A Semantic Approach to Metadata Management in Sensor Systems

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Abstract: With the increasing of multi-sensors system and the appearance of several standards for encoding metadata produced by sensors, the management and the interpretation of this metadata became hard due to their heterogeneity. In this paper we discuss the reasons, which drove to this high heterogeneity factor and we discuss the benefits of proposing a metadata integration system overcoming the heterogeneity issues. We also expose the challenges of its implementation.

Keywords: Semantic alignment, ontology matching, metadata interoperability, metadata management.

1. Introduction

Nowadays sensors are gaining more and more popularity with increased amounts of application areas (e. g., video surveillance, weather, military security, ionizing radiation, etc.). Sensors catch data for the processing and return the pertinent information as numeric values in order to use it for several application domains. Performant systems use multiple sensors in order to give precise and correct results (e. g., combining data from sound, video and speed sensors in order to detect potential danger in airports).

Using different technologies for capturing and storing different kind of data is the origin of a great heterogeneity. For instance, surveillance camera is one of sensors the most used in security systems. Within such systems, several processing services are applied in order to get the *semantic* information from video flows. Processing services use different technologies for extracting pertinent information from contents and using different tools for the description and storage of information. For example, MPEG7 descriptors are used in order to extract information from videos and images [1]. The data is stored in a specific MPEG-7 format that structure is defined by XSD language [2].

Dealing with knowledge from multiple independent metadata standards is one of the most important challenges in metadata domain due to the semantic and syntactic heterogeneity of information. Querying this heterogeneous metadata by multi-sensors system require a pre-knowledge about all existing metadata standards, which wean that the system must be able to interpret the meaning of metadata (semantics) and querying its encoding format. However, this requirement is hard to satisfy considering the numerous existing or future metadata standards.

An important prerequisite solution for this problem is to establish interoperability between the various metadata representations. This can be done by defining a framework for mapping and converting between the different metadata representations. The framework showed in Figure 1 represents the architecture of an integration system that can be used in order to resolve metadata heterogeneity problem.

This paper will first give an overview of metadata integration system that can be implemented as interoperability establisher for multi-sensors systems and we expose the challenges for its implementation. Then we show how to solve syntactic heterogeneity by converting all description language to a common representation, this step is called homogenization. Thirdly, we give an overview about some existing approaches for ontology matching, approaches that we believe that constitute a good candidate for the matching process. Finally, we give our point of view about some matching methods and we discuss some improvements.

2. Metadata management architecture system

Figure 1 shows the general architecture of metadata integration system that can establish interoperability of metadata produced by multi-sensors systems. This framework enables construction of single virtual integrated metadata source that presents information required by services or users dealing with metadata. With this framework user or service do need no pre-knowledge about all standards to be able to interpret their meaning.

User requests metadata from virtual integrated metadata source which is the interface between end user and all available metadata resources. Virtual integrated metadata source (common interface) send the query to metadata source mediator which will use translation rules to transform the query so it can be posed to the specific metadata sources containing the metadata corresponding to query. Translation rules are defined according to the semantic alignment done between the mediated schema and different schemas describing metadata standards. Finally, the mediator translates query results via rules back language used by virtual integrated metadata source.

To implement the framework described before, we have four main challenges which we should take into consideration [17]:

- *Syntactic heterogeneity due to the diversity of existing schema description language* – this kind of heterogeneity is resolved by the homogenization of all standards to a unique format able to express all semantics available in each standard. The conversion must capture all semantics in original schemas.
- *Finding the semantic alignment between mediated schema and sensor related metadata standards* – this step is called ontology matching and done after the homogenization.
- *Query translation rules definition* – according to the complex alignment done between mediated schema and metadata standards.
- *Identification of all information about a given object/event* encoded in different metadata format.

In this paper we will only talk about the two first challenges which are described in the next sections

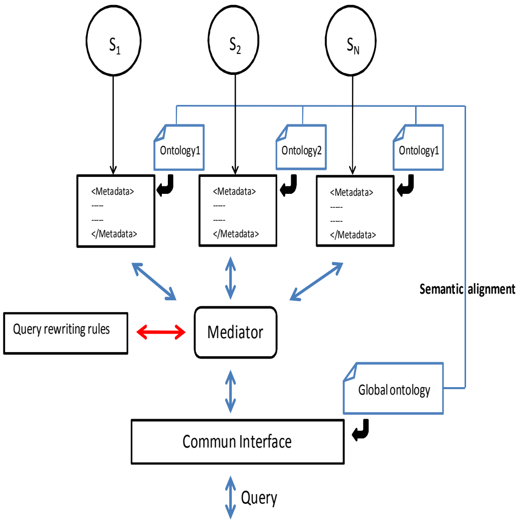

Figure 1: Metadata integration system architecture

3. Metadata Homogenization

Homogenization is a necessary stage to implement our suggested framework. In [3], authors consider that a common representation language is often necessary in order to create a semantic alignment between heterogeneous resources. Therefore, the challenge of this stage is to specify a translations rule to convert between different representations modalities (XML Schema [2], RDF Schema [8] and OWL[10] based languages).

These steps must be done with minimum lost of structural and semantic information. Several researches have been done during the last few years in order to resolve heterogeneity problem. Some of them focus on the syntactic level of resources to resolve semantic ambiguity [4]. Others have showed that using different syntax or different structure formalization is the sources of various errors when transforming a representation into another [5]. Since the emergence of XML, several multimedia standards have adopted XML to describe their metadata (SensorML [27], O&M [29], TML [28] , etc.).

The underlying schema definition language for XML metadata, XML Schema provides support for explicit structural, cardinality and datatyping constraints but provide little support for the semantic knowledge necessary to enable flexible dynamic mapping between metadata domains. RDF schema has appeared to cope with XML schema limitations. It provides support for rich semantic descriptions but provide limited support for the specification of local usage constraints. Finally, OWL appeared as extension of RDF Schema, it allows maximum expressiveness. These three description languages mentioned previously covers most of metadata representation standards. For this reason we will restrict our study on them for the framework we planned to implement.

In order to implement our suggested framework, we chose to use OWL-DL which is sub-language of OWL [10] as a common language. OWL-DL has a sufficient expressive for all types of metadata considered. Moreover, existing mapping approaches based on logic description methods cannot be applicable to OWL-Full ontology which is sometimes undecidable.

In order to convert XML Schema to OWL, several approaches have been proposed during the last few years to alleviate the lack of formal semantics in XML documents by converting this latest to OWL ontology. In [11], authors made a conversion only between XML schema and OWL without considering XML instance metadata. In [12], an approach to convert XML document to OWL ontology using XML Schema was proposed. If the XML Schema is unavailable, it is automatically generate it from XML data instance. In [13], authors proposed a framework for converting a single XML instance document to an OWL model. XSD2OWL[14] transforms an XML Schema to a series of OWL ontologies. Several ontologies are generated in order to alleviate some implicit semantic related to data typing and sequence ordering after the conversion of XML Schema. The XSD2OWL mapping has been applied to the MPEG-7 XML Schema producing an MPEG-7 Ontology. The results got from this conversion are interesting from our point of view due to semantic captured from XML schema. However, the ontology produced is OWL-Full which is undecidable. XS2OWL described in [15] is the algorithm that we think is more suitable for the homogenization step; this selection is done for three main reasons:

- Its output is an OWL-DL ontology which gives us the opportunity to use inference based on Description Logic [25] to find mappings;
- It conserves all structural information that can be used for the mapping;
- The XS2OWL model and its implementation have been applied to several well-accepted standards (IEEE LOM, MPEG-21, MPEG-7 and others) and its

results showed that the semantics captured are same with the manually created one [15].

Concerning the conversion from RDF Schema to OWL, we know that OWL is an extension of RDF Schema. It inherits all RDF Schema characteristics. Therefore, any document which is valid according to RDF Schema is valid as an OWL-Full ontology. However, this condition is not always satisfied for OWL-DL [16]. For this reason we must distinguish between OWL-Full and OWL-DL.

4. Ontology matching

The matching process [24] consists in finding relationships or correspondences between entities belonging to different ontologies. That is, given two ontologies, one should be able to map concepts found in the first ontology onto the ones found in the second one. Figure 2 schematized the matching process. The matching can have other parameters as input (e.g., similarity threshold) and other semantic resources in order to enrich and explicit the semantics of ontologies to be matched (e.g.: thesaurus like WordNet [23], DBpedia [21] and Yago [22] or other kind of semantic that can be helpful for matching).
A set of correspondences found between two ontologies by matching process is called alignment. When the alignment contains other types of correspondence more than the equivalence relationship (e.g., inclusion, subsumption, etc.), the alignment is called semantic alignment.

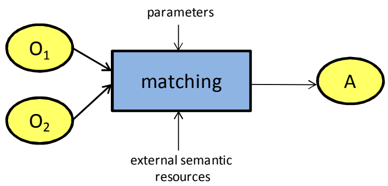

Figure 2: The matching process

Several matching algorithms have been proposed during the last few years, each of them has been implemented for a specific domain. Several surveys [18][19] about different existing method for ontologies alignment show that their applicability depends on utilization domain. Basic matching techniques can be classified into four categories [24]:

- *Name based techniques.* These techniques consider entities as sequence of letters. They calculate similarities between entities by using some string distances. If the similarity is greater then a threshold they consider that there is a correspondence between these entities. This technique is used for database integration but presents certain limitations for system with high level semantics and complex structures.

- *Structure based techniques.* Structure is helpful information for finding matching. Several matching systems using structure information of schemas have been developed [19]. These approaches, also referred in the literature as constraint-based make use of the internal structure of entities. Information about the set of properties of elements, the range of their properties, the cardinalities is used for the matching.

- *Instances based techniques.* When instances of schemas are available, they are very helpful of matching system. If two entities share an important number of instances, than there is a very probable alignment between these two entities. However, instances are often used in order the help ontology matching process, without using structural and semantic information instances that is not very suitable for our approach, where no pre-knowledge about instances is available.

- *Semantic based techniques.* These techniques often use external resources in order to get other information about entities and enriching the content of ontologies, (e.g., WordNet). Correspondences between the two ontologies to be mapped are also discovered by getting axioms from external resources. The axioms support the desambiguisation process by providing a common and formal representation tool.

  Matching systems combine several basic techniques and then they apply several methods in order to find correspondences between entities. Their methods come from different disciplines such as data analysis, machine learning, language engineering, statistics or knowledge engineering. In this article, we focus on *semantic based techniques.* We show how to exploit the expressive power of description logic and its reasoning techniques to implement ontology mapping.

5. Method considered for semantic metadata mapping

The semantic mapping process is a three steps process. The first one consists in associating explicit and common meaning to concepts issued from various standards created by communities having specific backgrounds. The explicit meanings are defined with regard to a neutral external semantic resource. In the following, we use WordNet to do explicitation. However other resources such as DBpedia or Yago can be considered as external resources in order to increase the neutrality of the explicitation process. Secondly, since external resources returns several synonyms set for each entity, structural information must be used in order to select the real meaning for each entity. This is done by keeping only synonyms having a relationship with other synonyms in children entities. Finally, we show how to validate the alignment using a Description Logic validation algorithm called Tableau algorithm [25].

5.1 Metadata explicitation

Because of the richness of natural language, different ontologies maybe use different terminologies to denote the same concept. The explicitation of concept meanings is a necessary step to offer adequate solution for facing the linguistic heterogeneity [20]. Explicitation is done by giving all possible interpretations of each concept via an external resource which contain a set of synonyms for each concept. We use WordNet [23] as an external resource for explicitation. WordNet is an on-line lexical reference system developed at Princeton University. It consists of synonym sets called *synsets*, and each *synset* represents a single distinct concept that can be associated with a given word.

For instance, Figure 3 is a part of Image description ontology created manually (fragment of DIG35). The explicitation of the embedded Organization concept is represented by seven synsets returned by WordNet : (Organization#1 $\cup$ …$\cup$ Organization#7). Each synset corresponds to a specific meaning of the Organization concept. For instance, the Organization#1 synset contains words (sister terms, hyponyms, etc) related to the notion of *a group of people who work together* and the Organization#2 synset contains words (sister terms, hyponyms, etc) related to the notion of *an organized structure for arranging or classifying*.

5.2 Semantic filtering

Concepts explicitation is a necessary step because it gives to each concept all possible interpretations for it. However, concepts explicitation can also result in a wide enlargement of the field of meaning of concepts. The selection of pertinent classes of concepts considered (sister terms, hyponyms, etc.) for each synset is an open issue. Sense filtering is a needful operation as it allows the selection of the real meaning of concept for a given context. In order to select the real meaning of a given concept C on the hierarchy H, sense filtering operation uses, the neighbours of C in the ontology definition ($C_{1,}\dots_{,}C_{1}$) with regard to the hierarchy H. Other resources can be also helpful for sense filtering operation (e.g.: extraction of information from documentation annotation, user comments, social tags …).

5.3 Mapping discovering using DL

Notwithstanding the existing approaches for ontology mapping, DL based techniques are more appropriate for that [25][9][30], since they rely on the explicit and formal semantics represented by ontologies. When used for comparing ontologies, they ensure that the original semantics of resources is preserved. Besides, DL provides an explicit and a formal interpretation of concepts.

A valid semantic mapping between two concepts C_1 and C_2 belonging, respectively, to ontologies O_1 and O_2 is a logical relationship ($\subseteq$ - left subsumption , $\supseteq$ -right subsumption, $\equiv$ - equivalence and $\perp$ - disjointness -).

DL Axioms		Set relations
$C1 \subseteq C2$	$\Leftrightarrow$	$C1 \cap \neg C2$ is unsatisfiable.
$C1 \supseteq C2$	$\Leftrightarrow$	$C2 \cap \neg C1$ is unsatisfiable.
$C1 \equiv C2$	$\Leftrightarrow$	$C1 \cap \neg C2$ is unsatisfiable and $C2 \cap \neg C1$ is unsatisfiable.
$C1 \perp C2$	$\Leftrightarrow$	$C1 \cap C2$ is unsatisfiable.

Table 1: DL axioms and corresponding set relations

This logical relationship can be computed starting from the explicitation results obtained from external resource and depending on the nature of the relationship it must satisfy one of the set operations presented in Table 1.

In order to do inference between concepts, the relationships between concepts in mediated schema and concepts in other metadata standards are computed by using the explicitation results provided by external resource. The results are transformed to the axioms as the premises of inference. To obtain this kind of axioms we analyze the relationship within the synsets provided by WordNet. WordNet organizes terms based on the semantic relations of them. Hence, these relations are the origin of the generation of axioms. The Table 2 here bellows shows the transformation of relations of terms from WordNet to corresponding subsumption axioms.

Relations in WordNet	Subsumption axioms
$term_1$ *meronym* $term_2$	$term_1 \subseteq term_2$
$term_1$ *holonym* $term_2$	$term_2 \subseteq term_1$
$term_1$ *hyponym* $term_2$	$term_1 \subseteq term_2$
$term_1$ *hypernym* $term_2$	$term_2 \subseteq term_1$

Table 2: WordNet relations vs. subsumption axioms

Once the axiom is obtained by analyzing the retrieved WordNet synsets, we use Tableau algorithm that can be easily applied to DL as illustrated in [26]. The Tableau algorithm establishes the relationships between concepts by observing one of the four conditions of satisfaction mentioned above, which corresponds to the axiom to be validated.

Tableau algorithm belongs to a class of algorithms that use subsumption expansion in order to prove the satisfability of a relation (e.g. $C1 \subseteq C2$). The Tableau algorithm expands each ontology concept by considering the subsumption axioms. In our case, the axioms are deduced from WordNet relations. Then it tries to prove the satisfiability of the considered relation by verifying the coherence of the set relations as indicated in Table 1. The relation itself can be seen as a *complex* concept (C) that is defined by the associated set relations.

The algorithm exhaustively applies tableau rules which decompose the syntactic structure of this *complex* concept in order to construct a so-called *completion* tree. Each node (x) of a *completion* tree is labeled with a concept set $L(x) \subseteq sub(C)$ where sub(C) is a set of sub-concepts composing the concept C. Each edge $<x, y>$ is labeled by $L(<x, y>) = R$ for some role R occurring in $sub(C)$, where the $sub(C)$ is the set of sub-concepts of C.

The algorithm terminates when the graph is complete (no further inference is possible) and returns "mapping satisfiable", or when contradiction have been revealed and return in this case "mapping unsatisfiable"; see [25] for details. This contradiction is called a *clash* and means that for some concepts C, $\{ C_1, \neg C_2 \} \subseteq L(x)$. This means that C_1 and the negation of C_2 co-occurs and hence the subsumption relation is unsatisfiable.

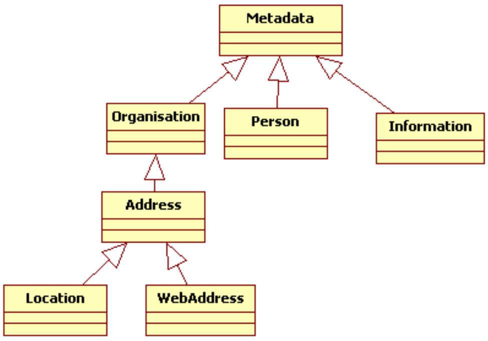

Figure 3: Fragment of DIG35 (Ontology created manually)

In the following we illustrate how Tableau algorithm can be used to validate a mapping between two concepts belonging to two different schemas. We use a fragment of the DIG35 standard (see Figure 3) and the mediated schema proposed in Figure 4.

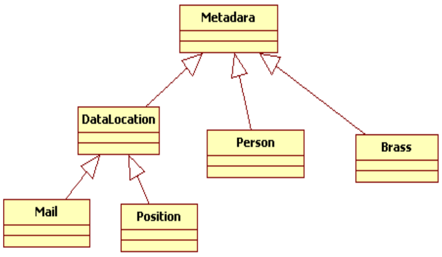

Figure 4: Mediated Schema

Firstly, we start to extract the logic formula for each concept in the two schemas , this step is done after concepts explicitation step:

C_1 = C (Organization)
=(Organization#1∪…∪Organization#7)∩
(Metadata#1) (1)

C_2 = C (Brass)
=(Brass#1∪…∪Brass#7)∩
(Metadata#1) (2)

Secondly, we apply the sense filtering operations on available *synsets*. The aim of this filtering is to identify which one of the *synsets* is closer to the meaning of the concept in the ontology where he was initially defined. Hence, the sense filtering operation is taking into account the context of the source ontology by examining the neighboring concepts. For instance, if we consider the DIG-35 fragment considered, *synsets* associated with the Organization concept but containing terms which are not at all related with at least one of neighbouring concepts: location, address or image will be left out. Same filtering is applied to the Brass concepts in the mediated schema.

In the current example, the Organization#1 and Brass#1 *synsets* are the result of filtering operations. Both *synsets* refer to "*the persons (or committees or departments etc.) who make up a body for the purpose of administering something*". As they are belonging to the same synset then they can be represented by the same label, which means that there is an equivalence relationship between the two atomic concepts according to WordNet. However, this is not always true when considering complex structures because the meaning of a given atomic concept depends also on its hierarchy in the schema. Therefore, this relationship is considered as an axiom and has to be validated. The axiom stating that C_1 and C_2 are equivalent is explicitated here bellow:

$C_1 \equiv C_2 \Leftrightarrow C_1 \cap \neg C_2$ is unsatisfiable and $C_2 \cap \neg C_1$ is unsatisfiable.

The tableau algorithm initializes a tree T which contains initially only one node x_0, called the root node and labeled with the following concept set : $L(x_0) = \{C_1 \cap \neg C_2\}$. We apply tableau rules in order to expand it with regard to the axioms extracted from the ontologies. If tableau algorithm returns unsatisfiable for C1 ∩ ¬ C2 as well as for the second tree computed starting from the concept set C2 ∩¬ C1, then the axiom C1≡ C2 can be considered as a valid mapping. Hence, with the extracted axioms and applying the Tableau algorithm we found that there is a valid semantic mapping between Organisation and Brass concept in the ontologies that we considered.

6. Conclusion

This paper has given an overview of metadata heterogeneity problems and discussed issues related to an integration system based on DL. We have shown how to homogenize different metadata format in order resolve syntactic heterogeneity of existing schema description languages. Homogenization is achieved by translating all schema specifications (done mainly in XML Schema or RDF Schema) to OWL-DL. Homogenization methods that preserve the structural information of originals schemas and that capture source schema implicit semantics were presented. We have migrated all schema description to OWL-DL as this ontology language fits well with metadata semantics representation and it supports DL reasoning. DL is a powerfull logical framework issued from the domain of knowledge representation which exhibits high expressiveness constructs. In order to facilitate the mapping between concepts, the precise meaning of concepts within the given context must be first explicitated. This is done via external resources in order to give all possible interpretation of concepts. As we have shown explicitation it must be done in order to select the real meaning of each concept with respect to a given context. Once all these steps are done, the mapping can be seen as a DL axiom which must satisfy some conditions. Conditions validation can be tested using Tableau algorithm and its rule-based extension mechanism.

We have shown DL characteristics and its advantages to discover a mapping between mediated metadata ontologies. Since DL is monotonic, we also consider getting other semantic resources involved especially in the explicitation process. They allow enriching schema semantic, sense filtering, enhancing semantic mapping between concepts. An external resource does not mean necessary thesaurus such WordNet but any kind of information that can be extracted from other corpus (e.g, user comment, social tags, documentation provided by communities that have created multimedia metadata standards, etc). Since these corpuses contain fuzzy information, we consider testing other methods based fuzzy logic or probabilistic approaches for discovering semantic mapping.

7. Acknowledgement

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8. References

[1] Ioan Marius Bilasco, Jérôme Gensel, Marlène , Villanova- Oliver and Hervé Martin: *On indexing of 3D scenes using MPEG-7*. ACM Multimedia, Hilton, Singapore, 2005.

[2] Thompson, H. S., Mendelsohn, N., Beech, D. & Maloney, M. *W3C XML Schema Definition Language (XSD) 1.1 Part 1: Structure*. W3C Candidate Recommendation 30 April 2009, http://www.w3.org/TR/xmlschema11-1/

[3] Kalfoglou, Y., & Schorlemmer ,M. *Ontology mapping: the state of the art*, The Knowledge Engineering Review, 18 (1), pp 1-31, 2003.

[4] Chaudhri, V. K., Farquhar, A., Fikes, R., Karp, P.D. & Rice, J. P. *OKBC A programmatic foundation for knowledge base interoperability*, the 10th Conference on Innovative Applications on Artificial Intelligence, Wisconsin, USA, 1998.

[5] Bowers, S., & Delcambre, L. *Representing and transforming model-based information,* First Workshop on the Semantic Web at the Fourth European Conference on Digital Libraries, Lisbon, Portugal, pp. 18-20. 2000.

[6] WG12: Learning Object Metadata– *Learning Object Metadata Standard*. http://ltsc.ieee.org/wg12/, IEEE LTSC : IEEE 1484.12.1-2002.

[7] Advanced Distributed Learning (ADL) Technical Team : *Sharable Content Object Reference Model (SCORM)*. 2004.

[8] Antoniou, G. & Harmelen, F. V. *A Semantic Web Primer*, Second edition. Cambridge, MA: The MIT Press, 2008.

[9] Samir Amir, Ioan Marius Bilasco, Md. Haidar Sharif, Chabane Djeraba: *"towards a unified multimedia metadata solution"* Intelligent Multimedia Databases and Information Retrieval: Advancing Applications and technologies, IGI Global, 2010.

[10] Patel-Schneider, P. F., Hayes, P. & Horrocks, I, *OWL Web Ontology Language Semantic and Abstract Syntax,* W3C recommendation, URL: http://www.w3.org/TR/owl-semantics/. 2004.

[11] Matthias, F., Christian, Z., & David, T, *Lifting XML Schema to OW,*. 4th International Conference of Web Engineering, Munich, Germany, 2004.

[12] S. Battle *Round tripping between XML and RDF*, International Semantic Web Conference, Galway, Ireland, 2004.

[13] Bohring, H. & Auer, S, *Mapping XML to OWL Ontologie,*. volume 72 of LNI, Leipziger Informatik-Tage,, 2005.

[14] Garcia, R., Celma, O.: *Semantic integration and retrieval of multimedia meta-data,* International Workshop on Knowledge Markup and Semantic Annotation at the Fourth International Semantic Web Conference, Galway, Ireland, 2005.

[15] Chrisa, T., & Stavros, C. (2007). *Interoperability of XML Schema Applications with OWL*, OTM, Part I, LNCS 4803, pp. 850–869, Domain Knowledge and Semantic Web Tools. In *On the Move to Meaningful Internet Systems*, 2007.

[16] Patel-Schneider, P. F., Hayes, P. & Horrocks, I, *OWL Web Ontology Language Semantic and Abstract Syntax*, W3C recommendation, URL: http://www.w3.org/TR/owl-semantics/

[17] Samir Amir: "*un système d'intégration de métadonnées dédiées au multimédia*", INFORSID, Toulouse, France, 2009.

[18] Shvaiko, P. & Euzenat, J. *A Survey of Schema-based Matching Approaches* Journal on Data Semantics IV, pp. 146-171, 2005.

[19] Rahm, E. & Bernstein, P. A. A *survey of approaches to automatic schema matching*, Springer-Verlag 2001.

[20] Bouquet, P., Serafini, L., & Zanobini, S, *Semantic Coordination: A New Approach and an Application*, International Semantic Web Conference, Hiroshima, Japan 2004.

[21] Auer, S. Bizer, C. Kobilarov, G. Lehmann, J. Cyganiak, R. & Ives, Z. *DBpedia: A Nucleus for a Web of Open Data* , Volume 4825/2008, pp. 722-735, 2008.

[22] F. Suchanek, Kasneci, G. , & Weikum, G. *Yago - A Large Ontology from Wikipedia and WordNet*, Elsevier Journal of Web Semantics, Vol. 6(3), pp. 203-217, 2008.

[23] Fellbaum, C. *WordNet: An Electronic Lexical Database*. The MIT Press, Cambridge. 1998

[24] Jerome, E. Pavel, *Ontology Matching, Springer, 2007.*

[25] Baader, F., Calvanese, D., McGuinness, D. L., Nardi, D. & Patel-Schneider, P. *The Description Logic Handbook, Theory, Implementation, and Applications.* Cambridge University Press, 2003.

[26] Baader F, Sattler U. *An Overview of Tableau Algorithms for Description Logics*, Studia Logica, Vol. 69(1), pp. 5-40, 2001

[27] Mike Botts., Alexandre Robin *OpenGIS Sensor Model Language (SensorML) Implementation Specification* University of Alabama in Huntsville, 2007.

[28] Steve Havens, *Transducer Markup Language (TML) Implementation Specification,* University of Alabama in Huntsville 2007.

[29] Simon Cox, *Open Geospatial Consortium Observations and Measurements – Part 1 - Observation schema*. University of Alabama in Huntsville 2007.

[30] Dan A. Simovici, Chabane Djeraba : *Mathematical Tools for Data Mining: Set Theory, Partial Orders, Combinatorics,* Advanced Information And knowledge processing, Springer, ISBN 978-1-84800-200-5, 2008.