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Multi-level Networked Knowledge: Representation and DL-Reasoning

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Abstract: Integrating pre-existing, heterogeneous, and complementary ontologies, and exploiting them jointly in reasoning remains a major challenge. Ontology alignments make explicit the correspondences between terms from different ontologies and must be taken into account in reasoning. Two forms of correspondences can be introduced: mappings represent predefined relations such as subsumption, equivalence, or disjointness, that have a fixed semantics in all interpretations; links can relate complementary ontologies by introducing terms defined by experts, and their semantics varies according to interpretations. Different experts can introduce different terms according to their points of view, which brings semantically heterogeneous links. Thus, integrating pre-existing networks of aligned ontologies requires aligning terminologies from different alignments, so as to form higher level alignments. This generates networked knowledge that can in turn be aligned with other networked knowledge. As a resultn we talk of multi-level networked knowledge, a concept that we formalise here and for which we propose a possible formal semantic for automating reasoning tasks. This semantic consists in reducing reasoning on networked knowledge to reasoning over DL formalisms for which we have reasoning procedures. The proposed approach is implemented and tested in order to compare results, for different networks.

Keywords: networked knowledge; ontologies; ontology alignments; DL-reasoning.

1 Introduction

In information systems, and more recently in Web Semantic, a number of heterogeneous, independently developed ontologies may be exploited in a single application that needs to share some knowledge. These ontologies are developed in different contexts and may well cover complementary domains.

In order to overcome the heterogeneity problem, complementary knowledge may be introduced in order to describe correspondences between ontologies to be exploited. These correspondences, represent relations between entities (terms or formulas) belonging to different ontologies. This set of correspondences is termed ontology alignment.

In order to exploit, during reasoning, a number of heterogeneous ontologies as well as correspondences, a simple solution consists in viewing the ontology system as a unique global ontology. Therefore, each local ontology as well as each alignment, is then considered as a knowledge complement over a larger domain. Taking into account all this knowledge, i.e., ontologies and alignments, may be performed using a fusion process obtaining a centralised system, or using distributed reasoning algorithms based on classical logic, (as shown in: SomeWhere [1], SomeRDFS [3] and SomeOWL [2]). Such approaches consider ontologies and alignments describing a unique global theory, however, presenting inconvenient if the ontologies to be combined are highly heterogeneous. They will, therefore, describe different contexts and points of view, potentially incompatible. The other possible solution consists in managing the set of ontologies as well as the corresponding alignments as a complex semantic network, where each node is represented by an ontology formalizing a given domain, with a different context than the ones given by the rest of the ontologies within the network. Such an approach, needs strong formalism modeling the already aligned ontology network, offering specific algorithms and techniques for contextual reasoning.

In that sense, a number of formalisms have been proposed to model an aligned ontology network for contextual reasoning. These formalisms may be divided into two categories based on definition and application purposes.

Alignment is a major concern, as it constitutes an important element of the complete system, distinguishing two major types of correspondences in order to define them. The first type is for instance given by Distributed Description Logic [6] and IDDL [27]) that define relations, termed proposed mapping, in order to reduce semantic heterogeneity problems between terms and entities belonging to different ontologies. These correspondences are associated with a predefined set of relations such as subsumption, equivalence, disjunction, etc. where the given semantic is fixed for all interpretations (*e.g.*, $\texttt{mt:belong} \xleftrightarrow{\perp} \texttt{eq:belong}$).

The second type of alignment is used to link ontologies covering complementary domains, it is the case of E-connection [21]. It is represented by inter-ontological links between entities, termed simply links (*e.g.*, $\texttt{pr:T}_1 \overset{\textbf{compose}}{\longleftrightarrow} \texttt{eq:FD}_1$). This type of relations is defined by experts in the context of domain ontology combination, as well as semantic representation of context links.

In this paper, we focus on proposing a formalism which supports both alignment types in order to permit heterogeneous ontology combination associated with different contexts covering complementary domains. Regarding the second point of difference, which is the application or treatment of alignments, the majority of proposed formalisms, such as Distributed Description Logic [6], E-connection [21] and Package-based Description Logic [4]), consist in integrating alignment as external knowledge for the corresponding target ontology. The alignment is then, defined and exploited following the target ontology point of view. In order to ensure reasoning over the ontology network, each ontology must be enriched with a reasoning mechanism which support external knowledge.

The other way of looking at the problem is to consider alignments to be exploited at a higher level independent from local ontologies and termed global level [27]. In this approach, the alignment language may be more expressive than the languages defining local ontologies, allowing better alignment reuse. However, only mappings are considered in this work, and no proposition concerning the integration of links at the global level is made.

Links are, supposedly, introduced by experts. However, this may be unfeasible if experts covering all ontologies domain cannot be found. Therefore, if distinct pairs of ontologies are aligned by different experts with different terms and points of view, then it is likely that the heterogeneity problem will needs to be considered this time between links.

The proposed contribution consists in a new formalism termed:"Multi Level Networked Knowledge (MLNK)".

The organisation of the rest of the article is as follows: Section 2 describes a scenario representing an ontology network aligned using heterogeneous pairs ontology alignments. Section 3 presents the state of the art for Multi level formalisms with similar works discussed. Section 4, describes the syntax formalism of the MLNK components. In Section 5, a Description Logic interpretation of a given node have been studied in the goal of applying reasoning strategies. Finaly, section 6 depicts the implementation and evaluation of the proposed approach, followed by a general conclusion.

2 Motivation example

In this section, a real life application example of gas turbine ontological representation is presented. Due to their wide usage in electricity production, gas turbine are often found in the center of large power systems that need to be managed in terms of knowledge and maintenance. Four ontologies describing gas turbine have been developed for the purpose of this example, namely:

- an ontology for equipment (`eq`), modeling the turbine technical and hierarchical knowledge. These information are provided by the constructor and contains 5033 concepts, where each concept describes an equipment or turbine component, such as the concept `flame-detector` given by instance $\texttt{FD}_1$;
- an ontology termed (`Pr`), modeling spare parts, such as the concept `trim` given by the instance $\texttt{T}_1$;
- an ontology for modeling the position of the equipment in the turbine hierarchy (`zn`);
- An ontology created from an existing database `mt`, using a semi automatic approach, covering, maintenance operations (both preventive and after breakdown). The `mt` ontology exploits the first ontologies (`eq`),`Pr` and `zn`) in order to provide details on equipments and spare parts concerned by maintenance operations.

Exploiting these ontologies requires their alignment and the integration of the latter in all reasoning or search strategies. For this purpose a number of alignement tools have been applied in order to provide *mappings* such as: $\texttt{mt:belong} \xleftrightarrow{\perp} \texttt{eq:belong}$ between $(\texttt{mt}, \texttt{eq})$ ontologies pair and $\texttt{pr:trim} \xleftrightarrow{\sqsubseteq} \texttt{eq:instrumentation}$ between $(\texttt{pr}, \texttt{eq})$. These sets of correspondences (or *mappings*) are enriched in a semi-automatic manner using *links* as well as consulting domain experts, an expert for a pair

Ontologies	Axioms
eq:	$\mathtt{flame\text{-}detector}(\mathtt{FD}_1)$ $\mathtt{flame\text{-}detector} \sqsubseteq \exists \mathtt{belong.instrumentation}$
pr:	$\mathtt{trim}(\mathtt{T}_1)$
zn:	$\mathtt{zone}(\mathtt{ANNA1TG01})$
mt:	$\mathtt{intervention}(\mathtt{I}_1)$ $\mathtt{team}(\mathtt{TE}_1)$ $\mathtt{intervene}(\mathtt{TE}_1, \mathtt{I}_1)$ $\mathtt{member} \sqsubseteq \exists \mathtt{belong.team}$
Alignments	
$A_{\mathtt{eq\text{-}zn}}$:	$\mathtt{eq{:}FD}_1 \xleftrightarrow{\textbf{part-of}} \mathtt{zn{:}ANNA1TG01}$
$A_{\mathtt{pr\text{-}eq}}$:	$\mathtt{pr{:}trim} \xleftrightarrow{\sqsubseteq} \mathtt{eq{:}instrumentation}$ $\mathtt{pr{:}T}_1 \xleftrightarrow{\textbf{compose}} \mathtt{eq{:}FD}_1$
$A_{\mathtt{mt\text{-}eq}}$:	$\mathtt{mt{:}I}_1 \xleftrightarrow{\textbf{concern}} \mathtt{eq{:}FD}_1$ $\mathtt{eq{:}belong} \xleftrightarrow{\perp} \mathtt{mt{:}belong}$
$A_{A_{\mathtt{pr\text{-}eq}}\text{-}A_{\mathtt{eq\text{-}zn}}}$:	$\mathtt{pr\text{-}eq{:}}\textbf{compose} \xleftrightarrow{\equiv} \mathtt{eq\text{-}zn{:}}\textbf{part-of}$

Table 1 an excerpt of ontologies and associated alignments

of ontologies. This operation revealed the existence of semantic's heterogeneity problems between alignments inter ontologies, and more precisely between links. As an example of heterogeneity, the appearance of different names within the alignment pair $A_{\mathtt{pr\text{-}eq}}$ and $A_{\mathtt{eq\text{-}zn}}$, it is $A_{\mathtt{pr\text{-}eq}}$:**compose** and $A_{\mathtt{eq\text{-}zn}}$:**part-of**, these *links* have similar semantic. it is clear that reasoning on the set of ontologies and their existing alignments, semantic heterogeneity problem between *links* need to be solved. For the previous case, this is done inserting an equivalence relation between *links* $A_{\mathtt{pr\text{-}eq}}$:**compose** et $A_{\mathtt{eq\text{-}zn}}$:**part-of** becomes necessary.

Example 1: an excerpt of ontologies and associated alignments are presented in Table 1.

In order to solve semantic heterogeneity problem between links, it is essential to represent and understand the semantics of the MLNK. Further than semantic connections of a MLNK representing local knowledge, we may find semantic connections between alignments themselves, Figure 1 represents the turbine example showing alignment levels.

3 State of Art and Related Work

In our best knowledge, no Multi Level Networked knowledge formalism has ever been proposed and developed. The problem of aligning alignment vocabularies is a novelty within our contribution. However, in this section only works related to the proposed approach are presented.

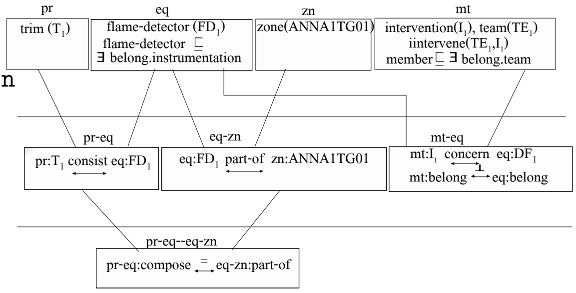


Figure 1 Knowledge representation levels

Research performed in order to ensure a contextual reasoning in a distributed environment, may be classified into three main research categories: Aligned knowledge networks, contextual modelling and modular ontologies.

3.1 Aligned Knowledge Networks

Aligned Knowledge Networks (AKN), are formed with ontologies linked to each other by an alignment process. Many formalisms specifies their syntax and semantic, generally using correspondences following the aforementioned definition. If we consider *mappings* only (leaving out links) then we can site, on the one hand, the following formalisms: Distributed Description Logic [6] and Integrated Distributed Description Logics [27], however with different semantics. On the other hand, Package-based Description Logics [4], even if the later does not use a mapping type correspondences it may be expressed using syntax in AKN terms.

Links are clearly shown in the formalism E-connection [21] but can be used in formulas implying terms of more than two ontologies. Combining links and mapping type relations in a single formalism is addressed in [26].

However, none of the aforementioned formalisms adresses the issue of links terms alignements between two distinct knowledge networks. Each of them, is associated with reasoning procedures, sometimes implemented such a in: Drago [24] implements a pair to pair reasoning for DDL; DRAOn [11] implements a distributed reasoning for IDDL. Resoaning in E-connection, was implemented in a former version of the famous DL Pellet reasoner [25]. Note that a multi-level network interpretation in DL, do not implies that DL suffice to interpret it.

All the aforementioned formalisms are based on DL. Other local logics are used to formalise AKN. In [17], the RDF formalism [8] is considered and a knowledge network is represented using quadruplet (c, s, p, o) where, c is a context identifier of the triplet (s, p, o) that is, an identifier of ontology in which it belongs. Bridges rules are defined between quadruplet of different contexts in order to allow knowledge reasoning through contexts. This formalism is also associated to a reasoning procedure using forward chaining, working only if bridges rules between contexts are acyclic. At a different level, Distributed First Order Logic [15], uses first order logic as a local logic completed with bridge rules completing DDL ones. Once again, these formalisms take into account only one level of heterogeneous knowledge integration.

3.2 Contextual knowledge modeling

A number of works on contextual reasoning, at the opposite of our proposal, do not use correspondences as defined here. Indeed, knowledge from multiple contexts are jointly exploited via a meta description of the contexts themselves. Established relations between contexts play a similar role, ensured by alignments between ontologies, however not expressing correspondences between entities from different ontologies. Klarman [19] proposes such a formalism structured on two levels. The first one concerns the meta ontology, expressed using DL, where contexts are considered as instances. The second level focus on local knowledge detailing contexts. This formalism is given by the $\mathfrak{C}^{\mathcal{L}_C}_{\mathcal{L}_O}$ language, which is a composition of the object language $\mathcal{L}_O$ and the contextual language $\mathcal{L}_C$. The implementation of this work, gave the WORKFLOW system which allows reasoning on both levels and the answer to SPARQL requests. Alternatively, the mentioned formalism permits also the integration of time as well as contextual knowledge origins. These later aspects are out of the scope of this paper and will not be addressed.

Contextualized Knowledge Repository (CKR [16]) introduces the notion of context class and generalise knowledge propagation by introducing the **eval** operator in order to represent concept's extension or expressing a role given in a different context. CKR is also structured on two levels; with the top one describing meta knowledge on contexts over a number of dimensions (spatial, temporal, etc.) and a lower level defining local contexts containing valid instances within the context. In order to encourage context reuse, each context knowledge are organised in a set of modules. CKR is based on three languages: The meta language $\mathcal{L}_\Gamma$, the object language $\mathcal{L}_\Sigma$ and $\mathcal{L}^e_\Sigma$ which is the extension of $\mathcal{L}_\Sigma$ including the **eval** expressions in $\mathcal{L}_\Sigma$. All three languages are DL based.

Joseph and Serafini [18], proposed also a two level formalism (meta and object knowledge) similar to CKR, however founded on RDF instead of DL. The strength is put on RDF knowledge depository constituted of a triplet set. The Contextualised Knowledge Base (CKB) is a pair $\langle \mathcal{M}, \mathcal{G} \rangle$ where $\mathcal{M}$ constitute meta knowledge which includes dimension graph (time, location, etc.), contexts definitions as well as their relations.$\mathcal{G}$ is either, a RDF graph set or a context graph representing the triplet ensemble valid within the context. This graph set, represent the object level of CKB. Reasoning is then performed over both levels, applying already defined inference rules, in order to ensure knowledge propagation through both levels as well as through contexts.

Once again, these formalisms do not resolve heterogeneity problem at a higher level. Indeed, context knowledge introduce specific terms to the meta language which may be different from one knowledge network to another.

3.3 Modularity

The topology of MLNKs permits the representation of a set of knowledge in a modular manner. Each aligned ontology constitute a module, where alignements permit to link a number of modules in order to form a larger one, when itself can be used.

It seems therefore, interesting to compare our approach to existing works in the domain of modular ontologies. Indeed, previous described formalisms (DDL, $\mathcal{E}$-connection, P-DL, IDDL) are described as modular ontology languages and compared as such [7].

A part of works on modularization undertake detection and decomposition of large monolithic ontologies into modules [9], along with proprieties permitting modular reasoning [20]. This approach will not be treated here, however, construction of modular ontologies starting with heterogeneous modules will be investigated. In that field, Distributed Ontology Language (*Distributed Ontology Language* [22]) allows the combination of a number of ontologies with the description of the existing *mappings* between them, along with providing metadata on the ontology set. This language has been submitted for standardization within the *Object Management Group*[1].

It is worth noticing that the formal semantic of the DOL is not yet defined in a unique form. This is also the case for MLNK. Indeed, authors proposed three possible semantics [23], following the distributed semantic analysis provided by Zimmermann and Euzenat [28].Again, the language does not address the heterogeneity highest level.

Modular construction may also be treated as a software engineering problem [14], where authors define a module using: (1) Its internal ontology, (2) interfaces permitting to expose certain terms and axioms in order to be reused by other modules, (3) Import modules and (4) alignment between them. These, will permit a hierarchical construction similar to the notion of multi level knowledge, as a composed module may be in turn imported with other alignments. However, this work does not consider alignment terms (i.e., *links*). Authors do not specify a unique semantic, but focus on a set of possible semantics that may comply with description logics such as DDL or P-DL. This approach has been implemented in a tool named ModOnto [5].

In the same manner, [12] propose a modular ontology formalism based on interfaces (*Interface-Based modular Ontology Formalism* ou IBF). In this case relations of *mapping* and *link* types are expressed in terms of axioms between the entities of different modular ontologies, using interfaces in order to encapsulate ontology axioms.

4 Multi-level Networked Knowledge syntax

Representation and formalization of MLNK implies on the one hand, represent each component of this network and formalize the semantics and on the other hand, that the relationships between these components can be represented. This section, is dedicated to the syntactic representation of a multi-level networked knowledge components, like ontologies, alignments and knowledge nodes.

4.1 Knowledge representation languages and ontologies

A knowledge representation language L, is defined by a syntax (how formulas are expressed) and a semantic (the meaning and sense of formulas). Syntax is characterized by a number of symbols and construction rules, permitting after combination to express well formed formulas. Description Logic, constitute a set of representation languages that may be used to represent a knowledge domain in a structured and formal manner.

We then speak of signatures or vocabulary in order to design structured terms which are subsets of a given language symbols. Each signature permits the definition of a set of formulas defined by the used language, and a set of formulas constructed from a common signature form an ontology.

Vocabulary: *A* vocabulary *is a structured set of terms.*

Example 2: In Description Logics, a vocabulary is a triple $\langle N_I, N_C, N_R\rangle$ where N_I is a set of individual names, N_C is a set of concept names and N_R is a set of role names.

In any ontology language, the signature of an ontology is a vocabulary.

Ontology: *Let L a knowledge representation language. An ontology O of L is a pair $\langle\Sigma(O), A(O)\rangle$ where $\Sigma(O)$ is a signature of L and $A(O)$ is a sub set of formulas which can be constructed with $\Sigma(O)$. Formulas in $A(O)$ are called proper axioms of O.*

Local ontologies or knowledge sources in a multi-level networked knowledge are linked using alignments

4.2 Alignment language

An alignment L_A language permits the description of correspondences between two vocabularies. It is also caracrterised by a syntax (how correspondences are expressed) and a semantic (how correspondences are interpreted). The syntax of L_A is defined by:

- a set of terms , called links, specific to the alignment language noted $V(L_A)$;
- a function $E(L_A)$, which associate to each signature of a representation language L, a set of entities that can be aligned;
- a set of relation's symbols $R(L_A)$.

Thus, the syntax of an alignment language L_A is defined by the triplet $\langle V(L_A), E(L_A), R(L_A)\rangle$, note $\langle V, E, R\rangle$ when no ambiguity exists. Two types of correspondences might be defined as *mapping* and *link* correspondences.

***mapping* correspondence:** *Let V_1 and V_2 two aligned vocabularies and $L_A\,\langle V, E, R\rangle$ an alignment language. A* mapping *correspondence is a triplet $\langle e_1, e_2, r\rangle$ noted $e_1 \xleftrightarrow{r} e_2$ where:*

- *$e_1 \in E(V_1)$ and $e_2 \in E(V_2)$ are matchable entities;*
- *$r \in R$ denotes an existent relation between e_1 and e_2.*

Others define it as a $4-tuple$ $\langle e_1, e_2, r, n\rangle$ where $n \in [0, 1]$ is a confidence value. We drop this component since it does not play a role in our formalisation.

Refering to example 1, `eq:belong` $\xleftrightarrow{\perp}$ `mt:belong` is a *mapping* correspondence. `belong` term can be found in both ontologies vocabulary, for instance `eq` and `mt`, formalized in description logic, with different meanings. *mappings* are constructed using the set of operators $R = \{\sqsubseteq, \equiv\perp, \in=\}$

***link* correspondence:** *Let V_1 and V_2 two aligned vocabularies and $L_A\,\langle V, E, R\rangle$ an alignment language. A* link *correspondence is a formula in the form $e_1 \xleftrightarrow{l} e_2$ where:*

- *$e_1 \in E(V_1)$ and $e_2 \in E(V_2)$ are matchable entities;*
- *$l \in V$ denotes an existent relation between e_1 and e_2.*

Always refering to example 1, `eq:FD`$_1$ $\xleftrightarrow{\textbf{part-of}}$ `zn:ANNA1TG01` and `mt:I`$_1$ $\xleftrightarrow{\textbf{concern}}$ `eq:FD`$_1$ are *link* correspondences. Terms **part-of** and **concern** do not appear in the ontologies vocabularies, they were introduced at the alignment level in order to link different vocabularies entities. The alignment, now, possesses its own vocabulary and therefore may be aligned with other vocabularies in order to avoid heterogeneity problems.

Alignment: *Let V_1 and V_2 be two vocabularies. An* alignment *of V_1 and V_2 is a tuple $\Lambda = \langle V, \kappa, \lambda\rangle$ where:*

- *V is an alignment vocabulary;*
- *κ is a set of* mapping *correspondences, $e_1 \xleftrightarrow{r} e_2$ where $e_1 \in E(V_1)$, $e_2 \in E(V_2)$ et $r \in R$;*

- λ *is a set of* link *correspondences,* $e_1 \xleftrightarrow{l} e_2$ *where* $e_1 \in E(V_1)$*,* $e_2 \in E(V_2)$ *and* $l \in V$*;*

Example 3:

- In DDL or in IDDL, alignments are between the ontologies signatures and the sets V, λ are all empty.
- In $\mathcal{E}$-connections, cross-ontology knowledge can involve terms from more than two ontologies. However, if one restricts to $\mathcal{E}$-connection axioms of the form $\langle E_i \rangle^j(a_i, b_j)$, where E_i is a link relation, a_i is an individual in ontology O_i and b_j is an individual in ontology O_j, then this can be represented as a correspondence in λ, with l being a term in the alignment vocabulary (the set κ is empty).

4.3 Knowledge node

Once the basic component of a MLNK are introduced, in the section 4, it is now possible to introduce the notion of knowledge node, which generalize the notion of ontology. Informally, an ontology is a level 0 knowledge node, while all knowledge node of level $m > 0$, is constructed from a number of nodes with inferior level, linked using alignment (figure 2). Formally the node is defined as:

Knowledge node: *A* knowledge node *is a pair* $K = \langle V_K, A_K \rangle$ *where* V_K *is a vocabulary, also written* $\mathrm{Voc}(K)$ *and both* V_K *and* A_K *are defined recursively:*

- *an ontology* O *is a knowledge node with vocabulary* $\mathrm{Voc}(O) = \mathrm{Sig}(O)$ *and* A_K *is the set of axioms;*
- *for* $n \geq 1$*, if* $K_1, \ldots, K_n$ *are knowledge nodes with vocabularies* $\mathrm{Voc}(K_1), \ldots, \mathrm{Voc}(K_n)$*, and for all* $i, j \in [1, n]$*,* Λ_{ij} *is an alignment of* $\mathrm{Voc}(K_i)$ *and* $\mathrm{Voc}(K_j)$*, then* $K = \langle V_K, A_K \rangle$ *is a knowledge node with the vocabulary:*

$$V_K = \bigcup_{i,j \in [1,n]} \{ij : l \mid l \in \mathrm{Voc}(\Lambda_{ij})\} \cup \bigcup_{i \in [1,n]} \{i : e \mid e \in \mathrm{Voc}(K_i)\}$$

and $A_K = \langle (K_i)_{i \in [1,n]}, (\Lambda_{ij})_{i,j \in [1,n]} \rangle$.

If a knowledge node includes only ontologies and ontology alignments, we call it a *network of aligned ontologies*. If a knowledge node is neither a single ontology, nor a network of aligned ontologies, we call it a *multi-level networked knowledge base* (see Figure 2).

5 Multi-level networked knowledge semantics

The representation of MLNK was defined independently of any language and can support multiple semantics. In this paper, we focus on the description logic semantics which is a way of MLNK interpreting, leading to a formal semantic representation allowing centralized reasoning.

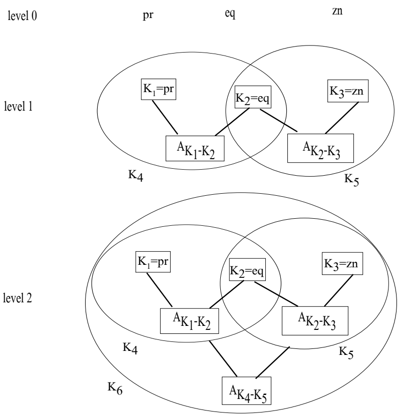


Figure 2 Recursive representation of nodes

5.1 DL Syntax and Semantics

A DL ontology is composed of concepts, roles and individuals, as well as axioms built out of these elements. A concept is either a primitive concept A, or, given concepts C, D, role R, individuals $a_1, \ldots, a_k$, and natural number n, $\bot$, $\top$, $C \sqcup D$, $C \sqcap D$, $\exists R.C$, $\forall R.C$, $\leq nR.C$, $\geq nR.C$, $\neg C$ or $\{a_1, \ldots, a_k\}$. A role is either a primitive role P, or, given roles R and S, $R \sqcup S$, $R \sqcap S$, $\neg R$, R^-, $R \circ S$ and R^+.

Interpretations are pairs $\langle \Delta^I, \cdot^I \rangle$, where Δ^I is a non-empty set (the domain of interpretation) and $\cdot^I$ is the function of interpretation such that for all primitive concepts A, $A^I \subseteq \Delta^I$, for all primitive roles P, $P^I \subseteq \Delta^I \times \Delta^I$, and for all individuals a, $a^I \in \Delta^I$. Interpretations of complex concepts and roles is inductively defined by $\bot^I = \emptyset$, $\top^I = \Delta^I$, $(C \sqcup D)^I = C^I \cup D^I$, $(C \sqcap D)^I = C^I \cap D^I$, $(\exists R.C)^I = \{x | \exists y. y \in C^I \wedge \langle x, y \rangle \in R^I\}$, $(\forall R.C)^I = \{x | \forall y. \langle x, y \rangle \in R^I \Rightarrow y \in C^I\}$, $(\leq nR.C)^I = \{x | \sharp\{y \in C^I | \langle x, y \rangle \in R^I\} \leq n\}$, $(\geq nR.C)^I = \{x | \sharp\{y \in C^I | \langle x, y \rangle \in R^I\} \geq n\}$, $(\neg C)^I = \Delta^I \setminus C^I$, $\{a_1, \ldots, a_k\} = \{a_1^I, \ldots, a_k^I\}$, $(R \sqcup S)^I = R^I \cup S^I$, $(R \sqcap S)^I = R^I \cap S^I$, $(\neg R)^I = (\Delta^I \times \Delta^I) \setminus R^I$, $(R^-)^I = \{\langle x, y \rangle | \langle y, x \rangle \in R^I\}$, $(R \circ S)^I = \{\langle x, y \rangle | \exists z. \langle x, z \rangle \in R^I \wedge \langle z, y \rangle \in S^I\}$ and $(R^+)^I$ is the reflexive-transitive closure of R^I.

Axioms are either subsumption $C \sqsubseteq D$, sub-role axioms $R \sqsubseteq S$, instance assertions $C(a)$, role assertions $R(a, b)$ and individual identities $a = b$, where C and D are concepts, R and S are roles, and a and b are individuals. An interpretation I *satisfies* axiom $C \sqsubseteq D$ if and only if $C^I \subseteq D^I$; it satisfies $R \sqsubseteq S$ if and only if $R^I \subseteq S^I$; it satisfies $C(a)$ if and only if $a^I \in C^I$; it satisfies $R(a, b)$ if and only if $\langle a^I, b^I \rangle \in R^I$; and it satisfies $a = b$ if and only if $a^I = b^I$. When I satisfies an axiom α, it is denoted by $I \models \alpha$.

An ontology O is composed of a set of terms (primitive concepts/roles and individuals) called the signature of O and denoted by $\Sigma(O)$, and a set of axioms denoted by $\mathrm{Ax}(O)$. An interpretation I is a model of an ontology O if and only if for all $\alpha \in \mathrm{Ax}(O)$, $I \models \alpha$. In this case, we write $I \models O$. The set of all models of an ontology O is denoted by $\mathrm{Mod}(O)$. A semantic consequence of an ontology O is a formula α such that for all $I \in \mathrm{Mod}(O)$, $I \models \alpha$.

5.2 DL-Multi-level networked knowledge

A MLNK is presented as a unique ontology in DL. This latter is constructed from one node or more, linked with each other's using alignments. The singularity of such ontology, is that its elements are prefixed using the index of the corresponding knowledge sources, in order to distinguish between entities coming from different knowledge source. The representation of such ontology implies the introduction of newer notions such as combined signatures and combined set of formulas.

In this section, it will be demonstrated that reasoning on knowledge networks comes to apply a reasoning algorithm in DL. Before defining the new notions of combined signature and combined set of formulas which are the component of the DL ontology generated from a multi level knowledge node, a complementary function permitting the indexing of the ontology elements is firstly defined.

index the element of ontology: *Let* i *an indice, we define the function* prefix *on the terms, axioms and ontologies as follows:*

- $\mathsf{prefix}(X, i) = \{i{:}X\}$ *where* X *is an atomic concept, atomic role or an individual;*
- $\mathsf{prefix}(\Sigma, i) = \{\mathsf{prefix}(X, i) \mid X \in \Sigma\}$ *where* Σ *is a signature of ontology and* X *is an atomic concept, atomic role or an individual;*
- $\mathsf{prefix}(\square, i) = \square$ *where* $\square \in \{\bot, \top\}$*;*
- $\mathsf{prefix}(X \square Y, i) = \mathsf{prefix}(X, i) \square \mathsf{prefix}(Y, i)$ *where* $\square \in \{\sqcup, \sqcap\}$ *and* X, Y *can be two concepts or two roles;*
- $\mathsf{prefix}(\square R.C, i) = \square \mathsf{prefix}(R, i).\mathsf{prefix}(C, i)$ *where* $\square \in \{\exists, \forall\}$ *and* R *is a role and* C *is an concept;*
- $\mathsf{prefix}(\square n.R, i) = \square n \mathsf{prefix}(R, i)$ *where* $\square \in \{\leq, \geq\}$ *and* R *is a role;*
- $\mathsf{prefix}(\neg X, i) = \neg \mathsf{prefix}(X, i)$ *where* X *is an concept or a role;*
- $\mathsf{prefix}(R^{\square}, i) = \mathsf{prefix}(R, i)^{\square}$ *where* $\square \in \{+, -\}$ *and* R *is a role;*
- $\mathsf{prefix}(X \sqsubseteq Y, i) = \mathsf{prefix}(X, i) \sqsubseteq \mathsf{prefix}(Y, i)$ *where* X *and* Y *are two concepts or two roles;*
- $\mathsf{prefix}(C(a), i) = \mathsf{prefix}(C, i)(i{:}a)$ *where* C *is a concept and* a *is an individual;*
- $\mathsf{prefix}(R(a, b), i) = \mathsf{prefix}(R, i)(i{:}a, i{:}b)$ *where* R *is a role,* a, b *are an individuals;*
- $\mathsf{prefix}(a = b, i) = \{i{:}a = i{:}b\}$ *where* a, b *are an individuals;*
- $\mathsf{prefix}(F, i) = \{\mathsf{prefix}(f, i) \mid f \in F\}$ *where* F *is a set of description logic axioms;*
- $\mathsf{prefix}(O, i) = \langle \mathsf{prefix}(\Sigma(O), i), \mathsf{prefix}(F(O), i) \rangle$ *where* O *is a description logic ontology.*

A combined signature is an ontology signature resulting from the transformation of a MLNK. It consists in the union of local node signatures as well as alignment vocabularies used to link them.

Combined signature: *Let* N *a multi-level knowledge node, the combined signature* Σ_{comb} *is defined recursively:*

- *if* N *is an ontology then* $\Sigma_{comb}(N) = \Sigma(N) = \langle \mathcal{C}, \mathcal{R}, \mathcal{U} \rangle$*;*
- *if* N *is a multi-level knowledge node compound of subnodes and alignments between them, for* $n \geq 1$, *we have* $\Sigma_{comb}(N_1), \ldots, \Sigma_{comb}(N_n)$ *combined signatures of the local nodes and for all* $i, j \in [1, n]$, V_{ij} *is the alignment vocabulary between* $\Sigma_{comb}(N_i)$ *and* $\Sigma_{comb}(N_j)$ *and* prefix *given in the definition 5.1 . We define* role *a function which assigned for all* link *of* V_{ij} *a specific role in description logic. Then* $\Sigma_{comb}(N) = \bigcup_{i \in [1,n]} \{\mathsf{prefix}(\Sigma_{comb}(N_i), N_i)\} \cup \{\mathsf{role}(l) \mid l \in V_{ij}\}$.

The combined set of formulas is the set of formulas of the resulting ontology from the network transformation. It is the union of local node formulas as well as generated formulas from correspondences. Firstly, the function associating each correspondence in to an axiom is defined.

Correspondence transformation in to axiom: *Let* A_{ij} *for* $i, j \in [1, n]$ *an alignment between a node* i *and a node* j. *We define* trans *a function which assign for each correspondence of* A_{ij} *a DL axiom:*

- $\mathsf{trans}(\{i{:}A \overset{\sqsubseteq}{\longleftrightarrow} j{:}B\}) = \{\mathsf{prefix}(A, i) \sqsubseteq \mathsf{prefix}(B, j)\}$*;*
- $\mathsf{trans}(\{i{:}A \overset{\equiv}{\longleftrightarrow} j{:}B\}) = \{\mathsf{prefix}(A, i) \equiv \mathsf{prefix}(B, j)\}$*;*
- $\mathsf{trans}(\{i{:}A \overset{\perp}{\longleftrightarrow} j{:}B\}) = \{\mathsf{prefix}(A, i) \sqsubseteq \neg\mathsf{prefix}(B, j)\}$*;*
- $\mathsf{trans}(\{i{:}u \overset{\in}{\longleftrightarrow} j{:}A\}) = \{\mathsf{prefix}(A, j)(i{:}u)\}$*;*
- $\mathsf{trans}(\{i{:}u \overset{=}{\longleftrightarrow} j{:}u'\}) = \{i{:}u = j{:}u'\}$*;*
- $\mathsf{trans}(\{i{:}u \overset{l}{\longleftrightarrow} j{:}u'\}) = \{\mathsf{role}(l)(i{:}u, j{:}u')\}$*;*
- $\mathsf{trans}(\{i{:}A \overset{l}{\longleftrightarrow} j{:}B\}) = \{\mathsf{prefix}(A, i) \sqsubseteq \exists\mathsf{role}(l).\mathsf{prefix}(B, j)\}$

where A, B, u *et* u' *are the matchable entities and* l *is a* link.

Combined set of formulas : *Assume N a multi-level knowledge node. Combined formulas F_{comb} for combined signature Σ_{comb} is defined recursively:*

- *if N is an ontology then $F_{comb}(N) = A(N)$ the set of N axioms;*
- *if N is a multi-level knowledge node compound of sub nodes $N_1, \ldots, N_n$ and alignments between a pair of nodes A_{ij}, for all $i, j \in [1, n]$ $F_{comb}(N_1), \ldots, F_{comb}(N_n)$ are a sets of local nodes axioms, $\mathsf{trans}(A_{ij})$ is a function which assign for each correspendence of A_{ij} a description logic axiom (see definition 5.3) and* prefix *the function which assigns indices to elements of th sub nodes (see definition 5.1). Then, combined formulas $F_{comb}(N) = \bigcup_{i \in [1,n]} \{\mathsf{prefix}(F_{comb}(N_i), N_i)\} \cup \bigcup_{i,j \in [1,n]} \{\mathsf{trans}(c) \mid c \in A_{ij}\}$.*

From these definition, we can currently introduce a DL-multi-level networked knowledge.

DL Multi-level networked knowledge: *Assume N a multi-level knowledge node, we define F_{DL} a function which transform recursively the node N in to DL ontology:*

- *if N is an ontology then $F_{\mathsf{DL}}(N) = N$;*
- *if N is a multi-level knowledge node compound of sub nodes N_i for $i \in [1, n]$ and alignments between a pair of nodes A_{ij} for $i, j \in [1, n]$ then $F_{\mathsf{DL}}(N) = F_{\mathsf{DL}}\langle\{N_i\}, \{A_{ij}\}\rangle = \langle \Sigma_{comb}(N), F_{comb}(N)\rangle$ where $\Sigma_{comb}(N)$ is a combined signature and $F_{comb}(N)$ is a combined formulas.*

In Tables 2, 3 definitions 5.1 to 5.5 will be applied in order to generate a DL ontology from the MLNK given in example 1.

Remark: Node K_6 is composed of nodes K_4 and K_5, each including node K_2. Terms in K_2 are therefore duplicated as they can be represented in different point of views in K_4 and K_5.

An interpretation I in DL is assigned to a DL ontology generated from the transformation of a given multi level knowledge node. The satisfaction relation at a node level, depends on the satisfactory relation in DL.

knowledge node interpretation: *A DL-interprtation of multi-level knowledge node X is a description logic interpretaion for combined signature of X.*

knowledge node satisfaction relation: *Let X a multi-level knowledge node, I a DL-interpretation of X and $F_{\mathsf{DL}}(X)$ a function given in definition 5.5. Then I DL-satisies X (denoted $I \models_{N-DL} X$) if and only if I satisfies $F_{\mathsf{DL}}(X)$ in description logic. In this case, we can say I is a DL-model of X.*

Nodes	Combined signature
K_1=`pr`	$\Sigma_{comb}(K_1) = \{\mathtt{trim}, \mathtt{T}_1\}$
K_2=`eq`	$\Sigma_{comb}(K_2) = \{$`flame-detector`, `instrumentation`,$\mathtt{FD}_1$, `belong`$\}$
K_3=`zn`	$\Sigma_{comb}(K_3) = \{\mathtt{zone}, \mathtt{ANNA1TG01}\}$
K_4= $\{K_1, K_2, A_{\mathtt{K_1\text{-}K_2}}\}$	$\Sigma_{comb}(K_4) = \{k_1$:`trim`, k_1:$\mathtt{T}_1$, k_2:`flame-detector`, k_2:`instrumentation`, k_2:$\mathtt{FD}_1$, k_2:`belong`, **compose**$\}$
K_5= $\{K_2, K_3, A_{\mathtt{K_2\text{-}K_3}}\}$	$\Sigma_{comb}(K_5) = \{k_2$:`flame-detector`, k_2:`instrumentation`, k_2:$\mathtt{FD}_1$, k_2:`belong`, k_3:`zone`, k_3:`ANNA1TG01`, **part-of**
K_6= $\{k_4, K_5, A_{\mathtt{K_1\text{-}K_2}}\}$	$\Sigma_{comb}(K_6) = \{k_4$:$k_1$:`trim`, k_4:k_1:$\mathtt{T}_1$,k_4:k_2:`flame-detector`, k_4:k_2:`belong`, k_4:k_2:$\mathtt{FD}_1$, k_4:k_2:`instrumentation` , k_5:k_3:`zone`, k_5:k_3:`ANNA1TG01` , k_5:k_2:`belong`, k_5:k_2:`instrumentation` , k_5:k_2:`flame-detector`, k_5:k_2:$\mathtt{FD}_1$ k_4:**compose**, k_5:**part-of**

Table 2 Combined signatures

Example 4: Let a node $X = \langle\{O_1, O_2\}, \{A_{12}\}\rangle$ with $O_1 = \{C \sqsubseteq D\}$, $O_2 = \{C \equiv B\}$ and $A_{12} = \{1{:}C \overset{\perp}{\longleftrightarrow} 2{:}C\}$ O_1 model is an interpretation of signature $\{C, D\}$ and O_2 model is an interprtation of signature $\{C, B\}$. X transformation into DL-ontology:

- $\mathsf{prefix}(O_1, 1) = \{1{:}C \sqsubseteq 1{:}D\}$;
- $\mathsf{prefix}(O_2, 2) = \{2{:}C \equiv 2{:}B\}$;
- $\mathsf{trans}(\{1{:}C \overset{\perp}{\longleftrightarrow} 2{:}C\}) = \{\mathsf{prefix}(C, 1) \sqsubseteq \neg\mathsf{prefix}(C, 2)\}$;
- $F_{\mathsf{DL}}(X) = \{1{:}C \sqsubseteq 1{:}D, 2{:}C \equiv 2{:}B, 1 : \mathsf{C} \sqsubseteq \neg 2 : \mathsf{C}\}$;

X model is an interpretation I of combined signature $\{1{:}C, 1{:}D, 2{:}C, 2{:}B\}$ then we have $I \models_{N-DL} X$ if I satisfies $F_{\mathsf{DL}}(X)$ and I satisfies $F_{\mathsf{DL}}(X)$ if $I \models 1{:}C \sqsubseteq 1{:}D$, $I \models 2{:}C \equiv 2{:}D$ and $I \models 1 : \mathsf{C} \sqsubseteq \neg(2 : \mathsf{C})$ with:

- $I \models 1{:}C \sqsubseteq 1{:}D$ if and only if $(1{:}C)^I \subseteq (1{:}D)^I$
- $I \models 2{:}C \equiv 2{:}D$ if and only if $(2{:}C)^I \equiv (2{:}B)^I$
- $I \models 1 : \mathsf{C} \sqsubseteq \neg(2 : \mathsf{C})$ if and only if $(1 : \mathsf{C})^\mathsf{I} \subseteq \neg(2 : \mathsf{C})^\mathsf{I}$

Automatic reasoning on a given node X, is limited to reasoning on the generated ontology $F_{\mathsf{DL}}(X)$, where the coherence of X is deducted from the coherence of $F_{\mathsf{DL}}(X)$. The knowledge level structure permits to use the implication relation, between nodes of different levels.

Nodes	Combined axioms
K_1=`pr`	$F_{comb}(K_1) = \{\texttt{trim}(\texttt{T}_1)\}$
K_2=`eq`	$F_{comb}(K_2) = \{\texttt{flame-detector}(\texttt{FD}_1),$ $\texttt{flame-detector} \sqsubseteq$ $\exists\texttt{belong.instrumentation}\}$
K_3=`zn`	$F_{comb}(K_3) = \{\texttt{zone}(\texttt{ANNA1TG01})\}$
$K_4=$ $\{K_1, K_2,$ $A_{\texttt{K}_1\texttt{-K}_2}\}$	$F_{comb}(K_4) = \{k_1{:}\texttt{trim}(k_1{:}\texttt{T}_1),$ $k_2{:}\texttt{flame-detector}(k_2{:}\texttt{FD}_1),$ $k_2{:}\texttt{flame-detector} \sqsubseteq$ $\exists(k_2{:}\texttt{belong}).(k_2{:}\texttt{instrumentation}),$ $\mathbf{compose}(k_1{:}\texttt{T}_1, k_2{:}\texttt{FD}_1)\ \}$
$K_5=$ $\{K_2,\ K_3,$ $A_{\texttt{K}_2\texttt{-K}_3}\}$	$F_{comb}(K_5) = \{k_2{:}\texttt{flame-detector}(k_2{:}\texttt{FD}_1),$ $k_2{:}\texttt{flame-detector} \sqsubseteq \exists(k_2{:}\texttt{belong})$ $(k_2{:}\texttt{instrumentation}),$ $k_3{:}\texttt{zone}(k_3{:}\texttt{ANNA1TG01}),$ $\mathbf{part\text{-}of}(k_2{:}\texttt{FD}_1, k_3{:}\texttt{ANNA1TG01})\}$
$K_6=$ $\{k_4, K_5,$ $A_{\texttt{K}_1\texttt{-K}_2}\}$	$F_{comb}(K_6) = \{k_4{:}k_1{:}\texttt{trim}(k_4{:}k_1{:}\texttt{T}_1)$ $k_4{:}k_2{:}\texttt{flame-detector} \sqsubseteq \exists(k_4{:}k_2{:}\texttt{belong}).$ $(k_4{:}k_2{:}\texttt{instrumentation}),$ $k_4{:}k_2{:}\texttt{flame-detector}(k_4{:}k_2{:}\texttt{FD}_1),$ $k_5{:}k_3{:}\texttt{zone}(k_5{:}k_3{:}\texttt{ANNA1TG01}),$ $k_4{:}\mathbf{compose}(k_1{:}\texttt{T}_1, k_2{:}\texttt{FD}_1),$ $k_5{:}\mathbf{part\text{-}of}(k_2{:}\texttt{FD}_1, k_3{:}\texttt{ANNA1TG01}),$ $k_5{:}k_2{:}\texttt{flame-detector}(k_5{:}k_2{:}\texttt{FD}_1),$ $k_5{:}k_2{:}\texttt{flame-detector} \sqsubseteq \exists(k_5{:}k_2{:}\texttt{belong}).$ $(k_5{:}k_2{:}\texttt{instrumentation}),$ $k_4{:}\mathbf{compose} \equiv k_5{:}\mathbf{part\text{-}of}$

Table 3 Combined axioms

Implication relation: *Assume X, Y be two multi-level knowledge nodes, it is said that X DL-implies Y if and only if all DL-models of X are DL-models of Y.*

Property 1: Let X a global knowledge node, including local nodes $N_1, \ldots, N_k$, prefix the function affecting a node prefix to all its terms, then X implies all local prefixed nodes noted ($X \models_{N-DL} \mathsf{prefix}(N_i)$ for all $i \in [1,k]$) however the contrary is not implied. It is said that a node X implies directly its local nodes in the particular case where, local node terms are disjoint, as this case do not necessitate the addition of prefixes to terms in order to be distinguished.

Proof Let $X = \langle\{N_i\}, \{A_{ij}\}\rangle$ and an interpretation I is X DL-model noted $I \models_{N-DL} X$ and $I \models_{N-DL} X$ if $I \models F_{\mathsf{DL}}(X) \Rightarrow I \models F_{\mathsf{DL}}(\{N_i\},\{A_{ij}\}) \Rightarrow I \models \bigcup_{i=1..n} prefix(N_i, N_i) \Rightarrow I \models prefix(N_i, N_i)$ for all i=1..n

Example 5: Let a node $X = \langle\{O_1, O_2\}, \{A_{12}\}\rangle$ with $O_1 = \{C \sqsubseteq D\}$ et $O_2 = \{C \equiv B\}$ O_1 model is an interpretation of signature $\{C, D\}$, O_2 model is an interprtation of signature $\{C, B\}$ and X model is an interpretation of combined signature $\{1{:}C, 1{:}D, 2{:}C, 2{:}B\}$ $\mathsf{prefix}(O_1, 1) = \{1{:}C \sqsubseteq 1{:}D\}$ $\mathsf{prefix}(O_2, 2) = \{2{:}C \equiv 2{:}B\}$ Applying property, X node implies $\mathsf{prefix}(O_1, 1)$ and implies $\mathsf{prefix}(O_2, 2)$, because $X \models_{N-DL} 1{:}C \sqsubseteq 1{:}D$ but X does not satisfy $C \sqsubseteq D$ and $X \models_{N-DL} 2{:}C \equiv 2{:}B$ but X does not satisfy $C \equiv B$.

And $\mathsf{prefix}(O_1, 1)$ does not implies X because $\mathsf{prefix}(O_1, 1)$ does not satisfy $2{:}C \equiv 2{:}B$

A multi Level Knowledge node transformation permits to link it to DLs which includes many reasoning operational tools such as: Fact++[2], Pellet[3], HermiT[4], exploited when reasoning on a node.

6 Implementation and Experimentation

In this section, the implementation of a JAVA interface for the purpose of reasoning on a MLNK using DL semantics, presented in section5.2.This GUI, named Description Logic for Multi-Level Networked Knowledge Reasoner (DLMLNKR), permits reasoning either to verify consistency, testing axiom's satisfaction or for inferring new knowledge using Pellet or hermit reasoners.

6.1 Architecture

DL MLNKR accepts as inputs ontologies on OWL/RDF format, as well as alignments over a number of levels saved in RDF files under the format API Alignment [13], expanded to stock *links*. The steps of the DL MLNKR architecture (See Figure 3), are cited and described below:

- Loading source ontologies specifing their localisations or IRIs;
- Load alignments, this operation consists in loading alignment saved in RDF files "results", resulting from alignment discovery tools available on the World Wide Web. Alignment may be enriched in a semi-automatic manner using *links*;
- Fusioning loaded ontologies obtaining a global one;
- Alignement parsing, this consists in extracting *mappings* and *links*. Links are transformed in specific roles and *mappings* in axioms, these are then inserted in the global ontology;
- Testing the consistency of the global ontology as well as testing axioms satisfaction;
- Inferring new knowledge permitting, thus, alignment composition transformed in axioms;
- Construction of a knowledge node, and saving it for further alignments with other ontologies and/or networks.

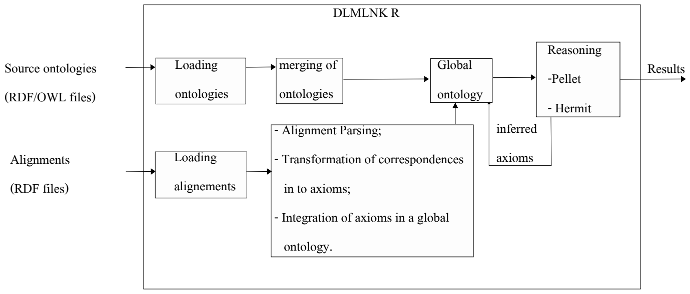


Figure 3 Architecture reasoning DLMLNKR

6.2 *Experimentation and evaluation*

Tests were performed on complex ontologies with their respective alignments obtained from the Anatomy, Conference and benchmark :"http://oaei.ontologymatching.org/2014/". Alignment were enriched using a semi-automatic manner with *links* and correspondences between alignments. Table 4, describes the size of the used ontologies and alignments constituting the MLNK. Through these tests, the impact of ontologies size will be shown, along with the ontologies number impact and level impact during the transformation of the MLNK in a DL ontology and consistency check.

The evaluation put the focus on the execution time of the two main operations, for instance:

- The transformation of the MLNK in a sole global ontology, focusing on the source ontologies fusion time **(fus)** and the parsing time **(pars)** divided into recovery of correspondences time from alignments, transfer time into axioms as well as insertion time of these axioms into the global ontology;
- The consistency test time for the resulting ontology (**Consist**).

6.2.1 *Impact size*

The tests were performed on Anatomy ontologies with corresponding alignments (see Table 4). In order to measure the mpact of size, we conducted first tests on Approximately 25% then Approximately 50% and finally 100% of ontologies human, mouse, and alignment $A_{human-mouse}$. The test results are shown in the table 5.

6.2.2 *Impact number*

The tests were performed on Conference ontologies with corresponding alignments (see Table 4). In order to measure the impact of ontologies and alignments number, we started with a network consisting of two ontologies and alignment for a first case and for each case, we have integrated into the network a new ontology and corresponding alignments where integrated to the network. The test results are shown in table 6.3.

Example	Ontologies/alignments	Size
Anatomy	Human	3.27 MB
	mouse	1.33 MB
	$A_{human-mouse}$	371 kB
Conference	cmt	27.8kB
	conference	38.4kB
	confOf	36.5kB
	edas	100kB
	ekaw	35.1kB
	iasted	70kB
	sigkdd	15.1 kB
	Ontologies alignment	65.76kB
Benchmarks	101	71.5kB
	103	80.4kB
	104	46.1kB
	$A_{101-103}$	44.4kB
	$A_{101-104}$	49.3kB
	$A_{101-103-101-104}$	4.45kB

Table 4 Ontologies/alignments size

6.2.3 *Impact level*

The tests were performed on benchmark ontologies with corresponding alignments for three possible typologies.The first typology (T_1) consist in loading the set of ontologies and alignments in a sole operation, and then reason on the complete set. The second typology, (T_2), consists in creating a node for a pair of ontologies with their respective alignment, then reason on the network constituted by the pair. The third typology (T_3) consists in reasoning on the knowledge node constructed and aligned using the third ontology. The three typologies are depicted in figure4, and The test results are shown in the table 7.

6.3 *Discussion*

The test results (table 5) showed that the size of the ontologies and alignments has no impact on the transfer of MLNK as well as the consistency test in DL ontology obtained. It is clear that the increase in the size of ontologies and alignment advances the transfer time and test consistency time. We notice the same for testing the impact on the evolution of the number of ontologies and alignments on the network. The results in (table 6.3) show that the number has no significant impact on the transfer and on the consistency test. As against the complexity of ontology influences largely on the test consistency, it's the case5 and case6 where integration of ontology 'iasted' despite its size is smaller than 'edas' ontology size, but the test consistency time is much higher. This is confirmed by testing cases7 where the network consists of cmt, iasted, $A_{cmt-iasted}$ and case8 with cmt, edas, $A_{cmt-edas}$. The (table 7) shows that the test consistency time is approximately equal for different MLNK levels (level 0, Level 1 and Level 2) but the transfer time in to DL ontology is progressing with the evolution of the level, so there is no impact on the level.

Ontologies/alignments	**fus** (ms)	**pars** (ms)	Total (ms)	**Consist** (ms)
$\simeq$ 25% Human $\simeq$ 25% mouse $\simeq$ 25% $A_{human-mouse}$	152	248	400	332
$\simeq$ 50% Human $\simeq$ 50% mouse $\simeq$ 50% $A_{human-mouse}$	293	490	783	540
100% Human 100% mouse 100% $A_{human-mouse}$	570	821	1391	1290

Table 5 One-level networked knowledge example for impact size

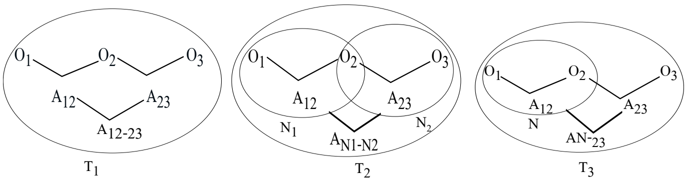


Figure 4 DLMLNKR Typologies

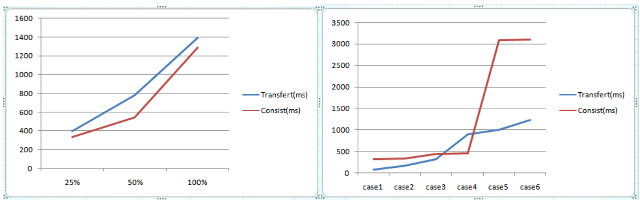
The typologies change is the only one to have an impact on the transfer of MLNK in to a DL ontology. The results in the (table 7) show that typology2 (T2) is the best for the transfer of the network concerning Level 1 and Level 2 (levels that contain alignments). But, for the consistency test, we notice that the typology3 (T3) gives slightly better results compared with other typologies consistency test.

7 Conclusions

In this paper a formalism capable of reasoning on a network of heterogeneous, complementary aligned ontologies, is presented. The alignment posses proper vocabulary and necessitate, sometimes, to be aligned at different levels which represent the novelty of the presented formalism called MLNK. The semantic interpretation of the formalism is based on the existing paradigm, disposing of complete reasoning procedures, along with operational tools such as description logic DL, used in this case. The proposed approach is implemented and tested in order to compare results, for different networks. As future work, and on one hand, a more complete implementation is planned, using a different semantic in order to make distributed reasoning, for instance DDL. However it will still be interesting to view the MLNK semantic, in a manner where a formal semantic is directly constructed on the structure of the MLNK, and propose then a correct and complete reasoning algorithm better adapted to the structure. On the other hand, an extension of the $XMAP^{++}$ alignment tool proposed in [10] in order to permit the automatic discovery of correspondences between

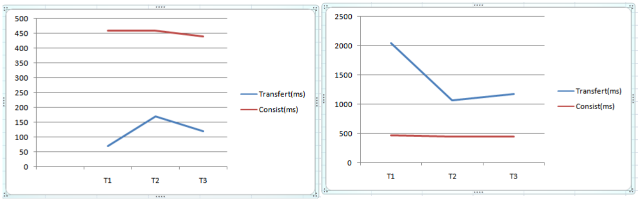
case	Conference ontologies/alignment	**fus** (ms)	**pars** (ms)	Total	**Consist** (ms)
case1	cmt, conference,$A_{cmt-conference}$	30	50	80	320
case2	cmt, conference, confOf	40	130	170	330
case3	cmt, conference, confOf, edas,	60	260	320	440
case4	cmt, conference, confOf, edas,ekaw,	70	882	892	450
case5	cmt, conference, confOf, edas,ekaw,iasted,	80	917	997	3090
case6	cmt, conference, confOf, edas, ekaw, iasted, sigkdd,	130	1101	1231	3110
case7	cmt, iasted,$A_{cmt-iasted}$	60	80	140	2280
case8	cmt, edas, $A_{cmt-ekaw}$	40	60	100	360

Table 6 One-level networked knowledge example for impact number



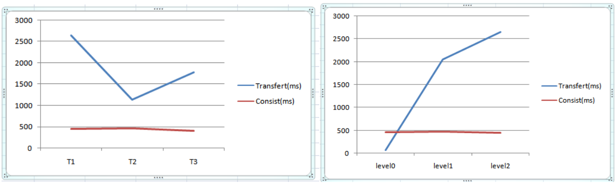
(a) (b)

Figure 5 (a) Impact size results. (b) Impact number results.



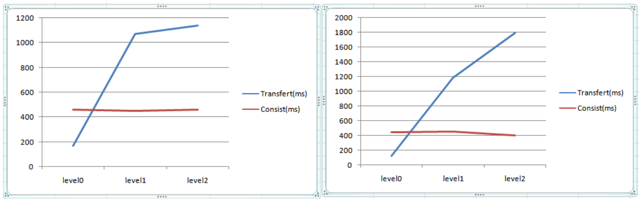
(a) (b)

Figure 6 (a) Impact typologies for Level0. (b) Impact typologies for level1.



(a) (b)

Figure 7 (a) Impact typologies Level2. (b) Impact level for Typology1.



(a) (b)

Figure 8 (a) Impact level for Typology2. (b) Impact level for Typology3.

alignments over different MLNK levels as well as semi-automatic insertion of links , is planned. Consider the possibility of exploiting alignments at a certain level may help discovering alignments on a superior one, and improve alignment techniques.

	fus(ms)	**pars**(ms) (101-103)	**pars**(ms) (101-104)	**pars**(ms) (101-103-101-104)	Total(ms)	**Consist**(ms)
level 0						
T_1	$(101, 103, 104) = 70$				70	460
T_2	$(101, 103) = 50$				170	460
	$(101, 104) = 40$					
	$(N_1, N_2) = 80$					
T_3	$(101, 103) = 50$				120	440
	$(N_1, 104) = 70$					
level 1						
T_1	$(101, 103, 104) = 70$	950	1030		2050	470
T_2	$(101, 103) = 50$	430			1070	450
	$(101, 104) = 40$		470			
	$(N_1, N_2) = 80$					
T_3	$(101, 103) = 50$	430			1180	450
	$(N_1, 104) = 60$		640			
level 2						
T_1	$(101, 103, 104) = 100$	600	1050	1000	2650	450
T_2	$(101, 103) = 50$	430			1140	460
	$(101, 104) = 40$		470			
	$(N_1, N_2) = 80$			70		
T_3	$(101, 103) = 50$	430			1790	400
	$(N_1, 104) = 60$		660	590		

Table 7 Multi-level networked knowledge example for impact level and typologies

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