CHAPTER 10

From characteristic shapes to form features : a recognition strategy

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A part needs to be considered from separate technical viewpoints. A need of form features transmutation and recognition derives from this assessment. This paper presents a recognition strategy to fulfil this need. The strategy consists in the separation of the process in two steps: first to produce elementary characteristic shapes from a pure geometric viewpoint, then to assemble these shapes in form features depending on the technical viewpoint used. The geometric viewpoint is detailed and follows a set of rules which characterize shapes as modifications of a succession of previous gross shapes. Each characteristic shape is extracted after recognition in order to produce the proceeding gross shapes, thus enabling an easier process for succeeding recognitions and producing a proposition for a global gross shape at the end of the process.

10.1. LIMITATIONS OF THE MODELLING BY FORM FEATURES APPROACH

It is now recognized by an increasing number of people that the Form Features approach for modelling presents an Achilles Heel: its need for a one to one correspondence between a Form and a Feature.

A part, or more generally an object, needs to be considered from several viewpoints (functional, stress analysis, machining, control,...). A specific form on a part can then bear semantics that depend on the viewpoint, modelling by form features can be efficient in such a case, provided that the semantics corresponding to each viewpoint are added to the original form features, either manually or automatically. Such an automatic process could be named Form-Feature Transmutation .

Unfortunately, the forms related to different viewpoints are not always the same. Some surfaces may appear in separate form features depending on the viewpoints; when such is the case, the part cannot be described by the concatenation of a gross

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shape and a set of form features since the set must include all the form features needed by all the viewpoints. A classical example is a viewpoint for which there is a slot in a block, and another one for which there are two ribs on another block. To take this problem into account, one must either describe the new form features related to a new viewpoint by the interactive collection of faces constituting such new form features, or do it automatically by a recognition process.

A comprehensive product modelling system is thus to provide simultaneously :

1 Modelling by form-features from a specific viewpoint
2 form-features transmutation between viewpoints
3 form-features recognition under viewpoints constraints

One can note that a neutral viewpoint can be provided , which corresponds to pure geometric modelling, taking into account the facts that a model can be imported from other modelling systems, and that some designers prefer to model freely, that is to say without any technological constraints.

10.2. THE FORM FEATURES TRANSMUTATION AND RECOGNITION

The basic idea underpinning this paper is that Form Features Transmutation and Form Features Recognition are closely related to one another, and that they are presently plagued with the very concept of Form Features.

The concept of Form Features was a healthy reaction to the CAD-CAM systems which were mere geometric modellers producing a form ands lacking all other informations, when these informations are precisely the meaningful ones for the part manufacturing. Since each detail of the part's geometry is either meaningful or to be discarded, it was decided to connect the details to their meaning and to name it a Form Feature.

The wrong issue was that this connection is made a priori for a specific viewpoint, instead of dynamically, depending on the active viewpoint.

Hence, one may consider a part as a set of Characteristic Shapes dynamically assembled into Form Features.

The characteristic shapes are related to the geometrical properties of the part, the assembly of characteristic shapes depends upon the viewpoint and produces different sets of Form Features specific to each viewpoint.

In this definition of the part as a dynamic set of Form Features built from a static set of characteristic shapes, the transmutation and the recognition of the Form Features problems are reduced to a single process in two steps:

1 recognition of the characteristic shapes out of the part's geometry and of existing Form Features
2 aggregation of characteristic shapes into Form Features under the semantic constraints

This chapter is devoted to the first step of the process.

10.3. TAXONOMY OF THE CHARACTERISTIC SHAPES

From a geometric viewpoint, one may separate the characteristic shapes into three categories:

1 Dimensional characteristics (aspect ratios, length values,...)
2 Curvature characteristics (roundness, planeity,...)
3 Topological characteristics (holes, concavities, ...)

One can also relate characteristic shapes to the modification of a basic gross shape, and classify the characteristic shape by the geometric element of this modified gross shape:

1 Modification of a vertex (rounding or chamfering of ...)
2 Modification of an edge (rounding or chamfering of ...)
3 Modification of the interior of a face (hole or boss)
4 Modification of the interior of two faces (hole or handle)
5 Modification of two faces along their common edge
6 Modification of *n* faces sharing *n* edges and a vertex

In order to avoid a complex recognition of uncontrolable combinations, it is convenient to eliminate the interferences between Form Features.

The basic strategy to do so is to reconstruct the gross shape step by step after each detection of an alteration by a Characteristic Shape. Such a strategy is best applied if one starts with the smaller alterations; it is named the Characteristic Shapes Extraction.

10.4. CHARACTERISTIC SHAPES EXTRACTION

To recognize more easily the morphology of shapes, it is convenient to extract first the shape characteristics that modify edges and vertices, namely chamfers, filets and roundings.

10.4.1. Edge and vertex characteristic shapes

The Characteristic Shapes of both edges and vertices are recognized thanks to the dimensional and curvature properties :

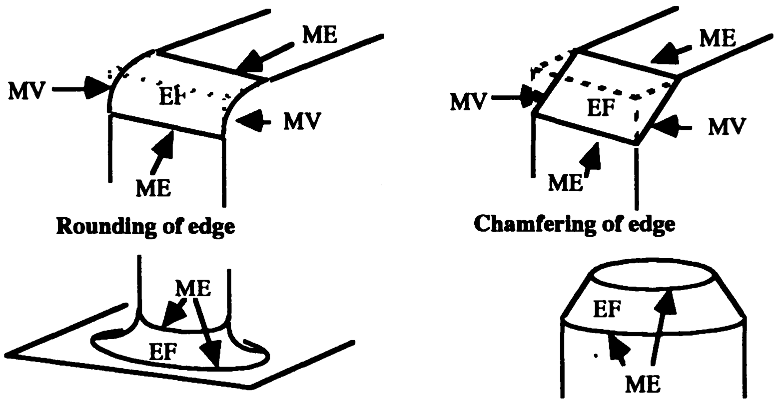
1 the high aspect ratio (length / width) faces
2 the parallel "long" edges of the faces which indicate the direction of the modified edge of the gross shape.
3 the "small" edges length (compared to the mean dimension of the part)

By using the properties of the face modifying an Edge (Edge Face) or a Vertex (Vertex Face), one can use the dimensional criteria to recognize the faces candidate to be Edge Face. Such criteria are:

1 a face with four sides and two opposite parallel sides has a probability to be an Edge Face, proportional to its aspect ratio;
2 a possible Edge Face connected to other possible Edge Faces has an Edge Face probability equal to the maximum value of all these possible Edge Faces.

The parallel sides of an Edge Face correspond to the modified edge and they are named Modified Edge; the other sides correspond to the vertices of the modified edges and they are named Modified Vertex. There are angular conditions over the Modified Edge which stands for that the faces connected to the Edge Face along the Modified Edge must have angles equal to 0 (tangency) if the characteristic shape is a rounding, to 45, 30 or 60 if the characteristic shape is a chamfer (other angles stay under the responsibility of designers).

It is to be noted that two coaxial circles are considered parallel lines and that Edge Faces can be connected directly by their Modified Vertex or through a Vertex Face.

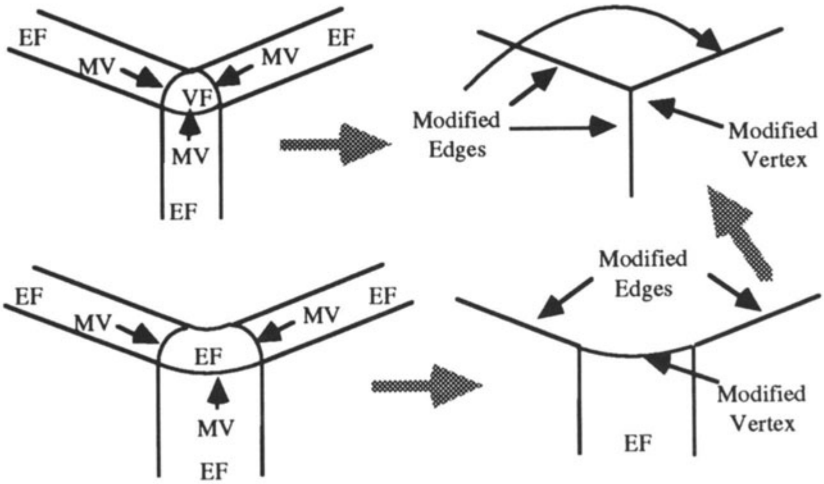


MV = Modified Vertex EF = Edge Face ME = Modified Edg

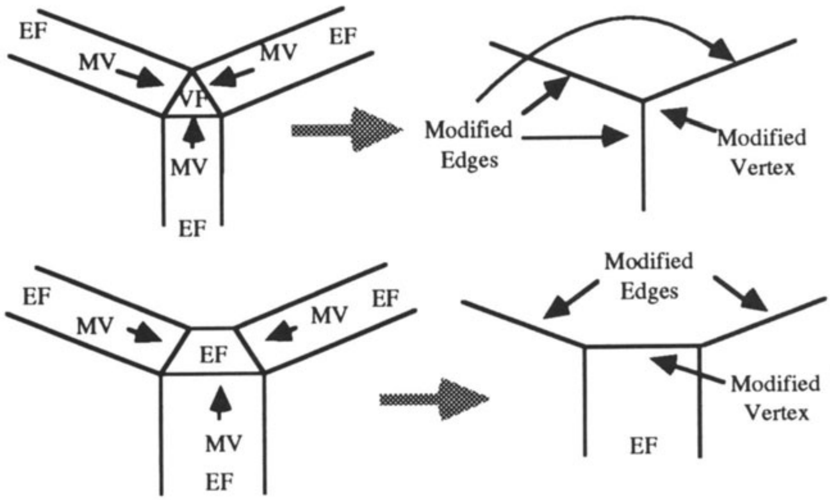
The Edge Face-Vertex Face recognition-reconstruction process can be summarized by the following drawings which present the sequence of the typical reconstruction process.

This typical reconstruction process can be summarized as follows :

1 Recognize the possible Edge Faces and compute their Edge Face probability,
2 Select the maximal Edge Face probability faces and chain the possible Edge Face by their Modified Vertex, while recognizing Vertex Face as connected to possible Edge Face only. Each Edge Face chain has the probability of its first Edge Face.
3 Reconstruct the modified edges and vertices of the chain having a serious Edge Face probability.



Reconstruction process of rounded edges



Reconstruction process of chamfered edges

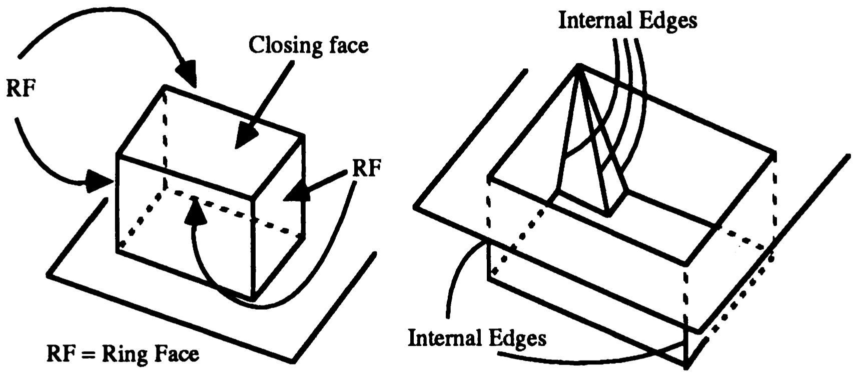
MV = Modified Vertex ; EF = Edge Face ; VF = Vertex Face

10.4.2. Interior of face characteristic shapes

The internal part of a face is modified by the creation of a circuit of edges inside the face (a ring). To allow the definition of elementary characteristic shapes needed for the multiple views recognition of Form Features, the recognition of the faces modifying a Ring (Ring Faces) proceeds by incremental collection of faces.

This incremental collection process is the following:

1 Collect the Ring Faces connected to an inside circuit of edges, and mark their connection edges as Modified Edge;
2 Chain the Ring Faces by the Modified Edge vertices and mark the connection edges of these Ring Faces as Internal Edges;



The Ring Characteristic Shape is the chain of Ring Faces built above; and the unmarked edges of the Ring Characteristic Shape constitute a virtual face which is named the Continuation Ring of the Ring Characteristic Shape.

The Continuation Ring of the Ring Characteristic Shape can either be a face or a set of faces. In each case, the faces of the Ring Characteristic Shape are removed from the object. This process of Characteristic Shape extraction reconstruct the original shape, on which the insertion of a ring produced this Characteristic Shape.

After the removal of the Ring Characteristic Shape, one proceeds further thanks to the Continuation Ring.

1 If the Continuation Ring is connected to one face only, (which could be a null face) this face closes inside of face Characteristic extraction and its faces collection;
2 If the Continuation Ring is connected to a set of faces, a successor of the inside circuit of edges is searched to loop back in the collection process.

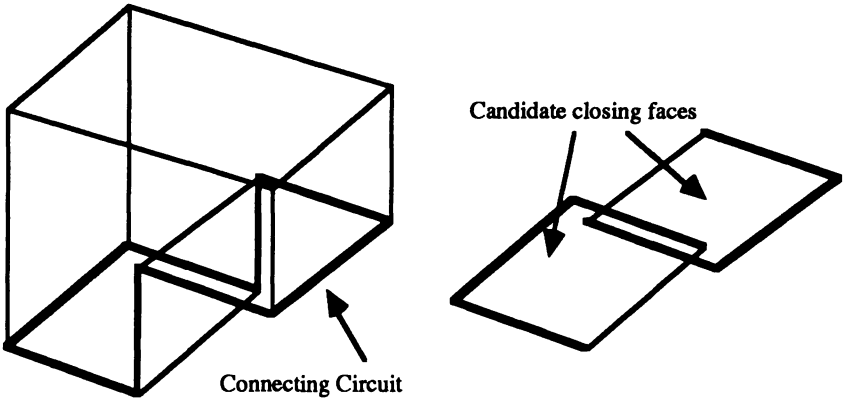
The successor of the inside circuit of edges is the continuation Ring itself if the number of faces connected to it is equal to its number of edges. When it is not the case, two strategies can be used :

1 Split down the Ring Characteristic Shape to produce the elementary geometric features needed for further recognition;
2 Extend the Ring Characteristic Shape to the faces having more than one edge connected to the Continuation Ring, and modify accordingly the Continuation Ring until it constitutes a successor to the inside circuit of edges.

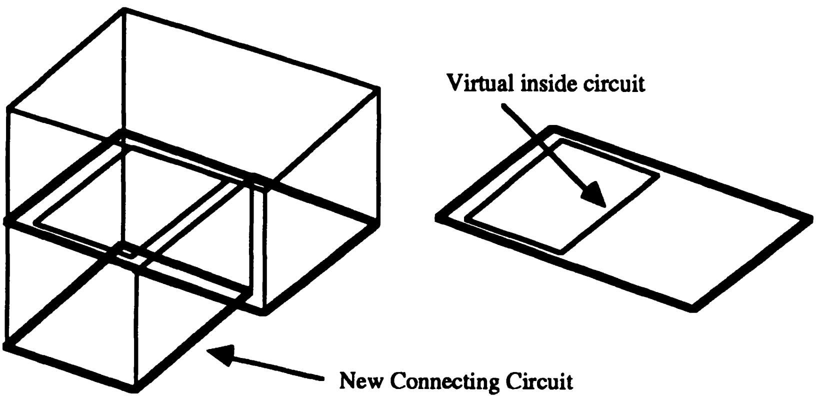
When the Continuation Ring is the successor of the inside circuit of edges, the Ring Characteristic Shape is closed by the face corresponding to the Continuation Ring and is removed from the part, then the successor of the inside circuit of edges is used to loop back in the process.

One can note that the Ring Characteristic Shape can be closed by an inside circuit of edges in a face; in such a case, the Characteristic Shape is connected to the interior of two faces and is a through hole or a handle.

The split down of a Ring Characteristic Shape is done to produce the elementary Ring Characteristic Shape required by the further dynamic recognition of Form Features. A face which is connected to more than one edge of a continuation Ring is a would-be closing face of a Ring Characteristic Shape which is still to be constructed. This situation evolves from the interference of several characteristic shapes. An example of this situation is shown hereafter:



Two faces are candidates to be closing faces, since they are connected to the continuation Ring by several contiguous edges; these contiguous edges can be the beginning of a Continuation Ring.



Split down of a Ring Characteristic Shape

If we extend these faces in the direction where their possible Continuation Ring are open, they can cut the faces of the Ring Characteristic Shape, or not. Whenever there is an intersection, the intersection splits down the Ring Characteristic Shape into two parts; the lines of intersection are then used to create a virtual closing face and a virtual inside circuit in it to continue the Ring Characteristic Shape collection process.

Do note that with the extension of the Ring Characteristic Shape strategy, all the faces connected to the original Continuation Ring would have been included and would have produced a concave shape that would be split down by the concavity removal process later on.

10.4.3. Contour Characteristic Shapes

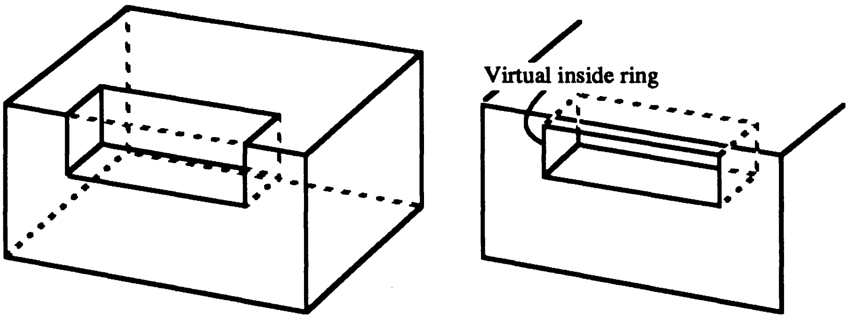
The last characteristic shapes correspond to concavities in the face (and in the solid) and they are connected to more than one face. Two strategies can be used to remove thee concavities ; they correspond to different possible viewpoints.

These strategies are :

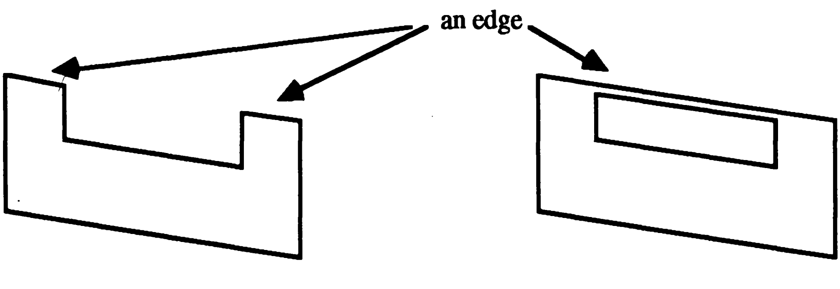
1 Fill the void between the concave shape and an enclosing convex shape;
2 Cut the material out of the basic convex shape.

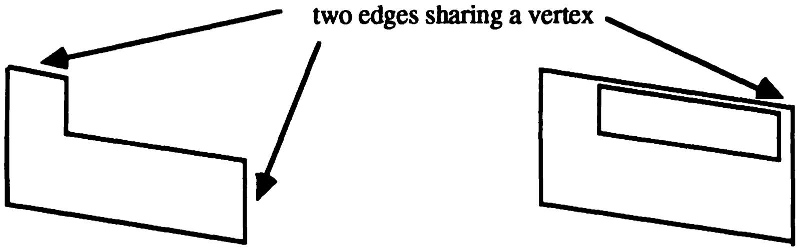
For each strategy, one would modify the faces by extension of edges instead of convex envelope creation.

In the first strategy, a concavity can be considered as a virtual ring when the concavity is removed from the contour.



When there is a concavity on a face, this concavity can modify the convex original face along:

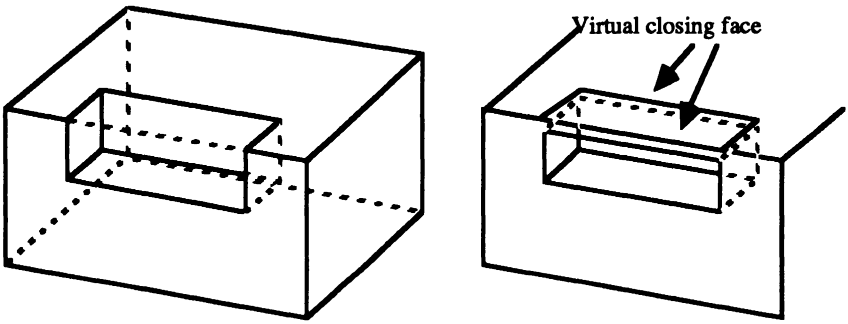




When the concavity is modified into a virtual Ring on a face, the faces connected to the modified edges are to be modified accordingly.

The virtual ring creates a virtual edge which has no connex face and a reconstructed edge on the face, this reconstructed edge has a connectivity lag on the portion corresponding to the virtual edge.

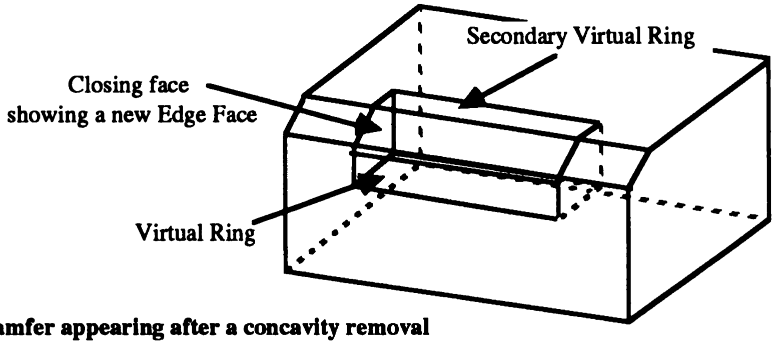
The vertices of the virtual edge are also vertices of edges on the connected face(s) which begin the contour of a virtual closing face. This virtual face closes the connected face(s) at the external side and the virtual collection of Ring faces connected to the virtual ring at the internal side.



These reconstructive properties of the concavities are used to define the faces collection process:

1 If a face is not processed, transform its concavities, if any, into virtual rings and mark the faces connex to the modified edges as processed at level 1, while the processed face is marked at level 2 if modified, and level 3 if not;
2 When all faces are processed at level >0, process again faces at level 1 and close them by union with the virtual closing faces built from the circuits of edges originating at virtual edges. These closing faces are also used with an opposite orientation to complete the set of faces before the Ring face collection.
3 Switch to the Ring face process to make the virtual Ring face collection, and the virtual continuation Ring.

Do note that the creation of the virtual rings on the faces processed at level 2, followed by the closure of faces processed at level 1, can show new Edge Faces due to interferences between the Edge Face and the Ring Face Characteristic Shapes.



Chamfer appearing after a concavity removal

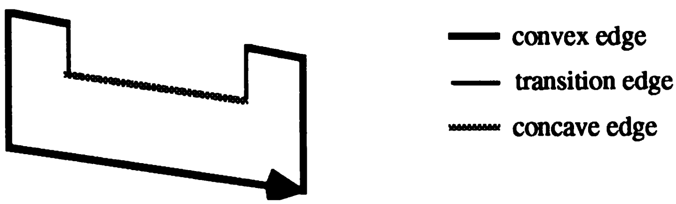
Since chamfers or roundings can appear after a concavity removal it is useful to have a new Edge Face process running before processing the virtual rings. In this process, the virtual edges of the virtual rings are modified by the Edge Face process as well as the reconstructed edge.

After the Edge Face process the chamfer or rounding is removed and a closing face can disappear, this creates two virtual rings corresponding to the same virtual edge; one of them must be replaced by a closing face. One can note that this Edge Face removal brings us back to the first concavity removal studied.

The second strategy corresponds to the split down of a Ring Characteristic Shape and needs to create new edges and new faces on the gross shape before removal of the Characteristic Shape. This strategy follows three steps :

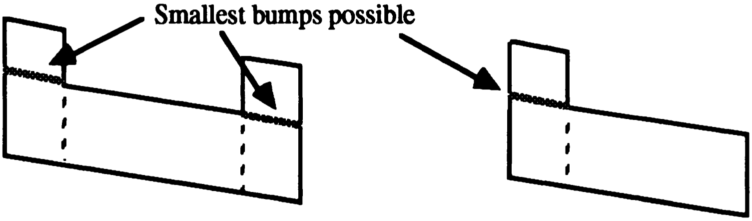
1 Cut concave faces by virtual edges to obtain a set of convex faces tessellating the original concave face;
2 Create virtual faces and virtual inside circuits from the virtual edges of step one;
3 Go back to the interior of a Face Characteristic Shape removal process.

The concavity removal process of step one begins with the orientation of the face ("material on the left" for example). The edges can then be characterized as :



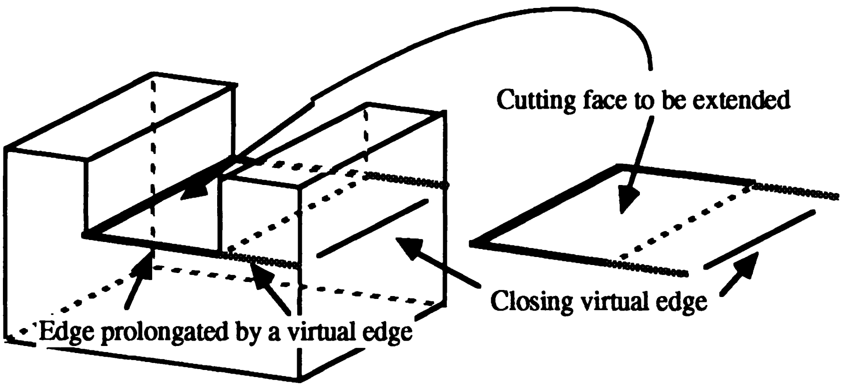
In the "filling the void" strategy, the convex edges preceding and following the transition edges are prolongated by virtual edges outside the face and create a virtual inside ring.

In the "cut the bumps" strategy, the concave (or transition) edges following or preceding the transition edges are prolongated by virtual edges inside the face and create a new face.



One can note that there are alternative solutions to cut the faces; a rule stating that one must cut the smallest possible bumps can be used, but would result in a non exhaustive recognition of the Characteristic Shapes of the part.

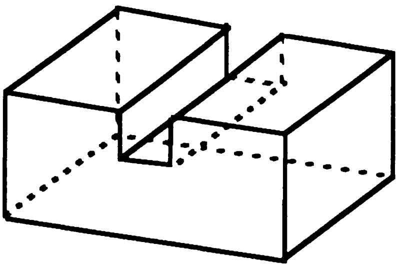
The creation of virtual faces and virtual inside circuits is done by extension of the virtual edges created in the first step.

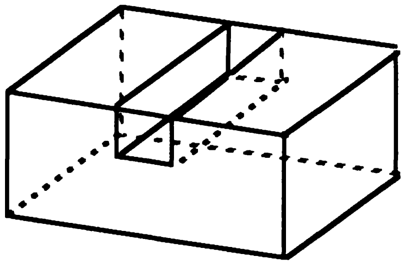


The virtual edges were created in a concave face by prolongation of edges of this face; these prolongated edges are connex to faces that are cutting faces for the part. The cutting faces are thus to be extended by this prolongation virtual edges and new virtual edges coming from the cuts. A cutting faces extended by these virtual edges would present original edges, connected to the virtual edges, inside the face contour. Such inside edges connected to duplicates of the virtual edges (properly oriented) creates virtual inside circuits in the cutting face.

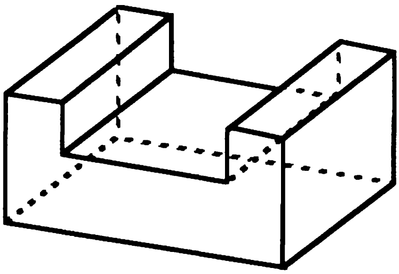
10.5. MISCELLANEOUS

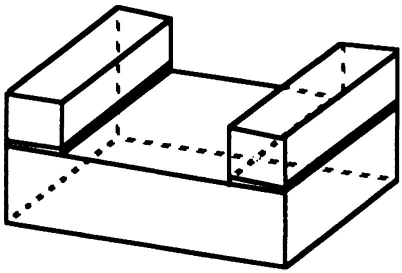
This hierarchical process of recognition-reconstruction must be done with some extra precautions in the looping between processes. For example, the Ring Characteristic Shape process is to be done from the smallest ring to the largest one, and in case of protrusive shapes, one would rather reconstruct a gross shape including the protrusion than one excluding it.





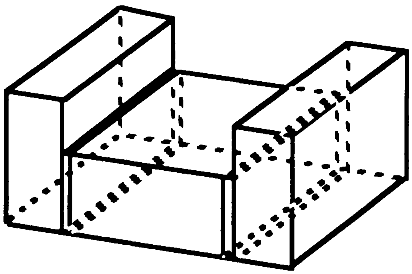
Conversely, the continuation Ring process produces an enclosing shape and one may consider that the exclusion of the concavities can be preferable if there is more void than full.





Both interpretations can be useful in terms of Form Features and are to be made from the basic characteristic shapes constructed by the above approach.

Moreover, at the Form Features level, one may prefer a third interpretation.



All these interpretations can be provided depending on the strategies of Characteristic Shape recognition/creation chosen. However, the global strategy of incremental Characteristic Shape extraction enables one interpretation at a time only. T enable all viewpoints on the Form Features, all the possible geometric strategies are to be used, knowing that each geometric strategy corresponds to specific technological viewpoints.

It is thus clear that even with sufficiently elementary characteristic shapes, some Form Features transmutation is still to be done. Such transmutations appear to be simple enough if they are based on the elementary characteristic shapes, and they would lead to a limited number of geometric transmutations. Basically, the geometric transmutations are related to the different ways of removing concavities.

This strategy was exercised over a number of parts and proved effective. at the theoretical level. The complexity of the algorithm would be low since it is basically linear and remain 2D to find and remove concavities Some programming experiments were conducted on the elementary algorithms but the implementation of the overall strategy is yet to be completed.

10.6. CONCLUSION

A comprehensive product modelling system must provide, atop of modelling by Form Features, viewpoint dependant form features recognition/transmutation.

From this study it appears that the recognition of Form Features can be seen as a two step process: a pure geometric process recognizing characteristic shapes, and a knowledge-based process assembling these characteristic shapes under an application-driven set of rules.

The recognition of characteristic shapes is a hierarchical process in which the shapes are classified by the elements that they modify: edges and vertices first, then internal parts of faces, to end with concavities on the faces contour. After each recognition, the modifying shape is extracted and the object is simplified accordingly. The characteristic shapes extraction makes further recognition easier and enables the global process to loop on the elementary processes to recognize all the characteristic shapes.

Some characteristic shapes transmutation can be necessary to provide the shapes needed to build specific Form Features. These transmutations are restricted to the different ways to remove faces concavities.

10.7. BIBLIOGRAPHY

[BRU-89] Brun J.M. "Brep to CSG Conversion as a Feature Recognition Process" International GI-IFIP Symposium November 8-10, 1989, Berlin, FRG.

[BRU-91] Bruzzone E., De Floriani "Extracting Adjacency Relationships From a Modular Boundary Model". Computer Aided Design, Vol 23, Nr. 5, 1991.

[CAM-85] CAM-I "Requirements for Supporting Fom Features in a Solid Modeling System". Final Report, R.85-ASPP-01, June 1985.

[CAM-88] CAM-I "Current Status of Features Technology" Revised Report, November 1988, R-88-GM-04-1.

[FER-90] Fereira J.C., Hindjura S. "Convex Hull-based Feature Recognition Method for 2.5 D Components" Computer Aided Design, Vol. 22, Nr. 1, Jan. / Feb. 1990.

[GOS-88] Gossard D.C., Zuffante R.P., Sakurai H. "Representing Dimensions, Tolerances and Features in MCAE Systems", March 1988, MIT, Boston, MA, USA.

[HEN-84] Henderson M.R., Anderson D.C. "Computer Recognition and Extraction of Form Features: a CAD/CAM Link" 0166-3615/84 Elsevier Science Publishers B.V. (North Holland), 1984.

[HUM-89a] Hummel K.E., Brooks S.L., Wolf M.L. "XCUT: an Expert System for Generative Process Planning" International Industrial Engineering Conference, May 11-18, 1989, Toronto, Canada.

[HUM-89b] Hummel K.E. "Coupling Rule-based and Object-oriented Programming for the Classification of Machined Features" ASME Computers in Engineering Conference, July 31 - August 3, 1989, Anaheim, CA, USA.

[HUM-89c] Hummel K.E., Brown C.W. "The Role of Features in the Implementation of Concurrent Product and Process Design" Symposium on Concurrent Product and Process Design, ASME Winter Annual Meeting, December 11-15 1989, San-Francisco, USA.

[HUM-90] Hummel K.E., Wolf M.L. "Integrating Expert Systems with Solid Modeling Through Interprocess Communications and the Applications Interface Specification" ASME Computers in Engineering Conference, August 5-9, 1990, Boston, MA, USA.

[KAN-91] Kang K., Woo T. "Algorithmic Aspects of Alternating Sum of Volumes". Part 1: "Data Structure and Difference Operation". / Part 2: "Non-Convergence and its Remedy". Computer Aided Design Vol. 23, Nr. 5, 1991.

[LAA-90] Laakko T., Mantyla M., Mantyla R., Nieminen J., Sulonen R., Tuomi J. "Feature Models for Design and Manufacturing". Proceedings of the Twenty-third Annual Hawaii International Conference on Systems Sciences. Kailua-Kona, HI, January 2-5, 1990.

[SHA-88] Shah J.J., Rogers M.T. "Form Feature Modeling Shell". Computer Aided Design. Vol. 20, Nr. 9, November 1988.

[SHA-91a] Shah J.J. " Assessment of Features Technology" Computer Aided Design, Vol 23, Nr. 5, June 1991.

[SHA-91b] Shah J.J., Mathew A. "Experimental Investigation of the Step Form-Feature Information Model". Computer Aided Design, Vol 23, Nr. 4, 1991.

[SHE-] Shepard M.S. "Integration of Finite Element Modeling with Solid Modeling Through a Dynamic Interface" Center for Interactive Computer Graphics. Rensselaer Polytechnic Institute. Troy, NY 12180-3590, USA.

[WOO-88] Woodmark R. "Some Speculation on Feature Recognition". Computer Aided Design, Vol. 20, Nr. 4, May 1988.