# Ontology Configuration Management for Knowledge-Centric Systems Engineering in Industry

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***Abstract*—The engineering of safety-critical systems is a complex process whose cost-effectiveness is very important. Reuse of system artefacts is an activity that can contribute to improving quality and to saving costs during the process. Reuse must pay attention to artefact configuration management, as an artefact evolves through different versions and such an evolution must be properly managed. An artefact type that is used nowadays in industry for the engineering of safety-critical systems and can be reused is ontologies, which represent system domain information via knowledge representations. However, academic approaches for ontology reuse do not meet industrial needs for their application for systems engineering. As a solution, this paper presents an industrial approach to define and operate ontologies as libraries of knowledge to enable ontology configuration management. The approach supports the reuse and exploitation of domain knowledge through operations for mapping, alignment, and merge of ontology elements. The proposed approach, the current implementation, and validation activities are presented on top of the Knowledge Manager tool.**

***Keywords*—ontology, configuration management, reuse, system artefact, knowledge representation, Knowledge Manager.**

## I. Introduction

Safety-critical systems are those whose failure can harm people, property, or the environment [5]. These systems are becoming more sophisticated and evolving towards cyber-physical systems and cyber-physical systems of systems. As a result, the complexity of the engineering processes is increasing, but the processes must still be cost-effective so that developers remain competitive. Means to ensure this are needed, e.g. approaches that facilitate system artefact reuse.

System artefact reuse can be defined as a process to systematically specify, produce, classify, retrieve, and adapt work products for using them during a system's lifecycle [10]. Reuse has the potential of increasing productivity of engineers, improving the quality of system artefacts, and enabling efficient engineering environments. Reuse must consider configuration management (CM) of the artefacts to ensure that their different versions and how they are handled are suitable. Tasks such as search, selection, copy, and merge of system artefacts are important, and it is necessary to guarantee that the results obtained from their execution are valid and consistent.

Different artefact types are used and can thus be reused during the engineering lifecycle of safety-critical systems [5], e.g. system specifications and source code. The types and their formats are also changing as a result of new engineering practices. An example is models when applying Model-Based Systems Engineering. Another specific artefact type that is used nowadays for systems engineering is ontologies; see e.g. [11]. Ontologies can be defined as explicit specifications of a conceptualization, which are, in turn, the objects, concepts, and other entities that are presumed to exist in some area of interest and the relationships that hold among them [8]. In other words, and in the context of systems engineering, an ontology represents system domain information and can be regarded as a knowledge representation of a system. When an ontology plays a major role or the main role in the engineering lifecycle, the lifecycle can be characterised as knowledge-centric systems engineering [6]. An ontology can be the main basis to specify requirements or system models, among other activities.

Therefore, an ontology is a system artefact that can be reused and whose configuration must be managed. Indeed, ontology reuse is an area to which the community researching on knowledge-based systems has paid great attention for the last two decades, e.g. [3][12]. Ontology reuse [9] includes aspects such as reusability, reuse operations, operation validation, guidance, and shareability, and relates to activities such as ontology building, mapping, and matching. However, past research on ontology reuse has not sufficiently focused on the provision of approaches that work in practice and as needed in industry in the context of engineering of safety-critical systems. The approaches should support and benefit from CM according to how ontologies are used in industry for complex systems whose dependability must be acceptable, e.g. considering different knowledge needs and information types such as semantic categories, specification structures, and rules. Although some related efforts have been conducted in e.g. aerospace [12], they can be regarded as academic proofs of concept that are still far from being fully applicable in practice.

This paper aims to introduce how a practical and industrial approach can be applied for ontology CM. The approach has been developed in the scope of knowledge-centric systems engineering and is implemented in the Knowledge Manager tool [11] by The REUSE Company (TRC). Based on how ontologies are specified in this tool through several layers and element types, the approach manages ontologies as libraries of knowledge and provides operations to this end, enabling different usage scenarios.

The paper shows the needs for ontology CM in practice for systems engineering and how it can be performed. This is valuable for both practitioners and researchers interested in knowledge-centric systems engineering, in the evolution possibilities of ontologies, and in their reuse. From a more general perspective, the paper presents a real and specific situation of artefact CM and reuse that is different to the most common ones, contributing to widening the characterisation of and the knowledge about these areas.

The next sections present the approach for ontology CM, its implementation, and our main conclusions.

## II. Approach for Ontology Configuration Management

The main basis for the approach is how ontologies are managed in Knowledge Manager (Fig. 1). The structure of an ontology in this tool consists of several layers, each depending on and extending the semantic information of the inner layer:

- The most inner layer (Terminology) corresponds to the terms of a domain together with their syntactic information, e.g. about whether a term such as 'car' is a noun.
- Relationships between the terms can be specified in the Conceptual model layer, as well as their semantics with clusters; e.g. the semantics of the terms 'car' and 'truck' can be 'system', and they specialise 'vehicle'.
- Patterns can then be developed to provide templates (aka boilerplates) for system information specification. The patterns refer to aspects of the two underlying layers; e.g. in the pattern "The [System] shall [Detect] [Item] at a minimum range of [Number] seconds", the elements in squared brackets correspond to semantic clusters.
- The Formalization layer deals with the semantic representation of system information according to patterns. This representation can correspond to system artefacts in different formats, e.g. text or a model, and of different types, e.g. requirements and design elements.
- Finally, at the Inference rules layer the data in all the others can be exploited for the specification of procedures to derive information, e.g. about specification correctness.

The ontology CM approach relies on a set of operations for the main elements of an ontology in Knowledge Manager. The operations (Table 1) are divided into four main types:

- Core operations, to create, retrieve, update, and delete ontology elements.
- Common operations, for unification and harmonisation.
- Retrieval operations, to index and search any kind of information and artefacts that can be included or referred to in an ontology.
- Reuse operations, to be able to copy a knowledge base into another, merge two different knowledge bases, and perform a delta operation (diff) between two different bases.

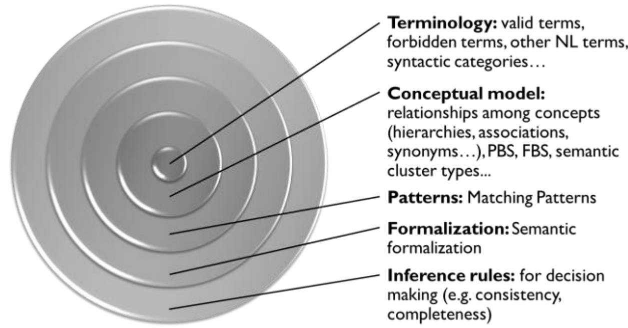


Fig. 1. Ontology layers in Knowledge Manager

When evolving and reusing an ontology, it is necessary to track and handle the changes in the ontology during its lifecycle. If any error is found, it can be helpful to revert the ontology to one of its previous states. The operations presented above enable a series of different ontology CM scenarios to meet these needs:

- View changes, which allows a user to see the differences between (1) an ontology and (2) one of its baselines or another ontology (new, changed, and deleted elements).
- View baseline, which allows a user to access a base state declared for an ontology.
- Copy, which allows a user to copy content to another ontology, considering all the dependencies. The user can decide upon either (1) a total copy (the whole ontology) or (2) a partial copy (by manually selecting elements).
- Merge, which allows a user to merge (1) the content of an ontology with (2) the content of one of its baselines or another ontology.
- Revert, which allows a user to change the current ontology

TABLE I. Operations for ontology configuration management per resource type

| | Core operations | | | | Common operations | | | | Retrieval ops. | Reuse operations | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Creation | Retrieve | Update | Delete | Harmoni-sation | Validation | Preferred | Related | Index & Search | Copy To | Merge | Diff |
| **Term** | X | X | X | X | X | X | X | X | X | X | X | |
| **Category** | X | X | X | X | X | X | | | X | X | X | |
| **Relationship type** | X | X | X | X | X | X | | | X | X | X | |
| **Pattern** | X | X | X | X | | | | | X | X | X | |
| **Rule** | X | X | X | X | | | | | X | X | X | |
| **Ontology** | X | X | X | X | | | | | X | X | X | X |

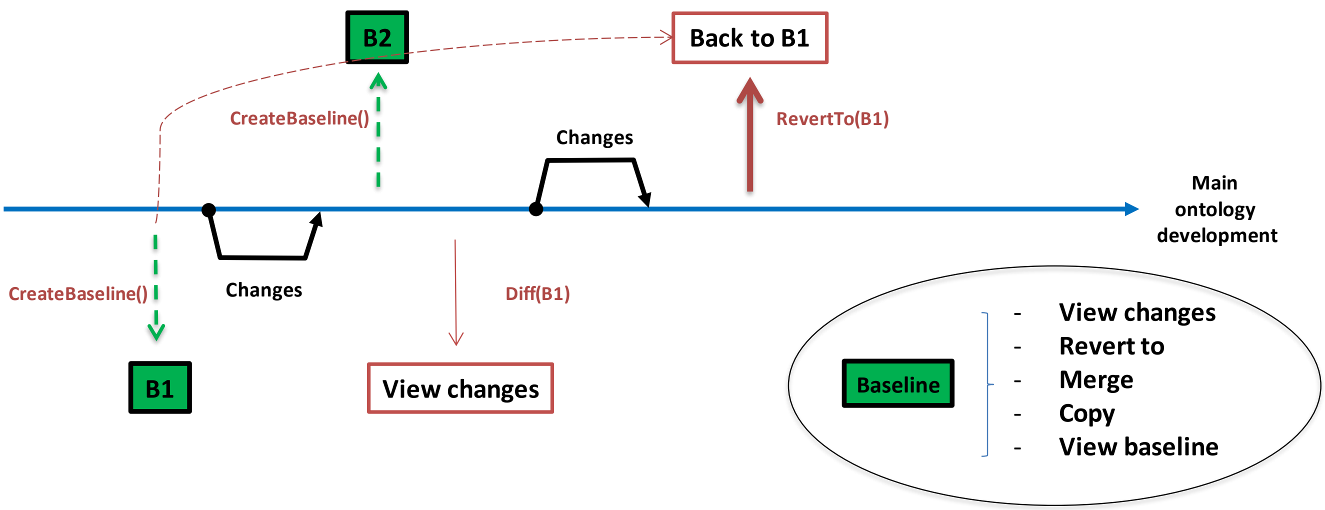


Fig. 2. Workflow for ontology configuration management

to a previous state.

These scenarios can be regarded as situations for CM of an ontology (Fig. 2), while an ontology evolves, and for which ontology reuse is necessary. All the scenarios, and thus the underlying operations, have been requested by TRC customers.

## III. Implementation

This section presents further details about how the approach has been implemented in Knowledge Manager and its usage possibilities in practice. An example of the actions that the tool allows a user to perform and of the kind of information that the tool shows is provided in Fig. 3 for the 'View changes' scenario introduced in the previous section. For example, the tool highlights when an ontology item has been added, modified, or removed. The approach for ontology CM implemented in Knowledge Manager further enables the following new features in the tool.

**Changes federation**. Knowledge Manager can manage several ontologies, e.g. to represent different domains. But at the end of the day, the content can be common in those different domains. In this case, making a change on one of the domains must be replicated by hand in the other domains. With the federation of changes, several ontologies are inter-connected, thus whatever change is made in any of the ontologies is automatically replicated in the others. This is useful when e.g. a company has different ontologies for different system parts (such as the different sub-systems in a vehicle) and the ontologies have elements in common that represent general domain or company knowledge.

**Ontology libraries**. When a piece of knowledge has been represented in an ontology, it often happens that it is also needed in a different ontology for different purposes. For this reason, it is possible to create a package (library) with any part of the ontology so that it can be shared and imported in another ontology. This way, the content of an ontology can be reused through libraries.

**Knowledge interfaces**. In many companies, the organization knowledge is represented in different tools, using different schemas. This is especially common for critical-systems engineering [5]. For instance, the domain vocabulary can be found in an RDF ontology, the Product Breakdown Structures of a system can be stored in Rhapsody models, and the physical simulations in Simulink. If this organization wanted to manage all this knowledge within Knowledge Manager, e.g. for quality assessment purposes, it would be a laborious process to represent by hand all the information in the tool, including the maintenance of all the changes. For this reason, Knowledge Manager supports the concept of knowledge interfaces, so that it is possible to create connectors to any source of information, i.e. to any external tool. This feature exploits the OSLC-KM approach [2], which provides generic means for tool integration, to automatically and dynamically load content via different connectors.

The implementation of the approach has been validated with reference, base ontologies provided with Knowledge Manager. For example, a case study was performed with information from the aerospace domain, with two ontologies: (1) the reference ontology, with 3472 terms, 137 semantic clusters, 286 relationships, and 11 relationship types, and (2) an aerospace-specific ontology, with 457 terms, five semantic clusters, 1370 relationships, and one relationship type. Information about an aerospace system modelled with SysML in the MagicDraw tool was imported into Knowledge Manager and the corresponding ontology was created. Next, the ontologies were merged. Further actions such as 'Copy' and 'View changes' were also performed.

Another example of validation activity was performed with a TRC customer from the railway domain, and more specifically with ontologies for EIRENE (European Integrated Railway Radio Enhanced Network) [4]. This allowed TRC to show the customer how ontology CM works in Knowledge Manager and how it could be exploited. Several ontology libraries were created and managed. Feedback was collected informally and it was positive.

Another customer has started to use ontology libraries and changes federation. We do not have detailed information yet about this usage, but no issues have been reported.

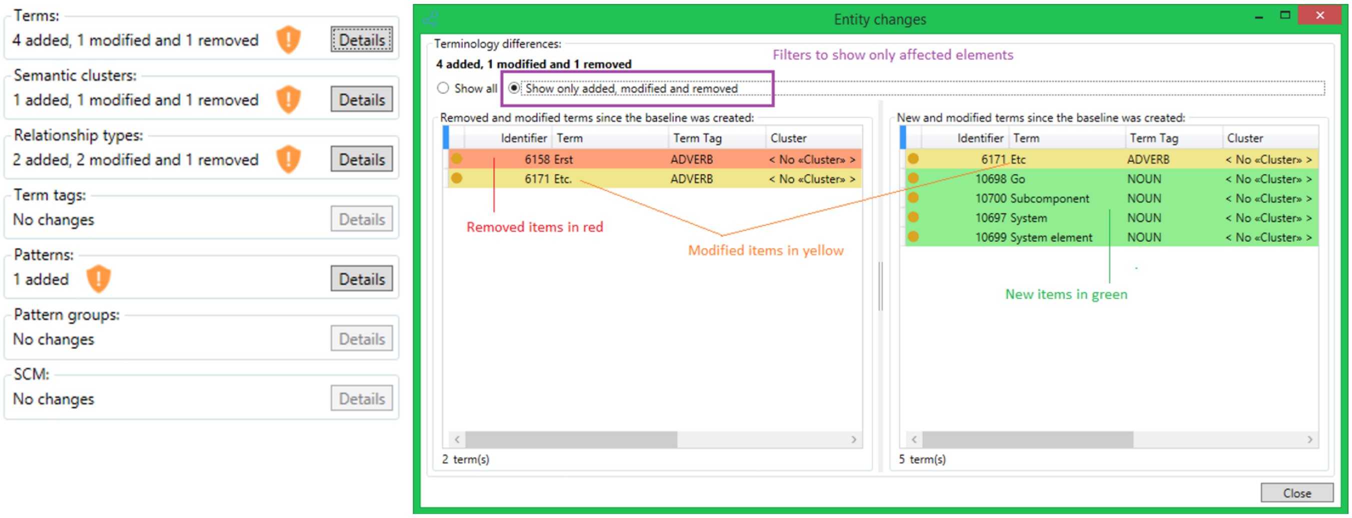


Fig. 3. Ontology change reports in Knowledge Manager

In the scope of the large-scale industry-academia AMASS project on assurance and certification of cyber-physical systems, we applied ontology CM on a case study about an advanced driver assistance function of an electric vehicle sub-system [1]. Ontologies of different aspects of the ISO 26262 standard were created and later managed.

Finally, the current validation needs to be extended in the future, e.g. for external validity. Validation activities with TRC customers and in real projects will be especially important, not only to validate the implementation itself but also to identify improvements opportunities on the approach.

## IV. Conclusion

The complexity of engineering complex safety-critical systems is increasing and new techniques are necessary to alleviate this situation. A possible means is the reuse of existing and validated system information, e.g. knowledge representations about a system in the form of ontologies, but this requires the provision of suitable approaches.

We have introduced an approach for ontology CM in the scope of systems engineering. The approach has been implemented in the Knowledge Manager tool, supports the management of the different elements that an ontology in this tool includes, and defines operations to enable and support element CM and reuse. As a result, engineers can check ontology baselines and the changes in an ontology, copy elements, merge ontologies, and revert changes. This has led to three main new features in Knowledge Manager: changes federation, ontology libraries, and knowledge interfaces. The approach is in line with the expectations and needs from TRC customers and its initial validation is positive.

Ontologies, as libraries of knowledge, can help engineers to tackle development complexity by providing support that drives engineering methods based on the reuse of existing information and artefacts. Nonetheless, and taking into account the multidisciplinary character of information, it is completely necessary to offer not just ontologies but advanced (and semi-automatic) operations to manage and reuse knowledge.

The main piece of future work is to gain insights into the application of the approach in real projects. This will be performed in collaboration with TRC customers. We also plan to quantitatively analyse the gain in using the approach.

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