The Link Between Mesh and Geometry in Pointwise

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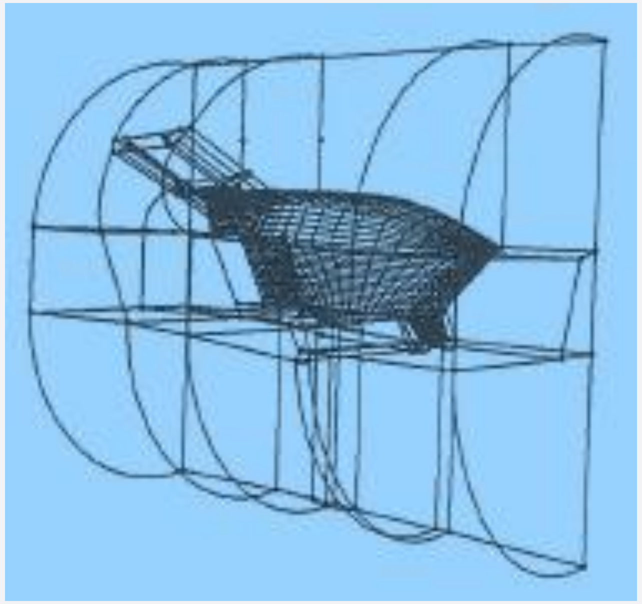
Outline

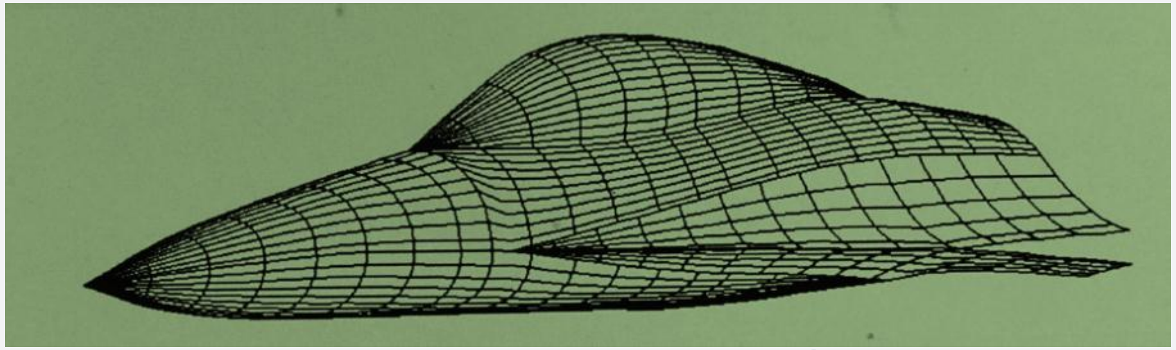
- Evolution of Pointwise Mesh and Geometry
- Difficulties With Meshing on CAD
- Mesh Adaption and Degree Elevation
- Conclusions

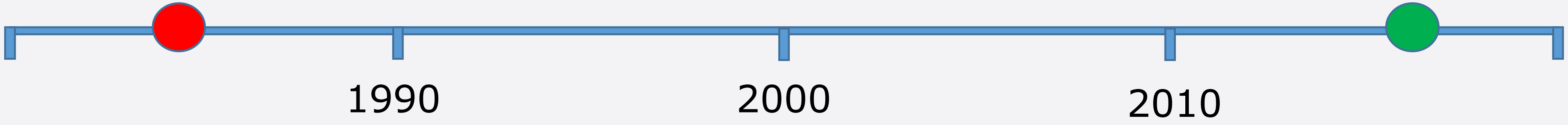
Evolution of Pointwise Mesh and Geometry

Evolution of Mesh and Geometry

- 1984 - Gridgen development began
- CFD solvers predominantly single-block
  - finite difference
  - structured grid
- Multi-block methods beginning to emerge
- Geometry was rare and sparse
  - Often provided from panel method codes
    - Stored as bilinear patches
    - PLOT3D format

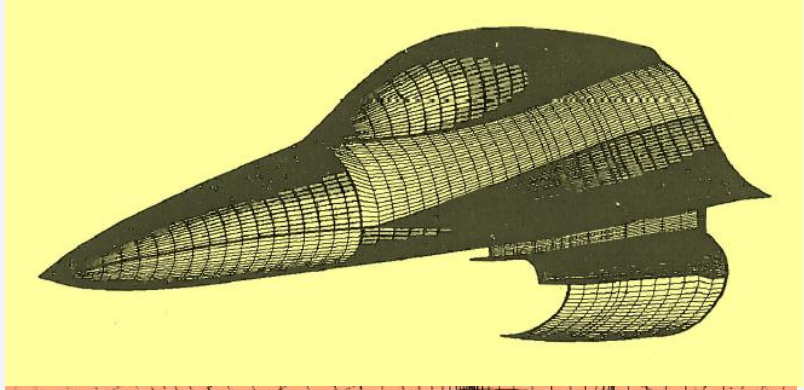


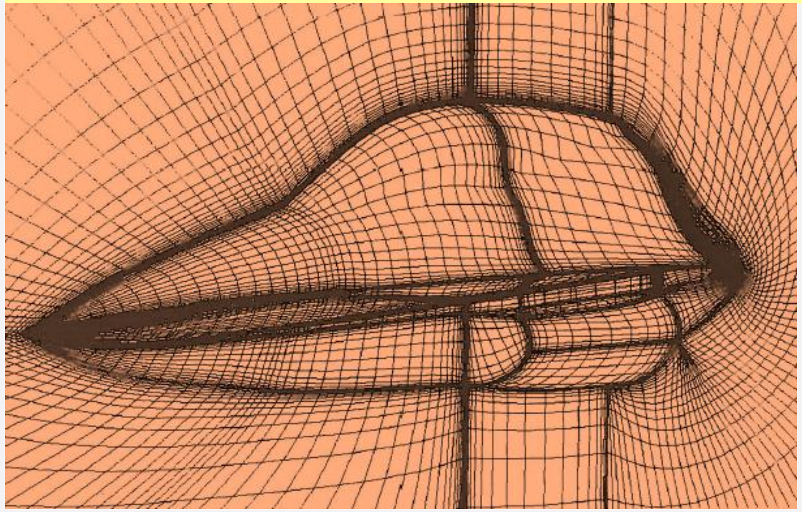


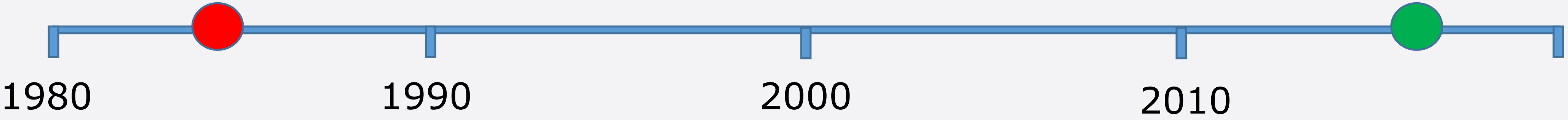


Evolution of Mesh and Geometry

- With multi-block, topology of surface meshes differed from the bilinear geometric representation
  - Required a topological structure for the grid
    - Vertex (*node*)
    - Curve (*connector*)
    - Surface (*domain*)
    - Volume (*block*)
  - Users applied care to ensure
    - Adjacent surfaces shared curves
    - Adjacent volumes shared surfaces
  - Duplicate checking procedures integrated at vertex, curve, surface level

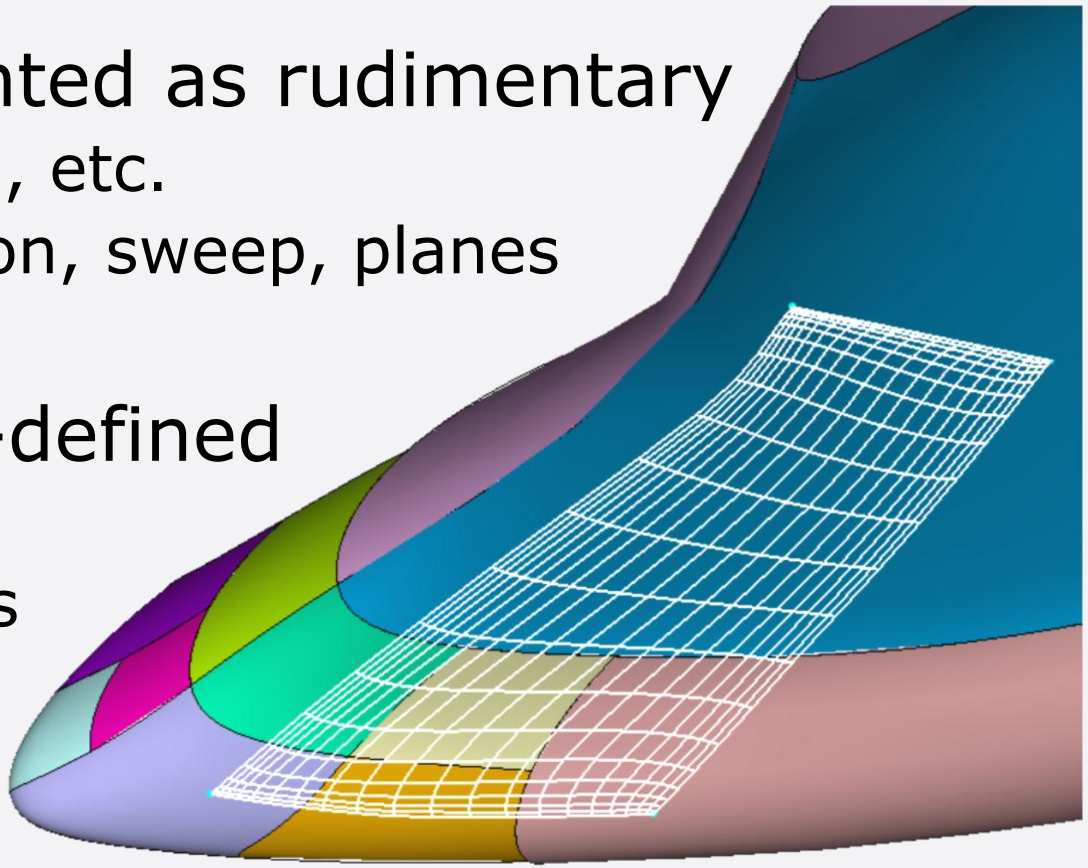


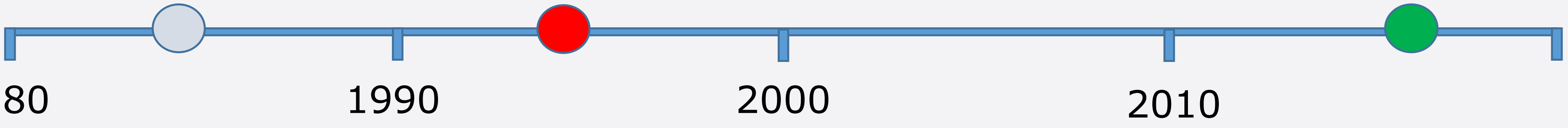




Evolution of Mesh and Geometry

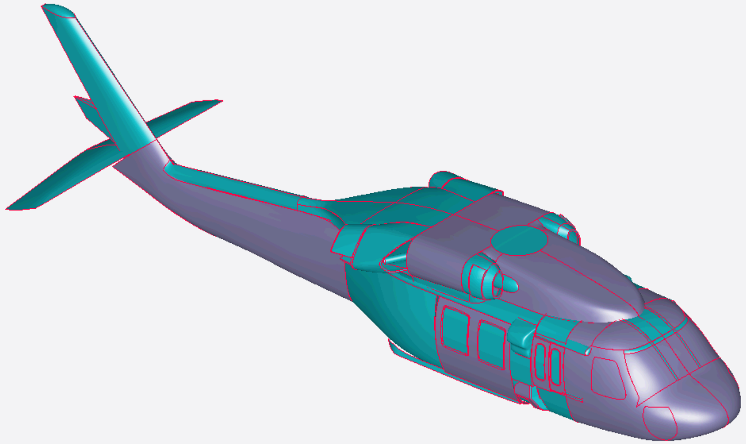
- 1994 – Pointwise incorporated
- Gridgen V12 – Geometry represented as rudimentary
  - Curves – conic, Akima, Catmull-Rom, etc.
  - Surfaces – ruled, polyconic, revolution, sweep, planes
  - Stored in Bezier/NURBS form
- Surfaces were "trimmed" by user-defined grid curves
  - Potentially spanned multiple surfaces
  - Small gaps, overlaps OK



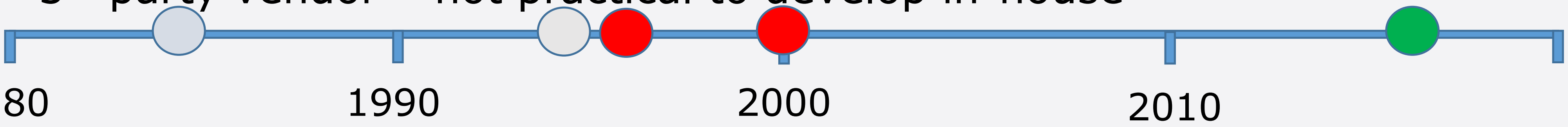


Evolution of Mesh and Geometry

- 1996 – Gridgen V14
  - IGES import
  - 141-144 entities
  - Limited 186 support
    - No solids
    - Extracted trimmed/bounded surf data only
  - Unstructured (triangle) surface grids, (tet) volume grids
    - Reduced surface topology on unstructured grids offered potential for auto creation of curves, surfaces



- 2000 – Gridgen V13.3
  - Interoperability (CatiaV4, V5, UG, Pro/E)
    - CAD file import via file translation
    - 3rd party vendor – not practical to develop in-house



Evolution of Mesh and Geometry

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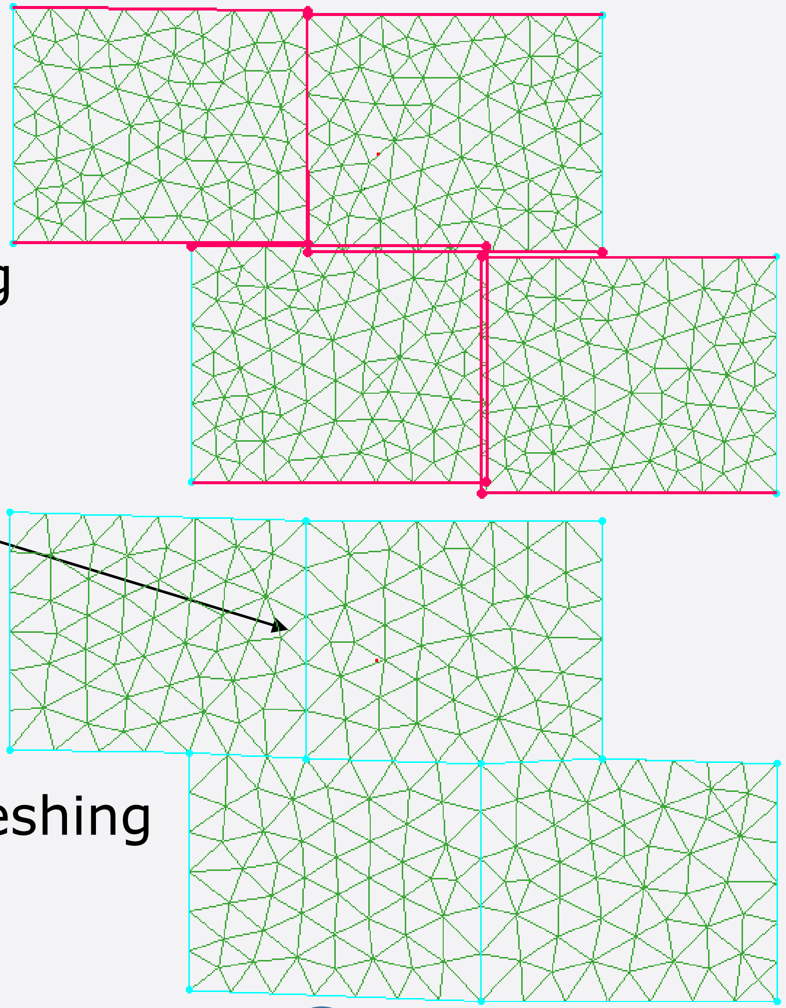
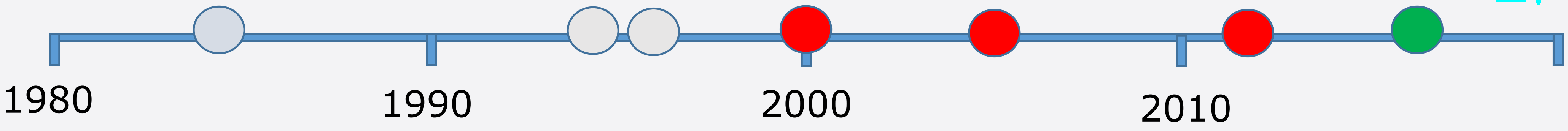
- 2 Methods for Creating Watertight Meshes
  - 2000 – Fault Tolerant Meshing (FTM)
    - CAD models imported w/o solid information
    - Gaps, overlaps in CAD models ignored by maintaining mesh connectivity at the *mesh* curve, surface level
    - Curve discrepancies reconciled by splitting at node locations, removing duplicate nodes, curves
    - Automation possible via recursive operations with ever-increasing tolerances
  - 2005 – Solid Modeling (Gridgen V15)
    - Solid topology imported from CAD file
    - Repaired using similar algorithms as fault tolerant meshing
    - Surface stitched together prior to creating mesh
  - 2012 – Solid Modeling (Pointwise V17)

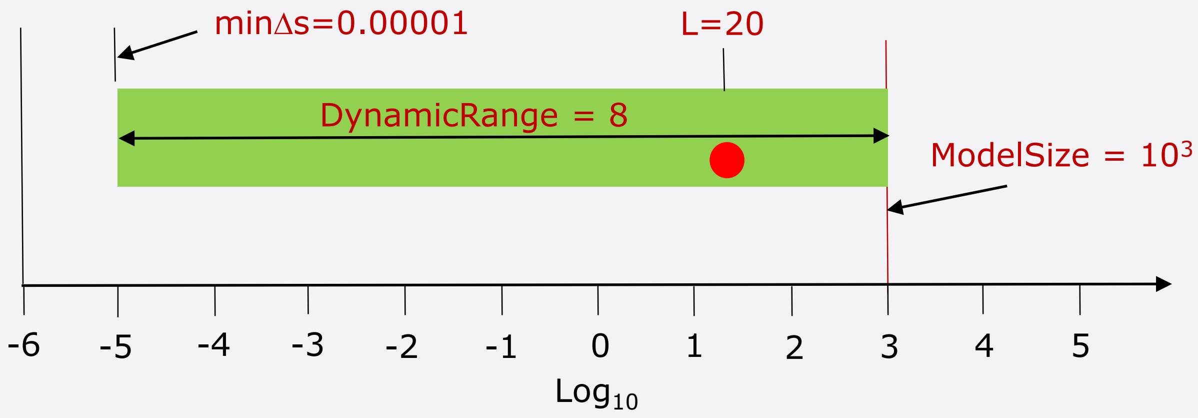




Difficulties with Meshing on CAD

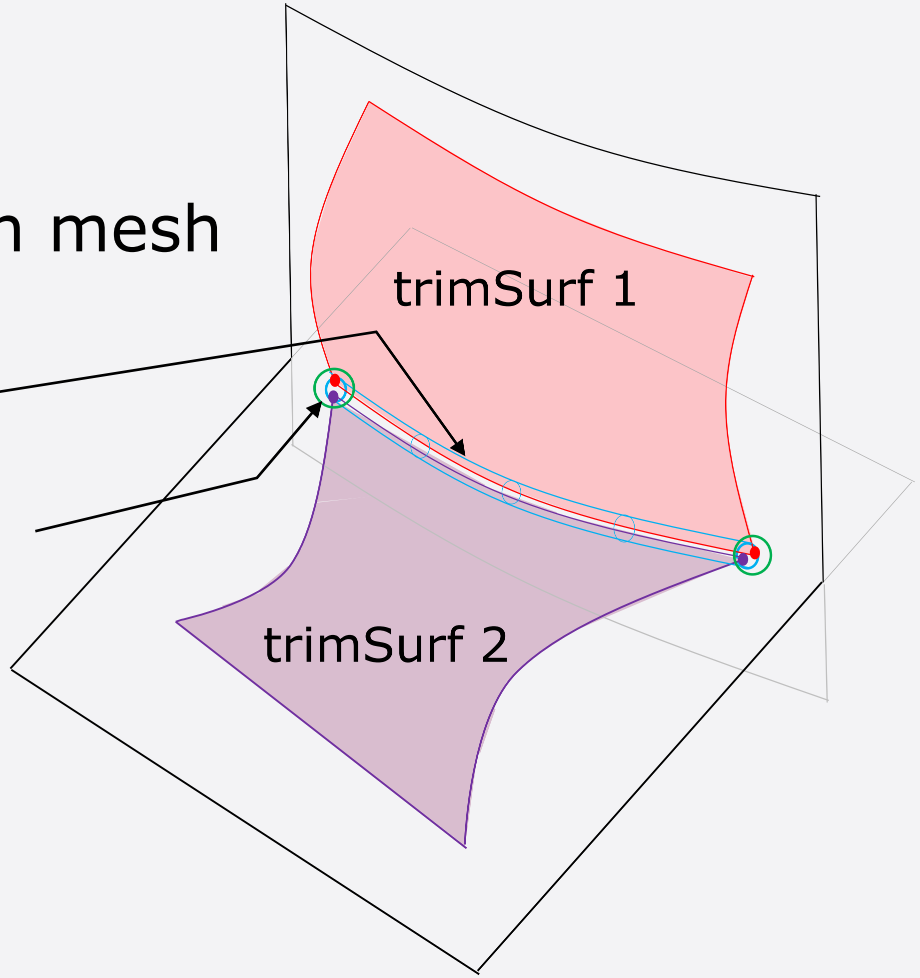
Difficulties with Meshing on CAD

- Watertight Meshes
  - Solid Modeling and FTM each routinely used
  - Effectiveness depends on quality of CAD file and proper usage of CAD/Mesh tolerances
  - DynamicRange
    - $\log_{10}$ of the ratio between the largest expected number in the model (ModelSize) and the smallest relative query/calculation (min surf Δs)
    - Unstructured Delaunay mesher: DynamicRange = 5-6
    - CAD systems: DynamicRange = 7-11 (Pointwise = 9)



Difficulties With Meshing on CAD

- Tolerances (similar for Solid Modeling & FTM)
  - ModelSize (default = 1000)
  - SamePntTol = ModelSize/DynamicRange
    - (default = $10^3/10^9 = 10^{-6}$)
  - GridPointTol = smallest spacing anywhere in mesh
    - (default = 10^{-7})
  - Implicit Tolerances
    - CurveTol –minimal cylinder radius
    - VertexTol (≥ CurveTol) – minimal sphere radius



- Tolerance should be modified sparingly!
  - Confusing – required in-house training

Difficulties With Meshing on CAD

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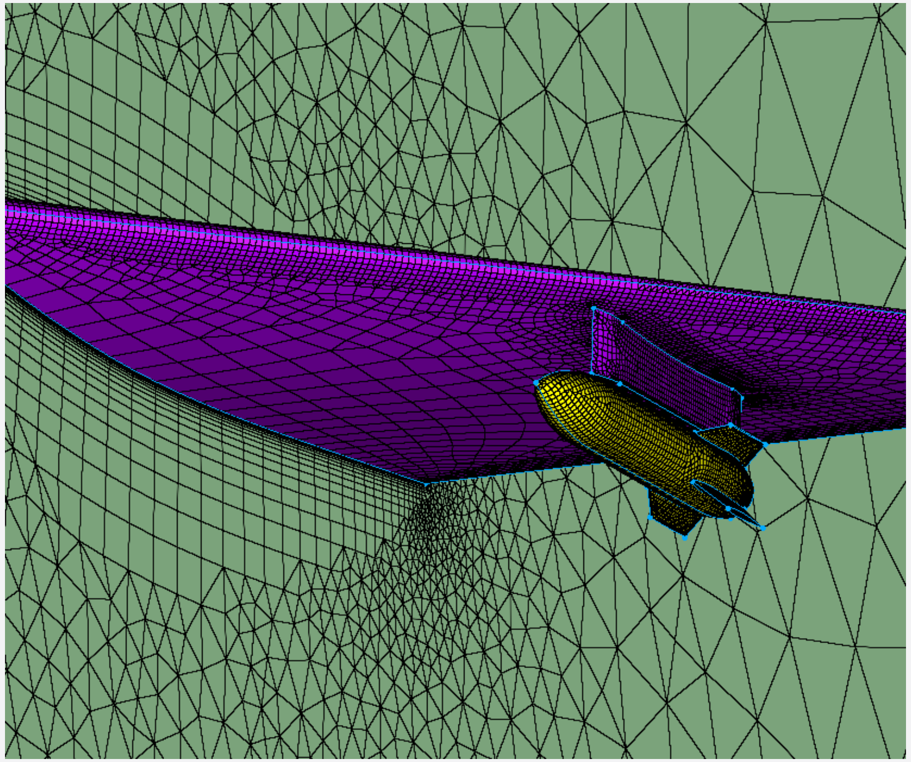
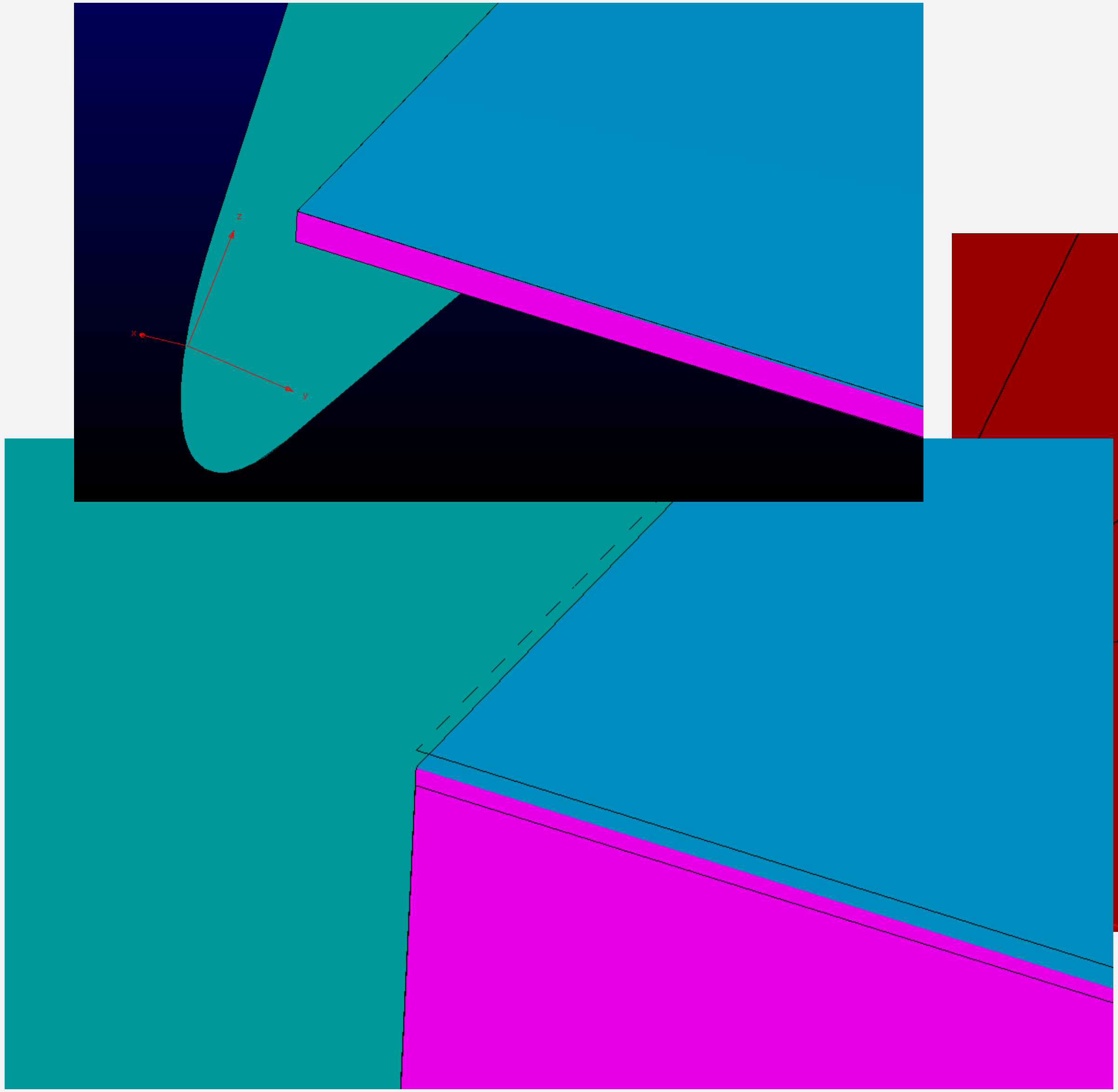
- Surface-Surface Intersections
  - Can yield Curve/VertexTol 1 order larger than samePntTol
    - Balance between accuracy and point density of parameter space curves
- Legacy Files
  - Tend to be sloppy, redundant, too detailed, etc.
- 3rd Party Interop Libs attempt to regularize all CAD
  - Matrix of import options prohibits most automation
  - Pointwise is currently using 3rd vendor
- IGES files still frequently encountered
  - IGES format is adequate
    - Implementations of readers/writers is not
  - CAD vendors not incentivized to produce accurate IGES export

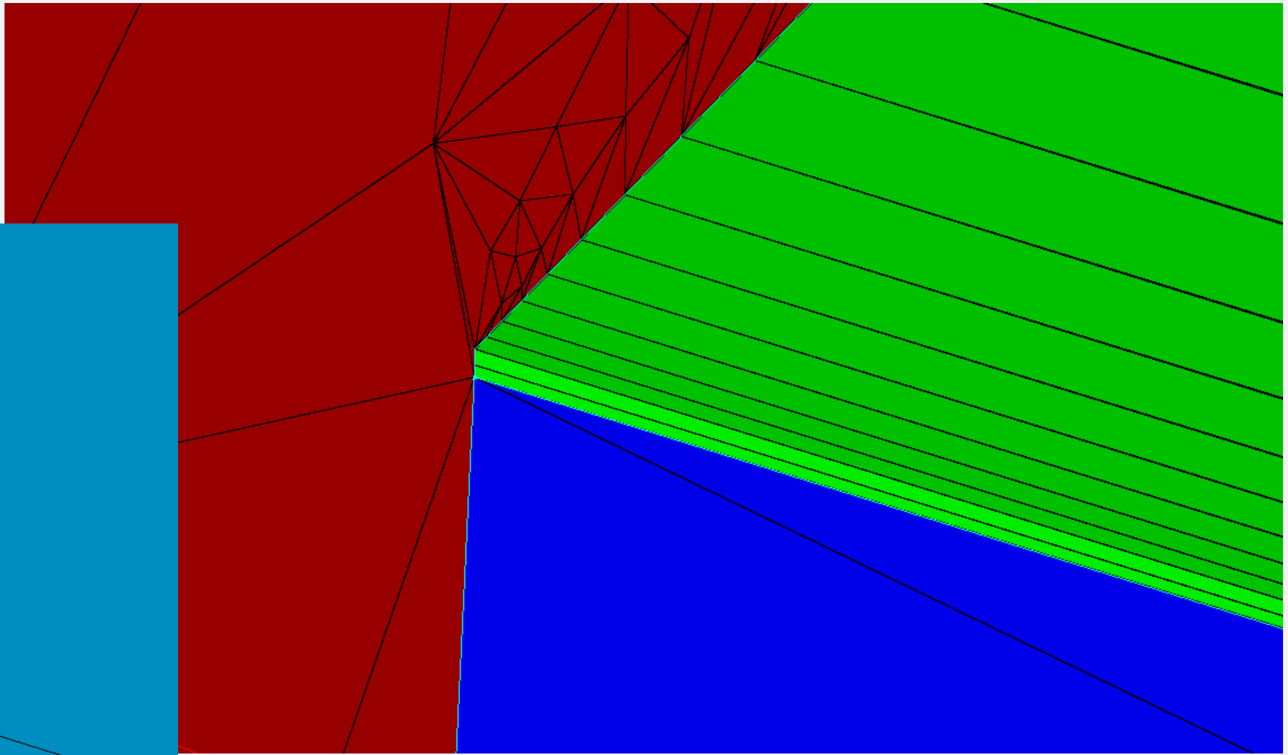
Difficulties With Meshing on CAD

- With **Poor** Geometry…
  - FTM is difficult to automate, tedious with complex models
  - CAD cleanup takes up to 50% of effort
    - Sorting entities into layers
    - Removing details
    - Stitching unrecognized topology breaks
    - Both methods require surface grid point spacing to be greater than geometric gaps
      - curve tolerance in vicinity of surface-surface junctions
  - Surface-Symmetry junction problems
    - Viscous spacing « curveTol or samePntTol
    - FTM is often used



Difficulties With Meshing on CAD





Difficulties With Meshing on CAD

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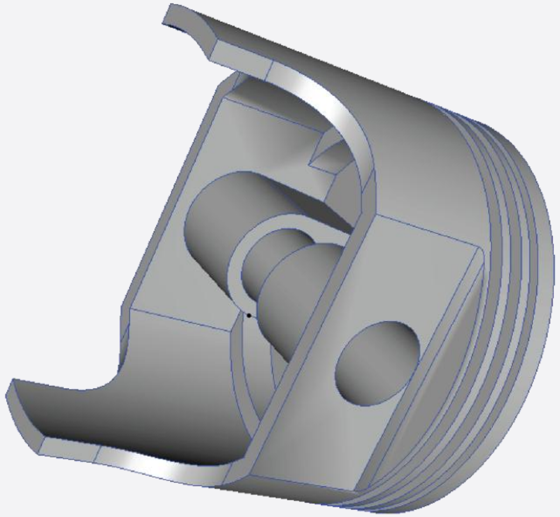
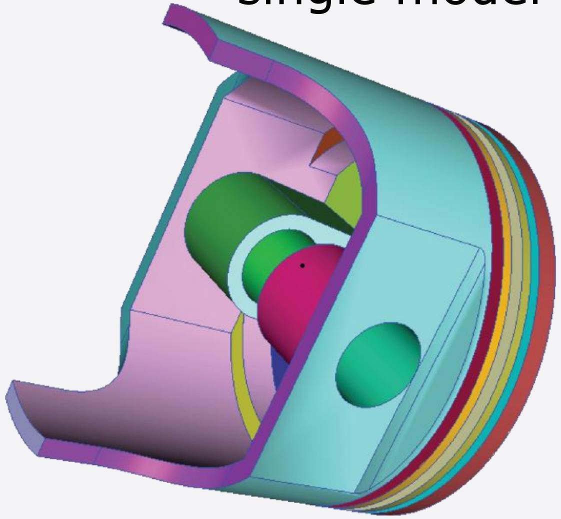
- With **Good** Geometry…
  - Hard edges (CAD edges preserved in grid) usually not defined in CAD model
  - Pointwise uses Quilt entity
    - Engineering surface on which a single mesh is created
    - Quilt ⊆ Model
    - Boundaries of quilts are hard edges
  - Automation of mesh generation for CFD difficult
    - Depends on…
      - Corporate best practices
      - Anticipated flow physics
      - 2 customers have developed sophisticated templates (using Glyph) to automate mesh generation procedure
        - Surface meshes made in < 1 hour
        - Volume meshes made automatically



single model



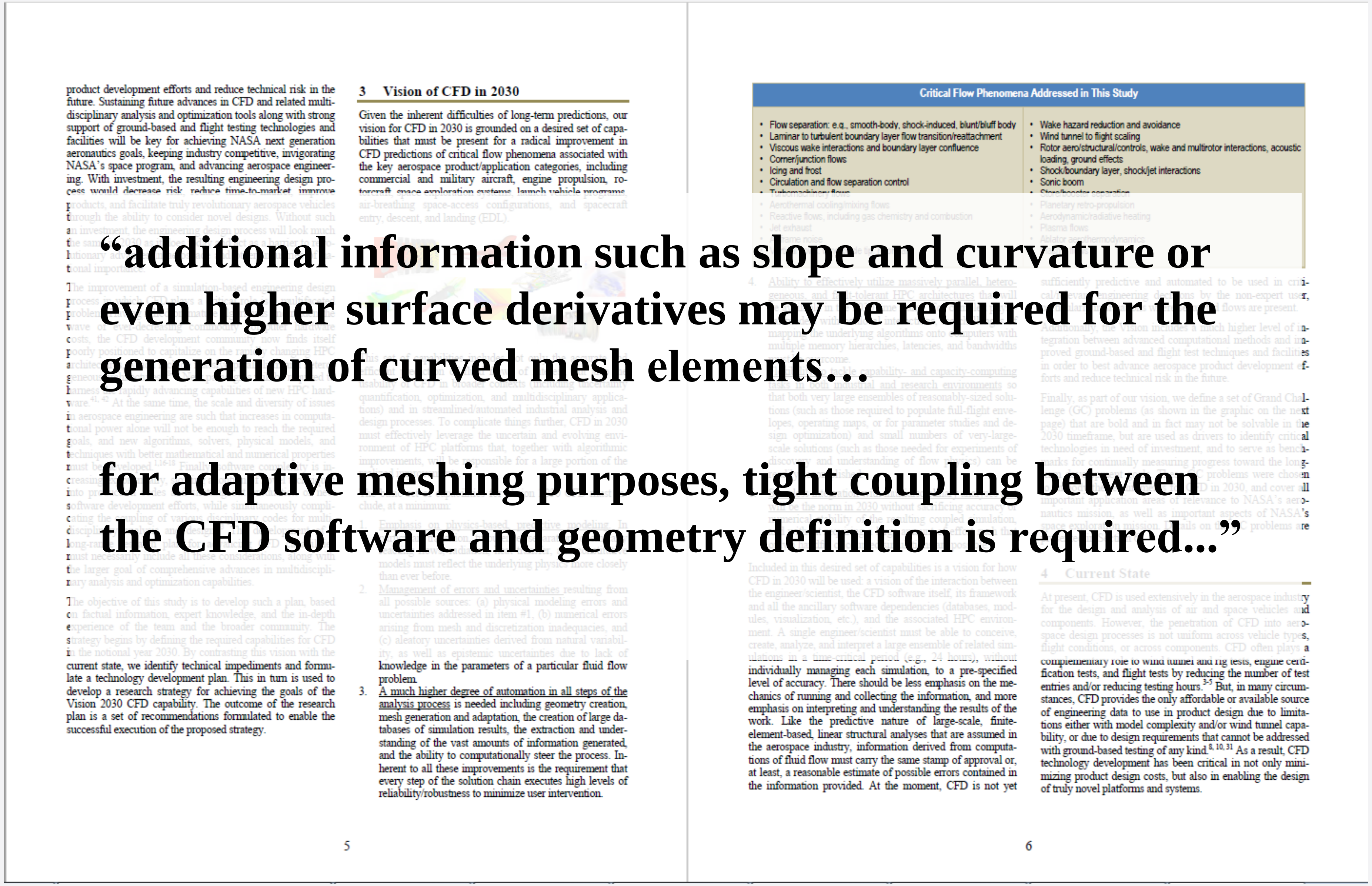
multiple quilts

Difficulties With Meshing on CAD

- Towards automation of mesh generation
  - Attributed CAD – mesh parameters tagged to geometry
    - Pointwise effort funded by US Air Force and MIT
      - Commencing Oct 2017, duration 1-2 years
    - Transverse, normal spacing, BC types, etc. defined in pre-CAD environment
      - Exported to Pointwise
      - Meshing proceeds automatically from attributes
  - Geometry API integrated into CFD software
    - Allows basic yet non-optimal/complete mesh to be handed to solver
      - Solution Adaption
      - Degree Elevation for higher order solvers

Mesh Adaption and Degree Elevation

Mesh Adaption and Degree Elevation



“additional information such as slope and curvature or even higher surface derivatives may be required for the generation of curved mesh elements…

for adaptive meshing purposes, tight coupling between the CFD software and geometry definition is required...”

Mesh Adaption and Degree Elevation

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- Pointwise's geometry engine
  - 4th generation non-manifold solid modeler
  - Project Geode – ongoing private beta program with 7 different CFD code teams
    - SU2 (Stanford)
    - Integrate API into solver for mesh adaption and node insertion
    - Primary need is grid point surface projection
    - Geometry exported from Pointwise using proprietary format
    - Plans for no-cost public beta are next
  - Feedback
    - Stronger link needed between grid points and geometry
    - Grid point needs to know if it is constrained to surface interior, edge or vertex
    - Surface grid entity needs to know which trimmed surfaces it can project to

Mesh Adaption and Degree Elevation

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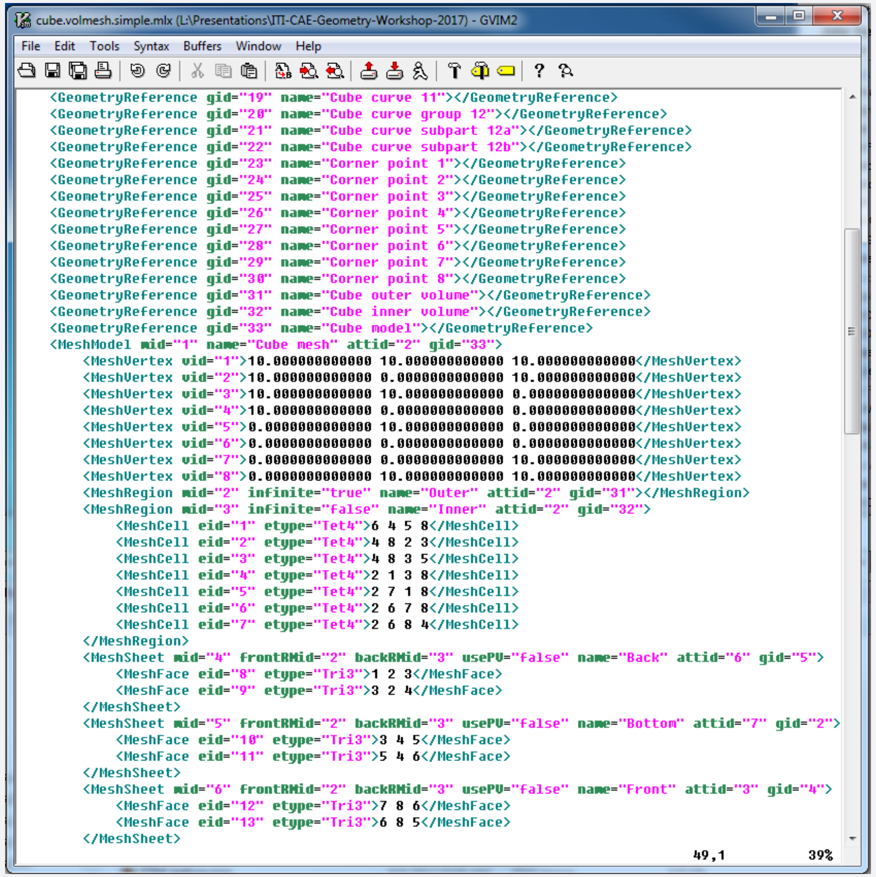
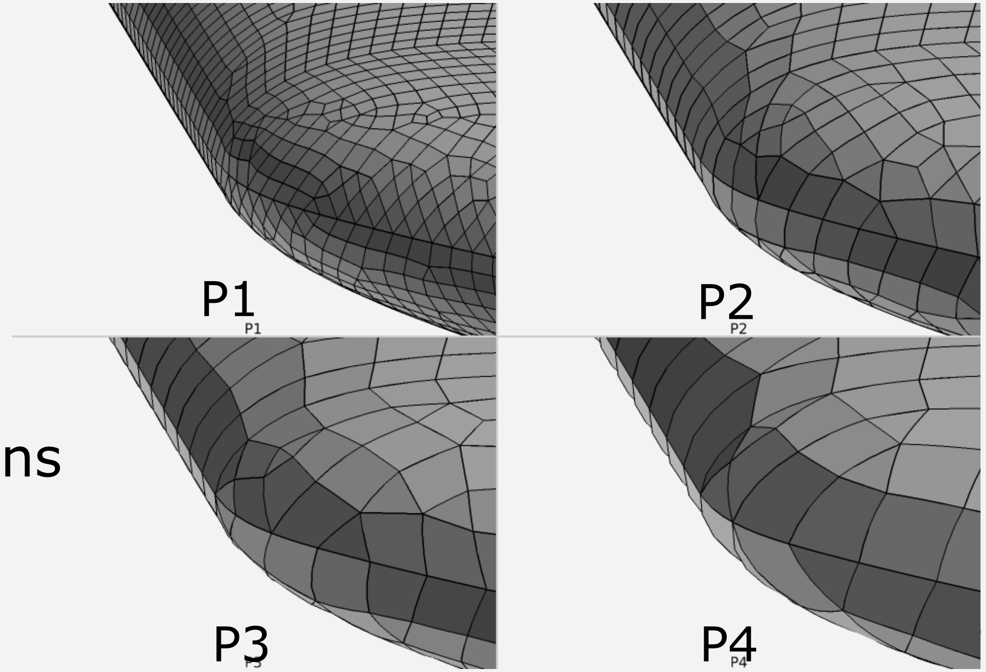
- Schema for linking geometry to mesh for subsequent grid editing
  - will allow grid points to remain attached to limited entity groups
    - e.g., surf1, surf2-surf5, edge1-edg6
  - Atomic classes (XML elements)
    - MeshLink, GeometryReference, AttributeReference
    - MeshModel, MeshVertex, ParamVertex, MeshRegion, MeshSheet, MeshString, MeshPoint, MeshCell, MeshFace, MeshEdge



- Geometry and XML files define adaptive/elevation space

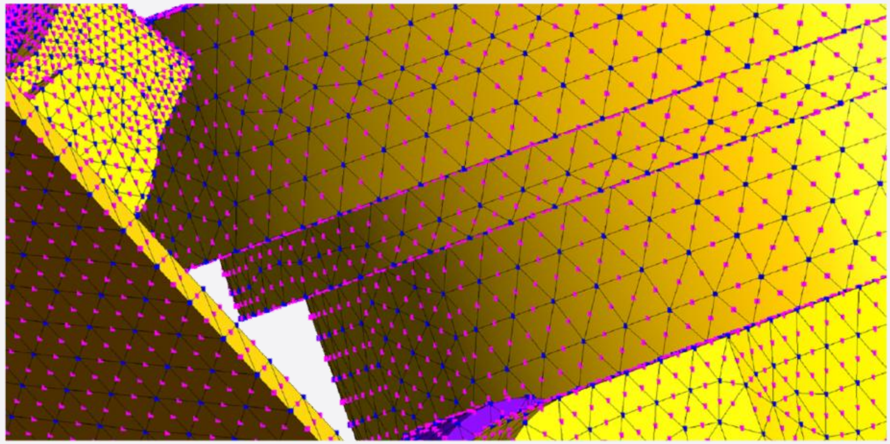
Mesh Adaption and Degree Elevation

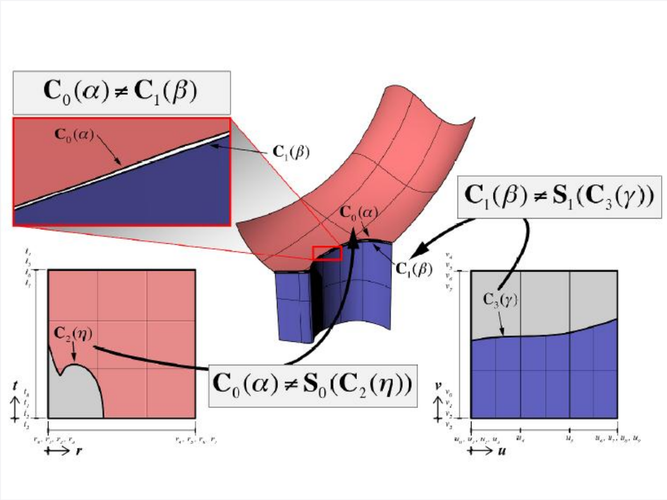
- Anticipated Problems
  - Some CFD apps will require multiple order of magnitude surface mesh refinement (LES, DNS)
    - Grid point projections are unpredictable when points lie within curveTol of the CAD edge
    - Reduced tolerances won't help if surface mesh has regions of very sharp curvature
  - Higher-order meshes
    - Pointwise SBIR effort funded by NASA
      - Convert surface and volume cells to curved elements
    - More projections per element
    - Blind (e.g., evenly spaced) placement of interior nodes can result in negative Jacobians at higher (e.g., 6^{th}) order
    - Tight spacing near edges problematic



Mesh Adaption on CAD Surfaces

- Potential Solution?
  - Replace the NURBS rep with an alternate geometric basis that provides C0 continuity at quilt boundaries
    - Modifies original geometry
    - Refinable to near machine zero
  - Possible alternate geometric bases
    - High order (degree 3) triangular surface
      - Requires reasonable linear triangle surface mesh as starting point
      - Optimization problem balancing C1 continuity with surface shape
    - nVariate, Austin, TX (Ben Urick)
      - Complex method of reparametrizing adjacent trimmed surfaces so that the parameter-space curves share the exact control points and parametrization
      - curveTol is 0, though the intersections are generally not exact w.r.t. surfaces
    - Each method is early in development





Conclusions

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- CAD usage in meshing has come a long way in 30+ years
- Pointwise will continue to rely on semi-automated cleanup tools (FTM) for problematic files
- CAE will continue to see inadequate models until it is seen as a critical component of the design process
- Pointwise is developing methods for automating and embedding mesh process
- Alternate geometric representations may be required for fine-grained solution adaption