THE USE OF FUNCTION, STRUCTURE AND BEHAVIOR IN DESIGN

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Abstract

This paper discusses the types of knowledge associated with design objects, examines some of the representational needs of each type, and considers how they might be used for analogical reasoning.

1. KNOWLEDGE TYPES

The purpose of design is to produce knowledge about a designed object which can then be used to manufacture that object. Obviously this knowledge is not produced from nothing, but is developed using some other, given knowledge. The knowledge associated with design objects is often classified into the following types:

- *Structural knowledge* -- knowledge about the components which comprise the object and their relations;
- *Behavioral knowledge* -- knowledge about the behavior of the object, i.e., about ways the device responds to changes in its environment and/or in its own state;
- *Teleological knowledge* -- knowledge about the purpose and the way the object is intended to be used;
- *Functional knowledge* -- knowledge about how the behavior of the object is used to accomplish its intended use.

It is important to note an essential difference between the nature of the first two and the last two types of knowledge. This difference results from the following:

> For a given object both structure and behavior are objective in the sense that the former is given by the physical existence of the object, while the latter can be (objectively) determined based on physical principles.
>
> On the other hand teleology and function of an object are subjective. The first one reflects the intention of a human (the designer or the user) in using the object. The second one (the functional knowledge) is an abstraction of the behavior by a human through recognition of the behavior in order to utilize it [Umeda & Tomiyama, 1993].

In design, the ultimate purpose is to produce sufficient structural knowledge about the design object to allow the manufacturing or construction of the object. The knowledge given about the object in the formulation of a design problem can be of any of the above mentioned types, or any combination of them. Due to this, design problems can be of various forms. Here we are only interested in design problems where functional knowledge plays an important role (note that in parametric design functional knowledge is not necessarily used).

2. A CLASS OF DESIGN PROBLEMS

In order to discuss the role of functional knowledge let us consider a simplified form of a class of design problems, where the design object is given only by its intended use (teleological knowledge). In this case the design process can consists of the following coarse steps:

1. Recognize the function which supports the intended use;
2. For this function apply the process P (given below) to produce some structural knowledge about the design object;
3. Detail the structural knowledge to a sufficient degree.

Process P (applied to a function):

P.1. If possible, choose (using design experience) an object for which the considered function is a simple abstraction of its behavior and produce, as a result, the structural knowledge about this object.

P.2. If such an object can not be found, then decompose the function into subfunctions and recursively apply the process to each of the subfunctions obtained. Compose the results produced to obtain the structural knowledge corresponding to the given function.

Obviously many very important aspects of the design process have been left out of this description, such as its iterative nature and other things, but we think that this simplified form can be used to deduce some requirements on the representation some of the various types of knowledge used during design. These will be based on the way these types of knowledge interact during the design process.

3. REPRESENTATION

Since the representation of structural knowledge is well-discussed in the literature we are not going to address this topic here.

For the representation of behavioral knowledge the (partial) state transition approach seems to be the most widely accepted [Bhatta et al, 1994] [Chandrasekaran et al, 1993] [Keuneke, 1991] [Sembugamoorthy & Chandrasekaran, 1986].

In arguing about the representation of function we shall consider various aspects:

1. We can only speak about the “function” of an object in connection with its use (“in using object O to accomplish goal G its function is F”). An object which is not used (or thought of as being used) has no function, as the function is a result of using or the intention of using the object. This observation remains valid for components of an object.

The conclusion of this first aspect is that a function must always be associated with a goal and, as such, the representation of function must in some way capture this aspect.

2. According to our current view of the function of an object it is strongly connected to its behavior -- in fact we consider that function is an abstraction of the behavior. This strong relation between function and behavior can be, and actually is, extensively used in the design process. For example, it helps in the retrieving (by some kind of mapping) of a behavior of some existing design which can provide a required function. Note that this is not necessarily the same function the object provided in the previous design case.

The requirement which results from this aspect is that the representation of function must be such that it supports the association between functions and behaviors. The most direct way to do this is to derive the representation of function from the representation of behavior. Since we are considering the (partial) state transition representation for behavior, this would mean representing function in a similar way, disregarding some "behavioral" aspects not important from a functional point of view.

One of the most important trends in representing knowledge about design objects is the SBF (Structure-Behavior-Function) model, as used, for example, by Chandrasekaran, Gero, Goel, and Maher. Although their models are slightly different, the main idea behind them is the same: the three types of knowledge must be all considered in close interaction. This is especially true in order to be able to use experiential design knowledge.

In our opinion, a flaw in this idea is the strong linking of functional knowledge to the structure/behavior one: a function can be provided by more than one structure/behavior, and the behavior (of some structure) can provide more than one function (abstracted in different ways). This suggests that the relation between structure/behavior and function should be an indexing one (or some other mapping) rather than a strong association.

Although the topic of teleological knowledge is addressed in many papers its representation is either omitted or discussed implicitly in the context of functional representation. The intended use of an object is either formulated using a name associated to it (e.g., to sit on) or by describing the function it should provide when the object is being put to its intended use. Thus the representation of teleological knowledge should be able to capture both of these possibilities, i.e., it should provide a dictionary of usage names (which associate functions to a name) and a way to describe functions (possibly in an incomplete way). The latter can either be the same as the representation of functions or some other form of representation which makes indexing into the set of (known) functions easy. It will also be useful to represent key structural or behavioral aspects of the environment in which the intended use is supposed to take place.

4. RESEARCH PLANS

Our plans with respect to the above mentioned types of knowledge and their representation is twofold. First, to explore the various kinds of interaction between them during the design process. The most important ways they interact are the different kinds of indexing (mapping) across knowledge types and the way this directs the exploration of the design space. Second, we are interested in the possibilities of using these types of knowledge in a creative way and/or to produce creative design objects.

As stated earlier, the goal of the design process is, given some knowledge (structural, behavioral, functional, teleological), to produce a full structural description of the design object. In this process the given knowledge is combined with some design experience (knowledge about previously designed objects). A great part of this process consists of moving back and forth between various types of knowledge. This can be accomplished based on various types of associations, ranging from simple, dictionary-type indexing, through CBR, to Analogy.

Our general research goal is to explore what kinds of associations are possible and reasonable between the different types of knowledge already discussed, and to explore their use in design problem-solving. Since the second plan stated above is to study creative design, it is clear that we will need to study Analogy. Analogy has already been identified as a very important tool in this area (for example, see [Quian & Gero, 1992] and [Zhao & Maher, 1992]).

In what follows we briefly discuss the possibilities of using Analogy in association with the different types of knowledge.

5. ANALOGY BETWEEN THE SAME TYPE OF KNOWLEDGE

This is the most common and widely used type of analogy. The structure-to-structure case is rather well studied and applied in practice. Although behavior-to-behavior and function-to-function are not that extensively used, the following considerations should make it clear that the same or similar techniques can be used as in the structure-to-structure case.

Let us first consider the case of behavior-to-behavior analogy. Since we consider behavior to be a (partial) state transition process, by constraining it to a finite number of states it can be represented by a directed graph with the states as nodes and state-transitions as arcs. Analogy can then be made on this kind of graph in a way similar to the structure-to-structure case. This would include any of the normal use of knowledge-based or heuristic reasoning to help reduce the complexity of the graph matching process.

Since we have defined function as an abstraction of behavior, the possibility of function-to-function analogy can clearly be derived from the previous case.

Teleology-to-teleology analogy can be thought of as analogy between functions if teleological knowledge is given by function description. In the case of using names to denote teleological knowledge the only way to think of analogy would be by syntactic/semantic analogy. This needs to be considered in more detail. The use of this type of analogy would be when trying to borrow characteristics of objects with similar intended use, without initial consideration of function.

6. ANALOGY BETWEEN DIFFERENT TYPES OF KNOWLEDGE

Since structural knowledge is different in nature from the others, in the sense that the others refer to processes, a "direct" analogy between structural knowledge and any of the other three types of knowledge is not possible. However, both (dictionary-like) indexing and CBR can be applied to make associations between them.

On the other hand the strong link between behavioral, functional and teleological knowledge make the use of across-type analogy possible, and similar to behavior-to-behavior analogy.

Let us give two general examples to illustrate such analogies:

> 1. function-to-behavior: the goal of using analogy in this case is, given a function, to find a behavior which can be abstracted such that the function can be mapped on this abstraction. This can be useful when searching for a previous design which could provide a given function.
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> 2. behavior-to-function: here the given behavior must be abstracted such that it can be mapped on a function. The situation when such an analogy could be used is when trying to find new functions for a given, previous design.

In the case when teleological knowledge is given by function description, analogy can be used as well, although this requires a lot more investigation.

7. CONCLUSION

All the above-mentioned types of analogy can be used to select various previous design cases for use in trying to build a solution to the given design problem. The ideas presented here still require a lot more exploration and development, but we feel that they are very promising and will lead in a variety of rewarding research directions.

8. REFERENCES

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