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STRATEGIES FOR USING FEATURE INFORMATION IN MODEL SIMPLIFICATION

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ABSTRACT

At an early stage of design, models created by Computer Aided Design (CAD) applications are not sent as-is for analysis in Computer Aided Engineering (CAE) applications, especially the non-trivial models. Analysis engineers use their domain expertise to simplify these models so that analysis gets performed with lesser resources without compromising much on accuracy of the results. Such Model Simplification involves suppressing small-irrelevant features, dimension reduction, use of symmetry-patterns etc. This process is still widely a manual process and has lot of potential for automation. Most of the current automation approaches work on the final CAD geometry. Only a few attempts seem to have been made which use feature information effectively. CAD Feature information, which used to be hidden due to its proprietary nature, has started becoming available in the contemporary CAD applications.

Features carry higher level information, such as Designer's intent, than what's available in the geometry-topology (Brep - Boundary representation). One of the major tasks in Model Simplification involves suppressing Holes, Fillets, and Chamfers under certain parameters. Model simplification becomes far more straightforward using feature information as features are readily available to be suppressed; which is not possible with the plain Solid Model. In Model Simplification one can leverage use of features such as Pattern, Mirror to detect symmetry and just keep the master portion for the analysis. In Dimension Reduction aspect of Model Simplification models which are inherently of slender or thin-wall in nature are idealized to Curves or Midsurfaces to be used for Beam or Shell elements respectively.

This paper surveys various attempts of Model Simplifications using feature information. It lists issues faced and explores possibility of addressing some of them by a new-proposed technique. In this, high level algorithms for de-featuring and Midsurface generation are elaborated. Midsurface is built on per-feature basis and is connected looking at the feature interactions. The process is elaborated with a step-by-step example.

Keywords: CAD, CAE, FEA, Model Simplification, Midsurface, Feature-based Design

1 Introduction

Time-to-Market being a crucial parameter for success of the product, development cycles have started reducing drastically. Simulations are now performed at the conceptual design stage itself. At this stage, expectation is of a quick assessment of the viability of the design and for this a detailed CAD model is not used but a more simplified, idealized one is analyzed. Unnecessary details add to complexities in mesh generation, and need more resources in terms of computational power-time for a relatively smaller gain in the accuracy of the results. So it is important to utilize simplified models that retain the important details and eliminate the irrelevant ones. The process of this conversion is known as Model Simplification (Figure 1). Even today it is a tedious and mostly a manual process taking significant amount of time [1]. As elaborated by Thakur et. al. in their survey paper [2] there have been many research efforts to automate the simplification process so far. However, at present, only limited automated capabilities exist requiring significant improvement [3].

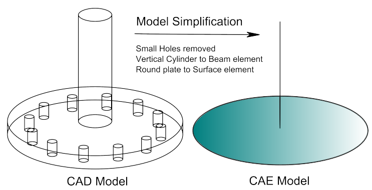


Figure 1. Model Simplification

Model Simplification, according to Dabke [4], can be classified into two parts, namely, Global and Element Idealization. Global Idealization deals with suppressing irrelevant features and takes advantage of the symmetry to analyze only a portion of the model. In Element Idealization, shapes like slender-bar, thin-wall are converted into lower dimension geometries.

Many Model Simplification approaches do not utilize the feature information. They operate on the final CAD geometry as a whole and extract idealized shape. While doing so, connection of the analysis geometry with the features, corresponding semantics and the constraints that define the design model, are lost [5].

2 Global Idealization using feature information

Global Idealization involves suppressing irrelevant features like small Holes, Fillets, Chamfers under certain parameters. Detection and suppression becomes far more straightforward with the features than doing similar process on just a Brep. One can leverage use of features such as Pattern, Mirror to detect symmetry and just keep master portion for the analysis.

Lee [6] proposed a method to reorder design features in the history tree and then re-execute the history of the reordered features up to the given level of simplification. Since re-evaluation of boundaries of a solid model is computationally heavy, he used cellular model for increasing the performance.

To accomplish consistent simplification results independent of modeling history, it is necessary to recognize features to be removed directly from the final model. As in design by features, the feature order governs the final result [1], Model Simplification done on such models may result in unacceptable results due to order dependencies between features. To avoid this, Woo [7] proposed a new method which has subtractive features recognized directly from final solid. Thus during simplification process if these subtractive features are removed, result becomes far more acceptable.

3 Element Idealization using feature information

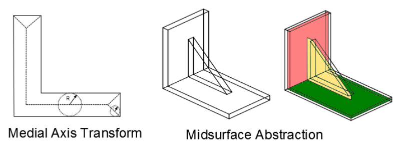


Figure 2. Midsurface Extraction Methods

In Elemental Idealization, slender potions are abstracted to lines-curves where as for thin portions Midsurface is used as an idealized form. Such idealizations are expected to have proper connectivity (no gaps) and they should follow shape of the base part. In Mid-surfacing techniques there are two broad categories namely, 'Medial Axis Transform (MAT)' and 'Midsurface Abstraction(MA)'.

MAT is a locus of the center of an inscribed disc of maximal diameter as it rolls around the object interior. In 2D its called

Medial Axis Curve (Figure 2) where as in 3D it is called Medial Surface. Major drawback of this method is that it creates unnecessary branches and its shape is smaller than the original corresponding faces. Plus there is major issue of perturbations, meaning slight change in the base geometry forces recomputation of MAT and the result could very well be different than the original. Ramanathan [8] modified MAT method to remove erroneous branches. As most of the MAT algorithms are piecewise polygonal approximations, Fischer [9] suggested method of parametric mid-curve which would have no branches and would represent shape of the parent curves.

MA (Figure 2) involves constructing 3D mid-surface for a part model by sewing the mid-surface patches obtained from each of the 'pairs of surfaces'. The surface-pairing approach has benefits over MAT techniques because the resultant geometry is cleaner and requires less reconstruction. However the surface pairing approach also has problems because it can be difficult to identify all of the surface pairs.

Hamdi et.al. [10] used features for small details removal as well as talked about idealization in basic primitives liked Parallelepipeds, Cylinder and Wedge.

Robinson et. al. [11] utilize information contained in the CAD feature tree to locate sketches associated with suitable features in the model. Slender regions in the sketch are used to create sheet bodies representing thin regions of the component.

Roland Stolt [12, 13, 14] has developed idea of feature based Midsurface for a small set of features namely Pad and Pocket. He has elaborated how to treat negative volumes, fillets but did not elaborate much on how to create the mid-curves for complex 2D profiles. Also his work had restrictions like of using thin wall parts with preferably constant thickness and also did not provide thickness values on the Midsurface which is necessary for creating Shell elements.

Smit [5] linked CAD and CAE model on the basis of individual features. Method was developed to decide which feature gets abstracted to what level and which features can be ignored in the creation of analysis model. But even though individual features created their own abstraction, connecting them became a challenging task.

The above mentioned techniques do not elaborate much on how feature interactions are dealt with and also are based on extraction algorithm applied on the final shape. Many a times, due to complexity in recognizing forms, and due to complex interactions between them, Midsurface of the part does not follow its form and is not fully connected [15] . Solution could be, to create Midsurface while building the model itself.

In Features-based Solid Modeling, input feature-parameters are used to build tool-bodies and the whole part gets built using direct or indirect boolean of base and tool bodies. Creating Midsurface for individual tool bodies appears to be a more deterministic problem than recognizing the feature forms. With well-defined boolean operations, correct Midsurface connectivity can be ensured.

4 Model Simplification using feature information

Availability of the feature information makes the task of Model Simplification easier. The model feature tree is traversed and candidate features for suppression are identified based on a set of criteria. Suppression of these features results in a much simplified model suitable for creating meaningful midsurfaces. Earlier approaches [4, 10] seem to test individual feature. Russ [1] had just hinted about taking care of child features due to dependencies.

Proposed Algorithm

1. **Size criterion**: Get Part's Bounding Box (**pBB**), it's diagonal length and based on a threshold (say, 5%). calculate the threshold size **D** below which a feature(set) is considered 'small'
2. Traverse the Feature tree one by one. Initialize Suppress feature list **SL** to which features will get added and at the end of the pass, features from **SL** will actually get suppressed.
3. For each feature,
   (a) Get Bounding Box (**fBB**) of self
   (b) Find diagonal length d of the **fBB**
   (c) Switch (feature type)

i. Hole: Add to **SL** if Diameter **<** **D**
ii. Tweak: Fillet, Chamfer: Add to **SL** if Radius or Side **<** **D**
iii. Sweep Based (Extrude, Revolve etc.) and Primitives (Block, Cylinder etc.), Protrusions or Depressions or Standalone: Get all the child features and update the Bounding Box to (**fcBB**) with the Union of Bounding boxes of self + child features (called feature-set **FS**). Find diagonal **d** of **fcBB**. Add **FS** to **SL** if **d** < **D**

4. Regenerate model by excluding the features in **SL**

The resultant model can then be used for Midsurface generation.

5 Generation of Midsurface using feature information

In the proposed approach, Midsurface is generated at individual feature level. At each feature step, as shapes are relatively simpler than the final shape, creation of Midsurface becomes relatively straight-forward. For a typical work-flow, here are some of the steps/rules that are applied:

1. Sketches of the profile based features are extracted first. The mid-curves are then created in the sketch profile itself. If information regarding Sketch sub-commands like 'Sketch-Offset', 'Circle', 'Rectangle', are available, they can be leveraged to create standard mid-curves. If such information is not available, slender portions need to be identified using MAT and then post-processed MAT curves can be used as mid-curves.

2. In operations like 'Extrude', 'Revolve', 'Sweep', a profile is swept to create a tool body which then gets boolean-ed with the base part. The mid-curves get swept similarly during feature creation. Along with the tool body thus formed Midsurface-patches are boolean-ed as well. Midsurface gets built as part is getting built.

3. One can apply de-featuring rules at each stage as well, as demonstrated in the last step of Table 1. Here small Holes are ignored in the Midsurface output.

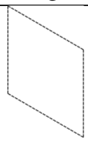
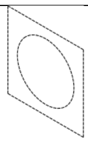
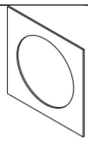
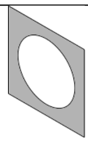
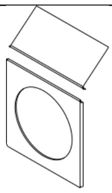
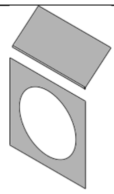
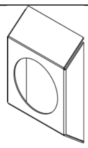
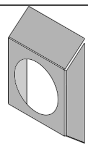
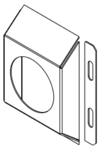
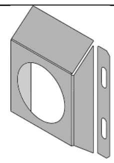
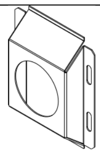
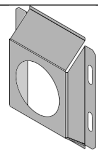
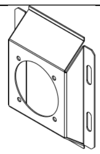
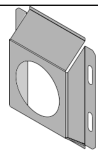
4. **Proposed Algorithm**

(a) Traverse the Feature tree one by one
(b) For each feature, decide its contribution to the Midsurface model
i. **2D Profiles**
A. Use internal Sketch commands information, like Offset-Curve, Mirror, Fillet to arrive at the Mid-curves profile
B. If such command's information is not available then try other approaches like MAT, Parametric Equation, and Chordal Axis Transform etc.
ii. **Primitives**: For positive primitive shapes (protrusions or stand-alones) create a pre-defined Midsurface
iii. **Sweep based Features (Extrude Sweep Revolve Loft)**: For positive primitive shapes (protrusions or stand-alones) sweep Mid-Curves profile similar that of the parent feature.
iv. **Boolean (External)**: Extend and Trim the Midsurfaces coming from Base part and Tool bodies.
v. **Tweak**: Features like Fillet, Chamfer, ignore if small as part of the de-featuring process.
vi. **Shell**: Use half the Shell distance and offset the same faces as in the parent feature to arrive at the Midsurface.
vii. Intersect Midsurface with the feature faces to make sure that it lies inside the feature volume.
viii. Assign the Thickness values on the Midsurface with pre-defined grid spacing.
(c) Check for validity of the Midsurface output, especially for gaps and overlapping surfaces and correct the problems.

6 CASE STUDY

A part with medium complexity is run through the algorithm to evaluate its validity.

Table 1: Step by step creation of part along with Midsurface

Modeling Input	Modeling output	Procedure to create Midsurface	Midsurface
Sketch Feature: Create Rectangle (Length, Width)		For non-thin profile like this, no mid-curve entities are created. For thin profiles, they are created.	-
Sketch Feature: Add Circle as inner loop		For non-thin profile like this, no mid-curves are created. If inner geometry was rectangle making concentric profiles, mid-curves would be generated.	-
Offset/Face/Thicken Feature: Thickness		Fill the face with sketch curves and Offset it by 0.5*thickness value. In case of mid-curves in sketch, just extrude by 0.5*thickness value.	
Flange (Edge, distance, angle)		For Flange tool body, create Midsurface with given parameters. Need to find out corresponding edge on previously created Midsurface, to attach this tool-Midsurface to.	
Similarly add other Flanges		Similarly join other tool-Mid-surfaces	
Ready Extensions, or user defined features booleaned		Tool bodies need to follow same Midsurface procedure and then Boolean them. Here complexities like L, T, K shapes come into picture. Need to come up with various heuristics for such connections.	
Similarly add other Flanges		Similarly join other tool-Mid-surfaces	
Add small holes		No change in Midsurface as small holes are ignorable. This takes care of Model Simplification as well.	

This procedure has ample scope of further development due to large number of feature types, not just in the Solid Modeling domain but also in the environments like Sheet Metal Modeling, Injection Molding etc.

7 Conclusion

Although Model Simplification using geometry has been in practice for many years, with possibility of extracting feature information, it can be taken to the next level. Feature information gives ready data needed for Model Simplification. In Dimension Reduction, it can give tips for creating medial geometries. Features such as Pattern leverage the symmetry in the part thereby reducing analysis time-resources.

This paper apart from listing various approaches for Model Simplification using feature information, proposes a relatively novel approach of building Midsurface using feature information. In this approach Midsurface is concurrently built as part gets created (called forward create). This approach can also work on feature based model which can be played back. At each feature step, shapes are relatively simple than final shape, thus creation of mid-surfaces at each stage is far simpler. After development of boolean of the non-manifold shapes, this method can build well connected, isomorphic mid-surfaces better than extraction methods.

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