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Product Lifecycle Metadata Harmonization with the Future in OAIS Archives

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Abstract

Metadata plays a crucial role in supporting the discovery, understanding and management of the large product data collections generated throughout all phases of the product lifecycle. Product data models are annotated with metadata which represent meaning in conformance with evolving metadata schemas while, for business, contractual and legal reasons, these semantically enriched models are ingested into OAIS (Open Archival Information System) based archives for later reuse. Notably, it is not uncommon for a product service provider to operate products for several decades; even after the engineers whose embodied knowledge supports their operation retire or leave the company. This product longevity and volatile knowledge, alongside rapid technological innovations and evolving metadata schemas, require that special preservation processes be used to keep the archived product data and metadata interpretable. While preservation of the data is concerned with product data model normalization, validation and file format migration, the preservation processes for metadata are of a different nature given that referenced schemas evolve independently from the products they describe. Although widely referenced, the OAIS reference model unfortunately does not observe metadata schema versioning or metadata harmonization in any depth. This paper therefore aims to introduce dedicated metadata preservation functionality into OAIS archives, based on operational schema update processing.

Keywords: Long-term Preservation; OAIS; RDF; Linked Schema; Metadata; Product Lifecycle Management, Interoperability; Harmonization

1. Introduction

Before information technology found widespread use within the economy and wider society, libraries and archives fulfilled, with relative ease, the role of culture heritage archivists and preservers. Preservation of tangible objects such as books and manuscripts generally implied the careful control of storage environments, usage and access. In the digital age, archiving processes have changed. If an author takes his work as a word processed document on a DVD to a library, in order to safely archive it, it is far from certain that the document or its medium will be usable 50 years later; for example, data might become corrupt, DVDs might be unsupported and unplayable, and the document file format may evolve without support for older versions. The preservation of digital objects necessitates their active modification.

Digital object preservation is a complex task because over decades, or even centuries, archived objects face many threats like those listed above (i.e. the obsolescence of media, file formats, hardware and software). Special long-term digital preservation systems seek to ensure the continuous accessibility of archived objects via transformation, migration or emulation. Implementations of such systems are often based on the OAIS (Open Archival Information System) reference architecture, which provides a common vocabulary and data model, as well as an outline of essential archival functionalities and responsibilities, facilitating more consistent thinking among practitioners (CCSDS, 2002).

Although long on the agenda of libraries and archives, long-term digital preservation has only recently become a topic for other industries reliant on information technology to support the management of products and services. For example, the preservation requirements of the design and engineering domain (airplane and automobile manufacturers, architects and design firms) are

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being addressed by the EU-funded SHAMAN project (SHAMAN, 2009). Important business (e.g knowledge reuse), legal (e.g. product liability) and contractual requirements imply the implementation of long-term digital preservation processes (Heutelbeck, 2009). To meet these requirements, product lifecycle data has to be archived and preserved for long time periods - which is not as easy as it sounds in a domain with a huge amount of heterogeneous product data. In addition, product data models tend to contain a large quantity of annotations that contribute valuable metadata for search, retrieval and understanding of the product data.

This metadata and related metadata schemas must be preserved in order to fully reuse, access and understand the complete set of product lifecycle data. Although several existing projects examine long-term preservation in the engineering domain, these concentrate on addressing format obsolescence or on the preservation of geometry data, while obsolescence of metadata is not studied in sufficient detail (Brunsmann, 2011). Yet metadata schema versioning and schema exchange result in syntactic and semantic heterogeneity, which poses a threat to future interoperability. This paper offers a timely and vital characterization of metadata harmonization methods which enable semi-automated long-term preservation of product lifecycle metadata in OAIS based archives.

The remainder of the paper continues in the next section with a characterization of product lifecycle metadata and gives relevant metadata usage scenarios. Section 3 describes the existing metadata preservation functionality in OAIS archives and section 4 presents extensions of OAIS archive functionality for metadata preservation that includes processing of operational metadata schema updates. The last section concludes with a discussion and a description of future work.

2. Product Lifecycle Metadata

The design and engineering domain includes a variety of sectors such as aerospace, computer, defense, automotive, medical, chemical, telecommunication, electronics, energy, architecture and shipbuilding. These sectors typically use *Product Lifecycle Management* (PLM) tools to integrate processes, systems, resources and data that are all used for maintaining the lifecycle of a product. This lifecycle includes phases like product ideation, design, manufacturing, service and recycling (Kiritsis, 2010). Data that is created during these phases is stored in special repositories according to customizable product data models.

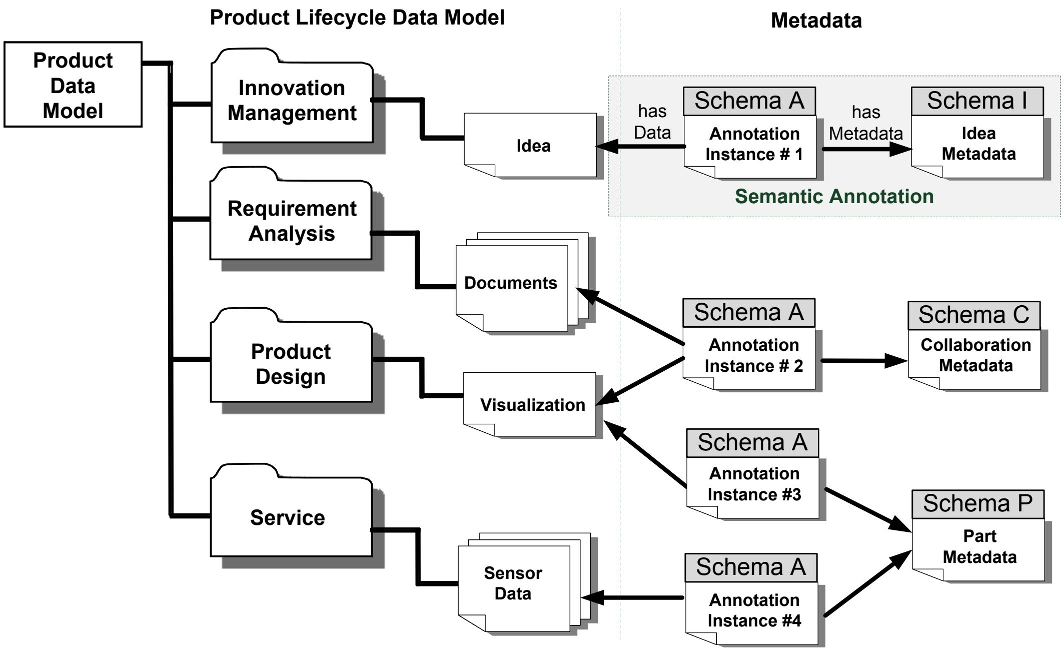

FIG. 1. A Product Data Model with Annotations and Metadata

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Along all product lifecycle phases, different agents (e.g. human actors, computers and sensors) collaborate across countries, enterprises, domains, time and technologies to produce valuable metadata (Jun, 2007) that is linked to the product data model by means of annotations (see figure 1). Annotation instances (conforming to a special annotation schema) contain date, author etc. as well as references to data and metadata. An annotation instance together with a metadata instance builds a semantic annotation that adds meaning to specific product model entities. Annotation instances can be referenced more than once and can be edited separately from data and metadata which makes it possible to preserve data and metadata separately.

Specific domain metadata schemas make meanings shared by particular communities explicit and help agents (humans, machines) to communicate precisely by defining common domain concepts. In addition, schema vocabularies enable faceted semantic search for annotated product data entities. Therefore, the semantically enriched product data models are suitable for exploitation during later reuse in subsequent product lifecycle phases. The metadata that is captured along the entire product life cycle is particularly important, since it enables the *discovery, understanding* and *management* of product lifecycle data. Some usage scenarios illustrate these aspects:

Ideation metadata reuse in innovation management by an innovation lab engineer: during the early innovation management phase, engineers discuss and rate their ideas which are tagged with metadata (e.g. business category). Although nearly all of the ideas are not realized, they remain valuable intellectual property that needs to be preserved for possible future reuse. The semantic tags can be used to find an archived idea in order to avoid reinventing the wheel or to identify the reason why an idea was rejected.

Reuse of collaborative design metadata for a product variation by a design engineer: product design engineers exchange rationales regarding decisions by executing collaborative electronic (ECAD) and mechanical (MCAD) design processes. The reasons for rejecting or accepting incremental design change proposals are design rationales and legitimate targets for archiving. The documents of a design review also represent design rationale, because during such reviews arguments and justification are exchanged by expert designers (Brunsmann, 2009). Finally, if a design is changed (e.g. failure report, new requirements), the history of the design is important to document. In all these cases, it is necessary to capture, annotate and archive the design metadata in order to reuse and fully understand the product designs later on (e.g. product variation).

Reuse of service metadata for product and process improvements by an engineer: during product service, human actors (e.g. product owner, mechanics) gain valuable knowledge about the product behavior (Brunsmann, 2011). If such knowledge is annotated as metadata, it can be reused for improvements in product design or manufacturing. In addition, when sensors monitor product (e.g. car) status information in real-time, it can be broadcasted to the manufacturer who could plan efficiently the maintenance scheduling for process improvements (Brunsmann, 2011).

Exploitation of project and provenance metadata during accident examination by an accident investigator: airplanes are in operation for several decades, have extensive maintenance requirements, and tend to suffer technical problems. If unintended malfunctions occur, an accident investigation requires the exploration of all relevant product data to find the reason for malfunction. If it is assumed that the accident was caused by a specific product part, the investigation also includes the questions why, when, and by whom, was the part used and modified? However, over several decades, it is likely that employees have retired or have left the company. Project related metadata assist in this investigation, since it contains a list of project participants including their social networks and their participation in collaboration sessions.

Spare part search of archived product part metadata by a service mechanic: standard product classifications are annotated to product parts as metadata. If a long-life product contains a broken part which is not manufactured anymore, a mechanic has to search for contemporary spare parts. This search for alternative suppliers and manufacturers is based on the archived metadata (e.g. technical requirement specifications).

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These use cases illustrate different important legal, contractual and business motivations for companies to preserve product lifecycle data and metadata. If companies do not take account of such factors, major economic and reputational damage could be the result. Under current practice, organizations tend to "archive" product data on an external storage device, deleting it from their active data repositories when a product reaches its "end of life" - despite the fact that the product is still in operation. It is important to recognize that archived product lifecycle data and metadata can deliver additional value when kept accessible and understandable (Wilkes, 2009). Therefore, the data and metadata has to be preserved in a special long-term archive integrated as a permanently accessible repository and knowledge base within the product lifecycle toolset and process chain. Assuming that relevant archive access interfaces exist and that bit-preservation of data is guaranteed, it is necessary to investigate next the preservation of the *understandability* of data and metadata in more detail.

It is important to note that product data models are usually proprietary, and for competitive reasons, it is common that single vendors will invent non-backward compatible file formats. Therefore, before being ingested into an archive, 3D CAD file formats are normalized to open standard representations (e.g. STEP) with the assumption being that standards change less often than vendor formats (LOTAR, 2011). This paper does not look into preservation of product data in detail; rather, it focuses on the preservation of metadata. The following section evaluates the existing functionalities of metadata preservation in OAIS archives.

3. Metadata in OAIS Archives

In the previous section it was argued that metadata is as important as data since it enables the discovery, understanding and management of that data. Therefore, both data and metadata should archived together (Day, 2005) and wrapped in a single package to support coherence which both are well accepted requirements for libraries. The preservation of content is managed by strategies including emulation and migration (during file format evolution for instance). But in order to keep the data accessible during the operational life of products, special emphasis has to be put on the preservation of metadata during *schema evolution*. This section provides an overview of existing metadata usage and treatment in archives based on the OAIS model.

The OAIS reference architecture defines both a high-level *functional model* and an *information model*. The functional model outlines the functionality which must be provided by a compliant preservation system—access, administration, archival storage, data management, ingest and preservation planning. The data management entity provides all functions required for maintaining the descriptive metadata which identifies archived digital content.

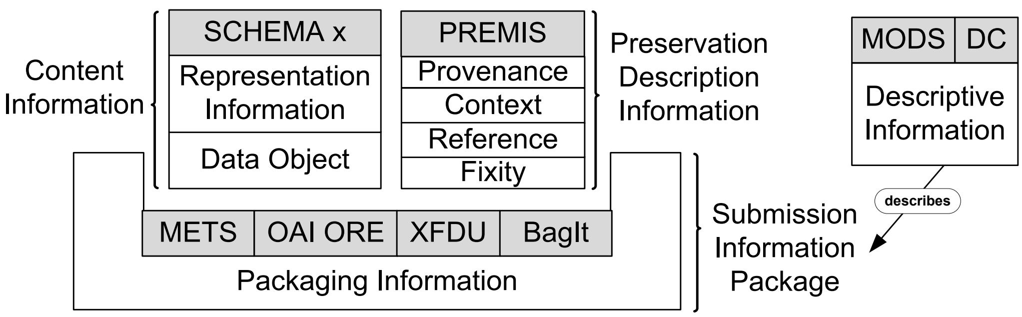

FIG. 2. A Submission Information Package and Standard Preservation Metadata Schemas

The information model defines the information types (both content and metadata) that are required in order to preserve and access the data and provides a high-level description of the information objects managed by the archive. A *Submission Information Package* (SIP) is ingested by a producer into the archive and an *Archival Information Package* (AIP) is generated and then

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stored and preserved by the archive while a *Dissemination Information Package* (DIP) is delivered to the archive consumer. Figure 2 shows a SIP and related standard preservation metadata schemas that are now described in more detail:

Preservation Description Information enables adequate preservation of content information and the PREMIS (Preservation Metadata Implementation Strategies) standard is used to describe provenance (migration logs), context (related data), reference (persistent id) and fixity (checksums) of the content information (Coppens, 2009).

Packaging Information aggregates and identifies the constituents of an information package. Here, METS (Metadata Encoding and Transmission Standard), OAI-ORE (Open Archives Initiative Object Reuse and Exchange), XFDU (XML Formatted Data Unit) and BagIt are used to describe the ingested information package.

Descriptive Information supports the search and retrieval of archived information. MODS (Metadata Object Description Schema) and DC (Dublin Core) are used as metadata schemas. Descriptive metadata may be captured manually or extracted automatically (Marketakis, 2009) by inspecting the data object at data creation or submission time. Descriptive metadata is essential for supporting long-term access requirements for product model data (Lubell, 2009). However, later on in this paper it will be argued that descriptive information without specific domain metadata schemas is not enough to fully explore, understand and reuse product lifecycle data.

Content Information contains the digital object (or, Content Data Object) to be archived and the representation information that, accompanying a digital object, provides it with meaning, allowing for the recreation of its significant properties. Representation information has a recursive nature, since it may contain references to other representation information. It associates high-level meanings with one another and can have complex inter-relationships, building what is termed a "representation information network" (see figure 3). It contains semantic information that needs a fixed schema in order to be understood.

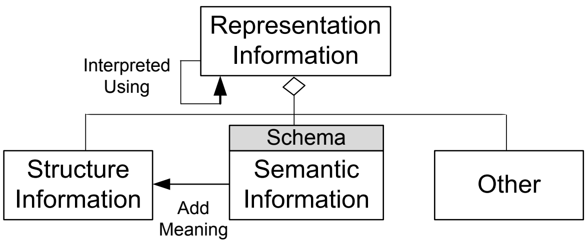

FIG. 3. Representation Information Network and Domain Specific Metadata Schema

Although preservation metadata schemas have mainly been created for the library domain, they are also used for archiving product data models; further, the OAIS model was designed to be applicable to "any archive" or organization with information requiring long-term preservation (CCSDS, 2002). Efforts do exist to create dedicated preservation schemas for product metadata (Lubell, 2010). However, the engineering domain is characterized by a variety of applications, heterogeneous lifecycle data, a diversity of actors, and a multitude of industry sectors. These facts make it very complicated and nearly impossible to define one metadata schema standard that covers all use cases for product lifecycle metadata exploitation. Therefore, it must be assumed that domain specific metadata schemas that are not controlled by the archive are used to annotate product models. These metadata schemas are represented by the semantic information that accompanies the representation information.

3.1. Metadata Schema and Instance Evolution

Preservation metadata and domain specific semantic information conform to metadata schemas expressed in some schema language (e.g. XSD, RDFS) - and most preservation metadata

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standards are described by an XML schema supporting exchange and interoperation. Since metadata schemas model real world phenomena and the real world changes, schemas must also evolve. Metadata formats (syntax) or semantics will change (e.g. schema versioning or switching domain schema entirely). Such schema heterogeneity poses the threat of *semantic obsolescence*; losing the understandability of product lifecycle data and metadata. Thus, the preservation of metadata is as important as the preservation of data.

Metadata schema and instance evolution concerns both preservation metadata schemas and domain-specific metadata schemas, which are also expressed in different languages. Most often, new schema versions do not break backwards compatibility (e.g. adding a class or property). However, sometimes real world changes do demand the creation of non backward compatible changes (e.g. deleting a class or property). In domain schemas that model product catalogues for instance, (Hepp, 2007) schema changes are very frequent. Metadata schema engineers should be supported in documenting the consequences of changes and operational updates should be derived accordingly. For example, if a property is renamed, a change set could be created which help renaming of the property in all existing instances stored in a knowledge base.

Some work has already been done on establishing metadata preservation techniques but generally lack completeness: (Lee, 2007) focuses on changing descriptive metadata without taking schema updates into account, (Day, 2003) introduces schema registries into digital preservation systems and (Shaon, 2008) describes conceptual extensions of OAIS archives without considering practical methods for achieving metadata preservation during metadata schema evolution. The next section builds on this work by presenting how to implement metadata harmonization by means of normalization, transformation, migration and query rewriting.

4. Metadata Harmonization in OAIS Archives

As defined in (Nilsson, 2010), *harmonization* is "the ability of two or more systems or components to exchange combined metadata conforming to two or more metadata specifications, and to interpret the metadata that has been exchanged in a way that is consistent with the intentions of the creators of the metadata". In this paper, metadata harmonization across time is regarded as the continuous processes that guarantee the correct long-term understandability of both ingested content and metadata for consumer access both now and in the future. This section describes the integration of necessary harmonization functionality in OAIS archives.

The usage of metadata schemas for annotating archived digital content ensures consistent entity labeling. If archives and accessing software agree on using the same metadata schema, they are able to interoperate. However, if archives use different schemas or different versions of the same schema, interoperability is in danger. Therefore, (Alemu, 2011) gives an overview of four different approaches to enable metadata interoperability in digital libraries. Archives that contain metadata harmonization functionality must be able to handle different and previously unknown metadata schemas (domain as well as preservation schemas) and different schema versions.

As described above, several motivations exist to archive annotated product data models. These semantically enriched models contain metadata expressed as references to RDF based vocabulary instances. If the metadata schemas evolve, the archived product data is in danger of becoming obsolete because the metadata might not be interpretable anymore with current schemas. Since the aim of digital archives is maintaining the accessibility of the content across time, the accompanying metadata must be preserved. Therefore, special functionality needs to be added to OAIS archives that will enable harmonization of archived metadata with the future.

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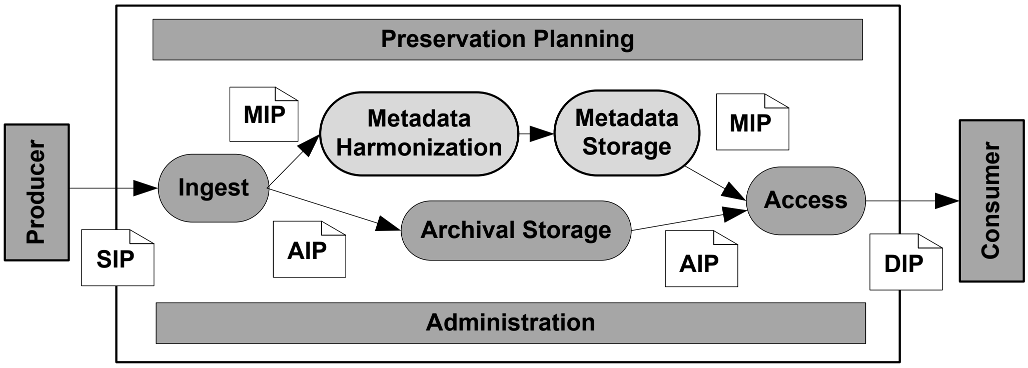

FIG. 4. OAIS Functional Entities with Dedicated Metadata Harmonization

The original architecture of the OAIS functional model splits the SIP into an AIP and descriptive information. Since it is not predictable which metadata will be available when a product data model is ingested into the archive, this paper proposes a special metadata harmonization functional entity and metadata storage that are marked as light gray in figure 4.

The *metadata harmonization entity* handles all descriptive, preservation and domain metadata that is included in the SIP. Therefore, the ingest functionality will divide the SIP into an AIP and a MIP (Metadata Information Package). In order to do so, the ingest functionality could parse the file types of the ingested data collection or could demand that all metadata is stored in a special sub folder of the SIP. The MIP is delivered to the metadata harmonization entity that processes and manages the MIP (see below) and finally stores it in a special metadata store.

The *metadata storage entity* provides the functionality for the storage and querying of MIPs and associated metadata schemas. It receives the MIP and metadata schema updates (MSU) from the metadata harmonization and it provides the MIP to the access functionality entity in order to create a DIP. If a consumer queries or accesses the archive, the metadata harmonization functionality translates queries or transforms the metadata. Metadata can be stored and referenced in different ways (Prasad, 2009). In this paper it is assumed that the metadata and the schemas are stored within the archive using the metadata storage entity.

Figure 5 shows the metadata harmonization functionality entity in more detail:

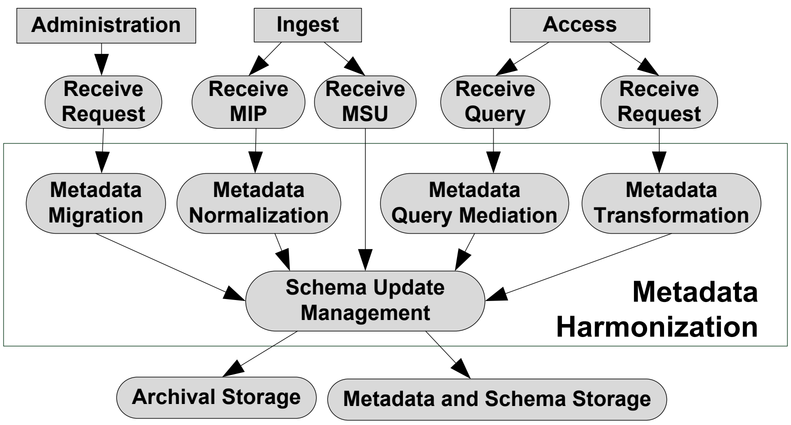

FIG. 5. Metadata Harmonization Functionality

Metadata normalization: metadata conforming to a global (externally maintained and independently evolving) schema can be normalized into metadata conforming to a local schema which makes preservation more controllable.

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Metadata transformation: during access, the transformation carries metadata conforming to schema X into metadata conforming to schema Y upon request by the consumer. For this transformation, archived metadata schema updates can be exploited.

Metadata query mediation: instead of the metadata, an incoming query is rewritten so that it conforms to the archived schema. The result set must also be processed for correct interpretation.

Metadata migration: upon request from the administration entity, metadata can be migrated so that if conforms to a new version of the same metadata schema.

Metadata schema update management: when metadata schemas evolve, MSUs can be identified and then be used to migrate the archived metadata, to rewrite a query or to transform the metadata at request time.

The MSUs must be captured and edited carefully. The following requirements can be identified while considering practical engineering of operational metadata schemas updates:

Capture rationale of collaborative domain experts during schema engineering: metadata schemas and associated schema mappings are created and modified by one or more domain experts after a collaborative decision finding process. The agreed upon rationale of the change should be captured, so that consumers of the MSU are able to understand the change semantics.

Release specific schema versioning: the release planning for schemas should include the notion of major releases, minor releases and service packs. The changes that are allowed in such specific releases are different in their consequences and in their frequency. For example, version 5.1.2 denotes the fifth major release (every 3 - 4 years), the first minor release (once or twice a year) and the second service pack. Translations and corrections of clerical errors belong to a service pack, the addition of a class belongs to minor release and changing a class hierarchy is a major release since the latter is a non-backward compatible change.

Change semantic oriented schema engineering: complex schema modifications like moving a class in a class hierarchy include atomic operations like the deletion of the class and adding a new class. These atomic operations should be aggregated into one transaction whose semantic is easy to understand by consumers of schema modifications.

On-the-fly schema mapping generation: if a new version of a metadata schema is derived, all existing mapping can be reused for the new version. If the change semantic is known, new mappings can also be created automatically.

Operational schema mappings: if schema mappings are pushed to interested clients, they can be used to execute relevant schema and data migrations (semi-)automatically after inspection. Alternatively, they could be archived for later use or they could be pulled by clients on demand.

All of the schema engineering requirements and the implementation of metadata harmonization functionalities are based on operational *linked schema* assertions. While *linked data* (Bizer, 2009) follows the principle that web resources are identified with interlinked resolvable HTTP URIs expressed by the Resource Description Framework (RDF), linked schema maps classes and properties that are semantically similar. In figure 6, bidirectional dotted arrows visualize similarity on the schema (*ls:isSimiliar*) and model (*lm:isSimiliar*) level, whereas on the data level it visualizes linked data identity (*owl:sameAs*). As the M3 Meta Meta Model layer is not applied in this paper, it is not shown in figure 6. In addition, the namespaces for similarity (*ls;* and *lm:*) are fictional and currently lack a specific vocabulary definition.

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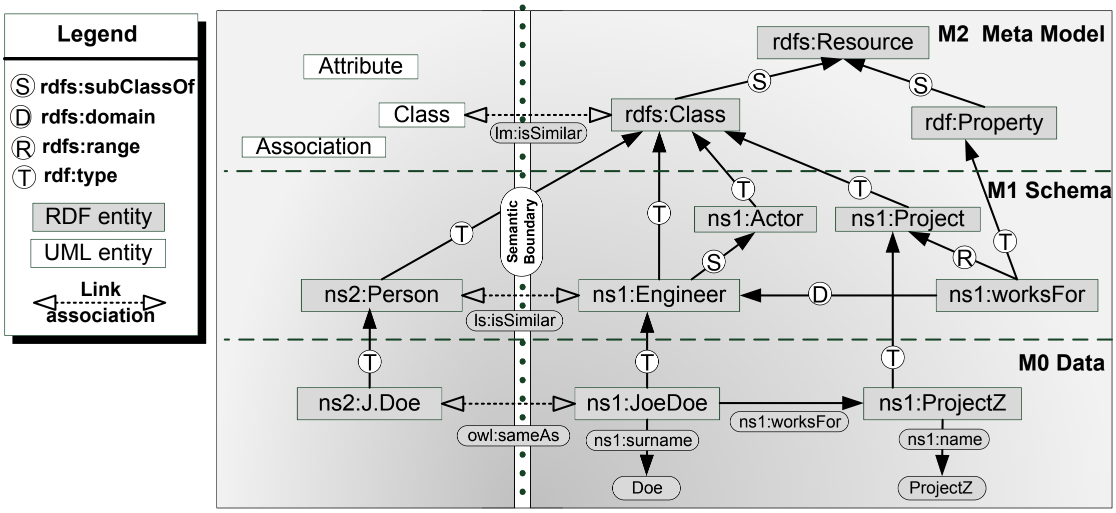

FIG. 6. Metadata Levels, Linked Data, Linked Schema and Linked Meta Model

Linked schema can be used to map between versions of schemas and to map between different domain schemas. These mappings can be exploited as MSU during metadata harmonization in long-term archives. As linked data is an instance of a schema, a schema is an instance of a model (Haslhofer, 2010). In consequence, a schema element could also be ready for dereferencing to provide a provenance of queried metadata schema elements (e.g. the history of a schema class or property). In combination with the Memento Content Negotiation (Coppens, 2011), schema information could also be exploited for other machine reasoning use cases. For example, a suitable system architecture could make use of either pulling or pushing linked schema updates. Schema updates could be pushed actively to archives or other registered clients. Alternatively to schema update propagation, the archive could check for schema updates and pull them on demand (e.g. during migration and transformation).

5. Conclusion and Outlook

This paper presented extensions to OAIS archive functionality that help ensure the harmonization of currently-existing metadata repositories with future requirements and obligations for data and metadata preservation, placing particular emphasis on preservation within the engineering domain. Such harmonization across time is needed for maintaining the understandability of product lifecycle metadata that is threatened by the evolution of metadata schemas and instances as well as the exchange of domain schemas. This semantic heterogeneity must be managed by operational schema mappings that define similarity relationships between schema elements. Special schema engineering methods already exist to help create and maintain these linked schemas (Nikolov, 2010; Haslhofer, 2010), the definitions of which require, in turn, their own vocabularies (Bizer, 2010).

Future work will include the specification of an operational metadata harmonization vocabulary taking into account the fact that metadata will not only be formulated in RDF based vocabularies but also in RDBMS DDL and XML schema (e.g. standard preservation metadata). To accomplish this, the methods presented in (Hartung, 2011) will need to be evaluated in relation to other kinds of metadata schema. Further, based on archived domain schemas, a semantic exploration of product data models will be implemented that also respects schema and instance evolution by exploiting operational schema mappings.

Future work also concerns the system architecture, since the functionality described was integrated into one operational archive. Whether metadata storage functionality would be better modeled as a separate archive, is also worthy of investigation. Given this architecture, it can also

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be evaluated if and how these harmonization concepts can be applied to websites hosting linked data and relevant schema definitions. Finally, while linked schema help to overcome semantic heterogeneity, linked model definitions might be used for resolving syntactic heterogeneities.

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