Computer-aided Creative Mechanism Design

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Knowledge-based Design Knowledge-based design systems, such as ICAD, are currently used in the context of large engineering projects. They provide design knowledge in the form of prototypes which can be instantiated and updated automatically according to the design context. Many designers are sceptical of the technique because the prototype library creates a preference for established solutions and thus inhibits innovation.

A popular saying claims that *"innovation is 1 % inspiration and 99 % perspiration."* While it is usually very difficult to endow a computer with sufficient breadth of knowledge to provide the inspiration, tools which *support* innovation by automating the *perspiration* seem much more feasible. The goal of our research are techniques which provide such support using artificial intelligence techniques.

This video presents the FAMING system, a program which illustrates an approach to supporting creative design on the example domain of elementary mechanisms. This class includes devices such as gears, escapements or ratchets which consist of two parts and achieve their function by interaction of their shapes. They are very easy to model and simulate, but variations of part shapes give a very rich variety of designs. In fact, novel devices are invented to this day. Elementary mechanisms are thus an ideal domain for studying how creative design could be supported by computer, even if the domain is too specialized for commercially viable design tools.

Innovation in knowledge-based design As innovations are by definition unknown to the designer of a computer tool, knowledge to support them cannot be very specific, but must be based on general principles which remain valid even in innovative solutions. Approaches using *model-based reasoning* ([Williams, 1990; Neville and Weld, 1993]) work well whenever interactions between the individual models can be precisely identified (the *no-function-in-structure* principle).

Kinematic pairs achieve their function through the possible contacts between elements of the part shapes. Because all contacts have to be integrated into a common geometry, they interact in very unstructured ways: any contact can *subsume* (inhibit) any other one and make it impossible. Kinematics therefore does not respect the no-function-in-structure principle. Thus, while Joskowicz and Addanki ([Joskowicz and Addanki, 1988]) have attempted to apply methods of model-based design to kinematic pairs, their method is restricted to simple cam-like mechanisms and incapable of producing devices such as escapements or ratchets.

Humans often produce creative designs by *reinterpreting* known solutions in a novel way [Wills and Kolodner, 1994]. FAMING supports this form of creativity by two major innovations over existing techniques. The first is the use of *case-based reasoning* as a main source of design knowledge to handle the context-dependence inherent in geometry; FAMING is one of the first programs which actually generate novel devices by combining and adapting previous cases. The second is that FANIHG uses a general theory of *qualitative kinematics* ([Faltings, 1990; 1992]), capable of reasoning about any imaginable qualitative function, to provide the knowledge for case adaptation and combination.

As input to FAMING, the designer provides a formal specification of the desired functions, and examples of shapes that can implement aspects of them. In agreement with common design methodology (e.g., [Pahl and Beitz, 1984]), functions are qualitative and indicate an *interpretation* of the example device. They are specified as logical expressions with reference to an *envisionment* of all possible behaviors of the device they interpret. In contrast to fixed functional vocabularies used in current intelligent CAD systems, this qualitative formalism can express any imaginable qualitative function including creative ideas unknown to the programmer.

The theory of qualitative kinematics is used to map specifications into constraints on the part shapes provided in the examples, and thus their adaptation into novel uses. The new prototypes are then added to the knowledge-based system's vocabulary ([Faltings and Sun, 1993; Sun and Faltings, 1994]) and can subsequently be integrated in designs using all functionalities provided by the intelligent CAD tool. FAKING thus makes it possible to integrate creative designs in a know ledge-based CAD system.

FAMING Results FAMING has successfully designed several devices of practical interest, including various types of gears and clock escapements. As an example, the video shows the design of a novel forward-reverse mechanism which is much simpler than designs found in the literature on mechanism design. The program has also been tested on design of actual products which are to be marketed in the near future, showing that using the tool can decrease design time for such mechanisms from 6 months to only 1 day.

FAMING is mainly intended as a proof of concept that qualitative physics can indeed provide support for creative design. The combination of case-based reasoining with qualitative physics is applicable to many other domains which may be commercially more promising, such as nanotechnology, drug design or biomedical engineering.

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