Toward Dynamic Ontologies for the Industrial Manufacturing Domain

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Abstract. The manufacturing enterprise as a whole is a highly dynamic environment, because of the continuous changes of the market. This happens as a result of the evolving variables that restrict it. Such aspect forces the enterprise to be more competitive. Despite of such needs, there are situation where the approaches commonly used have reached an inflexion point. On the other hand, newer approaches, as ontologies and the Semantic web are appearing and are gaining progressive interest in this domain. Nevertheless, ontologies and the Semantic web also present limitations to model the manufacturing enterprise. In this work, we present: a review of these limitations, explaining use cases where dynamic ontologies can be useful for manufacturing. Furthermore, we deliver an open problem and some questions related with this domain. The advantages of solving this open problem are outlined using the Semantic Web Virtual Enterprise Model, as a new method for managing dynamic ontologies in the manufacturing domain.

Keywords: Ontology, Semantic web, Manufacturing, Agents.

1 Introduction

The benefit of using Ontologies and the Semantic Web in the industrial manufacturing domain, as a way for the representation and reutilization of product, process and expert knowledge, has been studied and demonstrated in several recent studies. These researches include, studies related with specific aspects of this domain, as for example: product configuration modeling [1], reconfigurable and flexible manufacturing systems [2], machining ontologies [3], process ontologies [4] and products data exchange among heterogeneous CAD software tools [5]. Some other research efforts present more general approaches as the one indicated in [6], in which it was tried to cover the whole Life Cycle of the Product, and delivered software tools based in Semantic Web.

Despite of the considerable quantity of research done in this newer direction, all these approaches present substantial limitations to represent this domain, not at fault of the approaches themselves, but due to the nature of this domain, languages and technologies that are being used. Thus, a wide horizon appears, in which new challenges and research directions are presented [7].

Our work aims to contribute presenting use cases and scenarios from the manufacturing domain, in where we can identify the benefits of using ontologies and the Semantic web to model enterprises and processes planning. We also demonstrate why dynamic ontologies are needed and describe the problems and questions that appear when we try to achieve the goal of modeling this domain. But, we also include possible courses of actions that can be taken to overcome this problem.

This article is divided as follows, in section 2, the Web Ontology Language and some of its limitations are described. In Section 3, a use case for manufacturing process planning is illustrated. In Section 4, The Semantic web Virtual Enterprise (SeVEn) is delineated. In Section 5, an Open Problem and Some Open Questions are described. In Section 6, we present our conclusions and an overlook of our future works.

2 The Web Ontology Language (OWL) and its Limitations

OWL is intended to be used when the information contained in documents needs to be processed by applications, instead of being processed by humans [8]. This language has three levels of expressivity or sublanguages, which have to be taken in account at the moment of delineating the scope of any project or application. This levels are, OWL – Lite, which supports classification hierarchy and simple constraints; OWL – DL, which guaranties maximum expressiveness while retaining computational completeness and decidability, and OWL – Full, which facilitates maximum expressiveness, but with no computational guarantees. In this Section we are considering the OWL – DL, because we have the possibility of maintaining a high level of expressivity, but not so high to lose the computational results.

Some of the limitations of OWL – DL were presented by [9] as a result of simple examples (as the authors titled themselves). They demonstrated that whilst OWL – DL had a rich set of class constructors, expressivity of properties was much weaker. So, OWL did not support making assertions about the equality of the objects at the end of two different objects. They tried to solve this situation using the Semantic Web Rule Language (SWRL) [10], and getting finally satisfied all the conditions that they had established previously in their experiments.

Although, the combination of OWL and SWRL extends their set of axioms, this extension must be managed carefully, in order to maintain extensibility and interoperability [11]. Moreover, [12] incorporates the limitation of OWL to represent *exchange* and *reciprocity*. They posed that using rule-base systems is problematic and not desirable. They presented an approach based in the notion of transaction (Fig. 1), with which changes of values, transfers and transformation are possible. Likewise, they indicated that such changes can occurs in context of exchange. Nevertheless, the notion of exchange involves additional constrains with regards to reciprocity, as for example the balance (or mass and energy conservation). It is possible that such restrictions are not straightforward to represent in a manufacturing domain.

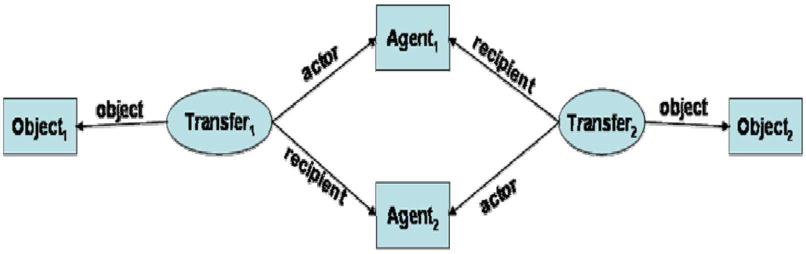

Fig. 1 Structure of a transaction [12].

Despite of the limitations found in OWL to represent changes, some other researches have been led recently in this direction. In [13] a Change Ontology was presented to manage such changes, but their proposal was closer to the versioning control of ontologies, and the maintenance of existing ontologies. Finally, [14] ratified the limitation of OWL to model dynamically changing information. These authors summed up, that some of the proposals related with changes and time representation are fairly elaborated and none has resulted in practical representations. These authors presented a methodology that combines a temporal model, OWL – DL, SWRL and the Semantic Web Query Rule Language (SWQRL) [15]. They mentioned that this approach facilitates the encoding of temporal dimension information in OWL ontologies, allowing temporal reasoning and querying, but this approach is not given to manage changes in ontologies, based in their reasoning and querying process.

3 Manufacturing Process Planning Aided by Ontologies

The manufacturing domain has been defined by [16] as the sum of products, process and resources concepts. A close relation appears among these concepts when we plan a process to manufacture a product. The manufacturing process planning is a highly time consuming activity, and requires experimented planners with good knowledge of the manufacturing facility. These experts, as human beings, have the possibility of making mistakes in the process [17]. Because of these factors, several Computer Aided Process Planning (CAPP) software tools have appeared in the market for commercial use, aiming the reduction of errors and time consuming of the manufacturing process stage. The goal of these software tools is that, given a product (mechanical or geometric parts), machining features are recognized, machining operations and sequences, are determined, and sometimes machining costs are also estimated. To get these tasks done, a CAPP software tool has to read a file generated from Computer Aided Design (CAD) software tools, in order to get the features to be machined. This first task of the CAPP system is called Automated Features Recognition (AFR). Nowadays, there are still problems to identify features from CAD files, limiting the scope of CAPP systems [18].

In this point, we consider that ontologies and the Semantic Web can be proposed to weaken the limitations of standard CAPP software tools, due to the ease that these approaches have to represent, manage and reuse the knowledge in the manufacturing domain, as has been reported by [19], [20] [21]. The problem here is that the tasks of the CAPP system do not finish with the features extraction, after they are identified; there is at least another task to do. A machining sequence has to be generated; this action implicates reasoning over changes of states, which means that procedural knowledge has to be implemented [22]. Machining sequences can be seen as changing transitions over time intervals, and as indicated in Section 2, Ontologies and The Semantic Web have limitation for these kinds of representations.

To illustrate this problem, we are going to use a methodology for AFR, proposed by [23]. This author suggests the generation of a raw material gotten from the input CAD file. This raw material is identified as "boundary box" in Figure 2. With the boundary box, the features are extracted and following a preexistent set of rules; a sequence of operations can be delivered to manufacture the product.

If we move toward the Ontological Representation of CAD file, we encounter that even software tool to exchange from CAD files to OWL has been reported [24]. So, the product (mechanical element) shown in Figure 2 can be represented as an instantiated Knowledge base of a CAD Ontology. Using rules written with the SWRL and making a classification, the edges that are part of the boundary can be inferred. With the SQWRL is also possible to get the features applying AFR, and we would have a result similar to Figure 3, where we can see four identified features. Such features have to be machined over the raw material to get the product indicated in Fig. 2.

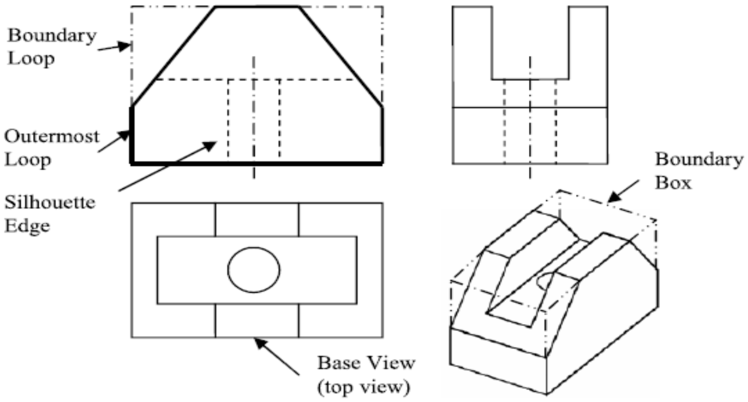

Fig. 2 Sample of some basic concepts [23].

In Figure 4, we encounter a description of the machining process and its results, step by step. The sequences presented there, did not have to be the most accurate, and did not have to have considered specific workshop facility constraints. Here the problem consists in reasoning about the mechanical operations that are necessary to become the raw material in a terminated product and how to make this knowledge reusable. We have to consider constrains as machine load, material, sequence, tools, etc., to get the order of occurrences of such operations. There is another requirement of preserving the information of the transition in order to have access in the future to the "history of the product" [25].

So, we have two main alternatives:

1. To generate progressively and automatically as many copies of the raw material ontology as processes we identify, and change them according to the order of execution of the mechanical operations or,
2. To modify progressively and automatically the product ontology, including an order of execution tag in each feature gotten by AFR.

As a result, of applying any of both alternatives, we will have made the AFR and defined the sequence of operation based on our input CAD ontology. Here our approach differentiates from [26]. While in that research, those authors reported integration among two software tools for CAD/CAPP, we aim to make reasoning about transitions among a terminated product and a raw material, which has been generated by inference too, to generate automatically a set of instantiated ontologies. This set of evolving inferred ontologies will represent the process transitions themselves. Thus, such set of ontologies can be queried as a Knowledge base by a simpler CAPP system based on SQWRL or SPARQL [27]. In this last case, SPARQL can be combined with a repository as SESAME [28].

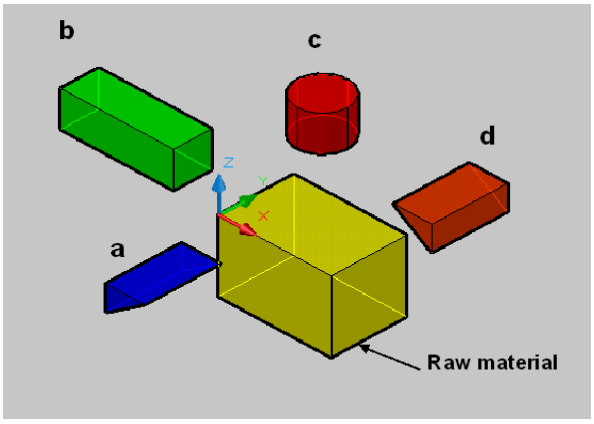

Fig. 3 Raw material and features to be machined [23].

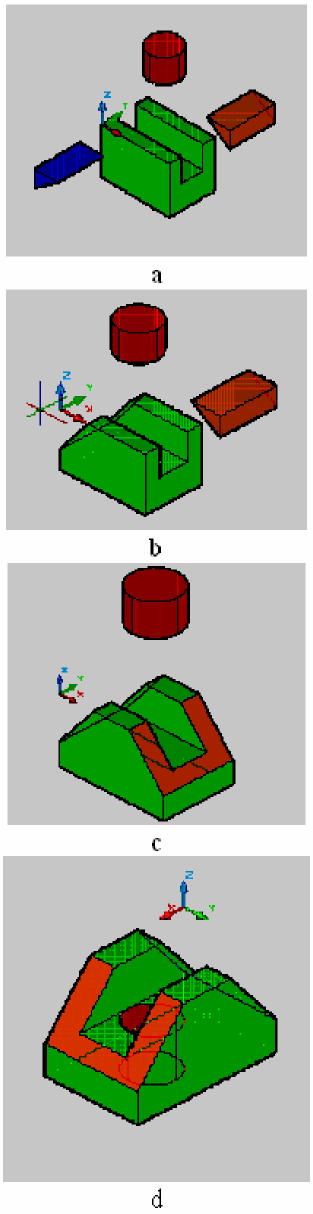

Fig. 4. Progressive changes in the raw material.

But, any of the courses of actions enumerated above implicates changes in at least one ontology, and such changes must occur automatically as the result of a reasoning process over a set of rules or axioms. With reference to this, [29] has proposed a framework which facilitates change in a Knowledge base. These changes consist mainly in variation in references or property's value. These authors recommended that the effectiveness of their proposal must be measured, to determine the achievement of goals. They also remarked that most of the OWL document enrichments get lost during serialization. Other approaches, related with the manufacturing domain as [20] and [2], show a trend to use agents, but neither of both reported to have the requirement of making changes in the Knowledge base to achieve their goals.

4 The Semantic Web Virtual Enterprise (SeVEn)

As we indicated in the previous Section, the manufacturing domain is composed by a number of elements. Each one of them has its own concepts, features, interrelations and constrains. So, making newer products, or modify them, can be awkward. One of the approaches to overcome this situation is computer modeling and simulation. Modeling an enterprise is not a new idea [30] and has been presented as a requirement for integration. The fundamental motivation for such integration is remain competitive in an every day more challenging market, facilitating decision making.

Ontologies and the Semantic Web are outlined to have an important role to make this challenge feasible, because of their easiness to represent and make reasoning about declarative knowledge. To support this assertion we present our approach in Fig. 5.

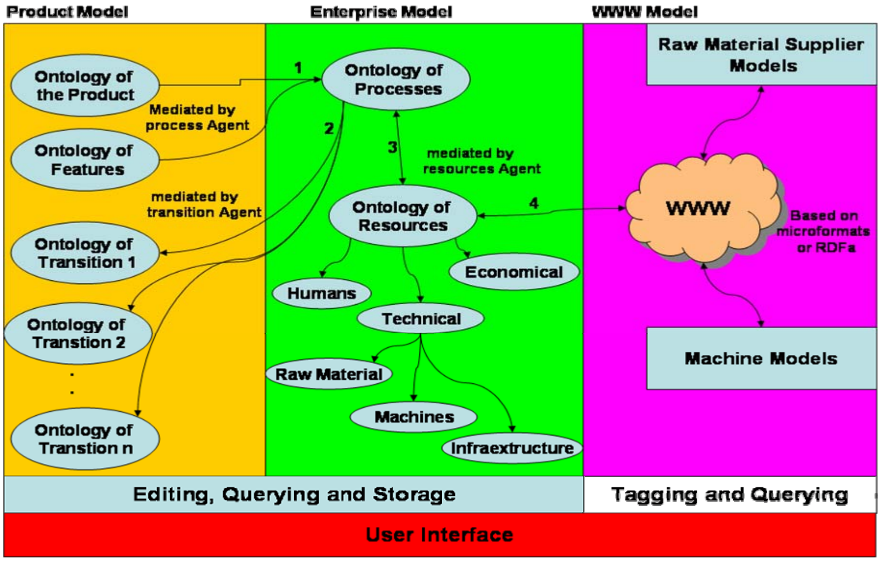

Fig. 5. Semantic web Virtual Enterprise Model.

This approach differs from the approaches presented in [31] and [20] fundamentally in the presence of three interacting model layers (Product, Enterprise and WWW), two operational layers (Editing, Querying, Tagging and Storage), an user interface and four mediation moments. These last are identified as 1, 2, 3 and 4 in Fig. 5. The first layer presents the product ontology and its transitions, modifiable by inference over the product ontologies itself. As another alternative, these changes can also involve the progressive creation of a set of tags over the ontology. These tags would indicate the process sequence of production.

Mediation 1 consists in the determination of the manufacturability of the product. This occurs among the first and second layer, it will be assisted by a process agent. A positive or a negative answer can be obtained as result of this mediation. If the answer is positive, Mediation 2 starts. It consists in the generation of a transition ontology, which represents a change in the ontology of the product. The generation of raw material can be included in this category. Here the Editor and storage tools get involved, to write and store the newer instantiated ontology, which represents the change or transition.

On the other hand, if the answer is negative, it indicates, that a specific process or action can not be carried out by the enterprise as it is modeled. That assertion is done, because the ontology of the process represents all the activities that can be done in the enterprise, based on their resources ontology.

Mediation 3 corresponds to the interaction among the ontology of the process and the ontology of resources. It consists in determining if the processes requires for manufacturing the product, are supported by the enterprise model. This action is started by the resources agent, just after the mediation of the process agent begins. To make this task possible, the querying tool is use. In fact, the resource agent gives the answer to the process agent. With a negative answer, both mediations 1 and 2 have to stop and a message to the user interface has to be sent. In this message, our system indicates that such product is not feasible to make under the current enterprise model.

With this negative answer Mediation 4 can be triggered. The resources agent has to find the missing resource. We consider that Microformats [32] and/or RDFa [33] are valid technologies to get this goal in a pragmatic way. There are Microformats of products as hproduct [34], but for other core elements as machines, the interest to represent them is just appearing [21]. In any case, assuming that we have access, by tagged web pages, to the resources in which we are interested. Then our agent will obtain the corresponding resources. This resources information can be used in two ways; in an existing enterprise, our system will present the resource to the user, indicating that such resource is necessary to make our product feasible. On the other hand, in a simulation environment, our enterprise model will be modified and updated, in order to include this newer resource. After any of both scenarios are completed, Mediation 4, stop until another resource search is triggered.

If we were in a simulation environment, with the stop of Mediation 4, the other mediations would start again in order to generate all the transitions of our product.

The presentation of the scenario drawn in Fig. 5 has been done with the interest of illustrate how important and advantageous will be concentrate efforts to generate effective frameworks to combine declarative and procedural knowledge in the manufacturing domain.

5 An Open problem and Some Open Questions

We have presented an example of a situation where the possibility of generating changes in a Knowledge base, can be useful in the manufacturing domain. At the same time, we have shown that there are constrains that overcome most of our technological possibilities. Despite of that, there are some proposals, from where we can continue researching and evaluating to improve them. Nevertheless, the problem of supporting an automatic dynamic and changing ontology, in the manufacturing domains to represent process planning remains. This problem and its state of the art let us present the following open questions:

Do we need to apply methods, based on OWL – FOL transformations, as proposed by [29], or we have another alternative to facilitate a reasoning process, based on procedural knowledge?

The exchanging from OWL to FOL is possible, but more of the OWL document enrichment gets lost during serialization. So there are two main alternatives, or we use techniques based in OWL – FOL to facilitate reasoning and inference, or we use another techniques and tools to try to achieve the same goals, as similar as possible. In any of both situations, a measurement of effectiveness is needed. This assertion is the foundation of our second question:

What kind of framework do we need and how is going to be facilitated the interchange of information (knowledge)?

The input in our dynamic environment is going to be a CAD file, which has to be exchange in OWL. After this, a raw material is going to be generated. From this model a reasoning process based in procedural knowledge will be started. This reasoning process implicates, other ontologies, namely: ontologies of processes, ontologies of features, ontologies of machines, etc, and (possibly) agents. That means, such ontologies must be disposed in an accessible environment, as ontologies repositories. We might integrate another aspect of ontological engineering, called modularity.

We finish this Section with this question:

What advantages will give this newer approach to the user of CAPP system, why they should migrate to this Ontology-based technology?

Even if we propose a method and get the goal of reasoning about declarative and procedural knowledge in manufacturing domains, there are other techniques and software tools, that achieve that goal with limitations, as discussed in Section 3, but they do it. So, it is necessary to demonstrate the feasibility of using dynamic ontologies in such domain, indicating how many resources can be save implementing this approach or which other advantage can obtain the final user.

6 Conclusions and future works

In this article we presented some of the limitations of ontologies and the Semantic Web. Among them, we emphasized the limitations related with the possibility of making dynamic changes in the same ontology using the Semantic Web. Our use cases were concentrated in the manufacturing domain. In the first use case, we saw that a CAPP system can be generated from a CAD file, for which we need a framework that facilitates automatic changes in our product ontology and to record such changes, we consider that this framework has to be develop, this task remains as an open problem. We leave a group of questions related with it.

We also presented a wider vision of a Semantic web Virtual Enterprise, that can be feasible if we find effective ways to overcome our open problem. This framework promises to be highly reconfigurable, interactive and modular.

Our research effort will be addressed to generate newer ontologies from instantiated ontologies of cad files, and use them as process planning Knowledge base. After we reach this goal, we will continue toward the Semantic web Virtual Enterprise.

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