

A Meta-Relational Approach for the Definition and Management of Hybrid Learning Objects

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ABSTRACT

Electronic learning objects (LOs) are commonly conceived of as digital units of information used for teaching and learning. To facilitate their classification for pedagogical planning and retrieval purposes, LOs are complemented with metadata (e.g., the author). These metadata are usually restricted by a set of predetermined tags to which the classification schema must conform (e.g., IEEE LOM). In our experience, certain complex LOs need to be complemented with different types of domain-dependent information for their pedagogical planning and retrieval: (i) classification metadata for enhancing contextualisation, search and retrieval (e.g., the tagged structure of an archaeological site where an archaeological object has been found) and (ii) additional data that can enrich the LO (e.g., the weight and other dimensions of an archaeological artifact described in a podcast). We refer to LOs enhanced with domain-dependent information as hybrid learning objects (HLOs). However, most learning object repositories (LORs) only permit a predetermined, fixed set of metadata attributes to be used in the classification of LOs. This rigidity is inappropriate when domain-dependent information schemas are used for the browsing, retrieval, and domain-specific pedagogical sequencing of HLOs. Thus, custom software applications are needed to manage LOs that must be tagged with information belonging to specific domains. This paper presents a theoretical approach that permits the use of a single LOR for classifying and enriching LOs according to domain-dependent information schemas, which can be dynamically changed after their definition. The key issue in our approach is the presence of a meta-relational model for the dynamic definition of specific domain-dependent relational database schemas used for classifying and enriching LOs.

Keywords

Learning object repository, Metadata, Domain-dependent information schema, Classification

Introduction

In recent years, e-learning and LOs have significantly impacted education. According to Hodgins (Cisco, 1999), LOs are “a collection of content items, practice items, and assessment items that are combined based on a single learning objective.” LOs are built with the aim of being reused in various learning environments as pieces that can be assembled to create new LOs (Wiley, 2000). Although LOs have been criticised (Polsani, 2003), they increase the benefit that can be derived from the creation of high-quality learning resources (Gibbons et al, 2000).

To facilitate their use, LOs are stored in learning object repositories (LORs) (Tzikopoulos et al., 2009). These repositories often use a fixed set of metadata, such as IEEE LOM (IEEE, 2002), for classifying, retrieving, and building pedagogical sequences of LOs (Neven & Duval, 2002).

However, these repositories are not suitable for creating highly specialised LO collections. This type of LO collection is usually created and used in university’s virtual campuses by communities of teachers and students working within a knowledge domain and having specific educational and research needs. These communities use shared terminology to represent and search their LOs, need to describe the specific features of their LOs, and prefer to define their own organisational and navigational schemas to be compatible with their didactic models.

Thus, in these contexts, traditional LOs must be complemented with domain-dependent information that can be used as (i) classification metadata for enhancing scientific characterisations, searches, and retrievals (e.g., the tags used in an archaeological site to describe the structure of the cultural context where an archaeological object has been found)

and (ii) additional data that can enrich the LO (e.g., the weight and other dimensions of an artifact described in a podcast). We refer to LOs enhanced with domain-dependent information as *hybrid learning objects* (HLOs). To some extent, this domain-dependent information acts as both metadata, because it enables a user to browse an LO based on non-intrinsic information, and data, because it enriches LOs with intrinsic information regarding the item to which the LO refers. The question of whether to refer to such information as data or metadata is a metaphysical question that is outside the scope of this paper. Therefore, for HLOs, we use the term “domain-dependent information” instead of “data” or “metadata.” This domain-dependent information is structured using domain-dependent information schemas.

Figure 1 depicts the difference between a regular LO and a hybrid LO. The regular LO has an authoring process and is then tagged with a fixed set of metadata that are used to retrieve it (Figure 1.a). Once retrieved, these metadata are not used. However the authoring process of an HLO includes the definition of a domain-dependent information schema used to enhance the LO with specific contextual knowledge and data (Figure 1.b). The retrieval engine takes into account this variable domain-dependent information schema when searching the HLO. In addition, when retrieved, the domain-dependent information is used as content for the LO.

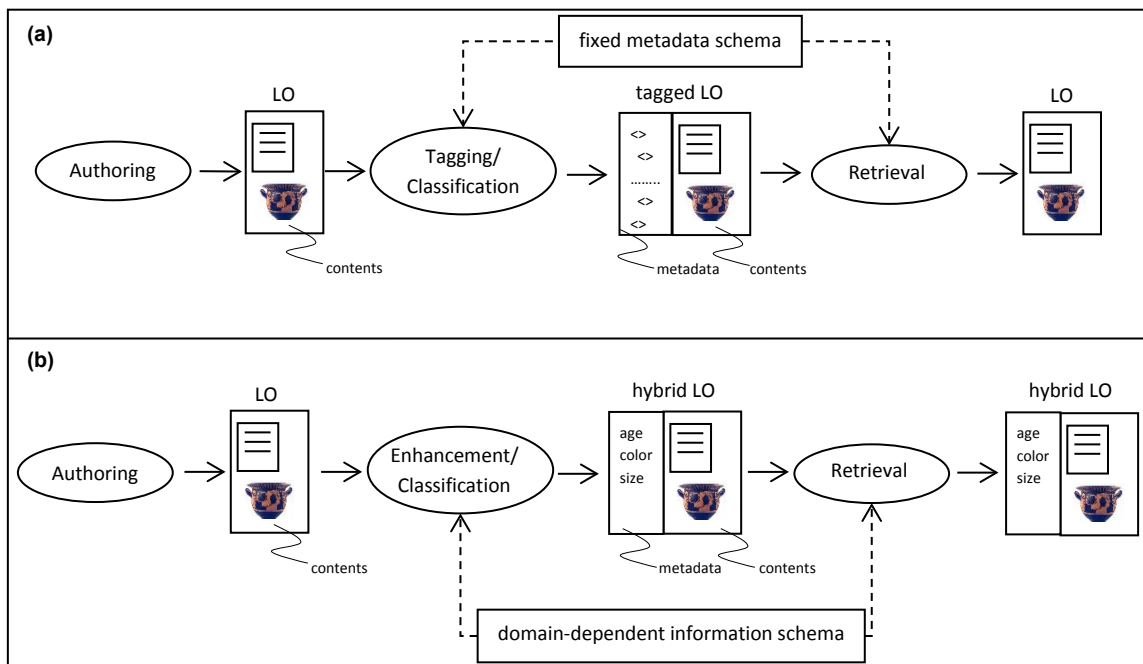


Figure 1. (a) In a regular LO, metadata are only used for retrieval purposes, and metadata schemas are fixed. (b) In a hybrid LO, domain-dependent information-schemas are used for both retrieval purposes and LO enhancements

However, HLOs present an important drawback: because domain-dependent information schemas vary from domain to domain (e.g., from archaeology to philology), specific repositories that enable the browsing and retrieval of HLOs according to all information schemas must be constructed for every case. This is an important disadvantage with regard to classic LO repositories (Ariadne, 2011; Merlot, 2011). These repositories do not permit the presence of domain-dependent schemas for browsing and retrieval, but they can be used for different LOs tagged according to a common metadata schema (IEEE LOM, 2011; DC, 2011; ISO/IEC MLR, 2011).

To overcome this problem, we have defined a meta-relational approach that permits the use of a single repository for different domains. Thus, the repository permits the definition of domain-dependent information schemas that can be used for both browsing and enriching the HLO. A previous version of the HLO approach was presented as virtual objects in Navarro et al., (2005) and Sierra et al. (2006). However, virtual objects are not supported by a strong theoretical model that defines the way in which relational databases can be dynamically defined in a single repository to characterise domain-dependent information. Thus, the domain-dependent information that was included in these virtual objects was much less structured, which forced the user to manually enforce the integrity restrictions. For example, if a painting was painted by an author, and this author was deleted, the painting had a reference to a null

author. Furthermore, it was not possible to import/export the domain-dependent information used to enhance the virtual object to or from a relational database because the underlying relational database schema was not explicitly codified in the virtual object model. We found the import feature very useful because, before many users started using our LOR, they used some type of relational database to structure their domain. Finally, the lack of a well-defined theoretical model made maintaining the LOR responsible for the management of virtual objects a complex task, which limited the understanding and evolution of the LOR.

Domain-dependent information schemas can be defined by communities of users, or they can be standardised in some domains. In both cases, specific LORs must be built for HLOs belonging to specific domains (e.g., archaeology vs. philology). With the approach presented in this paper, a single repository can be used to manage HLOs belonging to different domains and enriched with different domain-dependent information schemas. The need for single information schemas for specific domains and the use of different information schemas for the same domain are complex issues. In some cases, this results in the formation of information schemas by the aggregation of other information schemas or the presence of mappings that translate one information schema into another (Santacruz et al. 2010). This paper does not discuss the definition of one or several information schemas for structuring a specific domain; rather, it addresses the question of how to codify any information schema, which can be standardised or customised for a specific domain, into a single tool that can be reused across different domains.

In addition, in our experience, these schemas, once defined, can dynamically vary with time. Thus, after a specific schema for the archaeology domain is defined, this schema can be changed to include information about the country where the artifacts were found or about the artifacts' composition. Thus, it would be desirable to have an approach that enables dynamic modification of the underlying domain-dependent information schema.

This paper focuses on the theoretical approach that underlies HLOs. Section 2 describes previous studies related to LORs and highlights the advantages of our approach. Section 3 briefly describes Oda (Oda is a Spanish acronym that stands for *Objeto de Aprendizaje*, i.e., Learning Object), our custom LOR for HLO management. Section 4 provides a brief introduction to meta-modeling and describes the meta-relational level used in our approach. Section 5 describes the theoretical approach for managing HLOs. Finally, Section 6 presents conclusions and future work.

Related work

This section compares the characteristics of our Oda LOR with two LOR samples, ARIADNE and Merlot, and three open-source software applications for managing and accessing digital content, DOOR, DSpace, and Fedora. These are some of the most widely used software applications for managing LOs.

- *Ariadne* is a European association that has developed an open and scalable architecture based on standards for managing LOs in distributed repository networks (Ariadne, 2011). Currently, the Ariadne repository contains over 620,757 LOs. When GLOBE providers are included, this number is approximately 900,000 (GLOBE, 2011).
- MERLOT (Multimedia Educational Resource for Learning and Online Teaching) (MERLOT, 2011) is a well-known and recognised international LOR. It stores learning materials, learning exercises, comments, personal collections, and content builder web pages, designed to enhance the experience of using learning materials (Cechinel et al., 2010). Currently Merlot, a member of the GLOBE consortium, contains over 30,650 LOs. These characteristics make MERLOT an excellent LOR example.
- DOOR (Digital Open Object Repository) (DOOR, 2011) is an open-source application for creating LORs. DOOR permits users to search for, retrieve, and include LORs in courses or instructional units. DOOR is released under GPL.
- DSpace, an open digital repository (DSpace, 2011), is, together with Fedora, one of the largest open-source software applications for managing and providing access to digital content. Although DSpace is not a repository of LOs, it has been successfully used as such (Waller & Strunz, 2010).
- Fedora (Flexible Extensible Digital Object and Repository Architecture) was originally designed in 2001 at Cornell University and the University of Virginia as an open-source project (Staples et al., 2003). Fedora has a large international user community and is installed worldwide. It is a general digital content management system that supports the creation of LORs. Fedora provides a model for complex digital objects and an XML standards-based repository for managing and accessing them. The repository has a well-defined software architecture, and most of its services are presented as SOAP web services (Hansen, 2007).

- OdA LOR is our online database application designed for the definition and management of HLOs. OdA provides teachers, researchers, and students with a simple and flexible tool to disseminate their educational and research materials. Its primary goal is to treat the dynamic definition of domain-dependent information schemas used to enrich traditional LOs and thus transform them into HLOs.

These applications are powerful tools for managing traditional LOs, but, except for OdA, we have found them to be inappropriate for the dynamic definition of domain-specific information schemas for the browsing and enriching of LOs. They do not support the definition of these schemas, and most of these tools use standard metadata schemas (e.g., IMS LOM) that cannot be redefined by the user. Fedora is the only exception because it permits the definition of domain-specific information schemas. However, unlike our approach, it does not permit the dynamic modification of these schemas.

Table 1 compares OdA with the previously mentioned applications based on five characteristics:

- *Fixed metadata schema.* Presence of a fixed metadata schema for the classification of LOs.
- *Domain-dependent information schema.* Capability for dynamically defining domain-dependent information schemas for both browsing and enriching LOs.
- *Dynamic redefinition of information schema.* Capability for redefining a domain-dependent information schema.
- *Compound objects.* Presence of complex LOs, formed by the aggregation of other LOs defined in the LOR.
- *Import/Export.* Import/export capabilities according to some recognised standard (i.e., IMS CP [IMS, 2003]).
- *LMS integration.* LMS users can directly search the LO collection. In some cases, users can import the LO into the LMS and publish it.

The table shows that the most widely used LORs, Merlot, and ARIADNE, are based on a simple and fixed LO model. Consequently, their capacity to represent and manage highly specialised and complex HLOs is limited. Fedora uses proprietary standards, while OdA can use any metadata model when it is defined as a domain-dependent information schema.

Among the software applications used to create LORs, Fedora and OdA are the only tools that can define domain-dependent classification schemas for the management of HLOs. However, in Fedora, the LO model cannot be dynamically changed once the repository has been created. In addition, Fedora requires a substantial amount of installation and maintenance support because it is designed to create large institutional digital object repositories. In contrast, OdA has been designed for the dynamic creation and maintenance of HLO collections. OdA can deal with different domain-dependent information schemas, allowing their dynamic redefinition as needed. Thus, the same repository can handle different LOs that belong to different domains. In addition, it can be installed easily and quickly, which is crucial if IT resources are limited. Thus, OdA has been widely tested in different knowledge domains at the Universidad Complutense de Madrid (UCM) by teachers, researchers, and students.

Only DSpace, Fedora and OdA allow the presence of compound LOs formed by the aggregation of other LOs. This is a key issue in OdA because HLOs often reference other HLOs that have been deployed.

All the analysed applications permit the import and export of LOs. Fedora uses its own proprietary format, and OdA allows the import and export of IMS CP.

Finally, only Ariadne, Merlot, and DOOR permit integration with LMSs. This feature enables users to search for LOs in the LOR. The LOs can then be automatically published in the LMS. In future versions, OdA will be integrated with different LMSs.

Table 1. Comparison of LO repositories and digital content management systems

Repository/Feature	(i) Fixed	(ii) Domain	(iii) Dynamic	(iv) Compound	(v) Import/Export	(vi) LMS
Ariadne	✓	✗	✗	✗	✓	✓
Merlot	✓	✗	✗	✗	✓	✓
DOOR	✓	✗	✗	✗	✓	✓
DSpace	✓	✗	✗	✓	✓	✗
Fedora	✓/✗	✓	✗	✓	✓/✗	✗
OdA	✓/✗	✓	✓	✓	✓	✗

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- (i) Fixed metadata schema
 - (ii) Domain-dependent information schema
 - (iii) Dynamic redefinition of information schema
 - (iv) Compound objects
 - (v) Import/Export
 - (vi) LMS integration
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The OdA Hybrid LO Repository

The OdA LOR has five main modules that permit the management of HLOs:

- The HLO authoring module allows domain-dependent database schemas and domain-dependent information that complements the HLOs to be defined. Only the super administrator has access to this module.
- The HLO presentation module allows HLOs to be published, searched, and browsed. Using the dynamically defined domain-dependent information schema, different types of browsing and searching can be performed. Only super administrators and administrators have access to the publication feature of this module. The registered info seekers have access to HLOs that the administrator has declared not accessible to the general public.
- The OdA export module is designed to export and import HLOs. Two types of export are allowed: (i) domain-dependent relational database export and (ii) HLO export of the LO to another repository or platform using a content packaging specification. Currently, only IMS Content Packaging export is supported. Super administrators and administrators, with some restrictions, have access to this module.
- The repository access control module manages user roles, including super administrator, administrator, and registered info seeker, repository access permissions, authentication, and HLO privacy features. Only the super administrator has access to this module.
- The persistence module houses application data based on the domain model in Section 5.

To support the definition and use of an HLO, three steps, which often comprise an iterative authoring process, must be performed using the authoring and presentation modules: (i) the domain-dependent information schema is defined by the super administrators; (ii) the domain-dependent schema is instantiated by administrators; in this step, the digital files that compose the LO are uploaded and the data are completed in accordance with the domain-dependent schema; and (iii) info seekers browse the HLOs using the domain-dependent information schema.

Following step (i), let us suppose that we are working with HLOs related to the domain of archaeology. The archaeologists decide to use a specific domain-dependent information schema. The information schema chosen by the archaeologists is depicted in Figure 2. This simplified domain model illustrates the remainder of the presentation.

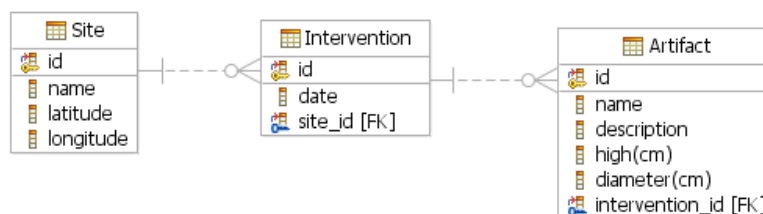


Figure 2. Simplified relational database schema for an archaeological site

This figure shows the definition according to the relational model of three interrelated tables: a `Site` that can have different `Interventions` where different `Artifacts` have been found. Once this schema has been defined as a domain-specific model for the HLO information schema, the user can define the HLO information schema based on the columns of these tables such as `Site.name`, `Intervention.date`, `Artifact.name`, `Artifact.high(cm)` and `Artifact.diameter(cm)`.

Using the OdA authoring module, the tables and columns depicted in Figure 2 are defined using the meta-relational model codified in OdA (Figure 3). Users must manually define these columns in the current version, but a graphical interface for defining this meta-relational model using relational schemas such as the one depicted in Figure 2 is planned for enhancing user experience.

Nombre Sección	Orden	Navegable	Visible
Modelo de Datos			
Tipo Colección	↑ ↓	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
Descripción	↑ ↓	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Archeological Objects	↑ ↓	<input checked="" type="checkbox"/>	<input type="checkbox"/>
Site	↑ ↓	<input checked="" type="checkbox"/>	<input type="checkbox"/>
id	↑ ↓	<input checked="" type="checkbox"/>	<input type="checkbox"/>
name	↑ ↓	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
longitude	↑ ↓	<input type="checkbox"/>	<input type="checkbox"/>
latitude	↑ ↓	<input type="checkbox"/>	<input type="checkbox"/>
Intervention	↑ ↓	<input checked="" type="checkbox"/>	<input type="checkbox"/>
id	↑ ↓	<input type="checkbox"/>	<input type="checkbox"/>
date	↑ ↓	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
site_id	↑ ↓	<input type="checkbox"/>	<input type="checkbox"/>
Artifact	↑ ↓	<input checked="" type="checkbox"/>	<input type="checkbox"/>
id	↑ ↓	<input type="checkbox"/>	<input type="checkbox"/>
name	↑ ↓	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>
description	↑ ↓	<input type="checkbox"/>	<input type="checkbox"/>
high(cm)	↑ ↓	<input type="checkbox"/>	<input checked="" type="checkbox"/>
diameter(cm)	↑ ↓	<input type="checkbox"/>	<input checked="" type="checkbox"/>
intervention_id	↑ ↓	<input type="checkbox"/>	<input type="checkbox"/>

Figure 3. Definition of database schema of Figure 2 in OdA

The three frame columns on the right in Figure 3 show that OdA allows the following aspects to be defined: (a) the data schema in Figure 2; (b) the display order of each table column of Figure 2; (c) whether or not a table column can be browsed in the navigation menu of the OdA Repository; and (d) whether or not the information in a table column will be visible to users other than the super administrator. These visualisation and navigation characteristics can be modified at any time.

Once the first step has been accomplished, step (ii) is performed. The domain-dependent schema is instantiated by populating it so that it represents the structured information of the HLOs, thereby completing the LO. In addition to this information, external resources, including the content files that compose the LO, are uploaded, and references to other HLOs are defined. Thus, the domain-dependent information of an HLO can be (El Caño, 01/02/2010, vessel, 7, 18.9), and its content can consist of several files that describe this vessel. Figure 4 shows the domain-dependent information for an HLO and its content, accessible under the tag “Recursos”. Finally, the HLO can be browsed using the domain-dependent information schema shown in Figure 5.

Currently, OdA is used at five institutional repositories at the Universidad Complutense de Madrid:

1. The historical collection of audiovisual materials for language labs (1940–1990), situated in the School of Languages, Linguistics, and Literatures (LLLS), with 120 Language LOs (OdALLS, 2012).
2. The newly created languages, linguistics and literatures LOs, also situated in the LLLS, with Language, Linguistics and Literature LOs (OdAPhilol, 2012).
3. The repository of pre-Columbian archaeology, Chasqui, situated in the School of Geography and History. It contains 2059 archaeological LOs and is the oldest OdA collection (OdAChasqui, 2012).
4. The historical collection of computers and computer equipment in the García Santesmases Museum in the School of Computer Science, with 115 IT LOs (OdAMIGS, 2012).

5. The collection of Physics Labs Instruments from the School of Physics. At present, it contains 544 Physics Labs LOs (OdAPhysics, 2012).

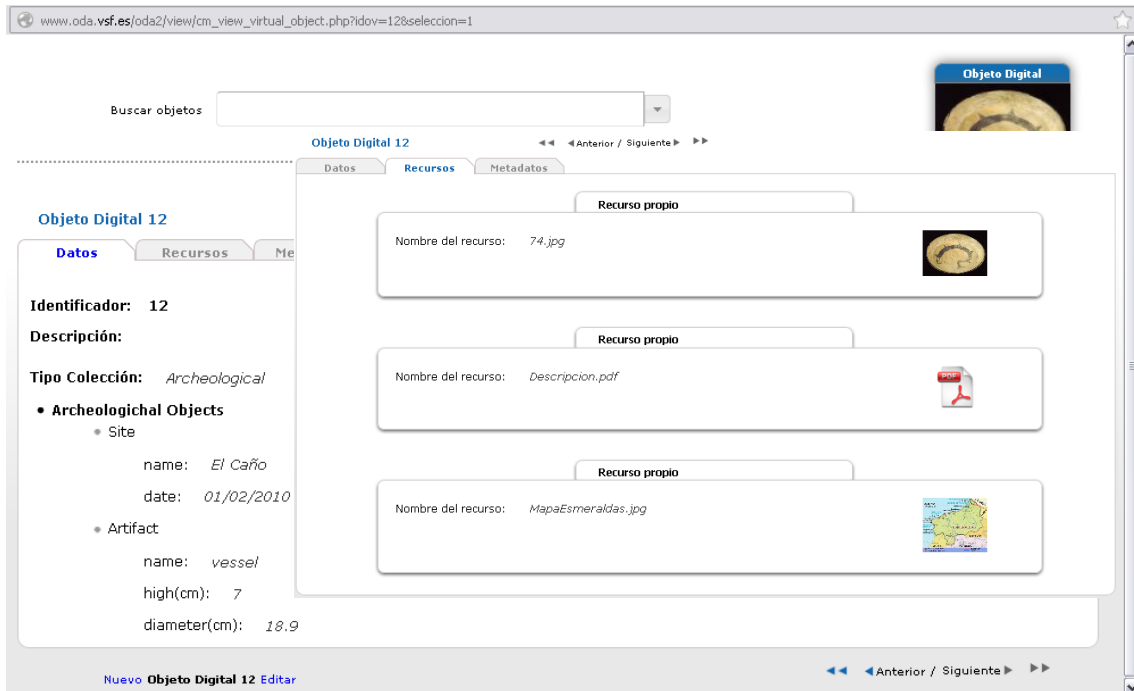


Figure 4. HLO domain-dependent information and content (resources) definition in Oda



Figure 5. HLO browsing according to domain-dependent information such as the site or artifact name

In addition, several repositories are under construction, including the Hispania Epigraphic collections in the LLLS, and a collection of Chemical LOs in the School of Pharmacy.

Due to the complexity of the meta-relational approach, we have selected a simple HLO example, an archaeological artifact, which is formed by a set of domain-specific attributes (El Caño, 01/02/2010, vessel, 7, 18.9) and a set of simple files. However, the HLOs depicted in these repositories can be complex, such as the one depicted in Figure 6. This HLO is a work of art that represents Cicero. The object comes from a collection of HLOs, created

by professors and students of the Philology School at UCM, which collects works of art representing Greco-Roman authors. Other examples of complex HLOs include multimedia LOs for language labs and LOs of standard Arabic.

Buscar objetos

Objeto Digital 13 ◀ Anterior / Siguiente ▶▶

Datos Recursos Metadatos

Identificador: 13

Descripción:
"Joven Cicerón leyendo" de V. Foppa (siglo XV)

- **OBRA DE ARTE**
 - CONTENIDO DE LA OBRA

Autor o autores antiguos representados: *Marco Tulio Cicerón / M. T. Ciceró*

Identificación:
Inscripción con el nombre.

Iconografía:
4.- Este bello fresco, en realidad un fragmento, conocido como "Joven leyendo a Cicerón", conservado en la Wallace Collection de Londres, fue pintado por Vincenzo Foppa (1430-1515), en torno a 1464, y procede de Milán, precisamente de la Banca Medici. Read more: <http://www.readperiodicals.com/201001/2200760141.html#ixzz1xWPMfMnz> El vestido es contemporáneo al pintor. El niño lee un libro y cerca hay otro cerrado. Aparece una inscripción con el nombre M. T. CICERO.
 - CIRCUNSTANCIAS DE LA CREACIÓN

Nombre del Artista: *Vincenzo Foppa*

Lugar de creación: *Brescia. Banca Medici de Milán*

Datación: *1464*

Motivación:
Si muy pocos años después Botticelli, al rebufo de la filosofía florentina, pintara su homenaje a la Urbs Florae con su

Figure 6. HLO representing information about Arts and Greco-Roman literature

Objetos Digitales Culturales de Aprendizaje

http://www.oda.vsf.es/oda2011/view/ls_ov_clasificacion.php?id=247&paginacion=10&idpadre=3

ODA v2.0

INAC Instituto Nacional de Cultura

VARADERO MUSEUM FACTORY

Fundación El Caño

Contenedor de Objetos Digitales de Aprendizaje

Nombre Apellidos >> Salir

ACCESO ODA's: DOCUMENTOS MANTENIMIENTO ENLACES

SECUENCIAL

CLASIFICADO

BUSQUEDAS

COLECCIONES ARQUEOLOGICAS

ARTEFACTOS

DOCUMENTOS

Excavado

ARTEFACTOS

METALES

CERÁMICAS

ESULTURAS

Estilos

Periodo

Caracteres de decoración

Decoración

Caracteres de forma

Caracteres de pasta

Aves(1)

Carafe Monocromo(1)

Cubité(1)

Decoración en forma...(1)

Diseños geométrico...(1)

Efigie Zoomorfa(1)

Ejemplo de Split Rep...(1)

Especial interes son...(1)

Espirales yc con gar...(1)

Este tipo de cerámi...(1)

Este tipo de hojas m...(1)

Este tipo de vajilla...(1)

NEGRO Y BLANCO SOBRE...(1)

Podemos observar dep...(1)

Policromo(1)

1-10 de 44 resultados 10 1 / 2 / 3 / 4 / 5

ID 1 - Con permiso
 Descripción : El objetivo general del proyecto arqueológico es determinar el grado político y económico de la jefatura representada en Sitio Conte y El Caño, su génesis sociopolíticas y económicas que intervinieron en el desaro...
 ARTEFACTOS:

ID 42 - Con permiso
 Descripción : Plato policromo
 ARTEFACTOS:

ID 45 - Acceso Público
 Descripción : prueba de objeto registrado
 ARTEFACTOS:

ID 46 - Acceso Público
 Descripción : Plato de borde alzado y acanalado
 ARTEFACTOS:

Ir a # en esta página

Figure 7. Complex browsing according to the full archaeological information schema that appears extremely simplified in Figure 2 and Figure 3

In addition, the domain-dependent information schema can provide complex browsing capabilities, such as the one depicted in Figure 7. In this figure, archaeological artifacts can be browsed according to a domain-dependent information schema that accounts for the material of an artifact, its decoration, and the style of this decoration. These browsing items are defined according to the domain-dependent information schema that is presented in a simplified version in Figure 2, codified in Figure 3, and used to provide the data instances that complement the LOs in Figure 4. This section has described the use of OdA, in which the meta-relational approach is codified and is thus not made explicit to the user of the LOR. However, the ability of OdA to treat the dynamic definition of domain-dependent information schema is inspired by a complex relational meta-model enhanced to treat the definition and management of HLOs. The following sections describe this meta-model.

Meta-relational level

Models can be defined as semantically complete abstractions of systems (Rumbaugh et al., 2004). Therefore, we can use relational models (Codd, 1970) to describe the domain-dependent information schemas of HLOs. For example, Figure 2 describes a relational model for part of the simplified database of an archaeological site. This case is used as an example of structured HLO data.

Figure 2 shows the definition of three interrelated tables: a *Site* that can have different *Interventions* where different *Artifacts* have been found. Figure 8 shows an example of an instance of such a database schema.

Site	<u>id</u>	name	latitude	longitude
	s1	El Caño	8.58N	79.32W

Intervention	<u>id</u>	date	site_id
	i1	01/02/2010	s1
	i2	06/01/2010	s1

Artifact	<u>id</u>	name	description	high (cm)	diameter (cm)	intervention_id
	a1	vessel	Decorated vessel...	7	18.9	i1
	a2	crown	Crown found...	10	60	i1
	a3	bracelet	This bracelet...	15	20	i2

Figure 8. Example of an instance of the database schema defined in Figure 2

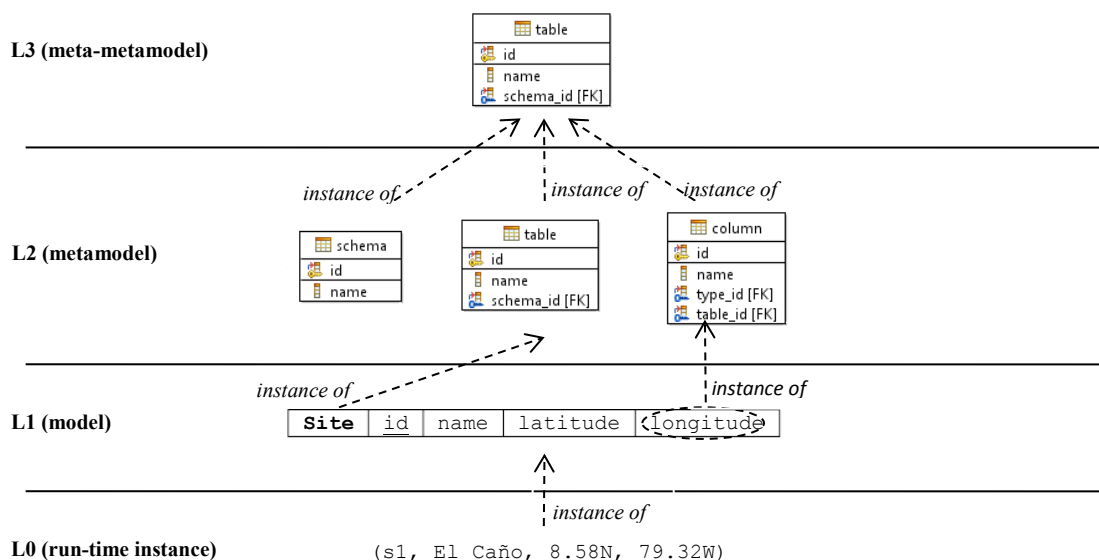


Figure 9. OMG's four-layer meta-model hierarchy

Models can adequately describe data and applications. However, if we want to use a common model to describe different data and applications, operating at the meta-level may be the best choice (OMG, 2003). Thus, meta-models can be defined as semantically complete abstractions of models, or models of models. Figure 9 describes the four-layer architecture for meta-modeling, defined by the Object Management Group (OMG) (OMG, 2010).

In this figure:

- Level 3 (L3) is the meta-meta-level. It describes the properties that meta-models can have at L2.
- Level 2 (L2) is the meta-level. Models that describe models of systems are defined at this level. For example, the meta-model for the relational model (Figure 10), which describes the elements that a relational database schema can have, can be defined at this level.
- Level 1 (L1) is the model level. Models of concrete applications are defined at this level. For example, relational database schemas, such as the one depicted in Figure 2, are defined at this level.
- Level 0 (L0) is the data level or run-time level. Specific elements are defined at this level. For example, the tuples that populate a relational database, such as the one depicted in Figure 8, are defined at this level.

The languages used in meta-modeling are reflective. Therefore, we can use the relational model to define a database schema at L1, or we can use it to define itself at L2. Figure 10 describes a simplified relational model defined at L2, using the relational model itself. For example, another language, such as Unified Modeling Language (UML), can be used to define the relational model at L2 (OMG, 2011). Indeed, the relational model defined in Figure 10 was defined considering the UML definition of the relational model provided in the *QVT Specification* (OMG, 2011).

The meta-model defined in Figure 10 has the following elements:

- `schema` represents the database schema. For example, a database schema for an archaeological site.
- `table` represents the tables that populate this schema. For example, the table `Artifact`.
- `column` represents the columns of the tables defined in the schema. For example, the column `name` of the table `Artifact`.
- `type` represents the type of the columns of the table. For example, the column `name` can be `varchar[50]`.
- `key` represents the primary and unique keys of the tables. For example, the column `id` of `Artifact` is a key. Therefore, no repeated values can exist in this column.
- `key_column` represents the columns that are part of a key. For example, the key of the table `Artifact` is formed by its `id` column.
- `foreign_key` represents the foreign keys of a table. For example, the `intervention_id` of an `Artifact` has to be defined in the column `id` of the table `Intervention`.
- `foreign_key_column` represents the columns of the foreign key. For example, the column `intervention_id` in the table `Artifact` references the column `id` in the table `Intervention`.

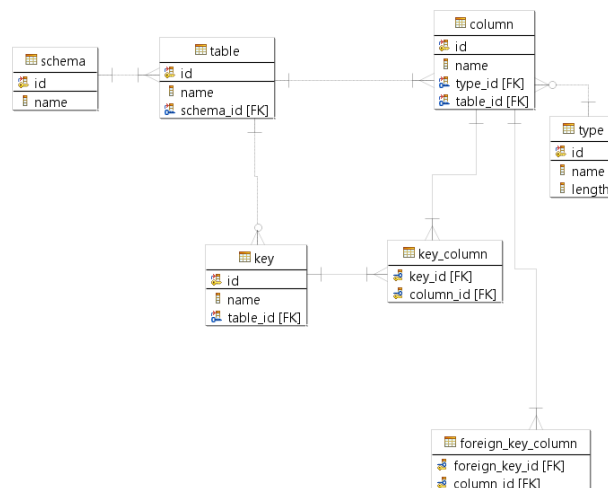


Figure 10. Simple relational meta-model for relational model

Using this meta-relational model, domain-dependent relational database schemas, such as the one depicted in Figure 2, can be represented as instances of the meta-relational model of Figure 10, as shown in Figure 11.

schema	<u>id</u>	name		
	sch1	archaeological site		

table	<u>id</u>	name	schema_id
	t1	Site	sch1
	t2	Intervention	sch1
	t3	Artifact	sch1

column	<u>id</u>	name	type_id	table_id
	c1	id	ty2	t1
	c2	name	ty3	t1
	c3	latitude	ty3	t1
	c4	longitude	ty3	t1
	c5	id	ty2	t2
	c6	date	ty3	t2
	c7	site_id	ty3	t2
	c8	id	ty2	t3
	c9	name	ty3	t3
	c10	description	ty3	t3
	c11	high (cm)	ty3	t3
	c12	diameter (cm)	ty3	t3
	c13	intervention_id	ty3	t3

Figure 11. Part of the relational schema for the domain-dependent relational database depicted in Figure 2, represented as an instance of the simple relational meta-model for the relational model defined in Figure 10

Meta-relational solution

Our goal is to define HLOs with domain-dependent content extracted from the instances depicted in Figure 8, with references to external resources (i.e., content files) and other HLOs. Thus, as Figure 4 depicts, we can have an HLO that provides information about a vessel, such as a picture or a video, with domain-dependent content formed by the values (El Caño, 01/02/2010, vessel, 7, 18.9). These values correspond to two joins and a projection of the tables Site, Intervention and Artifact depicted in Figure 2 and Figure 8.

This section describes the domain-model solutions to this problem, using the meta-relational level defined in Figure 10. These domain models can be directly used as a persistence model of a repository of HLOs, as any domain model in a software project can be used as a persistence model for the software application (Rumbaugh, 2004).

The proposed domain model describes both the domain-dependent database schema at L1 and its instances at L0 and at the meta-relational level L2. The L1 information stored at the meta-level permits the implicit definition of the domain-dependent database schema, including information about primary and foreign keys. The persistence schema for this solution remains constant for every domain, easing the definition of the database schema used by the repository.

In our approach, the database schema instances are hidden from the user. The repositories based on this solution allow high-level manipulation of these data using the meta-relational information, as shown in Figure 4. This instance is included to illustrate the meta-relational model and the codification of the relational level at the meta-relational level.

The model defined in Figure 10 permits the definition of domain-dependent relational database schemas at L1. However, it does not permit the definition of schema instances at L0. To cope with these instances, the meta-model defined in Figure 10 can be extended as shown in Figure 12.

The new elements included in this meta-model are:

- table_instance, which takes into account the tuples of a table. For example, a tuple for the table t1, Site.
- column_instance, which takes into account the instances of the columns that compose the components of a tuple in a table. For example, the values for a tuple instance of the table t1, Site.

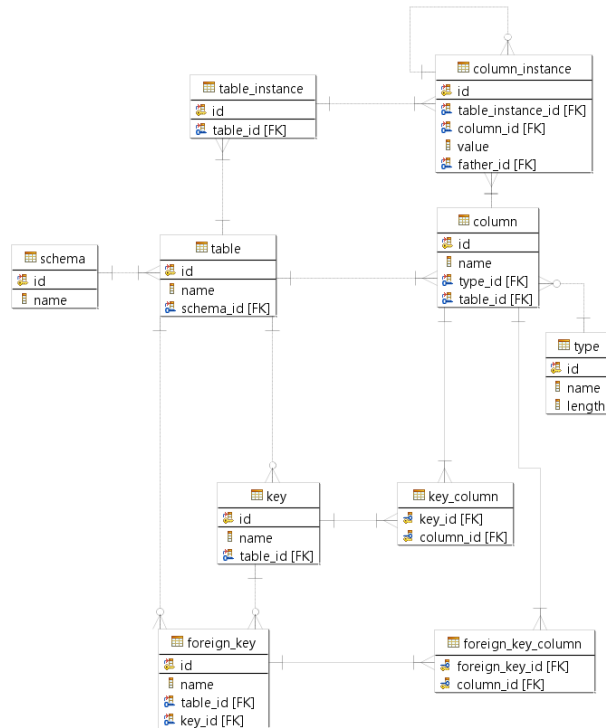


Figure 12. Simple relational meta-model for relational model extended to deal with instances at L0

table_instance	id	table_id
	ti1	t1
	ti2	t2
	ti3	t2
	ti4	t3
	ti5	t3
	ti6	t3

column_instance	id	table_instance_id	column_id	value
	ci1	ti1	c1	s1
	ci2	ti1	c2	El Caño
	ci3	ti1	c3	8.58N
	ci4	ti1	c4	79.32W
	ci5	ti2	c5	i1
	ci6	ti2	c6	01/02/2010
	ci7	ti2	c7	s1
	ci8	ti3	c5	i2
	ci9	ti3	c6	06/01/2010
	ci10	ti3	c7	s1
	ci11	ti4	c8	a1
	ci12	ti4	c9	vessel
	ci13	ti4	c10	Decorated...
	ci14	ti4	c11	7
	ci15	ti4	c12	18.9
	ci16	ti4	c13	i1

Figure 13. Part of the instance of the database schema depicted in Figure 8 and codified at the meta-level, according to the meta-model depicted in Figure 12. This instance complements the instance depicted in Figure 11

Using this extension, relational database schema instances, such as the one depicted in Figure 8, can be represented as instances of the meta-relational schema of Figure 12, as shown in Figure 13.

The domain-dependent tables (*Site*, *Intervention* and *Artifact*) defined in Figure 11 and their instances defined in Figure 13 are created when the user interacts with the system. The user is isolated from the meta-relational level, which interacts with the user in terms of tables, columns, and their instances. Thus, the user does not know if the provided information is used to codify the domain-dependent tables at the meta-relational level. The same applies to instances of these domain-dependent tables.

To characterise HLOs, the model depicted in Figure 12 must be enhanced with new elements. Figure 14 depicts the meta-model of our approach, which enhances the meta-model defined in Figure 12.

The meta-model defined in Figure 14 has the following new elements:

- `learning_object` defines the domain-dependent information structure of the LO in terms of columns of the relational database schema codified. For example, we can define the LO as `archaeological artifact`.
- `learning_object_column` defines the specific columns that compose a LO information schema. This is only structural information about the LO. For example, the LO `archaeological artifact` may consist of the columns `Site.name`, `Intervention.date`, `Artifact.name`, `Artifact.high(cm)` and `Artifact.diameter(cm)`. At the meta-relational level, these columns are those with `id` values of `c2`, `c6`, `c9`, `c11` and `c12` in Figure 11.
- `learning_object_instance` defines the instances of the LO domain-dependent information schema. For example, according to the structure defined in the preceding tables, three instances are formed by the join of the tuples of the tables `Site`, `Intervention` and `Artifact`, and the projection according to the columns defined in the table `learning_object_column`. This join and projection are made at the meta-relational level (Figure 13), not at the relational level (Figure 8).
- `learning_object_instance_column_instance` defines the values of the domain-dependent columns that compose a LO. For example, taking into account the LO defined in the example of `learning_object_column`, this table shows the values of its columns in terms of references to `column_instance` (Figure 13) of the LO instances defined in the example of `learning_object_instance`. In terms of the relational model, this table shows at the meta-relational level the instances (`El Caño, 01/02/2010, vessel, 7, 18.9`), (`El Caño, 01/02/2010, crown, 10, 60`), (`El Caño, 06/01/2010, bracelet, 15, 20`). This is the domain-dependent content of the HLOs.
- `external_resource` defines the external resources of a LO (i.e., its content files), such as photos, videos and audio files. For example, the external resource `photo145.jpg` can be located at `%PAHT%/oda/external_resources/`.
- `learning_object_external_resource` defines the specific external resources of a LO. For example, an instance of the LO `archaeological artifact` can be linked to the external resource `photo145.jpg`.
- `learning_object_instance_learning_object_instance` defines the references that an LO can have with other LOs.

In Figure 14, tables containing attributes for content packing export have been omitted for the sake of conciseness. Using this meta-model, any HLO can be defined. Its domain-dependent content is defined using instances of the domain-dependent database codified at the meta-level (`column_instance`, `learning_object_instance_column_instance` and `learning_object_instance` tables). Content is stored as an external resource (`external_resource` and `learning_object_external_resource` tables) and other HLOs are referenced (`learning_object_instance_learning_object_instance` table).

Figure 15 depicts instances of HLOs (`loi1`, `loi2`, `loi3`) that are defined in the `learning_object_instance` table and represented according to the model depicted in Figure 14. This instance complements the instance defined in Figure 13, which also complements the instance depicted in Figure 11. The domain-dependent information for `loi1` codified at the meta-relational level (`learning_object_instance_column_instance` table) is (`ci2`, `ci6`, `ci12`, `ci14`, `ci15`), which corresponds to the tuple (`El Caño, 01/02/2010, vessel, 7, 18.9`) at the relational level (`column_instance` table in Figure 13).

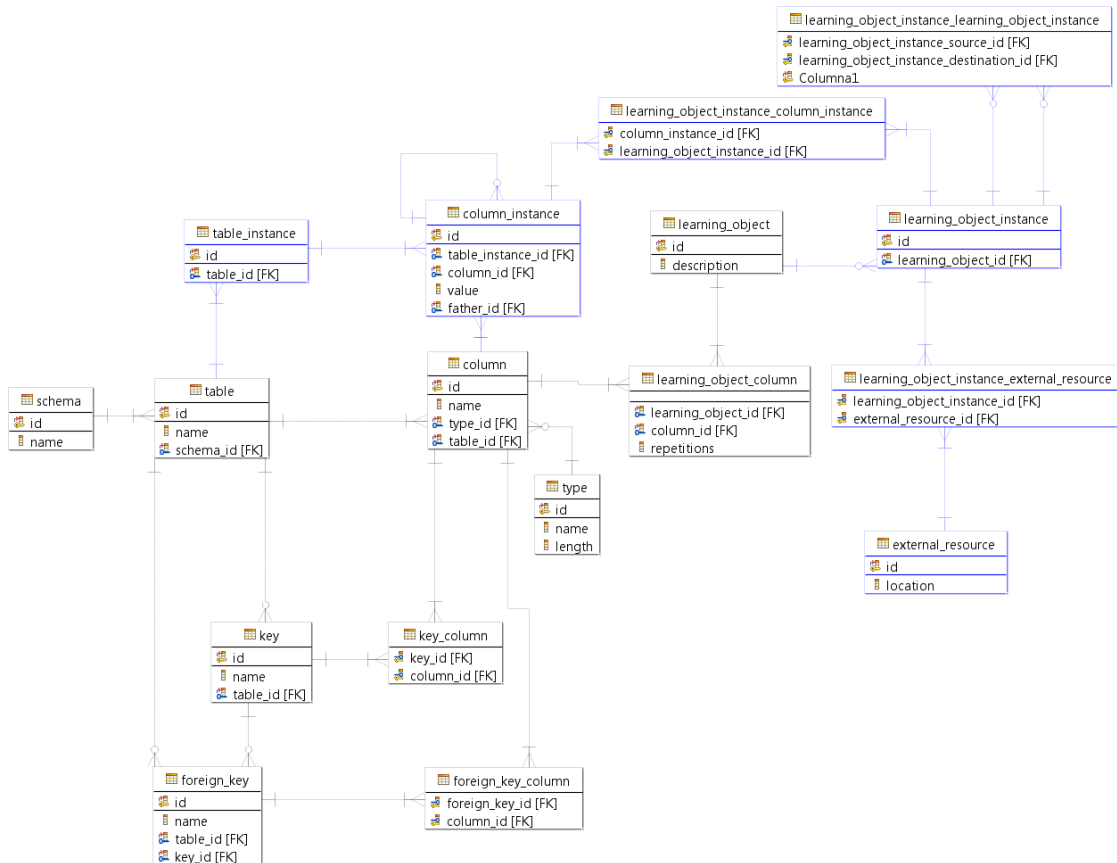


Figure 14. Representation at the meta-relational level of the domain-dependent database schema, its instances, the HLOs, and their instances. Tables containing attributes for content packing export have been omitted for the sake of conciseness

In our approach, a single database schema is defined for the HLO repository. However, some tables of this schema defined at L2 store information that describes domain-dependent relational schemas defined at the L1 level (depicted in black in Figure 14), while others store information that describes their instances at the L0 level (depicted in blue in Figure 14). Some of the tables that store information for instances at the L0 level store structured domain-dependent content for HLOs (*table_instance* and *column_instance*), while others store information for external resources and references to other HLOs. Table 2 shows the type of information stored in the tables defined in Figure 14.

Table 2. Type of information stored in tables according to meta-modeling levels

Tables that store information of domain-dependent database schema at L1	Tables that store information of domain-dependent database schema instances and external resources at L0
- schema	- table_instance
- table	- column_instance
- column	- learning_object_instance
- type	- learning_object_instance_column_instance
- key	- external_resource
- key_column	- learning_object_external_resource
- foreign_key	- learning_object_instance_learning_object_instance
- foreign_key_column	
- learning_object	
- learning_object_column	

learning_object	<u>id</u>	description
	lo1	archaeological artifact

learning_object_column	<u>learning object id</u>	<u>column id</u>
	lo1	c2
	lo1	c6
	lo1	c9
	lo1	c11
	lo1	c12

learning_object_instance	<u>id</u>	learning_object_id
	loi1	lo1
	loi2	lo1
	loi3	lo1

learning_object_instance_column_instance	<u>learning object instance id</u>	<u>column instance id</u>
	loi1	ci2
	loi1	ci6
	loi1	ci12
	loi1	ci14
	loi1	ci15
	loi2	ci2
	loi2	ci6
	loi2	ci18
	loi2	ci20
	loi2	ci21
.....		

external_resource	<u>id</u>	location
	er1	%PATH%/oda/external_resources/photo145.jpg
	er2	%PATH%/oda/external_resources/text99.jpg
	er3	%PATH%/oda/external_resources/video37.mp4
.....		

learning_object_instance_external_resource	<u>learning object instance id</u>	<u>external resource id</u>
	loi1	er1
	loi1	er2
	loi1	er3
.....		

Figure 15. Instances of HLOs (loi1, loi2, loi3) defined in the table learning_object_instance and represented according to the model depicted in Figure 14. This instance complements the instance defined in Figure 13, which also complements the instance depicted in Figure 11

Conclusions and future work

Current LORs have powerful capabilities. However, most of them cannot handle the dynamic definition of domain-dependent information schemas used to both classify and enrich LOs. This type of LO, referred to here as a hybrid LO, is common in specialised knowledge domains, and is very useful in the development of virtual academic museums.

Because current LORs do not permit the custom definition of specific domain-dependent information schemas or modifications of these schemas following their definition, the use of domain-dependent information requires the development of ad-hoc LORs. Therefore, to overcome this problem, we have developed an approach that permits the

definition and management of different domain-dependent database schemas using a single LOR. This approach supports efficient and dynamic definitions, searches and visualisations of HLOs.

The key issue of our approach is the definition of specific domain-dependent databases at the meta-relational level. Information stored at the meta-level permits the implicit and dynamic definition of domain-dependent database schemas, including information about primary and foreign keys, which are essential for maintaining data consistency. The persistence schema for this solution remains constant for every domain, easing the definition of the database schema used by the repository.

This approach underlies the learning object repository developed by our group called OdA. This LOR has been successfully used as a repository for HLOs in the domains of IT, physics, archaeology, pharmacy, and philology. In addition, we have used it to develop three virtual academic museums in the domains of physics, archaeology, and computer science.

This repository simplifies the definition of the underlying domain-dependent database schema while also facilitating the collaborative authoring, searching and visualising of HLOs according to this domain-dependent information schema. In addition, OdA requires a limited amount of IT resources, making it attractive for the development and use of specialised LO collections in academic environments.

In future work, our repository, OdA, will be enhanced to enable the use of an API, web services and multilingualism. Further, OdA will be integrated with different learning management systems. Finally, the repository will be used in the context of an international agreement between the Universidad Complutense de Madrid and La Fundación El Caño, which is responsible for an important archaeological excavation in Panama (Owen, 2011).

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