A Feature-Based Solution to the Persistent Naming Problem

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ABSTRACT

Current parametric modeling systems suffer from the persistent naming problem, which is responsible for the unpredictable, sometimes stunning, behavior of such systems when re-evaluating a model, even after simple editing operations.

This paper claims that the problem is an inherent difficulty of the approaches taken by current parametric modeling systems, in which various persistent naming schemes end up solving only a fraction of the problem. Instead, it is argued that the rationale behind such schemes should itself be revised. Alternative approaches to define a parametric model based on persistent parametric entities can, in fact, eliminate the flaws of using references to non-persistent geometric model entities, which is the real cause of the problem.

One such approach is described here, which is able to take full advantage of parametric modeling. It provides persistent entities in the parametric definition domain, which can always be consistently referred to. Basically, it proposes the use of the names of persistent feature faces, instead of the names of boundary faces, every time a reference to a face is required in a parametric definition. Furthermore, it makes use of these feature faces names in order to identify any edge of interest on the boundary representation of the model. These edge names can then be consistently referred to in further parametric definitions. Whenever ambiguities occur, e.g. due to multiple intersections, half-spaces are automatically defined by means of references associated to the features involved, which are kept in the parametric domain.

An implementation of this approach is also described, which takes care of maintaining the semantics of the parametric definition of a solid object. A number of examples illustrate how user specification of modeling operations can be transparently performed through interaction with a declarative feature model.

Keywords: Parametric modeling, feature modeling, boundary representation, persistent naming

1. INTRODUCTION

Most current modeling systems are parametric, history-based feature modeling systems using a dual representation for solid objects: on the one hand a parametric definition of the object, on the other hand a boundary representation (b-rep) of the resulting shape; see Fig. 1. The parametric definition can consist of a variety of information, usually organized in a graph structure. Typically, the graph represents relations involving instances of parameterized features, constraints, set operations, auxiliary geometric entities, etc. Among these relations, the most important is usually the *order of creation* of feature instances, defining the so-called *model history*.

Creating a new feature instance in the model, by providing a set of input values for its parameters, appends a new node to the model history, yielding a new parametric definition of the object. Similarly, feature instances can be modified by specifying new values for their parameters, or be deleted from the model. This is done by modifying, or deleting, the respective feature node in the model history. Whenever a new parametric definition is obtained, it can be input to the boundary evaluator, which generates the corresponding new boundary representation. This can be realized by, for example, sequentially re-executing all or a subset of the steps in the modified model history.

The ability to easily generate variants of a feature model is one of the main reasons for the popularity of current parametric modeling systems. An important characteristic of these systems, highlighted by the loop in Fig. 1, is that they allow the use of topologic entities (e.g. faces and edges) of the b-rep in the specification of subsequent parametric definitions. Consequently, each node in the model history typically contains references to topologic entities of the intermediate b-rep which resulted from the previous modeling step. As an example of this, the model in Fig. 2.a shows a cylindrical through slot, attached to the front face of a block, and positioned at a distance *a* from its right edge,

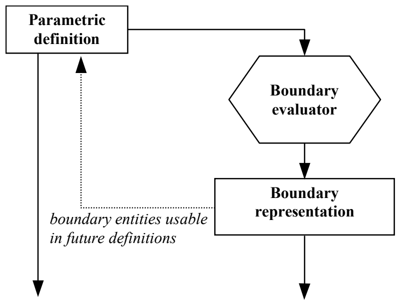
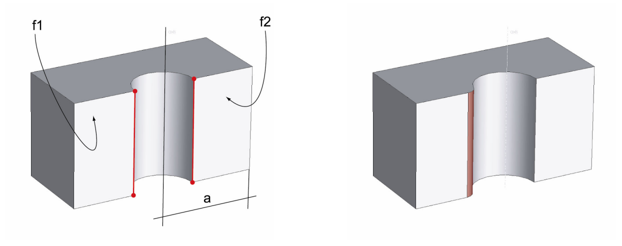


Fig. 1. Dual representation in current parametric modeling systems



(a) an attach face is split by the round slot

(b) a resulting edge of the round slot is blended

Fig. 2. Referring to boundary entities in a parametric definition

causing the front face of the block to be split into faces f_1 and f_2. In the next modeling step, one of the edges of the slot is blended, as indicated in Fig. 2.b.

Obviously, references to boundary entities in parametric definitions should always be unambiguous, so that these entities can be unequivocally identified, every time the boundary evaluator is called to create a new b-rep. However, a general property of b-reps is that topologic entities may be split, as the block face in Fig. 2.a, merged or deleted, as the blended edge in Fig. 2.b, because of modeling operations. As a result, parametric definitions referring to such entities can become ambiguous or invalid, and therefore no longer usable by the boundary evaluator. This is usually called the *persistent naming problem*.

This problem has been classified as one of the most serious difficulties plaguing current parametric solid modeling systems. As Ragothama and Shapiro [10] put it, "the new solid modeling systems no longer guarantee that the parametric models are valid and unambiguous, and the results of modeling operations are not always predictable".

This paper claims that the problem is an inherent difficulty of the approach taken by current parametric modeling systems, and that it is of little use to insist on developing more and more persistent naming schemes which end up solving only a fraction of the problem. Instead, it revises the rationale that led to such schemes, and presents an alternative approach to parametrically define a model, which does not involve tracking changeable boundary model entities, but instead uses references to persistent entities in the parametric definition only.

The paper first briefly surveys current approaches to the persistent naming problem (Section 2). Next, the alternative approach to the definition of parametric models is presented (Section 3). Subsequently, the method used for edge ambiguity resolution is discussed (Section 4), and maintenance of the semantics in parametric definitions is illustrated with a number of examples (Section 5). These examples have been kept simple, to best illustrate the basic ideas. Finally, some conclusions are given (Section 6).

2. CURRENT APPROACHES TO PERSISTENT NAMING

Persistent naming is the process of tracking and identifying topologic entities as a model evolves. Currently, all commercial parametric modeling systems use a b-rep, and have their own scheme for maintaining persistent names, based on their own taxonomy of situations, heuristics and matching rules. Little is known of their details, which are proprietary information, let alone of the underlying theory, if any.

The main goal of such schemes is to guarantee that the boundary evaluator produces a valid boundary, in a deterministic way. In practice, although they seem to work correctly in several foreseen situations, all these schemes exhibit unpredictable results after certain modeling operations, which are not even the same for all systems. Because there are no standards for defining persistent names and consistently using them in parametric definitions, "different systems employ incompatible, ad hoc, and often internally inconsistent semantics for processing parametric models" [11].

A typical situation is illustrated in Fig. 3, with a very simple operation on the model of Fig. 2.b. If the position of the round slot is modified, making the parameter value *a* equal to zero, by which face f_2 in Fig. 2.a disappears, the model of Fig. 3.a is obtained. However, making the parameter value *a* equal to the block width, by which face f_1 in Fig. 2.a disappears, one would expect the model in Fig. 3.b., but many current modeling systems produce the model in Fig. 3.c. One can conjecture about the cause of these disparate results: for example, because in this parameter configuration the edge on which the blend should be applied (see Fig. 2.b) cannot be found, the system retrieves for

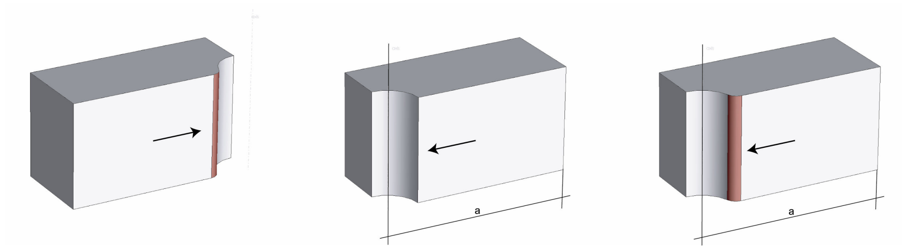


Fig. 3. Disparity of boundary evaluation results

that purpose the other edge resulting from the intersection of the same two faces (block front and slot), as shown in Fig. 3.c.

This example illustrates two major aspects of the persistent naming problem which have not always been clearly distinguished. They can be expressed through the following questions:

A. Given a b-rep, how to name a topologic entity that one needs to refer to in a parametric definition ?

B. When re-evaluating a b-rep after a modification in the parametric definition, how to map the named entities of the pre-edit b-rep to those of the post-edit b-rep ?

An answer to question A is required in order to blend the edge in Fig. 2.b, whereas an answer to question B is required in order to perform the edits in Fig. 3.

Since the first proposal for persistently naming topological entities by Kripac [5, 6], also several other schemes have been brought forward to alleviate the persistent naming problem [3, 4, 7, 12], so that the boundary re-evaluation can at least be consistently executed. See ref. [8] for a recent survey on persistent naming schemes, containing several more references. All these schemes use auxiliary data structures to keep track of how faces and edges evolve, but do not really solve the problem, as explained by Raghothama and Shapiro [10], who for the first time formalized the persistent naming problem. They introduced *boundary representation deformations* in their approach to the problem, which they related to the question of how to define families of objects in parametric modeling. The main issue in the latter is to determine which objects belong to a family, defined by a prototype model, and which objects do not. Basically they argue that as long as a continuous boundary deformation is possible from the prototype model to the new instance, the latter is considered to be a member of the family. However, as they also admit, continuous deformations seem to be too restrictive, and operations like splitting and merging of model entities would have to be dealt with, in order to allow topological changes such as the elimination of holes, but this has not been elaborated.

It can be concluded that the current approaches to persistent naming have not completely solved the problem. This is, in fact, caused by a wrong starting point: they all try to *keep track of b-rep entities that are not persistent,* and this is *impossible* in a truly generic way. It seems, therefore, more effective to develop a new approach, with a better starting point.

3. THE FEATURE-BASED APPROACH

All approaches mentioned in the previous section are in one way or another tied to the generic scheme of Fig. 1. As a result, parametric definitions are dependent on (the entities of) previously generated b-reps, while at the same time they determine a new resulting b-rep. Since this *interdependence* is the real cause of the persistent naming problem, one may legitimately wonder whether it is possible to eliminate it.

This question is affirmatively answered in this section, which presents an alternative approach to the *parametric definition of feature models*. Its basic idea can be summarized as follows:

1. provide and consistently refer to persistent entities in the parametric definition domain;
2. at each boundary evaluation step, ascertain that the semantics in the parametric definition still holds.

A similar idea to Step 1 has been hinted before by Pratt [9], and has been partially elaborated in [2]. Step 2 has not been proposed before.

The approach just sketched has the important advantage of clearly separating the two aspects of the persistent naming problem, A and B, highlighted in the previous section. In fact, Step 1 above will allow us, within a parametric definition, to refer to any entity of interest, whereas a successful Step 2 will guarantee that the post-edit b-rep conforms to all semantic requirements of the parametric definition. Because in Step 1 no topologic entities of the b-rep are referred to, solving the mapping problem of question B above is not at a stake. Instead, what Step 2 above is required to answer is the question:

B'. When re-evaluating a b-rep after a modification in the parametric definition, how to locate and validate in the post-edit b-rep the representation of the persistent entities used in the parametric definition ?

A clear and definite answer to this question is crucial because many edit operations result in significant topology changes in the post-edit b-rep. A typical example of this is that two originally intersecting b-rep faces intersect differently, after a modeling operation. If one such intersection edge is being referred to in the parametric definition, ambiguity should be avoided by using appropriate edge discrimination. In such situations, whenever it is possible to unequivocally determine where this edge is located in the post-edit b-rep, *this edge* should always be retrieved and used as specified by the parametric definition. The generic method for edge discrimination will be discussed in Section 4.

However, if such an unequivocal determination is impossible, it is certainly contrived, and a source of inconsistency, to have the system fetch some other edge instead, based on some pre-programmed criteria. We argue that *in such cases, which usually admit more that one acceptable way out, the choice should always be made by the user and not by the system*. Facilities for achieving this will be discussed in Section 5.

This section will introduce the basic elements required by the feature-based approach. First, three categories of persistent entities are presented: *reference* classes, *declarative feature* classes, and *procedural feature* classes. A parametric feature model basically consists of interrelated instances of these classes, and thus contains persistent entities only. At the end, the method for referring to intersection edges is described.

3.1 Reference classes

A *reference* is a uniquely named auxiliary entity with a predefined geometry, which can be associated to other entities in a parametric definition by means of geometric constraints. Basic examples of *reference classes* are a *plane reference* class, a *cylindrical reference* class and a *line reference* class, from which other classes can easily be derived or composed. Each reference class should provide its own positioning and orientation scheme, which fixes the degrees of freedom of its reference geometry relative to other persistent entities in the parametric model.

Reference instances play a very useful role in creating and editing features in a model. For example, in order to create an array of holes in a feature model, one can first place a reference plane in the feature model, followed by the creation of the hole instances, each one positioned relative to this reference plane. Subsequent displacement of these holes can then be easily achieved in one step by modifying that reference's position. Used in this way, reference instances allow positioning of features relative to entities in the parametric definition that do not even correspond to any face or edge in the b-rep of the object. Obviously, referring to such entities is always unambiguous and possible, as long as those entities remain in the parametric definition.

More importantly, in the context considered here, references can be used in a parametric definition to define half-spaces, which are instrumental in solving ambiguities among edges, as will be shown in Section 4.

3.2 Declarative feature classes

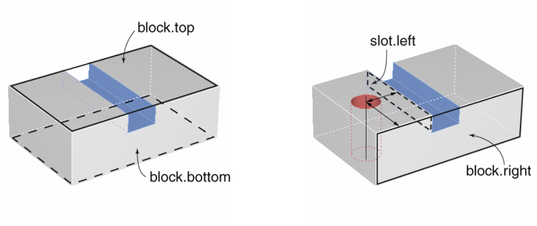
The notion of *declarative feature class* is central to our approach. A declarative feature class is a structured description of all properties of a given feature type, defining a template for all its instances.

Declarative feature class descriptions build on a parameterized volumetric shape, accounting for a bounded region of space. This parameterized shape, called *canonical shape*, allows us to think of a declarative feature class as a parametric family of objects.

On the boundary of the canonical shape, one can distinguish each boundary face with a unique, generic name. These entities are called *feature faces*. For example, the shape of a cylindrical hole class, has *top*, *bottom* and *side* feature faces. An essential property of feature faces is that, unlike b-rep entities, they are never split, merged or deleted, even though their geometric representation may be.

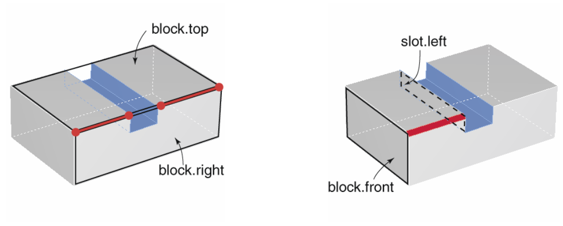
In addition to the feature faces just mentioned, several *feature references* can be specified within a feature class as auxiliary geometric entities. Examples of these for a cylindrical hole are the axis line reference or, along that axis, a longitudinal plane reference. Feature faces and feature references are here called *feature elements*.

Internally, a declarative feature class encapsulates a set of constraints which geometrically and/or algebraically relate its shape parameters and its feature elements. All these feature constraints and feature elements are members of the feature class, and are therefore automatically instantiated with each feature instance. Furthermore, a feature class



(a) attach faces (b) positioning faces

Fig. 4. Referring to feature faces to attach a through hole



(a) (b)

Fig. 5. Creating a chamfer on part of a feature edge

associates to its shape the notion of *feature nature*, indicating whether its feature instances represent material added to or removed from the model (respectively *additive* and *subtractive* natures).

Typically, the feature elements and a number of feature shape parameters are made public in a feature class, and belong therefore to the class interface. In addition, each feature class may specify in its interface a number of positioning and orientation schemes, which allows us to relate some of its feature elements to external entities. The latter can be chosen out of, for example, the feature elements of features already present in the model.

Using feature elements for attaching and positioning features relative to each other in a model has two main advantages. First, a dependency relation is established in the parametric definition among its features. Second, each of these elements is indeed *persistent*, and therefore its unique name is also *persistent*. Indeed, assuming no two feature instances have equal names, which is easy to realize, the combination

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<feature instance name>.<feature element name>
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unequivocally determines one and only one entity, which can always be found in the parametric definition domain, as long as that feature instance has not been explicitly removed.

In order to fully exploit the potential of the feature faces, it is necessary, in particular for their identification, that *each face in the b-rep of a feature model be always a geometric representation of (possibly a part of) one and only one feature face*. This is easily achieved by fulfilling the following two requirements: (i) every b-rep face carries an attribute with the name of the feature face from which it originates (called its *owner*), and propagates this name every time it gets split; and (ii) two adjacent b-rep faces that are coplanar are never merged, unless they have the same owner. Although the latter is in contrast to common b-reps based on maximal faces, this requirement poses no limitations regarding efficiency, model traversal, model visualization or face selection.

The above property is very important for user interaction purposes, e.g. at the moment of picking some *b-rep face* on the visualized model, in order to attach or position a feature: it is always possible to find out which corresponding feature face should be stored in the parametric definition for that operation.

For example, in order to attach a through hole instance to the model of Fig. 4.a, as shown in Fig. 4.b, all that is needed is to let it refer to the top and bottom feature faces of the block instance as its attach faces, and to choose two other feature elements for fixing the through hole's axis position, e.g. the block's right face and the slot's left face, as shown in Fig. 4.b. All entities referred to in this operation are persistent feature elements, and thus always available in the parametric definition of the object.

The canonical shape of declarative features can be fully determined, in the parametric domain, by solving the geometric constraints involving them, which takes into account all dependencies among features.

Similarly as for reference instances, each feature instance is assigned a unique name when it is created in a parametric definition. Actually, regarding persistent names and their usage in parametric definitions, say, a planar feature face and a plane reference are quite analogous. For this reason, unless otherwise stated, in the remainder of this paper we will simply mention *feature elements*, where various reference instances can be meant as well.

3.3 Procedural feature classes

The example in Fig. 4 deals with the use of feature faces for attaching and positioning declarative features. However, some features, e.g. chamfers and blends, are associated with edges, rather than with faces, on a b-rep.

Two characteristics of such features justify that they form a separate category, their classes being designated as *procedural feature* classes. First, the actual shape of a procedural feature is strongly dependent on the geometry of the b-rep edge it is attached to. Second, a procedural feature may have either additive or subtractive nature, according to the convexity of that edge. This means that (i) unlike declarative features, procedural features rely on the actual existence of a particular edge on the b-rep, and (ii) their shape can only be determined *after* that edge has been identified and located.

In other words, the semantics of a procedural feature is such that, whereas on the one hand it *poses specific requirements* on the evaluated b-rep (e.g. the edge must exist and be unambiguously identified), on the other hand that same semantics is *configured* by the evaluated b-rep (e.g. by the particular geometry or convexity of the edge). The difficulties raised by this necessity of referring to an edge from within the parametric definition of procedural features will be dealt with in the next subsection.

3.4 Referring to edges

Referring to b-rep edges presents the most challenging problems in all persistent naming approaches. Among other reasons, b-rep edges are strongly dependent on the particular way in which features intersect: a small parameter variation can have drastic consequences on the topology of the boundary model.

In order to characterize b-rep edges, one should first realize that for *every edge* in a manifold b-rep consisting of planar faces holds that it *has always two adjacent b-rep faces*. Similarly, *regarding the start and end vertices of any edge*, one can also observe that *there is always an additional face incident on each vertex*.

In turn, because each of these four b-rep faces is always representing some feature face, referring to a b-rep edge can again be transferred to the parametric definition domain, involving references to the corresponding feature faces. Indeed, these two pairs of feature faces are enough to unequivocally determine an edge, as illustrated by the example in Fig. 5, where a chamfer is to be applied on an edge. Although in this model two b-rep edges lie at the intersection of the feature faces block.top and block.right (Fig. 5.a), the desired edge can be distinguished by indicating one other feature face incident on its start vertex and one on its end vertex (Fig. 5.b). In other words, the pair

```
(<block.top,block.right>, <block.front,slot.left>)
```

can be used to identify that edge in the parametric definition of the chamfer.

Assuming that each b-rep face carries an attribute with the corresponding feature face name (see Subsection 3.2), it is always possible to search the b-rep for an edge having the feature face adjacency relations specified by a pair in the form:

```
(<adjacent feature faces>, <discriminator>)
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In the example of Fig. 5, the discriminator consists of the names of the start and end feature faces. These two feature faces names are always able to discriminate any edge resulting from the intersection of two planar feature faces.

However, such discriminators are not always sufficient to unambiguously identify intersection edges defined by non-planar faces, as illustrated by the example in Fig. 2.a, where a 'feature face' of the block intersects twice the cylindrical 'feature face' of the round slot, and both intersection edges have the same feature faces incident on their start and end vertices.

It is in such situations that it becomes necessary to further discriminate those edges. We use half-spaces, defined by means of references, to disambiguate multiple intersection edges using only vocabulary from the parametric definition domain, as will be described in the next section.

4. EDGE AMBIGUITY RESOLUTION THROUGH AUTOMATIC HALF-SPACE PARTITIONING

The basic idea of our method for disambiguation of multiple intersection edges between two intersecting faces consists of automatically defining (one or more pairs of) half-spaces such that no two edges lie in the same (combination of) half-space(s). Each pair of half-spaces is defined by a reference instance that is automatically positioned relative to (entities of) the two features whose faces are intersecting. Depending on the geometry of the intersecting faces and/or on the number of intersection edges, one or more pairs of half-spaces may be required to achieve a complete edge discrimination.

The procedure can be illustrated with the example of Figures 2 and 3. When the edge to be blended is selected, its two adjacent feature faces –block.front and slot.side– are analyzed. Because one of them is cylindrical, and two edges arise from their intersection (see Fig. 6.a), a plane reference is generated automatically and positioned relative to the two intersecting faces: *passing through the axis of the cylindrical face* (of the slot) and *orthogonal to the planar face* (of the block). As a result, the two intersection edges can be distinguished, in the parametric definition domain, by means of their half-space discriminator, using the following persistent names:

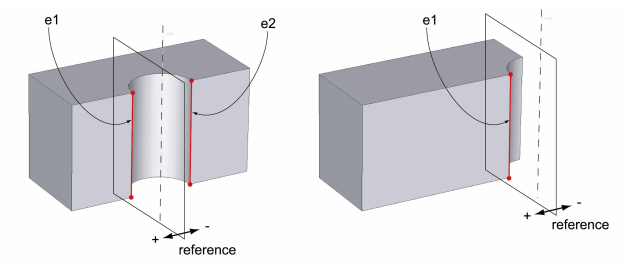

Fig. 6. Discriminating two intersection edges with a half-space

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e₁ → (<block.front, slot.side>, <block.top, block.bottom, reference.positive>)
e₂ → (<block.front, slot.side>, <block.top, block.bottom, reference.negative>)
```

Therefore, in the parametric definition of the blend feature (see Fig. 2.b), the name of edge e_1 can be used.

When the operation in Fig. 3.a is performed, the new location for the round slot is determined by the constraint solver and, consequently, also that of its dependent half-space reference. This is illustrated in Fig. 6.b, where the value of parameter *a* has been made equal to zero. When the parametric definition of the blend has to be evaluated, the corresponding edge e_1 is unequivocally located in the b-rep using its persistent name given above. The discussion of the operation depicted in Fig. 3.b and c will be dealt with in the next section.

A second example is given in Fig. 7.a, consisting of two crossing holes with coplanar perpendicular axes and different radii. The side faces of the two holes intersect along two edges, e_1 and e_2. Assuming that, for example, edge e_1 has to be blended, and thus needs to be discriminated from e_2, a plane reference will be generated and automatically positioned, passing *through the axis of hole$_1$* and *orthogonal to the plane defined by both axes*, so that the two edges lie in different half-spaces, as shown in Fig. 7.b.

The persistent edge name referred to in the parametric definition of the blend feature is then

```
e₁ → (<hole1.side, hole2.side>, <reference.negative>)
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If, for example, hole$_1$ is rotated so that the angle between both axes is modified, the reference plane will be oriented accordingly, therefore always correctly discriminating the two intersection edges, as shown in Fig. 7.c.

At each boundary evaluation step, a generic partitioning algorithm is responsible for the generation and positioning of new references whenever, as a result of that evaluation step, two feature faces intersect along more than one edge. Firstly, the algorithm identifies each group of intersection edges defined by the same two feature faces. This is straightforward, as each of those edges is adjacent to at most two b-rep faces, which in turn carry the persistent name of the corresponding feature face (see Subsection 3.2). Secondly, each of these groups is separately analyzed. Based on (i) the type of surface of each feature face involved, (ii) the type of the canonical shape in the respective features, and, possibly, (iii) the references already available from the respective feature class (e.g. axes), one or more references are generated and positioned, relative to elements of the two features whose faces are intersecting, so that each edge in the group falls in a different half-space combination. The algorithm is iteratively applied to each intersection group, discriminating its edges into new half-space combinations, by means of new references. In the end, all intersection edges arising from that boundary evaluation step are unequivocally discriminated, bearing names as described above.

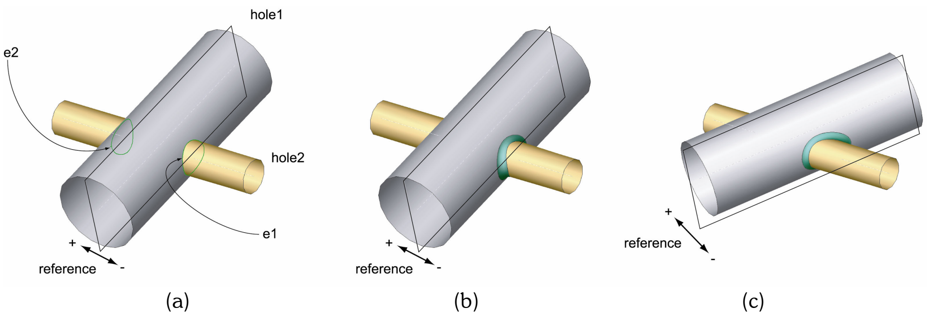
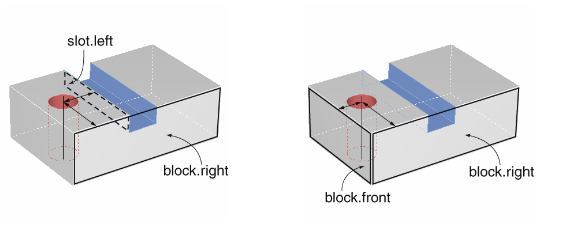


Fig. 7. Discriminating the intersection edges of two crossing holes



(a) positioning faces (b) alternative positioning faces

Fig. 8. Modification of feature dependencies in a parametric definition

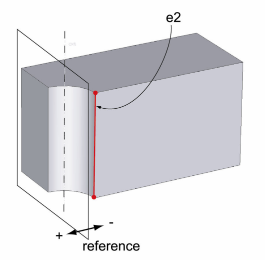


Fig. 9. Preserving semantics for the operation in Fig. 3.b-c

The disambiguating method just proposed has been successfully validated for the domain of faces with quadric surfaces (planar, cylindrical, spherical and toroidal). It has the obvious advantage that it consistently refers to persistent entities only, either feature faces or references. The method guarantees that, whenever the b-rep has to be re-evaluated, the names of these persistent entities can be used to unequivocally identify the corresponding b-rep entity. If the latter is indeed present in the b-rep, it is retrieved and used as required by the parametric definition being processed. If, however, *that entity* cannot be unequivocally found in the b-rep, we have an essentially different situation. The detection and handling of such cases is the subject of the next section.

5. PRESERVING SEMANTICS IN PARAMETRIC DEFINITIONS

In Subsection 3.2 an example was given of how, in a parametric definition, declarative features are related to each other (see also Fig. 8.a): the through hole is related to both the block and the slot, by means of attach and positioning relations. These relations define a dependency between the through hole and the features it refers to: the block and the slot. Through such dependencies, it is always possible to determine within a parametric definition which entities depend on a given entity, so that removal of the latter can be disallowed as long as those dependencies are not removed. In this example, removing the slot of the model is not possible as long as it has the through hole as a dependent feature instance. This dependency can be removed, by modifying the parametric definition of the through hole, for example, repositioning it relative to the block's front face (see Fig. 8.b).

Dependency relations among features express an essential aspect of the semantics in a parametric definition. Dependencies can be modified by the user, but their consistency should be guarded at all times by the system, so that all entities in the parametric definition always refer to existing entities only.

The same dependency relation exists when a procedural feature refers to a b-rep edge using persistent names such as described in the previous section: that feature is dependent on the features occurring in the persistent name of that edge. So, for example, the chamfer in the model of Fig. 5.b is dependent on both the block and the slot.

In addition to this, procedural features are also dependent on the actual existence of the specified edge in the b-rep. When this edge, once referred to in a parametric definition, no longer can be found in the b-rep, we say that there is a violation of the semantics expressed in the parametric definition, which becomes invalid. In these cases, as already stated in Section 3, there can be no generic procedure to *automatically* solve or circumvent the problem, because usually several 'equally admissible solutions' can be devised for each situation. Therefore, having the system unilaterally choosing one of them simply *cannot always be satisfying*. As a much better alternative, we propose to offer the user the possibility to fix the problem, choosing from the available options. For this, the boundary evaluator should temporarily suspend its execution, at each step where the semantics is being violated, and provide the available details on the violation, in order to assist the user in solving it. Only after that can the boundary re-evaluation process continue.

In order to detect such situations, a procedure is needed that checks, at each boundary re-evaluation step, whether it is possible to locate an edge in the current b-rep, given its persistent name in a parametric definition. There are three circumstances that lead to the impossibility of locating such an edge in the b-rep:

1. the two specified feature faces do not intersect anymore;
2. the two specified feature faces intersect, but no edge of this intersection complies to the discriminator requirements in the parametric definition;
3. the two specified feature faces intersect, and several edges of this intersection comply to the discriminator requirements in the parametric definition.

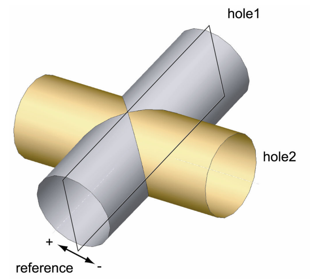


Fig. 10. Ambiguous situation: two edges comply to the discriminator requirements

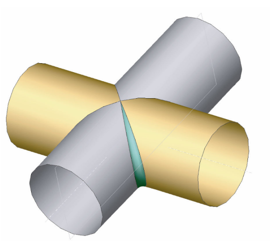


Fig. 11. Improper ambiguity handling: one of the edges is automatically chosen for blending

The first case is trivial, and can easily be detected by observing that no edge in the b-rep has as adjacent faces the two feature faces specified in the given persistent name.

For the other cases, the b-rep is also searched and all intersection edges defined by the two specified feature faces are retrieved. For each such edge, a check is performed on whether it complies to the discriminator requirements.

A simple example of Case 2 above is related to the operation in Fig. 3.b-c. Assume that the discriminator for the blended edge is that given in the previous section (see again Fig. 6.a). When the round slot, together with its dependent reference, is displaced to the left, as shown in Fig. 9, then there remains only one intersection edge between the block.front and the slot.side faces, but this edge is located in the half-space opposite to the one specified in the discriminator. Consequently, regarding the specification of the blend feature, its required edge does not exist anymore and the parametric definition becomes invalid.

Finally, an example of Case 3 above, based on the model shown in Fig. 7.a, consists of enlarging the radius of $hole_2$, so that both holes get equal radii, as shown in Fig. 10. In this modified model, the intersection of the two holes defines not two but four edges, of which two lie in the half-space specified in the discriminator of edge e_1, and two in the other half-space. Therefore, ambiguity occurs, and the parametric definition becomes invalid. As there is no unique answer to the question on which edge (or edges) should the blend feature be applied, the user is consulted. One can contrast this approach with the arguable result for this operation, obtained in a commercial modeling system, shown in Fig. 11, where one of the four edges is automatically blended by the system.

In all three cases, possible corrective actions offered to the user include:

- eliminate the feature at hand from the parametric definition;
- modify the parametric definition of the feature at hand to refer to one of the edges available in the b-rep;
- cancel the modification operation that caused the invalidity, and backtrack to the previous model situation.

Additionally, in Case 3 also the possibility should be given of adding to the parametric definition new feature instances (of the same class of the feature at hand) applied to the other edges that comply to the discriminator requirements.

Another aspect of preserving the semantics in a parametric definition has to do with the compliance of each feature to the validity criteria specified in the respective feature class [1]. A few simple criteria of this type can already be found in some current commercial parametric modeling systems, such as the requirement that a feature should somehow contribute to the object shape (think, for example, of a hole that is displaced, and falls completely out of the model). Other feature validity criteria, however, typically require enhanced b-reps suitable for more complex topologic analyses [1], and it is expected that these will be steadily incorporated into future parametric modeling systems. Implementation of the naming scheme introduced here is, however, independent of this, and can be done with standard b-reps too.

6. CONCLUSIONS

An alternative approach has been presented to solve the well-known persistent naming problem in parametric feature modeling systems. Usually, a dual representation is used in such systems: a parametric definition and a b-rep of the resulting shape. It was shown that the problem occurs because in the parametric definition of an object, non-persistent entities in intermediate b-reps are referenced to attach and position additional features in the model.

Previous attempts to solve the problem tried to keep track of all non-persistent entities with auxiliary data structures, but this has so far not been successful, and it is questionable whether it will ever be.

A completely different approach was therefore proposed, which distinguishes and separately deals with the two main aspects of the problem: (i) *entity naming* in parametric definitions, and (ii) *entity identification* in the b-rep. Regarding the former, all references are made to entities in the parametric definition, instead of in the b-rep. Such entities are persistent and so, obviously, their names too. Regarding the latter, feature-related information is deployed, both in the parametric definition and in the b-rep, to identify any entity being referred to.

One might say that in this way the persistent naming problem, at least in its original formulation, was actually avoided. However, in fact, this feature-based approach deals with unambiguous cases in a straightforward way, and with ambiguous cases in a realistic way: refraining from attempting to automatically manage them, because of their intrinsic ambivalence, but, instead, requesting user intervention in order to choose out of the available solutions.

The feature-based approach has been illustrated with several examples, and contrasted with results for the same operations obtained using current commercial modeling systems. Notably, the solution proposed poses no special requirements on the boundary representation used, and may therefore be used in any parametric modeling system, as long as there is a clear separation between the parametric definition and the representation of the resulting shape. It may, therefore, contribute to the solution of a long-lasting problem in parametric feature modeling.

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