Towards a Reference Ontology of Functionality for Interoperable Annotation for Engineering Documents

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1. INTRODUCTION

Functionality is one of the key concepts in knowledge about artifacts. The goal of this research is to manage the information content of design documents from the viewpoint of functionality of engineering products using semantic annotation about functionality (we call *functional annotation*). It enables engineers to access documents by specifying a function as a metadata query. Such function-oriented management is especially useful in the conceptual design phase to find previous design cases for the same required function and to find related patents. The semantic annotation about function is expected to solve the difficulty of current technical document management based on lexical expressions, that is, many terms (verbs) are used in documents for the same function (and vise versa) without clear semantics.

The research issues for realization of functional annotation are (1) to establish *ontological metadata schema* for consistent functional annotation and (2) to realize *interoperability* among various functional representations. For the former issue, although much research has been conducted on functionality in engineering design (e.g., [2][3][7]), there is neither common definition of function nor enough semantic constraints for consistent functional annotation. For example, "to weld metals" as a manufacturing machine's function in the manner of Value Engineering is not only a function but also implies a certain way to achieve the goal, say, "the metals are fused". This issue, that is, distinguishing "what to achieve" from "how to achieve", is not a terminological but ontological. Although PhysSys [1] is a well-established ontology in engineering domain, it does not include functionality.

On the latter issue on interoperability, firstly, there are some taxonomies of verbs for generic functions such as the *generally valid functions* [7] and the (reconciled) *functional basis* in the NIST Design Repository Project [3]. Secondly, many functions are captured for the same use of the same product according to the scope of interest. For example, a function of an electric fan can be captured as "to move air", "to cool human body" or "to make human comfortable". These differences are also not terminological but ontological, because such functions are based on different conceptualizations. A functional annotation schema proposed in [6] uses the functional basis [3] as taxonomy with neither ontological consideration nor interoperability.

The authors have investigated functionality of devices for long years and established an ontology-based framework for functional models [4]. It includes a device-centered functional ontology [5] and a functional concept ontology as functional taxonomy. It has been deployed successfully in industry [4].

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On the basis of the previous effort, the authors propose a multi-layered framework of ontology-based semantic annotation about functionality (called *Funnotation* (abbreviation of FUNctional anNOTATION) hereafter). It includes a metadata schema in OWL based on our functional ontologies [4][5]. Metadata in RDF based on the schema shows the function of the artifact mentioned in the document. Then, a document search system using the functional metadata helps engineers access to web documents about design in terms of what they want to realize, i.e., function, independently of lexical terms in the documents.

For interoperability of functional metadata, *Funnotation* includes a reference ontology of function (called *FuRO*) which defines categories (classes) of various kinds of function. It aims at clarifying ontological difference between the functional taxonomies and at enabling translation between them. It is an extension of coverage of our functional ontology to cover broader sense of function. A part of *FuRO* has been shown in [5]. This paper discusses its role in interoperability of functional metadata.

2. FUNCTIONAL ANNOTATION

Figure 1 shows an overview of the *Funnotation* framework for functional annotation. Its main schema consists of F-Core schema and F-Vocab schema. F-Core schema defines fundamental classes such as *entity, device, stuff, energy, function* and *way (of function achievement)* together with properties among them such as *has-function* and *selected-way*. The *way* (of function achievement) represents background knowledge of the function achievement (function decomposition [7]) where a function is achieved by a series of finer-grained (part) functions. The *has-function* property is a relation between an (subclass of) *entity* and a *function* where the entity can perform the function as an agent. The *selected-way* property is a relation between a *function* and a *way* where the function is achieved using the way of function achievement in a device. The F-Vocab schema defines a hierarchy of generic functions based on the functional concept ontology [4].

The *Funnotation* schema implemented in OWL enables us to describe metadata in RDF representing functionality of engineering devices in documents. For example, a part of a metadata m_a in Fig. 1 shows that the device appearing in annotated document d_a (a filter) can perform an instance of the *separating* function class defined in the schema. This metadata is annotated to the term "extract" in d_a. The metadata m_b shows that the distiller (the device mentioned in the document d_b) has the same *separating* function. It is, however, annotated to the different term "refine" in d_b. In this manner, functional metadata shows device's functions independently of the terms in documents and indicates pointers (URLs) to the original documents and/or terms. Moreover, the metadata shows how to achieve a function, i.e., in this case, two different ways (the filtering way and the distilling way) to achieve the same separating function.

By querying such functional metadata, a semantic search system provides access to the annotated documents based on the hierarchy of functions and/or relationship between functions and ways. Using the example in Fig. 1, if an engineer specifies the "separate" function as a goal function in a query, the system provides him/her with hyperlinks to the both documents d_a and d_b. We have implemented the search system using Jena and SPARQL.

3. REFERENCE ONTOLOGY OF FUNCTION

The *Funnotation* framework realizes interoperability of functional metadata based on a *reference ontology of function* (*FuRO*) as shown in Fig. 1. It defines generic (upper) classes of various kinds of function. By reference ontology, we here mean an ontology referred to for categorizing existing definitions of function and mapping them (in comparison with "reference for system design" such as the ISO's OSI network reference model). For example, a *device function* implies changes of entities (behaviors) within the system boundary, while an *environmental function* includes changes outside of the system boundary, especially, those related to users. For instance, an electric fan performs moving-air function as a *device function* and cooling function for human body as an *environmental function*, where the cool-down effect by wind is on human body and thus out-side of the system boundary. This cooling function implies physical changes (called *physical environmental function*), while an *interpretational* function sets up one of the necessary conditions of human's cognitive interpretation. The examples of the latter kind are "to make a man comfortable" function of the electric fan and "to inform time" function of a clock. In the literature, there are similar types of function such as "environment function" [2].

Moreover, we recognize the some kinds of *quasi-functions*. Although the authors do not consider them as kinds of function, it is found that a quasi-function is confused with a function. For example, a *function-with-way-of-achievement* implies a specific way of function achievement as well as a function. Its examples include washing, shearing, adhering (e.g., glue adheres A to B) as well as welding mentioned in Introduction. Because meaning of this type of function is impure, we regard this quasi-function.

Each function in the taxonomies is classified into a class of function in *FuRO*. Our functional concept ontology (F-Vocab schema) defines functions strictly from the device-centered viewpoint in three major categories of functions; base-functions, meta-functions and function types [4][5]. All base-functions are categorized into *flowing-object function* in *FuRO*. It represents that a device as a black-box changes a value of physical quantity of objects (or stuff) flowing through the device.

On the other hand, as an example of other taxonomy of function, the functions defined in the functional basis [3] (FB hereafter) are categorized into different classes in *FuRO*, though many of them are classified to the *flowing-object function*. For example, the "indicate" function in FB is categorized as an *interpretational function* in *FuRO* which requires human's cognitive interpretation. The "link" function in FB is a *function-with-way-of-achievement,* because it is defined as "to couple flows (objects) together by means of an intermediary flow" [3].

The mapping between F-Vocab and FB can be done via *FuRO*. Such functions categorized into the same class in *FuRO* can be associated with each other directly. In the simplest case, there is one by one mapping such as "couple" in FB and "combine" in F-Vocab. There are, however, many mismatches due to difference of categorization. On the other hand, if functions

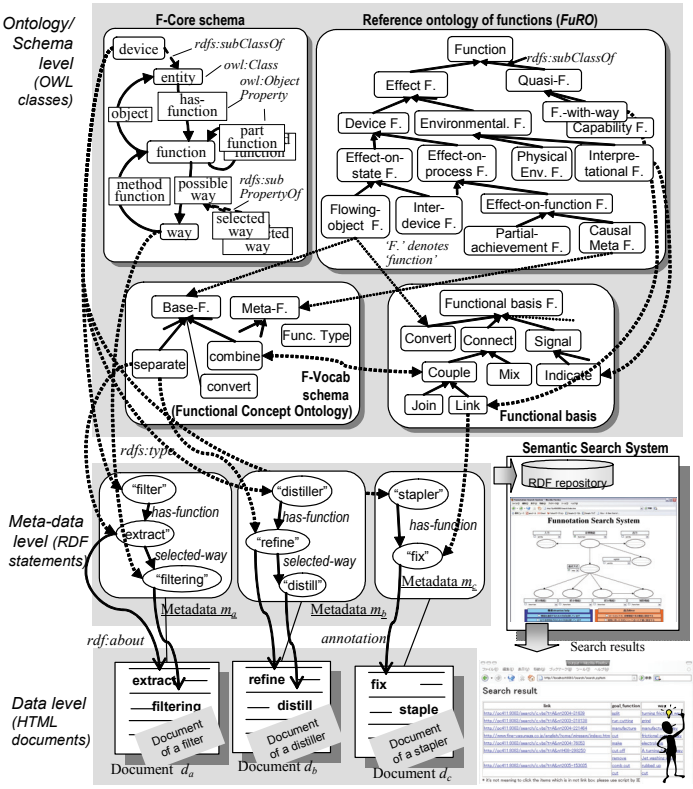

Figure 1. Overview of *Funnotation*: A Framework for Semantic Annotation about Functionality for Engineering Documents

are categorized into the different classes in *FuRO*, the mapping become complex. For example, "link" in FB is translated into "combine" in F-Vocab plus the "intermediate-object" way for combining. Thanks to *FuRO*, such ontological difference becomes explicit and thus we can realize the mapping without loss of information of impure terms in FB.

4. CONCLUSION

The reference ontology of functions can be used to clarify ontological differences between the functional taxonomies and to enable translation of functional metadata between them.

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