Proceedings of I-KNOW 2010
1-3 September 2010, Graz, Austria

Ontology based experience Management for System Engineering Projects

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Abstract: System Engineering (SE) is becoming increasingly knowledge intensive. Knowledge Management is recognized as a crucial enabler for continuous process improvement in engineering projects. Particularly, capitalization and sharing, of knowledge resulting from experience feedback are valuable asset for SE companies. In this paper, we focus on the formalization of engineering experience aiming at transforming information or understanding gained by projects into explicit knowledge. A generic SE ontological framework acts as a semantic foundation for experience capitalization and reuse. This framework is operationalized with Conceptual Graphs formalism and applied to a transport system engineering use case.

Keywords: Knowledge reuse, Information Search and Retrieval, Systems and Software, Reusable Software, Artificial Intelligence
Categories: M.8, H.3.3, H.3.4**,** D.2.13**,** I.2

1 Introduction

System Engineering (SE) is an interdisciplinary approach to enable the realization of successful systems. It is defined as an iterative problem solving process aiming at transforming user's requirements into a solution satisfying the constraints of: functionality, cost, time and quality. [Meinadier, 2000]
System engineering process begins at a high level of abstraction and proceeds to higher levels of detail, until a final solution is reached. This process is usually composed of the following seven tasks: State the problem, Investigate alternatives, Model the system, Integrate, Launch the system, Assess performance, and Re-evaluate. These functions can be summarized with the acronym SIMILAR: State, Investigate Model, Integrate, Launch, Assess and Re-evaluate. [Bahill, 1998]

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Transitions between these tasks stem from decision making processes supported both by generally available domain knowledge and experience. Engineers usually integrate diverse sources and kinds-of information about system requirements, constraints,

functions, and extant technology. In doing so, they make certain assumptions and develop criteria against which alternatives are evaluated for suitability. Unfortunately, much of this process is implicit, making later knowledge reuse difficult if not impossible. Valuable design knowledge situated in the context of a concrete problem and solution is usually lost. The analysis of current engineering practices and supporting software tools reveals that they adequately support project information exchange and traceability, but lack essential capabilities for knowledge management and reuse [Brandt, 2007]. The recent keen interest in ontological engineering has renewed interest in building systematic, consistent, reusable and interoperable knowledge models [Kitamura, 2006]

Aiming at representing engineering knowledge explicitly and formally, and sharing and reusing this knowledge among multidisciplinary engineering teams, our work builds upon ontological engineering as a foundation for capturing implicit knowledge and as a basis of knowledge systematization.

The research presented in this paper is a follow-up of our prior work involving the proposition of a generic ontological framework for system engineering knowledge modeling [Chourabi,2008]. The framework sets the fundamental concepts for a holistic System Engineering knowledge model involving explicit relationships between process, products, actors and domain concepts.

Here, we focus on problem resolution records during project execution. We address this problem through the use of the formal framework for capturing and sharing significant know-how, situated in projects context.

The main contributions of this paper are:

- Knowledge capitalization model : we introduce the concept of **S**ituated Explicit Engineering Knowledge (SEEK) as a formal structure for capturing problem resolution records and design rationale in SE projects
- Knowledge sharing model: we propose a semantic activation of potential relevant SEEK(s) in an engineering situation.

Both models are illustrated in a transport system engineering process.

This paper is organized as follows: the next section presents a motivating research example. Section 3 analyses related works concerning ontological engineering in SE. In section 4, we detail the formal approach for Situated Explicited Engineering Knowledge capitalization and sharing. Section 5, illustrates our proposal in a transport system engineering process.

2 Background and motivation

In this section, we focus on decisions related to component allocation choices and parameter configuration phase in SE process. In this setting, the main objective is to find configurations of parts that implement a particular function. Practically, system engineer team must consider various constraints simultaneously, the constituent part

of a system are subject to different restrictions, imposed by technical, performance, assembling and financial considerations, to name just a few. Combinations of those items are almost countless, and the items to be considered are very closely related. Figure 1, shows the intricate interplay of constraints in a system engineering process.

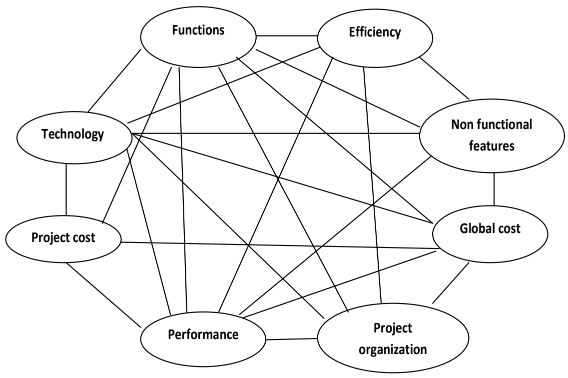

Figure 1. System Engineering process as a multi-objective decision problem

As an example, we consider a typical component allocation process of a transportation sub system: an automated wagon.
We assume that the system's functional view comprises the following functions: capture speed, capture position, control movement, propel, break, and contain travelers.
These functions should be allocated to physical components to configure an engineering solution. Allocation process can be one to one or many to one. In addition, Physical component choice is constrained with non functional requirements (or soft goals) such as: system performance, facility, acceleration limitation, comfort, and reliability.
The global requirements are traded-off to find the preferred alternatives solutions. An intricate interplay usually exists among alternatives. For example, the functions speed capture and position estimation choosing *inertial station* that delivers the speed as well as the position, for implementing the function *speed capture* would restrict the engineering choices to exclude specific transducers.
In practice, these choices are scattered in a huge mass of engineering documents, and thus not explicitly modelled. Engineers usually wish to adapt past solutions to new project context. In this context, a machine readable representation of engineering decision trace could enable effective reuse of previous decisions. To address these issues, we draw upon ontological engineering to provide a systematic model for

engineering background knowledge and we use it as a foundation for describing engineering choices emanating from previous engineering projects.

3 Ontological Engineering and System Engineering

Ontologies are now in widespread use as a means formalizing domain knowledge in a way that makes it accessible, shareable and reusable [Darlington, 2008]. In this

section, we review relevant ontological propositions for supporting engineering processes.

In the knowledge engineering community, a definition by Gruber is widely accepted; that is, “explicit specification of conceptualization” [Gruber,1993], where conceptualization is “a set of objects which an observer thinks exist in the world of interest and relations between them”. Gruber emphasizes that ontology is used as agreement to use a shared vocabulary (ontological commitment).

The main purpose of ontology is, however, not to specify the vocabulary relating to an area of interest but to capture the underlying conceptualizations. [Gruber,1993] [Uschold, 1996] identifies the following general roles for ontologies:

- Communication between and among people and organizations.
- Inter-operability among systems.
- System Engineering Benefits: ontologies also assist in the process of building and maintaining systems, both knowledge-based and otherwise. In particular,
    - Re-Usability: the ontology, when represented in a formal language can be a re-usable and/or shared component in a software system.
    - Reliability: a formal representation facilitates automatic consistency checking.
    - Specification: the ontology can assist the process of identifying a specification for an IT system.

One of the deep necessities of ontologies in SE domain is, we believe, the lack of explicit description of background knowledge of modelling. There are multiple options for capturing such knowledge; we present a selection of representative efforts to capture engineering knowledge in ontologies.

[Lin et al, 1996] propose an ontology for describing products. The main decomposition is into parts, features, and parameters. Parts are defined as a component of the artifact being designed". Features are associated with parts, and can be either geometrical or functional (among others). Examples of geometrical features include holes, slots, channels, grooves, bosses, pads, etc. A functional feature describes the purpose of another feature or part. Parameters are properties of features or parts, for example: weight, color, material. Classes of parts and features are organized into an inheritance hierarchy. Instances of parts and features are connected with properties component of, feature of, and sub-feature of.

[Saaema et al, 2005] have proposed a method of indexing design knowledge that is based upon an empirical research study. The fundamental finding of their methodology is a comprehensive set of root concepts required to index knowledge in design engineering domain, including four dimensions:

- The process description i.e. description of different tasks at each stage of the design process.
- The physical product to be produced, i.e. the product, components, sub-assemblies and assemblies.
- The functions that must be fulfilled by a particular component or assembly.
- The issues with regards to non functional requirement such as thrust, power, cost etc.

[Mizoguchi, 2004] has developed a meta-data schema for systematizing engineering products functionalities. This schema was opertionnalized using Semantic Web languages for annotating engineering design documents.

An ontology that supports higher-level semantics is Gero's function-behaviour-structure (FBS) ontology [S'gero et al, 2006]. Its original focus was on representing objects specifically design artifacts. It was recently applied to represent design processes.

For ontology reusability, hierarchies are commonly established; [Borst et al, 1997] have proposed the PhysSys ontology as a sophisticated lattice of ontologies for engineering domain which supports multiple viewpoints on a physical system.

Notwithstanding the promising results reported from existing research on SE ontologies, the reported ontological models don't provide a holistic view of the system engineering domain. They are either too generic or only focus on specific aspects of system representation.

As development of ontologies is motivated by, amongst other things, the idea of knowledge reuse and sharing, we have considered a coherent reuse of significant ontological engineering work as complementary interrelated ontologies corresponding to the multiple facets of system engineering processes.[Chourabi, 2008]

In the next section, we briefly remind our proposed ontological framework for SE knowledge modeling and we show how it is applied for experience capitalization and sharing.

4 Situated explicited engineering knowledge capitalization and sharing

Our generic ontological framework for system engineering knowledge modeling has been detailed in .[Chourabi, 2008]. The main objective was to provide a holistic view on system engineering discipline through a layered ontological model covering engineering domain knowledge i.e (system context, system functions and system organic components) and organizational knowledge i.e (project processes, actors and project resources).

In this paper, we study the potential application of this framework for describing SE project experiences. We address the dynamic aspect of engineering process with the aim to capture implicit knowledge, decision and argumentation, in order to provide relevant knowledge items to system engineers.

To this end, we introduce the concept of SEEK : Situated Explicited Engineering Knowledge to model formally engineering situation, engineering goals, engineering

alternatives and decisions as well as their mutual relationships. These dimensions are formalized as a set of semantic annotations defined over the ontologies defined in our framework.
A semantic annotation is defined as a set of ontological concepts and semantic relations instances. We use semantic annotation to express a particular modeling choice or a particular engineering situation. Figure 2, shows an example of semantic annotation defined over a system organic component ontology fragment.

The association of a formal knowledge description to the engineering artifact (e.g.: requirement document) in figure 2, allows to retrieve it by a semantic search. Semantic search retrieves information based on the types of the information items and

the relations between them, instead of using simple String comparisons [Brandt, 2007].

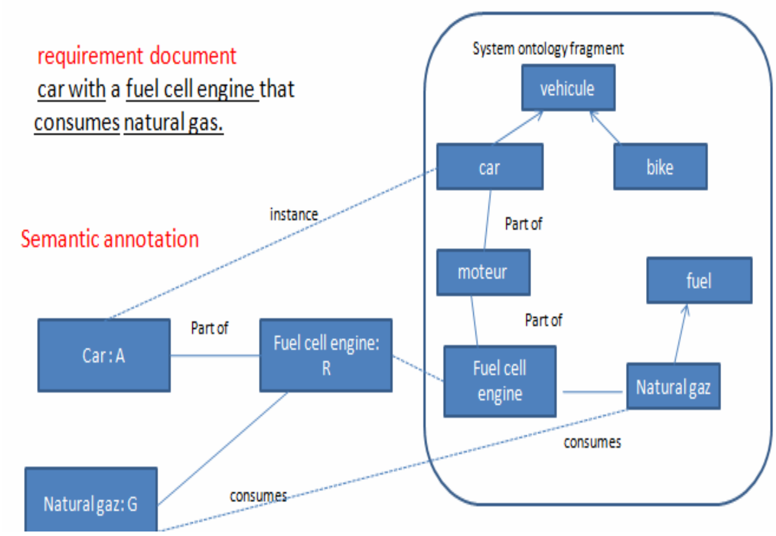

Figure 2 : relationships between semantic annotation, ontology and engineering product

To provide operational use of SEEK (s), must rely on solid theoretical foundations requiring an appropriate representation language, with clear and well-defined semantics. We choose conceptual graphs [Sowa, 1983] as a representation language. The attractive features of conceptual graphs have been noted previously by other knowledge engineering researchers who are using them in several applications [Chein et al, 2005][Corby et al., 2006][Badget et al,2002]. Conceptual graphs are considered as a compromise representation between a formal language and a graphical language because it is visual and has a sound reasoning model. In the conceptual graph (CG) formalism [Sowa, 1983], the ontological knowledge is encoded in a support. The factual knowledge is encoded in simple conceptual graphs. An extension of the

original formalism [Badget et al, 2002] denoted "nested graphs" allows assigning to a concept node a partial internal representation in terms of simple conceptual graphs.
To represent SEEK (s) in conceptual graph formalism we rely on the following mapping:
– The set of system engineering ontologies are represented in a conceptual graph support
– Each semantic annotation is represented as a simple conceptual graph.

– A SEEK is a nested conceptual graph, where the concepts engineering situation, engineering goal, alternative solution, engineering solution are described by means of nested CG. This generic model has to be instantiated each time an engineering decision occurs in a project process.
To share the SEEks, we aim to provide a proactive support for knowledge reuse. In such approaches [Abecker et al., 1998] queries are derived from the current Work context of application tools, thus providing reusable product or process knowledge that matches the current engineering situation.
Finding a matching between an ongoing engineering situation and goal and a set of capitalized SEEK(s) relies on a standard reasoning mechanism in conceptual graphs: the projection operator.
Let's remind the projection operation as defined by [Mugnier and Chein, 1992]

Mugnier and Chein Projection

Given two simple conceptual graphs G and H, a projection from G to H is an ordered pair of mappings from (RG, CG) to (RH, CH), such that:
– For all edges rc of G with label i, $\Pi(r)$ $\Pi(c)$ is an edge of H with label i.
– $\forall r \in$ RG, type $(\Pi(r)) <= \text{type}(r)$; $\forall c \in$ CG, type $(\Pi(c)) <= \text{type}(c)$.
There is a projection from *G* to *H* if and only if *H* can be derived from *G* by elementary specialization rules.
Using the projection, the reasoning system is able to find not only descriptions of experiences that are annotated by exact concepts and relationships but also those annotated by subtypes of these concepts. Besides, to search with imprecise and/or incomplete experiences or to answer a vague query, approximate projections [Corby, 2006] can be used. We also work on an extension to conceptual graphs projection in order to take into account partial (part-of) engineering situation matching. Our ultimate goal consists in defining an approximate situation matching, having as result a lattice (partial ordering) on the SEEK (s) according to their degree of relevance for the current engineering situation facets.

5 Case study

This section presents a case study of ontology based modeling for SEEKs. The application domain is automatic transport sub system: the automated wagon described in the motivation section.
To illustrate the use of the proposed ontological framework to define a Situated Engineering Knowledge, we use the ontology excerpt depicted in figure 3.
This ontology formalizes three domain engineering facets :

- Contextual facet: it formalizes transport systems typology , system features such as physical features e.g. (weight), functional features e.g. (path type for the transport system.
- Functional facet: it formalizes transport system function as well as their subsumption relations.
- Organic facet: it formalizes the physical components and their relationships such as "part of", "is a", "communication relations".

This ontology is operationalized with conceptual graph support i.e a concept type lattice and a relation type lattice [Sowa, 1983].

The SEEK capitalization model is operationnalized with a nested conceptual graph, and instantiates concepts and relations from the support c.f figure 4. In our use case we consider the following nesting dimensions:

- Engineering situation: a system engineer aims to configure a physical solution for:
    - the functions capture speed and capture position
    - an automated wagon that should operates in a complex path

- Engineering goal: functional allocation
- Engineering alternatives : inertial station or GPS component
- Engineering decision: GPS component is more suitable, and provides better precision for complex path.

If we consider a new engineering situation, described by the same contextual ontology, and aiming at allocating the function "capture" for an automated wagon. The capitalized SEEK is matched with this engineering situation by taking the specialization relation between ontological concepts into account.
We use the Cogui[1] platform for ontology editing , SEEK capitalization and sharing

[1] *www.lirmm.fr/cogui/*

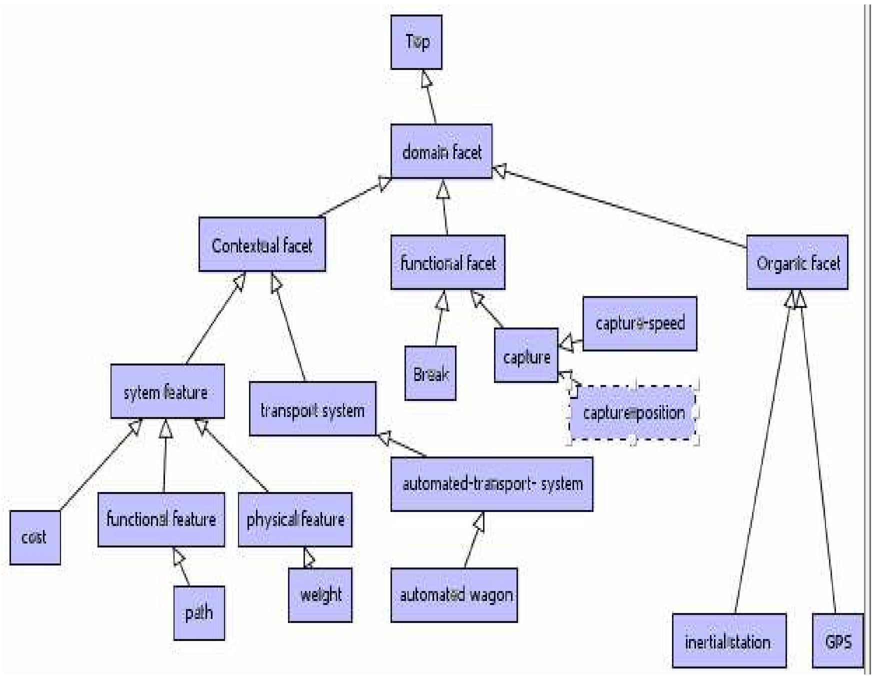

Figure 3: Transport system ontology excerpt

Conclusion

System engineering processes implies the management of information and knowledge and could be considered as a knowledge production process. In this paper we presented our ongoing work aiming to validate our proposed ontology- based framework for engineering experience capitalization and reuse. A principal strand of future research is the application of this modelling framework in the context of an engineering organization to trigger further improvement. We plan also to use the same framework for capturing “best practices” knowledge. We are investigating the way to build up a knowledge management integration interface for existing system engineering support tools.

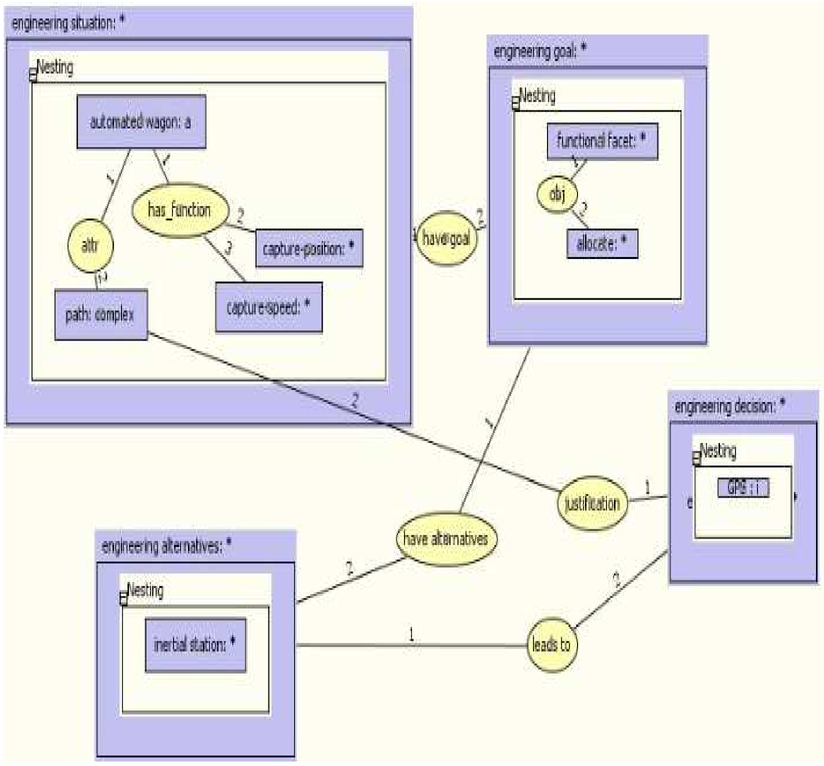

Figure 4: SEEK instantiation for an automated wagon.

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