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Proposal of an object-oriented model of the physical contradiction to facilitate the problem-framing phase in design

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Executive Summary

In this article, we present our study on the building of an object-oriented model to represent the physical contradiction. This model is based on the specification of objects, which are the basic elements of representation, rules linking the objects and heuristics guiding the instantiation of the model.
We will first discuss the interest of TRIZ as a problem-solving-centered method, and then establish the way expert systems are traditionally built in Artificial Intelligence. The way we propose our model is based on a tool that structure the knowledge base in expert systems.

Introduction

The design of new technical systems is a key stake of enterprises facing a market more and more complex and competitive. To increase the efficiency of the development of new products several methods exist. These methods have been largely and successfully diffused but there still remain a critical point, the step of conceptual solutions proposal during inventive design. To increase the efficiency of this step we develop a model of representation of the problems to be solved and heuristics to collect the data to fill in the model. We will present in this article the conceptual design viewed through the angle of problems resolution. Then we will present the way Artificial Intelligence tackles with problem-solving. In a last point, we present the model we propose to represent the problems during design of technical systems. We will also explain the methods of capitalisation of information to instantiate the model we developed as heuristics and illustrate their use by an example.

I. TRIZ, a design process based on problem-framing

a. Focusing on problem-solving, the TRIZ originality

The traditional approaches of the design have shown their limits in industrial environment **/Lit1/**. Prescriptive methods as the value analysis or the systematic approach are not used on the top level of their potential. The difficulty of their implementation is linked to the fact that they are provided to be generic. The objective of these methods is to propose good practices of design for every kind of design, so the taking into account of specificities and of the procedures of each designer cannot correspond to such an approach.

The systematic method defined by Pahl & Beitz **/Lit2/** describes the design process through a list of actions that have to be carried o ut, and for which are identified inputs and outputs. The main benefit of this approach is the proposal of a methodological and structured step **/Lit3/**. One of the paradigms of the Pahl & Beitz description of the process design is to consider this process as a succession of problem-solving activities. But what is missing is a good formalization of the way to capitalize the data of the problem. As Simon presents it in **/Lit4/**, problem-solving and problem-framing are two parallel processes not distinguishable. Thus problem-framing has to enable the integration of knowledge during the whole problem-solving process.

In **/Lit5/** Suh describes the evolution of the problem-framing by the transition through four domains (see **figure 1**):

- the customer domain is characterized by the needs the customer want to be satisfied. The Customer Attributes, {CA} are expressed here;
- the functional domain, in which the CAs are translated into the functions, {FR} the future system will have to perform;
- the physical domain provides the identifiaction of the physical design parameters, {DP} enabling the performing of the functions;
- in the process domain, the process variables, {PV}, are expressed to specify the variables realizing the physical parameters.

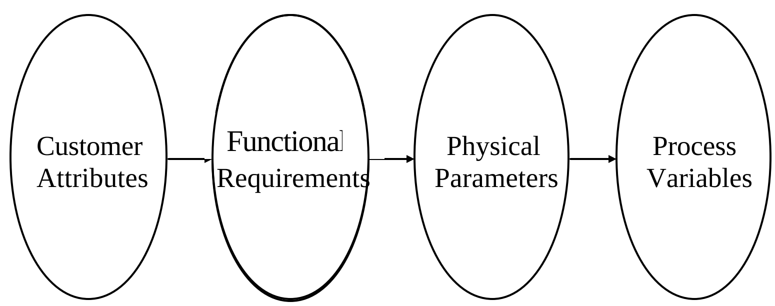

Figure 1. The design process as a way through four domains

In this description, each transition between two domains aims at making the problem-framing more precise. This generic description brings the foundations for a theory of design. Moreover, Suh has formalized axioms to qualify the concept solutions for design and to increase their viability and productivity. But the bridge between functional and physical domains is a non-aided step, for which tools has to be built to facilitate it **/Lit6/**.

Altshuller understood this gap and built TRIZ to bring such tools and to give keys to approach the design process through the angle of problem-solving **/Lit7/**. Problem-framing is one of the main step of the management of the design process with TRIZ. One of the major interests of this theory is to p ropose methods to guide the formulation of the contradiction. The main idea of these methods is the identification in the problematic situations of what are the specific

conditions of the problems in opposition to the objective laws that are limiting this problem. Each problem is seen as an opposition between a situation which one wishes to modify, this wish being specific to each one, they are the specific conditions of the problem: "the situation exists but does not satisfy me". On the other hand there are limitations that prevent us from making this situation evolve, these blocking aspects are the objective laws, which act on the problem.
The formulation of a problem is thus seen as a precise clarification of what one wishes to modify in the existing situation and of what prevents us from carrying out this evolution. The interest of this theory appears obvious to us from this focus on the problem and the methods that are proposed to guide the formulation of the problem. However, the experience show the difficulty of use of the methods, which require a sufficient level of expertise in order to apprehend the whole concepts used in the theory. The reduction of this difficulty implementation is the purpose of our study. To succeed we want to build a robust model of those concepts, by the use of the tools existing for expert systems.

b. ARIZ, a method of problem-formulation in TRIZ

In TRIZ, design of new system is based on a problem-solving process. Methods for problem-framing are inherent to the theory, and the basic mean to solve problems is analogy reasoning. To be able to solve problems by the use of analogies, it is required to have models to represent the problems, in order to classify them and compare them to generic solutions. In TRIZ two main models are proposed, the physical contradiction one and the Vepole one.
The main reformulation and resolution method of the theory is ARIZ **/Lit8/**. It tackles the resolution of “mini-problems”, as problems strongly constrained because they have to be solved with the minimum of modifications to the system. ARIZ is a heuristic method which interest is to identify systematically:

- the state we aim to reach, based on the ideality definition;
- the reason for which the goal is needed, to validate the well-founded of the mini-problem;
- the objective law disabling the reaching of the goal;
- the reason why we can not eliminate the obstacle, thus the characteristics of the future product.

ARIZ integrates the whole tools of the theory, enabling formulation and resolution of problems at different levels of abstraction. Thus ARIZ leads to the construction of the physical contradiction model and of the Vepole one, facilitating the use of the principles of physical contradiction elimination and of standards. *(Editor’s note: “Vepole” is usually called the Substance-Field or Su-Field model in English.)* The common goal of these tools is to resort abstraction to establish analogies with successful solutions in problems similar with the considered one.
ARIZ is then a complete and powerful method, as it integrates the whole concepts of TRIZ. But it is also a difficult method to implement, due to the high-level of expertise it required. The competencies to acquire, in order to apply ARIZ efficiently, are specific to the TRIZ approach. These competencies have been defined by Khomenko in **/Lit9/**. To make ARIZ more “user-friendly”, to reduce the required level of expertise, the increase of the level of formalization is a necessity. Our purpose is to build a clear, and explicit one, representation of the concepts inherent to the theory. This study, besides assuming the efficiency of TRIZ in terms of usability and pedagogical transfer, could be the foundations for an ontology of problem-solving in design.

II. Approaches of problem-solving in Artificial Intelligence

There exist a scientific domain in which problem-solving processes have been studied for long, Artificial Intelligence. Problem-solving process is based on various competences **/Lit10/**:

comprehension of the problem, i.e. building of a representation of the goals to achieve, constrains and available resources analysis, elaboration of strategies and actions planning, execution and follow up of planned actions and, at least, judgement of the achieved process. The whole of qualities required to achieve problem-solving process make it one of the most intellectual human activities, and thus a preferential subject of application for Artificial Intelligence.

When a mathematician has to solve a problem, he resorts to data, axioms and theorems, but there is no available procedure formalizing the steps to perform to reach the goal. The building of a tool to facilitate problem-framing, and then problem-solving, begins by the formalization of such a procedure. For Caplat (**/Lit10/**), this construction is the identification and representation of nominal object of reasoning. A lots of study, with various approaches, aim at understanding reasoning. The proposed approaches vary from low-level of formalization, as the psychology of thinking (**/Lit11/**), or the cognitive psychology (**/Lit12/**), to high-level of formalization in expert systems.

Which is the knowledge to be capitalized? Anderson et al., **/Lit13/**, identify four typologies of knowledge:

- factual knowledge, basic knowledge elements to be familiar with a domain and to be able to solve problems in this domain;
- the conceptual knowledge gives the structure of the factual ones by inter-related them. Categories, principles or models are conceptual knowledge;
- procedural knowledge is method and know-how, but it also is criteria of use of methods, algorithms and techniques;
- the meta-cognitive knowledge is generic knowledge about cognition. For example, the consciousness of know-how use strategies is a meta-cognitive knowledge.

The usual building of an expert system in Artificial Intelligence is based on identifying and structuring the knowledge. In the linguistic approach, this knowledge is acquired from texts reporting case studies in which are identified and formalized the generic concepts. Our study is then specific, in the terms that we aim to make the identification of concepts on texts in which concepts are already generalized. The texts we chose to work on are those of ARIZ and of the standard solutions, as the text of the standards is the most complete one in terms of representation of problems. The standards are 76 specific solutions for 76 specific problems, then they include the elements to differentiate 76 specific situations, for this point we consider them as a complete model to represent problems.

We represent the knowledge through a characterization based on three typologies, which is linked to the object tool of expert system building, Jess (**/Lit14/**):

- template, this is the object definition, including several fields, called slots, of characterization and the inheritance between objects;
- heuristics, or functions and queries, enable the instantiation of the templates, thus creating facts;
- rules, they can take actions based on the content of one or more facts.

We will now discuss the necessity of such a formalized model and present the one we propose for the representation of physical contradictions.

III. Proposal of an ontology of problem-framing

a. The need for a model

The approach of the design is done through the processes governing the act of resolution of problems. This approach raises the question of what is really a problem of design, which are the characteristics of such a problem and which are the parameters allowing its resolution. This description can be based on the previously quoted engineering methods that draw up an exhaustive list of the parameters to be taken into account. Contradiction has an acknowledged dialectical interest and can be a interesting way of clarification of the problems. Contradiction is the representation in an explicit shape of the problematic situation, it is a clear model of what one has to solve **/Lit12/**.

To make a system evolve it is necessary to begin by modelling it, it is exactly the same for a problematic situation. In order to understand what the model of the problematic situation must include **/Lit15/**, it is essential to define the objective of this model:

"The model representing a problematic situation must enable the identification of the parameter for which an evolution modifies the given situation by carrying out the expected objectives"

From this definition, we have to precise several points. First of all the concept of objectives, we hear here not only the aim set by the modification but also the non-degradation of the existing situation. No any improvement could b e useful if in addition the system is elsewhere degraded. It is a strong choice which we made in regards of the concept of increasing the ideality as it is defined in TRIZ **/Lit16/**.

Then we affirm that any problem can be reduced to the modification of one of the parameters of the system, this can be confusing and requires that we explain our point of view. This assertion is checked easily for simple problems but for complex ones, implying a significant number of components, a problematic situation will emphasize a whole of problems to be solved, which we call a network of problems, because these problems cannot will be inter-dependent. For each one of these problems it is then possible to build the description according to one parameter of the system that h as to be changed. The evolution of the initial situation will pass then by the resolution of whole or part of this network of problems.

b. Templates and rules to propose a robust model

The model we use to define the physical contradiction is the following one:

```
(deftemplate physical-contradiction extends problem
        (slot parameter)
        (slot value1
                (type INTEGER))
        (slot time1)
        (slot space1)
        (slot function1)
        (slot value2
                (type INTEGER))
        (slot time2)
        (slot space2)
        (slot function2))
```

This template is the object-oriented representation of the equation (1):

(1) $sp = p(v1,t1,l1).f1 + p(v2,t2,l2).f2$

where:

- sp: partial solution
- p: parameter
- vi: value of the side i of the contradiction
- ti: time of the side i of the contradiction
- li: spatial zone of the side i of the contradiction
- fi: function of the side f of the contradiction

The meaning of this equation is that a partial solution is the answer for at least one of the side of the contradiction. To be a partial solution it has to perform the function by the parameter with a certain value during the needed time and at the needed place.
This representation implies a precise specification of what the function is. We define the concept of function as the modification of the value of a parameter of an element. The modified element is the product and there exist a system that makes this modification. The definition of the function is the following one:

```
(deftemplate function
        (slot product)
        (slot parameter)
        (slot InitialValue
                (type INTEGER))
        (slot FinalValue
                (type INTEGER))
        (slot system))
```

As the fields, slots, created in the models are not independent; it is necessary to define rules acting on them, to assume the good relationships between them. For example the slot parameter defined if the template function has to be one parameter of the product. The following rule makes this link, by disabling the assertion of a false contradiction:

```
(defrule parameter
        (function (parameter ?functionparameter))
        (product (parameter ?productparameter&~?functionparameter))
        ?x <- (physical-contradiction (parameter ?functionparameter))
        =>
        (retract ?x))
```

This kind of rule is assuming the robustness of the model. Another kind of rule enables the linkage between elements under certain conditions. For example, in the definition of the Vepole model, a rule assert a Vepole model as a complete one only if the Vepole consists, at least, of a field and two substances.
The templates and the rules are way to build a robust, as well-formalized, mode of representation of the problems. But the can not assume themselves a good instantiation of the model. To guide the instantiation we propose heuristics that help the user to well understand the built model.

c. Heuristics to instantiate the model

In order to collect the information to instantiate the model we built heuristics enabling to guide the capitalization in the way we defined the concepts. If we propose the model without these heuristics the goal of the model could seem fuzzy. Giving the previous definitions and asking to collect the information to instantiate the model is not an efficient way. It is necessary to propose a method of capitalization to make the links between the different concepts clear and understandable.
We present here one of the heuristics of construction of the model of problem in order to illustrate our matter. We will take one general heuristic that enables the identification of the contradiction. The problem we consider is the one of hand welding machine. The problematic situation is the following one: it is desired to decrease the heat of the handle when the user is welding.

1. Question: "Describe the function for which the system was conceived."
   Answer: To weld two parts by addition of material.

Model: f1 = to weld two parts by addition of material

2. Q.: "List briefly the components of this system."
   A.: Point, handle, resistance, connector, cable
   M.: sp = point + handle + resistance + connector + cable
3. Q.: "Briefly give a list of the various resources of this system."
   A.: Air, lead, part 1, part 2, user
   M.: sp = sp + air + lead + part 1+ part 2+ user
4. Q.: "What is the effect which occurs and you would like to eliminate?"
   A.: The overheat of the handle
   M.: f2 = the overheat of the handle
5. Q.: "We will call this effect the Harmful Effect."
6. Q.: "What is the effect that must be preserved during the resolution of the problem?"
   A.: The precision of the welding
   M.: f1 = the precision of the welding
7. Q.: "We will call this effect the Positive Effect."
8. Q.: "We will now determine the parameter of influence."
9. Q.: "What is the parameter of the system for which a variation makes it possible to reduce the Harmful Effect?"
   A.: The length of handle
   M.: p = the length of handle
10. Q.: "What is the state of this parameter for which the Harmful Effect is present?"
    A.: Short
    M.: v1 = short
11. Q.: "If # The length of handle # is # Short # then there are # The overheat of the handle # but # The precision of the welding # is preserve, is it exact?"
    A.: Yes
12. Q.: "If # The length of handle # is contrary to # Short # then # The overheat of the handle # disappear, but # The precision of the welding # remains, is it exact? "
    A.: Yes

The modelled problem is then:
(air + lead + part 1+ part 2+ user + point + handle + resistance + connector + cable) = length of handle(short).precision of welding + length of handle(long).overheat of handle

Then the partial solutions have to be tested as elements to solve the problem. The first partial solutions we proposed are the elements already available in the system, as they do not increase the complexity or cost of the system.
This contradiction has been solved by the use of one of the fundamental resources: the air. To avoid overheat we need a good thermal isolation, and air provide it. The handle has then been modified in order to have a long length to provide a good thermal isolation but a short distance to assume precision (as shown on **figure 2**).
This is a quite simple example, which is similar to simple problems whose initial problematic situation is relatively clear, otherwise it is necessary to capitalize the various elements in a progressive and iterative way. We provide phases of validation of the capitalized elements to check the reliability of the built model. These phases enable the user to stop the way he is formulating the problem, and bring him a better comprehension of the problem, and of the way the problem is modelled.
Our purpose is to be sure that the process is well performed. The heuristics are built as questionnaires; it enables a quick collect of the information. It is one of the benefits of the use of heuristics, to increase efficiency and time of execution of the capitalisation ofthe data.

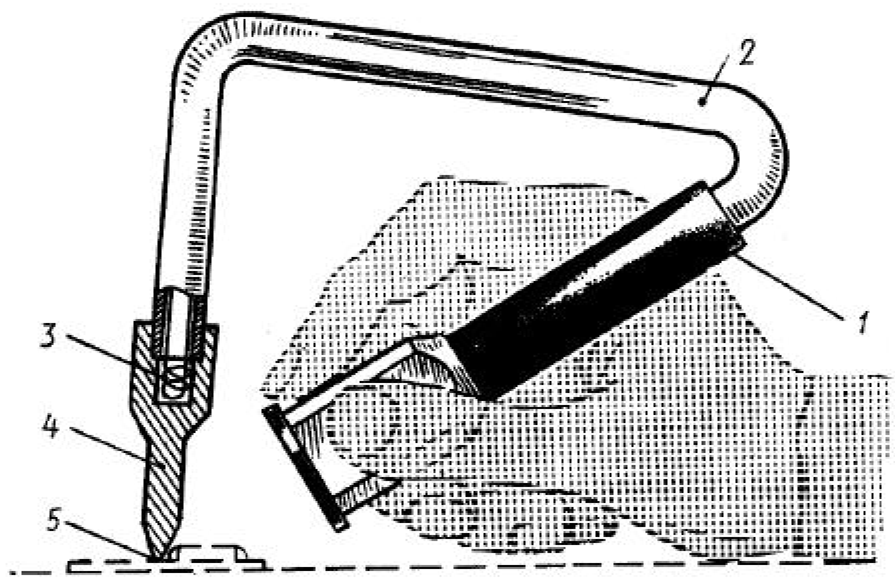

Figure 2. Use of air as thermal isolation

The last point we wanted to develop by the construction of the heuristics is to propose a pedagogical tool. The use of the heuristics, by giving the opportunity to formalize the process of problem formulation used by the designer, enables a good capitalization of experience and a feedback of what has been useful or what was source of errors.

Conclusion

The model we built aim at making the use of TRIZ, and in particular the principles of resolution of the physical contradiction and the standard solutions, more intuitive. Our two main goals are to provide a tool enabling non-expert users to access these powerful problem-solving tools, and to build it as a pedagogical one.
We bring the foundation of an ontology of problem solving in design by increasing the level of formalization of the TRIZ theory. Moreover this formalization enables a clear linkage between the different models of problem-framing, the physical contradiction and the Vepole ones. This link already existed in ARIZ but, as it was not formalized, it seemed not to exist and was not clear for non-experts. The objective is now to increase the interface of the expert system tool and to provide it as a tool that can be use for anyone dealing with design, whatever the used method is.

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