A Preliminary Formalization of Knowledge for Synthesis

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1. Introduction

In this paper, we investigate how synthesis process should be and propose a preliminary result of logical formalization of synthesis process.

Since we often mention analysis and synthesis together, we tend to assume that synthesis process have somewhat similar nature that analysis process has. But it is not good assumption because aims of synthesis and analysis are quite different. They are different in their aims so that knowledge for them should have different characteristics.

The aim of analysis is to clarify characteristics of objects. Clarifying objects is to explain different objects in the same manner. In order to apply different objects as much as possible, characteristics should be universal and minimum It implies that requirement for knowledge for analysis is also universal and minimum.

On the other hand, the aim of synthesis is to create objects having necessary characteristics. In this case, characteristics is not required as universal and minimum characteristics, rather it should *not* be. In order to capture human desire for objects, characteristics should be as rich as possible. Then requirement for knowledge for synthesis is not universal and minimum rather individual and various.

The last statement indicates that attitude of the traditional logical approach is not appropriate because it tries to capture our world with minimum and universal axioms. We are not going to deny logical approach, but we emphasize that we need new ways to satisfy the above requirements. We have already propose how synthesis can be captured in a logical framework[1]. It is still based on logical theory, but we introduce multiple theories in a logical framework. The heart of our formalization is that synthesis is not applying logical theories but to extend and compose logical theories enough to represent human desire to create new artifacts. In this paper, we extend our formalization to be able to explain dynamic nature of synthesis, i.e., synthesis process.

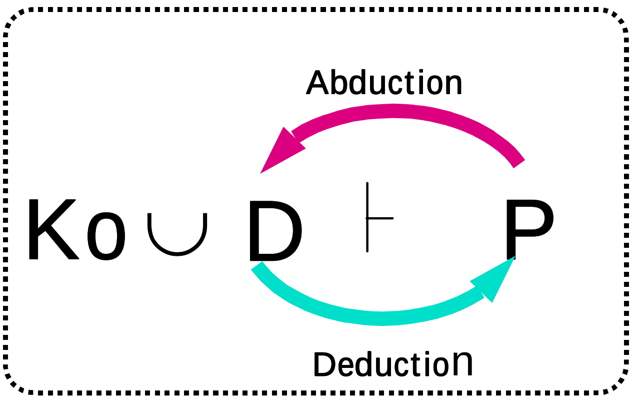
2. The three features of designing artifacts

In the previous section, we mentioned that synthesis is related to represent our desire to create new artifact. Then what is necessary to create "new" artifacts? What conditions are required to agree that "it is new"?

We propose three features to ensure "newness" for artifacts. One is *physicality*, which is ensure artifacts to exist in the world. It is no matter necessary for all existing artifacts that are not new. But it is better for designers to understand physicality because they can use relations between physical characteristics to realize their intention. Knowledge for synthesis should include knowledge for analysis in this sense. But it is not all about knowledge for synthesis. Knowledge for analysis tends to be minimum and universal, while knowledge for synthesis needs much variety to represent requirements for artifacts. It is the key issue for synthesis to provide not minimum but enough knowledge for given requirement.

The second feature is *unlikeness*, which means that there are no other artifacts. There are two problems in unlikeness. The first one is which set of artifacts we should take into consideration to assure unlikeness. Should we compare designing artifacts with all artifacts in the world? What we can do at most is to collect artifacts that we have design or encounter or learn. We say such artifacts as design experience. Anyway it is important to define a set of artifacts to compare. The second problem is how to compare designing artifacts with others. It is difficult to compare the designing artifacts with some design experience because every design experience is so different in which situation we encountered it that representation can be different from designing artifacts. It is the problem about ontological integration.

The third feature is *desireness*. Even if physicality ensures that the designing artifact can exist on our world and unlikeness ensures that it has no similar artifacts, it is not enough reason to realize it in our world. For example, there are no reason to create an artifact which is much more complicated to an existing artifact which has the same functions. We need criteria to ensure that is has reason to create a new artifacts. It is very difficult feature because many reasons come from society and they are implicit requirements. We can point out an example for it, i.e., "minimally". To make something minimize is a good reason to create a new artifacts. To make user operations minimize is a good reason to design a new consumer product.



Ds: Design Solution
P: Properties and Behavior of Design Solution
Ko: Knowledge on Objects

Fig. 1: A Logical Framework of design process

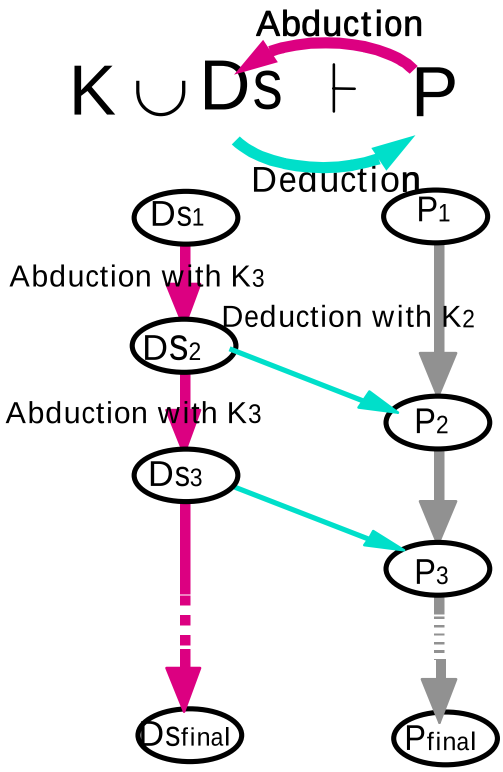


Fig 2: Iteration of abduction and deduction

3. Requirement for formalization of synthesis process

In this section, we verify our formalization of design process[2][3] in the light of the above three features of synthesis process.

The primary formula in our formalization is the following one(see Figure 1).

$Ds \cup Ko \models P$

Here Ds is a set of logical formula that represents description of design objects. P is a set of logical formula that represents description of properties of design objects. Ko is a logical formula that represents knowledge on object. This formula means that description of design objects and knowledge on object imply description of properties of design objects. To keep this formula is to keep physicality condition.

Ideal design process is defined as process inferring from knowledge on object and part of properties of design objects as design requirement to description of design objects. It is not deduction process but abduction process[4]. Furthermore design requirements and available design knowledge cannot be determined in advance but be defined during design in real design process. So real design process is defined as process repeating abduction and deduction (see Figure 2). Description of properties of design object inferred by deduction from description of design objects and knowledge can help further decision of design requirements. Description of design objects inferred by abduction from description of properties of design objects and knowledge can suggest what kind of knowledge is needed to infer more.

This formalization can explain design process in a computational way and also match actual design processes[5]. But the formalization has three unsolved issues. One is evaluation of design solutions. Abduction process can theoretically infer many solutions without any order[1]. We need some scheme to compare them. This problem corresponds to desireness condition. Other problem is how to provide knowledge. We assume that knowledge is provided a priori The other problem that is more fundamental one is how to provide representation of description of design object, properties of design objects, and knowledge. The second and third problems correspond to unlikeness condition, i.e., what ontology and knowledge we should take into consideration.

4. The first attempt to formalize synthesis process

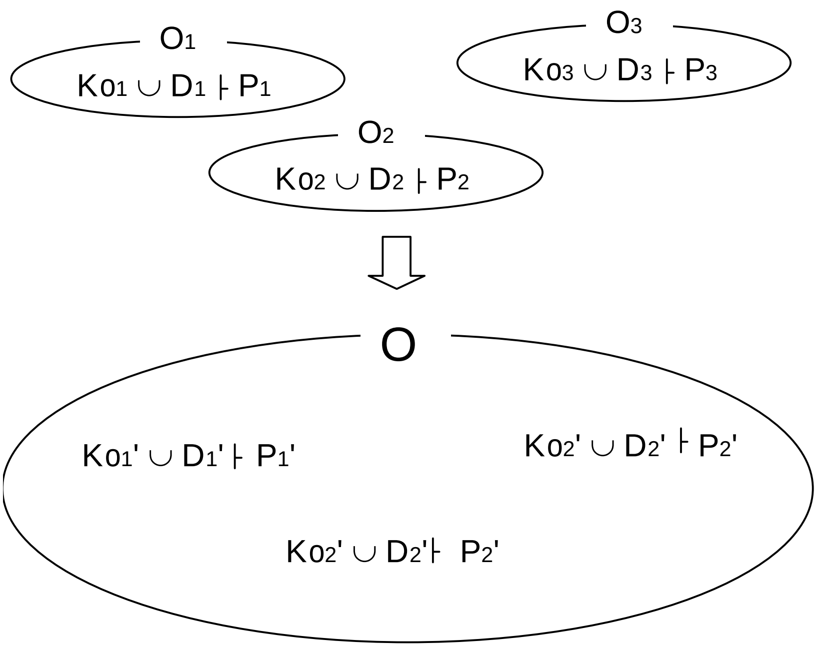
We model synthesis process as intended integration process of design experiences. The basic idea is that designers evolve their designing artifacts by using their design experiences as ontology and knowledge for the designing artifacts. We extend our formalization of design process to capture this process. It consist of three sub processes as follows (see Figure 3):

(1) Collecting of design experiences
(2) Forming a model to represent a set of design experiences
(3) Minimizing an element that we want to make it new.

(1) Collecting of design experiences

The first issue is how to represent design experiences. What we consider artifacts during design process means not only to remember an artifacts itself, e.g., to enumerate its attributes, but to remember or imagine what purpose it has and why it comes to have such attributes. In other word, we can imagine its design process. So we model design experience as a quartet of Ds, Ko, P, and O, i.e., design object, knowledge on objects, properties of design object, and ontology to represent three formulae. We represent a set of design experiences as

[1] Some logical methods of evaluation of abduction have been proposed. For example, to minimize propositoins in hypothesis (solution) or links from hypothesis to observation[6]. But there are no reason why we should do such a way.



$(Ko_1 \cup Ko_2 \cup \ldots \cup Ko_n) \cup Ds? \vdash P?$

Figure 3: Integration of Design Experiences

$de_1=(Ds_1, Ko_1, P_1, O_1)$, … $de_n=(Ds_n, Ko_n, P_n, O_n)$

$Ds_k \cup Ko_k \models P_k$, $Ds_k \in O_k$、$Ko_k \in O_k$、$P_k \in O_k$ $(1 \leqq k \leqq n)$

(2) Forming a model to represent a set of design experiences

Although we can collect a set of design experiences, there are based on different ontologies so that we should integrate design experiences.

It is to find a subsitition of predicates from all O_1, O_2, $\cdots O_n$ to a single ontology.

$O= O_1\phi \cup O_2\phi \cup \ldots \cup O_n\phi$,

$de_1'= (Ds_1', Ko_1', P_1', O_1')=de_1\phi=(Ds_1\phi, Ko_1\phi, P_1\phi, O_1\phi)$、

…

$de_n'= (Ds_n', Ko_n', P_n', O_n')=de_n\phi=(Ds_n\phi, Ko_n\phi, P_n\phi, O_n\phi)$

$Ko' = Ko_1\phi \cup \ldots \cup Ko_n\phi$

The new ontology O is a base to represent a new solution.

(3) Minimizing an element that we want to make it new.

For example, to find a simplest solution is to minimize Ds, i.e., to find Ds where $|Ds|<|Ds_k'|$ $(1 \leqq k \leqq n)$. To find minimum knowledge means to find O where Ko' is smallest.

5. Conclusion

We show the first step of logical formalization of synthesis process. It is a new approach to formalize synthesis process in a logical framework because it can explain how we can obtain knowledge which is often missing point when discussing logical framworks. But there are many unsolved problems, i.g., we could not show how to achieve desireness. We are planning how this formalization can work in actual design processes by testing it in protocol analysis.

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