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AI AND CREATIVE ENGINEERING DESIGN

N. J. I. MARS, V. V. SUSHKOV and P. M. WOGNUM
Knowledge-Based Systems Group
University of Twente
PO Box 217
7500 AE Enschede
The Netherlands

Abstract. We discuss the following question: can computers support the early phases of engineering design, and, if so, how? We argue that a large collection of domain knowledge is required for such a support tool, and that the design method developed by Altshuller in the Soviet-Union forms a good starting point for this. Much work will have to be carried out to restructure and complete the domain knowledge embodied in this design method, before we will be able to base machine reasoning on it.

1. Creative design

Designing technical systems has become almost unthinkable without the use of computers. The first generation of computer aids for designers was formed by drawing tools; numerical programs, for computation of stresses or simulation of fluid flows, followed soon. Almost all computer aids for technical design have in common that they are meant for the later phases of the designing process: those phases in which a principle for the solution has already been chosen.

Hardly any support is available for the early stages of the designing process, variously called creative design, conceptual design, or even invention. Many believe that computer support of creative design is very difficult or even impossible; some believe it is also undesirable.

Many methods and techniques have been developed to improve creative design. In many cases these concern methods that aim to generate a large number of alternative solutions to a given problem; the designer has to select from those alternatives. Obviously, enlarging the space from which solutions are selected may improve the quality of the ultimate selection, but the efficiency of this approach is questionable. *Brainstorming*, *synetics* and morphological analysis are examples of this group.

A completely different group of techniques, of much smaller size, is based on design theory. Already in the previous century an attempt was made to construct one theory that should provide a complete list of all fundamentally different ways in which a given kinematic function can be realized [Reuleaux 1876]. Unfortunately, this approach has been shown to be barren, for both theoretical and practical reasons.

Techniques from this second group have in common that they attempt to provide a very parsimonious description of the design process, in particular of the knowledge involved. The point of departure always seems to be that *one* simple theory can be used for every design problem: a kind of laws of Maxwell of design.

Experience in knowledge-based systems development has shown that many application domains do not allow such an approach: the world is complex. Developing a knowledge-based system therefore requires the acquisition and representation of much domain knowledge. Fortunately, knowledge engineering offers the possibility to handle large collections of unstructured knowledge. *Structuring* of design knowledge (in contrast to the previously mentioned *reduction*) becomes the task of the knowledge engineer.

One of the theories of creative design not based on the *the world is simple*-paradigm is the approach developed by Altshuller in the Soviet Union, called the Theory of Inventive Problem Solving (TIPS). In the following sections we will describe this theory, and discuss whether TIPS can form the basis for knowledge systems to support creative design.

2. The method of Altshuller

Since the forties, the Russian engineer G.S. Altshuller and his collaborators have worked on a theory of creativity, in particular of creative design. As the basis of his theory, Altshuller used an analysis of patents. His aim was and is to determine in which way the ideas described in the patents have come about.[1]

[1] Altshuller has indicated he used science fiction-literature, in addition to the patents. Again, his aim was less to find interesting ideas in this literature, than to determine in which way the authors had reached their ideas.

On the basis of the analysis of a large number of patents (the literature indications range from 100.000 to 1.5 million) Altshuller has reached the following conclusions that form the basis for his theory of creativity:

- Technical systems develop according to fixed rules (a kind of Darwinistic evolution theory for technical systems);
- Knowledge of these development rules can be used to effectively solve technical problems;
- The most important rule is that technical systems develop in such a way that a quality criterium achieves ever increasing values;
- The second important rule is that most technical problems can be reduced to a conflict between the requirements for two parameters; improvement of one parameter leads to deterioration of the second.

Much of Altshuller's approach can be seen as finding such a conflict, and recommendations for its systematic elimination. The theory is not easily understood, in part because its use of a rather idiosyncratic jargon. Three concepts play a central role in the theory: *standards, principles* and *effects.*

Standards are the most general problem solving methods. Presently, 76 standards are available. To be able to apply a standard, a problem has to be reformulated in terms of substances and fields; the result is called a sufield-model. The standards are transformation rules for different types of sufield-models.

Principles are rules of thumb, that can be used to solve conflicts (in the technical sense introduced above). The principles are organized in a matrix. Along one axis the parameters are listed which should be improved, along the other axis the parameters are listed which deteriorate because of this improvement. A simple example is the design of a car: improvement of the engine power (desirable) increases the fuel consumption (undesirable). The table lists rules that can be used to solve the conflict. Several rules may be available, in order of their likelihood of usability.

Effects, finally, are physical, chemical and geometrical phenomena, in order of the achievable function. An example of an effect is the piezo-electric effect, by which an electrical potential can cause a mechanical displacement.

Standards, principles and effects can be used in combination to create a design or to improve it. The systematic application is described in what Altshuller has called the Algorithm for Inventive Problem Solving (AIPS). Altshuller has many followers in engineering schools in the Soviet Union. Hundreds of institutes offer courses in creative design based to a large extent on his ideas. The theory also has many followers in Russian industrial practice. The benefits of this practical use have been difficult to ascertain because of the different economical system. However, the experiences of some Finnish companies (Nokia and Elektrolux) are more informative. Both companies claim to have realized large financial savings and patentable inventions through the use of the Invention Machine, to be described below.

Spread of Altshuller's ideas in the West is hampered by the fact that many of his publications have only appeared in Russian. In the bibliography at the end of this report, the main Russian publications are mentioned, as well as some more accessible articles. The most recent work, that is of importance for application in knowledge based systems, has not been translated; several groups, including the IMLab, are working on this.

3. The Invention Machine

Altshuller's approach for solving inventive problems has been used by the company Inventive Machine Laboratory (IMLab) as the basis for a suite of computer programs, called the Invention Machine. The IMLab was incorporated in 1989 by its present scientific director, Valery M. Tsourikov. Tsourikov has been working on computer support for Altshuller's method since 1975. The company has its main branch in Minsk, Belarus, and subsidiaries in Sankt-Petersburg, Ulyanovsk, Chelyabinsk, Novosibirsk, Odessa and Mariupol; recently an American subsidiary, Inventive Machine Inc., has been established.

The activities of the IMLab mainly comprise the further development of Altshuller's theory. On the basis of this theory new programs are being constructed and existing programs improved. Additionally, IMLab organizes training courses in the theory and offers advise to companies on the solution of technical design problems in many technological areas.

The three groups of techniques from Altshuller's theory—the standards, principles and effects—have been embodied by the IMLab in three computer programs. These programs allow experienced designers to use the knowledge from Altshuller's method systematically, much faster than using a manual approach. The programs, collectively called the Invention Machine, can be used much easier than manuals, by the much better indexing offered by a computer.

Originally, the Invention Machine was developed as a Prolog program; since, a C-version has been written to increase portability and speed. A PC with graphical card is all that is required for use of the Invention Machine. Suitable indexing leads the user quickly to possibly relevant standards, principles and effects. Illustrations—many on the basis of the original patents used by Altshuller—show the applicability to designers much clearer than text descriptions.

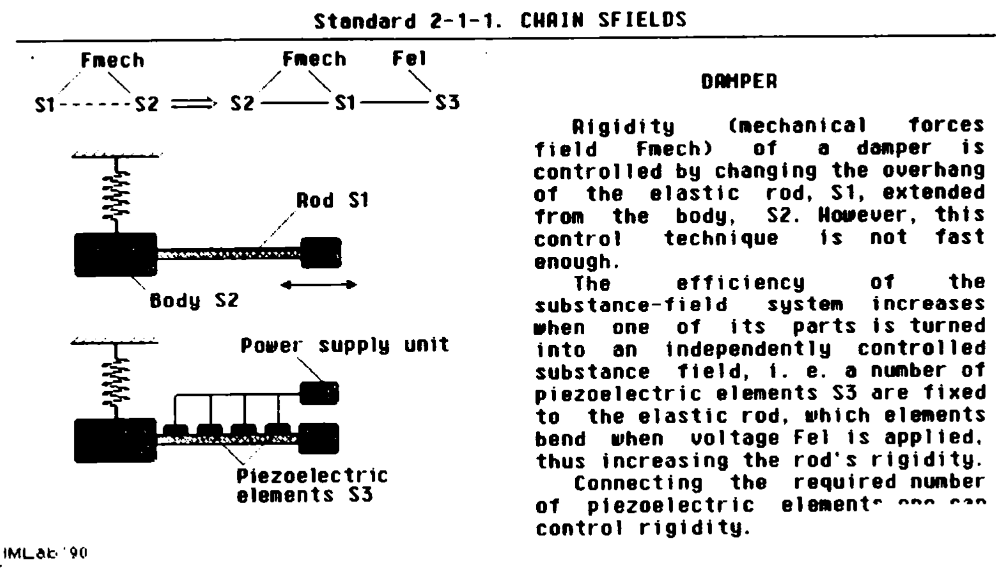

Figure 1: An example of output of the Invention Machine (screendump). © IMLab, 1992. This is an example of the use of standards. A mass-spring-system S2 damps the movements of a body, to which it is connected through an elastic stick S1. To allow control of the stiffness of this elastic stick, it is furnished with piezo-electric elements S3.

4. The contribution of knowledge-based systems

Seen from the perspective of computer science, the Invention Machine is a well-indexed hypertext system. This means that the user is supposed to possess a high degree of expertise in engineering design, and also that the role of the computer is a passive one: no machine reasoning takes place with the stored knowledge. The Invention Machine is divided into three parts, for standards, principles and effects, which to a user is a somewhat arbitrary subdivision.

The Knowledge-based Systems Group of the University of Twente, Enschede, The Netherlands, and the Inventive Machine Laboratory in Minsk, Belarus, have signed a collaboration agreement, with the aim to investigate jointly how knowledge-based systems technology can be used to perfect the Invention Machine. This collaboration started in May 1991, and was formalized in June 1992. It has both short and long term goals.

In the short run, the set of concepts used by the IMLab, following Altshuller, will be clarified. The concepts referred to by the terms standard, principle, and effect, will get a much more accurate definition, to allow their being used as the basis for a knowledge base on engineering design. This work has started already, in connection with earlier work in the Knowledge-based Systems Group (Alberts et al. 1991). It is conceivable that the three concepts standard, principle, and effect, will turn out to be only ways to refer to comparable entities at different levels of abstraction.

In the longer term, we aim to reorganize the multifarious knowledge in the three knowledge bases of the Invention Machine. Our aim is to integrate the three knowledge bases, the more so because users have been shown to find the difference between the concepts of standard, principle, and effect, very hard to master. We expect that the integration will show that additional knowledge, at both ends of the abstraction continuum, will be useful; in particular, knowledge about more basic, physical principles could be of use (without implying that we subscribe to the belief that all design knowledge can be reduced to a few basic laws).

Finally, our aim is to enable machine-reasoning with the restructured and integrated knowledge base. We will endeavor to establish a good link with the framework for the later stages of engineering design already developed in our research group.

As a aside, we investigate the relation between Altshuller's original approach (the analysis of the approach that has led to a patentable invention) and AI-techniques for analysing and reusing previous experience: machine learning and case-based reasoning. One handicap in this work is that patents are not readily available in machine-readable form.

We expect that the use of the knowledge that forms the basis for the Invention Machine, can be used in restructured form for the development of knowledge-based systems to support creative engineering design.

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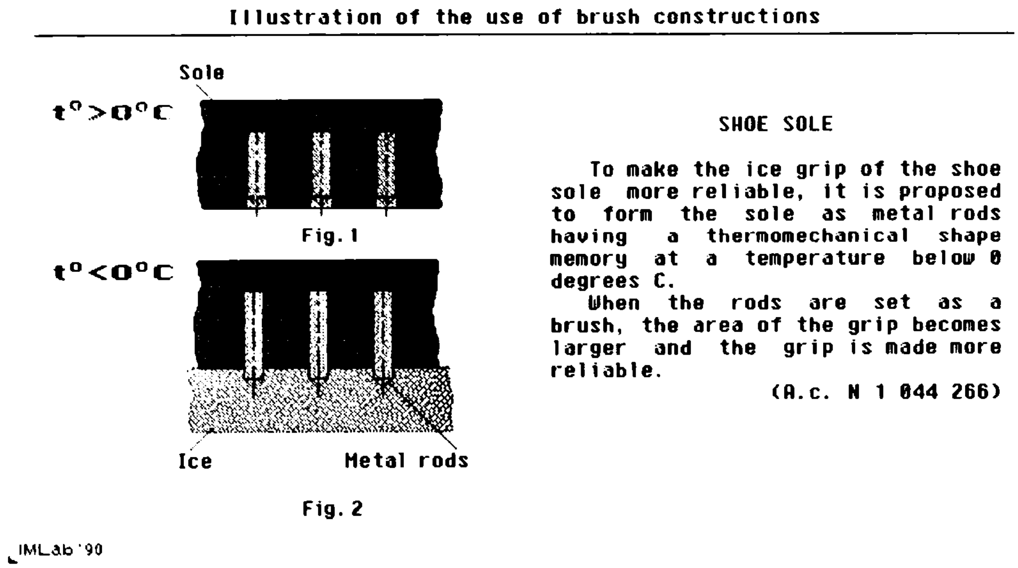

Figure 2: An example of output of the Invention Machine (screendump). © IMLab, 1992. Use of the 'memory-metal' effect in shoe soles. At temperatures below 0°C, metal pins are pushed out of the sole; at higher temperatures they are contained in the sole.

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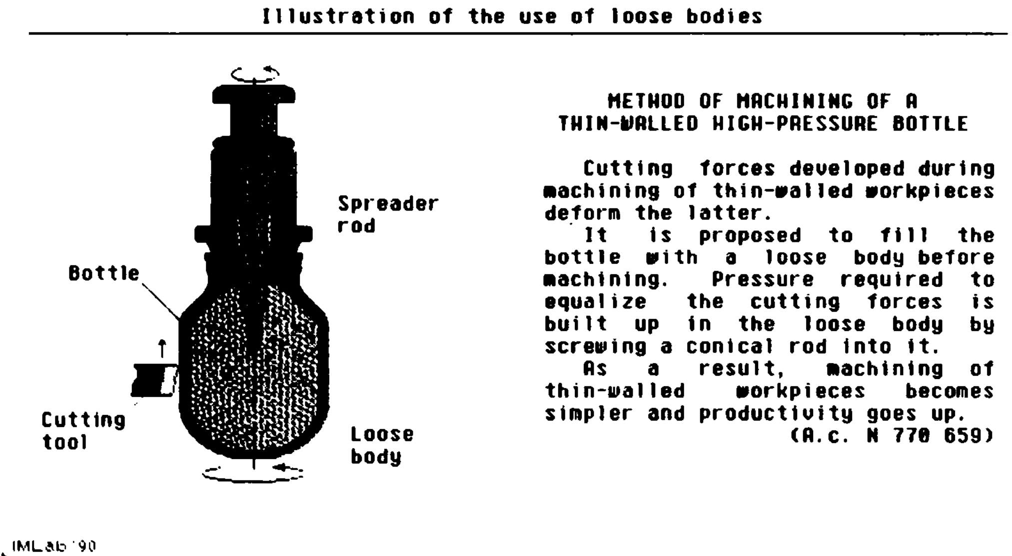

Figure 3: An example of output of the Invention Machine (screendump). © IMLab, 1992. Processing a thin-walled vessel on a lathe causes distortion of its shape. By filling the vessel with small objects (e.g., sand) that can be pressurized with a wedge, a counter force can be applied.

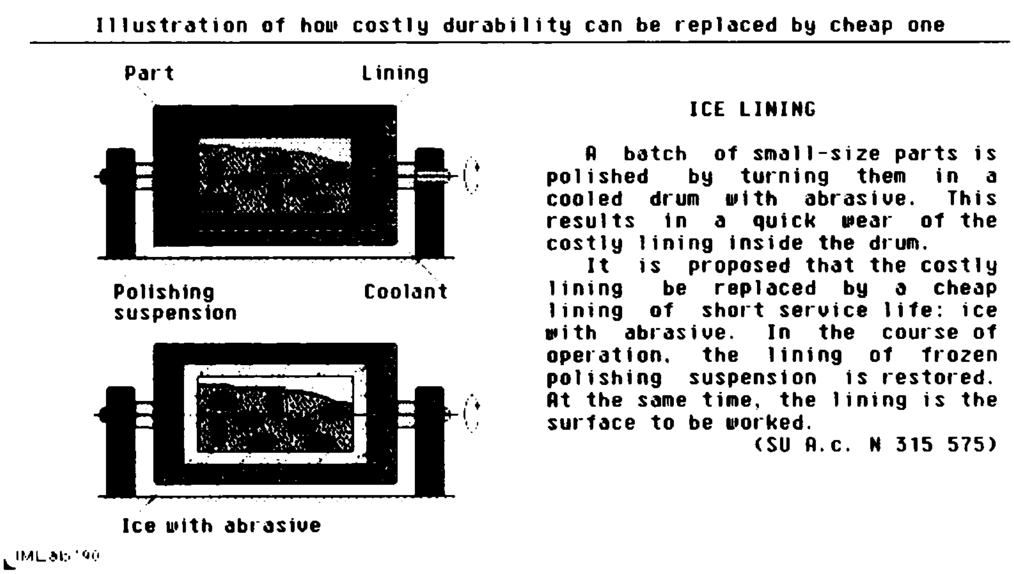

Figure 4: An example of output of the Invention Machine (screendump). © IMLab, 1992. Replace an expensive, durable element by a cheap one. The inner wall of a polishing drum shows excessive wear. By cooling the drum and inserting water, ice can be used as a cheap protection layer for the drum wall.