws upon the broad digital library literature to produce a comprehensive base of support. It was developed largely bottom up, starting with key definitions and elucidation of digital library concepts from a minimalist approach. It is built around five main concepts: (i) *streams* are sequences of elements of an arbitrary type, e.g. bits, characters, images, and so on; (ii) *structures* specify the way in which parts of a whole are arranged or organized, e.g. hypertexts, taxonomies, and so on; (iii) *spaces* are sets of objects together with operations on those objects that obey certain constraints, e.g. vector spaces, probabilistic spaces, and so on; (iv) *scenarios* are sequences of related transition events, for instance, a story that describes possible ways to use a system to accomplish some functions that a user desires; and, (v) *societies* are sets of entities and relationships between them, e.g. humans, hardware and software components, and so on.

Starting from these five main concepts, the model provides a definition for a minimal digital library which is constituted by: (i) a repository of digital objects; (ii) a set of metadata catalogs containing metadata specifications for those digital objects; (iii) a set of services containing at least services for indexing, searching, and browsing; and, (iv) a society.

### 2.2 DELOS Reference Model

The DELOS Reference Model [8] is a high-level conceptual framework that aims at capturing significant entities and their relationships with the digital library universe with the goal of developing more robust models of it. The DELOS Reference Model and the 5S model address a similar problem with different approaches; the former does not provide formal definitions, but it does provide a way to model and manage the resources of the digital library realm. The 5S on the other hand is a formal model providing mathematical definitions of the digital library entities that can be used to prove properties, theorems and propositions like in [16].

So the DELOS Reference Model is similar to the 5S model in its broader goal, but instead of using a mathematical formalism, it relies on concept maps [25,26] because of their simplicity and immediacy and it highlights six main domains in the digital library universe: (i) *content*: the data and information that digital libraries handle and make available to their users; (ii) *user*: the actors (whether human or not) entitled to interact with digital libraries; (iii) *functionality*: the services that digital libraries offer to their users; (iv) *quality*: the parameters that can be used to characterize and evaluate the content and behaviour of digital libraries; (v) *policy*: a set of rules that govern the interaction between users and digital libraries; and (vi) *architecture*: a mapping of the functionality and content offered by a digital library onto hardware and software components.

These six main domains represent the high level containers that help organize the DELOS Reference Model. For each of these domains, the fundamental entities and their relationships are clearly defined. Even though the 5S model and the DELOS Reference Model are at two different levels of abstractions and make use of different languages and formalisms to represent the digital library universe, it is possible to make bridges and mappings between the two, as for example has been done for the quality domain [1].

## 3 Modeling Quality in Digital Libraries

Quality is a fundamental aspect in DL [2,14,16,18,24], which is often related to and affected by the interoperability and integration among DL systems [9,28,31].

The quality domain in the DELOS Reference model, shown in Fig. 1 takes into account the general definition of quality provided by *International Organization for Standardization (ISO)* which defines quality as "*the degree to which a set of inherent characteristics fulfils requirements*" [21], where requirements are needs or expectations that are stated, generally implied or obligatory while characteristics are distinguishing features of a product, process, or system.

A `Quality Parameter` is a `Resource` that indicates, or is linked to, performance or fulfillment of requirements by another Resource. A `Quality Parameter` is evaluated by a `Measurement`, is measured by a `Measure` assigned according to the `Measurement`, and expresses the assessment of an `Actor`. With respect to the definition provided by ISO, we can note that: the "set of inherent characteristics" corresponds to the pair (`Resource`, `Quality Parameter`); the "degree of fulfillment" fits in with the pair (`Measurement`, `Measure`); finally, the "requirements" are taken into consideration by the assessment expressed by an `Actor`.

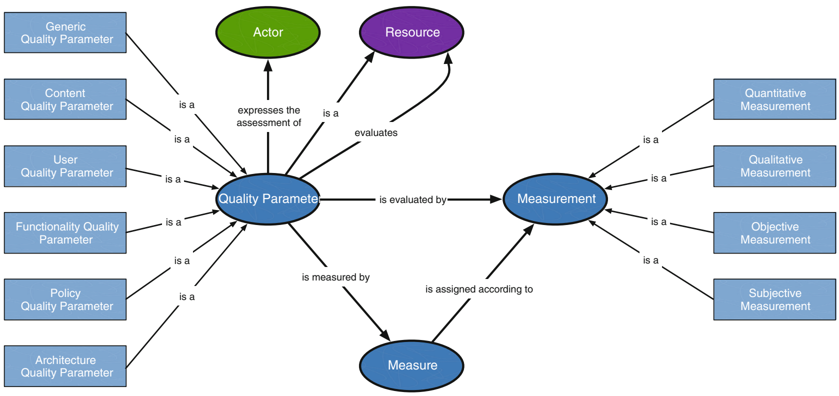


**Fig. 1.** Concept map of the main entities and relationships in the quality domain.

A Resource is any identifiable entity in the DL universe and resembles the concept of resource used in the Web [32]. In addition to this general concept, the Resource in the DELOS Reference Model has some additional features: it can be arranged or set out according to a resource format which, for example, allows a Resource to be composed of or linked to other Resources; it can be characterised by various Quality Parameters, each capturing how the Resource performs with respect to some attribute; it is regulated by policies governing every aspect of its lifetime; it is expressed by an information object; and, it can be described by or commented on by an information object, especially by metadata and annotations. An Actor is someone or something which interacts with the DL universe, being it a human being or a computing device. An Actor is a Resource and inherits all its key characteristics, even if they are specialized to better fit to the notion of Actor. For example, the policies represent the functions that Actors can perform or the information objects they have access to.

Quality Parameters serve the purpose of expressing the different facets of the quality domain. In this model, each Quality Parameter is itself a Resource and inherits all its characteristics, as, for example, the property of having a unique identifier. Quality Parameters provide information about how, and how well, a Resource performs with respect to some viewpoint and resemble the notion of quality dimension in [5]. They express the assessment of an Actor about the Resource under examination. They can be evaluated according to different Measurements, which provide alternative procedures for assessing different aspects of a Quality Parameter and assigning it a value, i.e. a Measure. Being a Resource, a Quality Parameter can be organised in arbitrarily complex and structured forms because of the composition and linking facilities, e.g. a Quality Parameter can be the compound of smaller Quality Parameters each capturing a specific aspect of the whole or it can be itself characterised and affected by various Quality Parameters. For example, Availability is affected by Robustness and Fault Management: in fact, when a function is both robust and able to recover from error conditions, it is probable that its availability is also increased. A Quality Parameter can be regulated or affected by policies. For example, the Economic Convenience of accessing a DL may be affected by its charging policy, since the latter is responsible for the definition of the charging strategies adopted by the DL. Finally, a Quality Parameter can be enriched with metadata and annotations. In particular, the former can provide useful information about the provenance of a Quality Parameter, while the latter can offer the possibility to add comments about a Quality Parameter, interpreting the obtained values, and proposing actions to improve it. In order to clarify the relationship between Quality Parameter, Measurement and Measure, we can take an example from the information retrieval field. One of the main Quality Parameters in relation to an information retrieval system is its effectiveness, meant as its capability to answer user information needs with relevant items. This Quality Parameter can be evaluated according to many different Measurements, such as precision and recall [27]: precision evaluates effectiveness in the sense of the ability of the system to reject useless items, while recall evaluates effectiveness in the sense of the ability of the system to retrieve useful items. The actual values for precision and recall are Measures and are usually computed using standard tools, such as trec_eval[7], which are Actors, but in this case not human. Quality Parameters are specialized and grouped according to the Resource under examination as follows:

- Generic Quality Parameters when the assessed Resources are a Digital Library, or a Digital Library System, or a Digital Library Management System;
- Content Quality Parameters when the assessed Resources belong to the content domain;
- User Quality Parameters when the assessed Resources belong to the user domain;
- Functionality Quality Parameters when the assessed Resources belong to the functionality domain;
- Policy Quality Parameters when the assessed Resources belongs to the policy domain;
- Architecture Quality Parameters, when the assessed Resources belong to the architecture domain.

It is important to note that the grouping described above is made from the perspective of the Resource under examination, i.e., the object under assessment. In any case, the Actor, meant as the active subject who expresses the assessment and knows the requirements a Resource is expected to fulfill, is always taken into consideration and explicitly modelled, since he is an integral part of the definition of Quality Parameter. For example, the User Satisfaction parameter is put in the Functionality Quality Parameter group because it expresses how much an Actor (the subject who makes the assessment) is satisfied when he uses a given function (the object of the assessment). On the other hand, in the case of the User Behaviour parameter, the

[7] http://trec.nist.gov/trec_eval/.

object of the assessment is an Actor together with his way of behaving with respect to some policy, while the subject who is making the assessment is another Actor, for example, an administrator; for this reason, this parameter is put in the User Quality Parameter group. Measurements are further categorized according to the following specializations:

– Objective Measurements can be obtained by taking measurements and using an analytical method to estimate the quality achieved. They could also be based on processing and comparing measurements between a reference sample and the actual sample obtained by the system. Examples of objective factors related to the perception of audio recordings in a digital library are: noise, delay and jitter.
– Subjective Measurements involve performing opinion tests, user surveys and user interviews which take into account the inherent subjectivity of the perceived quality and the variations between individuals. The perceived quality is usually rated by means of appropriate scales, where the assessment is often expressed in a qualitative way using terms such as bad, poor, fair, good, excellent to which numerical values can be associated to facilitate further analyses. Examples of factors related to the subjective perception of audio recordings in a digital library are: listening quality, loudness, listening effort.
– Quantitative Measurements are based on a unit of measurement that is expressed via numerical values. They rely on collecting and interpreting numerical data, for example, by means of the wide range of statistical methods for analysing numerical data.
– Qualitative Measurements are applied when the collected data are not numerical in nature. Although qualitative data can be encoded numerically and then studied by quantitative analysis methods, qualitative measures are exploratory while quantitative measurements usually play a confirmatory role. Methods of Qualitative Measurement that could be applied to a digital library are direct observation; participant observation; interviews; auditing; case study; collecting written feedback.

The quality domain is very broad and dynamic by nature. The representation provided by this model is therefore extensible with respect to the myriad of specific quality facets each institution would like to model. Quality Parameter is actually a class of various types of quality facets, e.g. those that currently represent common practice.

## 4 Expressing the Quality Domain via Semantic Web Technologies

In order to exploit Semantic Web technologies for enhancing the interoperability of DL we map the above defined quality domain into a RDF model. Within this model we consider a Resource as a generic class sharing the same meaning of resource in RDF [33] where "*all things described by RDF are called resources. [A resource is]* *the class of everything.*" Therefore, a `Resource` represents the class of everything that exists in the DL universe and it is related to the `rdfs:Resource` class.

The resources defined in the quality domain can be represented as *subclasses* of `Resource` and `Concept`. The main classes we take into account are: `Quality Parameter`, `Measure`, `Measurement` and `Actor` as shown in Fig. 2.

All these classes can be related to other classes defined in the *LOD cloud* by using the properties `owl:sameAs` or `schema:isSimilarTo`. For instance, the `Actor` class is the same as the `foaf:Agent` one, defined as "the class of agents; things that do stuff. A well known sub-class is Person, representing people. Other kinds of agents include Organization and Group"[8]; whereas, the `Measure` class is similar to the `basic:Measure` class in the OWL representation of ISO 19103[9] which is defined as a scaled number with a unity of measure. Also the `Quality Parameter` class can be related to an external class by means of the `schema:isSimilarTo` property; as we can see in Fig. 2 it can be related to the `observation:Parameter` class in the OWL representation of ISO 19156 (Observation model)[10].

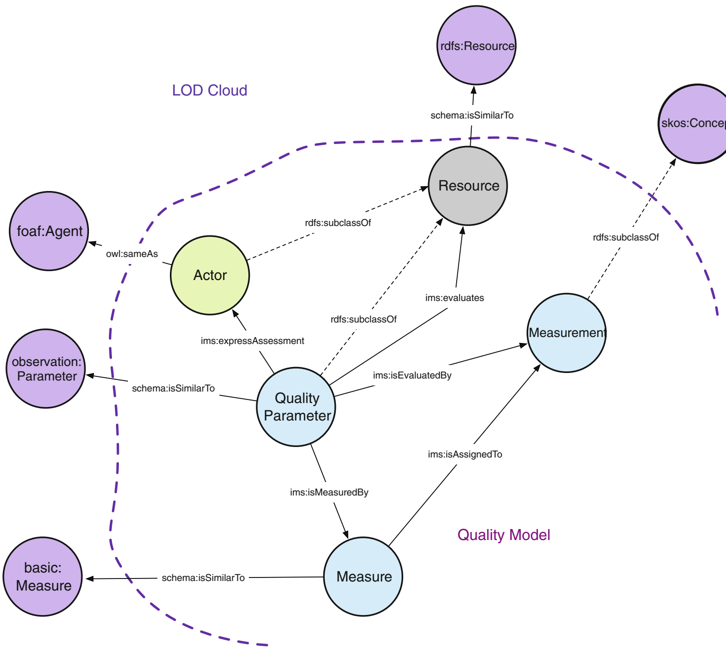


**Fig. 2.** The main RDF classes adopted for representing the quality model of a DL and some relationships with the LOD cloud.

8 http://xmlns.com/foaf/spec/#term_Agent.
9 http://def.seegrid.csiro.au/isotc211/iso19103/2005/basic#Measure.
10 http://def.seegrid.csiro.au/isotc211/iso19156/2011/observation.

`Measurement` can be defined as a subclass of the `skos:Concept` which is defined as an idea or notion, a unit of thought. Usually, `skos:Concept` is used to define the type of relationships in a semantic environment or to create a taxonomy [34,35].

As far as the vocabulary adopted in this model is concerned, we use the namespaces and prefixes reported in Table 1; `ims` is the only vocabulary which is not inherited from other domains and all the classes described above are defined within this vocabulary.

**Table 1.** Namespaces and prefixes adopted in the quality model RDF specification.

| Prefix | Namespace |
|---|---|
| `foaf` | http://xmlns.com/foaf/spec/ |
| `ims` | http://ims.dei.unipd.it/ |
| `owl` | http://www.w3.org/2002/07/owl/ |
| `rdfs` | http://www.w3.org/2000/01/rdf-schema/ |
| `schema` | http://schema.org/ |
| `skos` | http://www.w3.org/2009/08/skos-reference/skos.html |

In Fig. 2 we can see that the classes are related one to the other with properties defined by the `ims` vocabulary and that are the straightforward mapping of the labels of the relationships connecting the entities in the concept map drawn in Fig. 1.

As described in Sect. 3 both the `Quality Parameter` and the `Measurement` classes are specialized into several other classes defining two taxonomies. We can define these taxonomies by exploiting two properties of the `skos` vocabulary: `skos:broader` and `skos:narrower`. Given two resources, say `A` and `B`, then `A skos:broader B` asserts that `B` is a broader concept than `A`; whereas, `A skos:narrower B` asserts that `B` is a narrower concept than `A`. In Fig. 3 we show

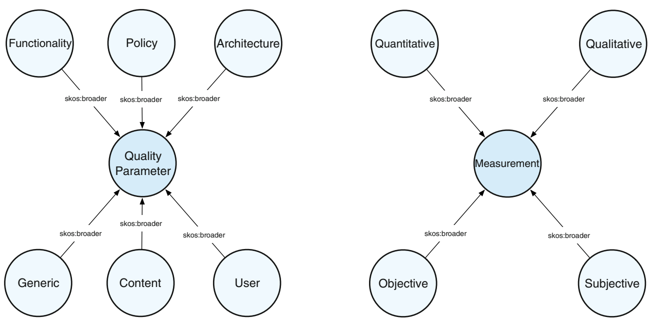


**Fig. 3.** The RDF representation of the taxonomies of the the `Quality Parameter` and the `Measurement` classes.

the two taxonomies defined for the `Quality Parameter` and the `Measurement` classes, where we report only the `broader` property given that `skos:broader` is `owl:inverseOf` of `skos:narrower` by definition.

We can see that this RDF representation allows us to express the quality domain of a DL by means of an RDF model, thus enabling the very interoperability promoted by the Semantic Web technologies. The model we define is easy to extend by adding new classes to the `Quality Parameter` and the `Measurement` taxonomies or connecting the classes with those defined in external vocabularies and ontologies.

## 5 Final Remarks

In this paper we discussed the need for a semantically-enabled representation of foundational DL models. This would allow for a deeper form of interoperability among DL systems and a better convergence in the context of *Libraries, Archives, and Museums (LAM)*. Moreover, it would open up the possibility for improved automatic processing and exchange of information resources among DL systems. In the paper, we have provided an example of what we would like to see embodied at a larger scale for full DL models, namely a semantically-enabled representation of the quality domain within the DELOS Reference model.

As future work we want to extend the unified model proposed for the quality domain to the whole DELOS Reference model by proving a general and extensible RDF model for enabling deeper interoperability among DL systems and lower the barriers between LAMs [4]. We also plan to exploit this semantically-enabled representation of the DELOS Reference model to bridge towards the common concepts shared with the 5S model, thus enabling a better understanding of DL systems built on these two different models [3,10].

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