A NOVEL KNOWLEDGE MANAGEMENT METHODOLOGY TO SUPPORT COLLABORATIVE PRODUCT DEVELOPMENT

Wai M Cheung
University of Durham, UK
w.m.cheung@durham.ac.uk
Paul G Maropoulos
University of Bath, UK
p.g.maropoulos@bath.ac.uk

This paper discusses the theoretical aspects and applications of a novel methodology for exploiting a knowledge management editor tool to structure organisational knowledge. An organisational knowledge framework for capturing and representing design and manufacturing know-how has been defined using an ontological approach. The key business benefit of adopting such an approach arises from the closer integration between the key technical and business activities taking place during early design. In particular the effectiveness of decision making is increased.

1. INTRODUCTION

Ontologies are increasingly becoming important in the fields of intelligent searching on the web, knowledge sharing and reuse, and knowledge management (Hausser 2000). Ontologies have been used to share and reuse knowledge and information, predominately in the field of medical informatics. The main reason ontologies have become so popular is the fact that they provide a shared and common understanding of a domain that can be communicated between people and application systems (Davies *et al*. 2002). Lately, there have been an increasing number of research projects applying ontological techniques in the context of product development (Ciocoiu *et al*. 2001, Duineveld *et al*. 2000, Lin and Harding 2003). However, none of these projects directly address the issues of utilizing ontology technique to share manufacturing knowledge during product development in a collaborative and distributed manner.

The aim of this paper is to discuss a methodology of creating an axiom-controlled ontology for use in an "organisational knowledge" framework. An axiom is a statement that defines or constrains some aspects of the knowledge model and is intended to control or influence the behaviour of the model (Ontoprise 2004). In addition, this paper describes a manufacturing know-how data structure which has been constructed as part of an "organisational knowledge" framework using an ontological approach. The term organisational knowledge is defined as "a collective wisdom of a firm which may be explicit, in the form of databases or documents, or tacit, expressed by action" (Rich and Duchessi 2001). An ontological approach can be used to elaborate the organisational knowledge by defining the semantics to capture the meaning of the terms and axioms (to define a set of rules if applicable). This is used to enhance and encapsulate the way of reusing the knowledge-based system in a collaborative manner within a production network.

2. KNOWLEDGE-BASED SYSTEMS AND ONTOLOGY

2.1 Introduction to Ontology

In information technology terms, an ontology is the working model of entities and interactions in some particular domain of knowledge or practices, such as electronic commerce or the activity of planning (Davies *et al*. 2002). In Artificial Intelligence (AI) terms, according to specialists at Stanford University (Noy and Klein 2004), ontologies can be used to express "a set of concepts such as things, events and relations that are specified in some way in order to create an agreed vocabulary for exchanging information, in particular over the World-Wide-Web (WWW)". Apart from providing a common understanding, Valarakos *et al*. (2004) also state that ontologies can be used to facilitate dissemination and reuse of information and knowledge. The main technologies used to create ontologies are the Process Specification Language (PSL) (Schlenoff *et al*. 2000) and Web-based technologies. The standard of Web-based technologies utilised in creating ontologies are the eXtensible Markup Language (XML), the Resource Description Framework (RDF), the Web Ontology Language (OWL) (W3 2005) and the XML Metadata Interchange Format (XMI) (OMG 2005).

2.2 Using Ontologies in Knowledge Based-Systems

Given that ontology has the potential to improve knowledge capturing, organization, sharing and re-use, it was chosen in this research to create a knowledge-based system to support the organisation knowledge framework. Furthermore, using ontologies in the organisational knowledge framework can provide the following advantages:

- Sharing knowledge domains across the www.
- Not relying on a set of rule-based techniques.
- Capable of handling complex and disparate information from different domains.

However, modelling organisational knowledge is a very complex task, often requiring a combination of different types of ontology-derived techniques. To support the organisational knowledge-based system in product development, the following ontology techniques are considered as being important:

- *Domain ontology*, which organizes concepts, relations and instances that occur, as well the activities that take place, into a domain (Van Heijst *et al.* 1997).
- *Top-level/generic/upper-level ontology*, which organizes generic domain independent concepts and relations, explicating important semantic distinctions (Sowa 1995).

- *Application ontology*, which consists of the knowledge of a particular application domain (Van Heijst *et al.*1997).

3. THE ORGANISATIONAL KNOWLEDGE FRAMEWORK

Figure 1, depicts the organisational knowledge framework which is an ontology-based environment that has been created specifically to manage the capturing of qualitative and quantitative knowledge statements related to manufacturing and assembly processes for complex products. These knowledge statements are generated by a distributed team as shown in Figure 1. The data exchange format used within the framework is the industrial standard XML. A Java-based XML Parser has been implemented for extracting the knowledge to be reused by a process planning system. The resulting process plans, which contain an evaluation of the likely quality, cost and delivery performance, can be stored into an information management system, as illustrated. The implementation of this framework is flexible, as the specific information systems must be adapted to the needs of the enterprise. For example, knowledge may be distributed via either a centralised PDM system or a decentralised Peer-to-Peer (P2P) network (Penserini *et al*. 2003). The research at this stage, however, has adopted the PDM system approach for knowledge management and distribution. This has been combined with a system that applies Web-based technologies to the captured knowledge statements. The captured knowledge is converted into an XML-formatted file and shared within a web-centric PDM system to support the collaborative product development process.

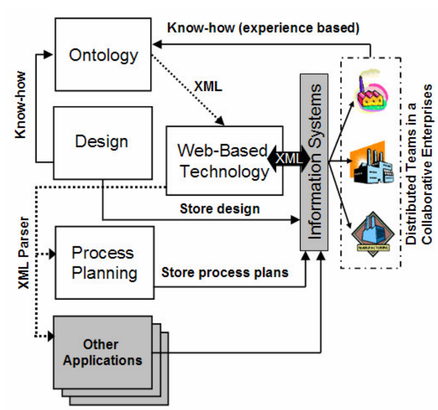

Figure 1: The Organisational Knowledge Framework

3.1 The General Structure of Organisational Knowledge

There are four kinds of knowledge that are generally recognised as being important in a knowledge-based economy (ITAG 1999). The first, *'Know-what'* is knowledge about facts. The second is *'Know-why'* and refers to scientific knowledge and understanding, for instance, the principles of why things happen. This also encompasses the skills often found in research laboratories or generated as a result of collaborative research between organisations. The third type of knowledge is *'Know-how'* which refers to skills and capabilities, for example, the ability to use a particular machine or skills gained through practice and experience. In industry, '*know-how*' is often used interchangeably with the term knowledge management from design to manufacturing, whether its context is described explicitly or implicitly. The final component is *'Know-who'*, which describes where in the enterprise knowledge is stored. Capturing *'Know-who'* requires a deep understanding of the expertise within an organisation. The approach to define and construct the organisational knowledge ontology was based on the four kinds of knowledge. In this particular application *'Know-who'* is only used to record the name of the knowledge owner and it has been implemented as an attribute of the '*Know-how*' class. In future versions of the work it may be possible to make a separate module, so that, for example, meta-information about confidence in the judgement of a person may be recorded.

3.2 The Main Organisational Knowledge Ontology

Figure 2 shows a class taxonomy of the organisational knowledge ontology which is specifically constructed to model manufacturing knowledge. According to Jenz & Partner (2003), an ontology is based on a taxonomy which represents a class hierarchy in the object-oriented world. The organisational knowledge ontology consists of three major modules, namely Organisation Knowledge *'Know-how'*, *'Know-what'* and *'Know-why'*, which are defined as *a_kind_of* organisational knowledge. The modules are imposed with *constraints* namely *Probability*, *LargerTheBetter*, *SmallerTheBetter*, *NominalTheBest*, *FactorTarget* and *FactorBenchmark*. The research work at this stage is mainly focused on applying *Probability* to define a constraint related to the instances captured within the ontology.

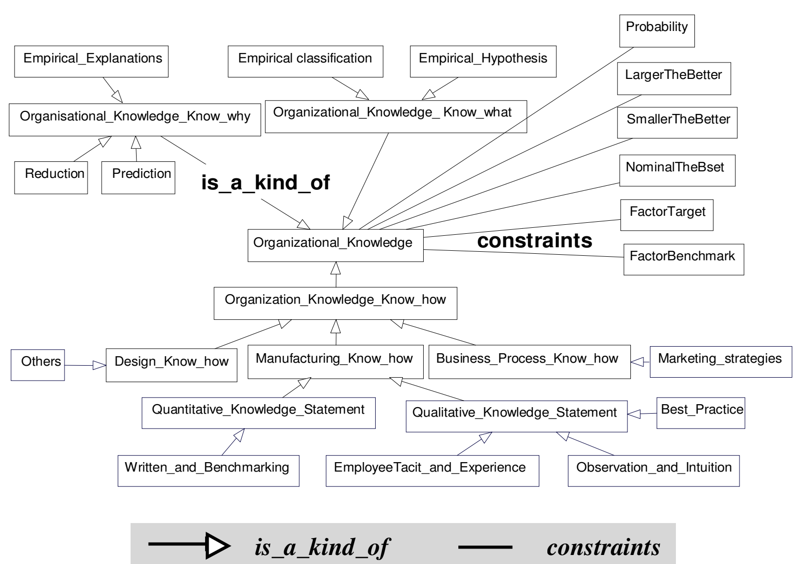

Figure 2 - The Structure of Organisational Knowledge Ontology

The Organisation Knowledge *Know-how* is further broken down into three separate classes namely, *'Business_Process_Know_how'*, *'Design_Know_how'* and *'Manufacturing_Know_how'*. The '*Business_Process_Know_how'* module defines marketing strategies, sales, purchasing, vendors, suppliers and costing data. *'Design_Know_how'* represents the information on product design and standards, including customisation such as bespoke customer designs. *Manufacturing_Know_how* forms an integral part of the framework and consists of quantitative and qualitative knowledge statements related to the production processes and equipment. It captures production skills, process best practice and experience-based information. The *'Organisation_Know_what'* module is used to define empirical knowledge based upon facts and hypotheses. Finally, *'Organisation_Know_why'* defines principles of why things happen.

The organisational knowledge ontology has been developed using the knowledge building system Protégé2000 (Protégé 2000, 2004). The class diagram, shown in Figure 2, was initially constructed to model the domain using the Unified Modelling Language (UML). The UML class diagram was imported into the Protégé2000 KBS Editor, via XMI (XML Metadata Interchange Format) to create the ontology. XMI is an open industry standard for applying XML to abstract systems such as UML. The intention of XMI is to propose a way to standardize XML for users to exchange information about Metadata in distributed and heterogeneous environments (OMG 2005). XML bridges part of the gap by providing the building blocks for "serializing" UML data textually. XMI is required for complex ontology-based systems, such as the one proposed herein, because it can capture and express the *relationships* that can be defined using UML class diagrams (Laird 2001).

3.3 The design of the knowledge-based system

To design a knowledge based-system using the ontology technique is a complex task. The approach in this work proposes a way of constructing a knowledge model which involves four activities as illustrated in Figure 3:

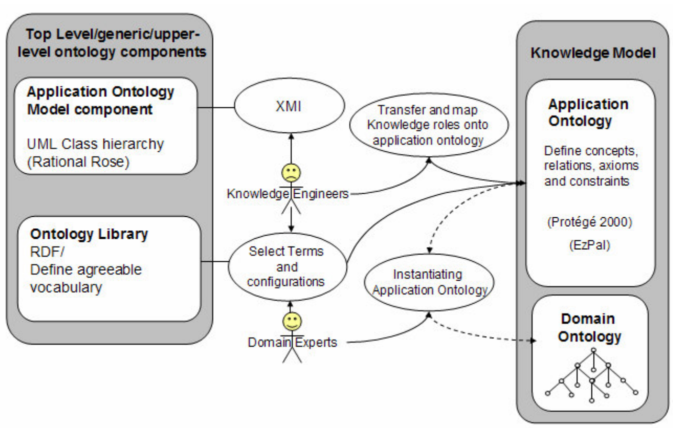

Figure 3- Activities in the design of an ontology-based knowledge system

a) The first activity in KBS construction is to form a UML (Unified Modelling Language) representation of the ontology and define the relations among the classes.
b) Transfer the UML class taxonomy onto the application ontology using XMI (XML Metadata Interchange) and subsequently map the roles and the concepts in the ontology.
c) Select and configure appropriate ontologies. This activity involves the construction of an application-specific ontology. In general, ontology construction is a difficult process that requires the expertise of knowledge engineers and domain experts. A library of reusable ontological theories can ease this process. The knowledge engineers and domain experts work as a team to select the reusable theories and, if necessary, tune them and define an agreed vocabulary to meet the demands of the application.
d) Instantiate the application ontology with domain knowledge. While the application ontology defines which concepts are used in the domain, the application knowledge describes the actual instances of these concepts. Hence, this requires the domain experts to gather all necessary knowledge to instantiate the domain ontology.

3.3.1 The application of axioms and constraints within the Ontology

It is important to be able to define axioms and constraints within an ontology. The axioms and constraints are used to define a specific value or condition in relation to a specific knowledge statement. The methodology of constructing these values in the knowledge-based system using axioms and constraints is described below.

In terms of the implementation of axioms and constraints within the ontology, there are several plug-ins available within the Protégé 2000 system. The EZPal tab (Hou *et al*. 2002) is designed to facilitate the acquisition of Protégé Axiom Language (PAL) based constraints without the need to understand the language itself. The plug-in uses a library of templates based on reusable patterns of previously encoded axioms. The interface allows users to compose constraints using a 'fill-in-the-blanks' approach. The EZPal tab makes use of a Protégé-2000 ontology to store three major categories of information which arw classified as *Property, Template* and *Pattern* as shown in Figure 4 (a).

- A *property* is an abstract description of the common features of a group of *templates*. Properties are not mutually exclusive: each *template* may satisfy more than one property.
- Each *template* describes a set of frequently used axiom design *patterns* based on their semantic and structural similarities. It stores the relevant 'variation' information to allow retrieval of a specific *pattern* to allow value entries for axiom generation.
- A *pattern* is defined as a logical sentence derived from a group of axioms that are structurally identical except for specific references. Individual *patterns* are not stored explicitly in the library but further generalized into *templates*.

For example, in the *Organisational_Knowledge* ontology, *Probability* has been declared as one of the *superclasses* used to define a constraint related to the instances captured within the ontology. In order to set the axiom constraint in the *Probability* class, there were three stages that must be executed as shown in Figure 4 (a). Firstly, the ontology builder must select which description under (*property)* is suitable to describe the constraint. In this case, the description "*Values of a slot contain slot values for related instances*" has been used. Under (*template)* there were several modes to be selected to describe the values of a slot. In this case "*At least one instances of class (name) contains (value) in slot (name)"* was the appropriate mode to be used to declare the values within the multiple slots. *Pattern* is the final stage for the ontology builder to fill in the actual values of the slots. As the selection processes are based on skill and experience, the above process may has to undergo a number of iterations in order to obtain the optimum solution. Figure 4 (b) illustrates an example of the constraints declared in the organisational knowledge ontology as a result of using the EZPal tab. The constraints were built upon the syntax of the axioms statements, descriptions and range. The syntax describes the *Probability* factor which contains the probability values shown as direct instances in the *Probability* class. The direct instances were then selected (*instances used by*) to form an association with a specific knowledge statement.

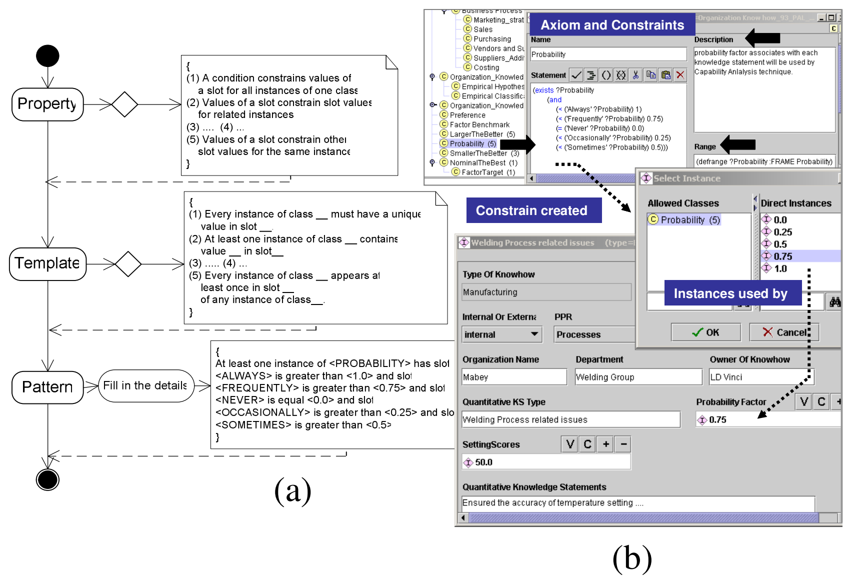

Figure 4 - (a) Method of defining constraints; (b) Example of using constraints

4. CONCLUSION

In this paper, an Organisational Knowledge Framework has been defined by using web-based technologies and information management systems to achieve the collaboration of distributed teams in product development. The novelty of this part of the work is the development of a know-how data structure which has been constructed as part of an Organisational Knowledge Framework using an ontological approach in relation to capturing and reusing design and manufacturing knowledge.

This paper has also discussed the implementation of capturing and reusing manufacturing know-how using various ontological activities and the application of axioms and constraints. With the development of user-friendly ontology editing software and automatic data exchange functions, the application of ontological approaches to exchange information across the WWW is most likely to be an essential aspect of the next generation of global knowledge management tools.

5. ACKNOWLEDGMENTS

The authors would like to acknowledge the financial support of the UK's Engineering and Physical Sciences Research Council (EPSRC), for the project Distributed and Collaborative Product Development and Manufacturing Knowledge Management (Grant GR/R26757/01). We are also grateful for the support of the industrial collaborators ArvinMeritor, LSC Group, Mabey & Johnson and PTC.

6. REFERENCES

1. Ciocoiu, M., Gruninger, M., Nau, D.S., "Ontologies for Integrating Engineering Applications", Journal of Computing and Information Science in Engineering, 2001, 1(1), 12-22.
2. Davies, J., Fensel, D., and van Harmelen, F., On-To-Knowledge: Semantic Web enabled Knowledge Management, (John Wiley and Sons Ltd, ISBN: 2002, 0470848677.
3. Duineveld, A.J., Stoter, R., Weiden, M.R., Kenepa, B., and Benjamins, V.R.,"WonderTools? - A comparative study of ontological engineering tools", International Journal of Human-Computer Studies, 2000, 52, 1111-1133.
4. Hausser, R., "The Four Basic Ontologies of Semantic Interpretation", The Tenth European – Japanese Conference on Information Modelling and Knowledge Bases, Finland, 2000, pp21-40.
5. Hou, C.S.J., Noy, N.F., Musen, M.A., "A Template-Based Approach Toward Acquisition of Logical Sentences", *Intelligent Information Processing 2002, World Computer Congress*, Montreal, Canada, 2002, pp77-89 5.
6. ITAG, "The Knowledge Economy", A submission to the New Zealand Government by the Minister for Information Technology's IT Advisory Group, August, ISBN 0-478-23435-X, http://www.med.govt.nz/pbt/infotech/knowledge_economy/. 1999.
7. Jenz & Partner, "Document of Frequently ask Questions in Ontology", Jenz & Partner GmbH, 2003, http://www.jenzundpartner.de/FAQ_Ontology.pdf
8. Laird, C., 2001, "XMI and UML Combine to Drive Product Development", Vice president, Phaseit Inc., http://www-106.ibm.com/developerworks/xml/library/x-xmi/
9. Lin, H.K., and Harding, J.A., "An Ontology Driven Manufacturing System Engineering Moderator for Global Virtual Enterprise Teams", Proceedings of the 1st International Conference on Manufacturing Research (ICMR), Glasgow, UK, 2003, pp.365-370
10. Noy, N.F., and Klein, M.C.A., "Ontology Evolution: Not the Same as Schema Evolution", Knowledge and Information Systems, Publisher: Springer-Verlag London Ltd, ISSN: 0219-1377 (Paper) 0219-3116, 2004, 6(4), 428 – 440.
11. OMG., 2005, http://www.omg.org
12. Ontoprise, 2004, http://www.ontoprise.de/products/ontobroker_en, Last access on 4th March 2004
13. Penserini, L., Liu, L., Mylopoulos J., Panti M., Spalazzi L., "Cooperation Strategies for Agent-Based P2P Systems", International Journal of Web Intelligence and Agent System, 2003, 1 (1) 3 – 21.
14. Protégé2000, "Knowledge-Based System Development Tools", http://protege. stanford.edu/ last accessed, 3rd January 2004.
15. Rich, E., and Duchessi, P., "Models for Understanding the Dynamics of Organizational Knowledge in Consulting Firms", Proceedings of the 34th Hawaii International Conference on System Sciences, Maui, Hawaii, (HICSS-34) 3, 2001, pp3007-3014.

16. Schlenoff, C., Gruninger, M., Tissot, F., Valois, J., Lubell, J., and Lee, J.,"The Process Specification Language (PSL) Overview and Version 1.0 Specification," National Institute of Standards and Technology, NISTIR 6459, Gaithersburg, MD, 2000.
17. Sowa, J.F., "Top-level Ontological Categories", International Journal of Human Computer Studies, 1995, 43, 669-685.
18. Van Heijst G., Schreiber A.T., and Wielinga B.J.,"Using Explicit Ontologies in Knowledge-based Systems Development", International Journal of Human-Computer Studies (IJHCS), 1997, 46, 183–291.
19. W3., 2005, http://www.w3.org