Extending Geometric Modelling Systems for Design

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ABSTRACT: Current geometric modelling systems have focused on the complete and computationally efficient representation of solid parts. Particular attention has been given to the requirements of automated production. While satisfactory for their intended purposes, modellers built on this basis alone are of small utility in design. Only limited attention has been given in the literature to the relations that solid parts have to each other. If one looks at the representations used particularly during the early process of design, it is evident that an important class of entities being modelled are the relationships that exist between parts. The part themselves in a developing design are often of secondary importance. This paper proposes two constructs, geometric design rules and groups of instances which together allow facile manipulation of geometric models consisting of many parts. The system is written in Pascal on a VAX 11/780 running Berkeley UNIX 4.1.

KEYWORDS: assemblies, interaction, modelling, polyhedra.

RESUME: Les systemes traditionnels de Modelisation Geometrique se sont attaches a la representation, complete et performante, de composants solides. Une attention toute particuliere a ete consacree aux exigences des techniques de production automatisee. Satisfaisants, dans le cadre de leurs propos specifiques, les systemes elabores selon cette base seule apparaissent de mediocre utilite dans une optique purement conceptrice. Une attention trop limitee a ete consacree, dans la litterature, aux relations spatiales que les objets, composes en assemblage, possedent les uns par rapport aux autres. Une analyse attentive des representations plus particulierement utilisees au cours des premieres etapes de conception, revele la preponderance d'une importante classe d'entites que sont les relations spatiales definissant les positions respectives des differentes parties de l'assemblage. Les composants eux- memes apparaissent souvent, en cours d'elaboration du modele global, d'une importance secondaire. Cet article introduit deux notions nouvelles - regles geometriques de composition, et ensembles d'objets - dont la conjugaison permet une manipulation plus souple de modeles geometriques composes d'un grand nombre de parties. Le systeme, ecrit en Pascal, a ete developpe sur un VAX 11/780, equipe Berkeley UNIX 4.1.

MOTS-CLES : Assemblages, Interaction, Modelisation, Polyhedres.

Summary

Current geometric modelling systems have focused on the complete and computationally efficient representation of solid parts [12] [8] [3] [15]. Recently effort has been made to extend geometric modelling systems to explicitly support aspects of manufacturing processes [14] [5]. Requicha and Voelcker [12] outline current areas of research and development in geometric modelling. They emphasize the later phases of design where the shapes and relationships involved are well known to some approximation. Much emphasis has also been placed on the actual production process, including robotics and numerically controlled machining. Very little attention has been given to the early phases of design where concept and thus the designed artifact is incomplete and poorly known. In architecture at least this is a phase of design which occupies a significant portion of the intellectual effort if not the time of the designer.

Design, like all problem solving, is supported by an external medium which acts as a supplement to the memory of the designer. The external medium acts to reduce search by storing relevant information about the problem and its goals or constraints. The nature of the external medium can significantly affect the results of the problem solving process [9]. An example with which all instructors of architecture are painfully familiar is the use of words as a medium for the expression of architectural ideas instead of drawings. Compared to drawings, words are very inefficient as representations of spatial ideas. The computer is a tool with capabilities very different from those of drawings or of the written word. The potential of the computer as an interactive external medium to aid a designer in understanding and searching through problem structure is currently almost undeveloped. The external medium for design is often a geometric one. Drawings and physical models explicitly contain geometric information and act as implicit references to other non-geometric information which is often stored internally in the head of the designer. Since today's manual media for design tend to be geometric in nature it seems reasonable to think about things geometric when thinking about computer media which support design.

Design is an activity that can be described as ill-defined problem solving [13] [11]. In ill defined problem solving, the structure of both the problem space and the problem constraints are ill-defined. People engaged in ill-defined problem solving do not know to a great degree, either the space in which they are searching or ways to determine if they have arrived at a solution. It is impossible to predict the organization or structure of a solution prior to design activity. Yet this is what current geometric modelling systems do when they impose a particular structure on the models that they create. For example, the often used instance tree structure imposes a strict hierarchical or tree-like organization on the components which make up a design [15]. Different design alternatives require different structural organizations. The idea of design concept can be viewed as the selection of a part of problem space to search. The development of a concept partially defines the artifact which is being created and thus limits the structure of the developing solution. For example, a designer working on a housing design problem has little spatial structure to operate within until a decision of housing typology is made. Once the decision is made, many constraints and relationships are determined. If these constraints and relationships can be captured in a geometric model then the model can be used as a means to manipulate an idea within the bounds of some concept.

In the process of design, changes to the representation recorded by the external medium, be it on paper on in computer memory continually occur. These changes are not limited to the parts that together comprise a developing artifact, they also affect the relationships between these parts. For example,in Figure 1 when two windows in an elevation are located at the same sill height, they are in a geometric relationship to each other. This type of relationship is exploited by a designer to locate additional windows or other facade elements. Movement of the line governing sill height, something exemplary of the operations done in the course of elevation design, can cause movement or change of all elements related to that line. The creation of such lines as geometric expressions of internal designer intentions provides the ability to change form made up of parts within a conceptual framework. The development of such a framework of concepts or meaningful relationships, expressed in elevation design by construction lines, is as much a part of the design task as production of an elevation. For example, an examination of Louis Kahn's preliminary sketches will reveal an emphasis on the relationships amongst parts of a building rather than on the parts themselves [2].

Designers often move parts together as a group. These groups may be arbitrarily formed particularly at the earliest stages of design. An example is in floor plan layout, where the creation of a pathway diagonally through a floor plan may cause a formerly arbitrary group of parts to be moved together. Figure 2 demonstrates one such movement of parts.

These two phenomena, relationships supporting the movement and placement of parts and the grouping of parts for movement are separate aspects of interactive models that should be supported separately in any computer implementation. Relationships as the geometric counterparts of designer ideas provide the ability to directly manipulate models in their own frames of reference. Grouping provides the ability to change forms consisting of many parts in a general way which does not require a prestructuring of the data model. Existing geometric modelling systems tend to mix these two separate aspects of manipulating form. One well-known data structure for geometric modelling, the instance tree [4], [15], combines both of these aspects into a single data model. The instance tree groups parts together into a strict hierarchical,or tree, structure. The structure is used both to group parts together for moving and to define the location of each part in space. The strict hierarchical structure is necessary to avoid the multiple definition of locations in space, but at the same time it constrains the structure of allowable groups to a tree-like order. Groups organized into a tree cannot have two subtrees which contain the same data elements unless one group is a subtree of the other group. Such a constraint poses problems if two different groups which contain some common parts are to be moved.

This paper describes the design and implementation of abstract data types to specify and modify geometric relations amongst parts in an artifact and to allow the arbitrary grouping of parts for the purposes of moving or display. Together, these abstract data types allow specification of relationships between groups of parts. These abstract data types can replace existing modelling schemas such as the instance tree. All elements in space can be defined by characteristic values [7]. Therefore these abstract data types can theoretically be used to model many different applications in geometric modelling, including parametric definition of polyhedra and relations between polyhedra in space. This paper presents a modelling scheme for assemblies consisting of many parts. The model uses parametric transforms, a well known modelling formalism [10] [6] and the theory of sets [1].

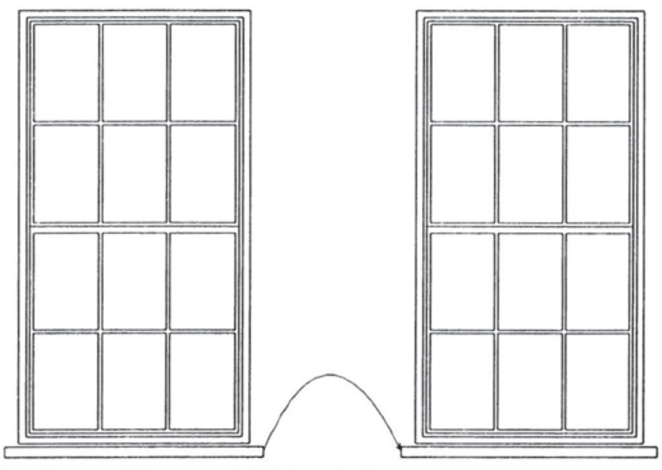

Figure 1: Relationships in elevation design

Other schemes for modelling geometric relationships, such as [7] focus on the automated satisfaction of constraints within a well-defined model or upon the simulation of relative movement of parts in mechanical assemblies [14]. This paper focuses upon different issues, namely the use of modelling systems as external media for design. It thus addresses the issues of modification of models and of representation of models which are in a state inconsistent with the constraints acting upon the model. A full version of the paper may be found in [16].

The user interface between the model and the designer is not developed. Development of the user interface is proceeding within the VEGA [15] geometric modelling environment at Carnegie-Mellon University. No empirical evidence of the power and efficiency of the model from a designer's point of view is presented here.

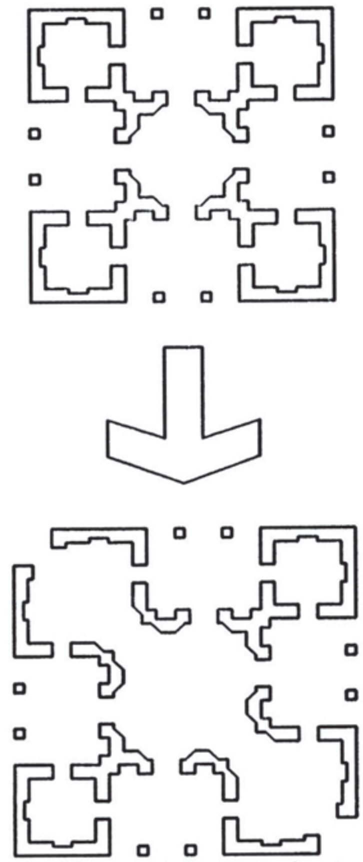

Figure 2: Movement of groups of parts

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Extending Geometric Modelling Systems for Design.
Submitted to Computer Graphics Forum, Journal of Eurographics Association.