Exceptional service in the national interest

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LayTracks3D: Hex Meshing using MAT

William Roshan Quadros

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Goal of LayTracks3D

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- Handle General Solids
- Orientation Insensitive
- Boundary Sensitive
- Preserve Sharp Features
- Preserve Imprints in Assemblies
- Geometry Adaptive
- Potential All-Hex
- Fast Remeshing
- Morphable Meshes
- Parallel Friendly

Medial Axis Transform

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Two-Way Mapping

f: p → Mp

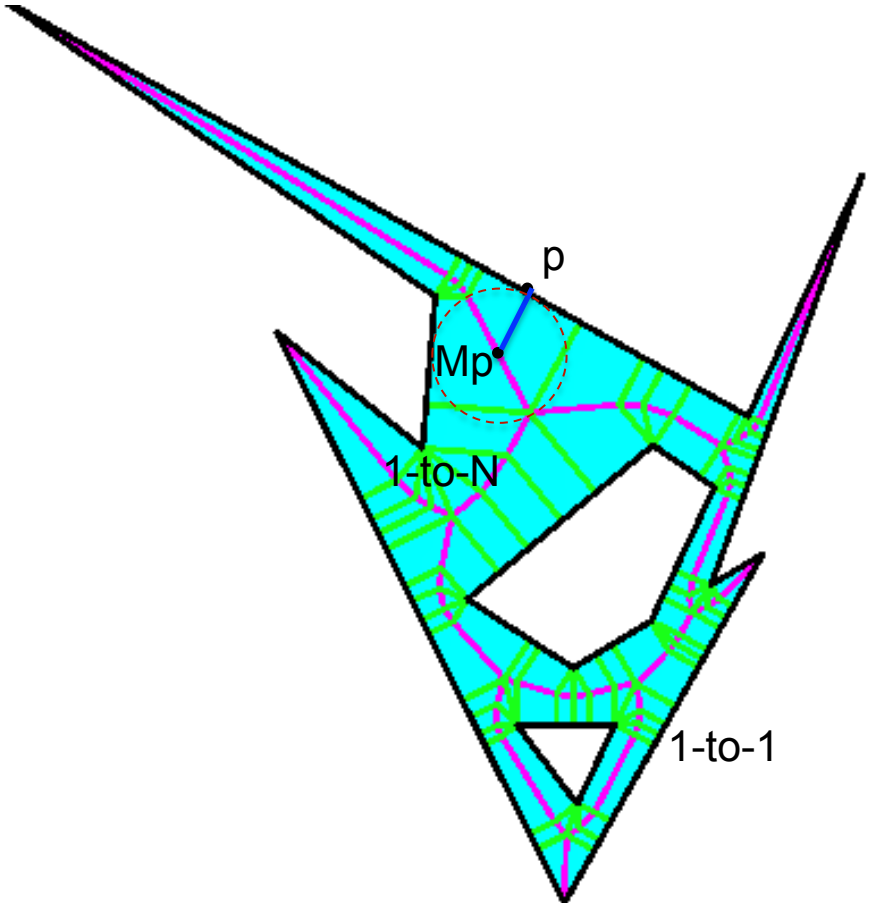
g: Mp → p

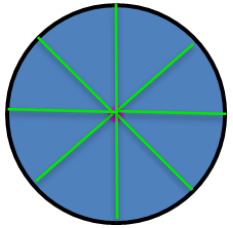
Types of Mapping

1-to-1

1-to-N

N-to-1

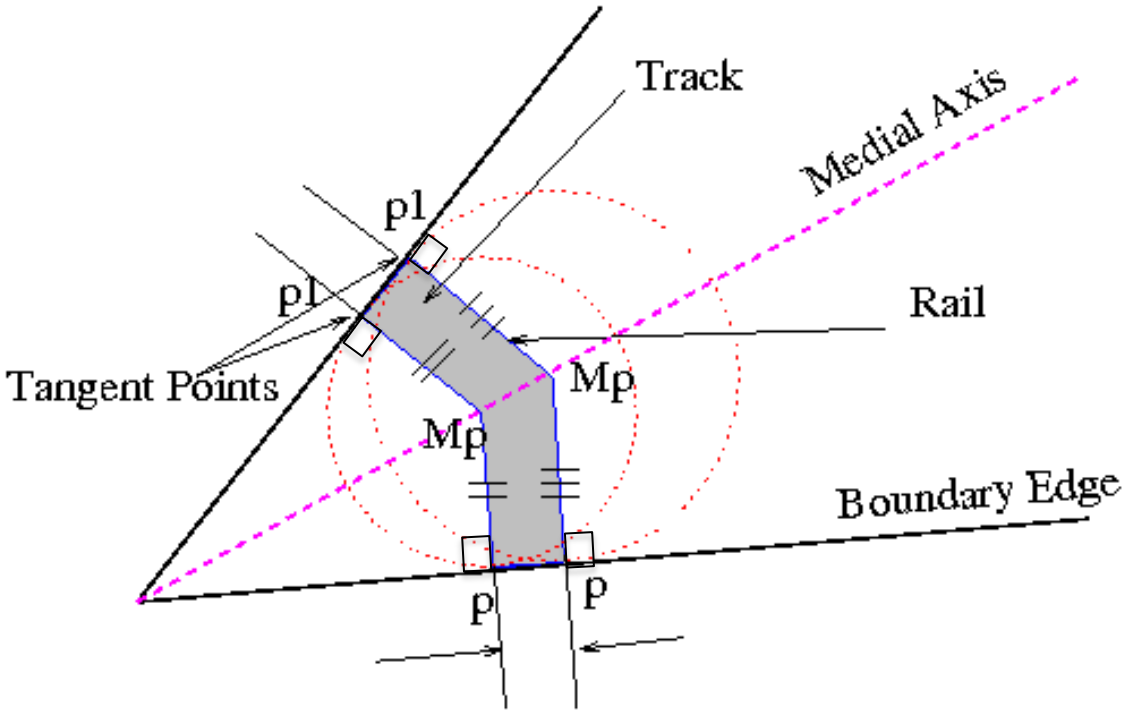




N-to-1

Projection Operator

- Uses map *f* to connect p → Mp
- Uses map *g* to connect Mp → p



Advantages of MAT

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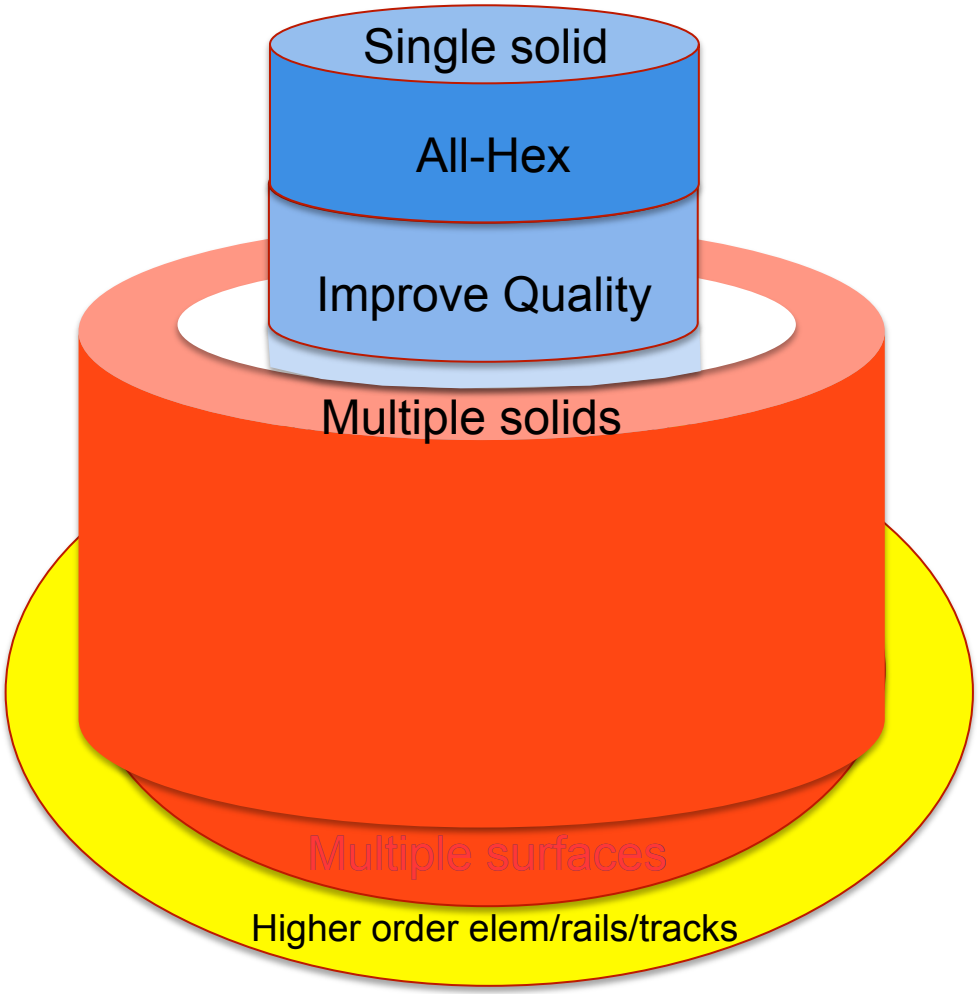
- Orientation Insensitive:
  - MA of a solid does not change with orientation of the solid
- Boundary Sensitive:
  - Advancing fronts meet at MA by generating structured mesh at the boundary and restricting irregular nodes at MA
- Robust Geometry Decomposition:
  - Medial branch points (critical singularities) are used for decomposition
- Dimension Reduction:
  - Hex meshing can be reduced to surface meshing on the medial surface
- Geometry Adaptive:
  - Medial radius function provides local feature size to control mesh size
- Symmetric Skeleton:
  - Simplifies interval assignment and provides theoretical foundation for all-hex
- Homotopy Equivalence:
  - Handles general solids with sharp boundary feature preservation

Layout of Presentation



LayTracks: All-Quad Meshing, 9th IMR, 2000

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Combines merits of decomposition and advancing front methods

- **Generate MAT:** establish two-way map between domain boundary and medial
- **Generate Corridors:** decompose domain using medial branch points via projection operator
- **Mesh Medial:** surface meshing is reduced to curve meshing. Medial radius function can be used to control mesh size.
- **Generate Tracks:** further decompose the domain/Corridors into simpler/meshable Tracks using projection operator
- **Mesh Tracks:** generate all-quad mesh in each track using symmetric property of the medial

Generate Corridors: Domain Decomposition

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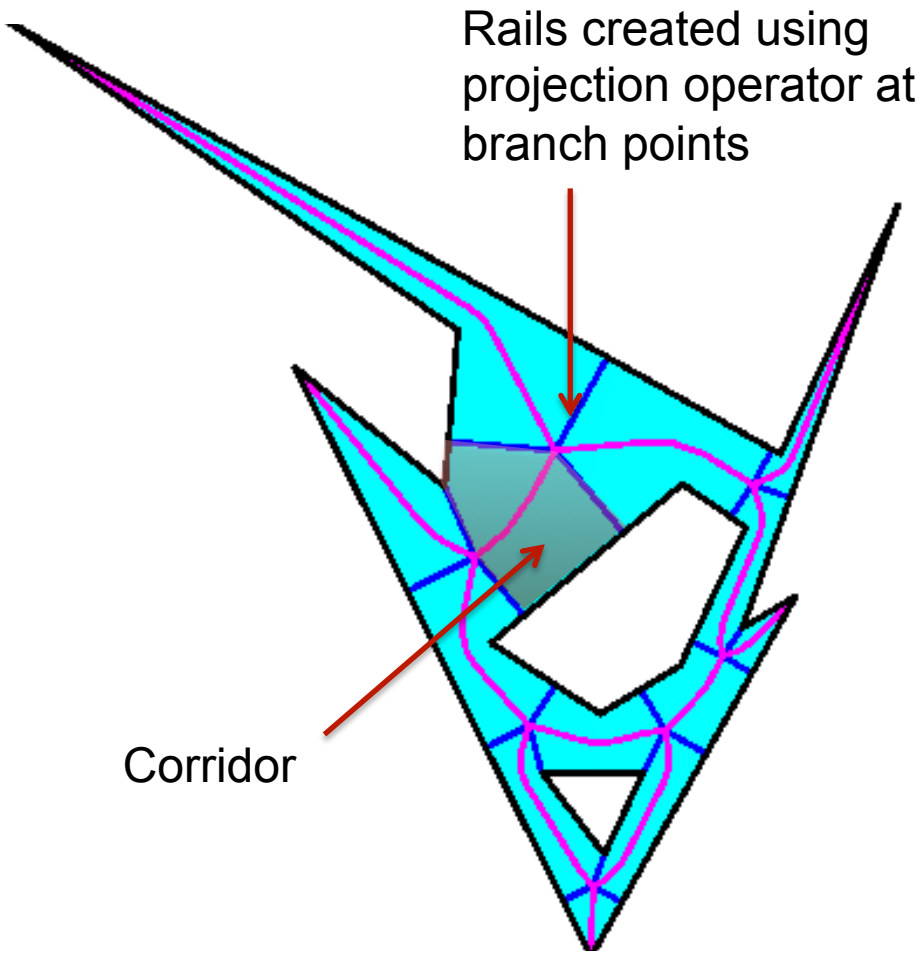

Mesh Medial: Surface meshing is Reduced to Curve Meshing

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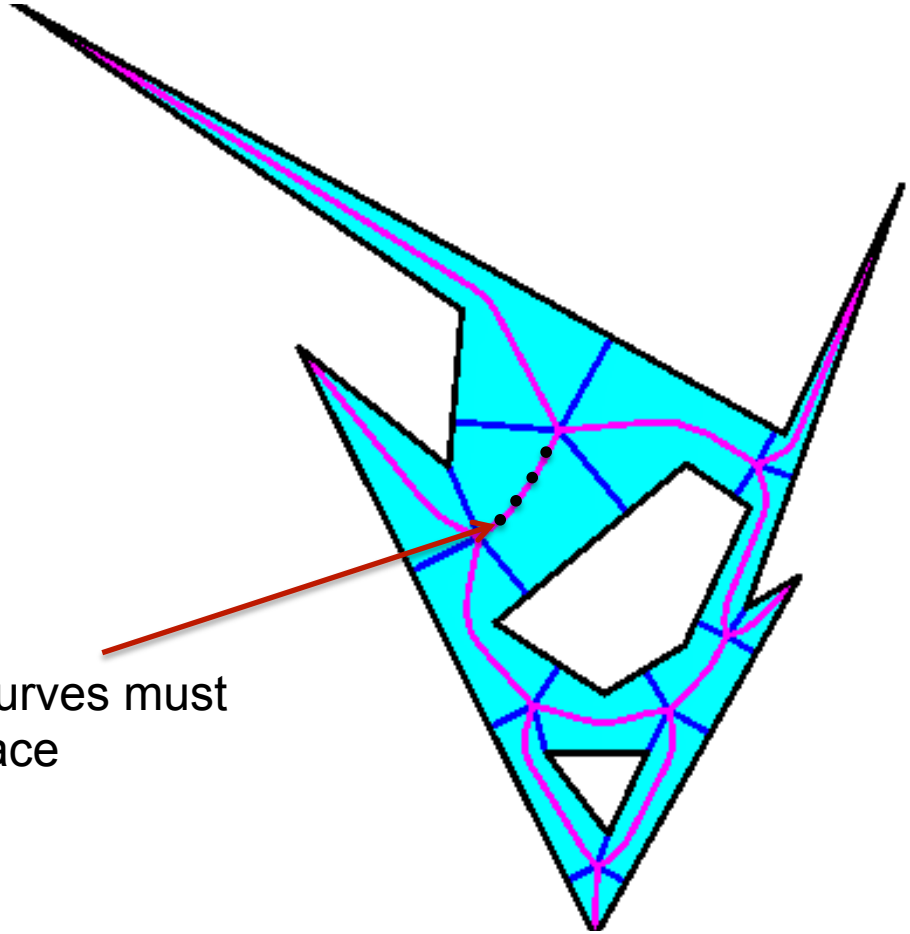
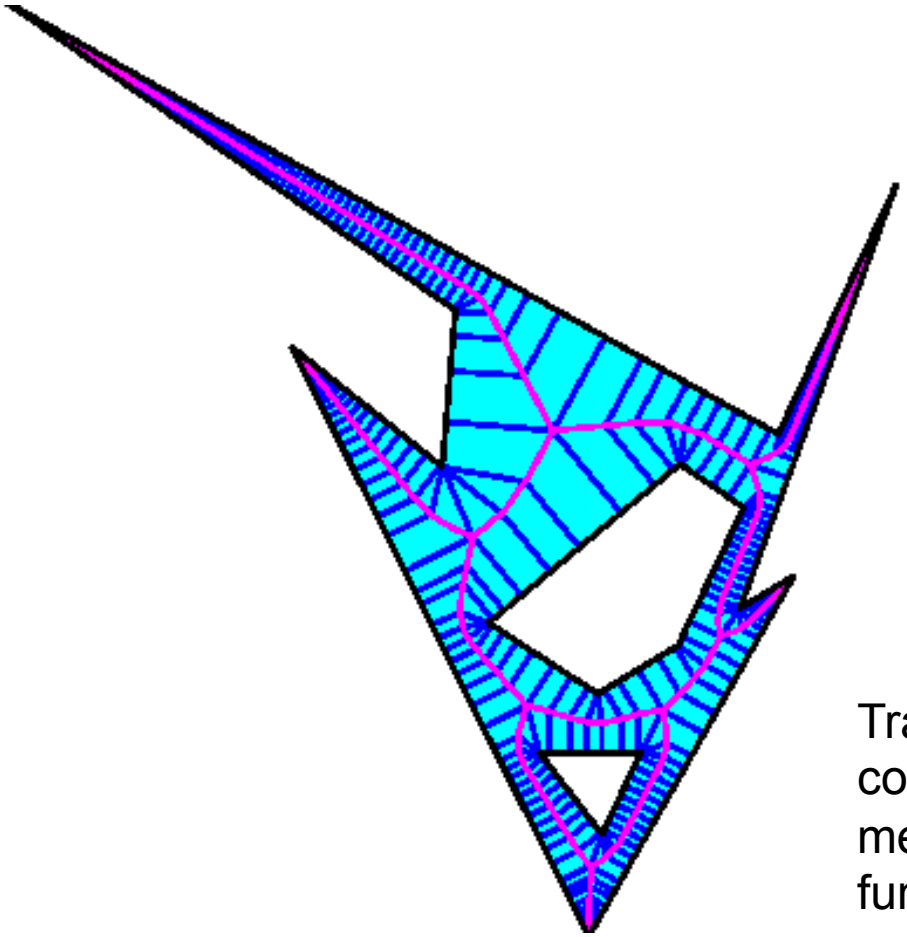
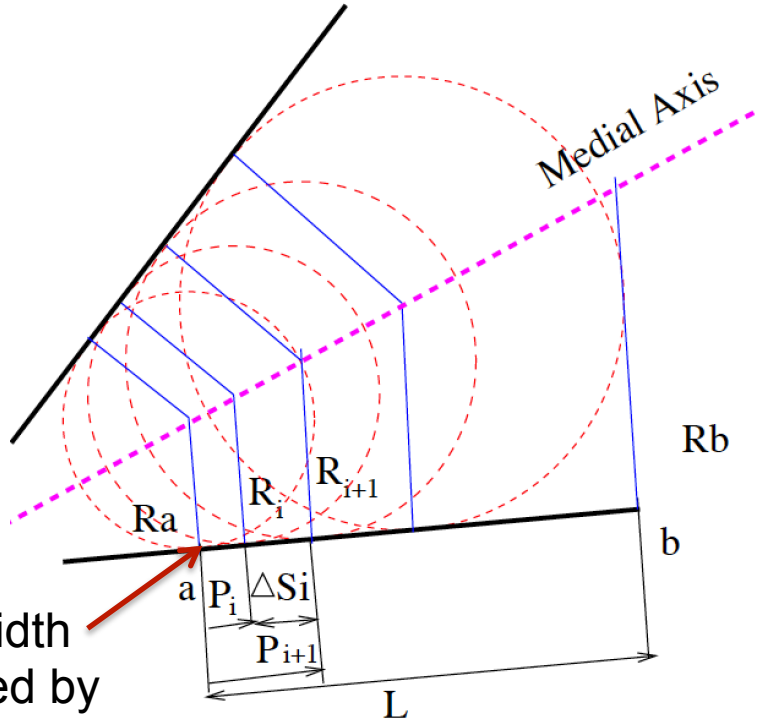


Meshing all medial curves must cover the entire surface

Generate Tracks: Projection Operator Connects MA Nodes to Boundary





Track width controlled by medial radius function

Mesh Tracks: All-Quad Mesh can be Generated in 2D

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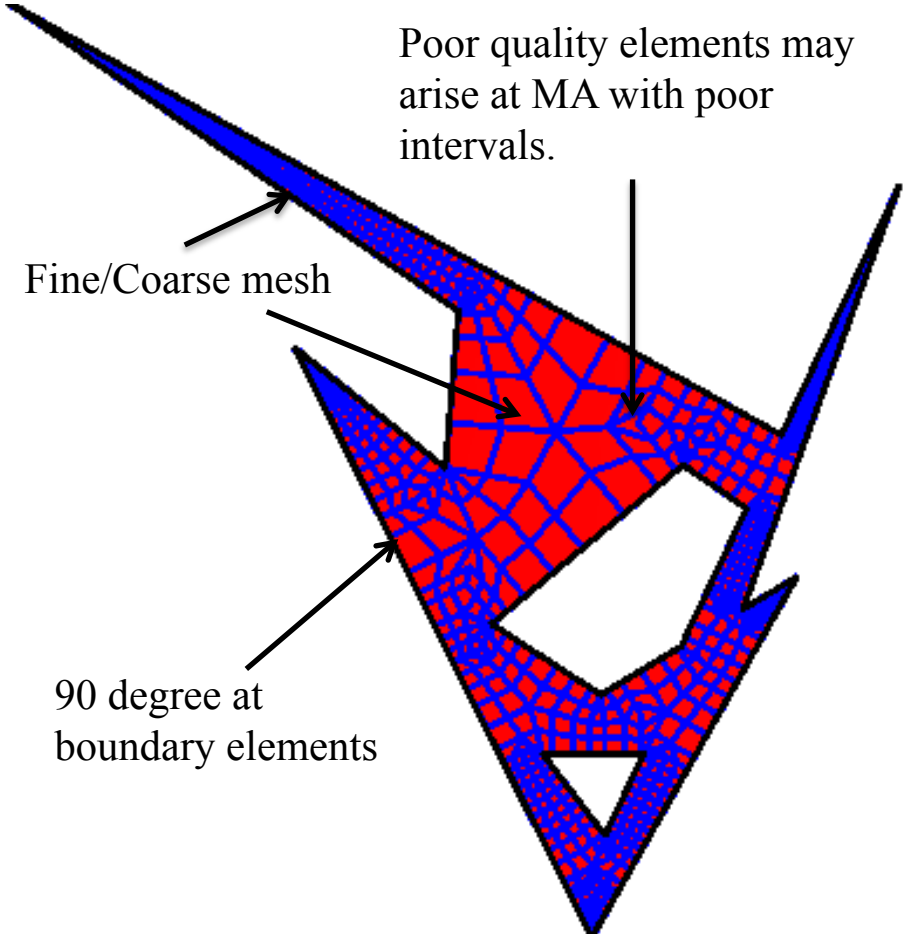
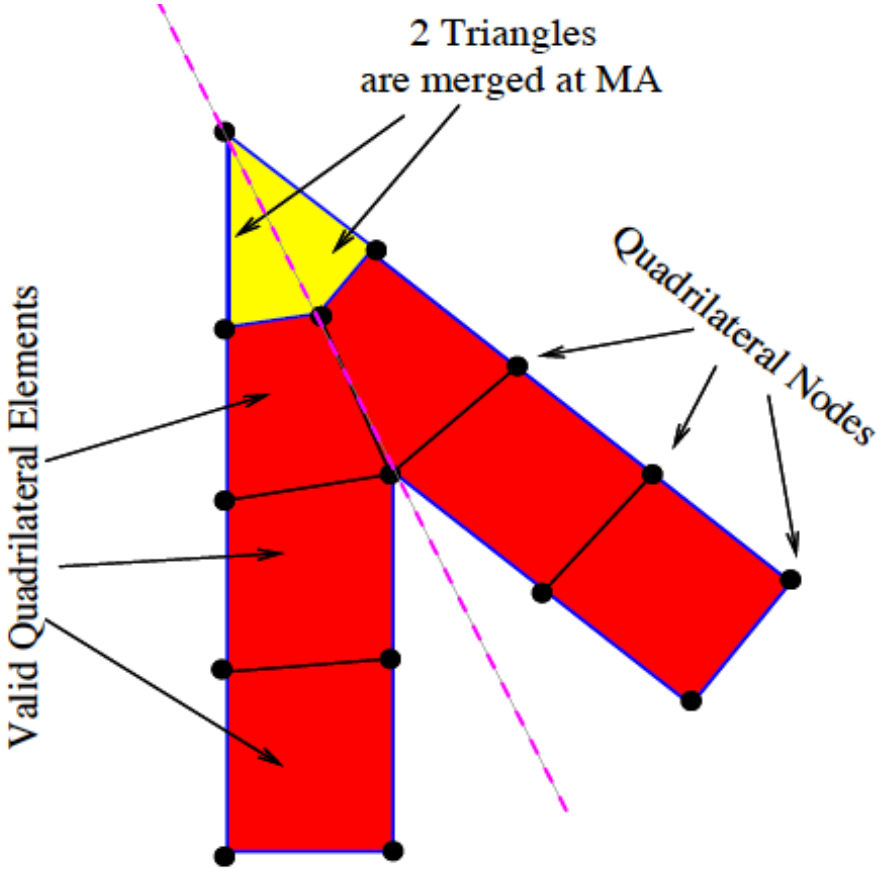
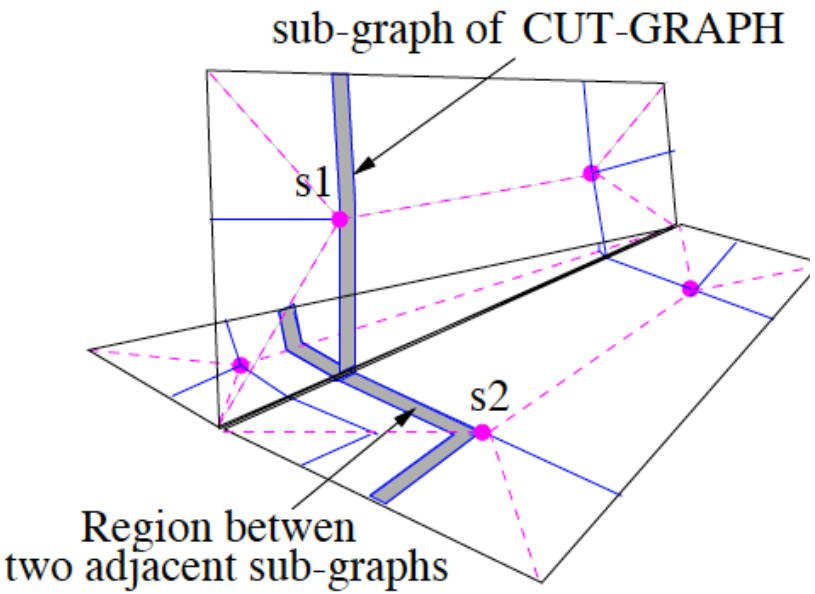
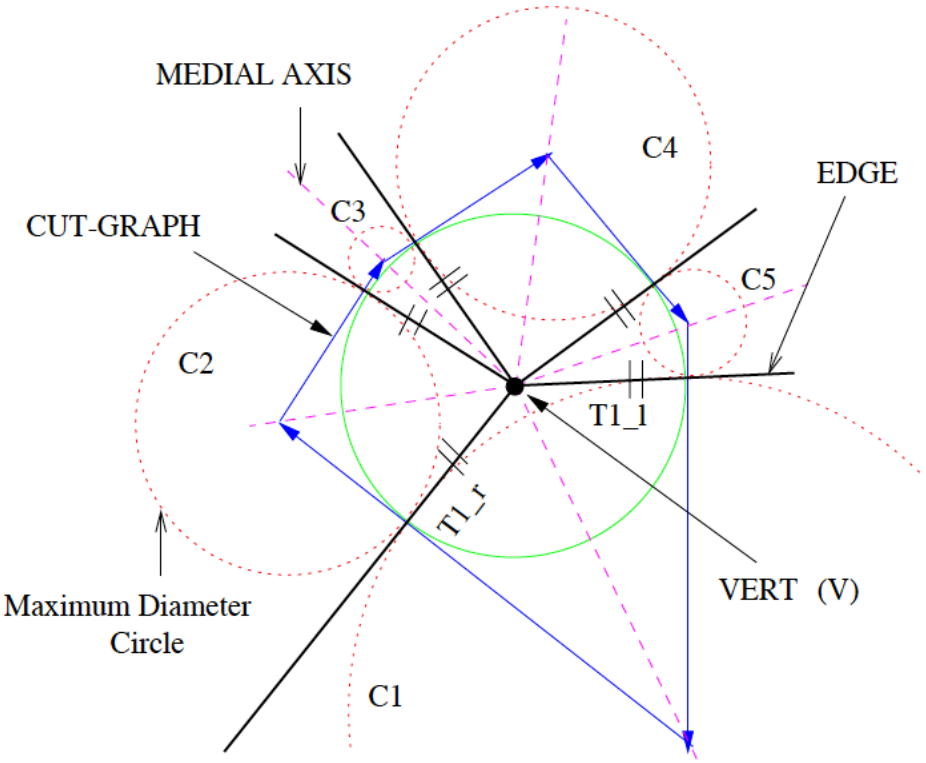




All-Quad: A track is bounded by even number of edges due to symmetric property

Extension to Multiple Surfaces





Multiple Surfaces

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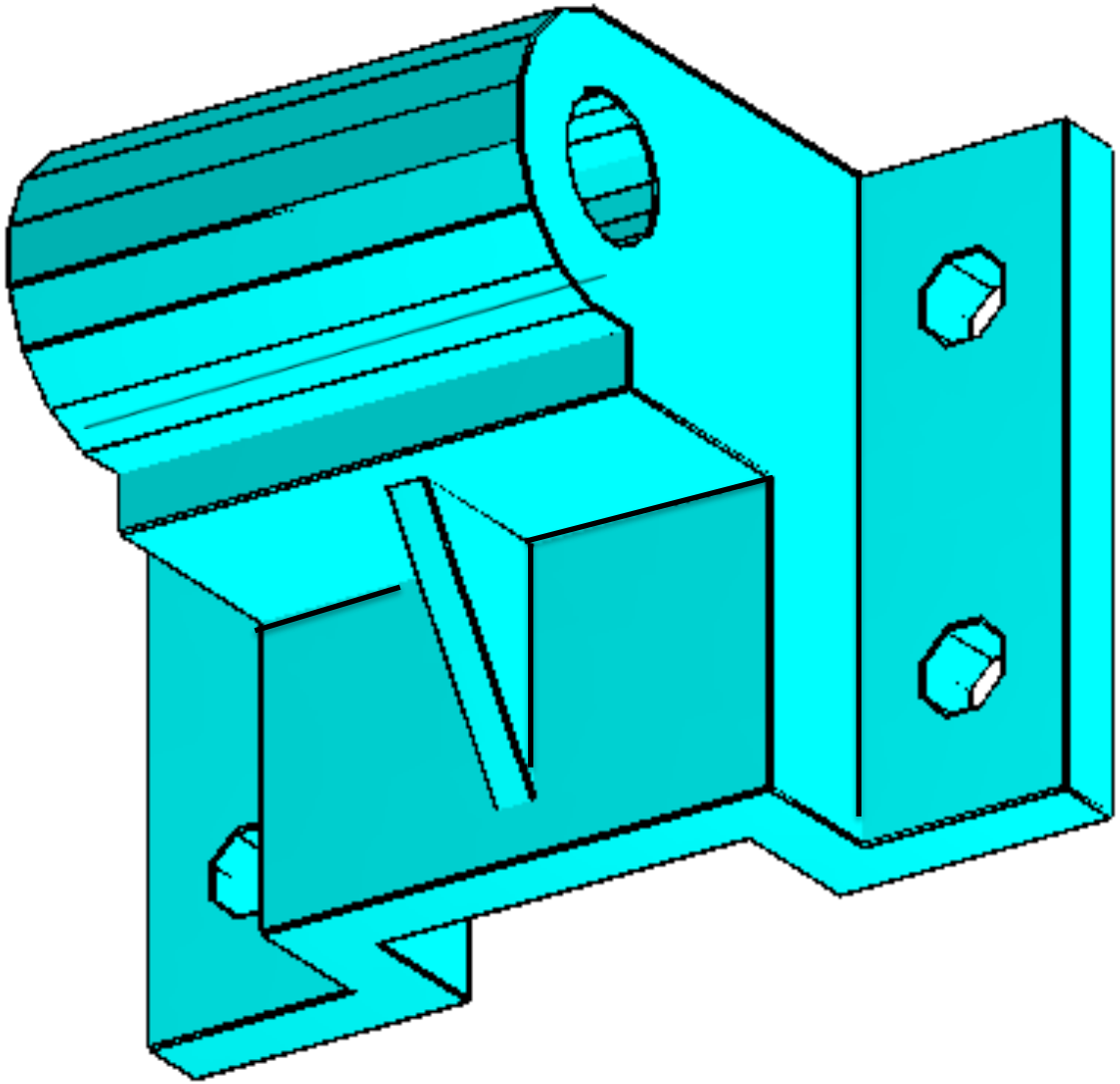

Medial of Multiple Surfaces

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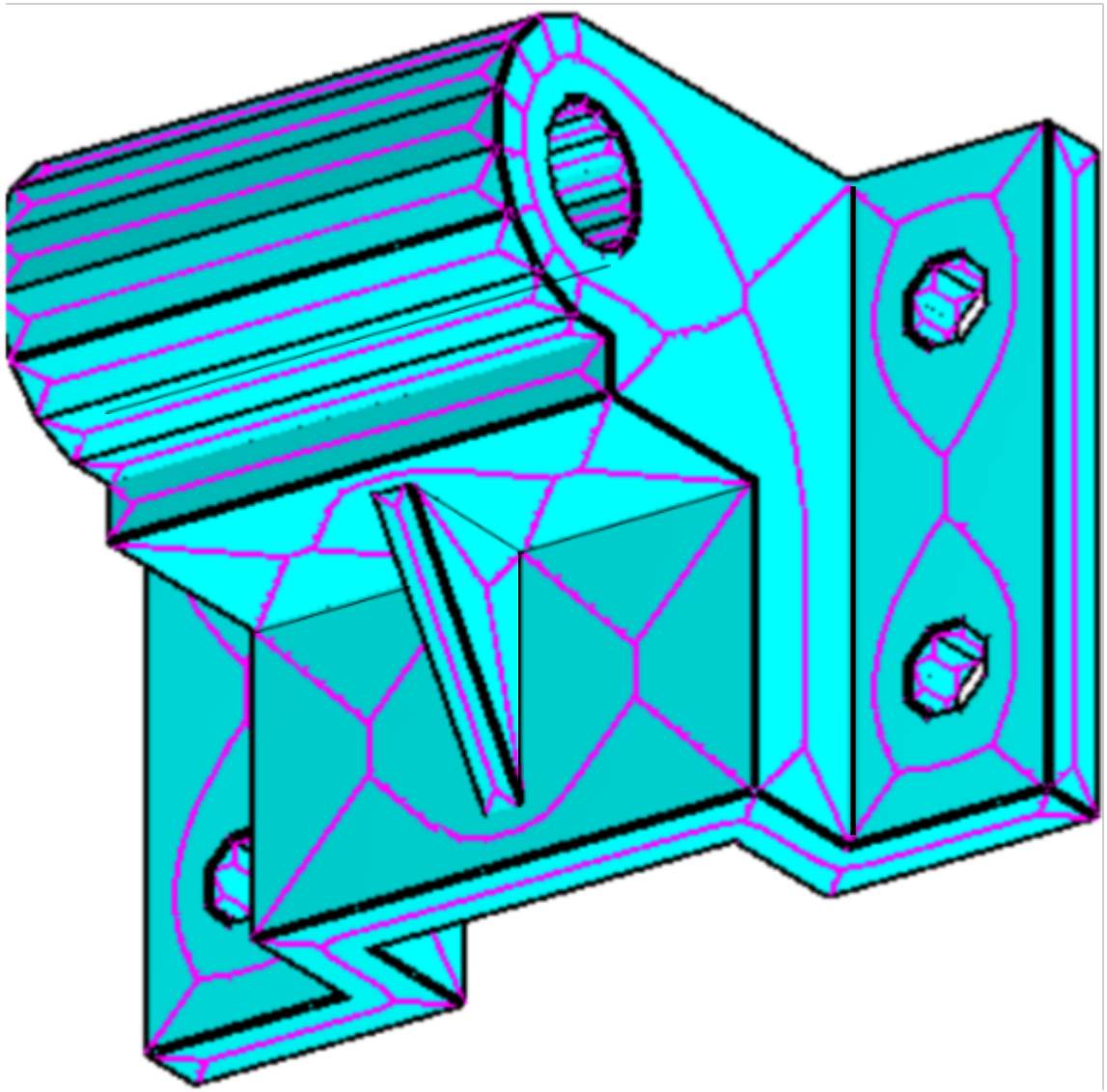

Two-Way Map on Multiple Surfaces

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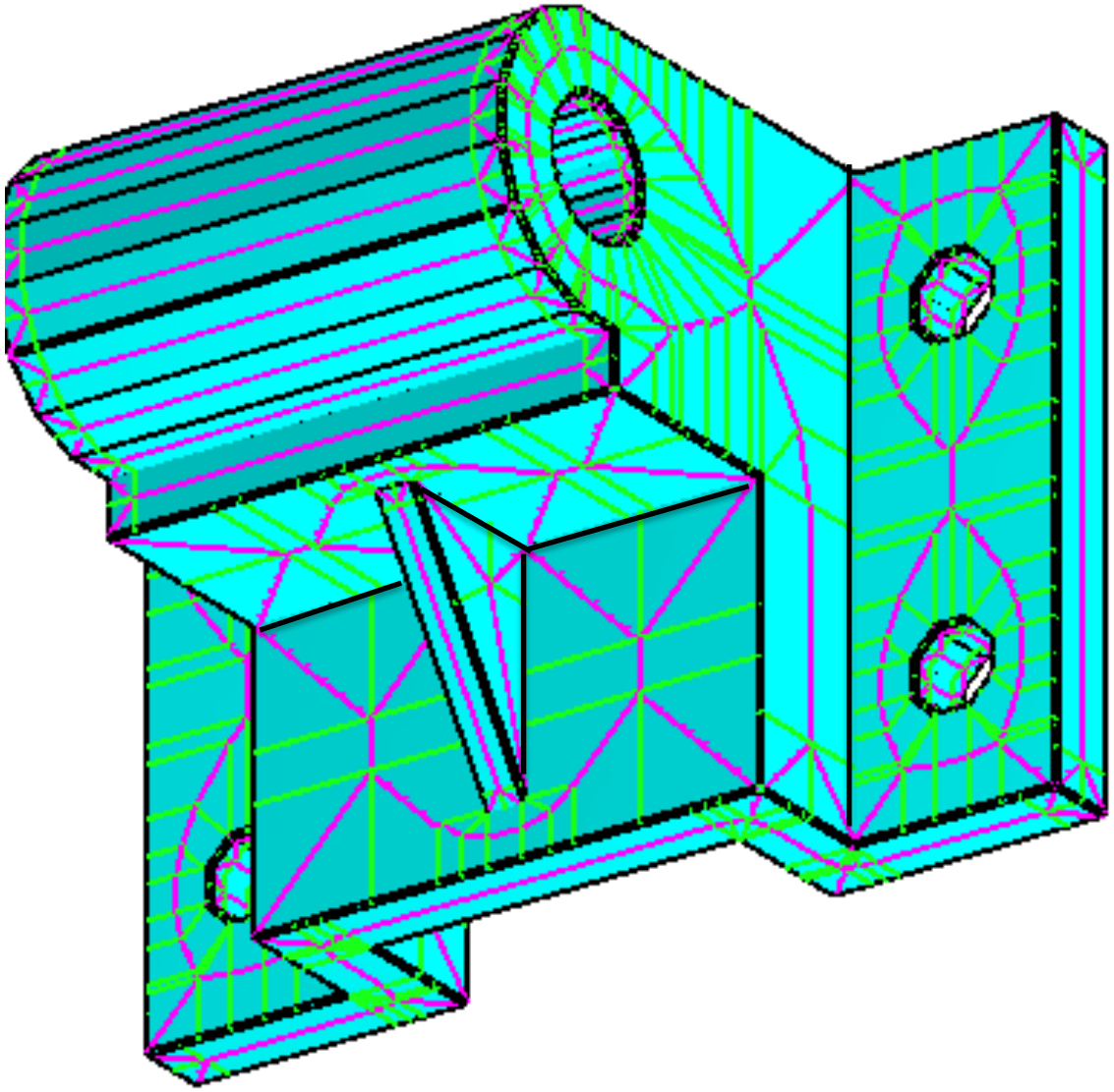

Automatic Domain Decomposition

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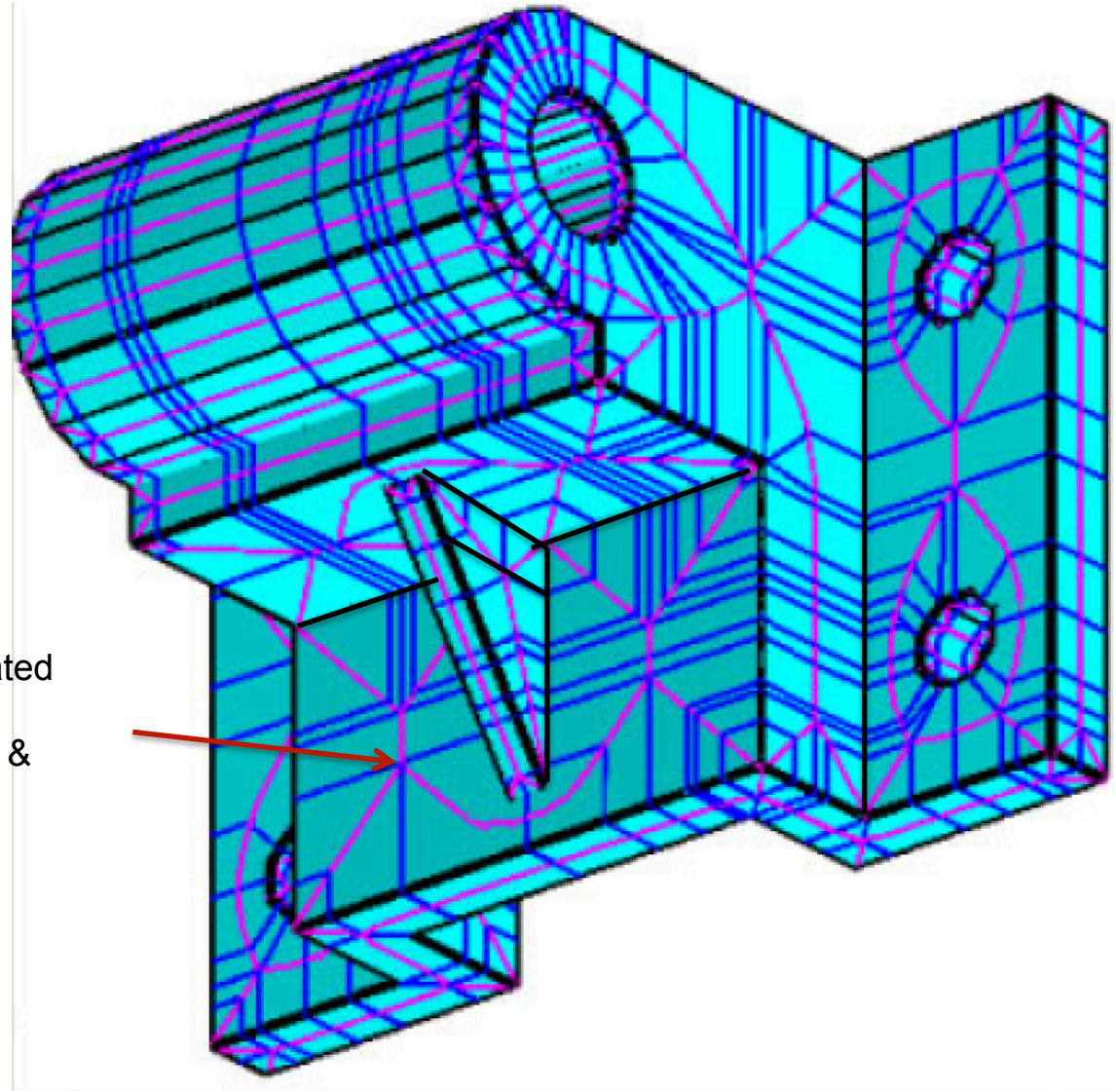

Rails propagated using medial branch points & imprints

Tracks on Multiple Surfaces

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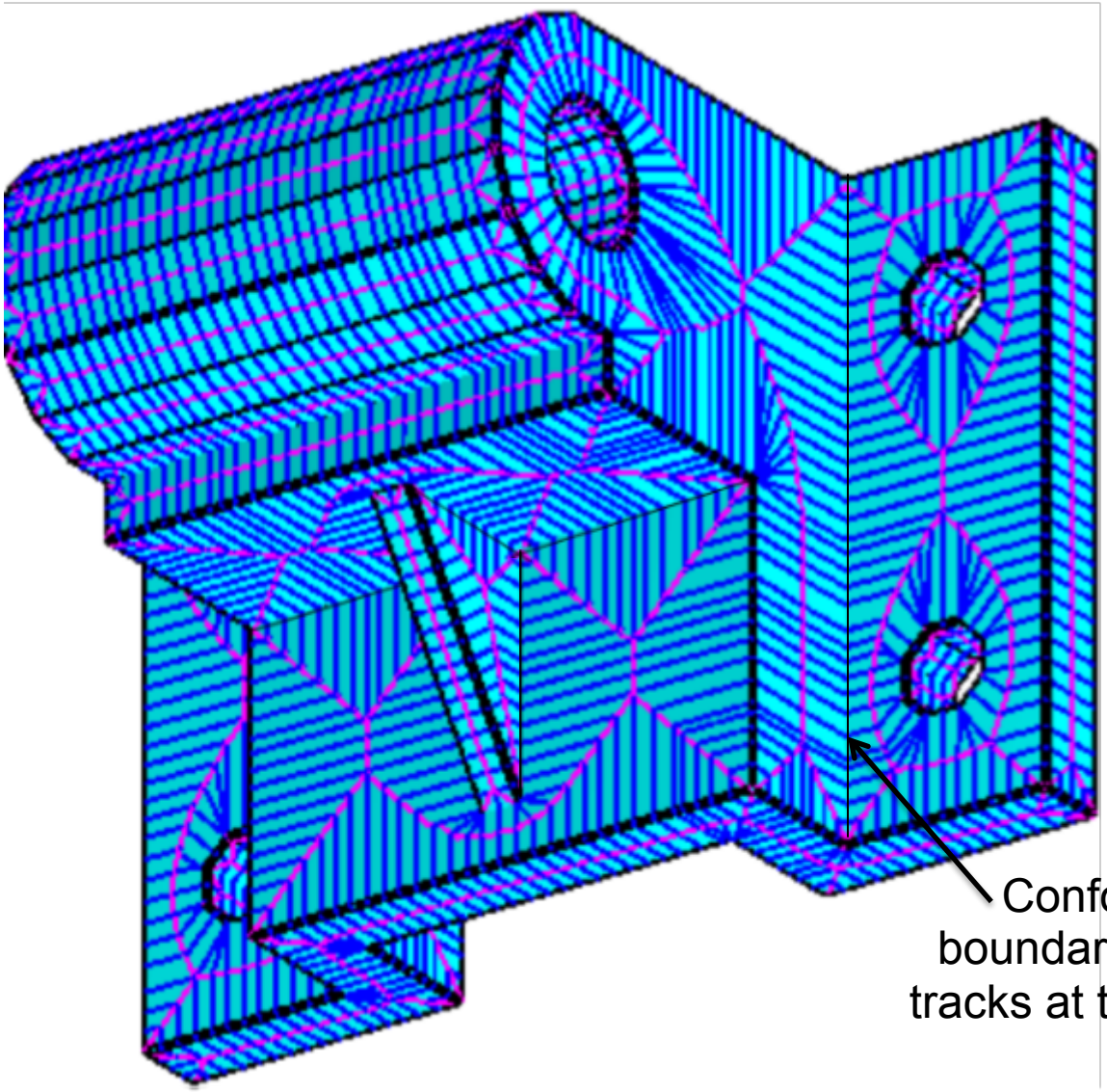

Quad Mesh on Multiple Surfaces

(with no post-meshing operations)

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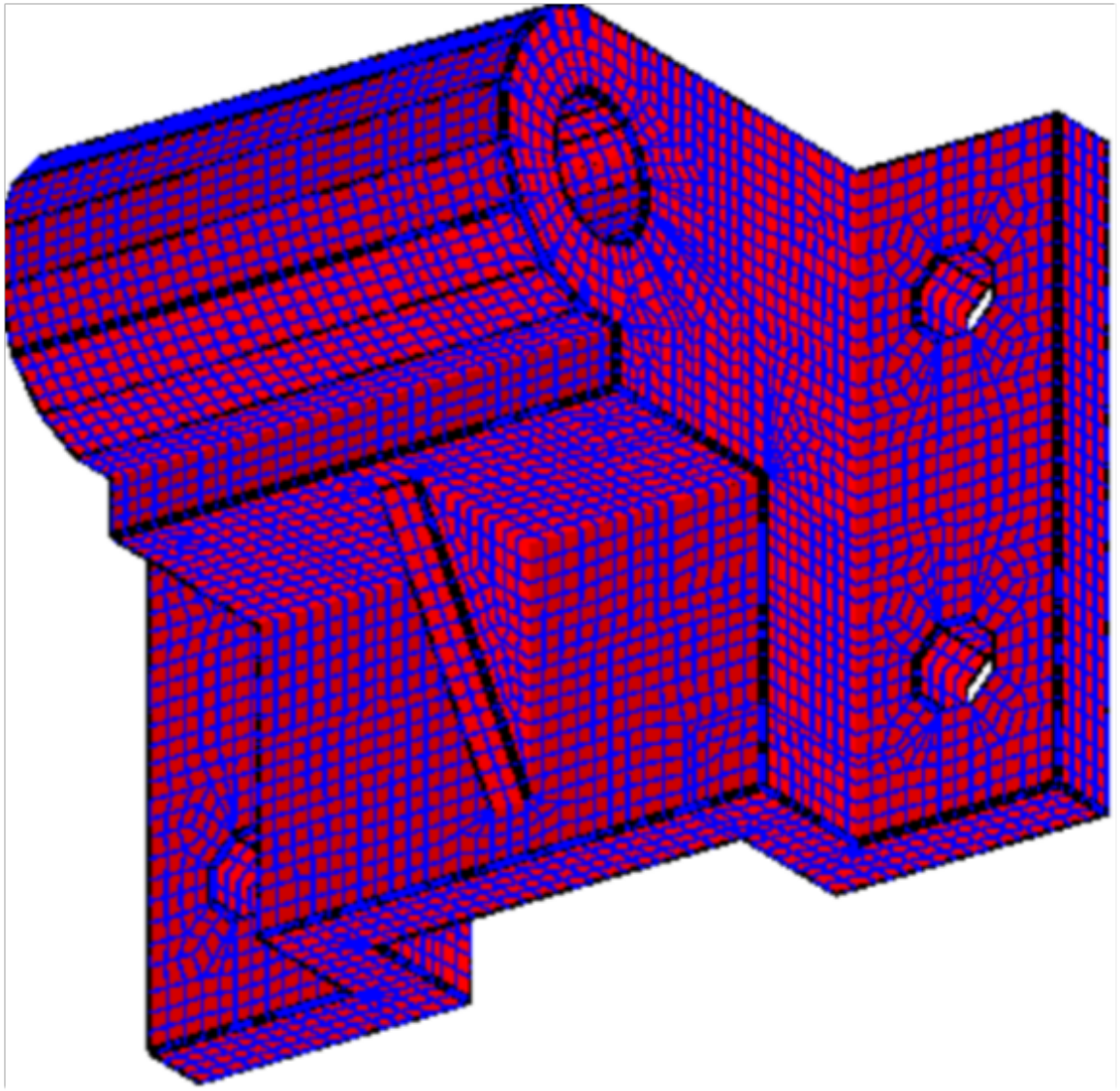
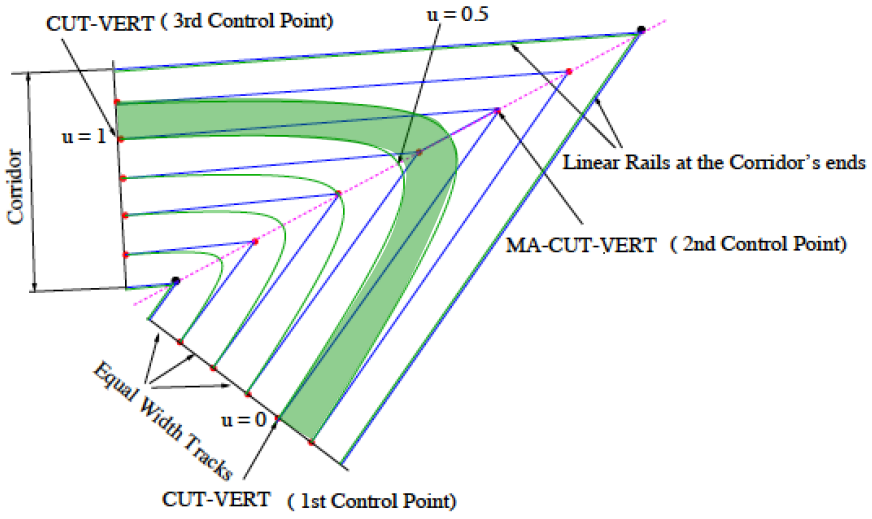
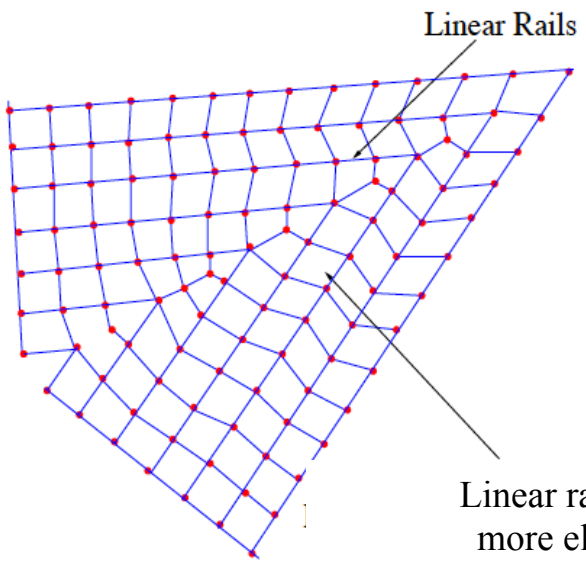
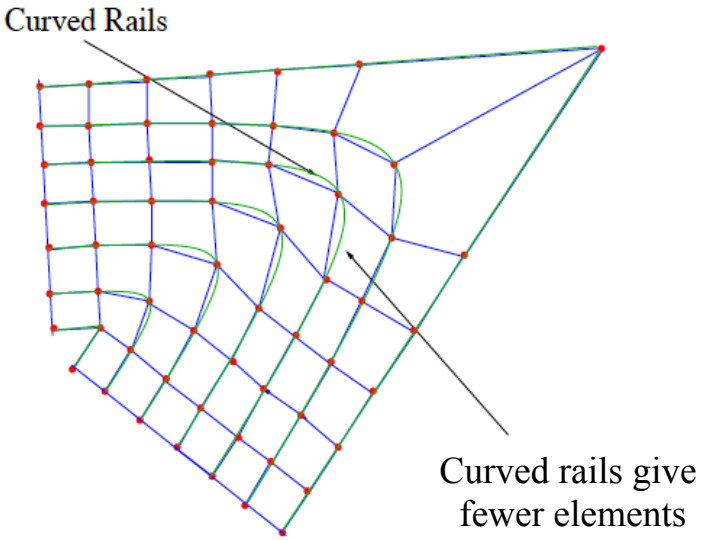


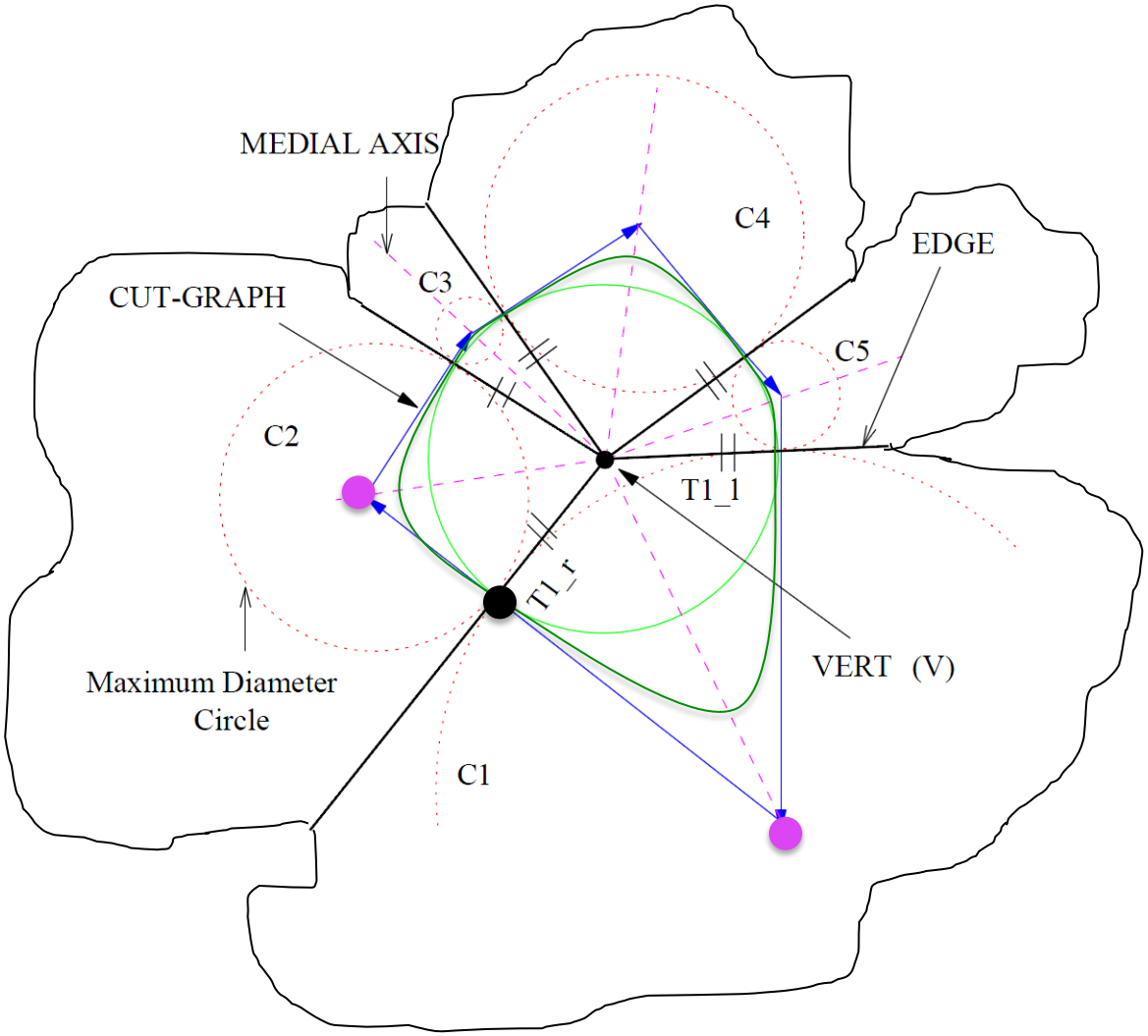
Extension to Nonlinear Rails & Tracks







Rail as Control Polygon Satisfies Orthogonality



Layout of Presentation

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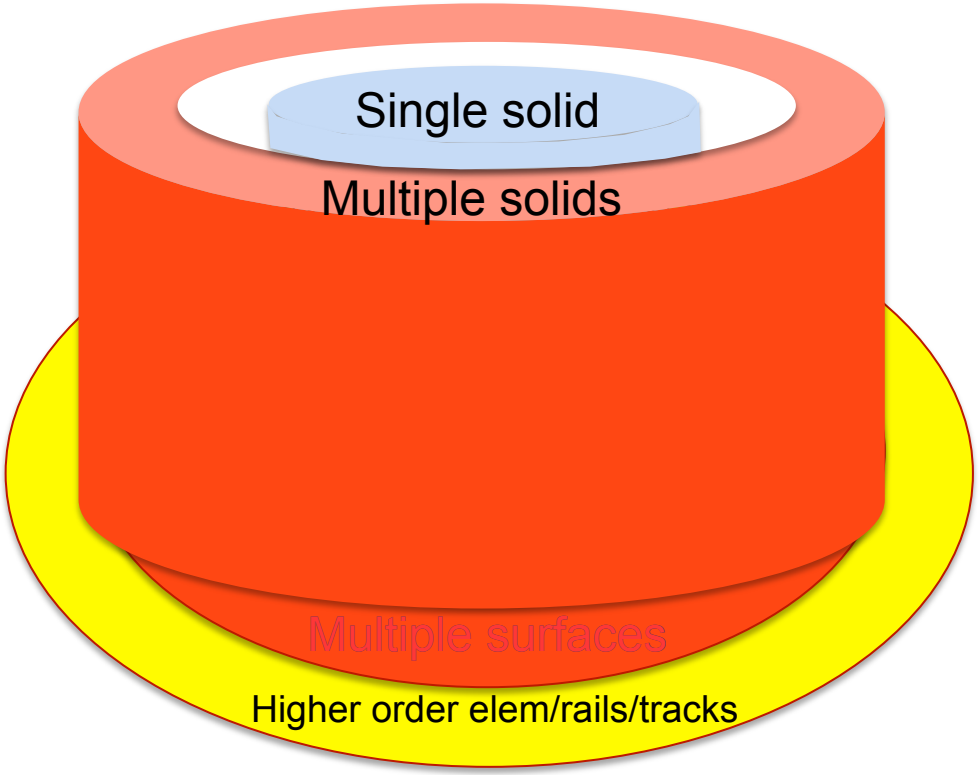

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LayTracks3D: Extension of LayTracks to 3D

Overview of LayTracks3D

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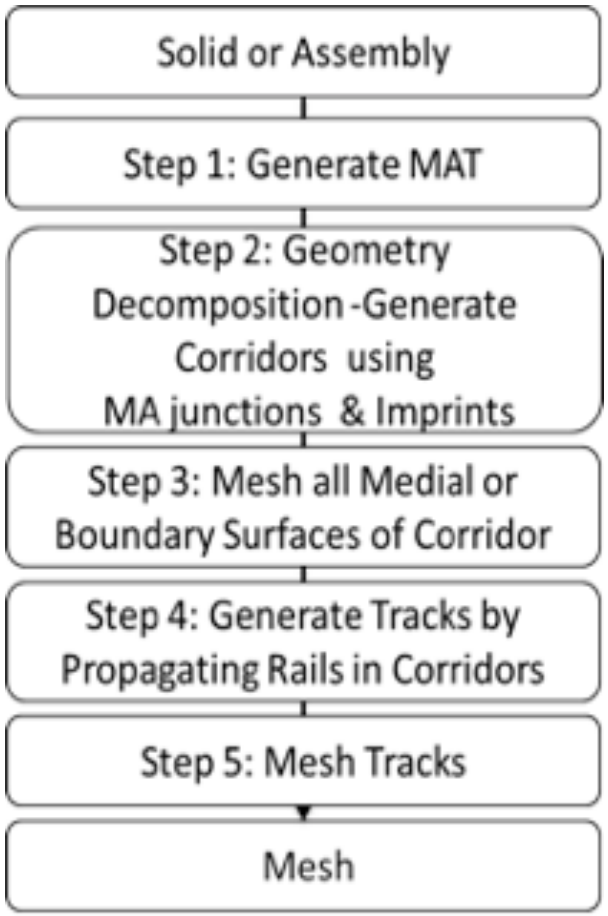
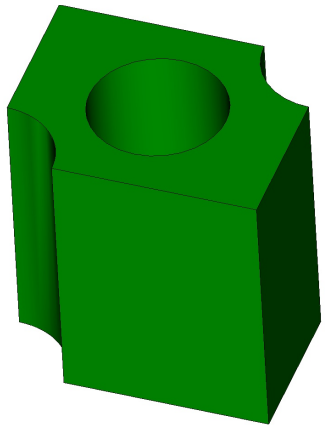
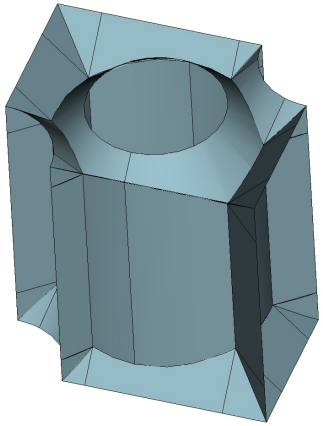
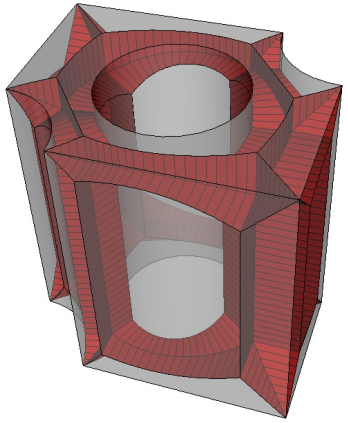




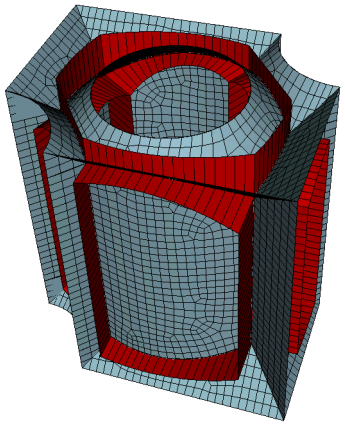
Input solid



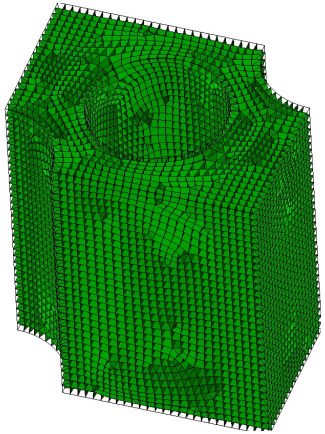
(1) Generate MAT



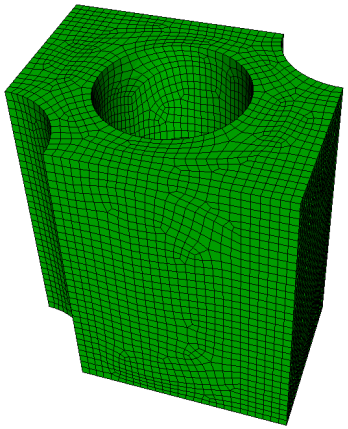
(2) Generate Corridors



(3) Mesh Medial

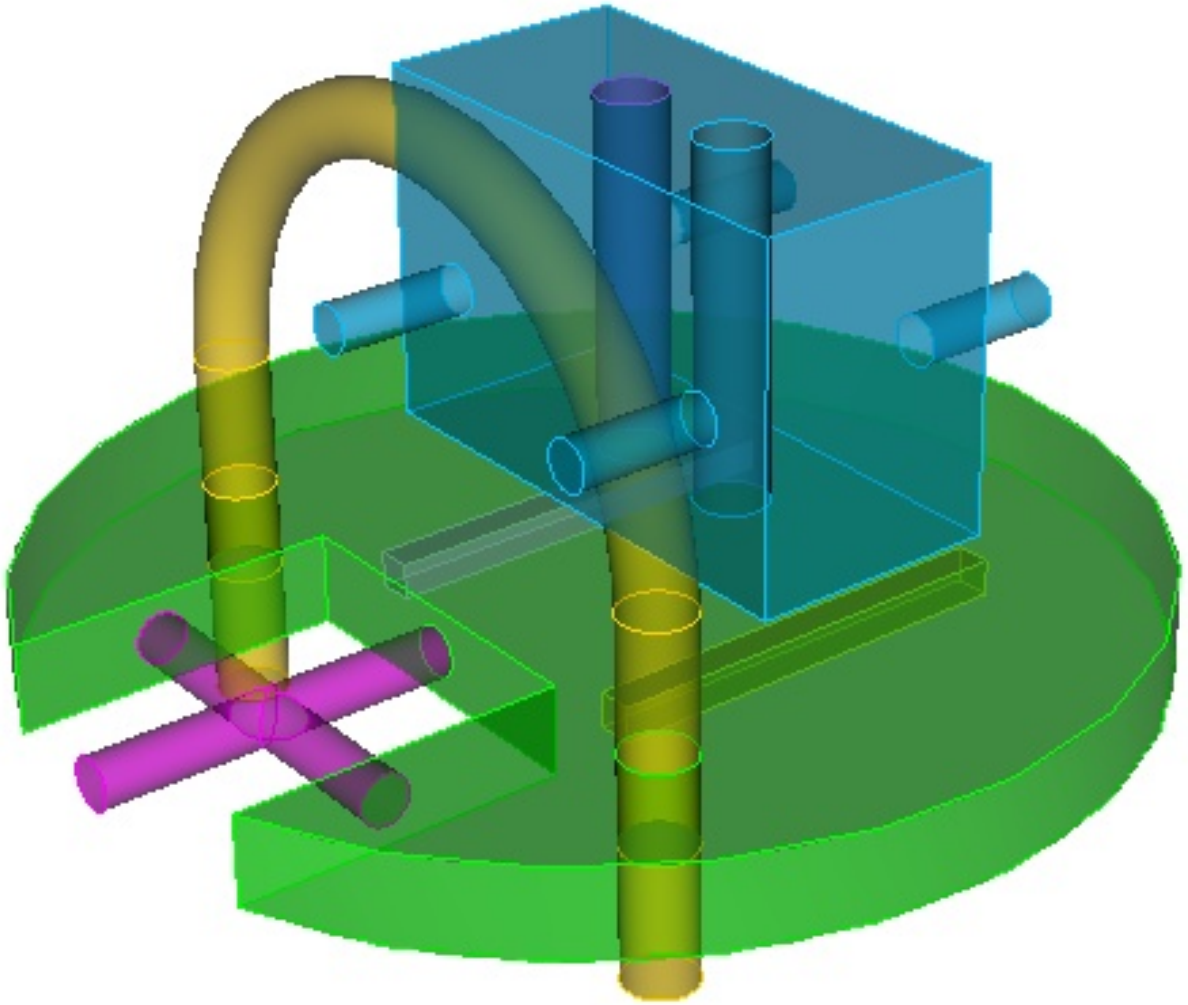


(4) Generate Tracks



(5) Mesh Tracks

Extension to Assembly Model



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Imprints on Top, Bottom, and Sides

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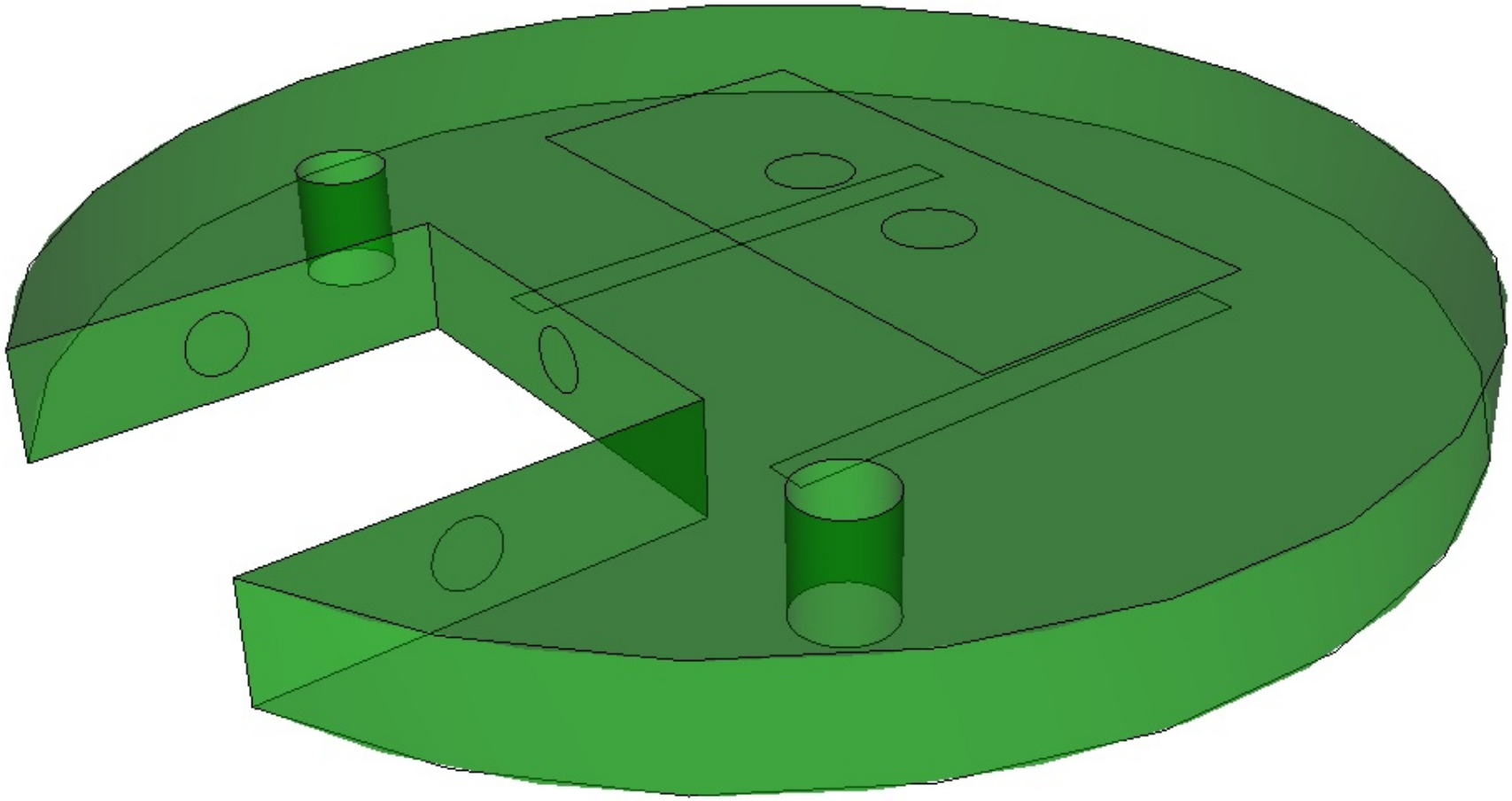

Medial Resolves Imprints from All Directions

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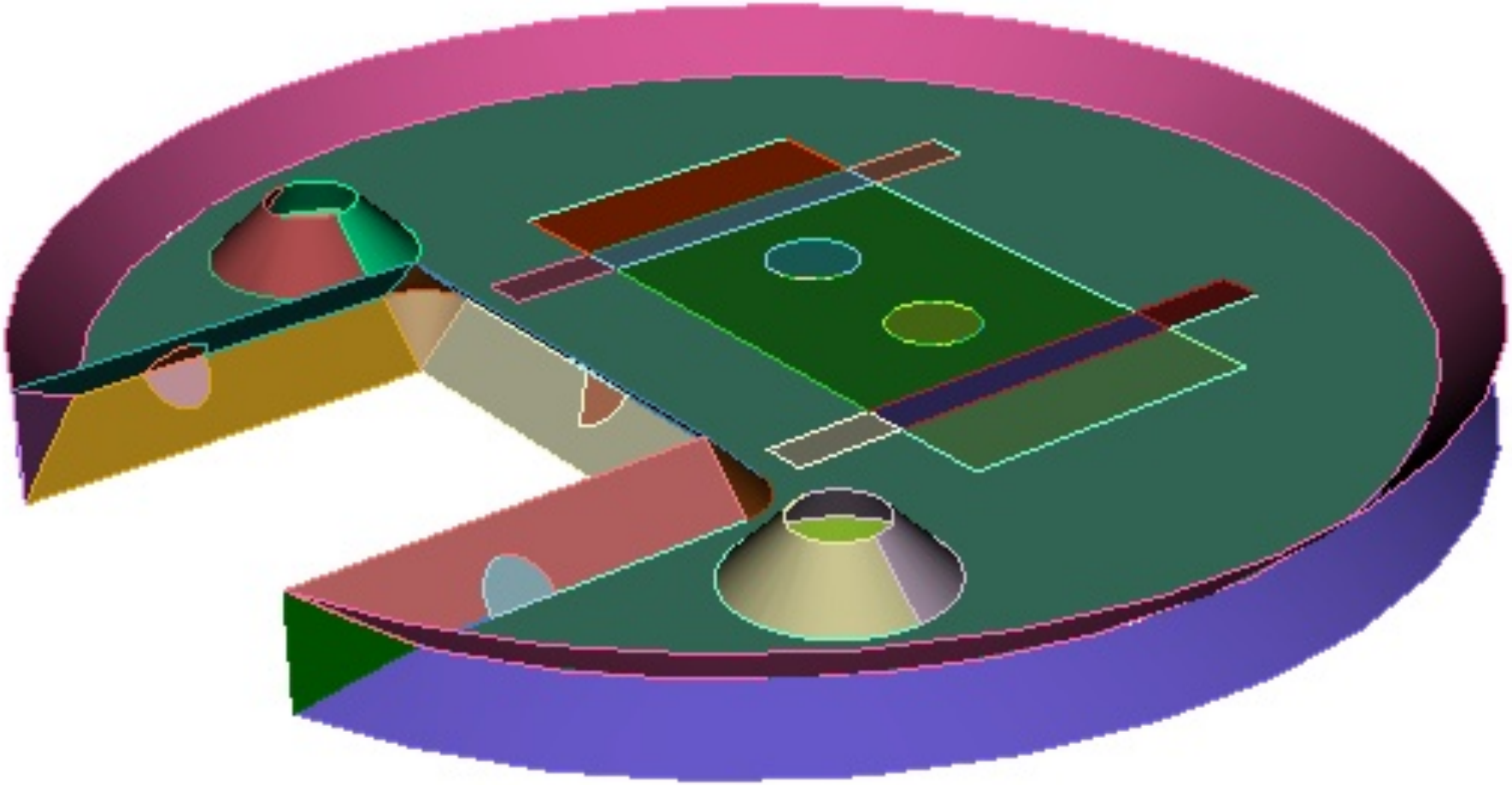

Automatic Geometry Decomposition using Imprints and Medial Junctions

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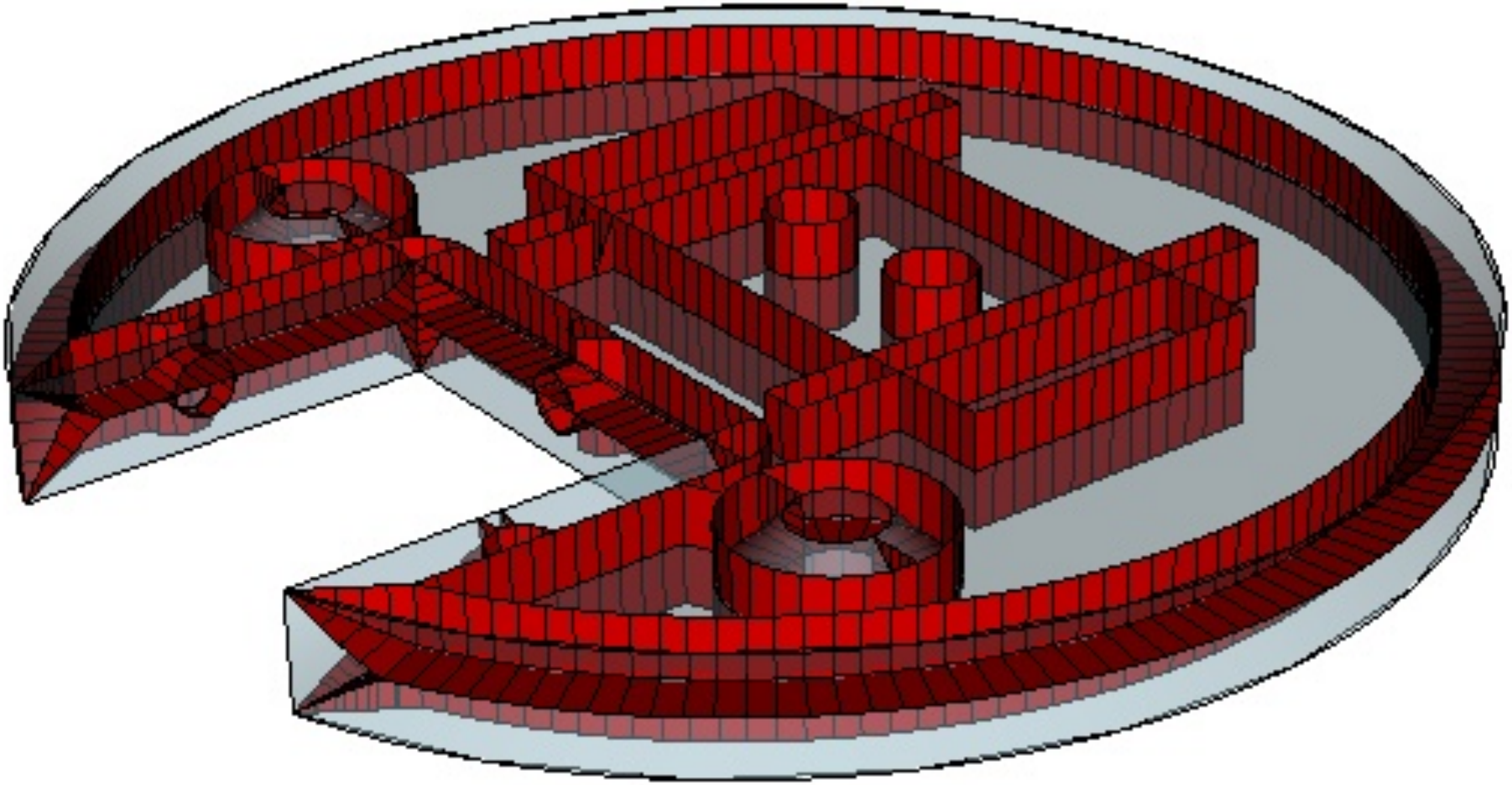
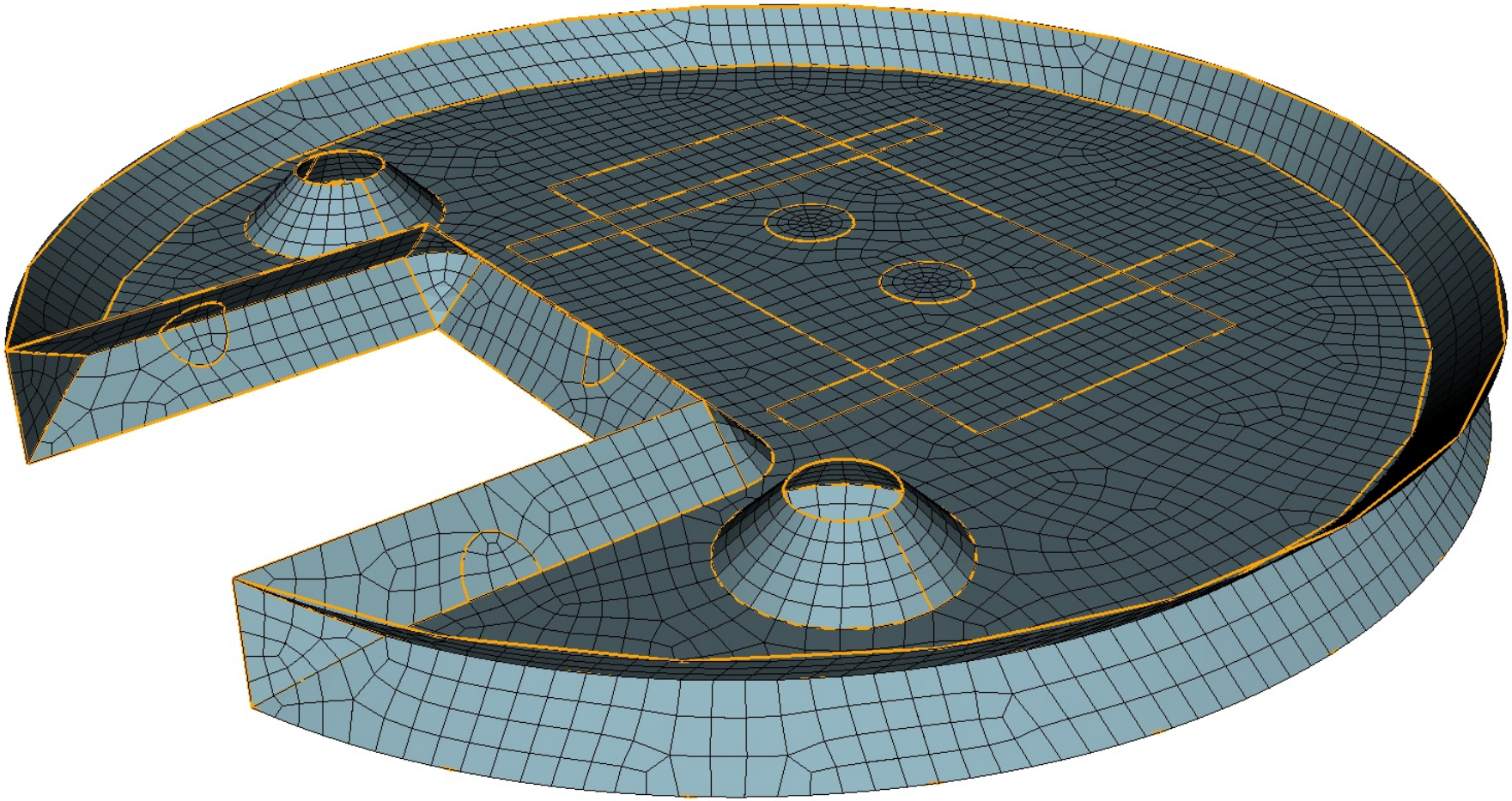


Corridors

Quad Mesh on Imprinted Medial



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Tracks in 3D

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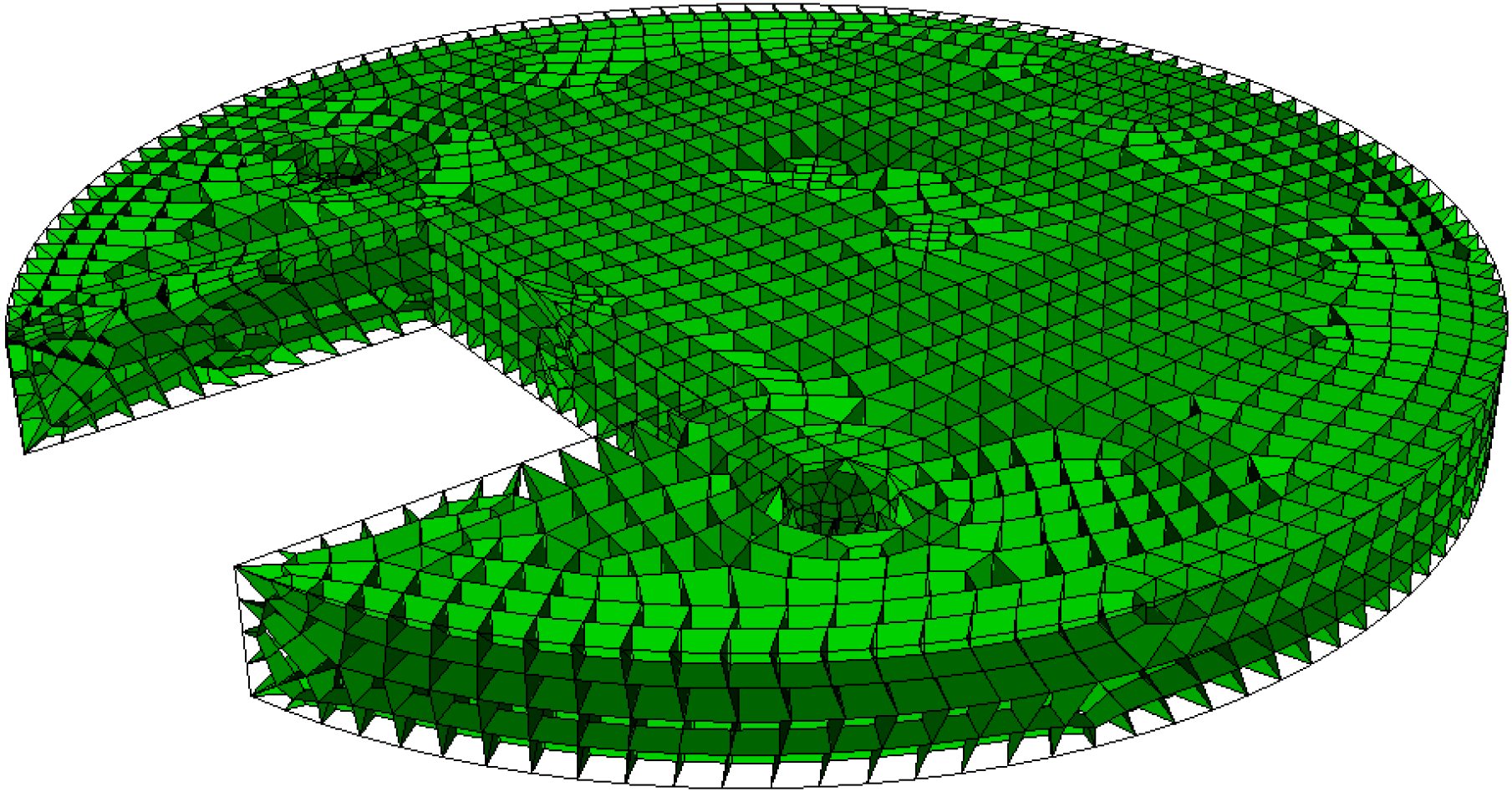

Hex-Dominant Mesh

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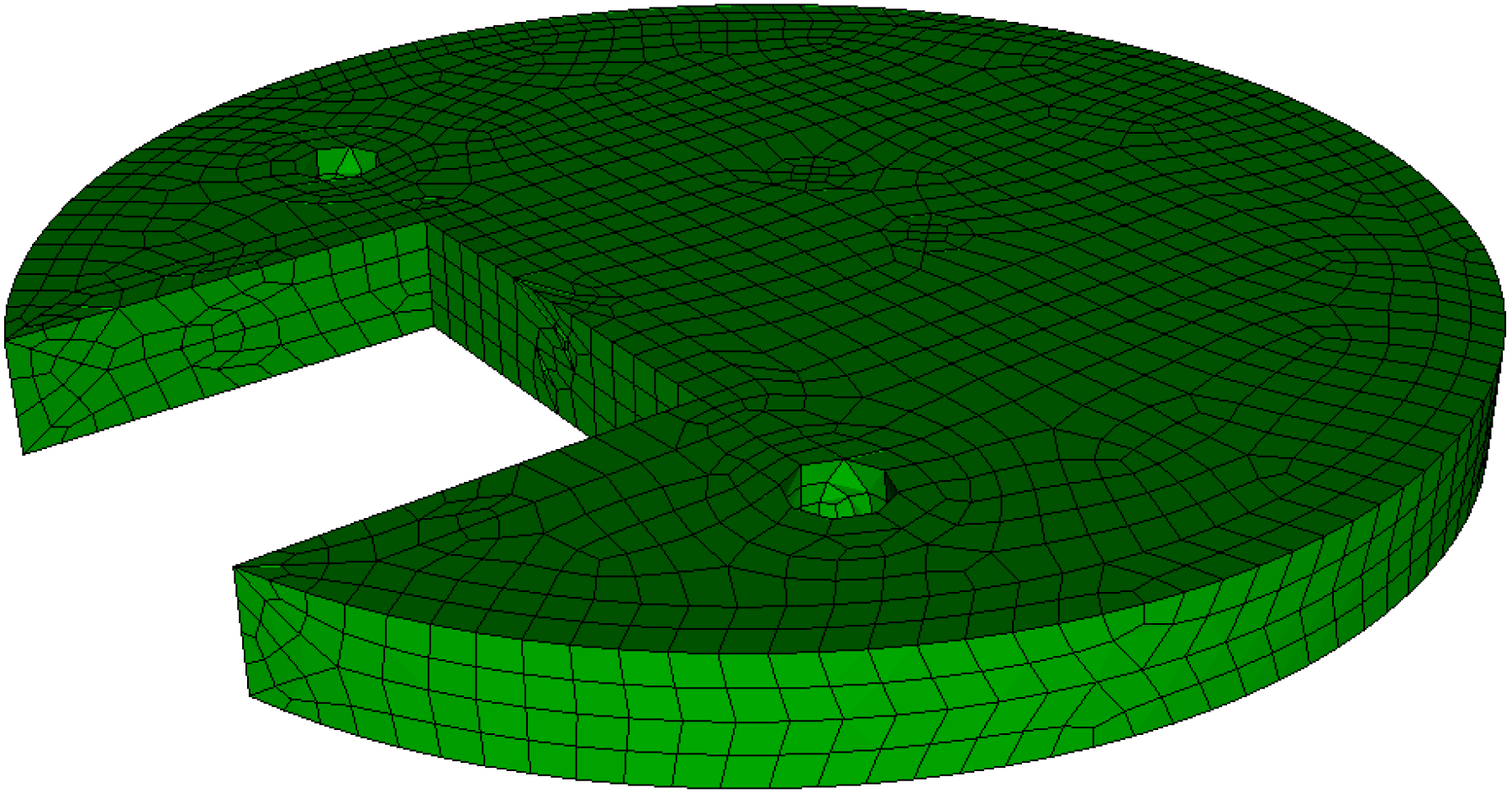

Layout of Presentation

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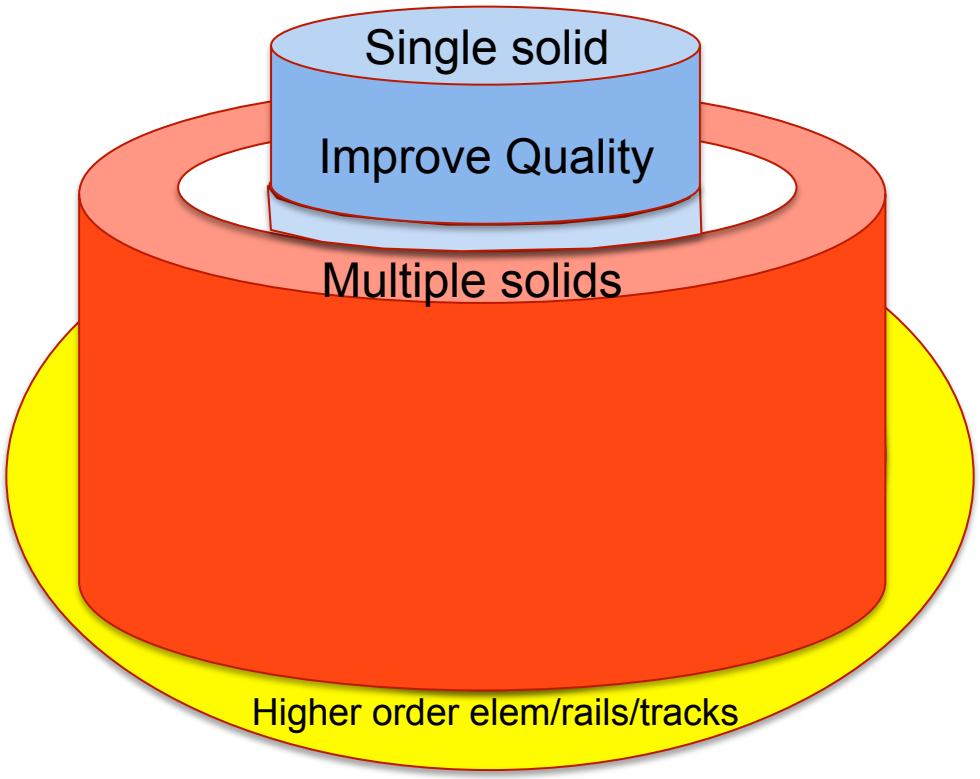

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Improve Quality at Common 3-manifold MA Curve

All-Quad Mesh on Medial is not Ideal!

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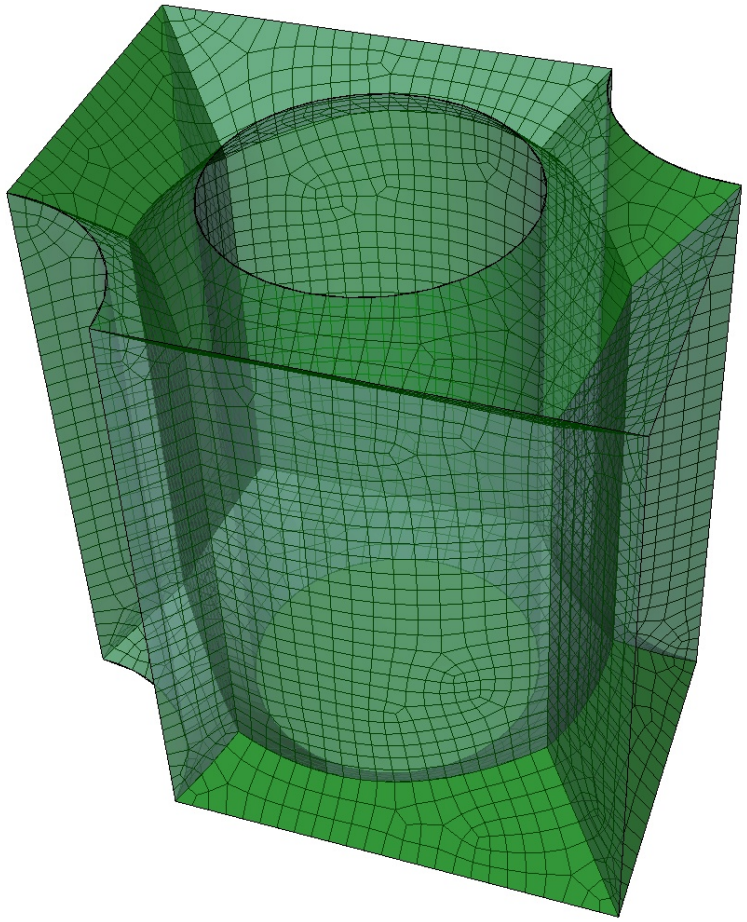

All-Quad Mesh on
Medial Surface

Poor Tracks at a Convex Vertex

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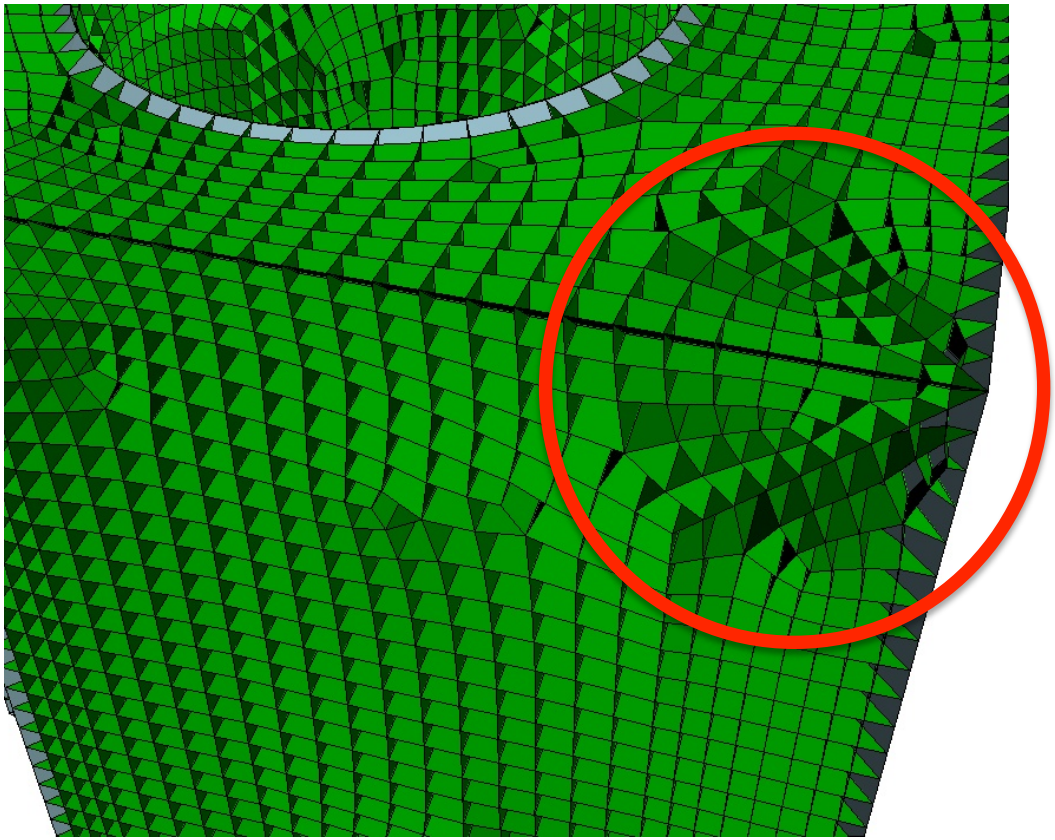

Hex-dominant Mesh at Convex Vertex

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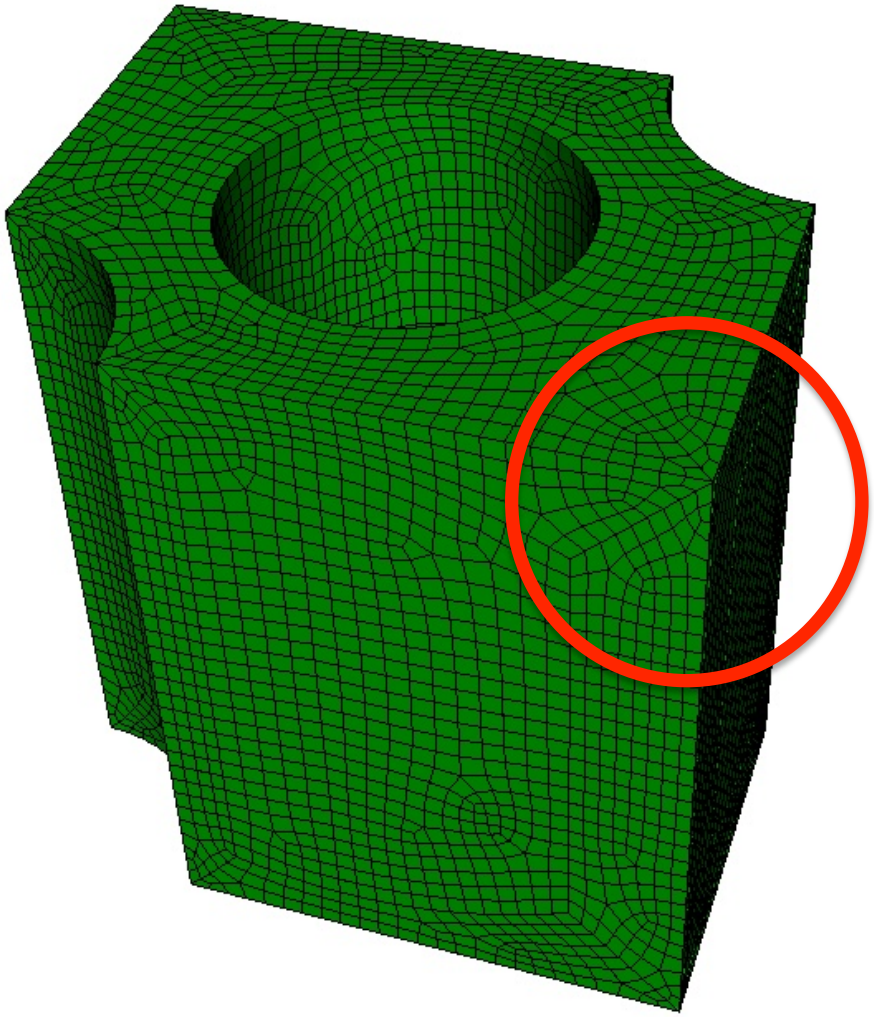

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How to Improve Hex Quality at a Convex Vertex?

Ideal Mesh Should Contain Tri Along 3-Manifold Medial Curve!!!

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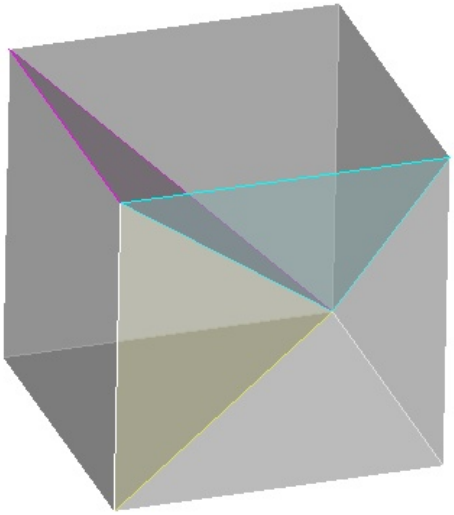
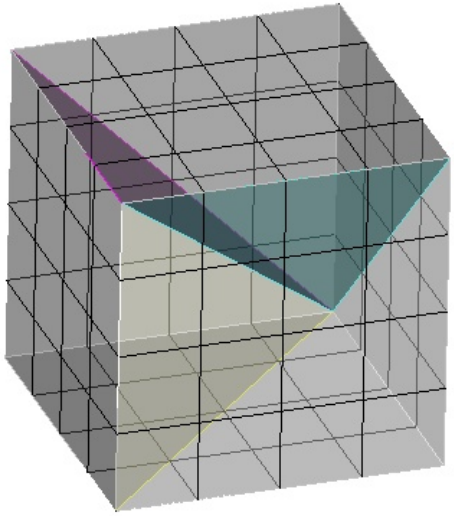
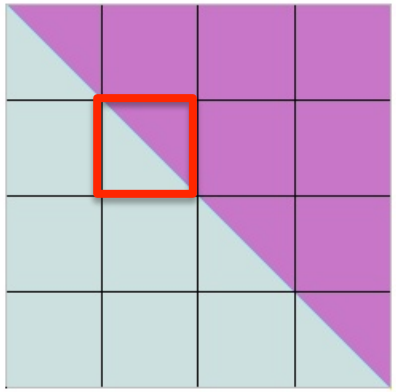


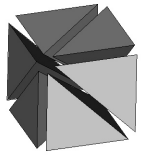
Typical 3-manifold MA



Ideal Hex Mesh



Surface Mesh on MA



6 Tets form a Hex

Improved Hex-dominant Mesh

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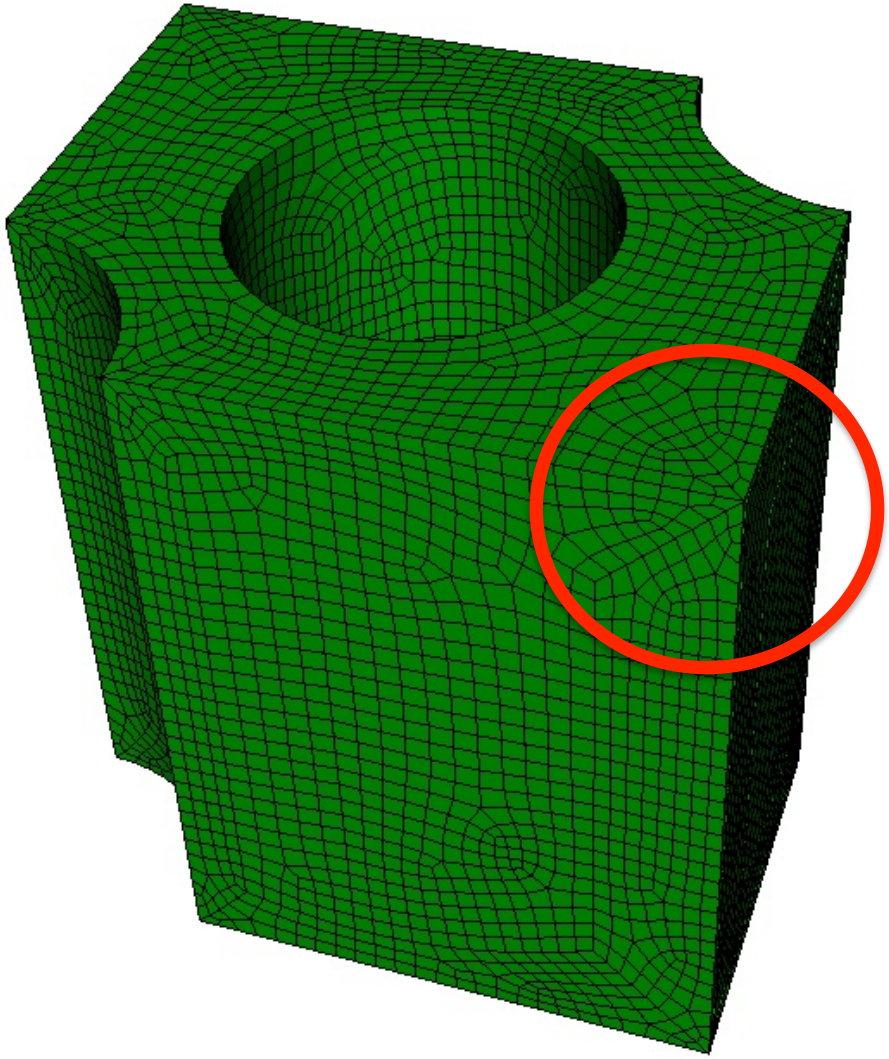
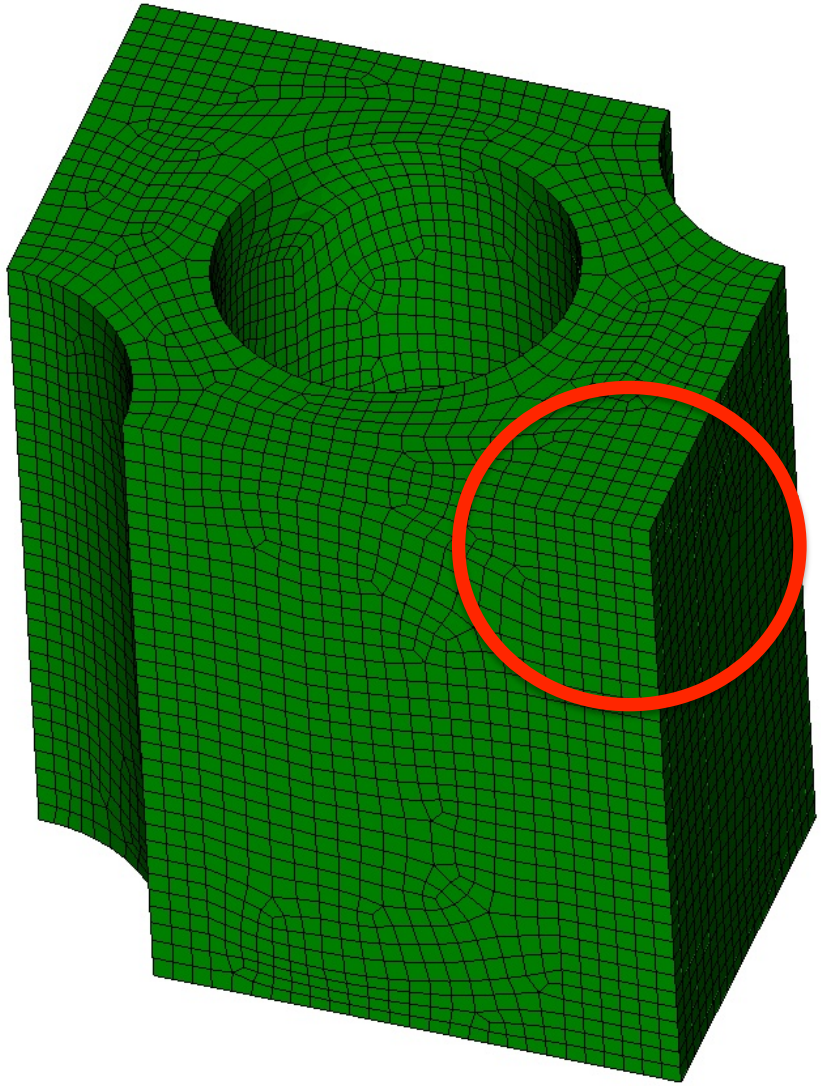


All-Quad Mesh on Medial



Tri at 3-Manifold Medial Curve

Sectional View

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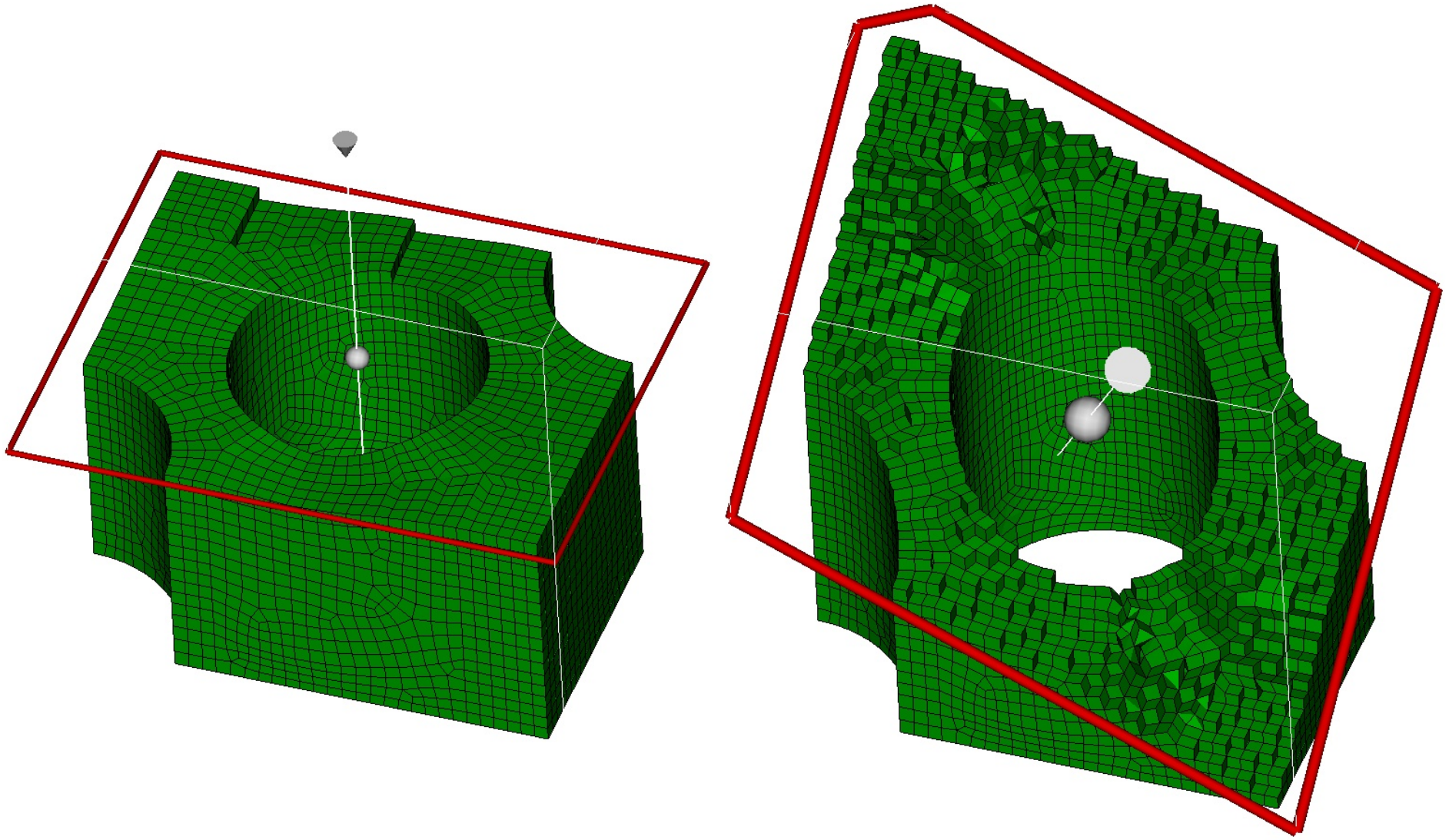
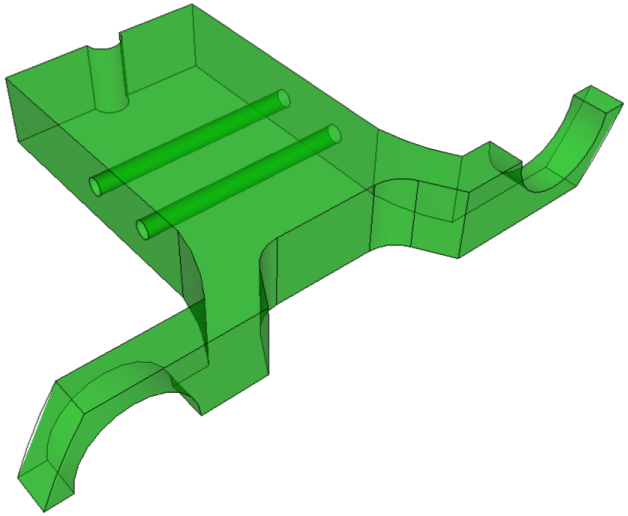
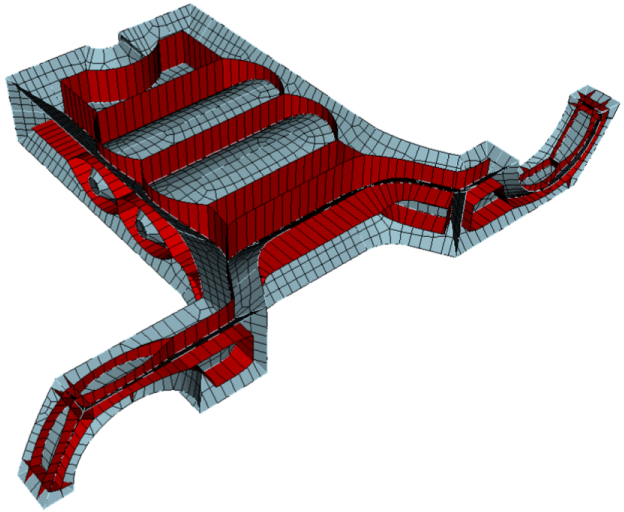


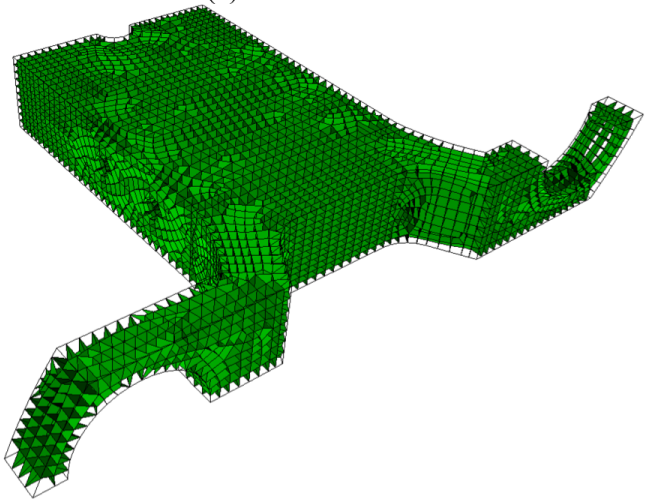
Demo



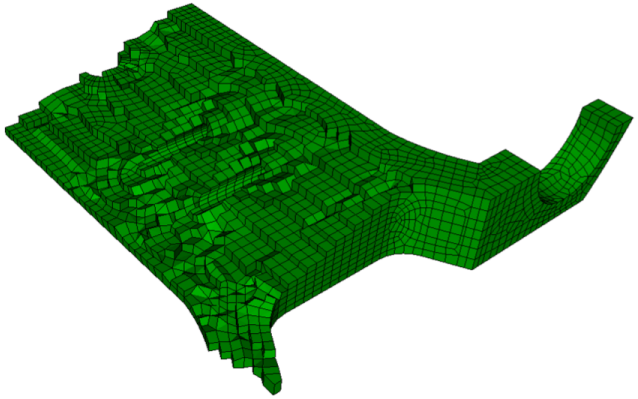
(a) Solid with holes



(b) Mesh on MA inside corridors

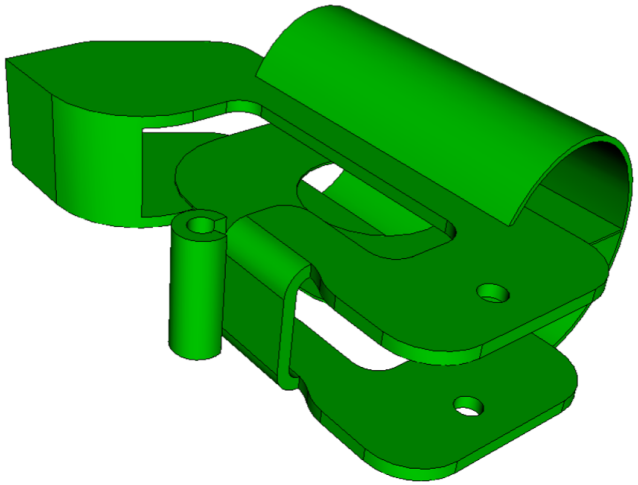


(c) Tracks in 3D

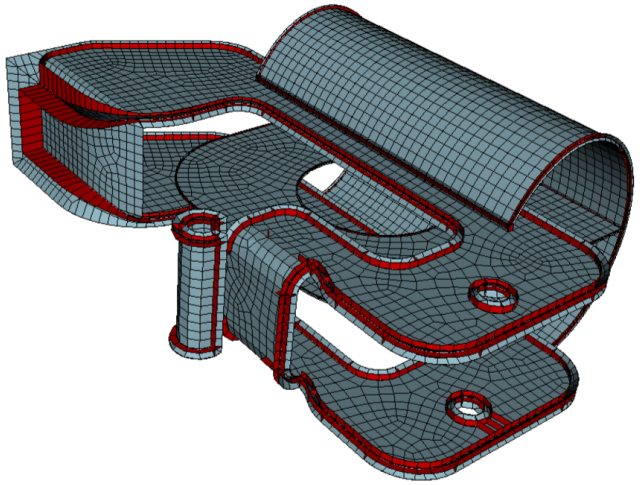


(d) Mesh cross section

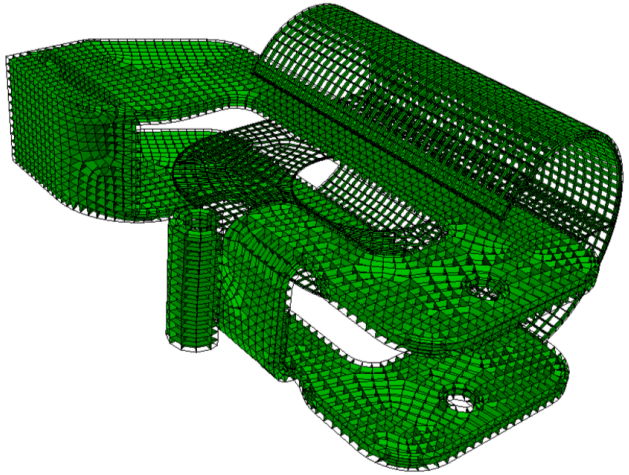
Demo



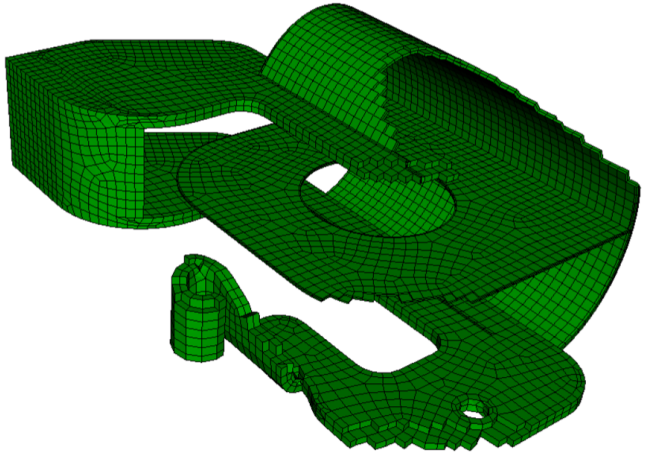
(a) Thin-wall solid



(b) Mesh on MA inside corridors

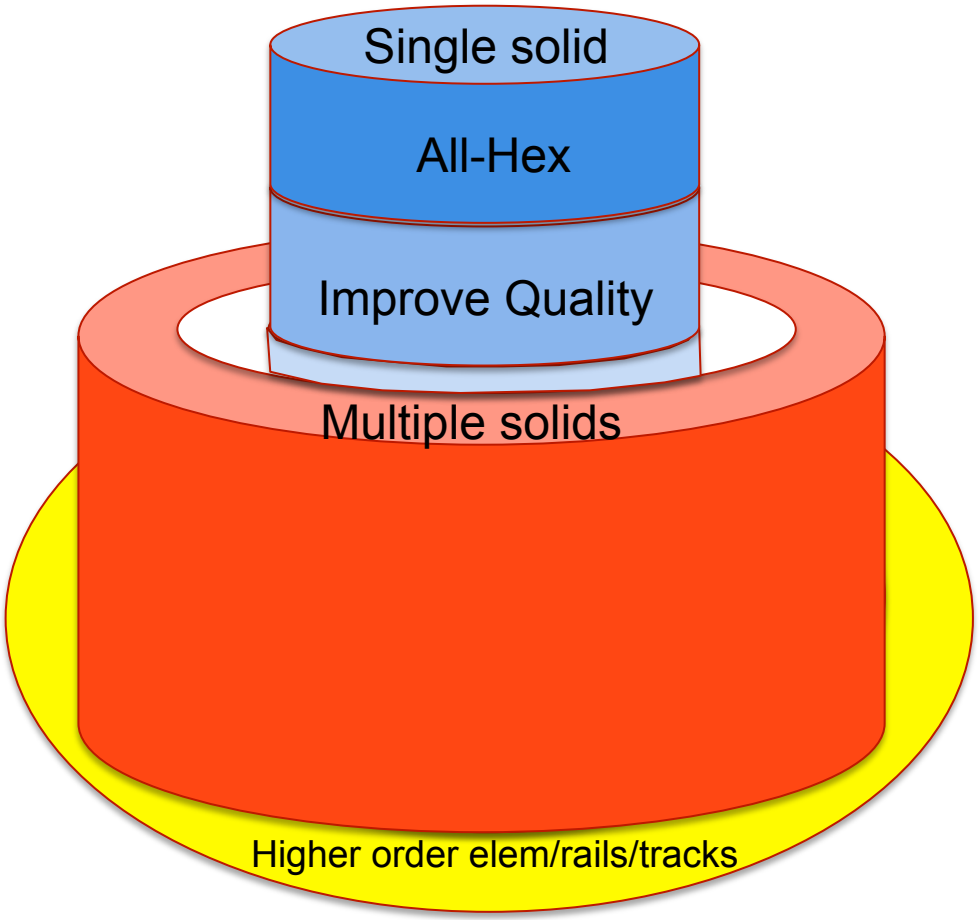


(c) Tracks in 3D



(d) Mesh cross section

Layout of Presentation



#1 Root Cause for Hex-Dominant: N-to-1 or 1-to-N Creates Non-Quad Tracks

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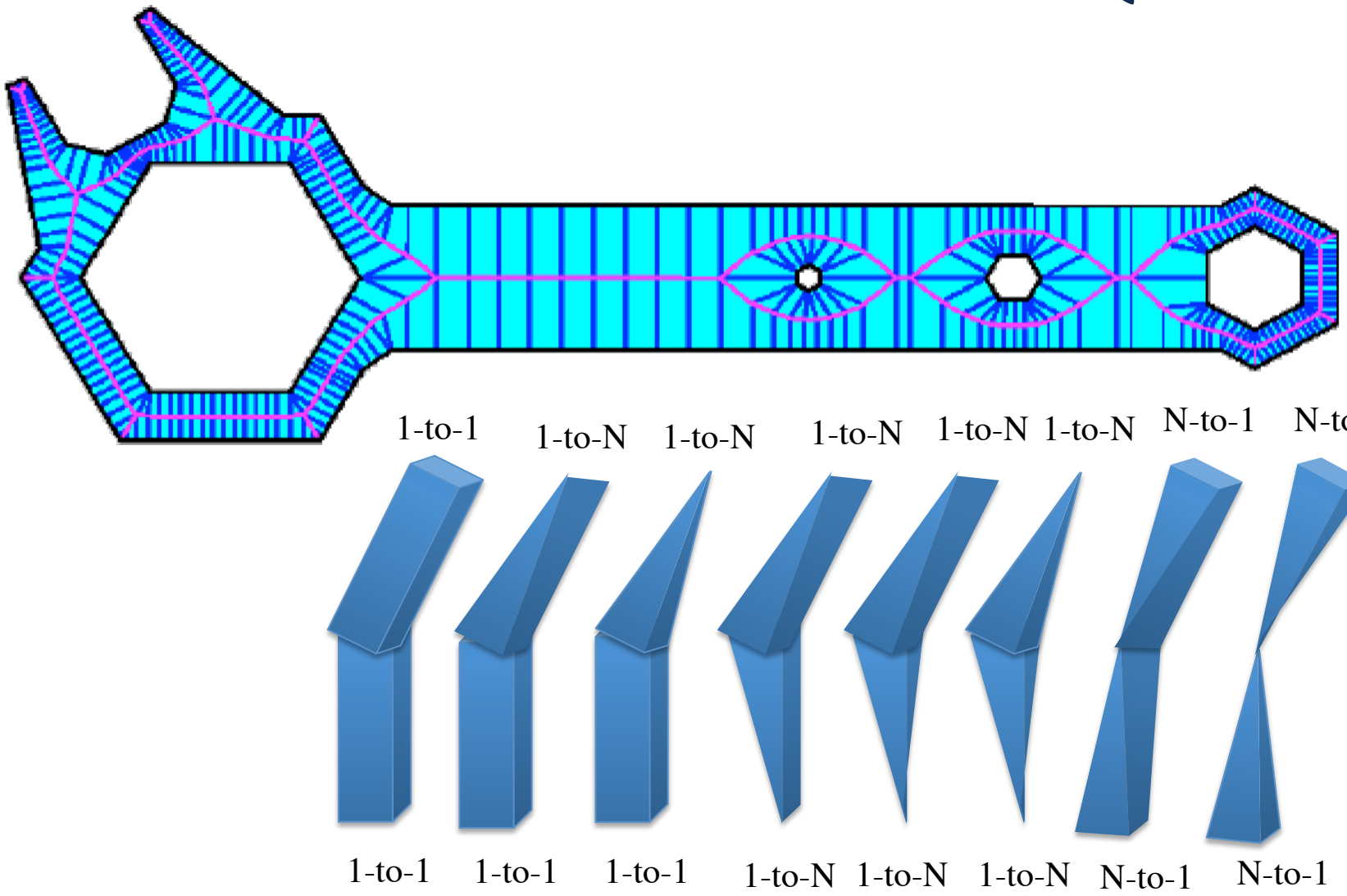
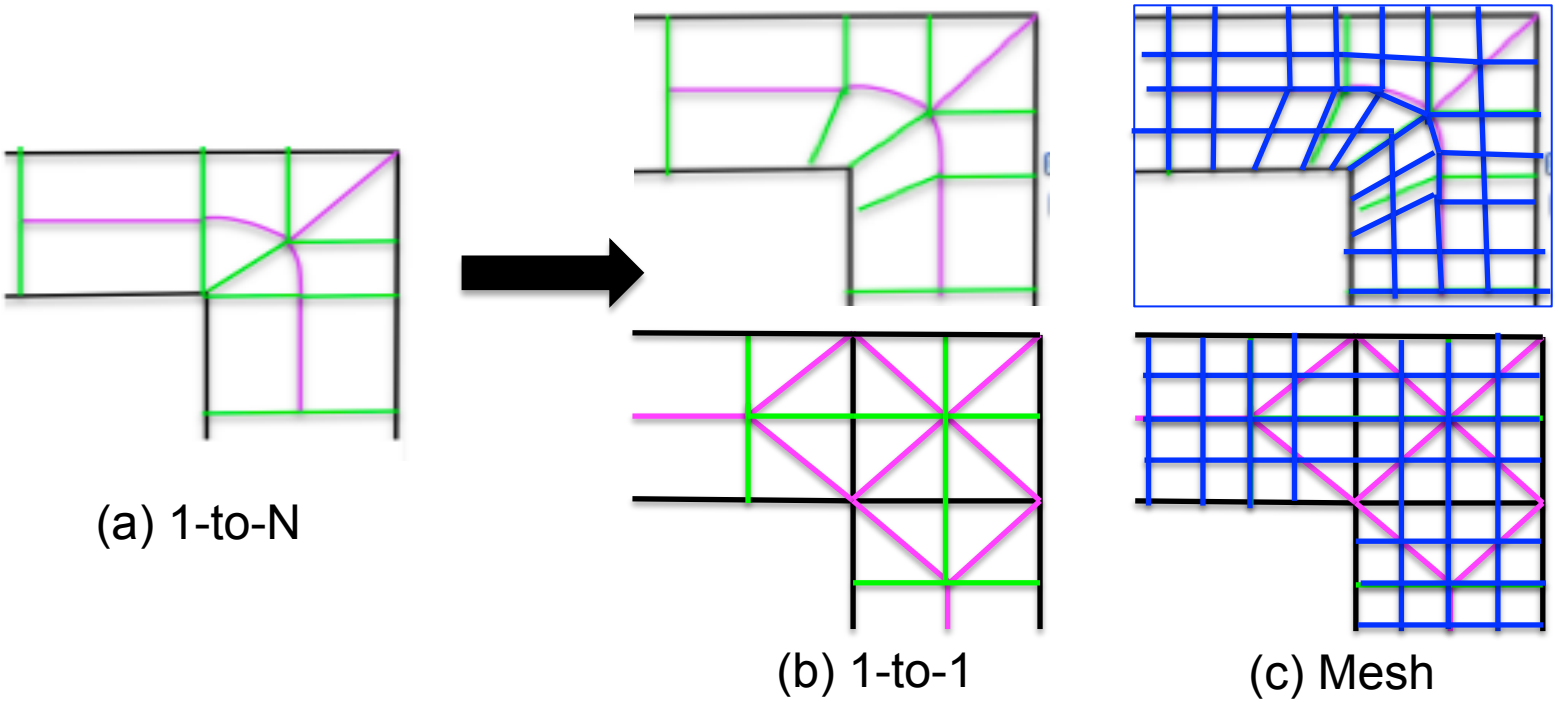
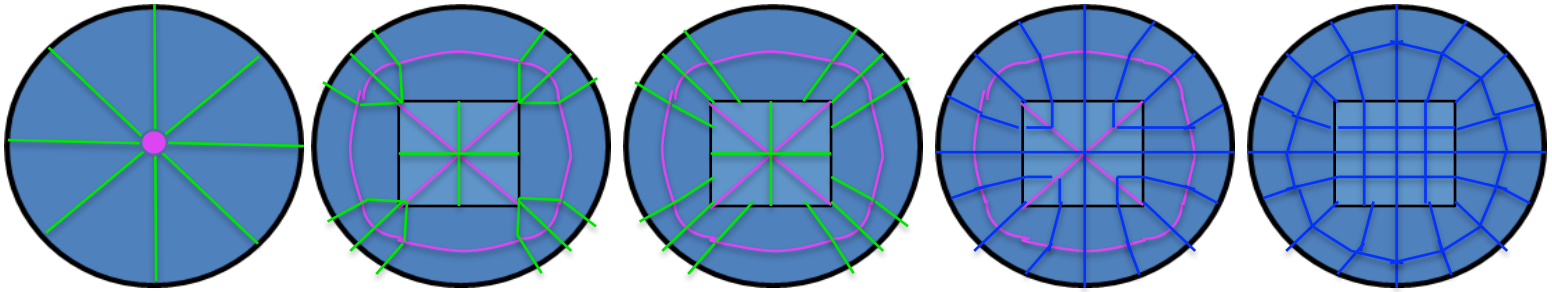


1-to-N & N-to-1 Track Transformed into 1-to-1 Track





#2 Root Cause for Hex-Dominant: Invalid intervals on 1-to-1 tracks

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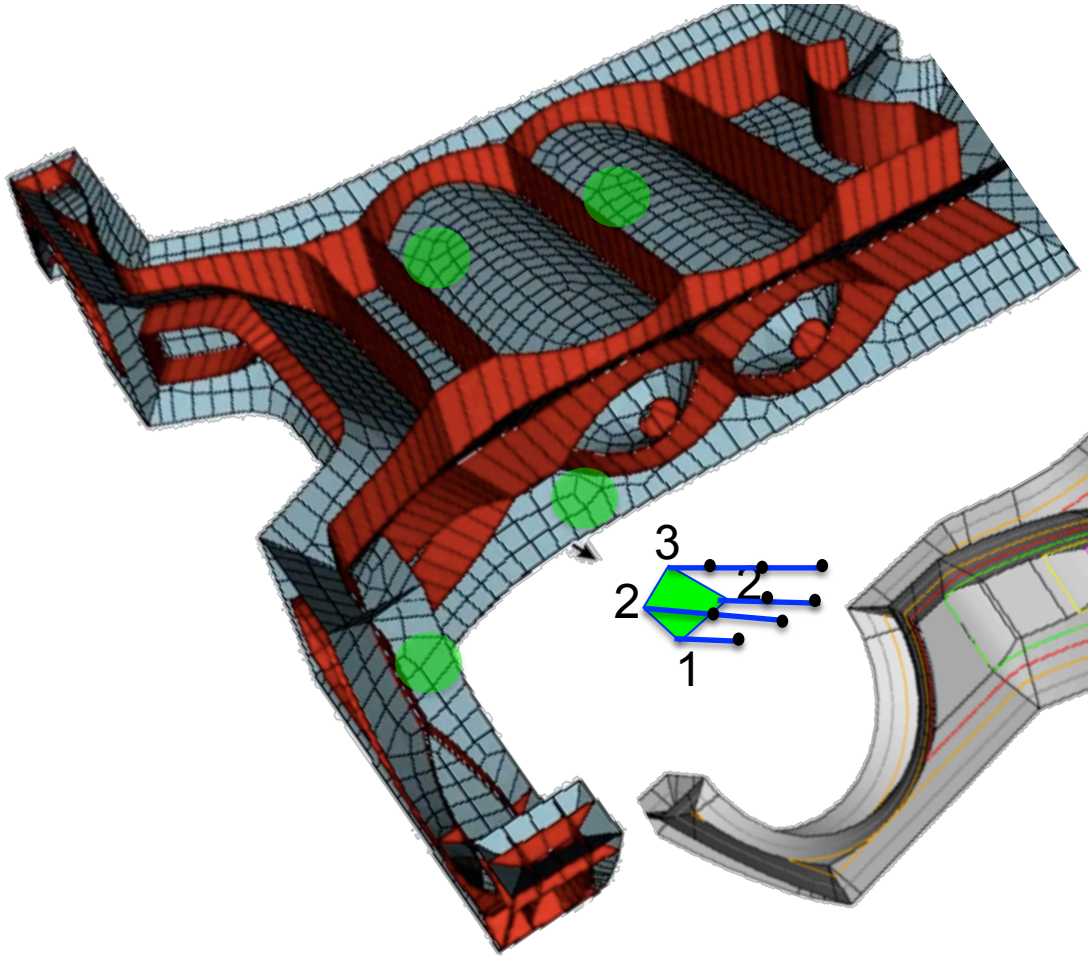

Isocontours of radius function for a given mesh size

Quad mesh generated without using radius function gives hex-dominant mesh

Isocontours of Medial Radius Function Provide Correct Mesh Intervals on Rails

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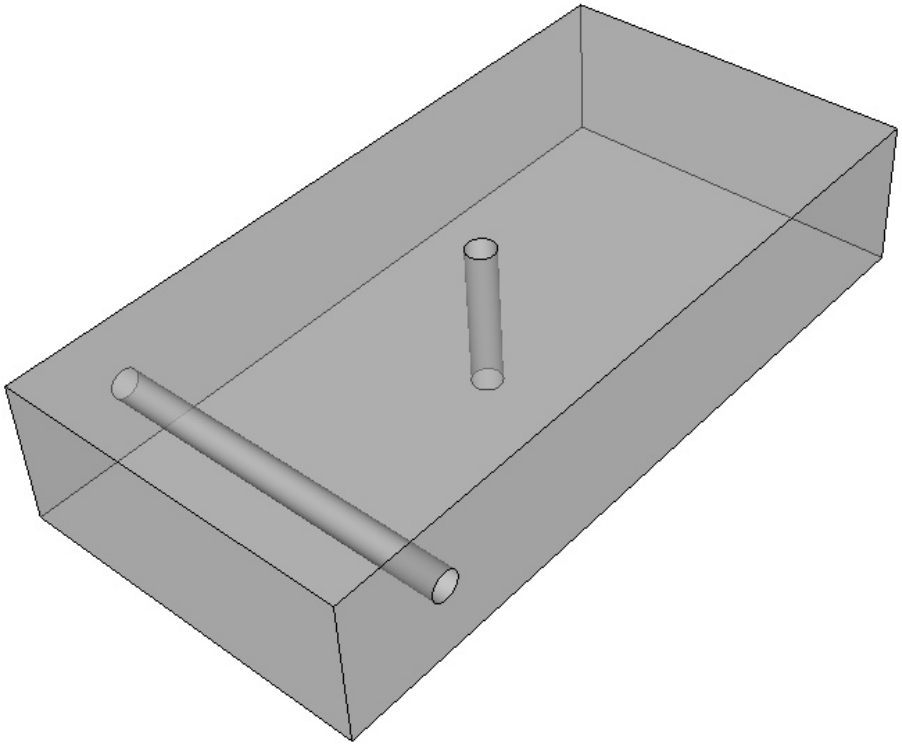
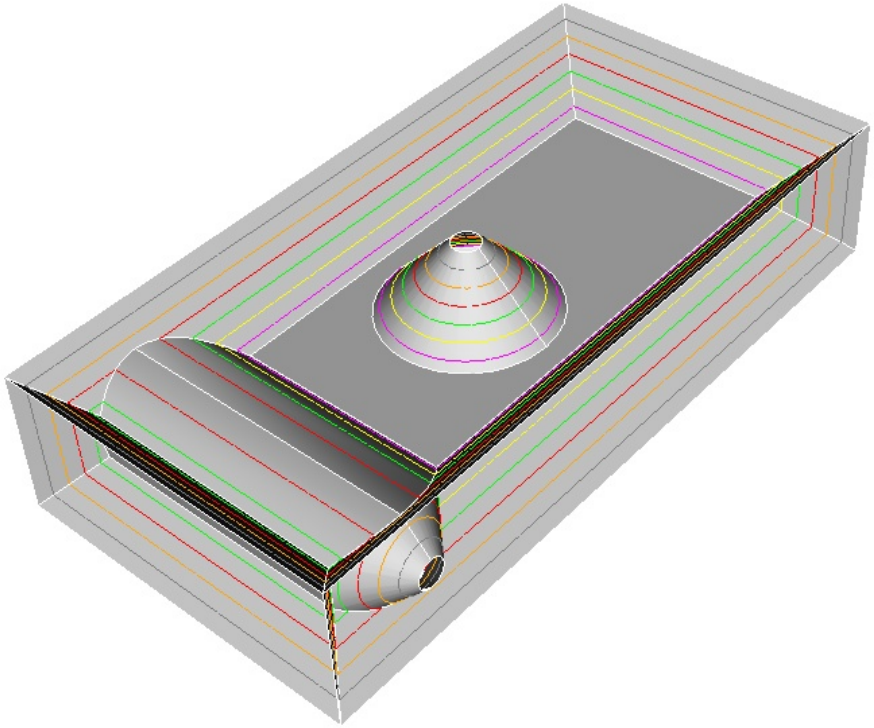


Non-Sweepable Solid



Isocontours of MA Radius Function

All-Hex Mesh Topology Visualization on Isocontours of MA

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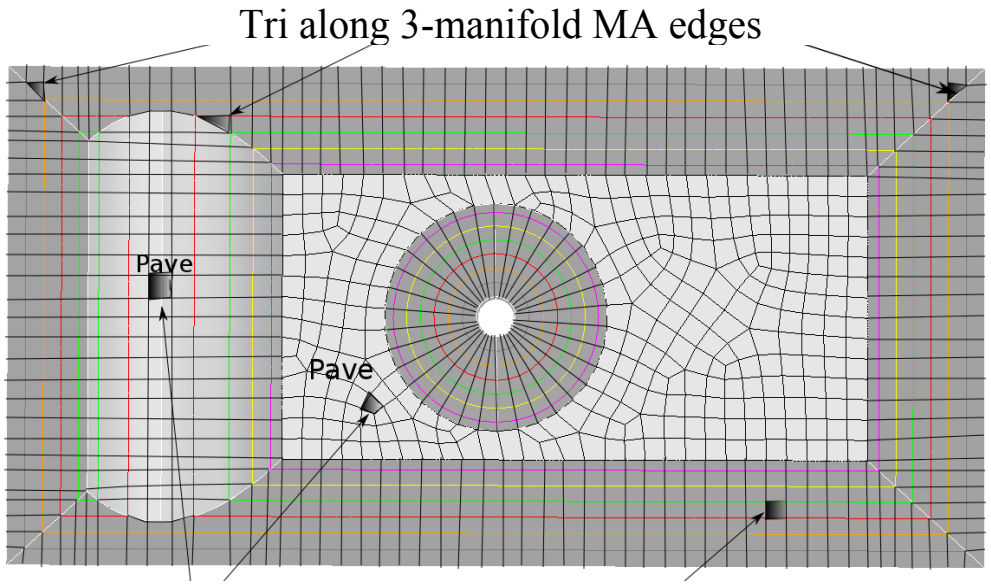
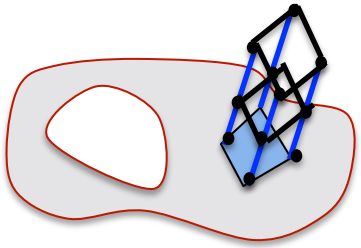
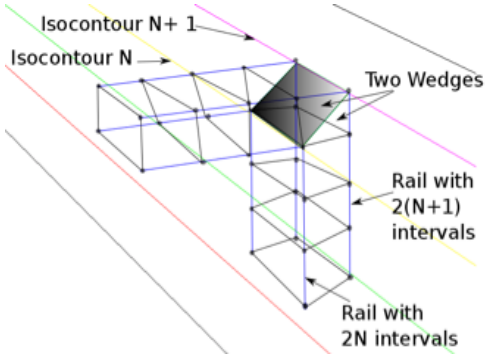


Case1: quad in region bounded by one isocontour

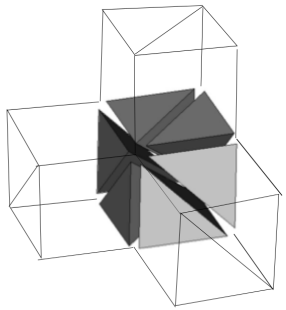
Case 2: quad incident on N & N+1 isocontours



(a) Case1: equal no. of hexes exist on both sides of MA



(b) Case2: two wedges form a hex



(c) Six tets form a hex at 3-manifold MA

Meshing MA using isocontours guarantees correct intervals on rails to satisfy Case 1 or Case 2 in each track

Conclusions

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- LayTracks has been successfully extended to 3D
  - Projection operator extends very well from 2D to 3D in performing geometry decomposition respecting imprints via rails, corridors, and tracks.
  - Automatic, Handles General Solids, Structured Boundary Sensitive Mesh, Irregular Nodes restricted at MA, Respects Sharp Features, Respects Imprints, Orientation insensitive,…
- Meshing medial surfaces without radius function gives 1% to 5% non-hex elements at medial
- Extension to All-Hex looks very promising
  - Requires transforming 1-to-N and N-to-1 maps to 1-to-1
  - Requires meshing medial surface via isocontours of radius function

Related Publications

Sandia National Laboratories

- W. R. Quadros, "***LayTracks3D: A New Approach to Meshing General Solids using Medial Axis Transform***", 23rd International Meshing Roundtable, London, Oct 12-15, 2014.
- W. R. Quadros, "***LayTracks3D: Mesh Generator for General Assembly Models using Medial Axis Transform***", 22nd International Meshing Roundtable -Research Notes, Orlando, Oct 13-16, 2013.
- W. R. Quadros, K. Ramaswami, F. B. Prinz, B. Gurumoorthy "***LayTracks: A New Approach to Automated Geometry Adaptive Quadrilateral Mesh Generation using Medial Axis Transform***", in International Journal for Numerical Methods in Engineering, Vol. 61, Issue 2, pp. 209-237, Sept. 2004.
- W. R. Quadros, K. Ramaswami, F. B. Prinz, B. Gurumoorthy, "***Automated Adaptive Quadrilateral Mesh Generation using MAT***", in Proc. of ASME DETC Design Automation Conference, Pittsburgh, Sept. 2001.
- W. R. Quadros, K. Ramaswami, F. B. Prinz, B. Gurumoorthy, "***Lay Tracks: A New Approach to Automated Quadrilateral Mesh Generation using MAT***", in Proc. of 9th International Meshing Roundtable, pp. 239 - 250, New Orleans, Oct. 2000.

Acknowledgements

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Thank You

Questions?

wrquadr@sandia.gov