

New Dimension in Relational Database Preservation: rising the abstraction level

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ABSTRACT

The work addressed in this paper focuses on the preservation of the conceptual model within a specific class of digital objects: Relational Databases. Previously, a neutral format was adopted to pursue the goal of platform independence and to achieve a standard format in the digital preservation of relational databases, both data and structure (logical model). Currently, in this project, we address the preservation of relational databases by focusing on the conceptual model of the database, considering the database semantics as an important preservation "property". For the representation of this higher layer of abstraction present in databases we use an ontology based approach. At this higher abstraction level exists inherent Knowledge associated to the database semantics that we tentatively represent using "Web Ontology Language" (OWL). We developed a prototype (supported by case study) and define a mapping algorithm for the conversion between the database and OWL. The ontology approach is adopted to formalize the knowledge associated to the conceptual model of the database and also a methodology to create an abstract representation of it.

Keywords

Digital Preservation, Relational Databases, Ontology, Conceptual Models, Knowledge, XML, Digital Objects

1. INTRODUCTION

In the current paradigm of information society more than one hundred exabytes of data are used to support information systems worldwide [1]. The evolution of the hardware and software industry causes that progressively more of the intellectual and business information are stored in computer platforms. The main issue lies exactly within these platforms. If in the past there was no need of mediators to understand the analogical artifacts today, in order to understand digital objects, we depend on those mediators (computer platforms).

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Our work addresses this issue of Digital Preservation and focuses on a specific class of digital objects: Relational Databases (RDBs). These kinds of archives are important to several organizations (they can justify their activities and characterize the organization itself) and are virtually in the base of all dynamic content in the Web.

In previous work [2] we adopted an approach that combines two strategies and uses a third technique — migration and normalization with refreshment:

- Migration which is carried in order to transform the original database into the new format – Database Markup Language (DBML) [3];
- Normalization reduces the preservation spectrum to only one format;
- Refreshment consists on ensuring that the archive is using media appropriate to the hardware in usage throughout preservation [4].

This previous approach deals with the preservation of the Data and Structure of the database, i.e., the preservation of the database logical model. We developed a prototype that separates the data from its specific database management environment (DBMS). The prototype follows the Open Archival Information System (OAIS) [5] reference model and uses DBML neutral format for the representation of both data and structure (schema) of the database.

1.1 Conceptual Preservation

In this paper, we address the preservation of relational databases by focusing on the conceptual model of the database (the information system – IS). It is intended to raise the representation level of the database up to the conceptual model and preserve this representation. For the representation of this higher level of abstraction on databases we use an ontology based approach. At this level there is an inherent Knowledge associated to the database semantics that we represent using OWL [6]. We developed a prototype (supported by case study) and established an algorithm that enables the mapping process between the database and OWL.

In the following section, we overview the problem of digital preservation, referring to the digital object, preservation strategies and the preservation of relational databases. Section 3 describes our previous work and states the open issue

(database semantic representation) the lead us to the current approach. In Section 4 we outline the relation between ontologies and databases establishing the state-of-the-art and referring to related work. The prototype and the mapping process from RDBs to OWL is detailed in section 5. At the end we draw some conclusions and specify some of the future work.

2. DIGITAL PRESERVATION

A set of processes or activities that take place in order to preserve a certain object (digital) addressing its relevant properties, is one of the several definitions. Digital objects have several associated aspects (characteristics or properties) that we should consider whether or not to preserve. The designated community plays an important role and helps to define

"The characteristics of digital objects that must be preserved over time in order to ensure the continued accessibility, usability, and meaning of the objects, and their capacity to be accepted as evidence of what they purport to record"[7].

2.1 The Digital Object

Some distinction can be established between digital objects that already born in a digital context, and those that appear from the process of digitization: analog to digital. In a comprehensive way and encompassing both cases above, we can consider that a digital object is characterized by being represented by multiple bitstreams, i.e., by sequences of binary digits (zeros and ones).

We can question if the physical structure of the object (original system) is important, and if so, think about possible strategies for preservation at that level, e.g. "technology preservation" (museums of technology) [8]. Nevertheless, the next layer — the logical structure or logical object—, which corresponds to the string of binary digits have different preservation strategies. The bitstream have a certain distribution that will define the format of the object, depending on the software that will interpret it. The interpretation by the software, of the logical object, provides the appearance of the conceptual object, that the human being is able to understand (interpret) and experiment. The strategy of preservation is related to the level of abstraction considered important for the preservation [9]. From a human perspective one can say that what is important to preserve is the conceptual object (the one that the humans are able to interpret). Other strategies defend that what should be preserved is the original bitstream (logical object) or even the original media. Figure 1 shows the relationship between the different levels of abstraction (digital object) and the correspond preservation formats adopted for RDBs in this research.

2.2 Relational Databases Preservation

By focusing on a specific class or family of digital objects (relational databases), questions emerge such as: what are the effects of cutting/extracting the object from its original context? Can we do this even when we are referring to objects that are platform (hardware/software) dependent? The interaction between the source of the digital object and

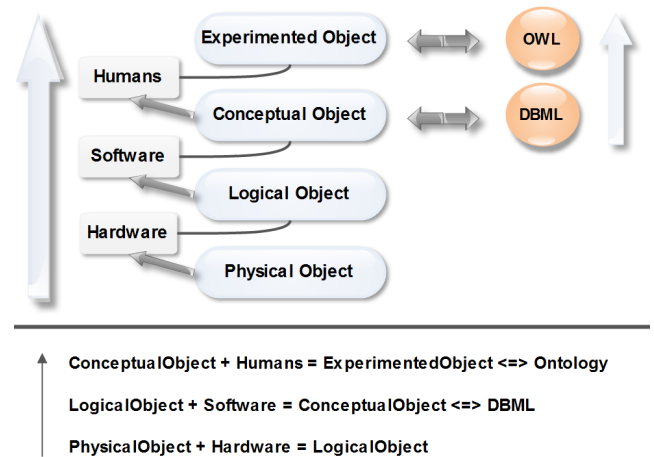


Figure 1: Levels of Abstraction and Preservation Policy

the platform results on a conceptual object that can be different if the platform changes [7]; the output can be different (will the object maintain its original behavior?). The important is the preservation of the essential parts that purport what the object where made for. Either the source or the platform can be altered if what is essential is obtained and also maintaining the meaning of the digital object over long periods of time (long-term scope).

Considering the nature of the digital artifacts that we are addressing – relational databases – there is an European strategy encompassed in the "Planets Project" [10] to enable their long term access. The project adopted the SIARD [11] solution, which is based on the migration of database into a normalized format (XML – eXtensible Markup Language [12]). The SIARD was initially developed by the Swiss Federal Archives (SFA).

Another approach, also based on XML, relies on the main concept of "extensibility" – XML allows the creation of other languages [13] (it can be called as a meta language). The DBML [3] (Database Markup Language) was created in order to enable representation of both **DATA** and **STRUCTURE** of the database.

Both approaches (SIARD and DBML) adopt the strategy of Migration of the database to XML, why? A neutral format that is hardware and software (platform) independent is the key to achieve a standard format to use in digital preservation of relational databases. This neutral format should meet all the requirements established by the designated community of interest.

3. PREVIOUS WORK AND CURRENT APPROACH

In previous work we address the preservation of the RDBs data and structure by developing a archive prototype that uses the DBML format for preservation. Our first approach covers the preservation of the logical model of databases (tables, structure and data). However, neither this approach nor others (e.g. SIARD [11]) is concerned with the database

Digital Object	Preservation Levels	Relational Database
Experimented Object	Ontology	Conceptual Model
Conceptual Object	DBML	Logical Model
Logical Object	-	Original Bitstream
Physical Object	-	Physical Media

Figure 2: Preservation Policy

semantics. The focus of our research then turned into this problem related conceptual model of the database, i.e., the information system on the top of the operational database.

3.1 First Approach

The prototype is based on a web application with multiple interfaces. These interfaces have the mission to take a certain database and ingest it into the archive. The access to the archive in order to do all the necessary interventions on the system is also done through those web interfaces.

Conceptually, the prototype is based on the OAIS [5] reference model. The OAIS model of reference does not impose rigidity with regard to implementation, rather it defines a series of recommendations. The OAIS model is accepted and referenced for digital preservation purposes since it is concerned about a number of issues related to preservation of digital artifacts: the process of information Ingestion into the system, the information storage as well as its administration and preservation, and finally information access and dissemination [14] [15]. Three information packages are the base of the archival process: Submission Information Package (SIP), Archival Information Package (AIP) and Dissemination Information Package (DIP).

3.2 Proposed Approach

Based on the first prototype we now intend to include in the information packages (SIP, AIP and DIP) an higher representation level of the database — the conceptual model of the database. Ontologies are used to address semantics and conceptual model representation.

Our hypothesis concentrates on the potentiality of reaching relevant stages of preservation by using ontologies to preserve of RDBs. This lead us to the preservation of the higher abstraction level present in the digital object, which corresponds to the database conceptual model. At this level there is an inherent **Knowledge** associated to the database semantics (Fig. 2).

We intend to capture the experimented object (knowledge) through an ontology based approach. This experimented or knowledge object is the "final abstraction". The ontology approach is adopted to formalize the knowledge present at the experimented object level and also a methodology to create an abstract representation of it. The system has evolved into an OAIS based architecture that allows the ingestion, preservation and dissemination of relational databases at two levels of abstraction — logical and conceptual (Fig. 2). This approach is also an extension to previous approaches in terms of metadata since the ontology provides information about the data at a conceptual level. Figure 2 also shows a possible preservation "lifecycle" of RDBs.

4. ONTOLOGIES & DATABASES

There is a direct relation between ontologies and databases: a database has a defined scope and intends to model reality within that domain for computing (even when it is only virtual or on the web); ontology in ancient and philosophical significance means the study of being, of what exists [16].

The (strong) entities present in relational databases have an existence because they were model from the real world: they relate to each other and have associated attributes. In information society and computer science, an ontology establishes concepts, their properties and the relationships among them within a given domain [17].

4.1 Database Semantics

A database can be defined as a structured set of information. In computing, a database is supported by a particular program or software, usually called the Database Management System (DBMS), which handles the storage and management of the data. In its essence a database involves the existence of a set of records of data. Normally these records give support to the organization information system; either at an operational (transactions) level or at other levels (decision support – data warehousing systems). In particular, the relational databases model is designed to support an information system at its operational level. Thus, RDBs are complex and their data can be distributed into several entity relations that related to each other through specific attributes (foreign to primary keys) in order to avoid redundancy and maintain consistency [18].

If we intend not only to preserve the data but also the structure of the (organization) information system we should endorse efforts to characterize (read) the database semantics. It is intended to raise the representation level of the database up to the conceptual model and preserve this representation. In other words, we represent the conceptual model of the database using an ontology for preservation.

4.2 Ontologies

The study of ontologies in computer science received new impetus due to the growth of the web, their associated semantics and the possibility of extracting knowledge from it. Tim Berners-Lee realized that years ago giving origin to the "Semantic Web" supported by W3C (World Wide Web Consortium) [19] which works on establishing a technology to support the *Web of data* [20]. Notice that a tremendous part of the web is based in (relational) databases — specially dynamic information.

Behind the ontology there is the need of knowledge representation for machine interpretation. Two technologies: a) the RDF (Resource Description Framework) [21] triples give support for the meaning in simple sentences b) and XML [12] is used for structuring documents [16]. The RDF document consist on a set of triples, – *object, property, value* – that we can also define as – *subject, predicate, object* [22].

The notion of ontology then emerges due to the need of expressing concepts in different domains (ontologies as collections of information). An ontology can provide readable information to machines [23] at a conceptual level (higher

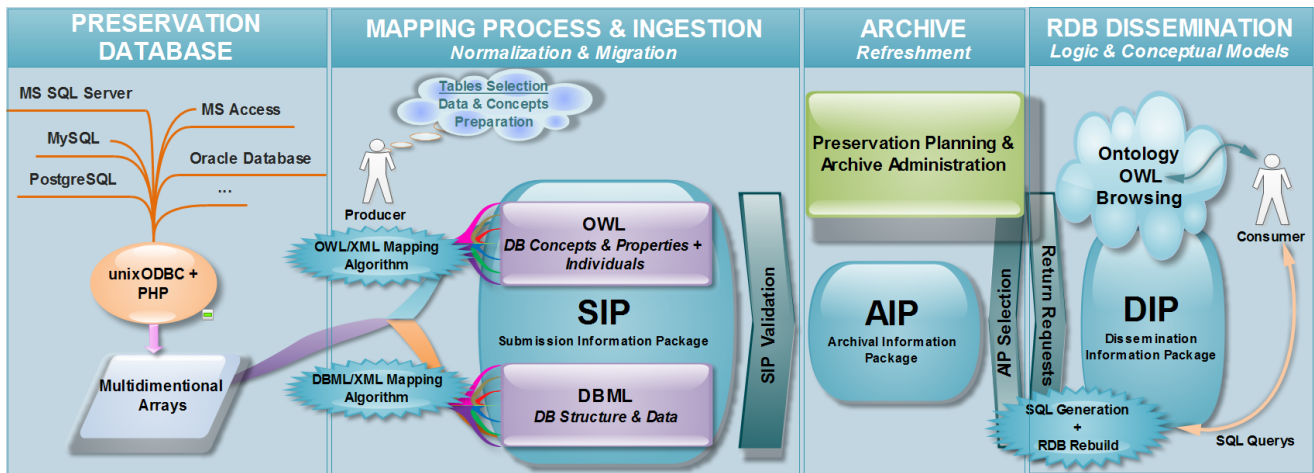


Figure 3: RDBs Preservation Framework

abstraction level). They also enable the integration and interpretability of data/information between applications and platforms. Ontologies benefit from the fact that they are not platform/system dependent when compared to traditional relational databases.

4.3 Related Work

Work related to RDBs and ontologies transformations proliferate and is addressed continuously. Considering the RDF [21], OWL [6], ontologies and RDBs, several frameworks, mapping approaches and tools exist: Virtuoso RDF View [24]; D2RQ [25]; Triplify [26]; RDBToOnto [27]; R2O [28]; Dartagrid Semantic Web toolkit [29]; SBRD Automapper [30]; XTR-RTO [31]; RDB2OWL [32]; DB2OWL [33]; R2RML [34]; OntER [35]; DM2OWL [36]; OWLFromDB [37] and also "Concept hierarchy as background knowledge" proposal [23] among others.

Several of these approaches and tools are referenced and analyzed in the W3C Incubator group survey [38] and also in [23].

The conversion from databases into an ontology could be characterized as a process in the scope of reverse engineering [35]. While some approaches and works try to establish a mapping language or a mapping process [39], others use different techniques and strategies for the database translation [36] into an ontology (e.g. OWL).

The R2RML (RDB to RDF Mapping Language) [34] working draft submitted to W3C is designed for mapping the data within the attributes of a **table** into pairs: property, object. Each record within a table share the same subject in this RDF triple map relation. This approach supports the input of "logical" tables from the source database, which can be an existing table, a view or a valid SQL query. Also in cases where attributes are foreign keys it is generated a pair (property, object) referencing the correspondent table. The rules for this mapping are then organized in a vocabulary with several classes and subclasses (*TripleMapClass*, *SubjectMapClass*, *PredicateMapClass*, *ObjectMapClass*, *Ref-PredicateMapClass*, etc).

For example, R2O [28] approach is based on a mapping document generation (mapping language). Virtuoso RDF View establishes a set of RDF statements by defining for each table: *primary key* (subject), *attribute* (predicate), *value* (object). In the RDB2OWL [32] a different strategy is used since it is created a mapping RDB schema. The "Concept hierarchy as background knowledge" proposal [23] gives special attention to the data preparation before conversion and to the knowledge that resides on the database.

5. FROM RDB TO OWL

This section presents the work developed to convert databases to ontology, based on a mapping process (mapping algorithm), for preservation. We intend to preserve a snapshot of the database (or a frozen database) by preserving the OWL generated from the database.

We start by concentrating our efforts on detailing the mapping process and analyzing the created algorithm. Then the conducted tests and some of the results are also presented.

5.1 Mapping Process of RDBs to OWL – Prototype

Our work implements the conversion from RDBs into OWL through an algorithm that performs the mapping process. The developed prototype enables the connection to a DSN (Data Source Name), extracts the data/information needed and gives the initial possibility of selecting the tables of interest (for conversion). It is assumed that the source database is normalized (3NF).

Lets start by enumerating the properties of RDBs that are address and incorporated in the ontology (OWL):

- **Tables** names;
- **Attributes** names and data types;
- **Keys** primary keys, foreign keys (relationships between tables);
- **Tuples** data;

```

tables = Array{ [1] => t1, ... , [n] => tn }
columns = Array{
  [t1] => Array{
    [a1] => Array{ [Name] => 'a1_name', [Type] => 'a1_type' },
    ...,
    [an] => Array{ ... }},
  ...,
  [tn] => Array{...}}
p_keys = Array{
  [t1] => Array{ [a1] => 'pk_t1', ... , [an] => 'pk_t1' },
  [tn] => Array{...}}
f_key = Array{
  [t1] => Array{
    [a1] => Array{ [pk_table] => 'tref', [pk_column] => 'tref.aref' },
    ...,
    [an] => Array{...}},
  ...,
  [tn] => Array{...}}
tables_data= Array{
  [t1] => Array{
    [1] => Array{ [a1] => 'a1_data', ... , [an] => 'an_data' },
    ...,
    [m] => Array{...}},
  ...,
  [tn] => Array{...}}

```

Figure 4: Multidimensional Array Structure

```

// classes (tables) & objectProperties (link tables - non-classes)
FOREACH [ table ]
  IF [ ( [columns[table]] = [p_keys[table]] ) AND ( [p_keys[table]] = [f_keys[table]] ) ] THEN
    non_class[] = table
    FOREACH [ columns[table] - 1 ]
      NEW 'objectProperty'
      Property_Description = 'is_' + f_keys[table][columns[table]][pk_table] + '_of'
      Domain = f_keys[table][columns[table]][pk_table]
      Range = f_keys[table][next(columns[table]][pk_table]
    NEW 'objectProperty'
      Property_Description = 'has_' + f_keys[table][columns[table]][pk_table]
      Domain = f_keys[table][next(columns[table]][pk_table]
      Range = f_keys[table][columns[table]][pk_table]
    NEW 'InverseObjectProperties'
      Property_Description = 'is_' + f_keys[table][columns[table]][pk_table] + '_of'
      Property_Description = 'has_' + f_keys[table][columns[table]][pk_table]
    END FOR
  ELSE
    class[] = table
  END IF
END FOR

```

Figure 5: Algorithm – Classes and Non Classes

These elements are extracted from the database into multidimensional arrays. Figure 4 shows the arrays structure.

For each `table` on the database we define a `class` on the ontology with the exception of those tables where all attributes constitute a composed primary key (combination of foreign keys). These link tables used in the relational model to dismount a many-to-many relationship, are not mapped to OWL classes, instead they give origin to **object properties** in the ontology. These object properties have on their domain and range the correspondent classes (database tables) involved in the relationship (Fig. 5).

The **foreign keys** of the tables mapped directly to OWL classes also give origin to **object properties** of the correspondent OWL classes (tables). The **attributes** of the several tables are mapped to **data properties** within the analogous OWL classes with the exception of the attributes that are foreign keys (Fig. 6).

The algorithm generates inverse object properties for all relationships among the classes. If the object properties are generated directly from a 1-to-many relationship (which is the last case) it is possible to define one of the object properties as functional (in one direction).

The **tuples** of the different tables are mapped to **individuals** in the ontology and are identified by the associated **primary key** in the database. A tuple in a database table is mapped to an individual of a class (Fig. 7).

The object properties that relates individuals in different

```

// sub classes of Thing & disjoint all & object and Data Properties
class_disjoint[] = class
FOREACH [ class ]
  NEW class 'subclassof' owl:Thing
  FOREACH [ class_disjoint ]
    IF [ class IN class_disjoint ] THEN
      NEW 'DisjointClasses'
      Class_Description = class
      Class_Description = class_disjoint
    END IF
  END FOR
pop(class_disjoint)
FOREACH [ f_keys[table] as fk ]
  NEW 'objectProperty'
  Property_Description = 'is_' + fk['pk_table'] + '_of'
  Domain = fk['pk_table']
  Range = class
  NEW 'objectProperty'
  Property_Description = 'has_' + fk['pk_table']
  Domain = class
  Range = fk['pk_table']
  NEW 'InverseObjectProperties'
  Property_Description = 'is_' + fk['pk_table'] + '_of'
  Property_Description = 'has_' + fk['pk_table']
  NEW 'FunctionalObjectProperty'
  Property_Description = 'is_' + fk['pk_table'] + '_of'
END FOR
FOREACH [ columns[table] as table_data ]
  IF [ f_keys[table][table_data['Name']] != table_data['Name'] ] THEN
    NEW 'DataProperty'
    Property_Description = 'has_' + table_data['Name']
    Domain = class
    Range = data_type
  END IF
END FOR
END FOR

```

Figure 6: Algorithm – Structure Generation

```

// tuples -> Individuals //
FOREACH [ class ]
  FOREACH [ tables_data[table] as tuple ]
    primary_key = class
    FOREACH [ p_keys[table] as pk ]
      primary_key = primary_key + pk
    END FOR
    NEW 'ClassAssertion'
    Class_Description = class
    NamedIndividual = primary_key
    FOREACH [ tuple as kt=>t ]
      IF [ NOT [ kt IN array_keys(f_keys[table]) ] ]
        NEW 'DataPropertyAssertion'
        dataProperty = class + '_has_' + kt
        NamedIndividual = primary_key
        Literal = t
      ELSE
        NEW 'ObjectPropertyAssertion'
        ObjectProperty = f_keys[table][kt]['pk_table']
        NamedIndividual = primary_key
        NamedIndividual = f_keys[table][kt]['pk_table'] + '_' + t
      END IF
    END FOR
  END FOR
END FOR
// tuples -> objectProperties (link tables) //
FOREACH [ non_class ]
  FOREACH [ columns[table] - 1 ]
    FOREACH [ tables_data[table] as tuple ]
      NEW 'ObjectPropertyAssertion'
      ObjectProperty = f_keys[table][columns[table]][pk_table]
      NamedIndividual = f_keys[table][next(columns[table]][pk_table] +
      + tuple[f_keys[table][next(columns[table]][pk_column]]
      NamedIndividual = f_keys[table][columns[table]][pk_table] +
      + tuple[f_keys[table][columns[table]][pk_column]]
    END FOR
  END FOR
END FOR

```

Figure 7: Algorithm – Individuals

classes are only defined in one direction. If in the inverse pair of object properties exists one property that is functional, is that one that it is defined; if not, the generated object property assertion is irrelevant.

In the next table (Fig. 8) we summarize the mapping process. From the conceptual mapping approach and some DBMS heuristics we start to manually convert a relational database (case study database) into OWL using Protégé [40]. The algorithm was then designed based on the defined mapping and from the code analysis (Protégé – OWL/XML format).

5.2 Prototype – Tests and Results

The algorithm was then tested with the case study database. Figure 9 shows the database logical model and the ontology conceptual approach. It was necessary to do some adjustments in order to achieve a consistent ontology. Then we successfully use the Hermit 1.3.3 reasoner [41] to classify the ontology. The inverse "object properties assertions" that the algorithm do not generates for the individuals were inferred. Some equivalent (and inverse functionality) object properties were also inferred.

In Figure 10 we present an example of the generated ontol-

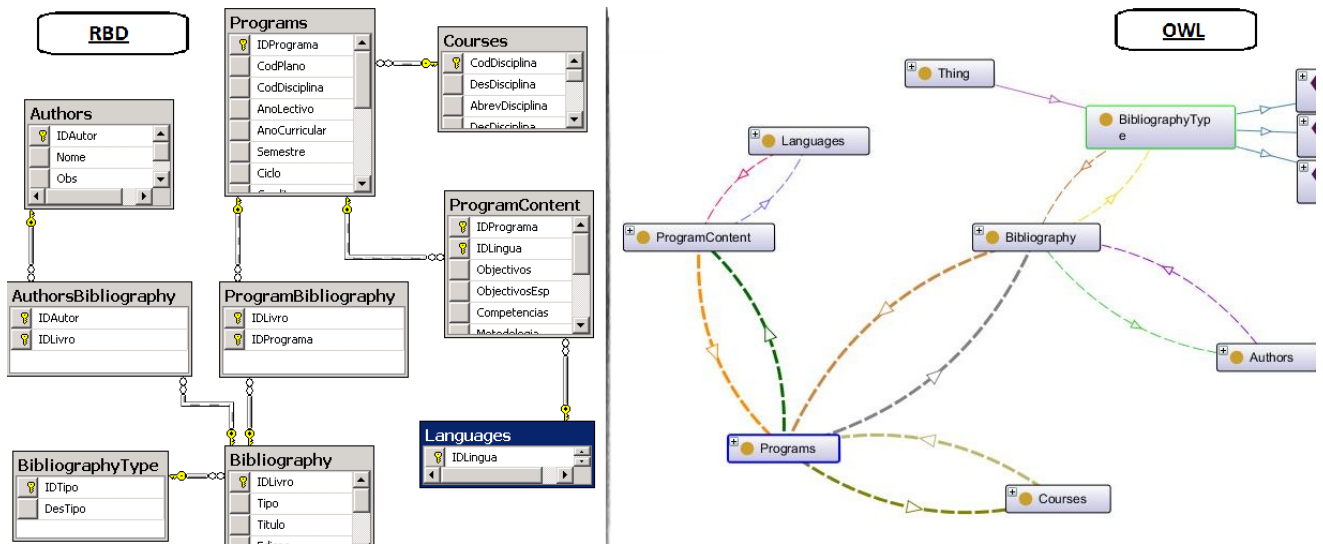


Figure 9: RDB Logical Model vs Ontology Overview

RDB	OWL
Tables	Classes
If (#attributes = #primary keys = #foreign keys) → Object Property	
Foreign Keys	Object Properties
Primary Keys	Individuals Identification
Other Attributes	Data Properties
Tuples	Individuals
	<ul style="list-style-type: none"> • Inverse Object Properties Generation • Functional Object Properties Definition • Disjoin All Classes

Figure 8: Mapping Process Sumarized

ogy. This example focus on the relationship that exists between the two tables ("Authors" and "Bibliography") where the link table "AuthorsBibliography" is mapped into an object property (and inverse object property) relating the correspondent mapped classes. It is also shown a portion of the generated OWL document where we demonstrate the results of mapping a table attribute into a data property of a class.

The next step consisted on testing the algorithm with other databases. We use one MySQL database and two MSSQL Server databases (the maximum tables size were about tens of thousands records). All databases used in this research are from the University Lusida information system.

The results were very satisfactory because the algorithm achieve similar results of the ones obtained with the case study database only with minor inconsistencies related with naming and encoding problems. The processing time is an issue directly related to the dimension of the database (it is necessary to test the algorithm with huge databases [millions of records] in machines with powerful processing capability).

6. CONCLUSION AND FUTURE WORK

Ontologies and databases are related to each other because of their characteristics. Using ontologies in database preser-



Figure 10: Results Portion: tables "Authors" and "Bibliography" relationship & "Authors" attribute mapping

vation is an approach to capture the "knowledge" associated to the conceptual model of the database.

In previous work we preserve the database data and structure (logical model) by ingesting the database in a XML based format (DBML [3]) into an OAIS [5] based archive.

Here, we present the work developed in order to convert databases to ontology, based on a mapping process (mapping algorithm), for preservation. In order to preserve a snapshot of the database (or a frozen database) we preserve the ontology (OWL [6], also a XML based format) obtained from the application of developed algorithm to the source database. We tested the algorithm with few databases and the results were acceptable in terms of consistency of the generated ontology (and comparing to the results obtained with the case study database).

This generated ontologies will induce the development of a new database browser/navigation tool.

Ontologies also have other potentialities such as the asset of providing answers to questions that other standards are limited. For example, in terms of metadata, one issue that we intend to also address in future work.

We also anticipate the possibility of integration between Web Ontology Language (OWL) and Semantic Web Rule Language (SWRL [42]) to consolidate the asserted and inferred knowledge about the database and its information system.

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