ENHANCING SEMANTIC INTEROPERABILITY AMONG SEMANTIC RESOURCES FOR CONSTRUCTION

Catarina Ferreira da Silva[1], Celson Lima[2], Lionel Médini[3], Parisa Ghodous[4], and Alain Zarli[2]

ABSTRACT

This paper proposes an application of fuzzy logic to assess the quality of (semantic) mappings linking concepts from two Semantic Resources[5]. The "*fuzzification process*", i.e., the way of modelling fuzzy membership functions and assigning membership, is based on the definition of the concepts semantically mapped, as well as on the common semantics associated to those concepts, such as properties, equivalent terms and annotations.

The work presented here extends the results achieved by the FUNSIEC project, which investigated the feasibility of creating an Open Semantic Infrastructure for the European Construction Sector (OSIECS). FUNSIEC produced a set of mappings amongst concepts from four semantic resources (e.g. IFC, ISO 12006-3, e-COGNOS, bcXML) currently available for the European Construction sector. We argue that semantic interoperability (at least in Construction) can be improved if we devise a way to measure the *quality* of the mappings. The challenges foreseen, conclusions and work to be done are also discussed here.

KEYWORDS

Semantic Resources, ontology, semantic interoperability, semantic mappings, fuzzy logic.

[1] PhD student, CSTB, Centre Scientifique et Technique du Bâtiment, Sophia-Antipolis, France, catarina.ferreira-da-silva@cstb.fr
LIRIS, Laboratoire d'InfoRmatique en Image et Systèmes d'information, CNRS UMR 5205, Université Claude Bernard Lyon 1, 43, boulevard du 11 novembre 1918, F-69622 Villeurbanne cedex, France, catarina.ferreira.da.silva@liris.cnrs.fr

[2] Researchers, CSTB, Centre Scientifique et Technique du Bâtiment, F-06904 Sophia-Antipolis, France, {c.lima ; alain.zarli}@cstb.fr

[3] Associate Professor, LIRIS, Laboratoire d'InfoRmatique en Image et Systèmes d'information, CNRS UMR 5205, Université Claude Bernard Lyon 1, 43, boulevard du 11 novembre 1918, F-69622 Villeurbanne cedex, France, lionel.medini@liris.cnrs.fr

[4] Full Professor, LIRIS, Laboratoire d'InfoRmatique en Image et Systèmes d'information, CNRS UMR 5205, Université Claude Bernard Lyon 1, 43, boulevard du 11 novembre 1918, F-69622 Villeurbanne cedex, France, parisa.ghodous@liris.cnrs.fr

[5] The *Semantic Resources* expression is a term coined in the SPICE project to refer to controlled vocabularies, taxonomies, ontologies, etc.

INTRODUCTION

More and more software tools rely on Semantic Resources (SRs) to accomplish their goals. SRs are generally heterogeneous and based on different representation models. Heterogeneities among SRs are the source of lack of interoperability when trying to use different SRs. Surmounting interoperability problems by dealing with different types of heterogeneities has been extensively discussed (Kashyap and Sheth 1994, Cruz et al. 2002, Park and Ram 2004). Information heterogeneities are grouped in the main following types: syntactic/format, structural/schematic and semantic (Ouskel and Sheth 1999), which have their counterparts of interoperability concerns. Semantic heterogeneity has been recognised initially in the field of databases as one of the toughest problems to bring out semantic interoperability (Kashyap and Sheth 1997). Semantic interoperability is the ability to exchange information and use it, ensuring that the precise meaning of the information is understood by any other application that was not initially developed for this purpose (Hughes 2004).

Semantic interoperability enables systems to process in a meaningful way the information produced by other applications and, as such, it represents an important requirement for improving communication and productivity. Indeed semantic interoperability is a precondition for software agents to exchange and communicate using different SRs.

Interoperability is living a paramount impetus demonstrated by the following facts: (i) the work carried out by the semantic web working group; (ii) the increasing number of standards (formal and *de facto*); and (iii) the huge investment made by the European Commission in interoperability-related projects, such as INTEROP[6], ATHENA[7] and InteliGrid[8].

In the semantic web context, where semantics and interoperability are key concepts, SRs play a strategic role in supporting semantic applications (Berners-Lee et al. 2001). More and more SRs have been created and published on the web. Due to the absence of *the* standard guiding the creation of SRs towards interoperability, there is a growing need to deal with several semantically heterogeneous SRs, i.e. to semantically link them.

In the e-Construction sector, the CEN/ISSS eConstruction Workshop delivered guidelines on how to build interoperable SRs (Böhms et al. 2004). In order to move a step further in this direction, the FUNSIEC project (Lima et al. 2005a) evaluated the feasibility of creating an Open Semantic Infrastructure for the European Construction Sector, named OSIECS. The FUNSIEC quest was to verify if it would be possible to identify and establish links (semantically speaking) amongst SRs tailored to the European Construction sector. In order to answer that question, FUNSIEC (supported by its own methodology) carried out the design and partial implementation of the OSIECS Kernel (a semi automatic piece of software), which in turn produced the OSIECS meta-model and OSIECS model. Briefly,

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[6] INTEROP stands for Interoperability Research for Networked Enterprises Applications and Software and more information can be found at http://www.interop-noe.org/

[7] ATHENA stands for Advanced Technologies for interoperability of Heterogeneous Enterprise Networks and their Applications. More information is available at http://www.athena-ip.org/

[8] The InteliGrid project is about Interoperability of Virtual Organizations on a Complex Semantic Grid. More information is available at http://www.inteligrid.com

OSIECS meta-model and model are respectively the set of tables mapping the meta-schemas and the schemas of the SRs forming OSIECS.

In order to extend the FUNSIEC results, the quality of the mappings produced which needs to be measured. Our basic goal is to answer the following question: *how good are the mappings*? Additionally, how can we use them? We argue that semantic interoperability amongst semantic resources can be enhanced if we are able to assign "degrees of quality" to each mapping identified and established.

The paper is structured as follows. Initially the related work is presented. This is followed by the context of work, together with the FUNSIEC methodology and the FUNSIEC results. Then we discuss the assessment of the FUNSIEC mappings using fuzzy logics. Finally, the last section draws some conclusions, identify the current challenges, and points out the future work and our expectations.

RELATED WORK

The literature presents several terms used in the same way *mapping* is used here, such as *alignment*, *merging*, *articulation*, *fusion*, *integration*, and *morphism* (Abels et al. 2005, Kalfoglou and Schorlemmer 2003, Euzenat et al. 2004).

Following the categorisation presented in (Euzenat et al. 2004), several methods can be used to find mappings between SRs, namely terminological, structural, extensional (i.e. based on instances) and semantic methods. Those methods come from different disciplines such as data analysis, machine-learning, language engineering, statistics or knowledge representation. On one hand, their applicability depends on the type of SRs features (e.g. labels, structures, instances) to be compared. On the other hand, they depend on the expected type of results. For the sake of conciseness we only mention here five systems/techniques presenting similarities to our work.

The Anchor-PROMPT (Noy and Musen 2001) tool determines possible points of similarity between ontologies by applying a structural approach. It takes as input a set of pairs of related terms – called anchors – from the source ontologies and traverses the paths between the anchors in the corresponding ontologies. A path follows the links between classes defined by the hierarchical relations or by slots (i.e. properties or no-hierarchical relations) and their domains and ranges. The authors say that Anchor-PROMPT does not perform well when the ontologies used as input are structured in a very different way.

The ONION (Mitra et al. 2000) system uses both graph-based and lexical techniques to suggest articulations. The former looks for similarities between nodes, such as similar attributes and common parent nodes. The latter uses external resources such as a thesaurus (e.g. WordNet) or a generated textual corpus. In our opinion, when the SRs being mapped are very domain specific, a generic thesaurus as an external resource for supporting textual terms comparison may not produce accurate semantic mappings. Indeed, concepts representing a given business domain are very context-dependent and hold specific definitions that generally differ from the generic ones. On the other hand, the generation of a relevant textual corpus for the SRs domain may represent a very high cost.

The iMapper tool (Xiaomeng and Jon Atle 2004) uses information retrieval techniques to identify mappings between ontological concepts. In particular, the mapping identification is based on the set of textual documents (represented as vectors of words) that are assigned to ontological concepts. The quality of the mappings depends on the number of instances of documents per ontological concept and on the natural language processing techniques to extract textual information (from documents) to construct the vectors of words.

The APFEL alignment process (Ehrig et al. 2005) produced interesting results based on a machine-learning approach. However, this methodology can only be successfully applied when a lot of instances are available. Moreover, training examples are also required which, according to the authors, represents a big challenge due to the absence of real examples. They have used initially a number of 160 possible alignments manually assigned.

Semantic methods may apply reasoning techniques. Most of computer-enabled reasoning that try to yield valid arguments is based on logic formalisms. Examples of Semantic methods are the propositional *satisfiability* techniques (Giunchiglia et al. 2004) and the description logic (DL)-based techniques (Baader et al. 2003). In the alignment of SRs, the propositional *satisfiability* (SAT) techniques aim to translate the matching problem, namely the tree-like structures (e.g., concept hierarchies) and mapping queries (i.e. pair of nodes and a possible relation between them) into a propositional formula and then to check if it is valid.

DL-based techniques rely on explicit and formal semantics represented by ontologies. Standard DL techniques apply *subsumption* algorithms used by some inference engines to establish relations amongst concepts.

Formal semantic methods enable to retrieve valid correspondences according to the unambiguous semantics of SRs and input axioms. The basic assumption behind semantic methods is that they intend to discover relations between (pairs of) entities (concepts, relations, etc.) belonging to different schemata based on the meaning of those entities. We agree with Bouquet et al. (2004) when they claim that mapping should have an explicit and formal semantics, as this is the minimal condition for their usability in any semantic-based application. Moreover formal and explicit semantics is crucial to automated deduction.

It is worth noting that literature does not provide many examples showing the applications of DL-based inference engine for detecting mappings between concepts of different SRs based on the explicit and formal definitions of the concepts of SRs. Therefore, we could not find similar works that would help us to make a close comparison with the technique applied in FUNSIEC project.

CONTEXT OF THE WORK

The core subject in FUNSIEC work was semantic interoperability. SRs are available in many forms and flavours even though their effective use (and exploitation) is still in a very embryonic level. The European Construction sector is not an exception, although it has been offered several results produced by international initiatives at standardisation level (e.g. CEN eConstruction workshop, IFC model, International Framework Dictionary, LexiCon Barbi, bcXML language, e-COGNOS ontology, etc).

Taking these results into account, the FUNSIEC project targeted the feasibility of building an Open Semantic Infrastructure for the European Construction Sector (OSIECS). Such an infrastructure was to be built by selecting semantic resources devoted to construction, exploiting some public results produced by international initiatives and European funded projects. A methodological approach was devised to support this work. The innovation in OSIECS is on the semantic mappings established among the existing semantic resources.

FUNSIEC developed its own methodology base on strengths of several established methodologies (Lima et al. 2005b). Shortly, it comprises the following phases: (*i*) *Domain Scoping*: characterisation of the domains covered by OSIECS; (*ii*) *SRs Identification*: SRs used to form OSIECS are identified and selected based on the analysis of features relevant to the FUNSIEC context; *(iii) Conversion and Similarities*: handles syntax-related problems as well as semantic heterogeneity and detection of correspondences among SRs; (*iv*) *OSIECS Meta-model and Model*: mapping tables produced by OSIECS Kernel representing the *meta-level* and the *level* itself; (*v*) *Testing & Validation*: assessment of the OSIECS *Triad* (Kernel, Meta-model and Model); and (*vi*) *Maintenance*: this phase is about correcting and updating OSIECS during its working life, which includes the work reported here.

THE FUNSIEC RESULTS

The FUNSIEC methodology is the first output of the project. The OSIECS *Triad* (*i.e.*, the OSIECS Kernel, the OSIECS meta-model, and the OSIECS model) are the major results of the application that methodology.

The OSIECS Kernel is a semi-automatic software tool that produces the OSIECS meta-model and the OSIECS model. It is composed by the Syntax Converter, the Semantic Analyser, the Converter, the Detector of Similarities, and the Validator. Experts are required to ‘feed’ properly the OSIECS Kernel in order to make the best use of it. The operation of the OSIECS Kernel is detailed described in (Lima et al. 2005b).

OSIECS META-MODEL AND MODEL

The following SRs were used as input to the creation of OSIECS meta-model/model: *bcBuildingDefinitions* taxonomy, e-COGNOS ontology, ISO 12006, and the IFC model (kernel only).

OSIECS meta-model and model are mapping tables showing semantic correspondences between concepts coming from different SRs. The OSIECS Kernel uses the ‘reasoning services’ of FUNONDIL to determine and identify semantic correspondences, i.e., the relations between pair of entities belonging to different SRs. The FUNONDIL inference engine uses two ontologies as input (*O* and *O'*) and a small set of axioms (*A*), producing a set of inter-ontology axioms (*A'*) that represents the mappings.

Four types of mappings are produced, namely *equivalence*, *subsumption*, *conjunction* and *transitivity*. E*quivalence* means that the concept A is 100% equivalent to the concept B, considering the semantic expressed in each SR. *Subsumption* has a rank relation that defines the relation subconcept → superconcept between concepts A and B, representing a subset relationship between the set of objects described by the two concepts. The *conjunction mappings* are consequence of the mappings obtained in the previous stage. Indeed a conjunction mapping represents a subsumption relation between two conjunction relations. One of the concepts involved in the mapping is part of both conjunction relations. The *transitivity* relation applies the transitivity property allowed for subsumption. A graphical representation available at the "read me first" menu of the FUNONDIL web site[9], details the different mapping types. Figure 1 shows a fragment of the graphical representation of the OSIECS model containing mappings between the eCognos and *bcBuildingDefinitions* SRs.

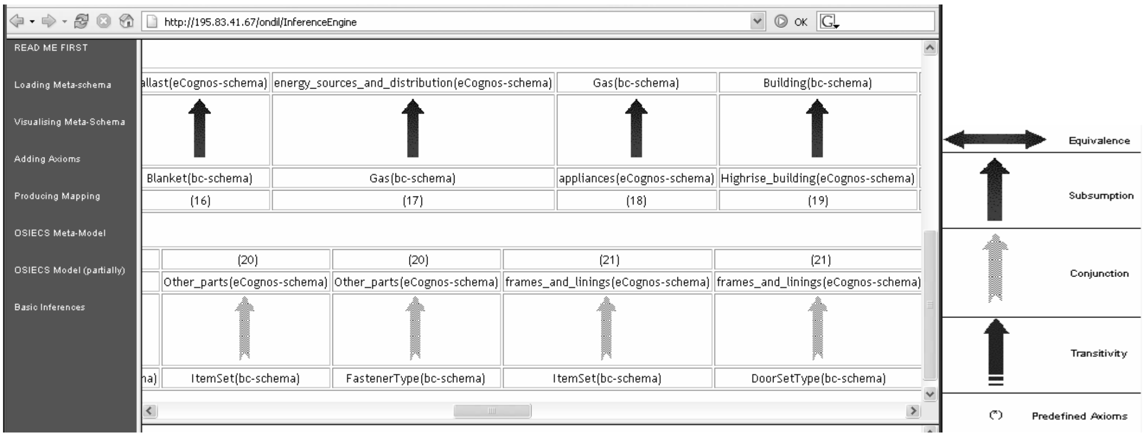

Figure 1: Partial representation of OSIECS model showing subsumption and conjunction mappings between the eCognos and the *bcBuildingDefinitions*

The mapping search is performed between each pair of SRs producing semantic correspondences considered equivalents and non-equivalents. The former refers to absolute equivalences among the entities mapped. The latter refers to mappings in which only a part of the concepts of the SRs is common. This is the case of subsumption, conjunction and transitivity.

We mapped each SR with itself in order to get a feedback about the correctness of the OSIECS Kernel. As expected, to map a SR to itself produces equivalences between the same concepts and only that kind of equivalences. In addition, results for subsumption and conjunction are also presented, but this means only redundant information. This exercise helped us to be sure that the mapping process was working properly.

ASSESSING FUNSIEC MAPPINGS USING FUZZY LOGICS

As previously explained, FUNSIEC relied on *semantic methods* to tackle the semantic heterogeneity problem. It is worth emphasising that these methods being semantically exact only provide an absolute degree of similarity for entities considered equivalent. Moreover only the information explicitly encoded in the OWL[10] was used during the mapping production process. Therefore, the continuation of FUNSIEC work depends on the quality of the mappings produced, which needs to be measured.

Part of the problem relies on the way of defining the quality of the mapping. How can we say that the "quality" of something is between 0 (bad) and 1 (perfect)? Fuzzy Logic theory (Zadeh 1965) provides a qualitative approach to this inherently vague idea. In fact, instead of

[9] The FUNONDIL web site is available at http://195.83.41.67/ondil/InferenceEngine
[10] OWL stands for Ontology Web Language and its specification is available at http://www.w3.org/2004/OWL/

relying exclusively on quantitative approaches, Fuzzy Logic represents these concepts using *linguistic variables* whose values are *terms* that represent the concept (e.g. *bad*, *acceptable*, *good*, *and excellent*). These terms are then mapped onto Fuzzy Sets that are extensions to the classic sets theory where the membership function can allow values between 0 and 1, thus denoting a degree of membership instead of the biblical dichotomy of '*right* or *wrong*'.

MODELLING INFORMATION FOR ASSESSING QUALITY OF MAPPING USING FUZZY LOGIC

A mapping is a binary relation between a concept C_1 (from SR_1) and a concept C_2 (from SR_2). In a non-equivalent mapping, the concept C_1 is not 100% equivalent to the concept C_2. We define a linguistic variable *non-equivalent mappings* (shortly *nem*) associated to the set of terms $D_{(nem)}$ = {*non-acceptable, acceptable, good, strong*}.

In order to model membership functions we define three input variables (E_1, E_2, E_3) to represent the similarities between two mapped concepts. E_1 is related to the property (object property or data type property considering the OWL notation) and the respective range type. In other words, we define it as the number of shared properties. E_2 is the number of 'lexical entries' shared by the two concepts. Lexical entries (Lima et al. 2003) are terms deemed equivalents to a given concept, which are used to enrich ontological concepts. They can be used, for instance, to provide a long list of terms that can be used to refer to a single concept (e.g. the concept *Actor* could be referred to by employee, person, driver, engineer, etc.).

E_3 captures the similarity between concept annotations[11]. An annotation contains natural language terms and expressions, which means that (part of) it can be labelled or tagged as an expression representing a rich semantic content. Let *n* (called *order*) be the number of terms in the expression *e*. By extension, a term is an expression of order $n = 1$. It is clear that *n* cannot be a meaningless term. The meaningless terms are *the*, *to*, *of*, *for*, etc., which are normally included in the so-named 'stop-list'.

The input variables are *fuzzified* with four linguistic terms: *non-acceptable, acceptable*, *good*, and *strong*. If the definition of two mapped concepts, C_1 and C_2, do not share a property then the similarity related to the two concepts properties is *non-acceptable*. If C_1 and C_2 share one or two properties then the similarity related to the two concepts properties is *acceptable*. If C_1 and C_2 share two to five properties then the similarity related to the two concepts properties is *good*. Finally, if C_1 and C_2 share more than four properties then the similarity related to the two concepts properties is *strong*. A similar argument is applied to the E_1 and E_2 input variables. For instance, if C_1 and C_2 share two to six 'lexical entries', then the similarity between the two concepts regarding their 'lexical entries' is *good*. If C_1 and C_2 associated annotations share more than six expressions then the similarity between both concept annotations is *strong*.

Table 1 provides an example of definition of the fuzzy linguistic terms which are to be provided by experts involved in the validation of the mapping process. It shows intervals where the number of properties (for E_1), lexical entries (for E_2), and similar terms in the annotations (for E_3) define the *class* they belong to. The intervals assigned are initial values intended to be tested in a real scenario and further refined according to experts'

[11] Concept annotation here is defined following OWL context, meaning comments, free text associated to a given concept. This annotation can also hold the *definition of a concept in natural language*.

recommendations. Based on this table, validation rules are created and can be automatically applied to assess the quality of the mappings produced.

Table 1: Summary of the assignment of the fuzzy linguistic terms, where ***z*** is *integer*

		Linguistic terms			
		Non-acceptable	***Acceptable***	***Good***	***Strong***
Input variables	E_1	*0*	*{1,2}*	*{2,…,5}*	*{4,…,z}*
	E_2	*0*	*{1,2,3}*	*{2,…,6}*	*{4,…,z}*
	E_3	*0*	*{1,…,4}*	*{3,…,7}*	*{6,…,z}*

For illustrative purposes only, figure 2 depicts the membership functions for E_3. For instance, if $E_3 = 3$, i.e., C_1 and C_2 annotations share a term and an expression of order 2, then the C_1 and C_2 annotations similarity is *acceptable* to a degree of membership of 0.66 and is *strong* to a degree of membership of 0.33.

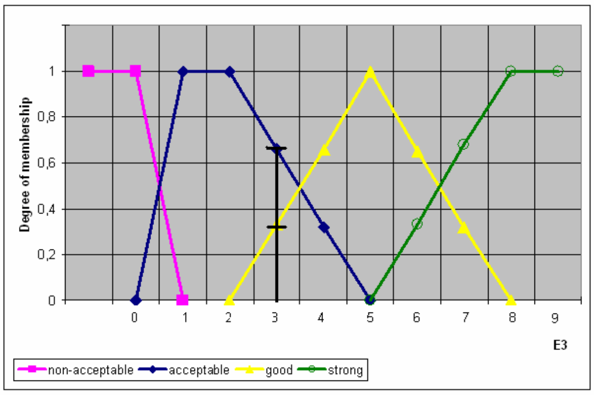

Figure 2: fuzzy membership function of the E_3 input variable

CONCLUSIONS & FUTURE WORK

This paper describes the *fuzzification* process for the purpose of modelling information for assessing quality of the mappings using fuzzy logics. The work presented here extends the results achieved by the FUNSIEC project, which investigated the feasibility of creating an open semantic infrastructure for the Construction sector in Europe. FUNSIEC produced a set of mappings amongst concepts from four semantic resources currently available for Construction. This work aims to assess those mappings in order to enhance the semantic interoperability of the SRs. In order to do that we take into account the common elements found between the concepts mapped as well as the semantics associated to them. We have presented a way of model fuzzy membership functions and of assign membership based on the available information about the mapped entities.

We intend to define appropriate rules to support the reasoning process of a fuzzy inference engine. The next task is to define an appropriate *defuzzification* method in order to obtain quantified mappings. We target the implementation, evaluation and assessment of this approach in a real Construction scenario.

ACKNOWLEDGEMENT

The authors would like to thank the support from the FUNSIEC team as well as the financial support from the European Commission under the eContent programme.

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