Design of Fundamental Ontology for Manufacturing Product Lifecycle Applications

Dimitris Kiritsis[1], Soumaya El Kadiri[1], Apostolos Perdikakis[1], Ana Milicic[1], Dimitris Alexandrou[2], and Kostas Pardalis[2]

[1] LICP laboratory, Ecole Polytechnique Federale de Lausanne, Switzerland
[2] UBITECH, Athens Greece

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Abstract. In today's world of fast manufacturing, high quality demands and highly competitive markets, it has become vital for companies to be able to extract knowledge from their operating data, to manage and to reuse this knowledge in efficient and automated manner. Ontology has proven to be one of the most successful methods in fulfilling this demand and to this day, it has been applied in number of scenarios within companies of all scales. The most appealing features of the ontology are well-defined structure of the knowledge organization; being machine understandable enables automatic reasoning and inference and finally, well defined semantics enables easy interoperability and design of the plug-in modules. Still, one key downfall of ontology is that it usually has to be manually designed from the beginning for each new use-case. This requires highly specialized knowledge experts working closely with the domain experts for, sometimes, significant period of time. In this paper we propose LinkedDesign solution for described issues, as an example of design of fundamental ontology which can be easily adjusted and adopted for different production systems, thus eliminating the need for repetition of entire design process for every individual company. We also discuss and point to a new and challenging fields of research emerging from application of ontology into manufacturing companies, mainly concerning rapidly growing amounts of knowledge which are beginning to exceed human ability to process it.

Keywords: Ontology design, Knowledge Management, Design and Manufacturing, Product Lifecycle.

1 Introduction

As we enter the knowledge society, ownership of knowledge and information as a source of competitive advantage is becoming increasingly important. In other words, organizations depend more on the development, use and distribution of knowledge based competencies. This is particularly relevant in knowledge intensive processes such as product innovation. Consequently, research and development (R&D) organizations are paying more attention to the concept of managing their knowledge

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base in order to increase competitive advantage, through effective decision making and innovation (Nonaka 1991), (Davenport et al. 1996), (Sveiby 1997). Further on, it's becoming increasingly important to enable exchange of knowledge between all stages of product life cycle (PLC), as a prerequisite for optimization of all critical procedures in the design and manufacturing of a product. One of the methods, which has proven to be a very efficient tool for knowledge structuring and exploitation, is ontology. Through the definitions of concepts and relations, it is possible to describe entire domain of interest in a very convenient and details manner. Semantics enrichment opens a possibility for automatic reasoning and inference, which leads to automatic generation of new knowledge. Finally, using different plug-ins, ontology enables interoperability between different systems. All of these benefits are vital in a case of large production companies, which are struggling with ever increasing amounts of data and facing problems of exchanging knowledge between different systems employed for different stages of PLC. This is why it comes as no surprise that ontology has quickly found its place in academic research, as well as industrial research and development.

Popularity and employment of ontology is to some level suppressed by sometimes long and challenging process of ontology design for every specific application. It requires an ontology experts working together with domain experts, often trying to describe highly complex company activities. Although, there are number of standards and methodologies for ontology design, it often comes down to long hours of discussion over hand-sketches. Additional concern is that every domain can be modeled into an ontology in many different ways and it takes experience to be able to judge which is the optimal solution.

LinkedDesign is a FP7 project which, among other things, has a goal of overcoming the above-described problem. It will result in system that allows fast and efficient design and production. LinkedDesign Ontology (LDO) is being designed to utilize knowledge extraction, knowledge structuring, knowledge exchange and knowledge reuse for three use-case companies with highly diverse products and activities. Such challenging task, resolved in a generalized solution which is now applicable for almost every design and manufacturing business, after very light adjustment and installation.

2 State of the Art

Ontologies play an important role for many knowledge-intensive applications, since they provide formal models of domain knowledge that can be exploited in different ways. Ontology development has become an engineering discipline, Ontology Engineering, which refers to the set of activities that concern the ontology development process and the ontology life cycle, the methods and methodologies for building ontologies, and the tool suites and languages that support them (Suárez-Figueroa et al. 2011). Foremost methodologies for building ontologies are:

METHONTOLOGY (Gomez-Perez et al. 2004), On-To-Knowledge (Staab et al. 2001), DILIGENT (Pinto et al. 2004) and a new methodology, called the NeOn Methodology (Suárez-Figueroa et al. 2010). The Major ontology languages are: RDF (Klyne & Carroll 2004), RDF Schema (Guha & McBride 2004), OWL (Dean et al. 2004), OWL 2 (Motik et al. 2009) (OWL 2 EL, OWL 2 QL, OWL 2 RL), and SPARQL (Prud'hommeaux & Seaborne 2008). Finally, the leading ontology tools were identified. These are: The NeOn Toolkit (http://neon-toolkit.org/), Protégé (http://protege.stanford.edu/) and TopBraid Composer (http://www.topquadrant.com/products/TB_Composer.html). Ontology design is still one of the relevant research questions and number of methodologies has been developed. As previously mentioned, METHONTOLOGY, On-To-Knowledge, and DILIGENT were up to 2009 the most referred methodologies for building ontologies. These methodologies mainly include guidelines for single ontology construction ranging from ontology specification to ontology implementation and they are mainly targeted to ontology researchers. In contrast to the aforementioned approaches, a new methodology, called the NeOn Methodology, suggests pathways and activities for a variety of scenarios, instead of prescribing a rigid workflow.

The NeOn Methodology for building ontology networks is a scenario-based methodology that supports a knowledge reuse approach, as well as collaborative aspects of ontology development and dynamic evolution of ontology networks in distributed environments. The key assets of the NeOn Methodology are:

- A set of nine scenarios for building ontologies and ontology networks, emphasizing the reuse of ontological and non-ontological resources, the reengineering and merging, and taking into account collaboration and dynamism.
- The NeOn Glossary of Processes and Activities, which identifies and defines the processes and activities carried out when ontology networks are collaboratively built by teams.
- Methodological guidelines for different processes and activities of the ontology network development process, such as the reuse and reengineering of ontological and non-ontological resources, the ontology requirements specification, the ontology localization, the scheduling, etc. All processes and activities are described with (a) a filling card, (b) a workflow, and (c) examples.

All of the named methods are guidelines for creating specific ontology from the beginning. LDO is created as form of template, which can be easily adjusted and adopted by almost any design and manufacturing company, with little or no knowledge about ontology design. The ontology design research is a field in which great amount of work is done within industrial research teams and their results are not always public. Still, to our knowledge. A number of recent works (A. Matsokis & D. Kiritsis 2010), (Kim et al. 2009), (Fiorentini et al. 2008), (Demoly et al. 2012), (Panetto et al. 2012) and (Batres et al. 2007) in various phases of the lifecycle have already provided promising results.

3 LinkedDesign Ontology

3.1 Methodology for the Design of the Fundamental Ontology

Based on some previous work, a first list of fundamental concepts of all data relevant for the product in all stages of its life cycle has been defined following a bottom-up approach described in (A. Milicic et al. 2012).

In order to design the fundamental ontology, the list of top level concepts has been updated lining up with the NeOn methology (as described in the state of the art), based on the following actions:

a) Ontology requirements specification: define the purpose, scope, intended end-users, intended uses, ontology requirements analysis (non-functional and functional).
b) Analysis of existing resources: reusing and reengineering of non-ontological resources (UDEF[1], Standards for product data management); reusing, merging and mapping ontological resources.
c) Conceptualization and formalization.

3.2 The LinkedDesign Fundamental Ontology

The LinkedDesign fundamental ontology can be seen in Figure 1 and some of the top level concepts are given in Table 1.

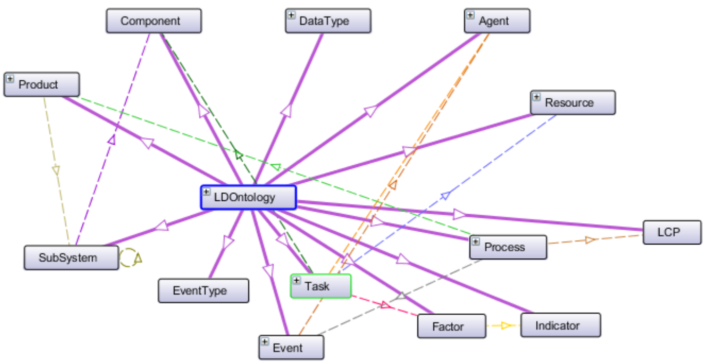

Fig. 1. The LinkedDesign Ontology

[1] Universal Data Element Framework.

Table 1. Top Level Concepts

No.	*Top Level Concepts*	*Description*
1	Task	Groups scheduled actions
2	Process	Groups all processes
3	Product	Groups all products
4	Subsystem	Groups all sub-systems composing a product
5	Component	Groups all components composing a subsystem
6	Resource	Groups all the required elements for product manufacturing
7	Agent	Groups all the agents
8	LCP	Groups life-cycle phases of the product
9	Event	Groups the list of event
10	EventType	Describes the type of the event
11	Factor	Groups relevant issues related to product which need to be examined
12	DataType	Describes the obtained data

3.3 Application in the Context of LinkedDesign

LinkedDesign ontology is designed as centralized network of functional unit-ontologies, each dealing with specific task. As sub trees of this core ontology, network contains ontologies which utilize specific needs and requirements of each of three industrial partners. Use-case 1 deals with hot stamping process and aims at analyzing and learning from correlations between production process parameters, geometric and microstructural properties, and cracks revealed within work pieces, thus enabling a better quality and reducing errors and defects and finally improve and adapt production process. Use-case 2 deals with knowledge based engineering and knowledge capture with KBE systems. The purpose of implementing an ontology for this use-case is the ability to manage KBE solutions (basically KBE Script) and to provide semantics for a business layer which controls the GUI. Use-case 3 deals with lifecycle cost analysis and assessment in order to optimize engineering decisions and facilitate efficient allocation of resources. This use-case aims at exploiting knowledge coming from previous projects and experiences from lifecycle cost analysis perspectives, leading thus to optimize new product's characteristics and costs. Concepts are connected with relations and the rules are defined, describing the functionality of the domain. The graph of the network ontology is shown in figure 2.The idea is that, beside three industrial partners involved in LinkedDesign, practically any company dealing with design and manufacturing will be able to reuse the core, data sources and knowledge subontologies, with a little or no adjustments. They will also have the ability to define and add ontology covering their specific

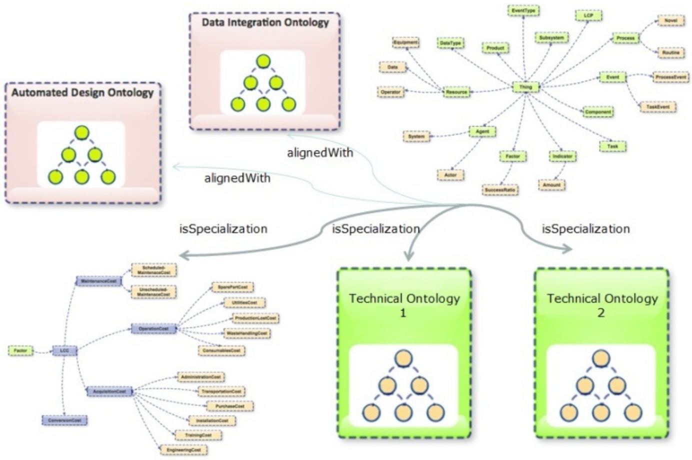

Fig. 2. The LinkedDesign Ontology Network

needs if any, as it was done for the three industrial partners. This significantly reduces the resources needed for design of ontology from the beginning and hopefully will lead to even bigger popularization of ontology implementation.

4 Open Research Topics

The question which needs to be raised, concerns the increasing amount of knowledge in digital systems. The time when increasing amount of unstructured data was the issue will soon be over, as the research community is progressing in the field of data mining, knowledge extraction and knowledge management. Currently, the most common usage of knowledge bases and ontologies is querying, but this assumes that the user is aware of the topics and amount of available knowledge. The new challenge needs to be in further exploitation of ontology being machine understandable, more precisely, ontology should be very convenient base for the next generation of recommendation systems. Based on a context and data retrieved through ontology, system should be able to assume the profile and the activity of a user, and present him with a knowledge which will be useful to the user, but he wasn't aware of its existence. Such system should come as valuable tool for design & manufacturing community, as this is precisely the field where a number of different-profile users are working on the same product, and it is very difficult to be informed about the details of the product from all stages of product life cycle.

5 Conclusion

Implementation of ontology for the industrial needs leads to great partnership where researchers and companies are motivating and inspiring each other for great achievements. LinkedDesign Ontology is a step toward bringing research results closer to their implementation and exploitation. It greatly simplifies the design and usage of ontology for a wide variety of companies as an efficient and productive tool for knowledge management. As the popularity and usage of ontology progresses, there will be more need for further improvements and solutions. There will be new challenges for the research community, such as one proposed in Chapter 4.

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