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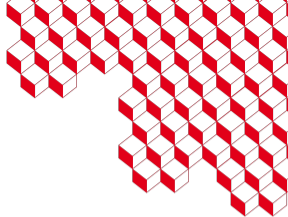
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Curved Hexahedral Block-Structure Generation by Advancing Front

SIAM IMR 2024, 7 march, 2024

C. Roche^{1,3} (claire.roche@cea.fr)

J. Breil¹ (jerome.breil@cea.fr)

S. Calderan² (simon.calderan@cea.fr)

T. Hocquellet¹ (thierry.hocquellet@cea.fr)

F. Ledoux^{2,3} (franck.ledoux@cea.fr)

¹ CEA-CESTA

² CEA, DAM, DIF, F-91297

³ LIHPC, CEA, UNIVERSITÉ PARIS-SACLAY

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- Fields Computation

- Generation of One Block Layer

- Conflict Management on a Layer

- Examples of Linear Blocking

Bézier Block Curving

- Block Curving Using Bézier Elements

- From Blocks to Final Mesh

- Examples of Final Meshes

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Context

- This work aims to provide a solution to generate block-structured hexahedral meshes automatically for a legacy Computational Fluid Dynamics (CFD) code developed for atmospheric re-entry.

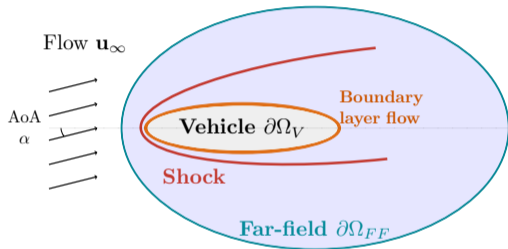


Fig. Flow around a supersonic vehicle

- Our meshing algorithm is freely available and implemented in the open-source C++ meshing framework GMDS [LWB]^a.

^a<https://github.com/LIHPC-Computational-Geometry/gmds>.

Ideal meshes:

- ◆ Near-wall **orthogonality**
- ◆ **Thin cells** in the boundary layer
- ◆ Smooth mesh **size transition**

Input meshes for the code:

- ◆ **Block-structured** meshes

Hypotheses on the domain:

- ◆ Vehicles are **completely immersed** in the fluid
- ◆ Far-field is a **smooth boundary**
- ◆ **Single-wall** vehicle



Approach Overview

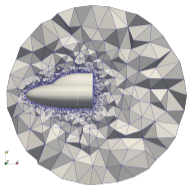


Fig. a Tetrahedral Mesh

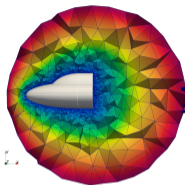


Fig. b Distance Field

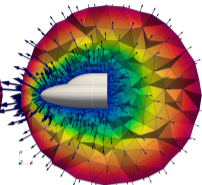


Fig. c Vector Field

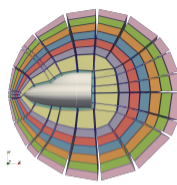


Fig. d Linear Blocks

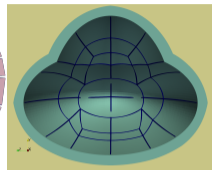


Fig. e Curved Blocks

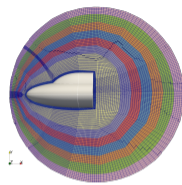


Fig. f Mesh

- ◆ Starting from a tetrahedral discretization of the domain (a)
- ◆ We first generate and combine distance fields (b)
- ◆ And build a vector field that ensure wall orthogonality and other properties (c)
- ◆ Using those fields, we generate a linear block structure (d)
- ◆ The block structure is curved using Bézier elements (e)
- ◆ And a final hexahedral mesh is generated (f)

Ruiz-Gironés E, Roca X, Sarrate J. The receding front method applied to hexahedral mesh generation of exterior domains. *Engineering with computers*, vol. 28, no. 4, 391-408, 2012.

Roche, C., Breil, J., Hocquellet, T., Ledoux, F. "Block-structured quad meshing for supersonic flow simulations". In *SIAM International Meshing Roundtable Workshop 2023 (SIAM IMR 2023)*.

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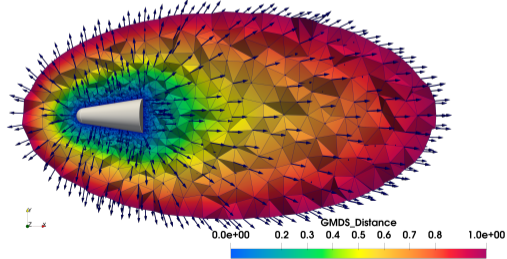
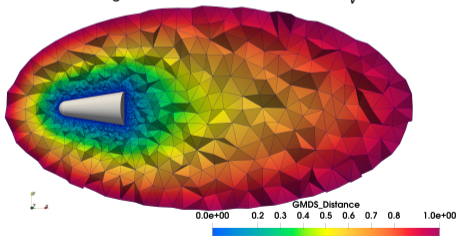
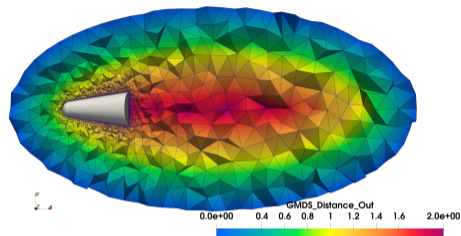
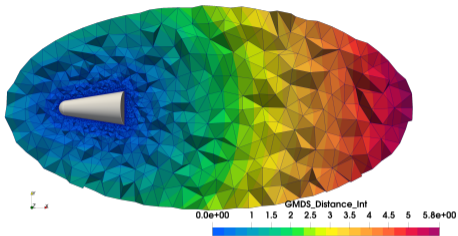
- Examples of Final Meshes

Conclusion





Fields Computation





Generation of One Block Layer

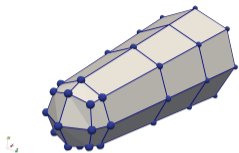


Fig. a A Front

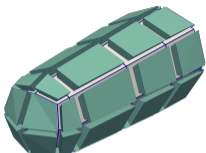


Fig. b A Layer

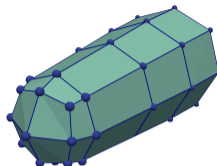


Fig. c A new front

- Each face of the front (a) creates a hexahedral block by extrusion. This set of blocks is the layer (b).
- Each block corner of the front (a) computes the position of the next block corner in the next layer.

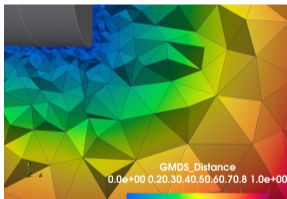


Fig. d Distance Field

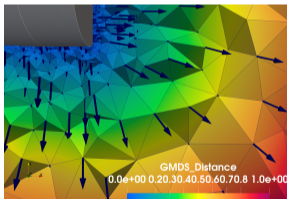


Fig. e Vector Field

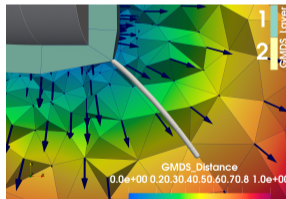


Fig. f Advected Block Corner

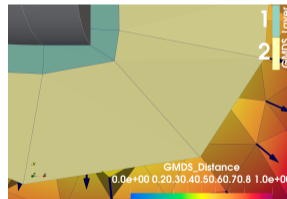


Fig. g New Blocks

- Need to solve conflicts due to expansion/contraction in a layer



Conflict Management on a Layer [RGRS12]

- Geometric classification of the edges of the front

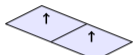


Fig. a Side Edge

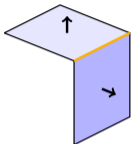


Fig. b Corner Edge

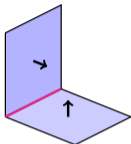


Fig. c End Edge

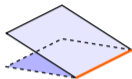
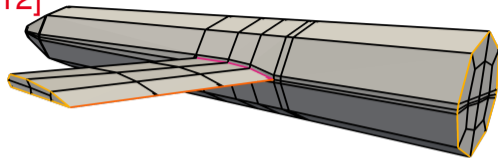


Fig. d Reversal Edge



Edges_Classification



Fig. e Example of Edges Classification

- Apply a set of patterns on edges and nodes of the front, according to the geometric classification of edges

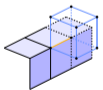


Fig. f Edge Patterns

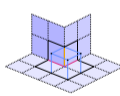
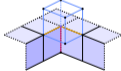
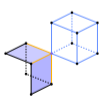
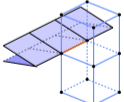
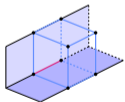


Fig. g Examples of Node Patterns

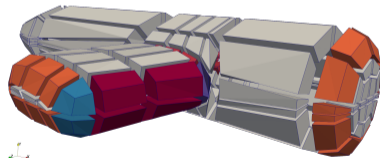


Fig. h Layer Generated on Front of Fig.e



Linear Blocking around Double Ellipsoid [AADLC91]

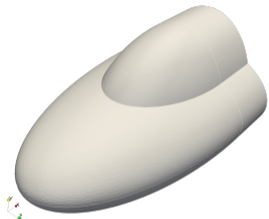


Fig. a Double Ellipsoid Geometry

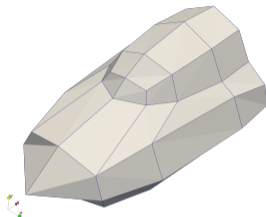


Fig. b Double Ellipsoid Surface Blocking

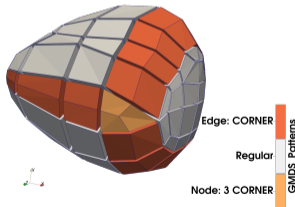


Fig. c Patterns on Second Layer of Blocks

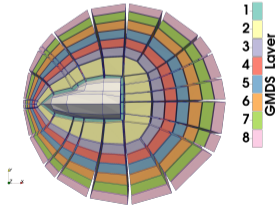


Fig. d Layers of Linear Blocks

Fig. e Extrusion of Layers

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Block Curving Using Bézier Elements [Bez86, Feu19]

Aim: Improve the representation of the geometry to avoid the smoothing step on the final mesh.

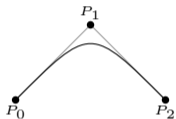


Fig. a Bézier Curve of Degree $p = 2$

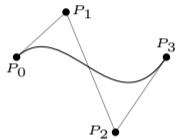


Fig. b Bézier Curve of Degree $p = 3$

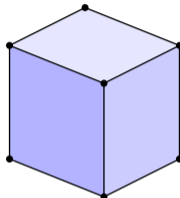


Fig. c Linear Hexahedral Block

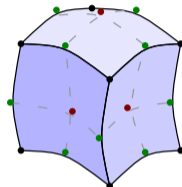


Fig. d Bézier Block of Degree $p = 2$

- Control points of all the block faces corresponding to the surface of the geometry are computed to approximate the geometry surface
- Control points of the blocks adjacent to those faces are moved to avoid overlapping blocks

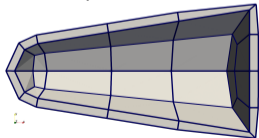


Fig. e Linear First Layer of Blocks

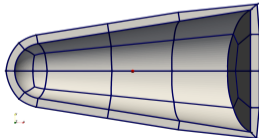


Fig. f Curved First Layer of Blocks

◆ For a more accurate and elegant way to process, you can attend the talk of KETAN MITTAL on *"Mixed-Order Meshes through rp -Adaptivity for Surface Fitting to Implicit Geometries"*



Interval Assignment: Set the Discretization of Each Block Edge

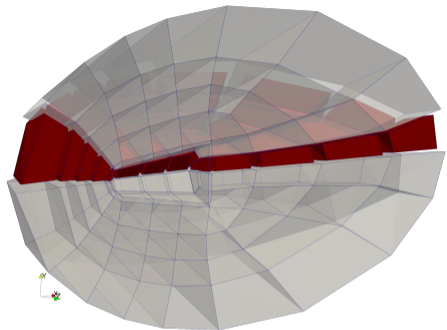


Fig. a Topological Sheet (■)

Topological Sheet

A set of opposite block edges.

◆ All edges of the same topological sheet share the same discretization

- For each topological sheet, an optimization problem is solved to compute the number of mesh edges of the block edges
- Each block is discretized uniformly in the parametric space of the Bézier Element

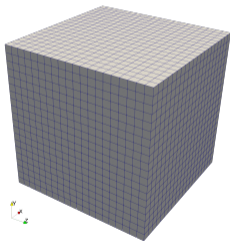


Fig. b Parametric Space

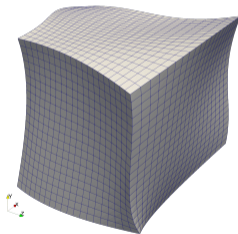


Fig. c Physical Space



Examples of Final Meshes

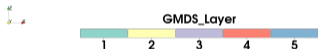
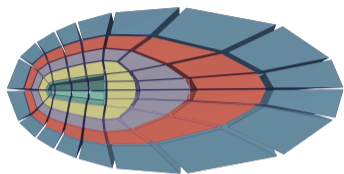


Fig. a Linear blocks around RAMCII geometry [Sca07]

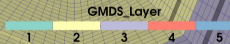
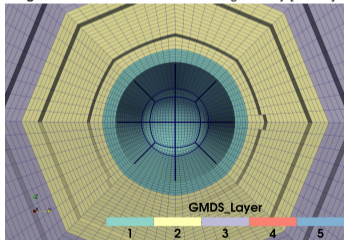


Fig. c Mesh of RAMCII nose surface view from inside

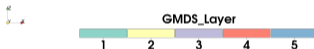
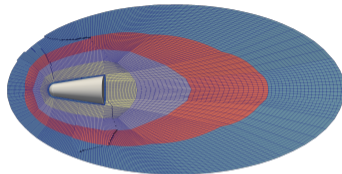


Fig. b Mesh around RAMCII geometry

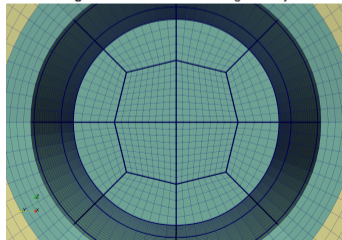


Fig. d Mesh of RAMCII back surface view from inside

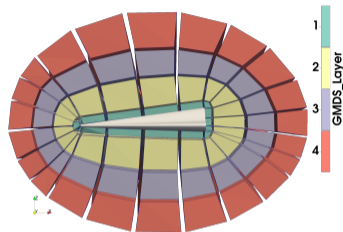


Fig. e Linear blocks around HyTRV geometry [QLYT21]

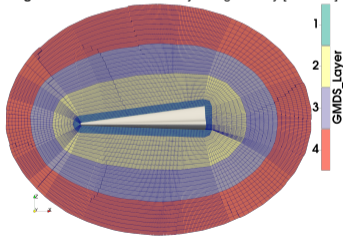


Fig. f Mesh around HyTRV geometry

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Conclusion & Perspectives

- ◆ This work proposed a solution to generate block-structured hexahedral meshes dedicated to CFD
- ◆ Extension of the work of RUIZ-GIRONÉS ET AL. to high-order blocks

Perspectives

- ◆ Use the meshes generated for numerical simulations
- ◆ Improve the way to compute the curved blocks to approximate the surface of the geometry
- ◆ Work on curved blocks smoothing under constraints due to the applications

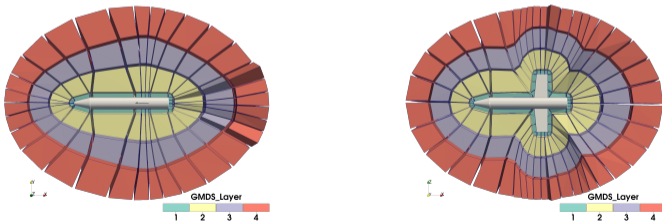


Fig. a Linear blocks around a geometry with wings

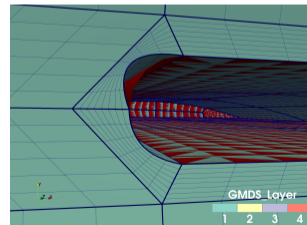
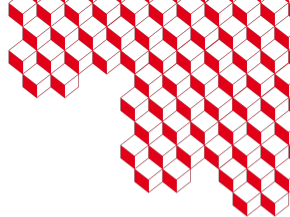


Fig. b The way the blocks are curved is not always sufficient to represent the geometry (■)



Thank you! Any question?



References I



D Aymer, T Alziary, Luigi De Luca, and G Carlomagno, *Experimental study of the flow around a double ellipsoid configuration*, Hypersonic Flows for Reentry Problems: Volume II: Test Cases—Experiments and Computations Proceedings of a Workshop Held in Antibes, France, 22–25 January 1990, Springer, 1991, pp. 335–357.



Pierre Bezier, *Courbes et surfaces, mathématiques et cao*, 4, Hermès, Paris (1986).



Rémi Feuillet, *Embedded and high-order meshes: two alternatives to linear body-fitted meshes*, Ph.D. thesis, Université Paris-Saclay, 2019.



Franck Ledoux, Jean-Claude Weill, and Yves Bertrand, *Gmms: A generic mesh data structure*.



Han Qi, Xinliang Li, Changping Yu, and Fulin Tong, *Direct numerical simulation of hypersonic boundary layer transition over a lifting-body model hytrv*, Advances in Aerodynamics **3** (2021), 1–21.



Eloi Ruiz-Gironés, Xevi Roca, and Josep Sarrate, *The receding front method applied to hexahedral mesh generation of exterior domains*, Engineering with computers **28** (2012), no. 4, 391–408.



Leonardo C Scalabrin, *Numerical simulation of weakly ionized hypersonic flow over reentry capsules*, Ph.D. thesis, Citeseer, 2007.



Annexes: 3D Surface Block Curving



Fig. a Part of the geometric surface

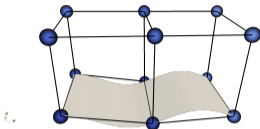


Fig. b 2 blocks of the linear block structure

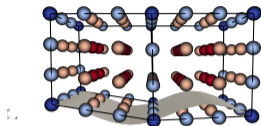


Fig. c Initial control points (elements of degree $p = 3$), set uniformly on the linear blocks

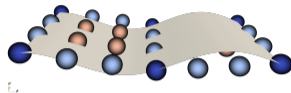


Fig. d Initial control points on the faces corresponding to the geometric surface

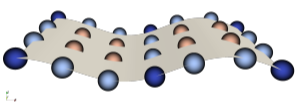


Fig. e Points to interpolate on the geometric surface (Fig. a), computed as the projection of the control points of Fig. d onto the geometry

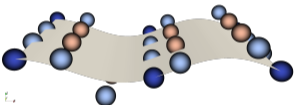


Fig. f Control points computed to interpolate positions of Fig. e

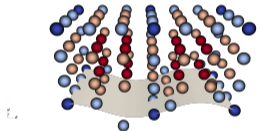


Fig. g Control points of the 2 Bézier elements



Fig. h Final mesh generated with the 2 Bézier elements defined by the control points of Fig. f

Bézier Quadrangle Expression in the Parametric Space

$$\forall u, v \in [0, 1], h(u, v) = \sum_{i=0}^m \sum_{j=0}^n B_i^m(u) B_j^n(v) P_{i,j} \quad (1)$$

where $P_{m,n}$ is the matrix of the control points, and m and n are the degree in each direction

➤ As the first layer of blocks can be very thin, we add the same offset as the control points moved in Fig. f to the opposite face in the block. This step is not illustrated here and could be included between Fig. f and Fig. g.