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A Design Support System Using Analogy Based Reasoning

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Abstract:
This paper represents a procedure to support the designer in his/her process of mechanical system design, by inspiring the knowledge acquired from previous projects. To this end, the proposed method represents an appropriate means to capitalize the know-how of the professional experts.
Based on this approach, an interactive programme is implemented, which assist designers in the specification of new products. The data structure of the implemented tool is based on the object oriented modelling. This structure allows several classifications of a same design, using different levels of abstraction. This approach enables designer to begin with a more general description of the product, and to refine the description by referring to similar data in the pattern bases.

Key-Words: Analogy, Mechanical Design, Case, Pattern

1 Introduction
In an industrial context, designers frequently meet the same kinds of problems during the earlier projects they carry out. It means the possibility of reutilization of the solutions already tested [1].
In this sense, the techniques of artificial intelligence, which are based on knowledge memorization, are very useful to assist the designers. The principal approach of these techniques consists of acquisition, memorization and reutilization of the knowledge applied in similar experiences.
According to the abstraction level of the knowledge processed in decision making, there are two categories of knowledge based systems:

- **The Model Based Reasoning Systems**: in which the generalized knowledge extracted from the previous experiences are formalized in a model of knowledge, favourable to resolve a regular new problem of

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design. Among the methods introduced in the literature, ARCHIX [2], DAS [1] can be referred to.

- **The Case Based Reasoning Systems**: in which there are the private specifications of the former experience that applied to resolve a familiar new problem of design. Among the methods introduced in the literature CASECAD [3], DSSUA [4], IDEAL [5] can be referred to.

In the first category the capacity of the system to solve a new problem is limited to whatever is predicted in its knowledge model. As the knowledge become more complex its modelling becomes more and more difficult. In such cases, it is very complicated to develop the knowledge-based system. However, once the knowledge model is implemented, it is easy to be used.

In the second category, designers are in charge of searching for the nearest familiar problem to the current one and adapting its solution to the new requirements. To do so, the designers have to be satisfactorily experimented in the design area. However, the system aided design disposes the appropriate mechanisms to handling the knowledge. From this point of view, the knowledge system operates like a supervisor in the problem solving process. Consequently, the capacity of system to resolve a new problem improves from one experience to another.

The knowledge based approach which is presented in this paper helps designer to formulate the eventual specifications of the new product based on the initial requirements of design [6]. The application of this method is recommended in any stage of a product design developing from its conceptual design to its manufacturing process design.

According to the proposed method, a generic pattern of products, which integrates the common knowledge describing the product in general term, will assist the designer to formulate the outline of a new design. Once the product class is identified, a database which includes the individuals' specifications of the previously designed products of the same class, provide the appropriate values to complete the new design. In other term, the presented approach for processing the knowledge is an extension of the case-based method in which a framework of generic knowledge is used to classify the familiar experiences. In this sense, it is an articulation of model based and analogy based methods.

According the suggested algorithm an interactive computer tools called ABRAD (Analogy Based Reasoning Aided Design) is implemented. The discussion is exemplified by the design of a simplified prototype of an engine whenever required.

2 The descriptive knowledge of a product

It has commonly been recognized that it is possible to articulate a description of both existing and putative designs using a function- behavior- structure (FBS) framework [4]. This framework provides a satisfactory basis for developing the knowledge base systems aided design process.

The main objective of a product design is to achieve certain functions. These functions have to satisfy the requirements of whoever interacts with the product during its life time: producer, user, maintainer, etc. On the other hand, the functional description of a product reflects the different view points over the product's specification [7].

The behaviour of a product, individually or influenced by its environment effects represents the product competence to accomplish its functions. Consequently, the behavioral description of a product refers to its putative capacities and limitations.
The product structure, reveal its physical aptitude to achieve its behaviors. As a result, the structural description of a product includes the whole information necessary to realize the product.
Regarding the level of abstraction used to specify a product, ABRAD distinguishes between the information, which identify a class of products, and that which refers to an individual product. The first one, memorized in a specific Meta-data base named Pattern Bases, is used to develop the data structure of other databases envisaged in the ABRAD system, such as Case Bases and Project Bases. The individual information, memorized in Case Bases and Project Bases, can be consulted to argue the specification of a new product.

3 The Procedure of design in ABRAD

The principal steps of a design process in ABRAD are as:

- **Specifying the design problem**: the initial requirements of new design project are re-formulated in the familiar ABRAD context format.
- **Modelling an appropriate technical solution**: once the initial requirements are determined, ABRAD searches an appropriate pattern of products to achieve the requests. The descriptive arguments of the given pattern, improve the outline of the new product.
- **Concretizing the adopted technical solution**: regarding the initial requirements of the project, the designer specifies certain attributes predicted in the adopted product pattern. Referring to this product initial description, ABRAD searches the most similar product to the new one. Inspiring from what is documented about this familiar product, the designer can accomplish the new project. This information is used to accomplish the technical specification of the new product as well as the product manufacturing process design.

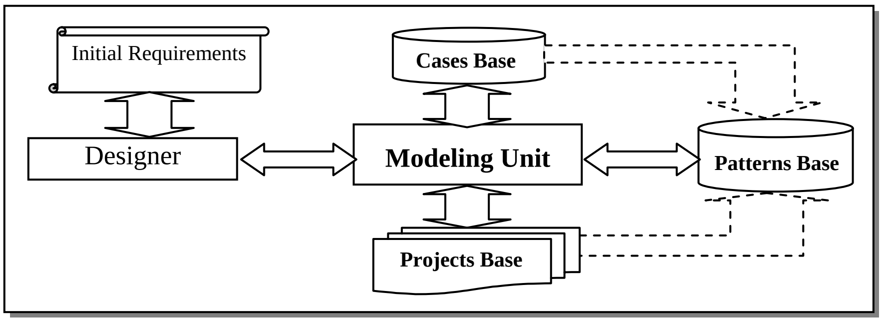
If any of the above-mentioned steps cannot be achieved, its preconditions have to be revised. Therefore, the current design may be modified several times.
When the design problem has not any proper anteriority in the knowledge bases, ABRAD proposes a set of models each of which satisfies a part of initial requirements. Inspired by these partial solutions, the designer can synthesize a new model of design never identified in the knowledge base. In this case, the existing knowledge can help the designer to specify the familiar parts of the new design.

4 The logical structure of ABRAD

ABRAD is structured through an articulation of the next modules, Figure 1:

⇨ The **Patterns Base**: It integrates the general descriptions of different products classes.
⇨ The **Cases Base:** It includes the individual specifications of different generic model instances.

- ⇨ The **Projects Base**: It memorizes the specifications of different versions of the current design project.
- ⇨ The **Modelling Unit:** It processes the memorized knowledge and puts what is required into the designer's disposition.



Remarked: the dotted arrow means that the data structure in the bases of case/project is in correspondence with the restrained of Patterns Base. The continuous arrow presents the flow of information between two components of the model.

Figure 1: The logical structure of ABRAD

5 The Patterns Base

The content of this database will be advised to establish the data structure of the Cases Base and so to formulate the model of the product to be designed. According to this later model a proper Projects Base will be established. Also, the data constraints, provided in the Patterns Base, can be interrogated to justify the consistency of the new product's specification.

The representation of products in the Patterns Base can be formulated through two procedures:

- Classifying the well-known products according to their common layout.
- Integrating the arguments which justify this classification. They are represented by attributes and integrity roles, which reveal different constraints among attributes. In a mechanical context of design, these arguments are information such as: the typical components of each instance of class, the relationships among these components, the common properties representative for the structure, functions and behaviours of products and also the other significant information which represents the classes.

The implementation of a function imposes several conditions to the product and to its corresponding environment. Then, the realization of a product's function can be evaluated via justification of its corresponding conditions.

To represent a number of product's functions, the specification of its environmental influences could be indispensable. To describe the environment effect over a product, ABRAD data structure applies the ontology of "Substance". As defined, the substance is considered the object which flows into a product while it accepts an external influence [8]. It can be a physical object such as water, which circulates into a working engine, or a conceptual object such as stress which propagate throughout a constrained piston.

In order to facilitate the management of different kinds of information, which represents a class of products, a suitable structure of data is implemented, see Figure 2.

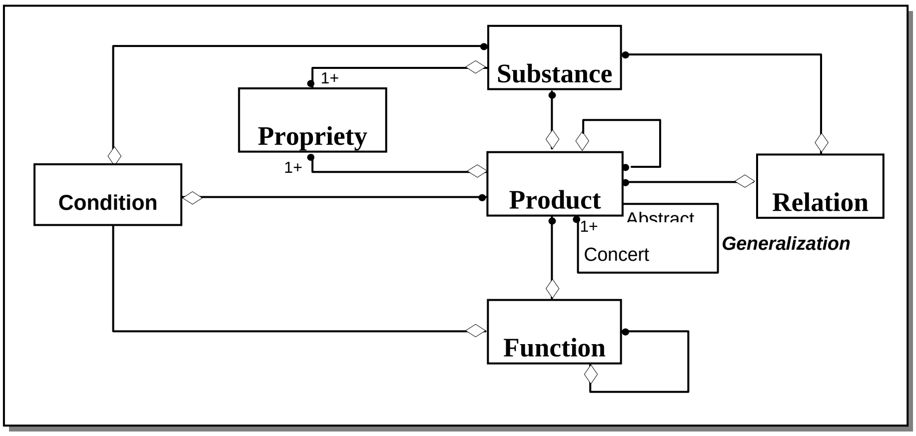


Figure 2: The structure of data integrated in the Patterns Base

6 The Cases Base

The Cases Base includes the individual specifications of different instances of the Patterns Base. Consequently, the structure of data in the Cases Base is founded on the information deduced from the Patterns Base, see Figure 3. In this concept the Patterns Base could be considered as the Meta-model of the Cases Base. What it implies is the necessity of reorganizing the Cases Base following each modification in the patterns' specification.

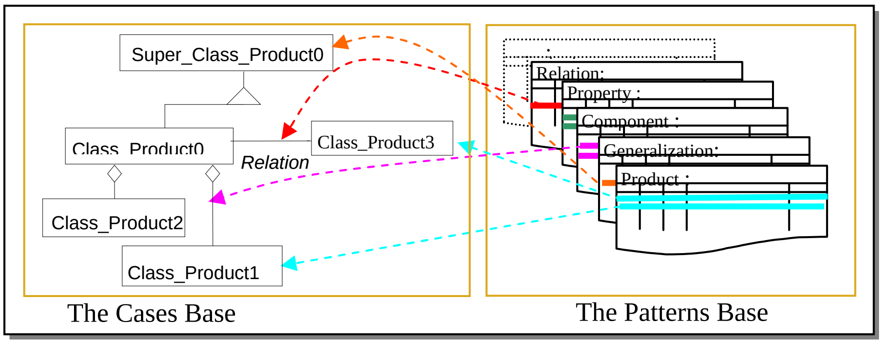


Figure 3: The structure of data in the Cases Base

Due to the fact that ABRAD must be able to analyze the similarity between a known product and the new one, it is necessary that each product disposes a presentation familiar to the Patterns Base. The complementary knowledge, which is not provided in the formalism of the Patterns Base, has to be memorized in the specific databases. The references of these sources of data are to be memorized in the Cases Base. These complementary data are very useful to develop the new products.

7 The Modelling Unit

The Modelling Unit is the exploration engine in ABRAD. It assists the designer to exploit the knowledge capitalized in the Cases Base and the Patterns Base and to adapt this knowledge to the current project requirements. In this concept, the principal missions of the Modelling Unit are:

- **I.** Aiding the designer to characterize the requirements of the design problem.
- **II.** Verifying the consistency of the information given by the user.
- **III.** Seeking the Patterns Base, the susceptible prototype(s) which contains the characteristics of the product to be designed.
- **IV.** Implementing a suitable structure of data to store the specification of product to be designed. In this step the Modeling Unit establishes an appropriate Project Data Base.
- **V.** Suggesting the appropriate values to accomplish the new design.
- **VI.** Assisting the designer to append new information into the databases. To this end, it provides an appropriate graphical user interface.
- **VII.** Enriching the Cases Base following each design project.
- **VIII.** Announcing the last state of project.
- **IX.** Examining the non-formalized constraints among the products' specifications. To achieve this goal, the Modelling Unit formulates a statistical study on the specifications of the products similar to the desired one.

8 The Projects Base

It is a database into which one stores the specifications of the product to be designed. When the new product has a typical representation in the Patterns Base, the Projects Base can be implemented to consult this representation. For instance, if the generic representation of the "petrol engines" is well known, it will be interrogated to establish the Projects Base for designing a new "petrol engine".
The Projects Base can memorize the specifications of the several versions of new product. This aptitude enables the designer to analyze them and select the best one.
After validation of the project, its information is stored in the Cases Base.

9 A demonstrative application of ABRAD

The suggested method is applied to design a simplified example of petrol engine.
Supposed that the initial requirements, expected from the new engine, are the next ones:

- ✓ Number of cylinders = 4
- ✓ Diameter of cylinder = 70mm
- ✓ Piston displacement = 76mm
- ✓ Volume of engine = 1200cm3
- ✓ Compression rate = 9.25 :1
- ✓ Maximum power = 45hp
- ✓ Rotation in maximum power = 5000rpm
- ✓ Maximum torque = 10kgfm
- ✓ Rotation in maximum torque = 3000rpm

To be competent in designing, the Patterns Base has to be familiar with the design of petrol engines. For the same reason, the Cases Base has to include examples of the existing petrol engines. Then, the bases of knowledge have to include whatever is appropriate in designing a petrol engine.

To manipulate the knowledge bases, ABRAD disposes a convenient graphical interface. However, to develop the Patterns Base, one has to be satisfactorily skilled in the object modelling techniques. For instance: the class of "Petrol-Engine" inherits certain characteristics of the class of "Engine", see Figure 4.

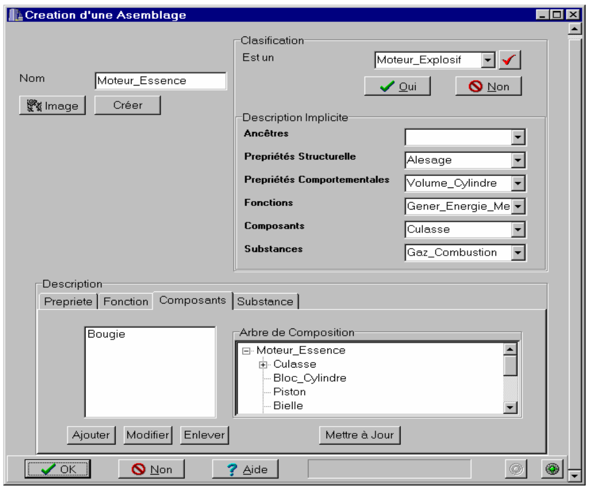


Figure 4: Creating a new class of product

Following each modification in the Patterns Base, the structure of data in the Cases Base will be improved automatically.

The aptitude of the Cases Base, for disposing good suggestions to achieve a new design, depends on the number of familiar cases which are similar to the new design. In this experience the specifications of 16 four cylinder petrol engines which are assembled in different model of "Renault 5" are registered.

At the beginning of new project a void database will be introduced. During the design processes, this database has been developed according to the new requirements. In ABRAD, the designer is in charge of organizing the design process. To supervise perfectly the expected tasks in the project, their status is registered in the corresponding Projects Base.

The first stage in designing a product is dedicated to confirming the corresponding pattern of the new product. There are two ways to reach to this stage:

- Declaration: reference to the pattern via its identification.
- Exploration: search the pattern(s) which responds to a set of criterion.

In this case the pattern is identified as "petrol engines". Once the suitable pattern for the new product is selected, the designer can detail the items characterized its generic definition. Regarding its initials requirements, a preliminary representation of the new petrol engine is given in Figure 5.

The integrity roles applied in the pattern specification justify the reliability of the new product's elementary definition, Figure 6.

In this example, the declared volume of engine is not matched with the specification of the engine and it has to be changed to 1170 cm3.

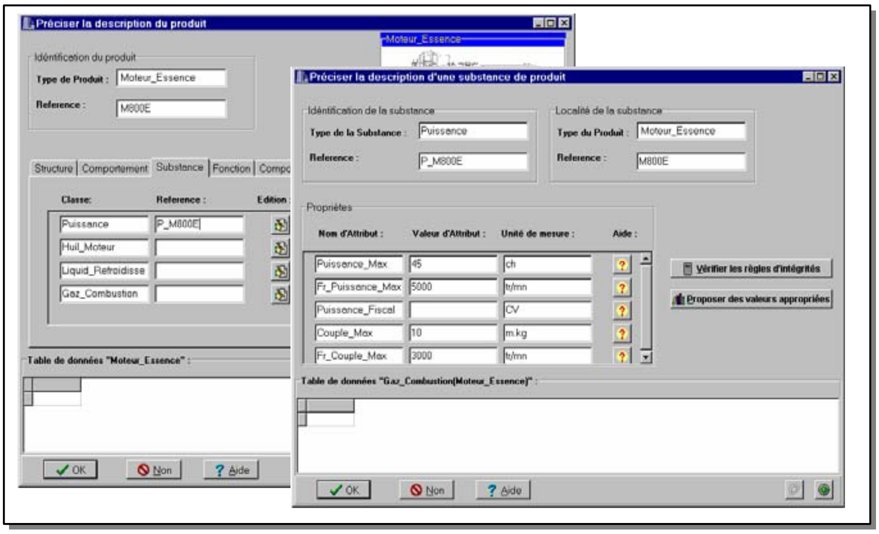


Figure 5: The preliminary specification of new product

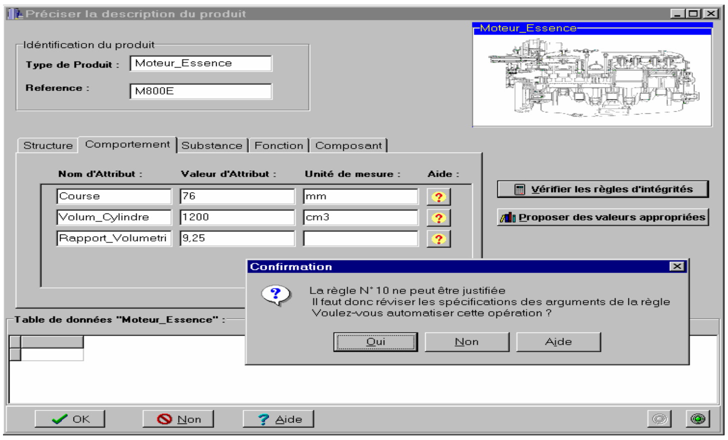


Figure 6: Verifying the integrated roles

The supposed pattern base contain an informal constraint, which explains that the maximum power of engine depends on other properties, among which, the diameter of cylinder, the volume of cylinder, the displacement of piston and the compression rate are very important. To justify these informal constraints the Modelling Unit formulates a statistical regression over the specifications of 12 more similar familiar engines of new design. This study shows that the maximum power has to be envisaged around 37.23hp.

To accomplish the new design the designer referred to the most similar case memorized so far. To find this case, the elementary definition of new engine composed the criteria of research. To do so, ABRAD disposes the nearest neighbor algorithm [9] formulated as:

$$\mu^c(s) = \frac{\Sigma_{i=1}^{n} \omega_i \times sim(f_i^C, f_i^S)}{\Sigma_{i=1}^{n} \omega_i} \qquad (1)$$

Where:

- "f_i": is the i[th] factor of comparison operation. It is an attribute of the target case which its assigned values are compared among the candidate cases.
- "n" : is the number of "f_i" attributes.
- f_i^C : is the value assigned to f_i attribute of the target case
- f_i^S : is the value assigned to f_i attribute of the compared case
- "$sim(f_i^C, f_i^S)$": is an appropriate function to compare f_i^C and f_i^S. Its formulation is in accordance with the compared attribute natures. In this case of study it is the subtraction of the compared values.
- ω_i : is the importance coefficient of f_i.
- μ^c(S): is the similarity factor of a given case. The case with the smallest factor is the nearest one to the target case

As indicated in the mentioned formula, to be more realistic in the result, the research is pondered by attributing the appropriate importance coefficient at each criterion. This coefficient interprets the designer perception of the key factors to verify the similarity.

The result of research among 16 memorized engines shows that the "C2J-P.7.13" which is assembled in "Renault R5 TX model 1981", is the nearest engine to the new one, Figure 7. Referring to the adopted engine, ABRAD proposed the appropriate values to accomplish the conceptual definition of new design.

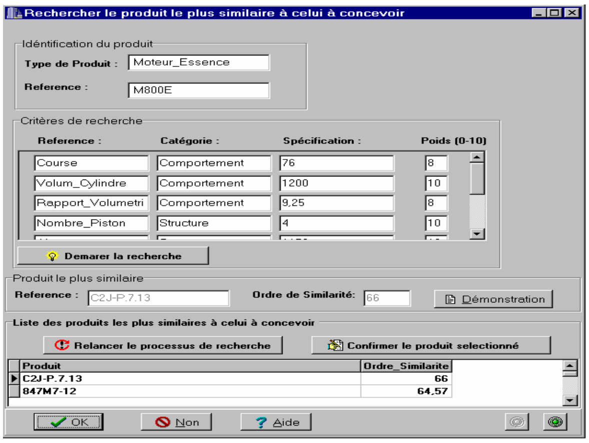


Figure 7: Searching the most similar project to the new one

If the conceptual design is deficient, the results of the integrity roles verification can be consulting to alter the design specification. Afterwards, in the remaining process, till realizing the new engine, the designer can inspire from what is done during similar projects.

10 Conclusion

The topics of the present research can be summarized as follows:

✓ Proposing an appropriate model of knowledge to characterize the mechanical design. This data modelling technique allows several classifications of a same design, using different levels of abstraction. Then the designer can consult the knowledge base from the beginning of a design project while the product description is very general, to the end of one, while the product description is well detailed.

- ✓ Applying the analogy based reasoning approach to formulate a method of processing the knowledge. The applied method, to approve the similarity between the cases, takes in account the designer experiences. The performance of the aided-design system improves by acquiring the new experience's results.
- ✓ The presented knowledge base approach distinguishes between the general information representing a class of product (a pattern) and the individual specifications of each class instance (a case). In which model, the data structure to acquired the cases specifications is built in according to the generic knowledge memorised in the base of pattern. In this sense, it is an articulation of model based and case based methods.
- ✓ Regarding the remarked principles, a software model can be developed which assisting designers to specify the concept of a new product and to detail its design by inspiring of what is known from the previous similar cases.

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