Intelligent Form Feature Interaction Management in a Cellular Modeling Scheme

Rafael Bidarra and José Carlos Teixeira

Grupo de Métodos e Sistemas Gráficos
Departamento de Matemática, Universidade de Coimbra, Largo D. Dinis, Apartado 3008
3000 COIMBRA - PORTUGAL
Tel:(+351) 39-28097
E-mail: rafa@uc.pt

1. INTRODUCTION

Considerable progress has been achieved in the last few years in clarifying the concept of form features [1] [5] [8], as well as in developing several representation schemes for them, e.g. [3] [7] [2]. However, there have not been many practical results in investigating the nature of form feature interactions and their consequences on the validity of features, since the early informal identification of the problem, with Pratt [4]. Feature interactions can take place both at feature insertion stage, due to some common geometry or location, or in post-insertion stages, by modification of any of these parameters. The degrees of freedom available in overlapping several volumetric features of different classes substantially raise the complexity of models, and of their manipulation, making it quite hard to systematically approach interaction phenomena. A semantic framework is here proposed, that supports the operation of reasoning mechanisms to cope with feature interactions.

2. FEATURE INTERACTIONS

Creating solid models using feature's vocabulary offers no special difficulties when they are inserted in the model disjoint from each other, provided that validity is enforced by insertion methods; such a model is shown in Figure 1.(a). However, if we are to model parts of real world solids, we need to cope with *feature interactions*, in order to model more complex shaped objects, as the one depicted in Figure 1.(b); this model illustrates that interaction between features can occur in two ways: volume interaction and boundary interaction. In both cases, there is always a region of the space where the *associated closed volumes* of each feature intersect: this overlapping region (whatever its dimensionality) is here called *interaction extent*, and its existence is a necessary and sufficient condition for the occurrence of form feature interactions. In this way, adjacent features are naturally considered to be in interaction.

Each volumetric form feature reflects a local shape of the part

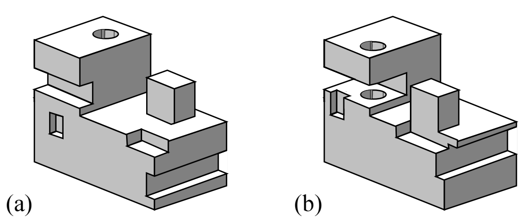


Figure 1. (a) disjoint features; (b) overlapping features

with specified and predictable properties, which is associated to some definite engineering semantics. Some of these properties are geometric and can be expressed by means of *dimension parameters*, for the global quantitative geometry of the feature associated volume, or *location* and *orientation parameters*, for the description of the actual positioning of the feature. Their values may be either directly obtained from the designer or inherited from those of other features' parameters, eventually related through some specified function.

The *local morphology* of a model is defined by the additive or subtractive nature of each volumetric feature that compose it. The semantic content of a feature brings together this morphological expression and the specification of its behaviour in terms of the characteristics of the *feature associated boundary*, namely the specific subsets of the boundary that do or do not actually belong to the model's boundary; the former are said to have positive status, while the later posess negative status. First, we propose to identify for each feature class the essential subsets of its boundary, based on their semantic behaviour: each of these consists of a collection of feature boundary faces, and is called a *definitional entity*. As shown in the example of Figure 2, SLOT features should always have the definitional entities *roof* and *floor*.

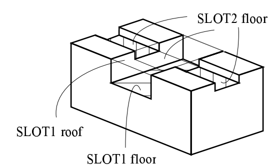


Figure 2. Example of definitional entities of slots in a model

3. SEMANTIC CONSTRAINTS AND VALIDITY CONDITIONS

All valid feature instances present in the model are expected to exhibit a specific behaviour, that of the respective feature class. This can be expressed in terms of the elements of selected definitional entities, by means of what we call *semantic constraints*, that restrict the number, the adjacency or the status of those elements. An example of semantic constraint is the requisite for a SLOT *floor* to contain, at least, one positive element.

Validity conditions are, thus, defined for each feature class, by logical composition of several semantic constraints. When all constraints are satisfied by a particular feature instance, we say it presents *semantic completeness* and the feature is, therefore, valid. Invalid features diverge, in some way, from the original behaviour desired with their insertion in the model. As a general rule, when a semantic constraint of a form feature is infringed, the feature becomes invalid. Such situations can occur due to some feature insertions or manipulations, and should be always signaled, providing an explanation on the reasons that are making it invalid. Invalid features can be maintained in the model, if not otherwise stated, although the respective desired morphology is, perhaps temporarily, overriden; in such situations they are considered as intentional features, just reflecting some intention of the designer on the corresponding functionality [6].

4. FORM FEATURE REPRESENTATION

To represent form features, we are using a cellular representation scheme called A-Crep (Adaptive Cellular Representation), that is based on the theory of adaptive cell complexes. An adaptive cell complex is a collection of generalized cell subcomplexes, each of which is labelled with P (positive) or N (negative). This model allows the secondary representation of form features by associating each form feature to a labelled cell subcomplex.

Whenever two features interact, the respective subcomplexes are further decomposed. This cellular decomposition is interaction-driven, i.e., part of the resulting cells represent the interaction extent and, thus, belong to both subcomplexes (interaction cells), while the remaining cells belong to the subcomplex of either feature (non-interaction cells).

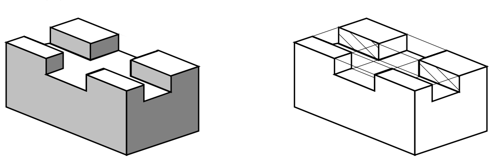
5. SEMANTIC BEHAVIOUR OF INTERACTING FEATURES

With the semantic framework previously defined, we can turn into the problem of feature behaviour throughout various types of interactions. For each interaction class, we explore its particular consequences on the validity of the involved interacting features. The occurrence of invalid features in a model is most often an indirect side effect that takes place as an undesired or, at least, unanticipated result of feature interactions. Our approach can be viewed as an intent to encapsulate interaction detection and reaction methods in each feature class definition, thus providing an automated mechanism for feature validity maintenance throughout interaction phenomena. When convenient, we illustrate the response of the cellular representation level to feature manipulations and interaction management; in this case, figures showing cellular decompositions will be presented in white, rather than shaded.

a) Topological Interaction

A large variety of interactions can be devised that preserve the designer intent for some specified local morphology, despite the overlapping of the involved features. These situations have the generic name of *topological interaction*: an interaction between form features that overlap (with boundary or volume intersection), while maintaining each one its own parameters and a semantically complete definitional entity set.

An example of topological interaction is given in Figure 3.(a). Both slots in this model are valid, although they exhibit non-standard or disconnected topology, i.e., two topological components, split apart by each other. At the representation level, they have undergone a cellular decomposition that captures the interaction extent of both, by means of a shared cell, as depicted in Figure 3.(b).



(a) (b)

Figure 3. Example of features in topological interaction

b) Transmutation Interaction

In certain conditions, operations that create or modify features may produce destructive consequences on their intended semantic behaviour in the model. One of these effects is called *feature transmutation*, which is an essential topological modification that causes a given feature to exhibit a definitional entity set specific of another feature class.

Transmutations may be expressed in terms of definitional entities, observing that they always cause a constrained definitional entity of a feature to become empty. A feature that suffers a transmutation is said to be in *transmutation interaction*. An example of transmutation interaction is shown in Figure 4: enlargement of the slot transmutates the pocket, whose behaviour becomes that of a slot.

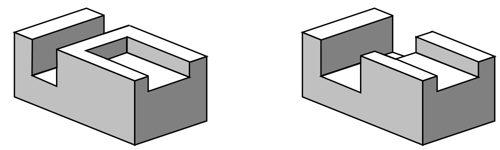


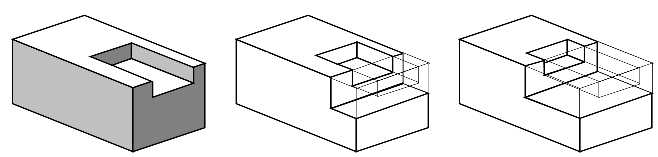
Figure 4. Example of features in transmutation interaction

Transmutation interactions are easily detected, provided that all feature classes inherit a method for signaling that some definitional entity has been modified. Each feature class specifies a set of transmutation rules, that check whether some other related feature behaviour is available, depending on the particular definitional entity modified.

Normally, assuming that the designer's degree of advertence is unpredictable, transmutations are always detected and signaled, requiring his/her confirmation before the transmutation is carried on.

c) Geometric Interaction

Some interactions do not affect the semantic behaviour of a particular feature, but instead cause a transformation on the geometry of its definitional entities, and we say it is in *geometric interaction*. This is defined as an interaction between features in which the particular interaction extent produced causes some dimension parameters, established at feature insertion stage, to loose their correspondence to the actual feature geometry.



(a) (b) (c)

Figure 5. Example of features in geometric interaction

Geometric interactions can occur to subtractive features whose geometry is modified by the edition or insertion of another interacting feature, while keeping the complete set of definitional entities. An example of geometric interaction is presented in Figure 5, where the internal cellular decomposition of each feature is also shown (white pictures). The pocket in (a) sees its actual length reduced, first due to the insertion of a slot, (b), and second because of the slot enlargement, (c).

The problem with geometric interaction is the indirect change in dimension parameters that were intentionally introduced by the designer for some feature. One solution consists in distinguishing between virtual (or insertion) parameters and real (or actual) parameters, and establishing for the real parameter an expression involving the former virtual value and the appropriate parameter(s) of the other interacting feature(s).

The interaction-driven cellular representation used also captures naturally this class of interaction: the final decomposition produced splits the affected feature's subcomplex in two, such that one of the parts, representing the interaction extent, is embedded in the subcomplex of the new interacting feature, and the other part still exhibits the desired behaviour, as expressed through the feature's original semantic constraints. This situation is clearly depicted in Figure 5.(b) and (c), where the cell decomposition exhibits both split parts of the interacting pocket.

d) Closure and Absorption Interactions

Subtractive features are supposed to be always accessible from outside of the model, as we cannot devise real objects with voids inside. When the associated volume of such features becomes a void completely closed inside of the model (Figure 6), they are said to be in *closure interaction*, defined as the interaction in which all definitional entities of a subtractive feature become composed of only positive elements, i.e., its boundary totally lies on the model's boundary.

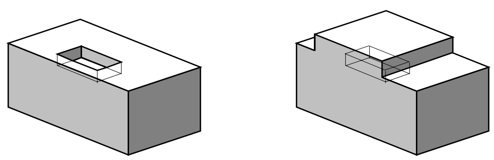


Figure 6. Example of a feature in closure interaction

When the associated volume of a subtractive feature becomes completely incorporated in some subtractive feature (Figure7), we say it is in *absorption interaction*, defined as the interaction in which all definitional entities of a given feature become composed of only negative elements, i.e., no subset of its boundary lies on the model's boundary.

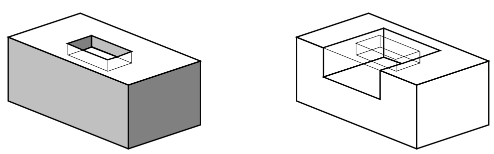


Figure 7. Example of a feature in absortion interaction

As defined above, closure and absortion interactions are dual, in terms of definitional entities modifications. They are detected in a straightforward way, just like the other classes of interactions, due to the semantic expressiveness of definitional entities. Their detection relies on the feature's capability of signalling changes in each definitional entity, which is easily achieved, in our object-oriented approach, by means of a general method defined for all feature classes with that purpose.

6. CONCLUSIONS

The necessity for modeling solid objects with complex shapes demands from feature-based solid modelers the ability to properly manage form feature interactions.

A semantic framework that supports reasoning mechanisms for handling interaction situations was developed, based on the morphological expressive power of form features and on their semantic composition. For this purpose, we introduced the concepts of definitional entities and semantic constraints, which proved to be of great utility for both the classification of the various types of interactions and their automatic detection.

Feature validity maintenance throughout interaction phenomena is a key point in feature-based modeling, and higher level mechanisms for assisting edition and interrogation of feature models need to be further investigated. Current trends in our research work include developing some of these mechanisms, validating them in an object-oriented version of A-Crep, that is currently under implementation, and extending the above concepts to compound and user-defined form features.

REFERENCES

[1] Dixon, J.R., Libardi, E.C., Nielsen, E.H.,: Unresolved Research Issues in Development of Design-with-Features Systems, In *Geometric Modelling for Product Engineering*, Proceedings of the 1988 IFIP/NSF Workshop on Geometric Modelling, Rensselearville, NY, September 18-22, 1988, Wozny, M., Turner, J., and Preiss, K. (Eds.), North-Holland, The Netherlands, 1990.

[2] Gomes, A., Bidarra, R., and Teixeira, J.: A Cellular Approach for Feature-Based Modelling. In *Workshop on Graphics Modelling & Visualization in Science and Technology*, Darmstadt, April 1992 Göbel, M. and Teixeira, J. (Eds.), Springer-Verlag (to be published)

[3] Gossard, D., Zuffante, R., Sakurai, H.: Representing Dimensions, Tolerances, and Features in MCAE Systems. *IEEE Computer Graphics & Applications*, vol.8, no.3, 1988.

[4] Pratt,M.: Recent Research in Form Features. In *Advanced Topics in Solid Modelling*, ACM Siggraph 87, Course #26, Anaheim, CA, July 1987.

[5] Pratt, M.: Synthesis of An Optimal Approach to Form feature Modeling. In *Proceedings of the 1988 ASME International Computers in Engineering Conference and Exhibition*, vol.1, The American Society of Mechanical Engineers, New York, pp.263-274, 1988.

[6] Rossignac, J.: Issues On Feature-Based Editing and Interrogation of Solid Models. *Computers & Graphics*, vol.14, no.2, pp.149-172, 1990.

[7] Rossignac, J. and O'Connor, M.: SGC: A Dimension-Independent Model for Pointsets with Internal Structures and Incomplete Boundaries. In *Geometric Modeling for Product Engineering*, Proceedings of the 1988 IFIP/NSF Workshop on Geometric Modeling, Rensselearville, NY, September 18-22, 1988, Wozny, M., Turner, J., and Preiss, K. (Eds.), North-Holland, The Netherlands, pp.145-180, 1990.

[8] Shah, J.: Conceptual Development of Form Features and Feature Modelers. *Research in Engineering Design*, vol.2, pp.93-108, 1991.