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TOWARDS MULTI-VIEW FUNCTIONAL KNOWLEDGE SERVER BASED ON A FUNCTIONAL ONTOLOGY

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Abstract: In conceptual design, a designer decomposes a required function into sub-functions, so-called functional decomposition. Our functional knowledge server is designed to provide designers alternative ways of achievement of the required function. In order to provide a wide range of alternatives, general ways of achievement are systematized based on an ontology of functional concepts. The server contains the knowledge as an is-a hierarchy and then reorganizes a decision tree suitable for the viewpoint of each designer. The server can facilitate innovative design and negotiation in a concurrent design team.

1. Introduction

This research aims at developing such a knowledge base system that answers how to achieve a required function of engineering products for both human designers and computer agents. In the conceptual design methodology so called functional decomposition [Pahl and Beitz, 1988], a designer decomposes the required function into sub-functions by selecting a “way” of achievement from his/her own viewpoint. For example, a designer may decompose the required function “to connect two objects” into “to insert a screw into a hole” and “to tighten the screw” by selecting the “screw way”. The role of our system is to show the designer some alternative ways such as “hook-fit clasp” in which the objects are connected by “to hook the crook”. Manufacturing (assembling) of the product in the case of “hook-fit clasp” is easer than that of the screw way.

Among the requirements for such systems, we concentrate on “wideness” of the alternatives and “adaptability” for viewpoints. The former means that the system should provide a wide range of ways of achievement in different domains. Because many inventions are based on techniques well-known in different domains [Sushkov, *et al.*, 1995], such a system can facilitate innovative design. The latter means that the system should provide the same chunk of knowledge in the different manners suitable for the viewpoints of designers. For example, the system should show different characteristics of a way for a product designer and a manufacturing designer. Furthermore, the system should show effects of a decision from a viewpoint on that from another viewpoint.

TechOptimizer [Invention Machine, 1999] is a software product based on a theory for innovative design [Sushkov, *et al.*, 1995], which contains generic principles of invention. It, however, just searches the knowledge for given criteria and are not adaptive for the designers’ viewpoints. Moreover, its product analysis and manufacturing process analysis are independent from each other.

We are tackling these issues based on Ontological Engineering [Mizoguchi and Ikeda, 1997] which aims at explication of conceptualization of a target world. We have built an ontology of functional concepts which provides a rich vocabulary for representing functionality of engineering

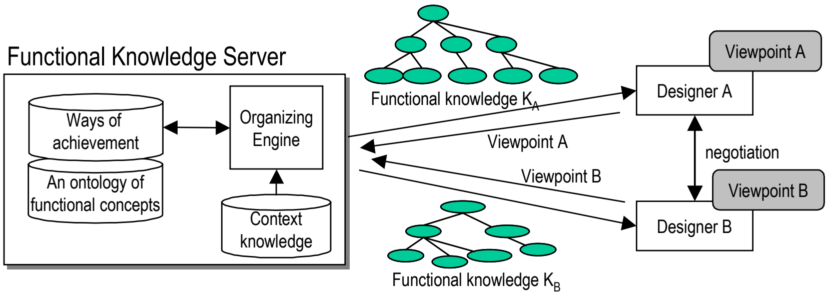

Figure 1. The framework of the Functional Knowledge Server

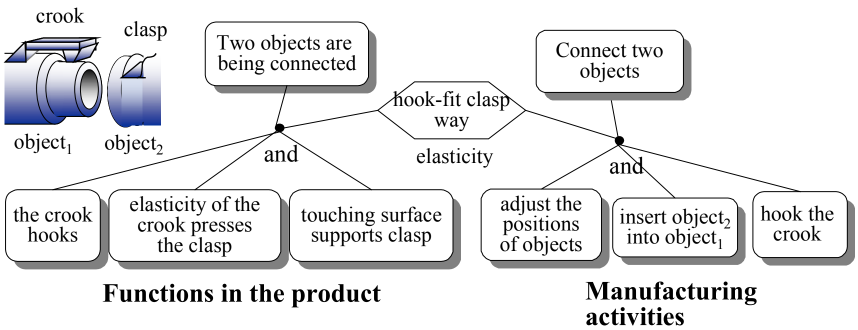

Figure 2. An example of way of "to connect"

devices [Kitamura and Mizoguchi, 1999]. In terms of the vocabulary, some general ways of achievement of functions have been systematized. A functional knowledge server also has been designed to display suitable decision trees of ways according to the given context.

2. Framework of the Functional Knowledge Server

The functional knowledge server supports conceptual design of engineering devices, providing suitable ways of achievement of the function that designers consider. Figure 1 shows its framework. The server contains the knowledge of ways of achievement of functions (see Section 3 for detail). Given a required function and a viewpoint of the designer, the server reorganizes the knowledge in a manner suitable for the viewpoint and then shows ways in a tree structure (see Section 4). After the designer selects a way, the system constructs a functional product model and its manufacturing model. The server provides a wide range of ways in different domains and then facilitates innovative design. Moreover, because the server can track effects of decisions made by both the product designer and the manufacturing designer, the server facilitates negotiation in a concurrent design team.

3. Ways of Achievement of Function

3.1 Methods and Ways

The key idea of our systematisation of knowledge of functional decomposition is "way" of achievement of function. A base-function can be achieved by the different groups of sub-functions (so-called functional decomposition). We call a group of sub-functions constrained by the relations among them "a functional method" of an achievement. On the other hand, we call the basis of the method "a functional way". The way is the result of conceptualisation of the physical law, the intended phenomena, the feature of physical structure, or components assumed in the decomposition. For example, Figure 2 shows a way of "to connect", where "two objects are being connected" is achieved by the sub-functions such as "the crook hooks" and "elasticity of the crook presses the clasp". Its way can be called as "hook-fit clasp way" whose principle is elasticity of the crook.

A way of achievement of a function in the product partially determines the manufacturing process of the product. For example, in the hook-fit clasp way, the product can be manufactured by the manufacturing activities shown in Figure 2 and the way of positioning is not determined.

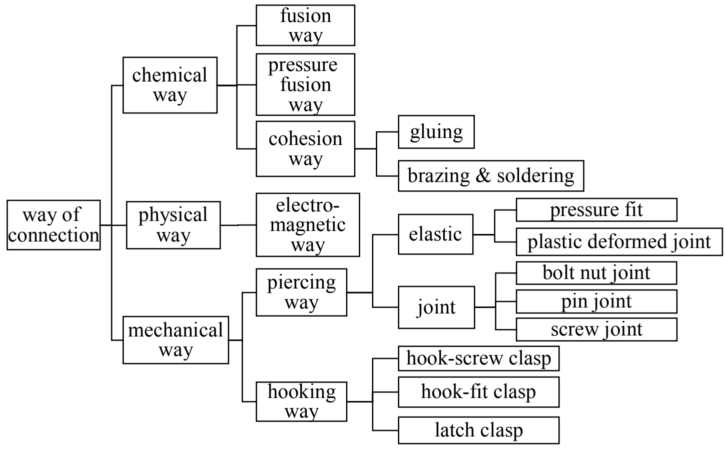

Figure 3. An is-a hierarchy of ways of achievement of “to connect”

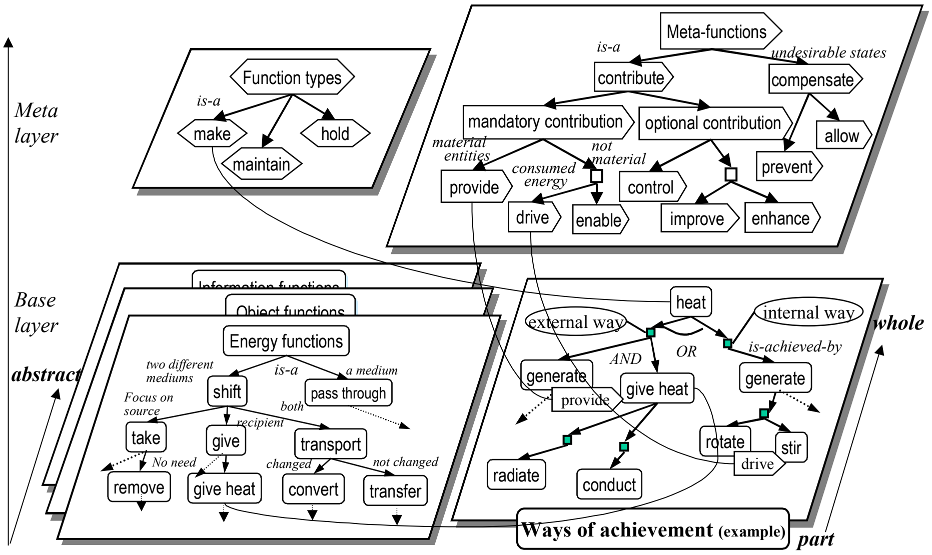

Figure 4. An ontology of functional concepts [Kitamura and Mizoguchi, 1999]

3.2. Systematization of ways of achievements

In general, there are many ways of achievement of a function. We can systematize them as an is-a hierarchy according to their principles. For example, Figure 3 shows an is-a hierarchy of the ways of “to connect”. Although such a categorization is often found in technical documents, the knowledge is scattered around gluing, welding, etc. The knowledge also tends to lack consistency of viewpoints, to be ill-structured, and to be categorized by the non-fundamental characteristics which can be derived from deeper principles. We systematize the fundamental ways according to their principles and define complex ways by composing them, which enables us to make the categorization consistent.

4. Ontology of Functional Concepts

The ontology of the functional concepts is designed to provide a rich and comprehensive vocabulary for functional knowledge such as ways of achievement. It consists of the three categories of functional concepts, that is, base-function, function type, and meta-function as shown in Figure 4. A base-function represents a teleological interpretation of changes in objects in a component. Using the functional modeling language FBRL (abbreviation of a Function and Behaviour Representation Language) [Sasajima *et al.*, 1995], we can define general meaning of a base-function independent of target objects and components. A function type represents the types of goal achieved by the function

[Keuneke, 1991]. A meta-function represents the roles of each function for another function [Kitamura and Mizoguchi, 1999]. A base-function represents a specific change of objects (at the base layer in the vertical axis), while a function type and a meta-function are concerned not with objects but with goal and function (at the meta-layer). Using these functional concepts as a vocabulary, the ways of achievements can be described as shown in Figure 2 and 4 and be systematized shown in Figure 3. For more detail of the ontology of functional concept, see [Kitamura and Mizoguchi, 1999].

5. Reorganizing Functional Knowledge

5.1 Types of Functional Knowledge

The is-a hierarchy of ways: The ways of achievement of a function are organized as an is-a tree according to their principles as shown in Figure 3. The other types of knowledge are results of reorganization of this knowledge.
Attributes tree: For selection of ways, ways are classified by value of attributes (so-called decision tree). Each leaf node represents a way. The structure of the tree depends on the viewpoints.
Functional decomposition tree: A kind of a description (model) of a product. It consists of sub-functions and description of the way as shown in the left part of Figure 2. This tree is constructed as a result of decision of the product designer.
General functional decomposition tree: It consists of possible ways of achievement of a function in OR relationship.
Manufacturing activity decomposition tree: It consists of manufacturing activities (process) of a product as shown in the right part of Figure 2.
General manufacturing activity decomposition tree: It consists of possible ways of manufacturing of a product in OR relationship.

5.2.Viewpoints

A viewpoint represents a context of designer's thinking process. It consists of a phase in the product lifecycle such as manufacturing, using (product design), and recycling, focused attribute set, grain size, and a domain of interest such as mechanical and electrical. The system contains context knowledge representing typical viewpoints such as product cost and manufacturing easiness.

5.3 Reorganizing attribute trees

Given a viewpoint, the server determines wideness, depth and evaluation criteria according to the context knowledge. The focused attributes in the context knowledge determine the wideness of selected ways and evaluation criteria. The focused life-cycle phase and grain sizes determine the depth. According to the wideness and the depth, the ways in the is-a hierarchy shown in Figure 3 are selected. Then, the selected ways are reorganized according to the evaluation criteria.

6. A scenario

This section shows a possible scenario of design using the functional knowledge server. Let us suppose a concurrent design team are designing a connection between an air-conditioner and a pipe. Firstly, a product designer is selecting a way of connection from the viewpoints of water-tightness for the fluid. Given the viewpoint "water-tightness", the server looks up suitable attributes such as "joint gap" and "water resistance" from the context knowledge. The server reorganizes suitable ways in the general ways for connection shown in Figure 3 and then shows an attribute tree shown in Figure 5a (see Section 5.3). If the product designer would select "brazing and soldering" way, a functional decomposition tree and a manufacturing activity decomposition tree are constructed (Figure 5b). A designer of manufacturing can select a device for heating, say, not a gas burner but an electric heater according to the characteristics of "brazing and soldering", that is, heat soluble.

Suppose that other designer from the viewpoint of recycling submits an alternative plan "to hook-fit clasp" according to another attribute tree shown in Figure 6 from the viewpoint of

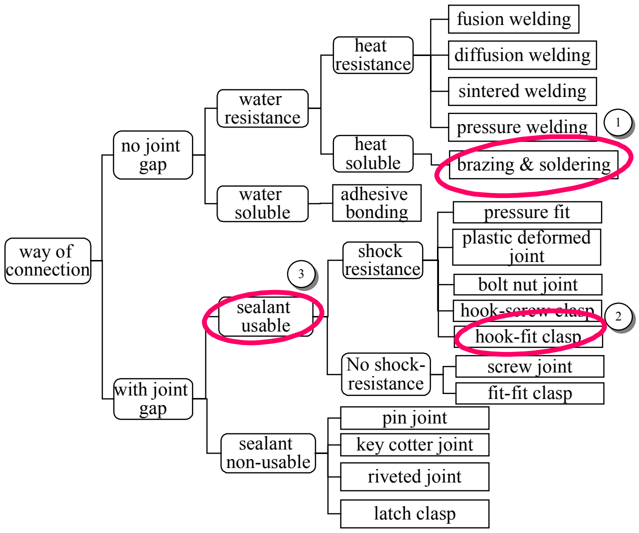

Figure 5a. An attribute tree of ways of connection from the viewpoint of “water-tightness”

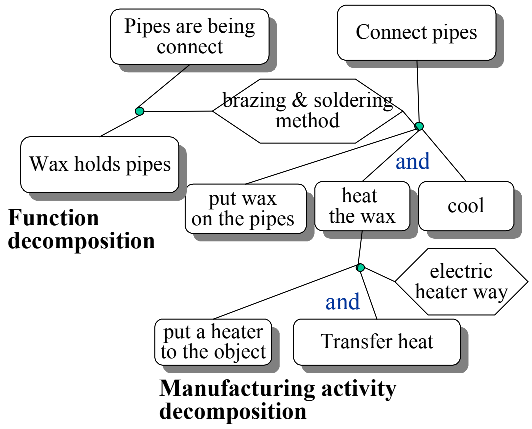

Figure 5b. Decomposition trees in the case of “brazing & soldering” way

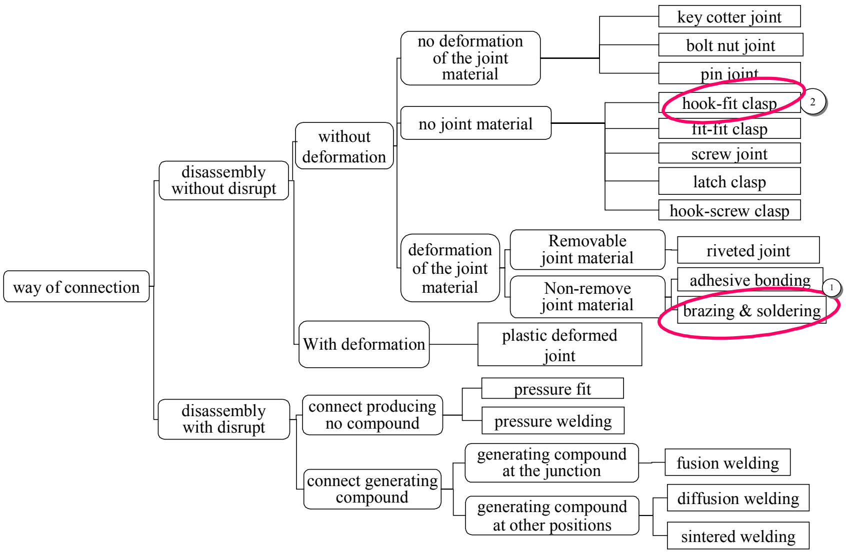

Figure 6. An attribute tree of ways of connection from the viewpoint of “disassembly”

disassembly (see Figure 2 for the functional decomposition in this case). The product designer would recognize the characteristics of “hook-fit clasp” in Figure 5a and thus add a sealant for water-tightness.

7. Related Work and Discussion

In a literature on design, many general “patterns” of synthesis are proposed (e.g., [Bradshaw and Young, 1991; Bhatta and Goel, 1997]). The major differences between our ways of achievement and them include explicit description of “way” and an ontology of functional concepts as follows.

Firstly, our general ways of functional achievement explicitly represent the feature of achievement such as theory and phenomena. They enable the system to facilitate the smooth interaction between models at the structural and functional levels. The designer can check the feasibility of functional decomposition using the features represented as the ways as behavioural constraint. The importance of such key concepts in design is pointed out in [Takeda *et al.*, 1990].

Furthermore, the description of the ways includes sub-functions (activities) and characteristics in both product and manufacturing. Thus, they enable us to integrate knowledge about functions in product and knowledge about manufacturing. Although the feature knowledge is also captured in [Malmqvist, 1997], it is concerned only with functional hierarchy of product.

Secondly, our functional knowledge is based on an ontology of functional concepts shown in Section 4. The conventional functional knowledge uses "vocabulary" representing functionality [Umeda *et al.*, 1990; Sembugamoorthy and Chandrasekaran, 1986]. Nevertheless, the meaning of such vocabulary is implicit. Then, the contents of such knowledge depend on the modeller and thus tend to be ad hoc. A rich and comprehensive set of functional concepts is needed. In [Hodges, 1992], the sets of "primitives of behavior" are proposed. Lind identifies a few general functions such as "storage of energy"[Lind, 1994]. We categorized functional concepts into three categories and organized in is-a and part-of hierarchy. In Value Engineering research, standard sets of verbs (i.e., functional concepts) for value analysis of artifacts are proposed [Tejima *et al.*, 1981]. It enables the human designers to share descriptions of functions of the target artifacts. However, they are designed only for humans, and there is no machine understandable definition of concepts.

8. Summary

The contribution of this research can be summarized as a framework of systematisation of design knowledge about functional decomposition, and an adaptive mechanism for concurrent design. We proposed "way" of achievement of functions as a key concept for systematization. The benefits of such functional knowledge in a concurrent design team were shown using a scenario.

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