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Ontologies versus relational databases: are they so different? A comparison

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Abstract Two main data models are currently used for representing knowledge and information in computer systems. Database models, especially relational databases, have been the leader in last few decades, enabling information to be efficiently stored and queried. On the other hand, ontologies have appeared as an alternative to databases in applications that require a more 'enriched' meaning. However, there is controversy regarding the best information modeling technique, as both models present similar characteristics. In this paper, we present a review of how ontologies and databases are related, of what their main differences are and of the mechanisms used to communicate with each other.

Keywords Relational databases · Ontologies · Ontology-based databases

1 Introduction

Several models for representing machine readable information have emerged since file-based models disappeared and relational databases increased in popularity due to their efficiency, flexibility and performance for representing and managing data. Many efforts have failed to change the hegemony of relational databases by means of alternative database models that complement their lacks such as Object Oriented, Multimedia, Deductive, Spatial models, etc. Simultaneously, knowledge level modeling techniques (Uschold 1998) propose alternative models to define information richer in expressiveness but also in complexity (Wand et al. 1999; Borgida 1995). Consequently these representations applied mostly in AI, like

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description logics (DL) or First Order Logic (FOL), have been less popularized than relational database representations specially in commercial applications. However, a successful new approach in this area to represent semantic information has been defined in the last decade: Ontologies. These representations are competing in growth and popularity with database schemas due to the emerging technologies related with ontologies that are being developed, especially regarding with the Semantic Web. At this point, developers and users have begun to wonder about what technology best suits their needs or even if it is worth changing their current system, based mainly on relational databases, in favor of the new one. There is currently much controversy regarding the best technology for representing information and knowledge in computers. Consequently, both technologies have been compared in order to establish their degree of similarity along with pros and cons. This discussion, however, takes several items into account, such as efficiency issues, representation capabilities, technologies involved, repercussions for actual systems, etc.

In this paper we try to answer the general questions arising in relation to databases and ontologies technologies: Where do these proposals disjoint, what are the main differences between them and more controversial, can the same information be represented with both approaches and can current database systems be considered obsolete?

In answer to these questions, a brief review of databases and ontologies is presented in Sect. 2. Subsequently, an in-depth comparison between databases and Ontologies is made in Sect. 3. In Sect. 4, the main mechanisms establishing the communication between both technologies is described. The representation of the relational database model as an ontology is presented in Sect. 5 and finally, several conclusions are discussed in Sect. 6.

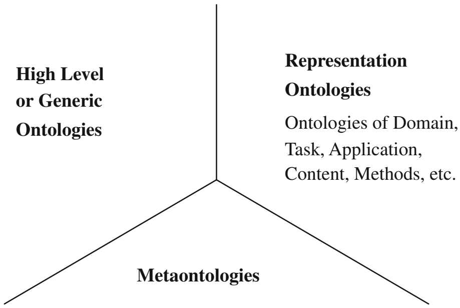
2 Antecedents

2.1 Ontologies

After the *Ontology* concept was first defined by philosophers to describe reality, several disciplines also interested in information modeling such as Computer Science (CS) have redefined them (Neches et al. 1991; Guarino 1995; Gruber 1993; Borst et al. 1997; Swartout et al. 1996; Studer et al. 1998; Shadbolt et al. 2006). One of the simpler visions of this concept in CS is proposed by Agarwal (2005) who states that *an ontology is, therefore, the manifestation of a shared understanding of a domain that is agreed between a number of agents and such agreement facilitates accurate and effective communications of meaning, which in turn leads to other benefits such as inter-operability, reuse and sharing*. Currently there is a well-defined ontology engineering process as described by Gómez-Pérez et al. (2003b).

Two basic criteria on ontology classification (Gómez-Pérez et al. 2003a; Bach 2006–2007; Agarwal 2005) have prevailed: The first one addresses the language used and the semantic enrichment of data (Uschold and Grüninger 1996; Lassila and McGuinness 2002; Zhang 2007; Ruiz and Hilera 2006). This classification considers *proper ontologies*: those which represent all the semantics of any representation problem and consequently require a considerable number of axioms or rules to achieve this purpose. Thus the remaining data representations that do not have as many axioms as these are considered *light weight ontologies* or even not considered as ontologies, for instance taxonomies, database schemas, XML schemas, UML Diagrams, etc. The second one addresses the semantics of the information represented (Steve et al. 1998; Guarino 1998; Mizoguchi et al. 1995; van Heijst et al. 1997; Fensel 2004; Jurisica et al. 1999; Gómez-Pérez et al. 2003a; Sharman et al. 2006). A generic classification involving this criterion establishes three kinds of ontologies (see Fig. 1):

Fig. 1 Generic ontology classification by content



– *Metaontologies* are those which establish the conceptual vocabulary for representing information (ontologies) using them. The most common metaontology is therefore the one which defines the concept of class, properties, axioms, etc.
– *High Level Ontologies* describe the more generic concepts or processes. They are not usually oriented to be instantiated, due to the fact that they represent relatively general concepts.
– *Representation Ontologies* are the remaining applicable ontologies: Domain ontologies, process ontologies, task ontologies, content ontologies, methods ontologies, applications ontologies, etc. In this category we can find several subclassifications in the literature.

However there is no consensus regarding what an ontology is. Some authors (Wilks 2002) criticize the "fixed" and "well-known" ontology definition and redefine it as an Artificial Intelligence (AI) knowledge representation schema. This definition attempts to be more flexible and applicable to all the areas of AI.

2.1.1 Semantic web and ontologies

Currently ontologies are being actively developed due to their application in the Semantic Web (SW) (Berners-Lee et al. 2001). Semantic Web appears as a solution to problems presented in the traditional Web, such as the unstructured and unrelated content described in most web pages (Lausen and Stolberg 2004; Berners-Lee et al. 2001) that do not enable retrieval of semantically related content. In the Semantic Web, each information source is extended with a semantically structured representation. There are several ways to include these semantics in the Web, but the most popular one is the use of Ontologies (Finin et al. 2005) although annotations are also quite popular (Sheth et al. 2005).

Several proposals to include ontologies in the Web involve adding them either to the web site where the information is available or in the own web page code itself (Finin et al. 2005). However McCool (2005) discovered the following problems in this solution:

– The Semantic Web becomes increasingly complex
– Poor user participation
– There is currently an increasing but insufficient number of applications in the Semantic Web
– The complexity of the ontology description languages (especially for representing axioms)

These problems can be solved with the annotation technology, which describes the web content using tags. This solution (McCool 2005, 2006) reduces the complexity of the Semantic Web and provides faster query answers and even higher user participation, as can bee seen in Flirck (http://www.flickr.com/ Web which annotates photographs with tags), del.ici.ous (http://www.del.ici.ous/ Web which annotates bookmarks using tags), or other *collaborative webs*. However, the disadvantages that it presents emphasize the absence of expressiveness concerning the annotated information and the distrust regarding correct description of the concepts.

In any case, current efforts involving the Semantic Web are aimed at developing many Semantic Web applications and services (Motta and Sabou 2006; Martin et al. 2007; d'Aquin et al. 2008). These technologies, even development environments (Corcho et al. 2006; Brambilla et al. 2006), enable users to exploit the SW potential through the use of ontologies. Moreover, the Web 2.0, also known as *Collaborative Web*, attempts to converge towards the Semantic Web by using ontologies and mapping operations (Heath and Motta 2008; Ankolekar et al. 2007).

2.2 Databases

There is abundant literature on databases since they replaced the file-based model around forty years ago. The relational model proposed by Codd (1970) caused a revolution in the management of mass data repositories and new technologies for data representation and exploitation subsequently emerged: Object Oriented Databases for representing complex data (Kim 1990), Multimedia Databases for storing multimedia files (Marcus and Subrahmanian 1996), Parallel or Distributed Databases for sharing the load of data or processes (Özsu and Valduriez 1991), XML Databases for interacting with the Web (Graves and Goldfarb 2001), Deductive or Logic Databases for making deductions using the data (Borgida et al. 1989; Reiter 1982), Datawarehouses for analyzing and extracting new information (Berson and Smith 1997), and so on. Moreover, other knowledge representation methods, like Borgida (1995) or Reiter (1982), has tried to enhance the modeling power of databases using DL or FOL. All these proposals have complemented the lacks of relational databases specially in semantic representation. But, in any case, the relational model has become standard de facto for information representation in the last few decades and relational databases the predominant choice for application development because of its efficiency and flexibility.

2.2.1 Semantic web and databases

With regard to the Internet, databases have become quite relevant. Several technologies have been developed (ASP, JSP, PHP) to represent dynamic web pages and generate their contents using data stored in databases online. Environments such as dynamic web pages or front-end applications for querying open databases like ISQLPlus (Oracle©) (Oracle 2007) or WebinTool (Hu et al. 1996) enable information stored in a database to be made available through the web.

However, this technology presents several problems in a Semantic Web context, because the information cannot be semantically annotated. On one hand, the content of these databases is only shown when a query is performed in the database, and on the other, the semantic description of the database is represented using its schema, often unavailable or even useless because it can not be exploited depending of the format chosen to represent it.

Current trends attempt to relate databases and Semantic Web to retrieve more enriched results, because most data is represented in databases. Communication between both technologies involves using ontologies that establish the proper relationships, as is clearly explained in the following sections.

3 Ontologies versus databases

Despite of knowledge level modeling area has defined several representation models, none of them have been popularized as much as ontologies are in the last decade. Ontologies have involved a revolution in the area of computation science, specifically in artificial intelligence and database disciplines. On one hand, from the start, databases have represented real world information, but they impose several restrictions to ensure efficient information access and management. On the other, current ontology engineering processes have to deal with the same kind of problems that databases had to solve several years ago (Meersman 2001). Problems such as heterogeneous information, mapping searching, schema alignment, matching conflicts, translations, etc., present in the ontology representation process appeared similarly in the database area in the past (Ma 2005; Mena and Illarramendi 2001; Staab and Studer 2004; Hai 2005).

Consequently there is currently much discussion regarding whether a database should be considered an ontology. The scientific community generally considers ontologies as the best method for representing reality due to their capacity for semantic modeling of concepts. Ontologies use classes, properties, instances, aggregation relations, generalization relations, etc., and especially axioms represented mainly with logic languages, as descriptive logic or first order logic to add semantics to the models. But an ontology does not describe a specific computer representation for information and is consequently implementation-independent. Surprisingly, it is quite easy to find direct relations between an ontology and a database: A class can correspond with a relational table, a property with a relational attribute, generalization relations or constraints with axioms, etc. However, this comparison is indeed not as trivial as it might first seem.

Thus, an analysis of the similarities and dissimilarities between ontologies and databases is developed and the following results categorized:

- Conceptualization of the information.
- Data Representation (tuples vs. instances).
- Data modelization.
- Efficiency.

3.1 Conceptualization of information

The ontology community labels databases as *light weight* ontologies due to the way in which they represent the structure of the information and what the purpose they serve. This description means that a database schema is not considered as a real ontology (Gómez-Pérez et al. 2003a; Breu and Ding 2004; Noy 2004) because it mainly lacks of axioms that describe the reality in its representation. A database schema is a representation mechanism that is designed mainly to meet the requirements of a particular application or corporation, so when these requirements change, the viewpoint and the schema also need to be modified (Tran et al. 2007). In contrast, ontologies are the result of a collective effort and should therefore be shared among the community (Breu and Ding 2004; Unchold and Gruninger 2004). Thus, a database is the result of a teamwork and an ontology requires the coordination among several work groups (Konstantinou et al. 2008). In short, ontologies are considered independent from text and implementation and as such, operate on a higher level of abstraction. Data models are, in contrast, situated at the lower level of abstraction (Dillon et al. 2008).

With regard to ontology definition, several authors (Dillon et al. 2008) consider ontologies to be only those whose knowledge is shared and the meaning thereof is commonly agreed upon and used by the community. Thus, those representations which do not fulfil these criteria or are developed only for a specific application are not considered as ontologies. However, numerous ontologies currently being developed represent similar realities: Indeed, new Semantic Web applications are intended to develop ontology searchers, such as Watson (d'Aquin et al. 2007), OntoSearch (Zhang et al. 2005) or Swoogle (Ding et al. 2004).

Furthermore, ontologies do not need to distinguish between basic or complex data types and what is more, their properties have much more semantics than database datatypes, since ontologies do not need to be normalized (such characteristics make for easier the information sharing and merging) (Breu and Ding 2004).

In any case, all the disadvantages observed when using databases and which result from the absence of the capability to represent axioms (which add more semantics to the information modeled) can be solved with the use of logic-deductive databases and logic rules (Reiter 1982). Furthermore, there are many different multipurpose database systems for dealing with heterogeneous information, such as temporal databases, spatial databases, data warehouses, multimedia databases, transactional databases, etc.

3.2 Data representation

Information represented by ontologies mixes the schema specification with real data, that is, the instances. Furthermore, it is not necessary that an ontology has data. However, a database makes a clear distinction between schema and data.

Schema information are stored as tuples in the database dictionary, and can therefore be managed like the rest of the system data (Cullot et al. 2003; Unchold and Gruninger 2004). Thanks to the absence of such distinctions when using ontologies, instances of classes can be instanced again: This characteristic does not exist in the relational data model (unlike the object-oriented data model, which also allows such a characteristic). But this flexibility presents disadvantages since deductions cannot be made with ontologies using this functionality. Consequently, a new generation of the ontology language OWL, OWL2 (W3C OWL Working Group 2009) does not allow such characteristic.

Concerning with the instance definition process, an ontology does not follow any rule (Cullot et al. 2003), in fact, a new instance definition does not require any defined constraint to be accomplished - these are simply added. Alternatively, a database representation must accomplish all the requirements defined therein in order to ensure data integrity (several authors consider that it is the main goal of the databases Unchold and Gruninger 2004). More specifically, a database tuple cannot be included in the database if it does not satisfy all the semantic constraints of the schema, for example the *checks* constraints, and all the relational model constraints, such as *primary keys, foreign keys, null rules*, etc. Consequently, the closed world assumption is applied to the relational database model, which represents a big semantic loss in the process of modeling information (Unchold and Gruninger 2004).

On the other hand, ontologies use reasoners to solve these problems. These reasoners determine which instances belong to the ontology, depending on whether they accomplish all the constraints or not: For example, if they are coherent with the defined disjoint axioms, inheritance rules, etc. As a result, each time an instance check is required, the reasoner must be executed, contrary to database system, in which information integrity is always ensured.

Evidently, ontology reasoners are also used to extract new information from ontologies. In a similar way, query languages like SQL are used to develop such tasks in the database area. The main difference between both technologies is that reasoners can find new information regardless of whether data is defined therein. But, as regards databases, we can only obtain new information using the tuples stored in the system and new information related to the schema or mixing parts of the schema, and tuples (Unchold and Gruninger 2004) are never obtained. Also taxonomic reasoning is a fundamental part of the ontology modeling (Guarino and Welty 2000).

Apart from reasoners, Ontology Query Languages are also used for querying information in the ontology, for example, SPARQL or SERQL. These languages return information on relationships via predicates, inherent graph structure and triples, whereas the SQL language represents a flat and tabular structure of information stored in a dictionary.

The user would likely prefer to query the information using the richer vocabulary of the ontology. These queries can be made when the ontology represents the conceptual schema to access the information stored in a database. But this process is not easy, the query is formulated in a very complex environment involving the data dimension which is much larger than the knowledge dimension (Franconi 2008).

3.3 Modeling technique

Unlike ontologies, the conceptual model used for representing data in databases is considered by several authors (Spyns et al. 2002; Cullot et al. 2003; Meersman 2001; Ruiz and Hilera 2006) to be semantically more enriched than the descriptive logic models used for representing most ontologies. Nowadays, however, there are conceptual models for representing ontologies based on frames very intuitive as well. However, ontologies require a higher expressiveness level than conceptual models can offer. Several authors (Jean et al. 2006) consider that conceptual models do not accomplish the consensus and shared knowledge representation qualities, or that ontologies cannot be considered conceptual models because they are reusable, whereas conceptual models are reusable at a lower level (Mylopoulos 2007).

Database model differences have also been taken into account. The logic representation of a database does not specify the same level of semantics as a conceptual modeling of the same database. The limitations of the data model chosen establish the amount of semantic loss in the information representation. For example, extended entity-relationship schema or a UML diagram presents IS-A relationships that disappear when this schema is not properly converted to the corresponding relational logic model, i.e. SQL. However, the majority of these conversions do not change the semantics of the information represented meaningfully, as techniques exist to solve all the problems detected.

The same problem occurs with ontologies: Their semantics depends on the representation language. Thus, an ontology represented using a specific language, such as KIF, RDF, OWL or LOOM or an ontology generation tool, such as Protege, WebOde, WebOnto, etc. also raises its own semantic restrictions and limits. Even so, conversions between these languages or representations can lead to some semantic losses in the process or even some incompatibilities. These disadvantages do not occur in databases, specifically in the Object-Relational model, which theoretically uses a standard language, ANSI SQL (International Organization for Standardization (ISO) 1999) in all of its implementations (Oracle©, MySQL©, PostgresQL©, Access©, etc.). Indeed it should be emphasized that OWL is becoming the most extended ontology language, due to the Semantic Web appearance, and consequently is considered as a standard too.

On the other hand, ontology languages are more expressive in the sense of expressing more semantic concepts than database languages which only include constructs for defining or extracting data (Dillon et al. 2008). Moreover, ontology languages provide a more correct and precise domain conceptualization.

3.4 Efficiency

In the context of database models, efficiency plays a major role in their degree of popularity. Consequently, databases are also present in the ontology environment. More precisely, ontologies represent reality quite well, but this technology is not efficient in managing instances (data), since these are quite often represented in plain OWL or RDF file. Consequently, when the number of instances increases, they need to be stored in a database environment, and then the ontology then provides an interface that enables them to be accessed. Accordingly, database access is established through the use of the ontology, not through the database schema. Therefore, a large amount of proposals communicating databases with ontologies, specially relational databases due to their hegemony, have been released. These proposals, which are described in the following sections, have been classified according to how communication between both technologies is established.

4 Ontologies and DB communication

Communication between ontologies and databases can be established if information represented by ontologies corresponds to data described in a database in a certain way. In order to establish this communication Vysniauskas and Nemuraite (2006) pointed the following classification:

- Using the same conceptual modeling technique for representing ontologies and databases.
- Generating database schemas from ontologies
- Obtaining Ontologies from database representations
- Using OBDB (Ontologies Based Databases)

Developed proposals, which relate databases and Ontologies, are classified according to the following criterion.

4.1 Using the same conceptual modeling technique

This proposal establishes that if an ontology and a database share the same conceptual representation, the data communication is easier. This is the Brockmans et al. (2006) approach that uses the same UML representation for generating both an ontology schema and a database schema. Consequently, this proposal requires the use of specific tools and representation mechanisms to combine both representation models. This occurs, for example, when using the object-relational database model with UML.

4.2 Generating database schemas from ontologies

This proposal consist of using a preexisting ontology to generate a database schema. Some approaches achieve this goal, such as Vysniauskas and Nemuraite (2006) or Gali et al. (2005), who propose several procedures for generating database schemas from OWL ontologies, or the proposal by El-Ghalayini et al. (2007), which generates a database conceptual model from an ontology. The main drawback of this approach is that it leads to big important semantic losses in the translation process. On the other hand, a common practice in the ontology community involves using other techniques for storing the information defined as instances, that is, OBDB systems (Jean et al. 2006; Fankam et al. 2008), which are described in detail in Sect. 4.4.

4.3 Obtaining Ontologies from a database representations

This proposal is the most popular in the community and consists of generating an ontology from a pre-existing database schema. This technique, also called *Ontologies Inverse Engineering* (Astrova 2005), mainly attempts to facilitate access to the information stored in databases.

Basically, the process of generating an ontology from a database consists of establishing correspondences among the database schema and the new ontology. Specifically these correspondences are defined among the relational database schema elements and the fundamental ontology constructors, such as tables, attributes, and several constraints with classes, properties and axioms, respectively. However, the ontology can be enriched with another data analysis for detecting new kinds of relationships among concepts such as heritage, logic constrains, dependencies, etc. Astrova (2005) identifies tree different ways of generating ontologies, which are described below:

- Using database data. This is the approach by Astrova (2005, 2004) which first analyzes a relational data model and then data, to search extra semantic relationships. Moreover, Tijerino et al. (2005) use data stored in relations to find new relations or constraints, not only among data but even among different ontologies. Another approach for developing an ontology in a semiautomatic way from the content of a relational database can be seen in the proposal by Benslimane et al. (2006) which uses an analysis of HTML forms.
- Using queries analysis. For example, Kashyap (1999) constructs a simple ontology using the relational schema, but refines the representation using user queries. Unfortunately, this ontology does not create any axioms.
- Using an analysis of the relational database schema: There are many proposals related with relational databases, since they are the most widespread database representation model as was previously discussed. Juric and Skocir (2007) propose a mapping table to generate an OWL ontology and then enrich it with additional information sources. Stojanovic et al. (2002) analyse relations, constraints and dependencies among the elements of the relational database schema for generating the elements and axioms of the ontology. Champin et al. (2007) formally represents the relational model to develop a tool that represents any ontology in OWL. Doan et al. (2002) map classes and attributes automatically. Sonia and Khan (2008) generate an OWL ontology from relational database relations in the absence of metadata.
  Moreover, there are proposals that analyze a higher representation abstraction level, specifically the conceptual model of a database (e.g. entity-relationship diagrams) to obtain a domain ontology in OWL richer than the one based in the SQL Schema, as in the proposal of Jean et al. (2006). Upadhyaya and Kumar (2005) and Xu et al. (2004) also propose two different tools for obtaining an OWL ontology from conceptual schemas using several mapping rules. Cerbah (2008) develops RDBToOntoTool which derives accurate ontologies by taking advantage of both database schema and data (identifying taxonomies). This is the same level of abstraction proposed by Lubyte and Tessaris (2007), who define a language for defining an ontology, called DLR-DB from the conceptual model of the database described in UML or Entity-Relationship diagrams. Cure and Bensaid (2008) exploit relational database schemata to design an ontology. They use the previously generated conceptual model.

This category can also include proposals attempting to establish mappings between a pre-existing database and an ontology, as these mappings can represent the whole database as an ontology (Konstantinou et al. 2008). Some significant approaches are: (i) the Datagenie program (Gennari et al. 2007), developed by Gennari et al., which obtains an ontology through the establishment of mappings between the database and the ontology. (ii) Dou and LePendu (2006), Bizer (2003) and Barrasa et al. (2003) propose defining languages for declaring mappings among a database and an ontology. All these languages describe an ontology and its restrictions using an SQL Schema. These languages are called Web-PDDL, D2R Map and R2O (R2O is based on the D2R MAP) respectively.

However, other authors (Juric and Skocir 2007) identify several problems of this inverse engineering process, that is, the construction of an ontology based on a relational schema analysis can be limited by the completeness and correctness of input information. For instance, when database schemas are denormalized to improve the efficiency of the database, some interesting information, such as dependencies, can be removed, some semantic information can be lost in the process of translation to a logic schema, several names of attributes or tables do not have the actual meaning that they represent, etc. Moreover, some authors (Konstantinou et al. 2008) consider that a database schema does not provide explicit and formal semantics for the data: Thus, finding a correspondence is quite difficult, due to the existing heterogeneity between them.

4.4 Ontologies based databases

There are alternative ways to communicate a relational database with Ontologies. One of these consists of using the relational data model to store the data represented in an ontology. The main purpose of this proposal is to store the instances defined by an ontology, often forgetting the semantics that this ontology represents. This proposal, known as *Ontologies Based Databases*, is defined as a *database model that enables the ontology and the data to be stored in a common and single model* (Jean et al. 2006). This system should explicitly represent ontologies, data schema, data and links among data and their schema and between the ontology (Fankam et al. 2008). But this does not always occur, and several systems only focus on storing just the constituent elements and their relationships.

Some implementations of this proposal are: The Jean et al. (2006) proposal, which divides the definition of the ontology classes and their instances for storing them in a database. Roldán and Montes (2005) developed a tool to store OWL ontologies in a relational database using XML files as configuration files. Pan and Heflin (2003) store ontologies in an Access ©Relational Database Management System (RDBMS), generating a relation for every class or property. The hierarchy of classes is stored in a vista-based system. Fankam et al. (2008) proposes an architecture of an OBDB that extends the ANSI/SPARC with semantic data.

Other proposals involves tools or APIs to provide methods and models for storing the ontologies using a fixed database specification: there are three approximations that represent an ontology in a data relational model: (i)store triples, e.g. JENA HP Labs Semantic Web Programme (2007) implementation, (ii) store ontology model in a fixed database specification, e.g. Sesame (Broekstra et al. 2002; Kampman and Broekstra 2007) or OntoDB (Dehainsala et al. 2007). These systems implementing persistent storage in relational databases make use of flat relational tables. This representation enables the instances stored in a database to be efficiently stored and queried using RDF or OWL language. The main advantage of these proposals is the independence of any RDBMS implementation, because they represent data regardless the used repository. Methods for accessing to different RDBMS

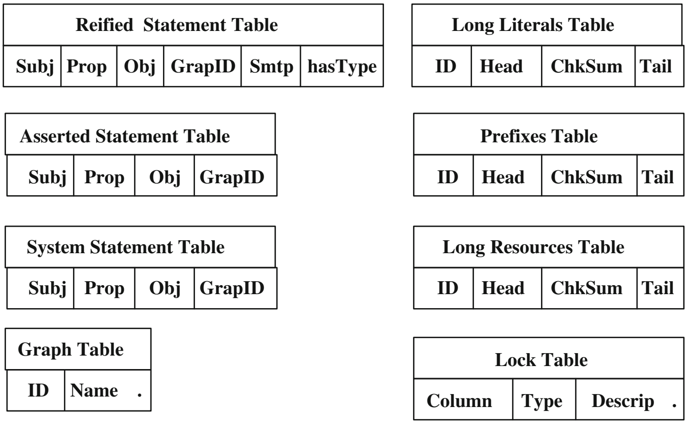


Fig. 2 JENA database layout

are specified in the APIs provided. As an example in Fig. 2 is shown the catalogue structure developed by JENA [1] for storing an ontology in a database. In short, this schema allows the ontology triples specification to be represented. Two types of statement tables are defined, one for asserted statements and another for reified statements. The resting tables store metadata as well as the long values for literals and resources in the statement tables. The statement tables may contain either the values themselves or references to values in the literals and resources tables. "Short" literals are stored directly in the statement table and "long" literals are stored in the literals table. Similarly, short URIs are stored directly in the statement table and long URIs are stored in the resources table. Obviously, this model has nothing in common with the conceptualization of a relational schema which organizes information according to its meaning. However, OBDB structures manages efficiently ontology information, specially, in the process of inferring data.

To summarize, there are several proposals for establishing communication between ontologies and databases. The use of one of them depends of the user needs: Thus, if a database exists, it can be used to generate an ontology. On the other hand, if a new concept representation needs to be developed and the semantic web is a prerequisite, an ontology might be the best choice. When the ontology needs to manage a repository, some mappings with a *"new"* database must be established, or a OBDB must be used. However, due to the hegemony of the Relational database, there are more proposals developed in this area, such as those described in Sect. 5. In any case, any choice involving a database and an ontology can be developed using any of the techniques shown.

5 Relational DB model representation

An alternative representation model consists of generating an ontology that describes the conceptualization of a relational database model. This proposal is the opposite of the OBDB proposal presented in the previous Sect. 4.4, because the aim of this proposal is to represent the basic elements of databases as an ontology and use them to represent the rest of the schema.

[1] http://jena.sourceforge.net/DB/layout.html.

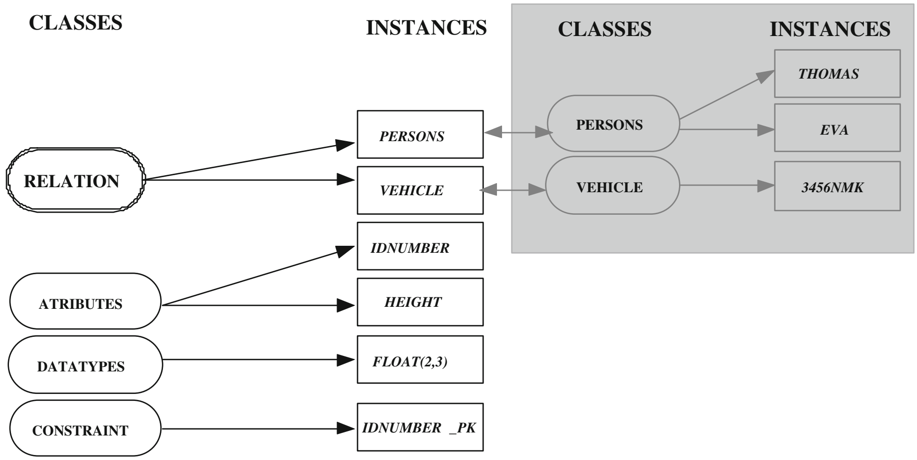


Fig. 3 Example of high level ontology and metaontology for representing the ANSI relational DB model Martínez-Cruz et al. (2008)

In view of all this, we can consider a database as an ontology, as the failings presented by the database model can be solved through the use of its analogous ontology. The process of defining a database in this proposal consists of: First defining the ontology, which represents the information of the data model, in this case, the relational database model. Such a representation is defined only once, and is hardly subject to change at any time. Subsequently, a database schema can be defined by instantiating the defined ontology. An example is shown in Fig. 3.

At this point, the distinction between a database schema and data is quite evident in the ontology. If the ontology has been represented as a *High Level Ontology*, a database schema is defined by instantiating it, but these instances cannot be instantiated again, as can be seen in the example in Fig. 3, shown against a white background. Consequently, the instances of the class *Relation* defines the tables *Person* and *Vehicle*, instances of the class *Attributes* defines *IDNumber*, and *Height*, etc. But these instances only describe the information domain, not the data itself. Most relational database which model ontologies use this kind of representation.

On the contrary, if the ontology has been defined as a *Metaontology*, or any classes have been defined as *metaclasses*, like the class *Relation* in the example shown in Fig. 3, instances of these classes also generate new classes, which is shown in Fig. 3 against a grey background. Therefore, *Persons* instances are automatically converted into a new class with the same name. This class could be instantiated again storing database tuples as ontology instances. This proposal has been developed by Martínez-Cruz et al. (2008, 2007), and shows how several problems have been identified with the metadata, like how to establish relations with attributes, domain definitions and others.

In short, once the ontology describing the structure of a database model is developed, the schema definition is defined as instances (and classes) of such an ontology. Therefore, final users can manage the information of a database as if it were an ontology, and then they can take advantage of all the advantages of ontologies, such as interaction with the Semantic Web.

Several proposals support this idea: Pérez de Laborda and Conrad (2005) propose Relational.OWL, a basic ontology that describes the relational data model to share information among heterogeneous databases using the OWL-FULL to represent the ontology,

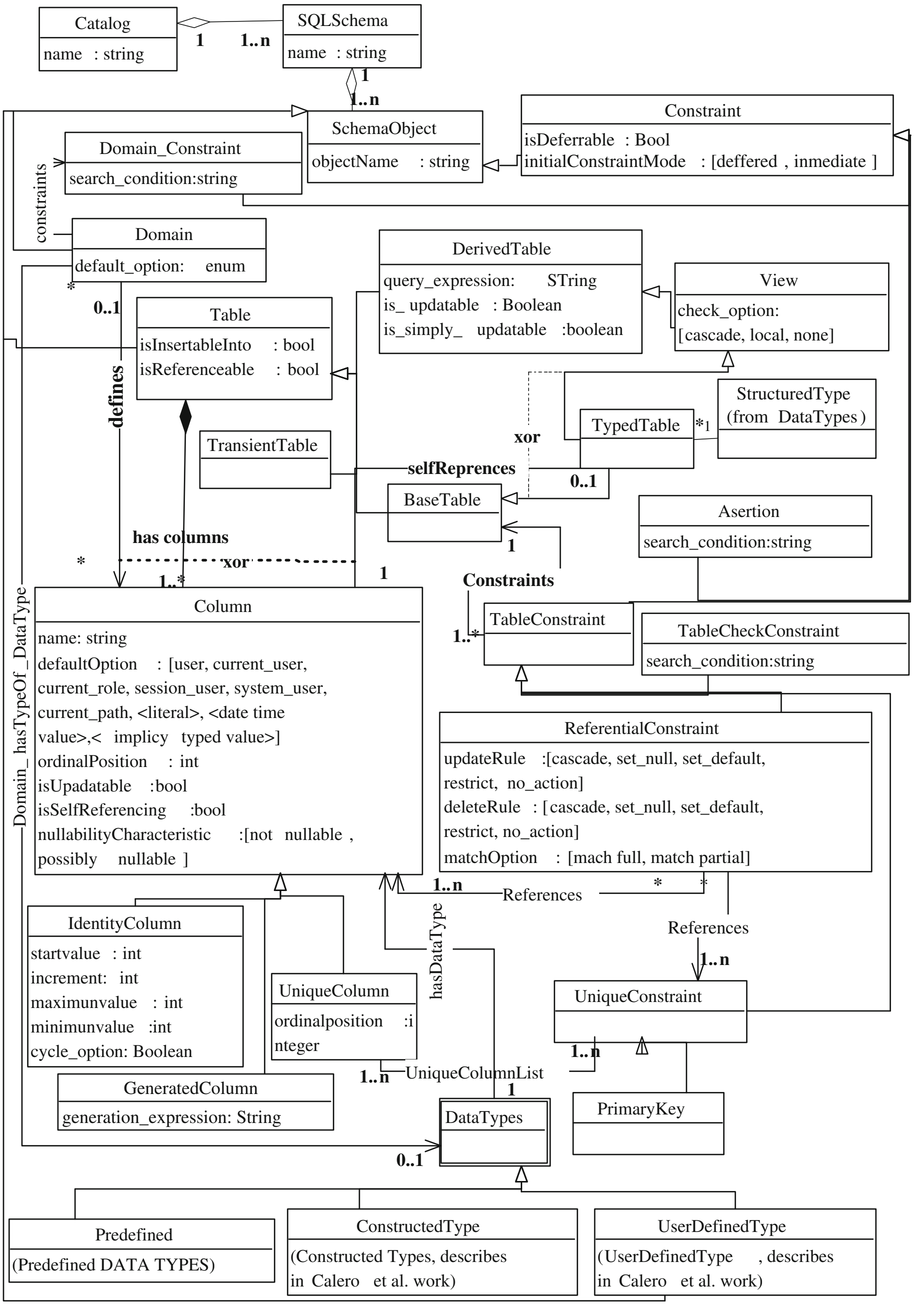


Fig. 4 Description of the ANSI SQL 2003 in UML by Calero et al. (2006)

Kupfer et al. (2006) present an ontology in OWL-Lite, called *Database Abstract Ontology*, which represents a database schema using the instantiation of such an ontology. Trinh et al. (2006) also propose an ontology called OWL-RDBO, which represents in OWL the basic

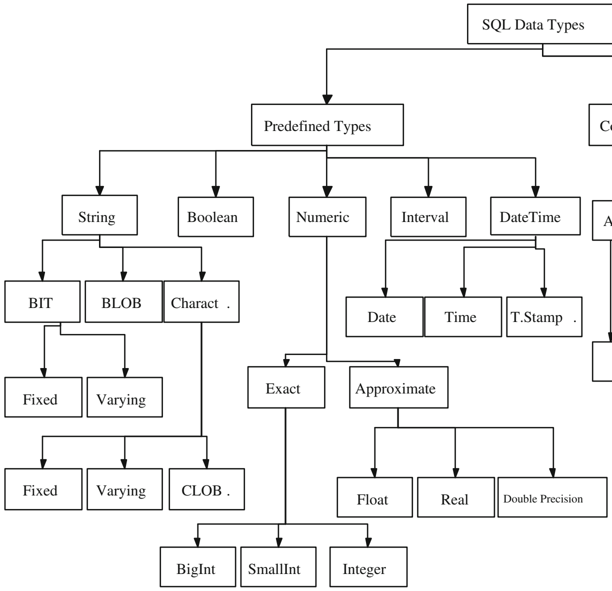


Fig. 5 Description of the ANSI SQL datatypes by Pardede et al. (2005)

element of a relational database and the semantic relations among them. Calero et al. (2006), Calero and Piattini (2006) represent the object relational database model formally described by the ANSI SQL 2003 (International Organization for Standardization (ISO) 2003). They use the UML model to describe this ontology which is shown in Fig. 4 and the OCL description to add the necessary constraints. Pardede et al. (2005) represent datatypes described by the ANSI SQL as a taxonomy, as can be seen in Fig. 5. Martínez-Cruz et al. (2008) unify the two previous ontologies, extending them to represent a fuzzy relational database in OWL-FULL. Concerning software proposals, Ontobase tool (Yabloko and Software 2007) represents the contents of a relational database automatically using Protégé (Gennari et al. 2003) as an ontology editor base tool.

5.1 Motivations for representing databases as ontologies

Some of the advantages of representing a relational database model as an ontology are described below:

- Makes the vision of a database simpler since it presents the model beyond a specific implementation of a database (Oracle, MySQL, PostgreSQL, etc.)
- Allows users access the database using another alternative to the classical one, that is, using a RDBMS client or the common applications.
- Represents the database information structure using the OWL or RDF language. This is useful in environments as the Semantic Web, where access to the semantic content of databases is not very common.
- Enables inclusion of the schema of the database in the Semantic Web, making possible the annotation of dynamic web pages or allowing to describe free databases accessible using front-end systems such as ISQLPlus©(Oracle 2007).

- Allows information sharing among heterogeneous database since the information represented is independent from any RDBMS specification.
- Allows establishment of relations among different models of data representations, this is, object oriented, ontologies, XML structures, RDFs structures, etc.
- Enables homogeneous management of distributed database.
- Allows an enrichment of the information represented in the database, since it is described as ontologies. They can therefore relate with other kinds of domain ontologies (using matching or alignment techniques), thus improving the quality of the information represented.
- Makes the representation of complex data types or different datatypes (e.g. temporal, spatial, fuzzy, etc.) easier to use. Thus, the user can manage any kind of information using the ontology, which is quite flexible in the management of any datatypes or representation of data.

6 Conclusions

Firstly, this paper describes a high level comparison about the two most widely used data representation models currently, they are databases and ontologies. Obviously, there are many works in the literature that compare knowledge bases and databases, however, no one tries to join the thoughts or answer the questions of the latest developers whose practical approaches are focused exclusively in relational databases or ontologies.

In this analysis, we cannot provide a simple answer to all the queries raised out in this paper, but we can try to extract several conclusions that can help the reader to come to his own conclusions. Ontologies and databases can represent the same reality, but depending upon the problem to be solved or the application to be developed one or another technology presents advantages, or even both.

There are no doubts as to the hegemony of relational databases in managing information. Other database environments have been developed to manage other kinds of data in a database, and we can therefore make deductions, extract knowledge or manage multimedia objects, etc. Obviously, all these technologies require specialization and integration procedures, and they are one-oriented-purpose. The main issue is that there are quite highly specialized database technologies for efficient management of a particular kind of data.

However, ontologies provide a restriction-free framework to represent a machine readable reality, even in the Web. This framework assumes an open world in which information can be explicitly defined, shared, reused or distributed. Moreover, information can also be interchanged and used to make deductions or queries. Such representation is widespread and used by most of the community, which has converted some of the languages used into de facto standards (such as OWL or RDF). Semantic Web plays an important role in this respect because of the emerging importance of Internet and the need to publish information therein.

Obviously, the decision to choose one or another technology depends on the final user's needs. If the information to be represented needs to be shared in the Web, an ontology should evidently provide a good solution. However, this decision probably would involve the use of both technologies, as a big amount of data needs to be stored and properly managed. Ontologies provide an excellent way to represent reality, but database is certainly the better method for storing such information when this is of considerable size.

Several mechanisms can be used for storing information represented in an ontology in databases: The two main trends involve the use of generic ontology environments which only use databases as a repository and do not consider how the information is stored (OBDB) or represent a proper database schema and subsequently establish the corresponding mapping relation with an ontology, using any of the previously described approaches.

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