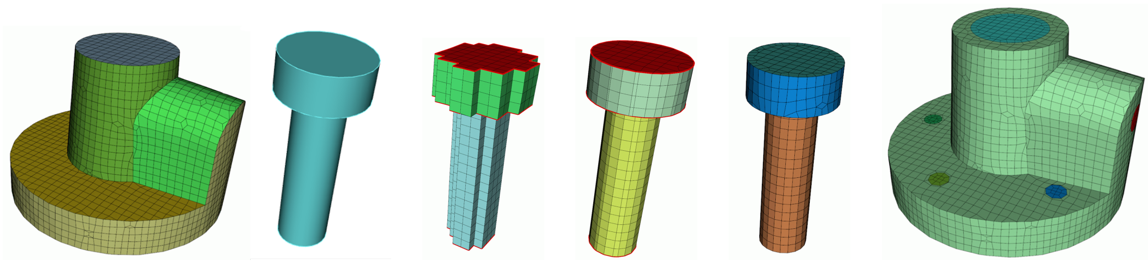
Hexahedral Mesh Adaptation to Imprint Geometric Details : Application to CAD Models

N. Le Goff[1], F. Ledoux[1] and J.-Ch. Weill[1]

[1]CEA, DAM, DIF, F-91297 Arpajon, France



(*a*) (*b*) (*c*) (*d*) (*e*)

Figure 1: *Insertion of a geometric element into an existing hexahedral mesh. In (a), the reference mesh M and the geometric element G_2 to be inserted; in (b), cells of M that will be in G_2 are selected and curves and surfaces classification is done; in (c), nodes are projected onto G_2 while a sheet is inserted to improve mesh quality in (d). In (e), several imprintings have been performed to enrich the reference mesh.*

Abstract

A novel algorithm is proposed to modify any unstructured hexahedral mesh in order to diminish the global time of numerical simulation processes, like optimization process and parametric studies. It consists in an imprinting algorithm that allows us to automatically add geometric details into an existing mesh. This addition is done using geometric projections, sheets (layers of hexahedral elements) insertions and combinatorial algorithms while preserving the hexahedral mesh structure as best as possible.

Categories and Subject Descriptors (according to ACM CCS): F.2.2 [Theory of Computation]: Nonnumerical Algorithms and Problems—Computations on discrete structures

1. Context

Hexahedral meshes are preferred over tetrahedral meshes in numerous computational engineering applications. However, automatic hexahedral meshing remains an unsolved issue. In practice, generating a hexahedral mesh is known as a time-consuming stage that requires many user interactions.

For optimization processes or theoretical studies, where the model is modified and enriched by new geometrical elements several times, generating a new full hexahedral mesh is prohibitive. Moreover, in order to measure the impact of a new geometrical element onto the global shape design, it is interesting to modify the mesh as little as possible. That is why we propose an imprinting method allowing us to automatically add geometric details into an existing hexahedral mesh. This addition is done using geometric projections, sheets (layers of hexahedral elements) insertions and combinatorial algorithms while preserving the hexahedral mesh structure as best as possible. It is limited to the insertion of manifold objects, which is usually the case of CAD volumes.

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2. Main contributions of this work

1. Contrary to existing algorithms [Mar09, OS09, QZ10], our method is not restricted to grids or octrees and can be applied to any unstructured hexahedral meshes;
2. Both the inner and outer volumes are considered;
3. The classification process is fully performed and robust using local topological changes.

3. Proposed algorithm

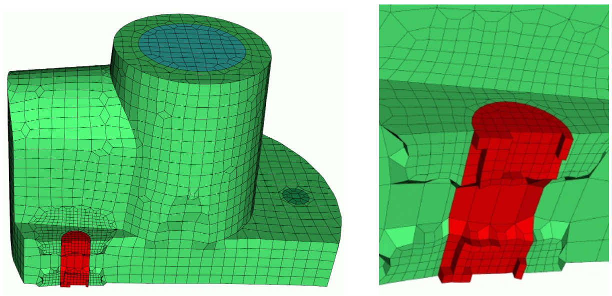
Our method relies on first selecting a good set of hexahedra that will capture the geometric volume to imprint; geometric vertices, curves and surfaces will then be respectively captured by nodes, edges and faces located on the boundary of this set of hexahedra. Starting from a hexahedral mesh $M(H,F,E,N)$ that discretizes a BRep geometric object $G(S,C,V)$, the aim of our algorithm is to adapt M in order to discretize both G and G_2, where $G_2(S_2,C_2,V_2)$ is a new geometric object fully enclosed into G. The global process of our method is the following one:

1. Cells of H are split into two sets: those inside G_2, denoted H_2, and those outside; a cell intersected by S_2 will either be classified as inside or outside depending on its volume fraction that is inside G_2; we estimate this fraction by checking how many Gauss points of the cell are inside and outside (see Figure 1-b). During this step, refinement patterns [ZB06] are applied to ensure the right topology of H_2 (see Figure 2). It must meet several requirements, such as being of the same genus as G_2 and being non-manifold. After this step we restrict ourselves to working exclusively on the boundary of H_2. Let ∂H_2 be this set of quadrilaterals;
2. Each vertex of V_2 is captured by a node located on ∂H_2 (see Figure 1-b). We currently simply select the nearest node that is incident to N_e edges in ∂H_2, with $N_e \geq N_c$ and N_c the number of curves incident to V_2;
3. Each curve c of C_2 is captured by a line of mesh edges located on ∂H_2 and such that the end-nodes capture the end-points of c (see Figure 1-b). This line of edges is built by computing the shortest path linking the end-nodes of the curve using the Hausdorff distance to the curve;
4. Each surface s of S_2 is captured by a mesh surface composed of faces of ∂H_2 and delimited by mesh edge-lines capturing the bounding curves of s (see Figure 1-b and 3-a). This step is straightforward as ∂H_2 corresponds to a manifold surface;
5. Nodes of ∂H_2 are orthogonally projected onto the geometric element they are classified on (see Figure 1-c);
6. Layers of hexahedra are inserted along ∂H_2 in order to improve the quality of elements (see Figure 1-d) and a smoothing algorithm is applied.

4. Experimental results and discussions

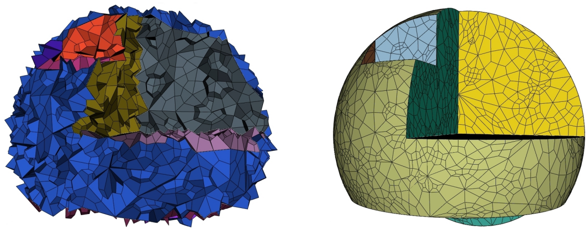
Our method has allowed us to insert many geometric details into existing meshes, including badly formed THex meshes (see Figure 3). It is quite robust in practice, but still requires performance improvement during the cell selection process, and to get a formal proof of our curve capture process.

Future works concern performance improvements and ensuring a better quality of hexahedral elements along the imprinted shapes.



(a) (b)

Figure 2: *The initial mesh is refined to insert the red cylinder. In (a) a global view is shown; in (b) the refinement area.*



(a) (b)

Figure 3: *Insertion into a badly shaped THex mesh. In (a), the geometric model is captured; in (b), the surface classification is shown and projection and smoothing was applied.*

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