TOWARDS ONTOLOGY HARMONIZATION OF MECHANICAL MANUFACTURE CONSTRAINTS THROUGH PLC

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Abstract. *The availability of a computational product representation where geometric and technical product data may be integrated makes easier the integration of services and applications among multiple production related computational tools. This is of great importance in the advent of dissemination of webservices world wide through internet, assisting product life cycle stages. However, the existence of a standard for its representation is essential to achieve complete interoperability, and fundamental to be possible to get consistent integrated data and knowledge management, and thus enhanced computational incorporation through the production chain.*
Ontologies facilitate the computational understanding, communication and seamless interoperability between people and organizations. They allow key concepts and terms relevant to a given domain to be identified and defined in an open and unambiguous way. Therefore, ontologies facilitate the use and exchange of data, information and knowledge among people and organizations, towards intelligent systems interoperability. Nevertheless, concurrent initiatives on distributed and heterogeneous systems originated more than one ontology development, and so support to seamlessly resolve arising issues will be needed. Multiple ontologies need to be accessed by the same, but also by different systems. Also the distributed nature of ontology development has led to dissimilar ontologies for the same or overlapping domains. Thus, various parties with different ontologies often do not understand each other.
To solve these problems, it is necessary to use ontology mapping geared for interoperability. This paper identifies some of the gaps in the product life cycle data model, when focused in the geometric and technical constraint aspects within manufacturing context, and proposes a methodology to support the development of a common reference ontology for a group of enterprises sharing this domain.
This methodology is based on the concept of Mediator Ontology, which assists the semantic transformations among each enterprise's ontology and the referential one. This methodology enables each organization to keep its own terminology, glossary and ontological structures, providing seamless communication and interaction with the others. The contribution in this area proposes the development of ontologies to capture simple product and process information and knowledge relative to elementary mechanical shapes. An use case is described and the proposed methodology demonstrated.

Keywords*: Ontology building; knowledge representation; interoperability; 3D semantic; manufacture constraints*

1. INTRODUCTION

Nowadays, with the actual level of enterprises' competition to reach customers, enterprises were conducted to perform strategic partnerships to improve their position in the market [1]. The formation of cooperation and collaboration alliances between several small organizations is proving, in multiple cases, to be more efficient and competitive by comparison with big companies. This is typically what leads companies to join efforts to survive in very evolutionary and dynamic markets [2].

However, partnerships cause some problems mainly in integrating Product Life Cycle phases. For instance, during manufacturing phase it is necessary the incorporation of different brought-in parts which requires detailed data check and update by different teams. Due to use of heterogeneous applications to keep valid the initial design conditions and, plus to the worldwide number of existing proprietary catalogue components, which adopts different terminologies for the same domain products, it results in an increase of the time consuming and in the difficulty to maintain the product assembly consistency.

Standardization rapidly became an evident priority, and several dedicated reference models covering many industrial areas and related application activities, from design phase to production and commercialization, have been developed enabling industrial sectors to exchange information based on common models [3]. In that sense, ISO10303 STEP, commonly known as the Standard for the Exchange of Product Model Data was developed, becoming in one of the most important sets of standards for representation of product information in industrial environments [4].

Since standardization was not able to solve semantic issues, companies envisaged the development of an ontology to use in its exchange of product information. Nevertheless, such action didn't help, because it conducted to the development of multiple ontologies with inevitably different perspectives of a same domain. For that reason, to envisage forcing stakeholders to adopt a same ontology, even based on standards, though appearing to be the compromise, it does not work at all.

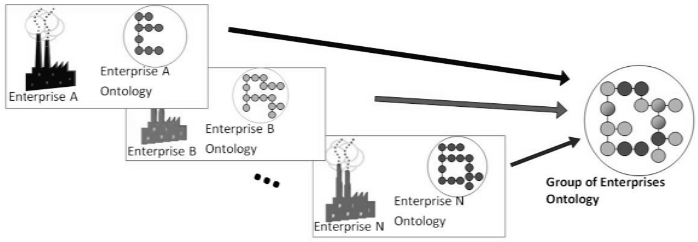

Figure 1. Reference ontology for a group of enterprises

Thus, a solution is to allow each enterprise involved to keep its terminology and classification in use, and use a reference ontology to serve as the third party in the communications between them (Fig. 1) and to surrounding customers. For this purpose the authors proposed the MENTOR methodology [5].

3. THE MENTOR METHODOLOGY

The MENTOR - Methodology for Enterprise Reference Ontology Development is a methodology that helps an organization to build and adapt, a domain reference ontology. MENTOR provides several step methods as semantic comparisons, basic lexicon establishment, mappings among ontologies and other operations on KB representations. This methodology is composed by two phases: the Lexicon Settlement (Phase 1) and the Reference Ontology Building (Phase 2) with three steps each (Fig. 2).

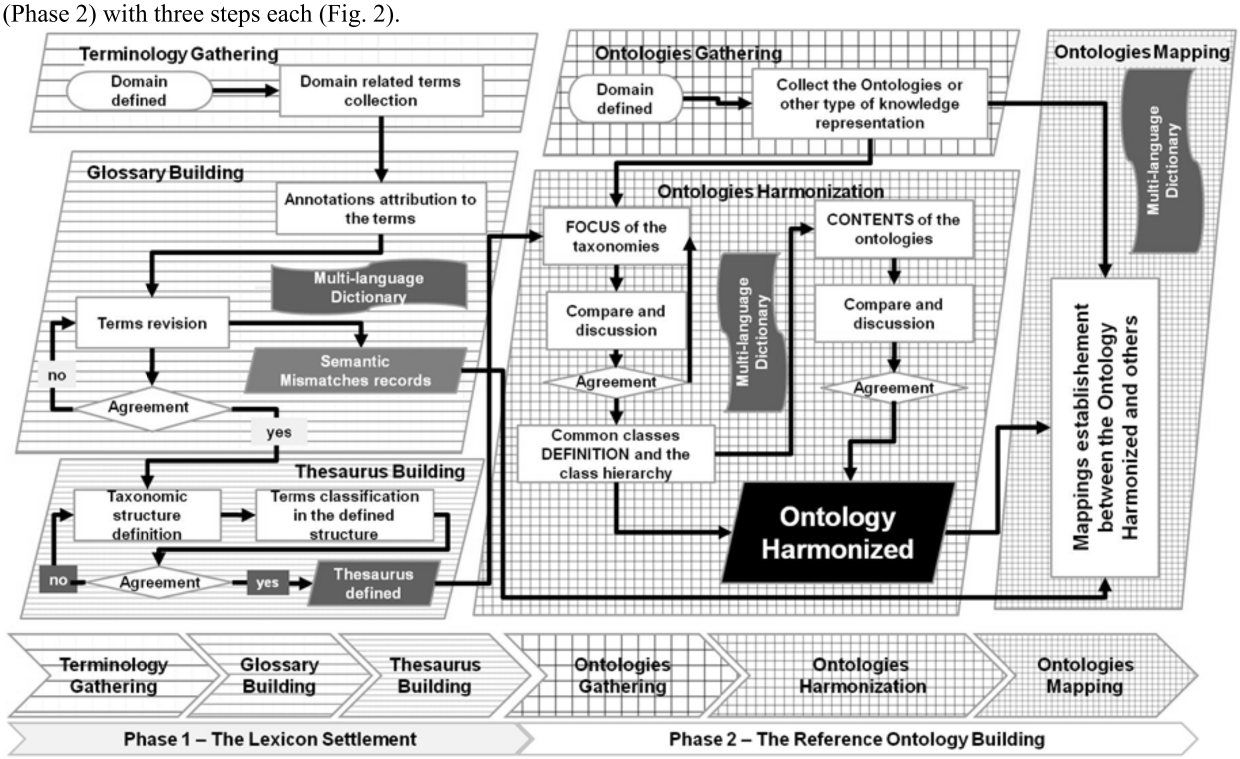

Figure 2. MENTOR Phases and Steps

In linguistics, the lexicon of a language is its vocabulary, including its words and expressions [6]. For a human, knowing a language implies having a mental lexicon, i.e. a memorized set of associations among sound sequences, their meanings, and their syntactic privileges [7]. The Lexicon Settlement phase (Phase 1) represents a domain knowledge acquisition which comparatively to the human language apprentice phase could be represented in computer science as a semantic organized structure with definitions.

The thesaurus can represent such words structure of associated meanings and thus should be built in order to establish the lexicon of a specific domain. This phase has three steps: Terminology Gathering; Glossary Building and

Thesaurus Building. These steps were defined based on the UPON, which defines a set of workflows that establishes a thesaurus of the domain before starting the ontology building.

Figure 2 (left part) depicts the state diagram of the lexicon settlement phase. The terminology gathering step concerns to the process of collecting all relevant terms in a specific domain previously defined. All the participants in the process should give their inputs. There is no rule from where the terms should come. Since they are related with the domain established. Tools for automatic extraction of domain related terms can be found, as for instance, the OntoLearn. This tool aims the extraction of domain ontologies from web sites, and more generally from shared documents among the members of virtual organizations [8], nevertheless there is always need of a human checking before close the terms list to not miss any domain terms. All the terms provided from the contributors are acceptable in this step. Nobody has authority to erase other's participant term. The term should be collected with reference to the contributor in order each contributor provide term's annotation in the next step.

Glossary is a specialized vocabulary with corresponding annotations. This vocabulary includes terms that are unique to the subject, have special meaning in the field of interest. The annotations include descriptive comments and explanatory notes for the terms, such as definitions, synonyms, references, etc. A Glossary can be used when communicating information in order to unify knowledge sharing. The Glossary Building step intends to build a glossary in the domain defined. It starts with annotations attribution to the terms collected in the step before. Each contributor should provide the annotations for his own terms. After having all the terms provided with annotations, it proceeds to the terms revision cycle. In this cycle it could be useful to use a multi-language dictionary in case of the organization members don't use the same natural language. The dictionary will help translations to the agreed language for the reference ontology. The terms revision process can have four semantic and syntactic cases of mismatches:

- Two syntactical different terms with the same meaning description – the solution is to adopt one of the terms for being the reference in such semantics meaning. This process needs to be recorded has a semantic mismatches for future mappings;
- Two syntactical equal terms with the same meaning description – the solution is to erase one of them;
- Two syntactical different terms with two different meaning descriptions – no action needed, both must be kept;
- Two syntactical equal terms with two different meaning descriptions – the solution is to consolidate all the provided descriptions together in one of them and erase the other. In this last case, a new term could be proposed to the list if there is no agreement in the conjunction of the input descriptions and if the term to born is not present in the terminology list.

After a careful revision in all the terms with a successful agreement in their meaning consolidation, the glossary is defined from the terminology list in the domain specified. Another output from this process is the semantic mismatch records: this is made using a specific ontology described in the following section.

The Thesaurus Building step is composed by a cycle where firstly, the knowledge engineers define a taxonomic structure from the glossary terms, establishing some as thesaurus node terms. Secondly, the other terms are classified to the right paths in the existent taxonomic structure, being the thesaurus leafs. If there is an agreement in the structure and in the terms classified, the thesaurus is defined. If not, the cycle starts again. The thesaurus defined will enhance the ontology harmonization process in the next phase.

The Reference Ontology Building phase (Phase 2) is the phase where the reference ontology is built and the semantic mappings between the organizational ontologies and the reference one is established. Figure 2 (right part) describes its steps.

The first step comprehends ontologies' gathering in the domain defined. Other type of knowledge representation could be used as input for the harmonization ontologies' process together with the thesaurus defined in the previous phase. The harmonization method for building ontologies was defined as an extension and adaptation made after work of Noy et al [9][10]. It proposes the development of a single harmonized Ontology's by two cycles where first the structure is discussed until having agreement on it and then the same process for the ontology contents definition. From this process new semantic conflicts are expected. After agreement, such resolution could be recorded in the Mediator Ontology (MO) for further mapping establishments. With all the agreements accomplished, the harmonized ontology is finalized together with the mapping tables, describing the ontological relationships between the harmonized ontology and each one of the individual ontologies.

Semantic difficulties related to the natural language of the potential users of the harmonized ontology are likely to happen. To assist on it, the ontology is complemented with a multi-language dictionary where a set of normalized tokens gives the reference to the corresponding concepts and definitions in different native languages.

3. MEDIATOR ONTOLOGY

Ontology mapping is an activity that attempts to relate the vocabulary of two ontologies that share the same domain of discourse [11]. The process of defining mappings between ontologies is not an easy task and requires currently human support. The MENTOR uses the MO as the reference for mediating the mapping establishment and its subsequent "mapping records" reasoning. One example is querying the MO for a correspondence to a reference term in a specific enterprise ontology.

The MO is able to represent ontology semantic operations: the semantic mismatches found in the Glossary Building step; the semantic transformations identified in the Harmonization process; the Ontologies Mapping; and other ontologies operations (e.g. versioning). It was built up as an extension to the Model Traceability Ontology defined by Sarraipa et al [12]. Traceability is ability to chronologically interrelate the uniquely identifiable entities in a way that matters. The mapping relations can be related to a traceability element, in a sense that a specific term defined in the reference ontology has a related one in an organization member ontology, considering ontologies as stages of the desired ontology life-cycle, that is in this case the reference ontology. This makes possible a way to trace ontology elements.

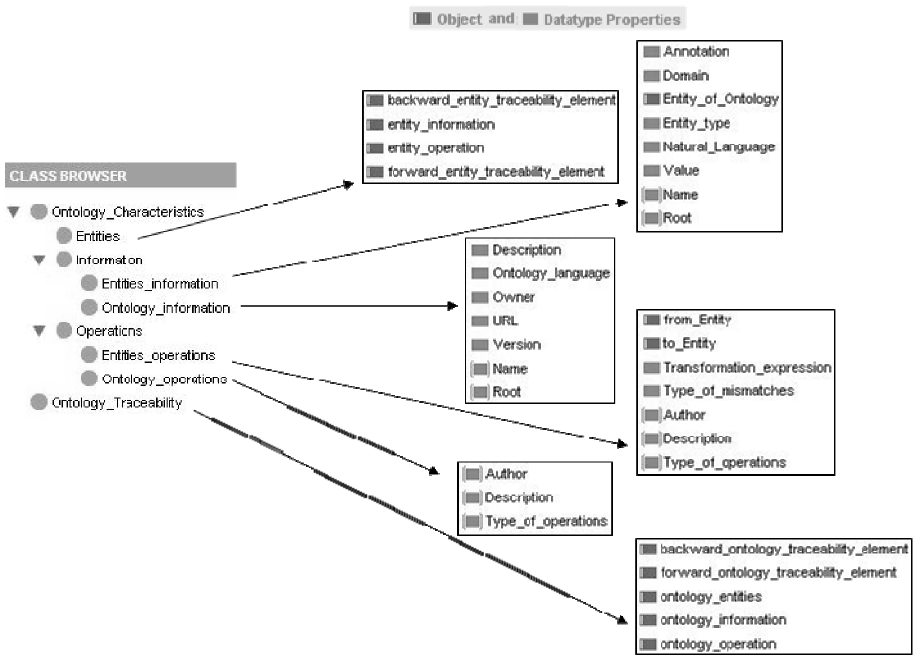

Figure 3. Mediator Ontology structure

The MO (Fig. 3) represents two classes: Ontology Characteristics and Ontology Traceability. The Ontology Characteristics class represents: 1) ontology general information related to ontology and ontology entities (Classes: Information; Entity Information; and Ontology Information); 2) ontology operations that an ontology or an ontology entity (e.g. classes; properties; instances) suffered in the various stages of the ontology life cycle (Classes: Entities; Operations; Entity Operations; and Ontology Operations).

The Ontology Traceability class represents the information related to the various ontology life-cycle stages. Figure 4 (on the top) depicts an abstract ontology life-cycle example with three ontology operations and three stages. Ontology N is the intermediate stage. From Ontology N is possible to make: a backward trace following an Ontology N entity to its related entity in the Ontology N-1 that is the root of this life-cycle, or a forward trace until the last version of the ontology (Ontology N+1) (check Ontology N Instance – left part of the Figure 4). The Entity δ in the Ontology N is the result of a transformation that uses Entity η in the same ontology, which is related to the Entity α of the Ontology N-1. The Entity δ of Ontology N is in Alignment to the Entity x of the Ontology N+1 (check Entity δ Instance – right part of the Figure 4). In conclusion this ontology is able to log ontology and entity operations in a way that is possible to trace changes in all the ontology life cycle.

Since the objective of the MENTOR methodology is to build an ontology that represents the knowledge of an organization domain, but keep working the old own enterprises ontologies, it is important to define how or in what processes all the ontologies involved should be maintained. To avoid inconsistencies in the MO it must be defined a collaborative method for updating it when a related ontology is changed, since the reference ontology must aggregate all the enterprise members' knowledge.

Another important input is when new enterprises want to interoperate with an existent MENTOR compliant organization. This implies to integrate all the new enterprises knowledge in the organization reference ontology The MO supports such integration that can be represented as a new stage in the reference ontology life cycle. For this, new enterprises knowledge has to follow all the MENTOR phases. But, in this case there is already a glossary, thesaurus and a reference ontology established. Thus, the process is to follow the entire MENTOR steps taking in account the results from the first building reference ontology, consequently all the steps will have a lighter discussion or process in its outputs. Only a slight refinement will be needed, since the previous results have a bigger weight in the new reference ontology version consolidation.

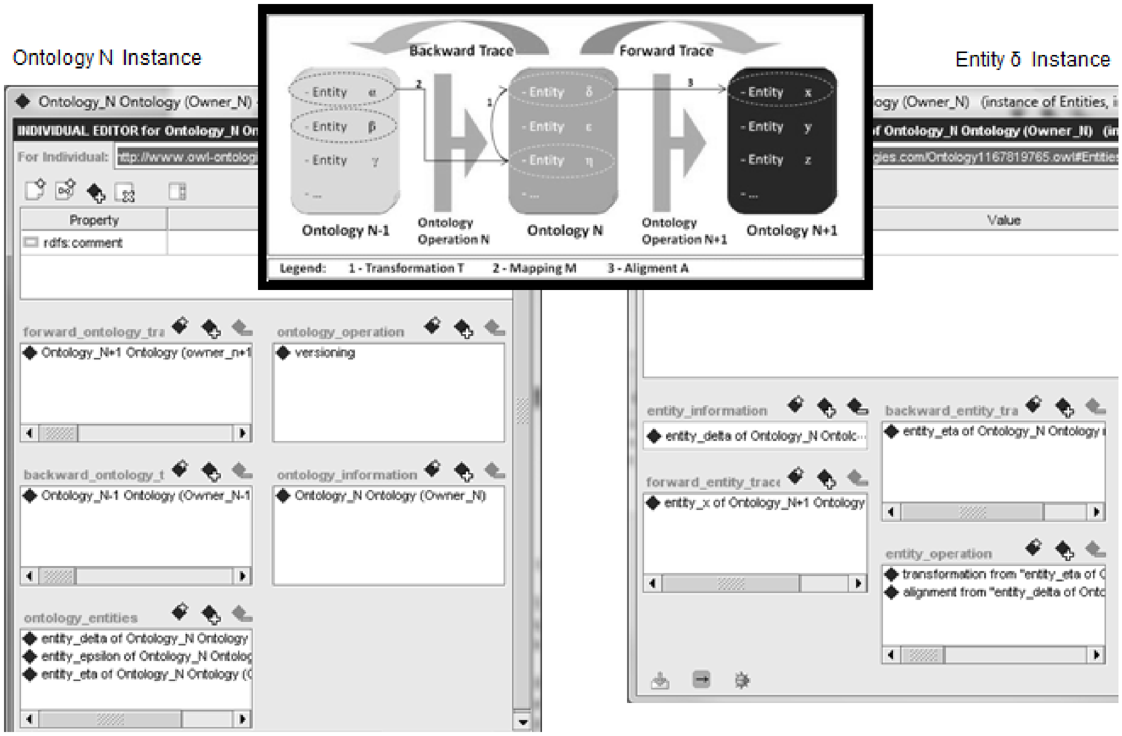

Figure 4. Operations in a three stage ontology life-cycle

5. VALIDATING MENTOR METHODOLOGY

The simple choice of a “bolt” supplier by a mechanical engineer/designer, very often brings interoperability issues. Suppliers usually define proprietary nomenclatures for their products and its associated knowledge representation (whatever format). As stated before, problems persist although Standardization bodies developed and proposed several standards focused in bolt specifications. Thus, the need to align product data and knowledge emerged as a priority to solve the dilemma.

The presented problem was used as a MENTOR use case scenario for validating purposes. The work began with a reference ontology building related to an organization composed by two “bolt” suppliers. Figure 5 pictures the MENTOR phases, where the two enterprises agreed to build a reference ontology as a knowledge front-end to their clients (though there where the condition to maintain own meaning and nomenclature of products of each other). Both enterprises have its product knowledge represented in an ontology format. Although its taxonomic structure and semantics of their ontologies, are a quite different as shown in the Figure 6.

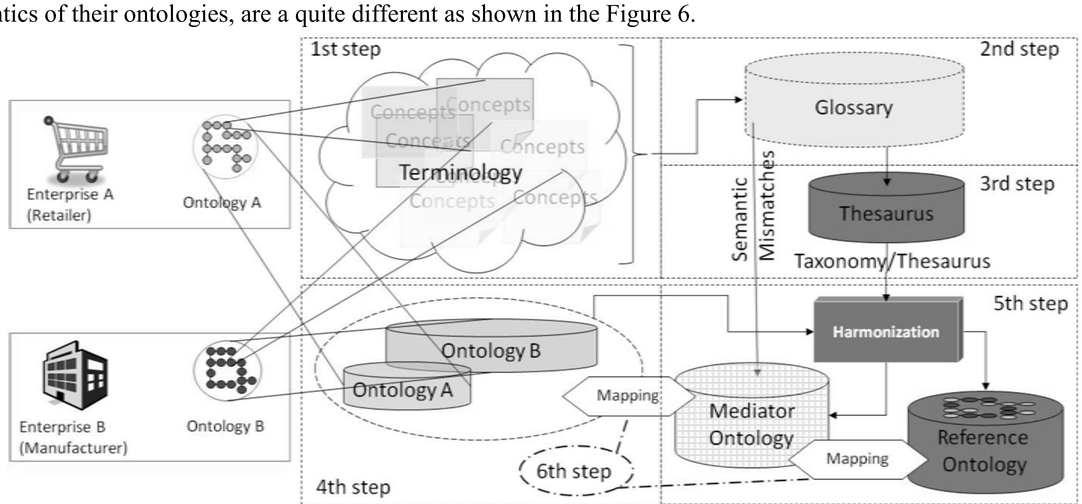

Figure 5. MENTOR use case scenario

The six main steps identified in Fig. 5 represent the ones identified by the MENTOR methodology, which were followed in this scenario. The domain and knowledge engineers start by collecting the concepts in the domain and attributing them definitions. After an agreement they choose the best definitions or compose them with contribution from the various enterprises visions (in this case, two) to achieve first a glossary and afterwards a thesaurus in the domain. With these actions they accomplish the first three steps. One example of such steps is related to definition of a reference concept that was defined from the two following proprietary concepts:

- Enterprise A -> Concept: "s"; Definition: "dimension across flats in a hexagonal head";
- Enterprise B -> Concept: "flat with"; Definition: "diameter across the flats of the bolt's head. It is also the size of wrench to use".

That resulted in the following reference concept:

- Reference -> Concept: "major diameter"; Definition: "in a hexagonal bolt's head, is the dimension of the nominal diameter tangent to the flats (also expressed as the dimension across flats which correspond to the size of wrench to use)".

These semantic mismatches were recorded in the MO, in order to be used in further mapping establishments. In the fourth step it was collected the two proprietary ontologies to knowledge engineers proceed to the definition of the reference ontology in the fifth step. With previous records in the MO, they are able to see semantic bridges between enterprises own terms with the ones established and existent in the built thesaurus. After that, they could identify the best taxonomic structures that they should use for the reference ontology. This is done by the harmonization process. For instance, the classes *Thread*, *Head* and *bolt* that are related by the properties *Has Thread* and *Has Head* in the reference ontology (see right part of the Fig. 6), was defined taking in consideration the direct hierarchy relation about the semantics that the thesaurus presented between those concepts. In conclusion, it is during the harmonization that properties (e.g. *Has Thread* and *Has Head*) should be related to its domain classes.

Sometimes during the harmonization phase it is semantically redefined previous concepts. In this scenario, emerged one semantic issue related to the concept "*major diameter*" (mentioned above). In the Glossary definition step, both enterprises' engineers totally agreed in one definition for the "*major diameter*" concept, taking in consideration its relation to the *head* class domain and by the conjunction of the *s* and *flat with* concepts proprietary definitions. Nevertheless, in the reference ontology, this concept was replaced by "*nominal diameter*" that was already defined in the glossary for the *thread* class domain. Conclusion: the concept "*major diameter*" was rejected and appeared the "*nominal diameter*" concept has the one, to be related to both domains *thread* and *head*. The "*nominal diameter*" reference definition is presented in the following, where the first definition was the first one defined and which only took in consideration the *thread* class domain. And, the second is the final version which the engineers tried to adequate it both classes domain (*thread* and *head*):

- First Reference -> Concept: "nominal diameter"; Definition: "the diameter of an imaginary cylindrical surface tangent to the crests of an external and (or) to the roots of an internal thread".
- FINAL Reference -> Concept: "nominal diameter"; Definition: "numeric value used to quantify the diameter of a cylindrical surface envelope of the feature, without precision neither tolerances considerations (either geometric or dimensional).

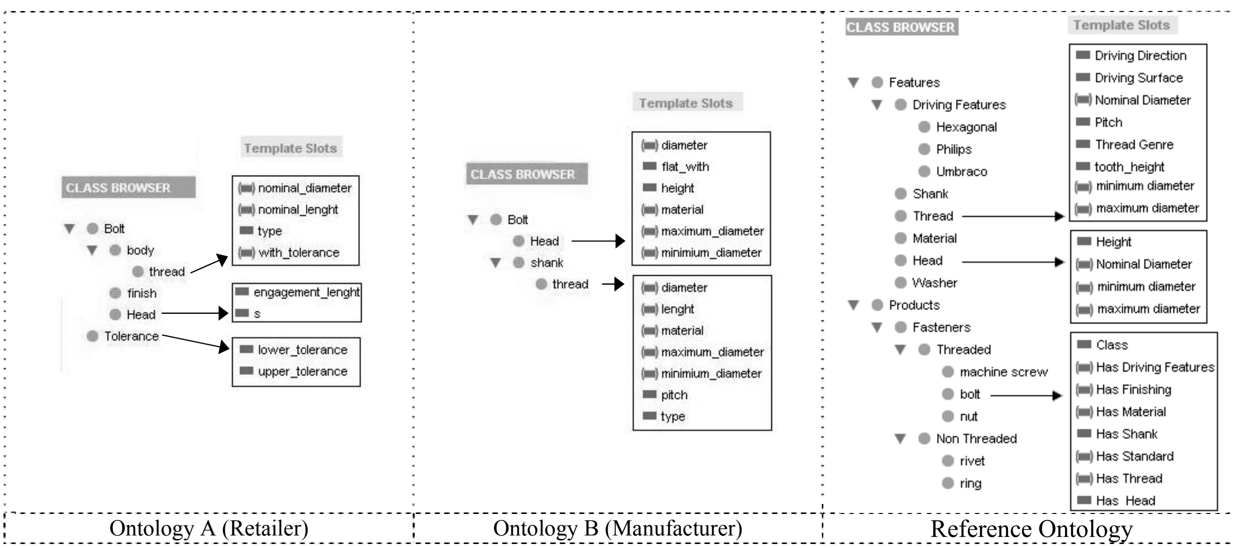

Figure 6. Parts of the Enterprises and Reference Ontologies

In the following is presented another example which intends to present the usefulness of the MO in supporting transformations of data. Engineers defined two properties, *maximum diameter* and *minimum diameter* as a reference related to the *tolerance* characteristic of a *bolt*. Moreover is indicated that *tolerance* was defined as *the interval of values of allowable deviation from a nominal or specified dimension*. These properties are equally used by the enterprise B. But, Enterprise A, uses the concepts *upper tolerance* and *lower tolerance* referring to such properties, which represents the same expected result but using different data values. Thus, it was needed to establish a transformation expression to relate them. Since *nominal diameter* concept has the same value and semantics in all the ontologies, from Reference to A ontology, the transformations equations related to the *tolerance* properties are the following:

upper tolerance = maximum diameter - Nominal Diameter (1)

lower tolerance = Nominal Diameter - minimum diameter (2)

And, from the A to Reference ontology the transformations equations are:

maximum diameter = nominal diameter + upper tolerance (3)

minimum diameter = nominal diameter - lower tolerance (4)

Since all the ontologies operations (mappings and transformations) are saved in the MO, appropriate queries could be used for semantic translations between the organizations members, including an hypothetical organizational front-end which uses the established reference knowledge. The example of Fig. 7 illustrates what happens if a customer wants to buy to an organization one specific bolt. The client system sends a "*getProduct*" message of a *bolt*, which the *thread* has a *nominal diameter* with a value equal to *10*; a *maximum diameter* of *10.2* and a *minimum diameter* of *9.9*. Then, the system's Mediator translates the message and forwards it to the bolt suppliers. Finally, each of them receives the message with its recognized semantics and data.

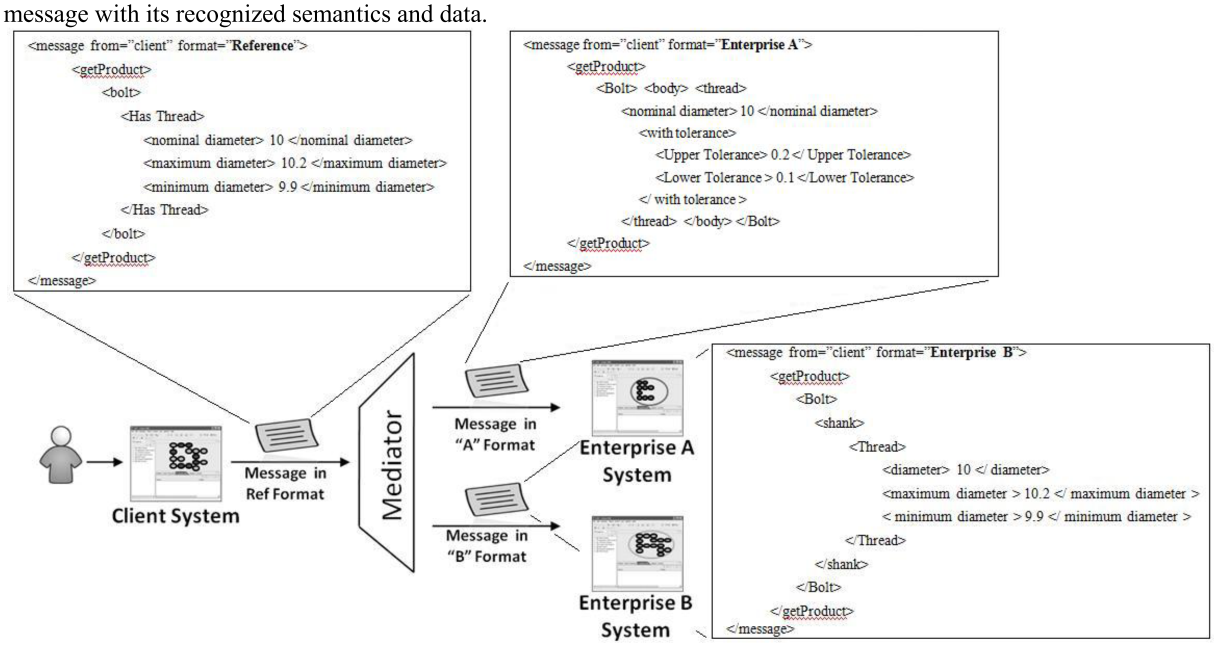

Figure 7. Mediator's Message Translation Example

Several advantages resulted through the MO use during communication among client and suppliers: a short term advantage was the acquired autonomy of computational systems of any enterprise to smoothly communicate with external parties as they were using the Reference ontology (which latent knowledge richness likely offers new business opportunities). This is also the main motivation that Enterprises may consider to join the Reference ontology building process, independently of its domain expertise or budget impact in the market.

Medium and long term advantages of described MO methodology adoption are also expected after the described encouraging results. In fact, the MO methodology introduces enhancements to the very early stages of product design and development, though it is expected that semantic correlated with product data models were an added value during product's manufacturing phase - not only at data level mismatches but also in manufacturing constraints assessment too. Lastly, in recent years, parallel efforts of research community lead to the development of computational Product models and Product data models, like those resulting from ISO 10303 STEP technology (addressing engineering issues) and more recently those from Semantic web (focused on business concerns). Both technologies have a strong potential in their specific application range, but promising enhancements may arise when providing existent product data models with semantic capabilities, thus merging those two worlds. The STEP computational product model offers a manufacturer the necessary confidence to manipulate geometric product data, but extending knowledge capabilities of such model (and in particular semantic enrichment) is a key improvement to fully profit of emerging electronic commerce.

3. CONCLUDING REMARKS

The proposed MENTOR methodology enhances inter and intra-organizational knowledge sharing, allowing its actors keeping their own ontologies or knowledge representations by producing a reference ontology in the domain. MENTOR brings together the building and reengineering of ontologies related to mapping competences.

Ontology maintenance is other characteristic which MENTOR facilitates by enabling traceability recording in MO and which information could be used to track changes or to go back to consistent previous ontology versions. Also, MENTOR enables dynamic and flexible seamless joining of enterprises to develop business in a network of partner organizations.

The authors have prototyped MENTOR with the main part of the functionalities described in the methodology proposed. In the methodology and its prototype tool have been tested by the funStep initiative under the INNOVAFUN project (www.funstep.org) in their furniture reference ontology building. The thesaurus and the reference ontology built in such process have been used for testing and consolidation of the ISO 10303-236 (Product data representation and exchange standard) model semantic enrichment. With such work, a carefully validation based on independent reviews followed by a consequent improvement has been carried out. For the future, the authors intend to have available a set of web services able to set up knowledge sharing organization through the web. Other ontology methodology categories were not in this evaluation process, such as ontology learning and ontology evaluation, postponed to another enhancement phase.

Several advantages were identified resulting from the use of MENTOR methodology, the most relevant being the semantic enrichment of standard product data models developed under ISO 10303 STEP standards. Product data models are well defined through STEP models, with necessary and sufficient geometric 3D detail, but lack of expressivity of such models as being identified as a major barrier to PLC integration capabilities. Therefore, present work may be seen as a contribution to semantic skills of product data models, looking for smooth integration between Design and Manufacture stages of product's lifecycle.

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