An Ontological Schema for Sharing Conceptual Engineering Knowledge

Yoshinobu Kitamura and Riichiro Mizoguchi

The Institute of Scientific and Industrial Research, Osaka University, Japan
8-1, Mihogaka, Ibaraki, Osaka, Japan
{kita,miz}@ei.sanken.osaka-u.ac.jp

Abstract

In the engineering design, engineers have been suffering the difficulty in sharing conceptual engineering knowledge about functionality representing design rationales because of lack of rich common vocabulary for functionality. In order to promote sharing of such knowledge, we have developed an ontological framework for its modeling including layered ontologies, which provides rich concepts for describing consistent and reusable knowledge. This article summarizes the framework and the successful deployment in a company. In the context of the semantic web, our framework can be viewed as a metadata schema of documents about engineering devices. This article also discusses metadata from the viewpoint of functionality as a usage of our ontologies in the semantic web.

Introduction

In the engineering design community, the importance of knowledge sharing among designers has been widely recognized. Although advancement of computer technologies has enabled easy access to structural information using CAD, such information does not include designer's intention such as so-called design rationales (DR) (Lee 1997). A model about functionality of devices (so-called a functional model) describes goals of devices intended by a designer and thus represents a part of DR (Chandrasekaran, Goel, and Iwasaki 1993). However, it is difficult to describe such a conceptual engineering knowledge consistently and share the functional models and generic knowledge about functionality. Although some functional modeling languages have been proposed (Chandrasekaran, Goel, and Iwasaki 1993; Lind 1994; Umeda et al. 1996), there is neither rich common vocabulary for representing functions nor well-established ontological commitment for capturing such knowledge. For example, one might describe "to weld objects" as a function of a manufacturing facility in the similar manner in value analysis (Miles 1961). However, "to weld" is not only a function but also implies a certain way to achieve the goal, the objects are fused. In fact, the same goal can be achieved in different ways (e.g., using bolts and nuts) without fusion. To allow freedom in design and to make selection of "bolt & nut" instead of "welding" possible, the achieved function should be the same; "to unify". This example suggests necessity of carefully designed vocabulary of functions and an ontological framework for functions beyond just lexical vocabulary.

The main goal of this research is to promote sharing of the conceptual engineering knowledge about functionality by providing a conceptual framework enabling systematic description of the functional knowledge. The framework consists of categorization of the functional knowledge and layered ontologies for capturing functions. It gives the knowledge authors a controlled vocabulary and guidelines for consistent and reusable knowledge. The framework has been deployed successfully in a company. In this paper, we summarize our framework and its deployment.

We view the semantic web as one of the enabling technologies for knowledge sharing in a community. Our framework can be viewed as a metadata schema of web documents. Our ontology and generic knowledge can be treated as a metadata schema represented in DAML+OIL (DAML+OIL 2001). This paper also discusses metadata from the viewpoint of functionality as a usage of our ontologies in the semantic web.

A framework for functional knowledge

Our framework for functional knowledge is shown in Figure 1 as layers of ontologies, knowledge and instance models. Basically, knowledge or a model in a certain layer is described in terms of more general (and/or fundamental) concepts in the upper layer.

At the bottom in Figure 1, a *function decomposition tree* is a functional model of a specific device (In the figure, a washing machine). It represents that a required function (called a macro-function) can be achieved by specific sub(micro)-functions (Pahl and Beitz 1988). We introduce the concept of "way of function achievement" as conceptualization of background knowledge of functional decomposition such as physical principles and theories as the basis of the achievement. The conceptualization of way of achievement helps us detach "how to achieve" (way) from "what is intended to achieve" (function). For example, "to weld something" mentioned in Introduction should be decomposed into the "unifying function" and "fusion way". This increases generality and capability of a functional model which accepts wide range of ways such as the bolt and nut way as an alternative way of achievement.

At the lower right, there is a *general function decomposition tree* that includes alternative ways of function achievement in OR relationship. It can be used when designers explore and investigate possible ways to achieve a specific required function.

We have developed an ontology of functions of components (called *a functional concept ontology* at the third layer from the top in Figure 1) (Kitamura et al. 2002) which are detached from ways of function achievement. It defines about 220 concepts in 4 is-a hierarchies with clear operational relationship with objective behavior of a device. Only a few (4-16) generic functions have been proposed to date (Pahl and Beitz 1988; Lind 1994). Tejima et al. proposed a set of 158 verbs representing function only for human comprehension in Value Engineering area (Tejima et al. 1981). In order to capture functions consistently, it is based on an extended device ontology (Kitamura and Mizoguchi 2003) and a top-level ontology. Using these functional concepts as vocabulary, the function decomposition trees at the bottom in Figure 1 are described.

The concept of "way of function achievement" also helps us generalize concrete ways into generic ways and organize generic ways in is-a relations according to their principles (called *functional way knowledge*). Although the feature of function decomposition is also captured in (Malmqvist 1997), he focuses strictly on the function decomposition tree of a specific product and little attention on general knowledge is paid.

A similar hierarchy of ontologies is proposed in (Borst, Akkermans, and Top 1997). However, it does not include an ontology of functionality that is our main issue.

Use and Deployment

Our framework contributes to making the authoring of consistent and reusable functional knowledge of a device easier. Because functionality can partially represent DRs, the functional model of a device can be representation of DRs. The functional knowledge can be used for redesign of artifacts by changing a way of function achievement in original design into an alternative way.

Our framework has been deployed in the Production Systems Engineering Division of Sumitomo Electric Industries for sharing functional design knowledge of production systems for semiconductors among designers since May, 2001. The preliminary evaluation by the Sumitomo engineers was unanimously positive. They said that this framework enabled them to explicate the implicit knowledge possessed by each designer and to share it among team members. One of the remarkable

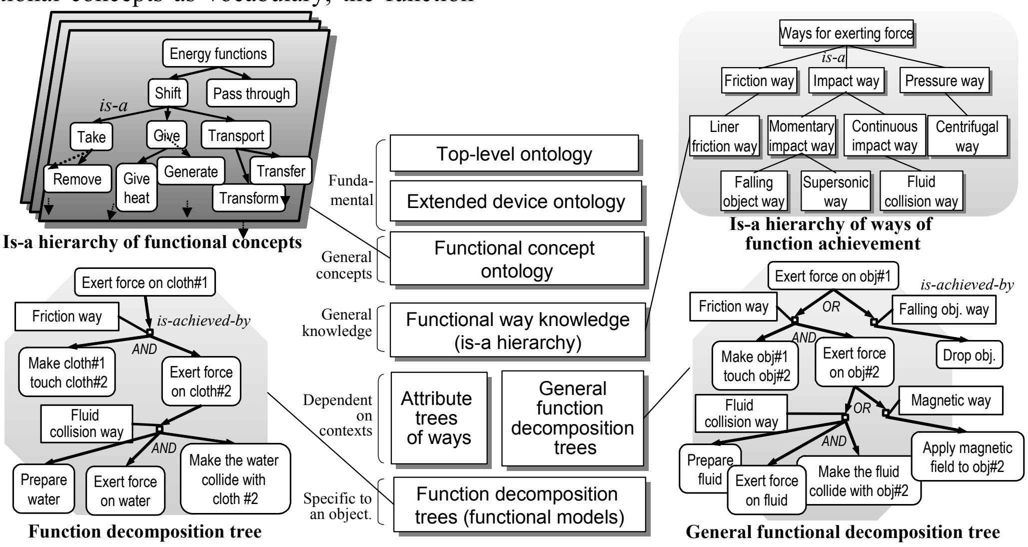

Figure 1: A layered framework of ontologies, knowledge, and models of functions

successes is as follows; designer was not able to solve a problem of low quality of semiconductor wafers after 4-month investigation. By exploring causes of the problem in the model of ways of function achievement with a clear description of physical principles, he found a solution for the problem within 3 weeks.

Metadata about functionality

In the semantic web context, our ontology can be used as a metadata schema for engineering documents as shown in Figure 2. It enables us to describe metadata representing functionality of engineering devices mentioned in the target engineering documents. Such metadata can be regarded as "content descriptors" like keywords or "logical structure" of "content representation" like a summary or an abstract in terms of categorization in (Euzenat 2002). Here, the logical structure means physical relationship among functions such as functional decomposition.

The functional concept ontology in our framework provides hierarchies of *classes* (types) as a metadata schema in the web-schema languages such as RDFS and DAML+OIL. The metadata about functionality as RDF statements are described as *instances* of those classes. The functional way knowledge also provides hierarchies of *classes* for representing types of "how to achieve a function" of a devices.

We implemented our ontological framework (Kitamura and Mizoguchi 2003) using our ontology development environment named Hozo (Kozaki et al. 2002). Hozo can exports ontologies and instance models in DAML+OIL (DAML+OIL 2001). The extended device ontology, the functional concept ontology, and the functional way knowledge are exported as classes in DAML+OIL. A specific way knowledge is represented as a sub-class of the "way" class in hierarchies by restricting (specializing) its range of the property to a specific function class in the functional concept ontology.

We categorize metadata about functionality into three types as shown in (a) - (c) in Figure 2. Figure 3 shows examples of metadata in RDF for a document mentioning a washing machine (the name space "fbrl" represents our framework).

Firstly, the classes of functional concepts solely can be used as a kind of "content descriptors" for documents of engineering devices. One can describe metadata that refers to a functional concept representing the whole function (or top goal) of a device described in the document. In Figure 3(a), the document is annotated with an (unnamed) instance of a specific function class "to separate objects" by the "top-function" property. It enables us to search documents of engineering devices using their functions using a common vocabulary and the *is-a* hierarchies of functional concepts. Also, one might add sub-functions of the devices (e.g., "to exert force") to the metadata. Such usage of ontologies has been extensively discussed to date in the semantic web community.

Here, the discrimination between functions and ways plays an important role. As mentioned in the introduction, usually both concepts are confused and thus it causes failure of search by functions. As well as the metadata by functions, secondly, one can describe ways of function achievement used in the device (e.g., "the friction way" for exerting force as shown in Figure 3(b)). So, based on our ontologies, a user can search functions and ways separately.

Lastly, a function decomposition tree of a device can be regard as metadata of a document about the device, which includes information of both metadata types (a) and (b). Figure 3(c) shows a part of such metadata of a washing machine, the function decomposition tree of which is shown in Figure 1. The functions in the model are instances of the functional concept classes in the functional concept ontology. The is-achieved-by relations among these functions are instances of a specific subclass of the way class.

Many design documents describe only objective result of design activities without subjective design

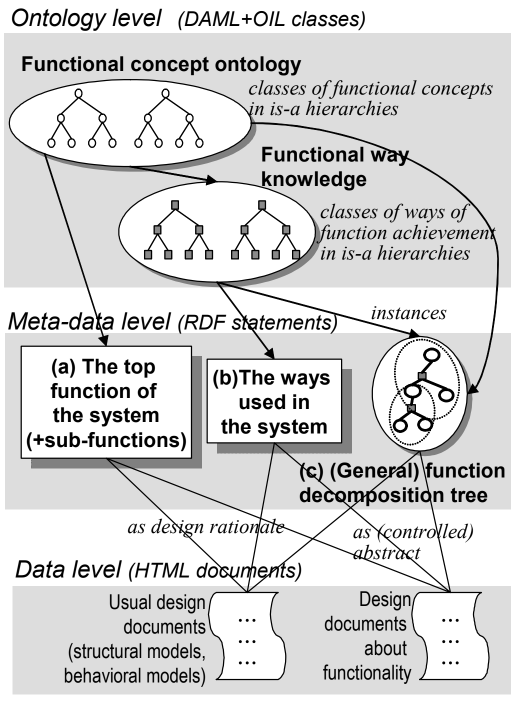

Figure 2: Ontology-based metadata about functionality

rationale. The functional decomposition tree as metadata gives a part of the *design rationale* of devices described in the document. For the rare documents describing functional structures, the functional decomposition tree gives a kind of a *summary* or an *abstract* of the document.

Furthermore, the general function decomposition tree can be regards as another kind of metadata. It can consist of several ways of function achievement used in different devices in OR relationship. Thus, it can give a *combined summary* of some documents from the viewpoint of functionality.

```
<rdf:Description rdf:about="http://..."
    rdf:type="fbrl:metadata_func">
  <fbrl:top_function><rdf:Description
    rdf:type="fbrl:Separate_objects"/>
  </fbrl:top_function>
  <fbrl:sub_functions><rdf:Description
    rdf:type="fbrl:Exert_force" rdf:about="..."/>
  </fbrl:sub_functions>
</rdf:Description>
```

(a) A metadata about its functionality

```
<rdf:Description rdf:about="http://..."
    rdf:type="fbrl:metadata_ways">
  <fbrl:used_ways><rdf:Description
    rdf:type="fbrl:friction_way"/>
  </fbrl:used_ways>
 </rdf:Description>
```

(b) A metadata about used ways of function achievement

```
<fbrl:Exert_force rdf:ID="Exert_force1">
  <fbrl:Function_hasPart_as_Agent
    rdf:resource="#Washing_machine1"/> ...
</fbrl:Exert_force>
<fbrl:Friction_way rdf:ID="Friction_way1">
  <fbrl:Friction_way_hasPart_as_Macro
    rdf:resource="#Exert_force1"/>
  <fbrl:Friction_way_hasPart_as_Micro1
    rdf:resource="#Prepare_object1"/>
  <fbrl:Friction_way_hasPart_as_Micro2
    rdf:resource="#Make_objects_touch1"/>...
</fbrl:Friction_way>
```

(c) A function decomposition tree as a metadata

Figure 3: Examples of metadata for a document of a washing machine

Conclusion

We have developed a modeling framework including ontologies for functional design knowledge. It has been deployed in a company successfully. It can be used as a metadata schema from a viewpoint of functionality of engineering devices. The functional metadata can include design rationales behind usual design documents such as design plans.

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