Mixed Order Mesh Generation for Curved Geometry

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Introduction
Introduction

- High order mesh curving is an emerging technology that will greatly benefit the Finite-Element Methods (FEM) Computational Fluid Dynamics (CFD) solver community.
- Research into mesh curving is taking place at a number of institutions.
  - Interpolation methods, such as Radial Basis Functions.
  - Linear and non-linear elasticity analogs.
  - Elliptic PDE, such as Winslow.
  - Mesh modification in response to Riemannian metric tensor.
- Meshing applications are beginning to include a mesh curving capability.
  - MeshCurve – Master’s student research code.
  - Gmsh – Full featured mesh generation tool with high order capability.
  - NekMesh – Component of Nektar with some high order capability.
  - Pointwise – Uniform curving up to Q4 for mixed element types.
Results: BANC III Landing Gear

- 3rd AIAA Workshop on Airframe-Noise included a complex landing gear configuration.
- The mesh was originally generated at Pointwise. It was coarsened and then elevated and curved to a Q2 mesh.
- The input linear mesh had ~7 million points and ~34 million tetrahedra.
- The Q2 mesh contained ~46 million points.
- This was constructed in serial on an iMac with 32 Gbytes RAM.
Results: BANC III Landing Gear

• Peter Vincent et al. used PyFR to compute a preliminary flowfield solution.
Introduction

- The Weighted Condition Number (WCN) used in Pointwise is being extended to mixed order curving under a NASA Phase II SBIR contract.

- Volume elements are elevated in response to geometry curvature.
  - Near highly curved geometry the degree can reach 4.
  - Near flat geometry and in the far field the element degree remains linear.

- The WCN method employs a cost function that enforces element shape and positive Jacobians.

- At completion the mixed order mesh is exported or uniformly elevated to the desired degree.
Geometry Access

• Geometry access for elevating and smoothing is provided through the MeshLink API*.

• MeshLink is a library for managing geometry and mesh data and provides a simple interface to query functions pertinent to mesh generation and mesh adaptation applications.

• At the completion of the creation of the linear mesh in Pointwise three files are exported.
  - CGNS mesh file.
  - NMB CAD geometry file.
  - MeshLink XML file that defines the mesh to geometry associativity.

• All projection queries during elevation and smoothing are handled through the MeshLink API.

Mesh Curving Process
Mixed Order Curving

• A bootstrapping approach is used to initialize a mixed order mesh with increasing maximum element order, starting at degree 2 and ending at a possible maximum degree 4.

• The polynomial degree of an element is indicated using Q1 through Q4 nomenclature.

• High-order nodes are evenly distributed through the elements using Lagrangian basis functions (CGNS indexing).

• Shape conformity at interfaces between elements of different order is imposed during smoothing and before export.
Surface Element Deviation Metric

- Surface elements are tested for deviation from the geometry at 6\textsuperscript{th} order quadrature locations.
- If the perturbation exceeds a fraction (~5\%) of the minimum edge length of the adjacent volume element the surface and volume element are elevated to the next higher order.
- Surface element edges are also tested for deviation.
Volume Element Deviation

- At interfaces between elements of different order the nodes are not shared. Gaps exist.
- During smoothing the higher order shape is imposed on the lower order element face. Otherwise, the smoothing will force the element to revert back to the linear shape.

![Physical Mesh](image1.png) ![Computational Mesh](image2.png)
Volume Element Deviation

- After all smoothing is completed the lower order shape is imposed on the higher order element face. All gaps are effectively eliminated.
- The flow solver needs to similarly enforce the solution from the lower order element on the higher order element face (constrained approximation).
Results
Hemisphere on Flat Plate

- The linear hybrid mesh contained prisms extruded from the hemisphere and tetrahedra in the volume.
- 4,290 linear nodes, 5,402 tetrahedra and 5,504 prisms.
Onera M6

- A linear mesh for the Onera M6 wing was generated in Pointwise with 37,813 nodes.
- The hybrid version contains 65,015 tetrahedra, 976 pyramids, and 50,043 prisms.
- A tetrahedra-only version contains 217,100 tetrahedra.
Onera M6

Hybrid

Wing Tip
Trailing Edge
Cut

Tet-Only
Onera M6

Hybrid

Wing Tip
Spanwise
Cut

Tet-Only
Weeble Wobble

• The linear mesh 16,340 points and 96,694 tetrahedra. Final mesh 182,136 points.
• The linear mesh has a maximum element aspect ratio of 1454. The initial spacing off the surface is 0.0001.
Weeble Wobble

- Q1-Q4 mesh
Weeble Wobble

- Middle section has concave and convex curvature.
- Top and bottom has convex curvature.

![Linear mesh](image)

![Curved surface element](image)
Weeble Wobble

- Hybrid mesh with tetrahedra, pyramid, prisms and hexahedra.
- High warp values on the surface ~30 degrees.
Generic Intake Port

• The linear mesh contained 611,924 points, 308,265 tetrahedra, 104,200 pyramids, 10661 prisms and 509,738 hexahedra.

• Final mesh has 1,242,681 points.
Generic Intake Port

- The final quadratic (yellow) element counts were 149 tetrahedra, 209 pyramids, 1506 prisms and 80,838 hexahedra.
Conclusions
Conclusions

• A method for creating curved, mixed-order meshes has been presented.
  - Geometry access provided through MeshLink API.
  - Optimization-based smoothing used to curve the meshes.
  - Deviation metric used to indicate when elevation is needed.
  - Shape conformity imposed at interfaces between elements of different order.
  - Hybrid meshes with element order up to Q4 possible.

• Several example cases demonstrated the capability to handle highly clustered, viscous meshes.

• These mixed-order meshes will be available in a future release of Pointwise.
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• Watch a demonstration to see how Pointwise creates HO grids: https://ptwi.se/2CB9Ly1
THANK YOU!

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