A Framework for Mesh-Geometry Associativity during Mesh Adaptation

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SciTech January 2021

Overview

Access to geometry and “an inadequate linkage with CAD” has become a pacing item in the advancement of applied CFD, see Slotnick et al., CFD Vision 2030 Study.

The MeshLink framework has been developed for describing how a computational mesh is associated to the geometry model it discretizes and to provide access to the computational geometry.

Applications include:

- Mesh adaptation
- Higher-order mesh curving
- Parametric design optimization

MeshLink Framework

Two components:

- MeshLink Schema
  - Describes mesh-geometry associativity
- MeshLink Library
  - A high-level programming API for accessing associativity data and providing kernel-neutral geometry access

Both are freely and openly available

MeshLink Schema

Geometry Association

- The relationship between a mesh element and the supporting computational geometry model used to constrain the location of the mesh element in Cartesian space.

Consistency

- Definition uses standards-based XML Schema
- Allows data content validation using existing tools

Flexible

- Association is independent of geometry kernel or mesh format
- One-to-many association
- Applicable to a broad range of CAE uses

Mesh Topology

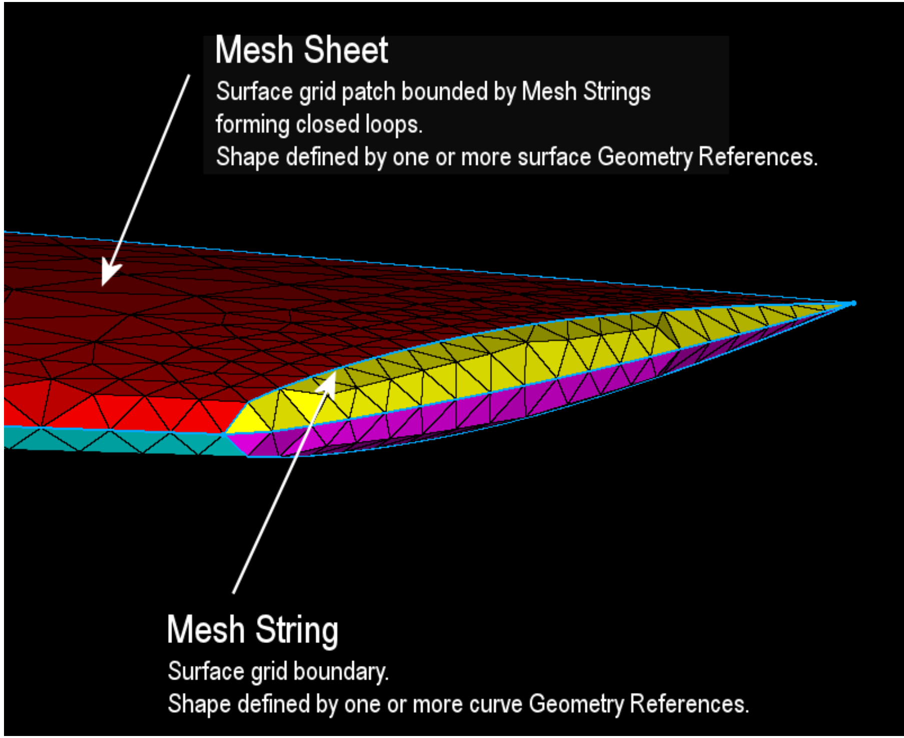
Mesh Elements

- Mesh Point – reference to a vertex in the mesh data
- Mesh Edge – 1D, defined by edge reference or vertices in the mesh data
- Mesh Face – 2D, defined by face reference or vertices in the mesh data

Mesh Topology

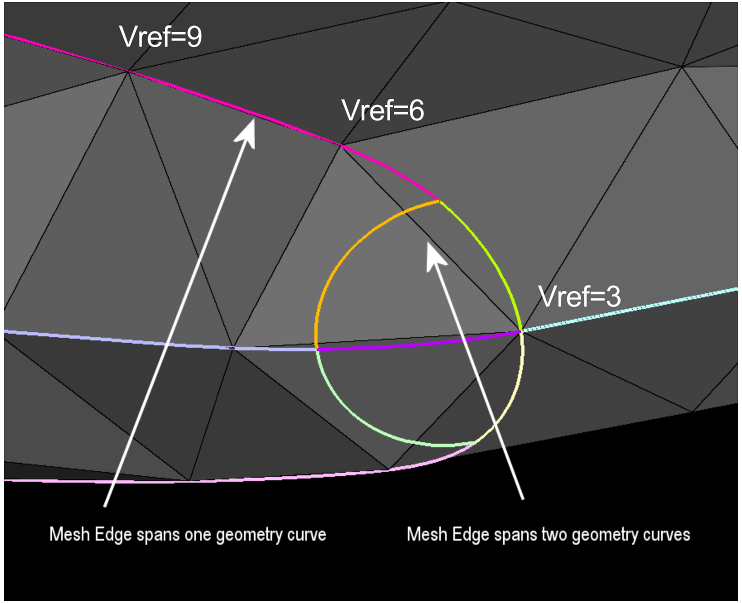
- Mesh String – 1D collection of Mesh Edges
- Mesh Sheet – 2D collection of Mesh Faces
- Mesh Model – 3D collection of Mesh Strings and Sheets

Optional geometry association at Mesh Element and Mesh Topology



Geometry Association

- Geometry Reference (gref) associates geometry entity identifier with Mesh Element and Topology
- May be different at each topological level
  - Edge on boundary of Sheet associated with geometry curve(s) and surface(s)
- Parametric Vertex
  - Each topological level allows definition of Mesh Point parametric location in associated geometry
  - Mesh String
    - ParamVert defines parametric location of Mesh Point on the associated curve
  - Mesh Sheet
    - ParamVert defines parametric location of Mesh Point on the associated surface



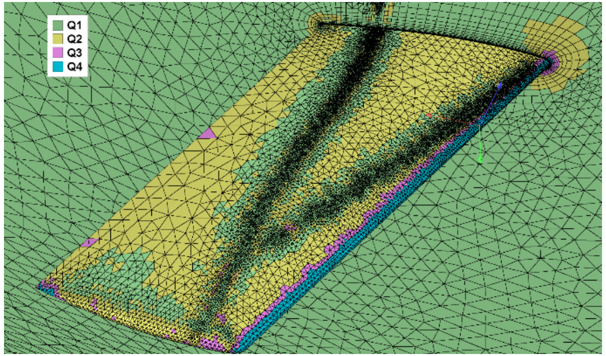

```xml
<MeshString name="root/con-8" gref="8">
  <ParamVertex vref="9" gref="8" dim="1">0.811</ParamVertex>
  <ParamVertex vref="6" gref="8" dim="1">0.924</ParamVertex>
  <ParamVertex vref="3" gref="2" dim="1">1.000</ParamVertex>
  <MeshEdge etype="Edge2" count="2">9 6 6 3</MeshEdge>
</MeshString>
```

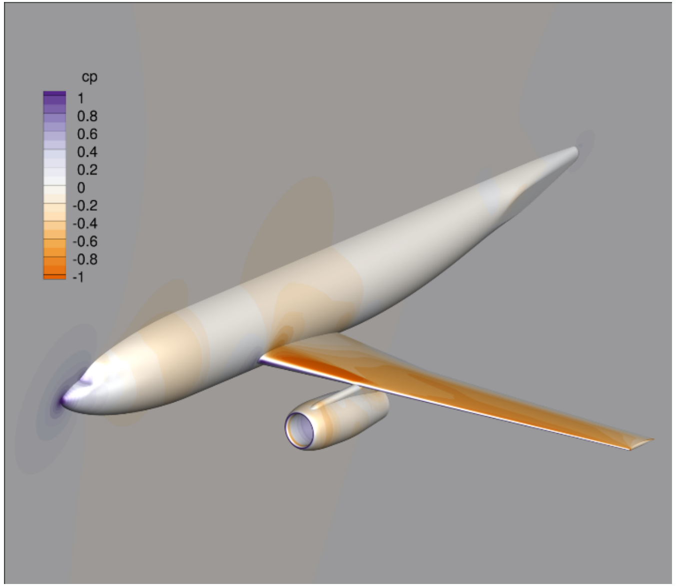
MeshLink Library

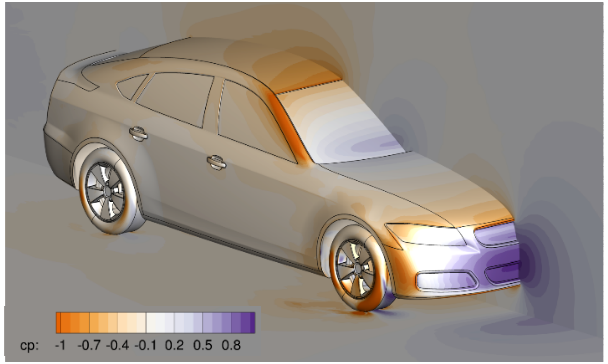
- High-Level API for CAE applications
  - Provides access to mesh-geometry associativity data
  - API covers common geometry operators
    - Forward and Inverse (point projection) evaluation
    - Inspection, e.g., surface normal, curvature, model tolerance
- Workflow designed for common analysis solver tasks
  - Knowledge of computational geometry topology, e.g., B-Rep, not required of user
- Application Neutral
  - Wrappers for geometry kernel, data parser
  - Reference implementation with Project Geode kernel and Apache Xerces XML parser
  - Native C++
  - Wrappers for C, FORTRAN, Python

Demonstration

- Examples in the paper
  - H-P mesh Adaptation
  - Aeronautics
  - Automotive

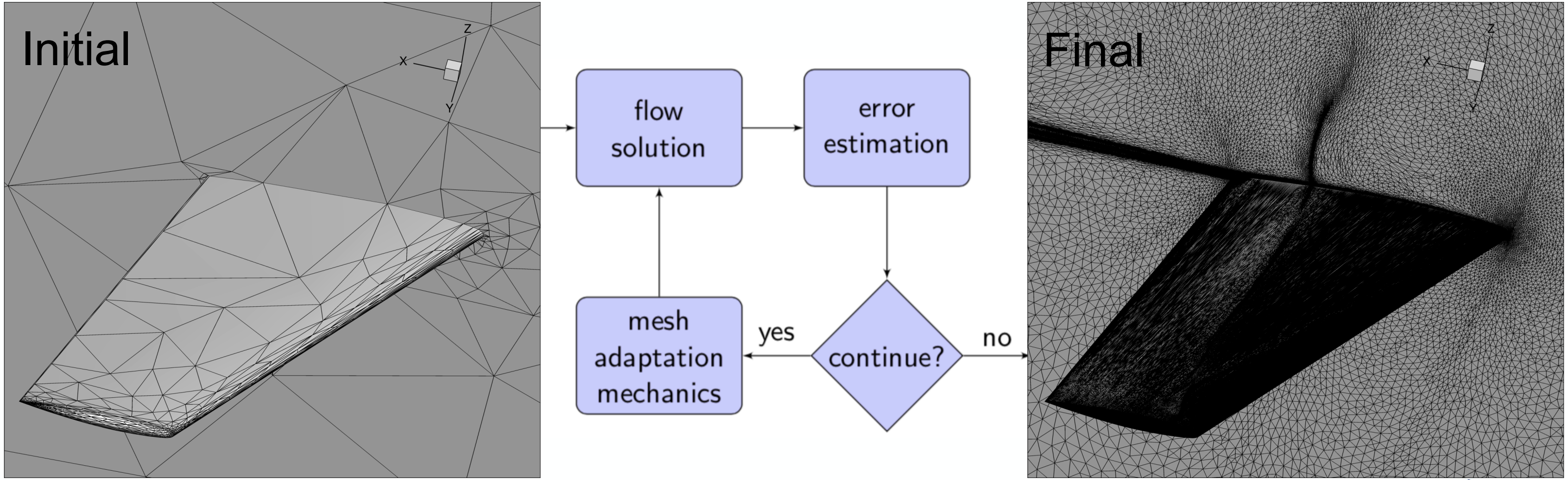






Anisotropic Mesh Adaptation

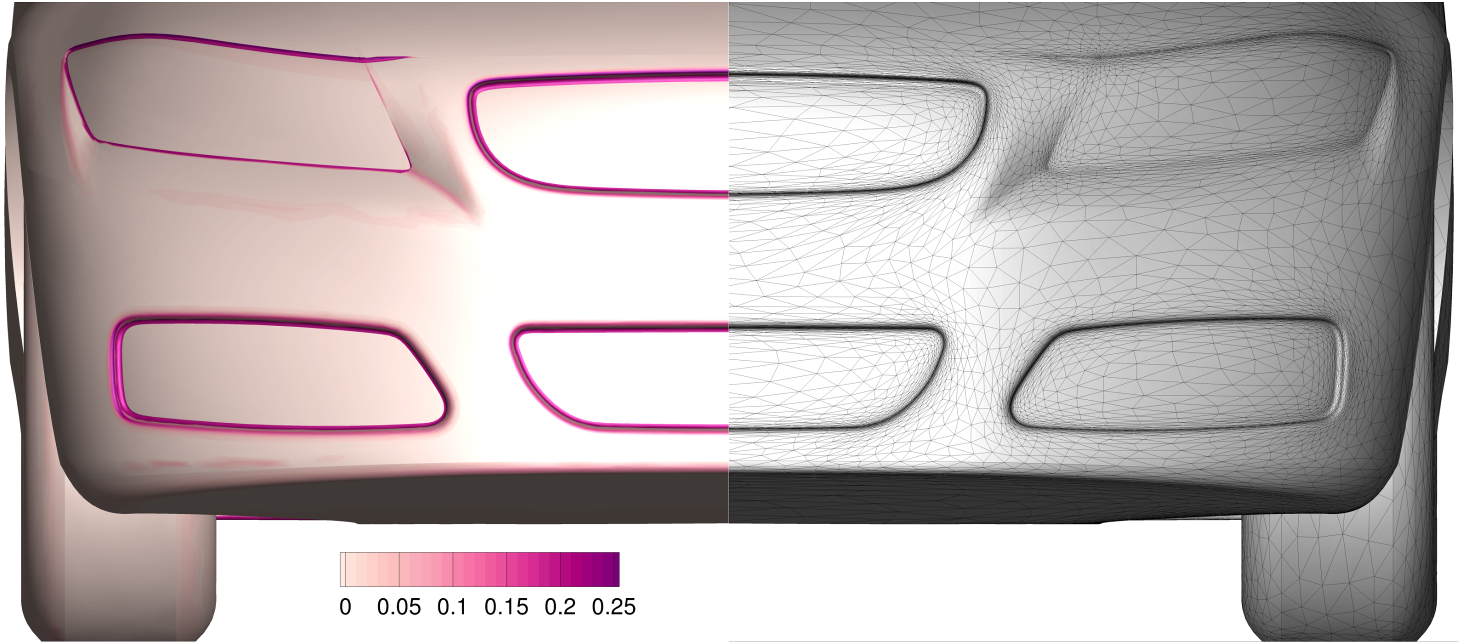
- A series of adapted meshes created from an inexpensive initial mesh (only resolves geometric curvature and features)
- Current (turbulent) solution is used to construct a more accurate mesh by controlling estimated interpolation error (AIAA-2019-2948)



Curvature-based Initial Meshing

```
ML_evalCurvatureOnSurface(geom_kernel, uv, entity_name, eval_point,
                          dXYZdU, dXYZdV, d2XYZdU2, d2XYZdUdV, d2XYZdV2,
                          normal, principalV, &minCurvature,
                          &maxCurvature, &avg, &gauss, &orientation);
```

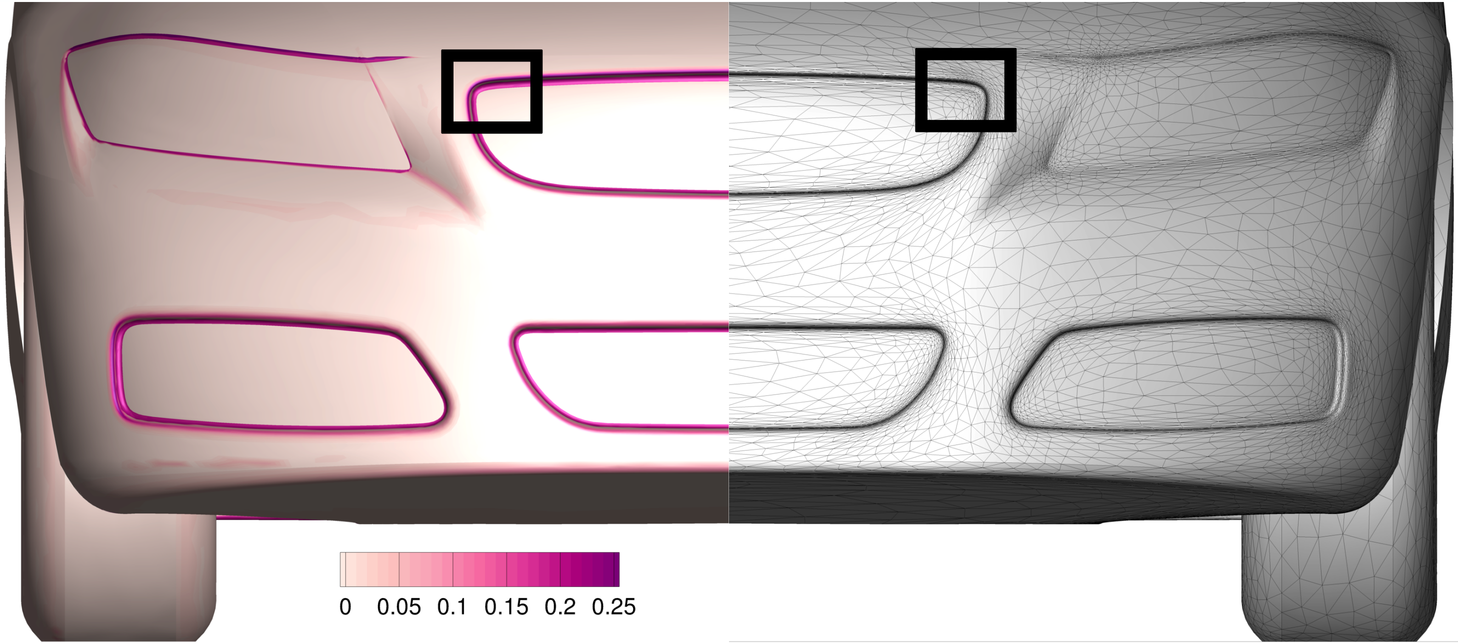
- drivAer grill initial mesh



Curvature-based Initial Meshing

- drivAer grill initial mesh

```
ML_evalCurvatureOnSurface(geom_kernel, uv, entity_name, eval_point,
                          dXYZdU, dXYZdV, d2XYZdU2, d2XYZdUdV, d2XYZdV2,
                          normal, principalV, &minCurvature,
                          &maxCurvature, &avg, &gauss, &orientation);
```



Curvature-based Initial Meshing

```
ML_evalCurvatureOnSurface(geom_kernel, uv, entity_name, eval_point,
                          dXYZdU, dXYZdV, d2XYZdU2, d2XYZdUdV, d2XYZdV2,
                          normal, principalV, &minCurvature,
                          &maxCurvature, &avg, &gauss, &orientation);
```

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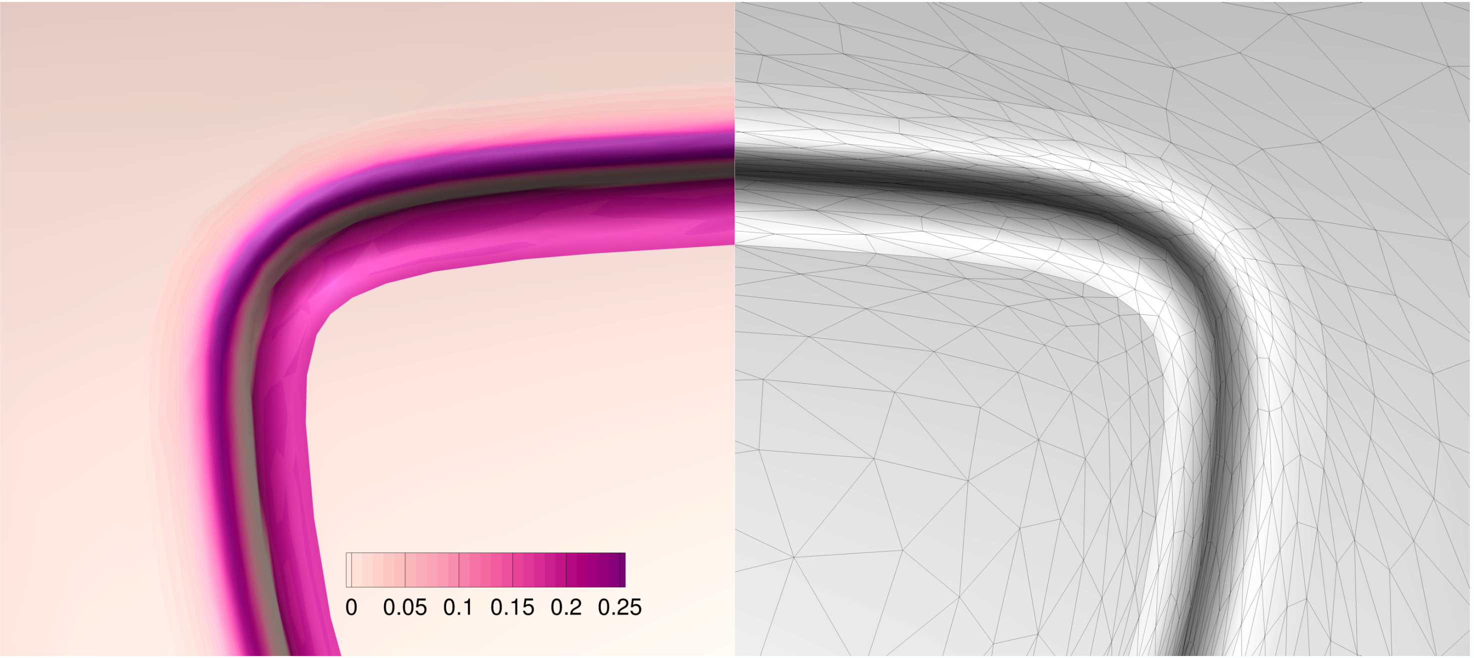

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Summary

- An open framework for mesh-geometry associativity and geometry access has been developed
- Geometry access for mesh adaptation in an HPC environment has been demonstrated

- Software
  - MeshLink: https://github.com/pointwise/MeshLink
  - Project Geode: https://www.pointwise.com/geode
  - FUN3D: https://fun3d.larc.nasa.gov/
  - *refine*: https://github.com/NASA/refine

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