Check for updates

Semi structured adaptivity for surfaces and volumes

R. Aubry^{*}, T. R. Tuckey^{***}, V. Lakshminarayan^{****}, E. Mestreau^{*}, M. Williamschen^{*}, W. Szymczak^{**}, and S. Dey^{**}

^{*}Jacobs, 7740 Milestone Parkway, Suite 400 Hanover, MD 21076, United States ^{**}US Naval Research Laboratory, code 7130, 4555 Overlook Ave SW, Washington DC 20375, USA

**** US Air Force, 46 RANG/VTSO, Eglin AFB, FL, USA

****Science & Technology Corporation, NASA Ames Research Center, Mofett Field, CA

A semi structured technique is presented for surfaces and volumes with mixed and simplicial elements in order to enhance the classical metric based adaptivity. The advantage of the current procedure is the guarantee that mixed elements will be preserved during the adaptivity, provided stronger angle bounds compared to simplices. The volume and 2D axisymmetric analysis is run by the CREATE AV Kestrel solver, while the surface mesh is run by the CREATE AV Helios Strand solver. Various improvements are presented, as well as issues found during the implementation. The boundary layer surface mesh generated in Capstone is not purely semistructured, which may lead to misinterpretations of the columns to be refined on the surface. The semi structured volume is more straightforward as long as multiple normals and tangential adaptivity are not triggered. Due to the semi structured fashion of the algorithm, a special smoothing has to be performed to begin with a consistent initial metric field.

Keywords: Adaptivity, Boundary layer, volume and surface mesh generation, semi structured mesh generation

I. Introduction

In order to maintain the topological structure of mixed elements, a semi structured adaptive method is proposed. The main process relies on the classical metric based approach.^{1,2,4} However, some solvers prefer the use of prisms and hexahedra inside the boundary layer, where the anisotropy is the strongest.⁶ The current procedure maintains the initial structure of the mesh. The current implementation considers surfaces and volume semi structured initial meshes. For surfaces, the initial surface meshes generated in Capstone have a much more complex structure than pure columns created at the boundary layer edge, and reaching the outer part of the boundary layer. This is due to the introduction of multiple normals and tangential adaptivity to better transition the semistructured mesh to the unstructured mesh. Regarding the volume, the columns are for the moment simpler. However, the conformity is much more complex in three dimensions, leading to potential blocking configurations such as the Schonhardt prism.

After this introduction, Section II presents the semistructured surface adaptive procedure. This is the most complicated topologically . Then, Section. III presents the conformity difficulties appearing in three dimensions. Section IV highlights the necessity to smooth the. metric field throughout the columns to avoid a non conforming sizing field to the underlying refinement. Finally, Section V illustrates the proposed optimizations through various numerical examples.

II. Surface adaptivity

Surface semistructured adaptivity is considered in this section. Topologically, this could be useful in a pure 2D setting, in an axisymmetric simulation, or finally in a fully three dimensional surface. Typically, the initial surface mesh has been generated in Capstone. Due to the construction of the BL surface mesh

DISTRIBUTION A: Approved for public release, distribution is unlimited.

in Capstone, the semistructured topology of the surface mesh is quite complicated, as illustrated in Figure II.1. Therefore, two modes of operations were designed. In the first case, a mesh generated by Capstone passes along the structure of the mesh. In the second mode, a procedure is called on meshes not generated by Capstone to get straightforward semistructured meshes. It is to be noted that the semistructure imposes numerous constraints on the topology of the mesh since vertical edges should not be exposed to the adaptive procedure. When non simplicial elements are used, the semistructure is clearly revealed, while it is much less clear for semistructured simplex meshes.



(b) Zoom close to multiple normals, tangential adaptivity and concavity treatment

Figure II.1. Structure of the Capstone surface mesh on the 2d HLCRM

The basic structure, referred as a mini-column, is composed of a base triangle, a column of quads and a top triangle, as illustrated in Figure II.2. Depending on the local structure, the bottom triangle may be empty, such is the case for a column abutting on the boundary layer edge. The column itself may be empty. Similarly, the top triangle may be empty or itself composed of various top triangles. In order to keep a consistent mini column representation, the 1-to-2 ratio between mini-columns must be conserved. Therefore, some operations such as collapse or refine can only be applied iteratively, in such a way that the operation propagates throughout the tree. Typically, the refinement comes from the bottom, while a boundary layer will be coarser at the top. The refinement should then propagate for the upper mini-columns to be split to present a consistent topology.



(a) Isotropic sizing

Figure II.2. A mini-column is displayed as the smallest unit in a 2d boundary layer mesh refined with multiple normals, tangential adaptivity and concavity treatment. As opposed to the previous figures, only transition elements are represented.

III. Volume adaptivity

The semi structured volume implementation has different complexity since unambiguous semi structured columns are generated from the volume mesher for the moment. However, the introduction of multiple normals and tangential adaptivity breaks the obvious columns and should lead to a more complicated implementation similar to the the 2D case. Nevertheless, the three dimensional conformity is much more complicated than its two dimensional counterpart. Each column receives a pattern to be split with potentially some tetrahedra on top of the column.⁶ The difficult part arises when the unstructured elements have to refine to match the refinement of the columns. Close to corners, various column may abut to the same element, which will receive as many refinement templates as the number of columns it is connected to. This multiplies exponentially the number of possible patterns. It may also lead to some blocking configurations since Schonhardt configuration appear as illustrated in Figure III.1. In order to avoid these blocking configurations two solutions have been implemented.

- A first scanning detects the potential blocking configurations before the splitting happens and imposes the problematic diagonal before hand.
- For the extremely rare cases where this is not enough, a Steiner point is inserted inside the blocking configuration

IV. Size smoothing along columns

Smoothing the metric field is a standard operation to ensure that the metric field is reasonably smooth. Since a semistructured approach is chosen, the algorithm will split a column of edges as soon as an edge



(a) Tetrahedron ABC has its four faces shared with the top of four columns



Figure III.1. Example of an unstructured tetrahedron where its four faces abut on four different prism columns that have each two edges to be split. The final configuration may generate a Schonhart polyhedron.

is too large compared to the metric provided by the solver. There is a need to reconcile the metric along the column that did not conform to the splitting and the split length. Therefore, a first metric modification should be performed along the columns to identify the edges that will be split by the refinement procedure and correct all the metric of the points in the same column. If that step is omitted, the unstructured mesh will not perceive the refinement, as illustrated in Figure IV.1. The procedure reads:

- For each semistructured column:
 - Find the longest edge of that semi column
 - Find the power of two closest to the longest length of that semi column. All the edges in that column will be split that many times.
 - For each edge of that semi column
 - * Given the real edge length and the number of refinements, correct the metric in the tangential direction

Note that the relevant correction is the one of the top edge since this is the one that will propagate in the semi structured mesh. A tangential smoothing on the number of refinements can also be performed to avoid to have too much refinement in one column compared to its neighbors. The surface case is more complex since the semi structured columns are replaced by mini columns. A similar propagation has to take place within the mini-column tree, taking into account the refinement or coarsening when moving from one mini-column to its father/son.

V. Numerical examples

In this section, various examples illustrate the proposed procedure.

A. Three element airfoil

This example illustrates 2D hl-crm geometry. The CREATE-AV Kestrel solver⁵ has been used for this example. Figure V.1 presents the airfoil in a large box, with some details of the boundary layer, as well as the capture of the wake.



Figure IV.1. Final mesh without smoothing along the columns. The unstructured mesh does not perceive the refinement of the column through the sizing field.



(c) Semistructured and unstructured adapted mesh

Figure V.1. 2D hl-crm example

B. Onera M6 wing with Helios Strand solver

This example illustrates the Onera M6 wing geometry. The CREATE-AV Strand solver³ has been used for this example. Figure V.2 illustrate the surface mesh before and after adaptation. After 15 steps, the lambda shock is clearly identified on the top of the wing. The mesh is solely composed of triangles here.



(b) after 15 adapt cycles

Figure V.2. Mesh and sectional pressure for static ONERA M6 wing simulation.

C. DPW6

This example illustrates the DPW6 geometry. Figures V.3 and V.4 display a cut of the volume mesh after the first iteration. Figure V.5 shows the corresponding semistructured boundary layer mesh. The initial mesh is comprised of 4 millions tetrahedra, 6 million prisms and 10^6 pyramids. After one iteration, the BL mesh is comprised of 33 million prisms and about 3.10^6 tetrahedra and pyramids, and the unstructured mesh contains 7 million tetrahedra. The increase in prisms in one iteration is drastic.

VI. Conclusion

A semi-structured adaptive procedure has been implemented in the surface and volume mesh. Various details of this process have been commented. The price to pay for more control on the angles of the elements in the boundary layer is a stiffer topology. Some remedies to avoid blocking configurations were mentioned. This procedure guarantees the respect of the semistructuredness during the adaptive process. Some numerical examples were given to illustrate the adaptive strategy with the AV Kestrel and Strand solvers.



Figure V.3. Initial DPW6 Boundary Layer

Acknowledgments

This work was partly supported through the CREATE element of the U.S. DoD HPC Modernization Program.

References

¹F. Alauzet. Size gradation control of anisotropic meshes. *Finite Elem. Anal. Des.*, 46:181–202, 2010.

²P.L. George and H. Borouchaki. Triangulation de Delaunay et maillage. Hermes, Paris, 1998.

³Vinod Lakshminarayan, Romain Aubry, Jayanarayanan Sitaraman, and Andrew Wissink. Fully automated surface mesh adaptation in strand grid framework. In AIAA Scitech 2022 Forum, 2022.

⁴A. Loseille and F. Alauzet. Continuous mesh framework. Part I: well-posed continuous interpolation error. *SIAM J. Numer. Anal*, 49:38 – 60, 2011.

⁵D. McDaniel. A summary of new and emerging features in hpcmp createtm-av kestre. In AIAA Scitech 2021 Forum, 2021.

⁶O. Sahni, K. E. Jansen, M. S. Shephard, C. A. Taylor, and M. W. Beall. Adaptive boundary layer meshing for viscous flow simulations. *Engineering with computers*, 24:267–285, 2008.



Figure V.4. The full DPW6 mesh with BL



(a) BL mesh cut in half



(b) Zoom of the BL mesh

Figure V.5. DPW6 boundary layer after one iteration