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Towards a Semantic Knowledge Life Cycle Approach for Aerospace Design Engineering

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Abstract. The efficient and effective management of knowledge is becoming increasingly important within the aerospace design engineering sector due to the complexity of product development. Semantic technology is becoming mainstream technology and is being applied by many disciplines for the management of complex knowledge. However, there is a lack of a semantic knowledge life cycle to support the semantic knowledge management discipline. This paper presents a systematic knowledge life cycle (KLC) for supporting the semantic knowledge management discipline with a particular emphasis on the importance of structuring knowledge. The semantic KLC comprises eight stages namely: (1) Understand the domain (2) Structure (3) Enrich vocabulary (4) Capture (5) Represent (6) Interpret the 'know how' (7) Share (8) KBE system. This research project adopts a qualitative approach and a five-phased research methodology. An illustrative scenario within the aerospace engineering industry for producing gas turbine systems is used to demonstrate the practicality and applicability of the proposed approach. The semantic KLC supports a shared agreement of meaning and understanding between design and manufacturing engineers.

Keywords. Design engineering, semantic knowledge life cycle, ontology, shared agreement of meaning.

1 Introduction

Aerospace engineering is considered to be one of the most advanced and complex branches of engineering. The complexity of designing and manufacturing flight vehicles requires careful understanding and balance between technological advancements, design, management and costs. Thus, it has become imperative to manage and maintain the appropriate capture, structure and dissemination of product and process knowledge within this sector in order to maintain competitive

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advantage and retain both design and manufacturing engineering experience built up over many decades. Figure 1 illustrates the main phases of the product development life cycle, which is described by Whitaker [12] as the product-creation process, this starts with a concept phase that is transformed into a detailed set of instructions for manufacture and assembly.

Due to the subjective and domain-dependent nature of knowledge, it has been identified that one of the major issues in traditional knowledge management is the complexity of establishing a shared agreement of meaning between people, processes and technology [5]. Consequently, miscommunication is a major barrier that exists between both design and manufacturing engineers. In regards to Information Technology, this barrier is usually the result of lack of computer supported open-source tools [8] to enable engineers within a specific domain to collaboratively share and reuse knowledge. However, recent research suggests that the barrier of miscommunication within the aerospace industry is a people issue rather than an IT issue [10]. This is inherently due to the diversity of individuals, different perspectives and inconsistent use of vocabulary. This has made it more difficult to develop a shared understanding of a given domain between a group of users. The semantic knowledge management discipline aims to address this issue.

Davies et al [4] describes semantic knowledge management as a set of practices that seek to classify content so that the required knowledge it contains may be immediately accessed and transformed for delivery to the desired audience in the required format. In this research, Semantic KM is not only about the technologies and platforms used to support such a practice. Semantic KM can be defined as a systematic process that aims to enrich and integrate both domain and operational forms of knowledge in order to ensure a shared agreement of meaning between domain experts and end users.

Figure 1. Phases of Product Development Life Cycle

Recently, some research work has been reported that use ontologies in conjunction with semantic web technologies within the aerospace sector. These are promising success stories that demonstrate the capability and benefits of semantic technology. However, there is lack of a knowledge life cycle to support the semantic knowledge management discipline. Consequently, many of the current ontological methodologies for semantic knowledge management are generic philosophical guidelines rather than explicitly defined activities.

This paper presents a systematic knowledge life cycle for semantic knowledge management using concepts from the soft system methodology (SSM) in particular rich pictures, software engineering (object oriented paradigm) and semantic web (ontologies) in order to enhance a shared understanding of a given domain. Emphasis is on the knowledge structure stage, which has often been neglected in traditional knowledge life cycles. An illustrative scenario within the aerospace industry for producing gas turbine systems is used to demonstrate the practicality of the proposed stages within the semantic KLC approach.

2 Related Work

The past decade has seen increasing interest in the field of knowledge management and ontological engineering for semantic web technologies as more sectors apply these disciplines. This section details some of the well-established knowledge life cycles within knowledge management.

Firestone and McElroy [5] suggested, “Knowledge management is about managing the KLC”. In 1995, Nonaka and Takeuchi pioneered the term knowledge life cycle (KLC) and proposed the SECI (Socialisation, Externalisation, Combination, Internalisation) model. This is a model that has been described as the knowledge creating process and represents various stages of knowledge conversion. Bukowitz and Williams [1] approach of the KLC is divided into two dimensions. These are tactical and strategic. The tactical stages of the KLC are to acquire, use, learn and contribute whilst the subsequent strategic stages are to assess, build, sustain and divest. The McElroy’s [7] KLC consists of two major processes, namely knowledge production and knowledge integration. The focus of this proposed KLC is on knowledge production, which formulates the following stages: individual and group learning, knowledge formulation, information acquisition and knowledge validation. The originality of this approach is in the single and double loop leaning processes. The five stages of the Jashapara [6] KLC are as follows: discover knowledge, generate knowledge, evaluate knowledge, share knowledge and leverage knowledge. The three stages of the Dalkir [3] KLC are as follows: knowledge capture and/or creation, knowledge sharing & dissemination and knowledge acquisition & application. Knowledge is assessed between stages one and two. However, no approach is mentioned as how this is achieved. This KLC is strongly attributed to the generation of new knowledge, which emphasise a cultural change in organisation learning. The methodology for knowledge based engineering applications (KBE) (MOKA) [11] is a generic KLC for the KBE domain. The 6 stages of MOKA KLC are as follows: identify, justify, capture, formalise, package and analyse. The main focus of the MOKA KLC is the capture and formalise stages. The Rodriguez and Al-Ashaab [9] KLC approach is considered to be distinguishable from other KLCs. This approach is also used within the knowledge based engineering (KBE) discipline. The KLC [9] proposed the use of a collaborative knowledge based system to support product development and manufacturing activities performed in dispersed locations. The stages of the KLC are as follows: identify, capture and standardize, represent, implement and use. The Chao et al [2] Semantic Web Life Cycle consists of 6 stages, which are as follows: representation, interconnection, reasoning, retrieving, validation and integration. Many of the KLCs reviewed suggest the importance of learning and understanding as an important step in achieving effective KM. However, there is no consistent vocabulary between some of the proposed KLC stages. For example, do identify, discover, and learn signify the same activity? The authors’ perspective has a significant part to play. It was discovered that there is a lack of clear consistent meaning between capture and represent. Something more clear and concise is needed at a stage before capture and represent, whereby knowledge is structured using appropriate vocabulary. This particular stage has commonly been neglected and has not been identified as a stage of its own in the reviewed KLCs.

3 Semantic Knowledge Life Cycle Approach for Aerospace Design Engineering

Figure 2 illustrates the various stages of the proposed semantic knowledge life cycle (KLC). The semantic KLC comprises of eight stages which are: (1) Understand the domain (2) Structure (3) Enrich Vocabulary (4) Capture (5) Represent (6) Interpret the ‘know-how’ (7) Share (8) and KBE system. Stages (2), (3) and (6) reinforce the semantic knowledge management KLC.

Understanding the domain involves definition of the scope as well as identifying knowledge sources. The next stage is to develop an initial structure/construct of domain knowledge. The structure stage is comprised of the modularisation of knowledge into different chunks. It is not enough to structure knowledge; it has to use an appropriate vocabulary that is agreed upon by both domain experts and users. Iteration may be required between stages (2) and (3) and it is possible to refine the vocabulary until a more universal and agreed vocabulary is reached by a group of users. The next stage is to capture knowledge; if new knowledge is captured, it is imperative to feed back to stage (2) and restructure/add to the domain knowledge construct. Once knowledge has been captured, it is then represented. Visual representation is always appealing and is deemed as one of the best ways of eliciting knowledge from experts.

Stage (6) allows for the declaration and interpretation of ‘know how’ rules. Rules are interpreted from the construct of the domain knowledge in stage (2) and these are considered as operational knowledge. Knowledge is only beneficial when it is used. Stage (7) allows for the sharing and validation of both domain and operational forms of knowledge. Stages (2 - 7) demonstrate the process used to integrate both domain and operational forms of knowledge. These stages also illustrate the knowledge creation process. In addition, extensive validation should occur within these stages (2 – 7). The last stage (8) of the semantic KLC process involves development of knowledge-based systems using a semantic or object oriented approach. Iteration is primiarily between stages 2-3, 2-4 and 2-7.

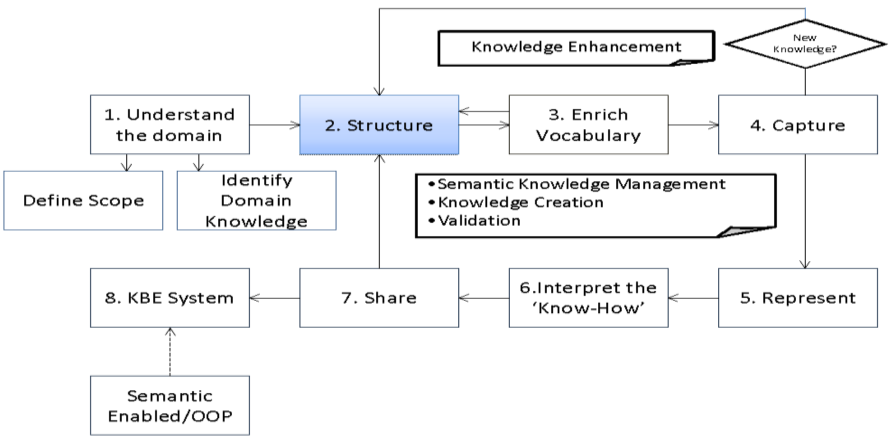

Figure 2. Semantic Knowledge Life Cycle

3.1 Understand the Domain

It is imperative to agree the scope of the problem domain before commencing with the semantic framework development. In the context of this research project, the manufacture of holes on a combustor wall (part of a gas turbine engine) has been selected and process-mapping activities have been used to help understand the domain. This has been achieved by mapping various design activities as well as identifying the various skill types, data inputs/outputs feeding into each activity, the roles involved in providing and consuming data, decision points as well as minor and major iteration loops. The process map has captured the preliminary design stage of the combustor product development process, which has helped in identifying key experts, end users, key documents, etc. IDEF0 functional modelling has been applied to support identification of the domain knowledge.

3.2 Structure

Having understood the engineering domain, it is imperative to begin structuring and categorizing knowledge into various segments in order to enhance knowledge systematisation. Figure 3 illustrates the proposed ontology framework. There are many similarities between ontological engineering and the object-oriented paradigm (OOP). The main three aspects of the object-oriented paradigm are: Inheritance, Encapsulation and Polymorphism. To incorporate the OOP way of thinking into the ontology development, the right questions must be addressed as illustrated in Figure 3. Fourteen concepts have been developed within the aerospace domain through the use of a suitable taxonomy and consistent vocabulary. The ontology can be readily extended as new knowledge is captured.

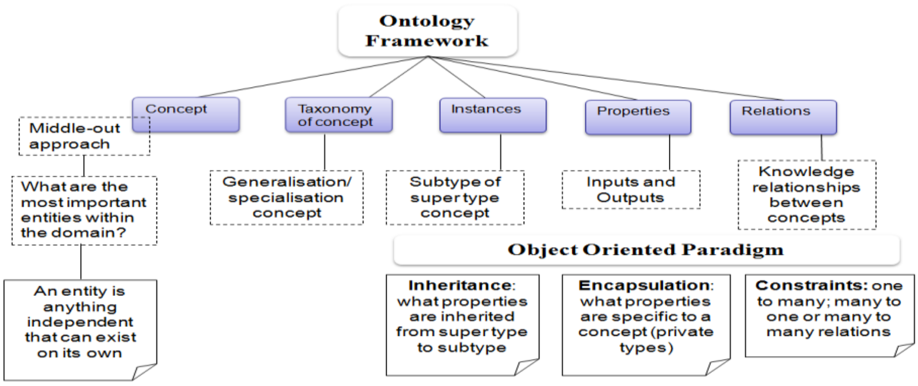

Figure 3. Object Oriented Paradigm way of thinking into Ontology Development

3.3 Enrich Vocabulary

The next stage of the semantic KLC is to enrich the vocabulary of the domain structure that was determined in the previous stage. This is a crucial aspect of the semantic KLC. Enriching the vocabulary includes ensuring a universal shared agreement of terminologies between domain experts. This includes identifying key terminologies within the ontology and quantifying their meaning.

After the development of the ontology, experienced design and manufacturing engineers contributed towards enhancing the vocabulary of the domain ontology with a view to develop a common understanding of meaning. To illustrate a scenario, one of the concepts within the domain ontology was defined as 'Tool', it was identified that the term 'Tool' in manufacturing engineering is interpreted as a physical manufacturing device (e.g. chipless machining). However, the term 'Tool' in design engineering is often thought to be computer software, excel spreadsheet with macros or even a design method. Due to the variety of meanings and context, it was identified that the term 'Tool' was not a suitable name for a concept within the domain ontology and this term was changed to the term 'Software' which was agreed and shared between both the design and manufacturing engineers. One of the enabling tools of this stage has been the use of rich pictures to display aspects of the ontology. This has proven to be effective in eliciting knowledge. The real value of this technique is in the way it encourages the creator to think deeply about the problem/scenario and understand it well enough to represent it pictorially. By having the domain experts contribute towards the creation of rich pictures, they helped develop a shared understanding of both design and manufacturing domain.

3.4 Capture

New knowledge will always be produced and captured within a domain as a result of new experience. Each time new knowledge is captured, it is essential to loop back to stage (2) and restructure/add to the domain knowledge construct (i.e. the domain ontology). This process is considered as the knowledge enhancement stage because the domain knowledge is enriched through this process. Through the capture and storage of new knowledge, the domain knowledge is enhanced.

3.5 Represent

It is important to represent knowledge in a manner that can be easily understood and interpreted in a consistent way. There is also a need to adopt a visual notation for the representation of the domain ontology. The Unified Modeling Language (UML) for the Object Oriented Paradigm (OOP) has proven to be an effective means of eliciting and representing knowledge within the software engineering discipline. Many researchers have suggested the use of UML as an effective way of representing ontologies, although there is still a need for a better notation for ontological representation. The use of the UML class diagrams can be used to represent the relationships and properties between various concepts.

3.6 Interpret the 'know-how'

Stage (6) of the semantic KLC involves interpreting a set of 'know-how' rules from the domain construct ontology developed in stage (2). Rules defined and interpreted from the domain ontology are known as the operational ontology. The operational ontology involves using the domain construct ontology (i.e. concepts, taxonomy of concepts, instances, properties, and relations) to define rules with particular emphasis on the vocabulary used to interpret such rules.

Figure 4 illustrates a design-centric user case to illustrate the interpretation of a 'know how' rule defined from the domain ontology. The advantage of this stage is in the reusability of the elements within the domain ontology construct.

IF (ROLE has *skillType* of "Aerothermal") AND (COMPONENT has FEATURE with *featureType* of "Cooling Hole" with *holeDimension* '**x-y cm**) AND (ANALYSIS TYPE required for COMPONENT has *analysisType* "CFD") AND (SOFTWARE has *softwareType* of "Code Z") AND (PILM Process is stage "**1**")

{
modelType: **3D CFD Model**
cfdModel3DanalysisGeometry
}

Concept
Property
Instance

Figure 4. Design-Centric User Case Scenario

3.7 Share

Both domain and operational ontology is disseminated to all experts in order to ensure the validation of the ontology. Workshops and one to one feedback sessions involving design and manufacturing engineers have been used to validate the ontology. Stages 2 to 7 demonstrate the semantic knowledge management process, which solidifies the integration of domain and operational knowledge.

3.8 KBE System

The final stage is the development of a KBE system, which will integrate and demonstrate both domain and operational ontology. Due to the ontological and object oriented nature of the semantic KLC, it is vital to adopt an object oriented or semantic enabled platform to demonstrate the KBE system.

4. Validation

The developed semantic KLC has been presented to key experts within the aerospace engineering domain. This includes participation of an engineering process lead, design and manufacture engineers and a knowledge management specialist. The semantic KLC has been deemed as a useful process with potential for delivering significant benefits if applied correctly. However, there is still need for extensive validation requiring a larger group of stakeholders. All of the interviewed experts suggested the importance of structuring and standardising knowledge using appropriate vocabulary and there is a strong focus on this in the semantic KLC.

5. Conclusions and Future Work

A semantic KLC to support the semantic knowledge management discipline within the aerospace industry has been presented in this paper. Practical scenarios alongside experts' validation have been used to demonstrate the applicability of the proposed approach. The semantic KLC is used to support a shared agreement of meaning between design and manufacturing engineers. Stages 2, 3 and 6 are significant stages emphasising the semantic knowledge management discipline.

Future work involves further demonstration of the semantic KLC and the development of a semantic KBE system to demonstrate the proof of concept. Extensive validation requiring a larger audience base will also be conducted. Lastly, the generic nature of the research will be quantified in the applicability of the semantic KLC to other sectors (e.g. medical, pharmaceutical, automotive, etc).

6. Acknowledgements

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