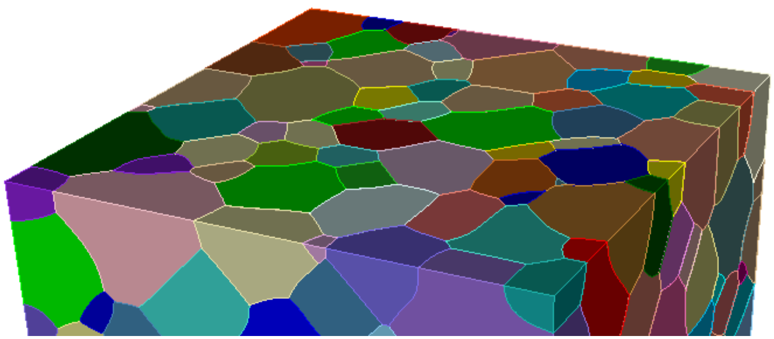
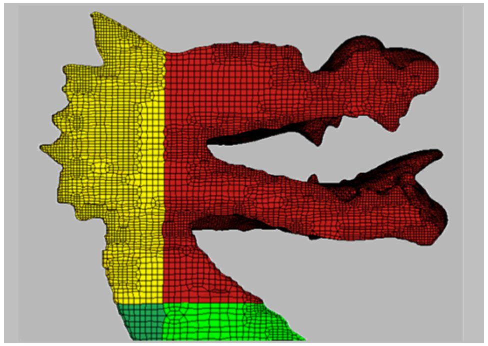
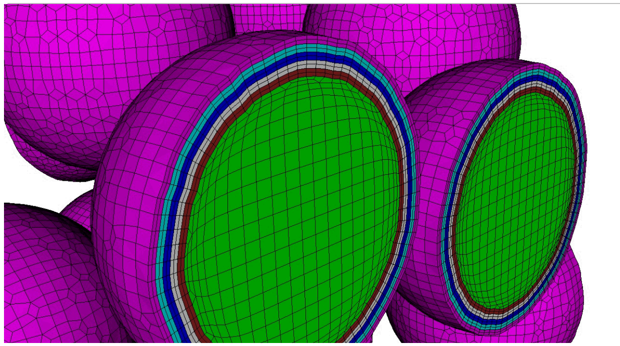
SAND2017-3840C







SIAM Conference on Computational Science and Engineering

February 27-March 3, 2017
Hilton Atlanta, Atlanta, Georgia, USA

Advances in Grid-Based All-Hex Mesh Generation for High Performance Computing

Steven J. Owen

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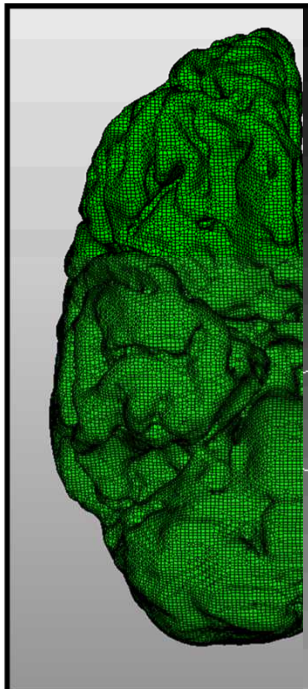
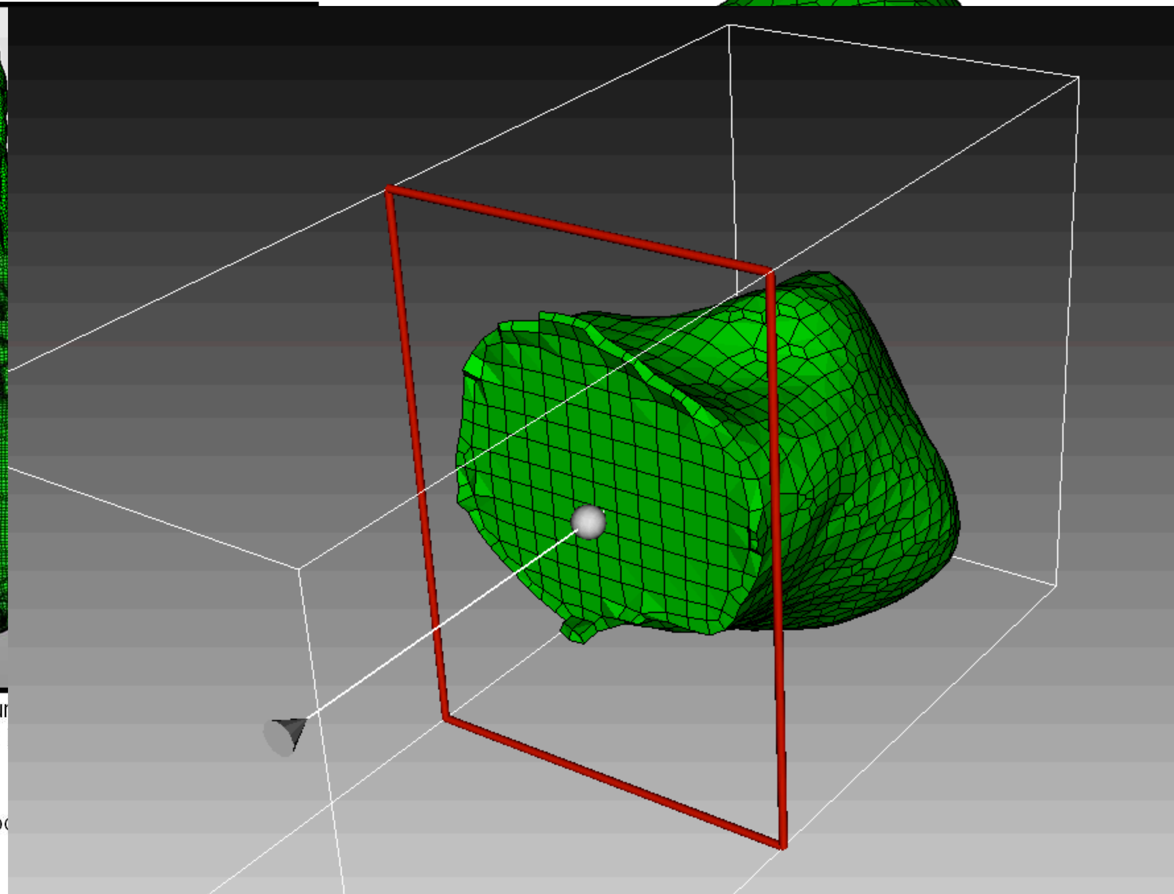
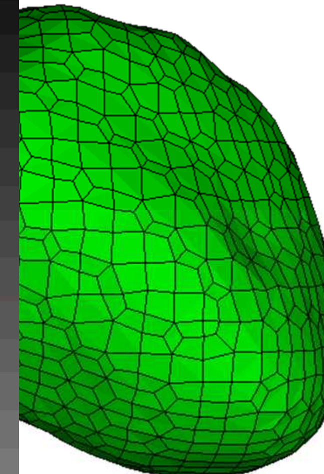
Sculpt Examples



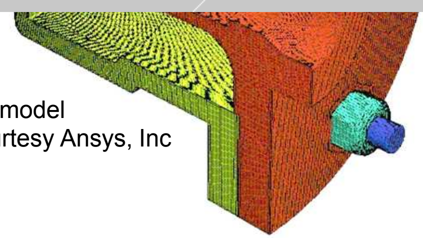
STL MRI Brain Model, Cour
Brigham Young University,

Mechanical Component Mod
Used with Permission

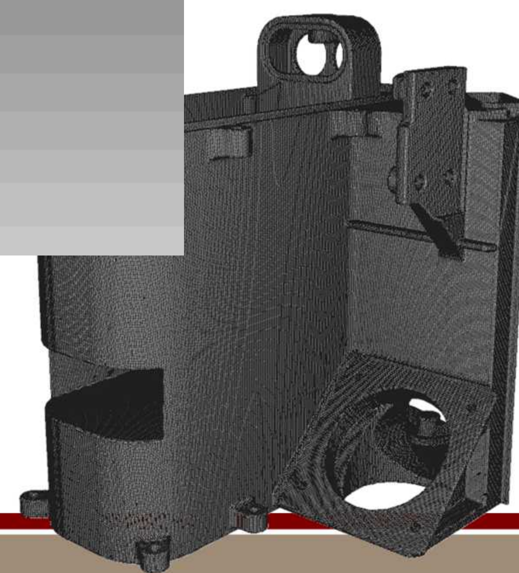




mponent Model

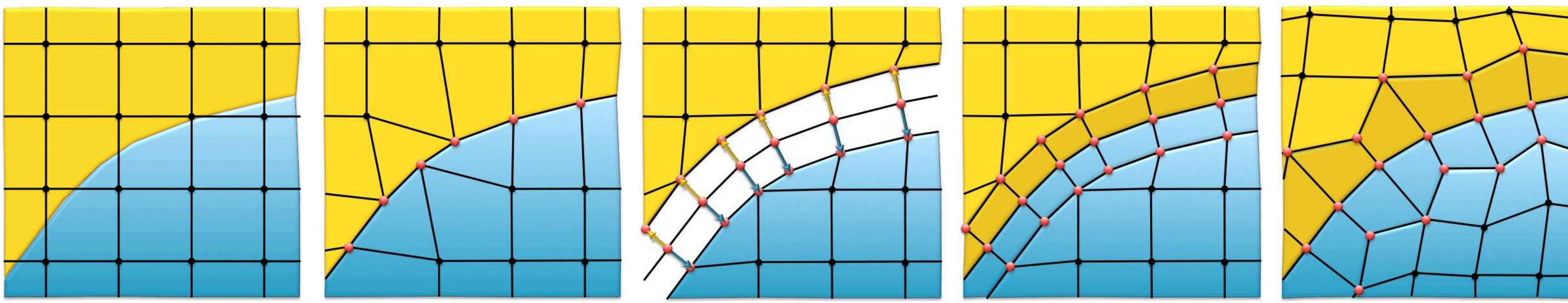


V2 model
courtesy Ansys, Inc



Sculpt Procedure

Overlay Grid Procedure used by Sculpt



Cartesian Grid overlaid on geometry

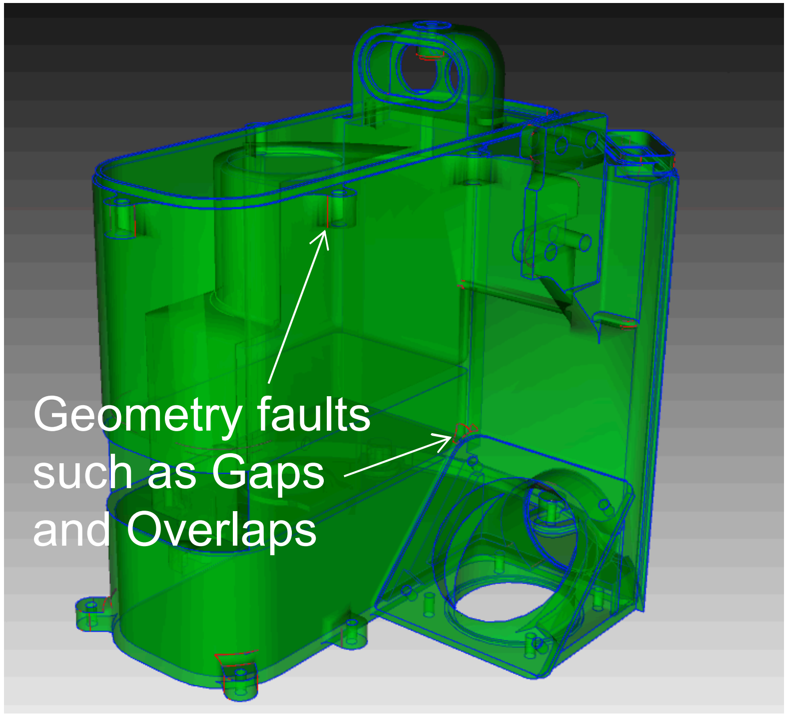
Nearby nodes projected to boundaries

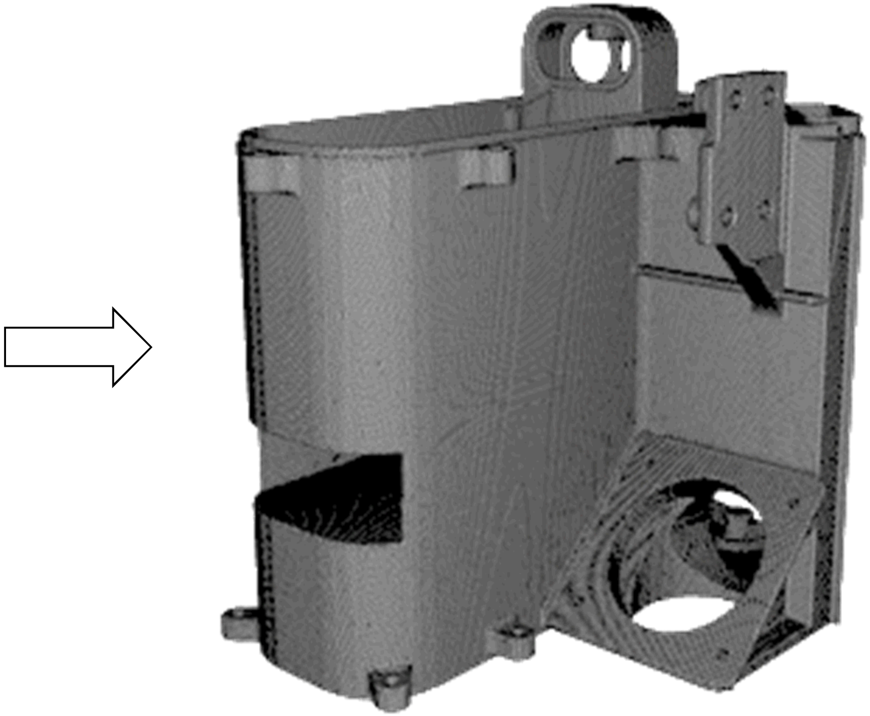
Mesh pulled away from the boundaries

And Layer of hexes inserted

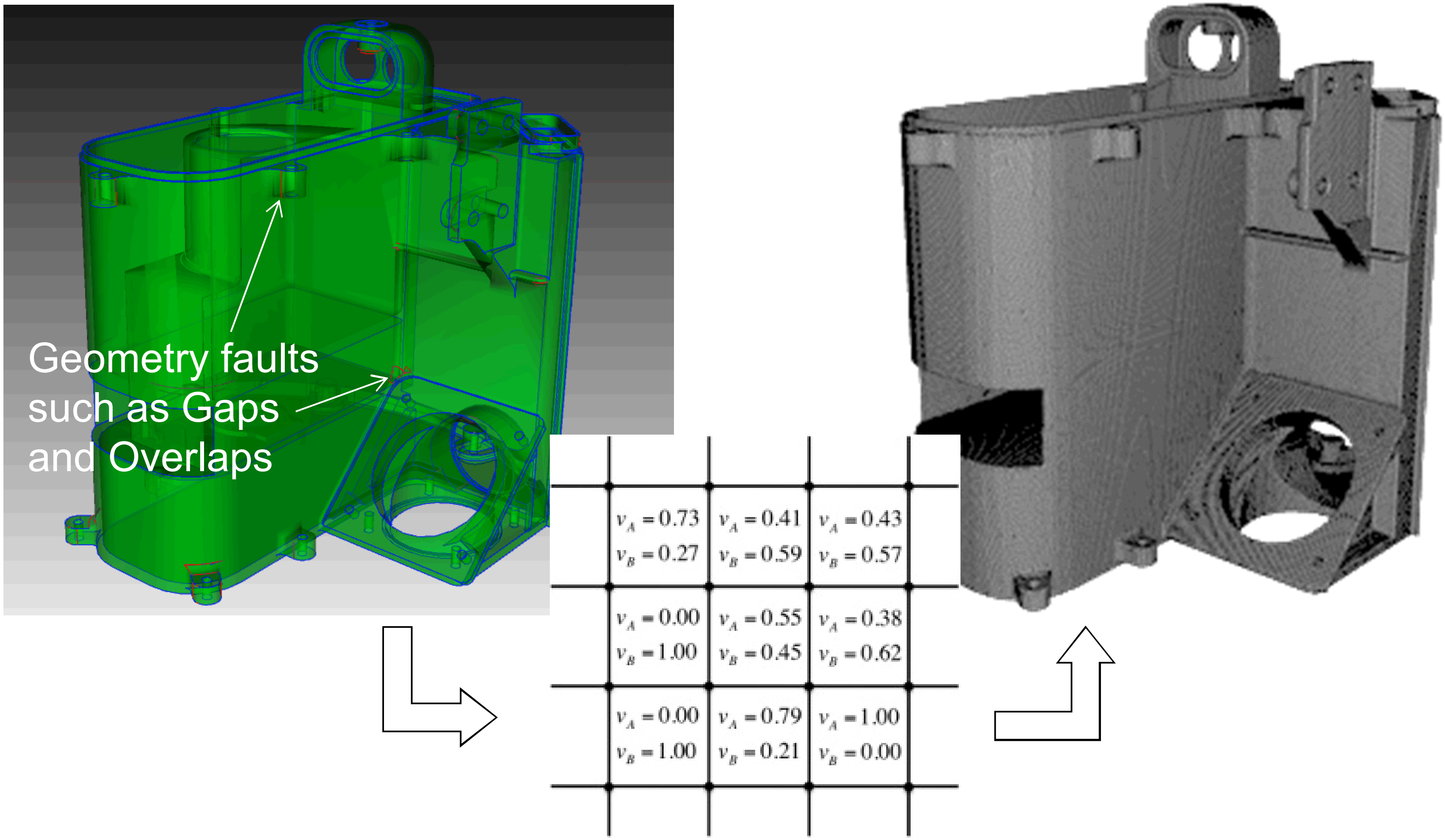
Smoothing performed to improve element quality

Sculpt Application



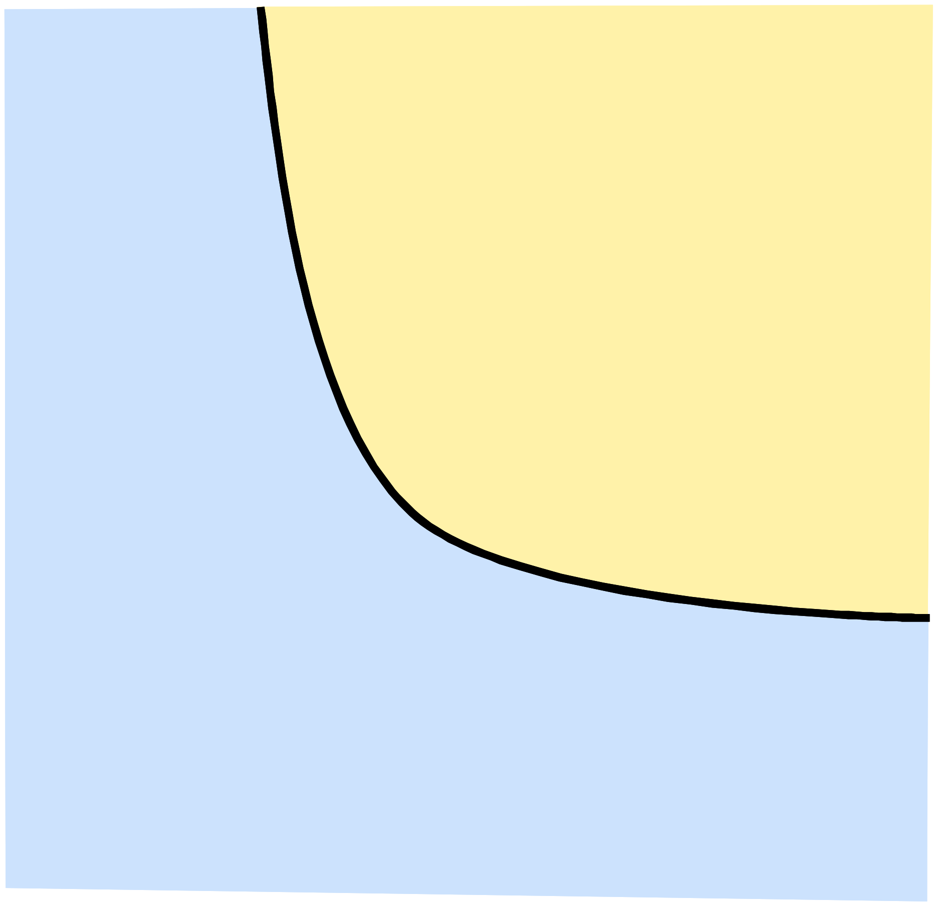


Sculpt Application

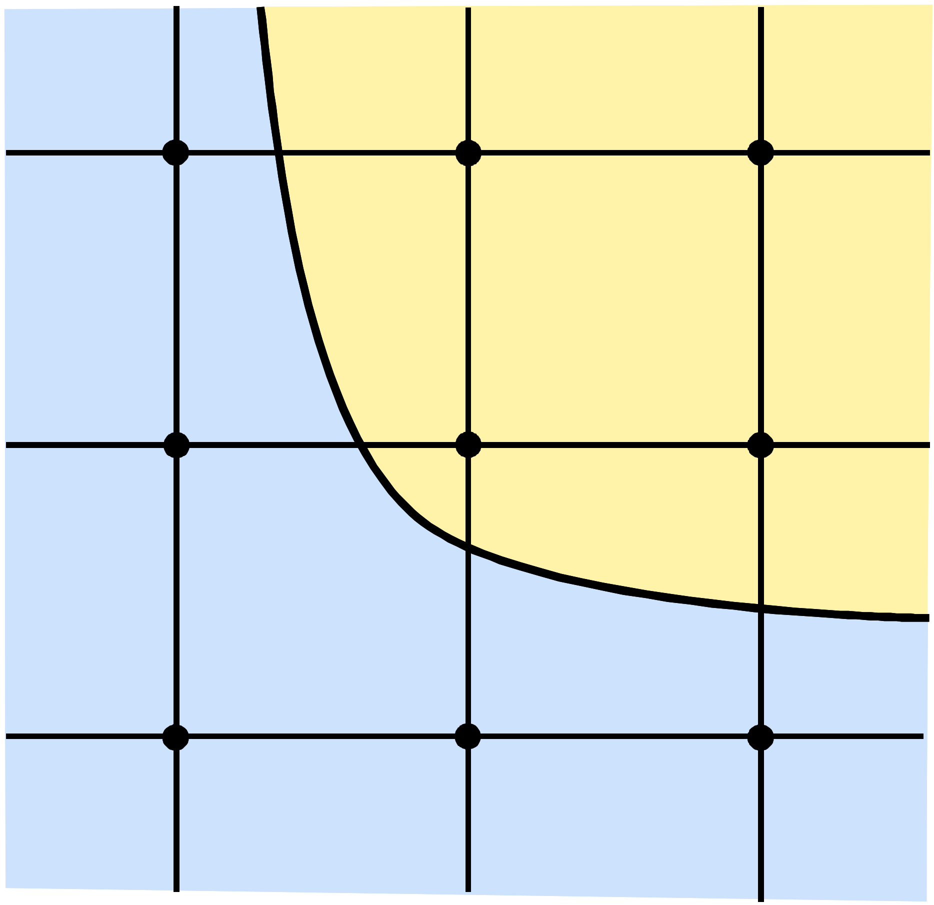


Geometry is first converted to “Volume Fraction” Data before meshing.

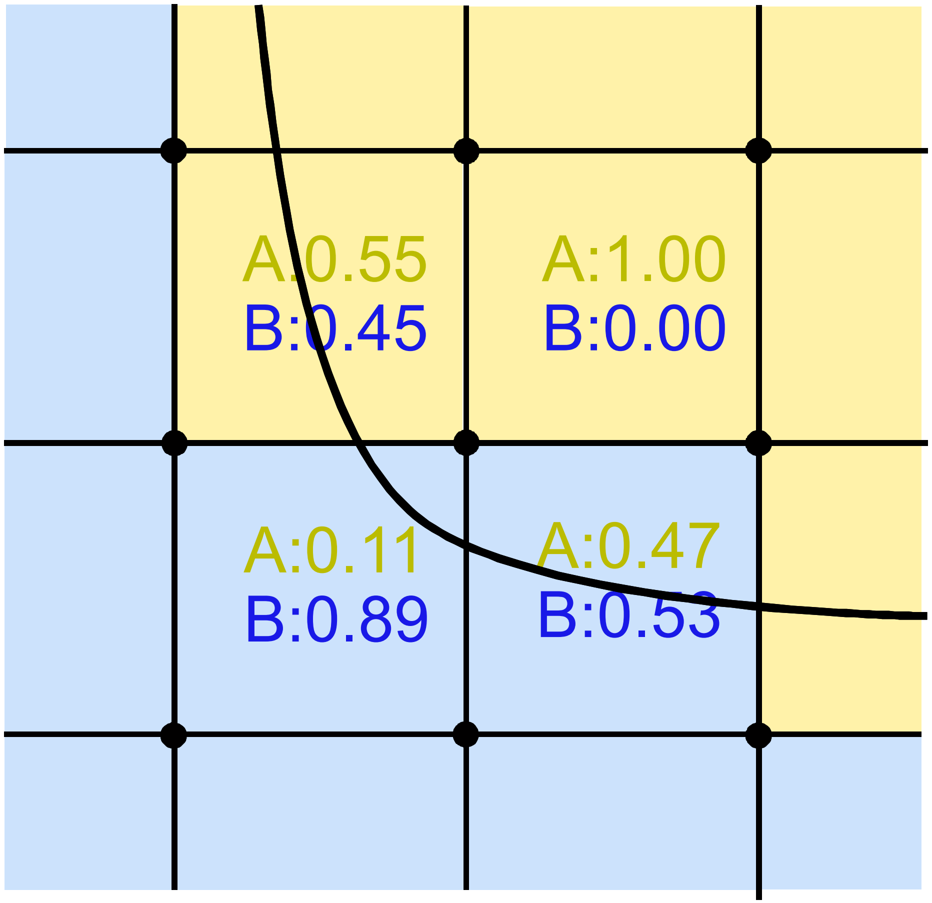
Interface Approximation



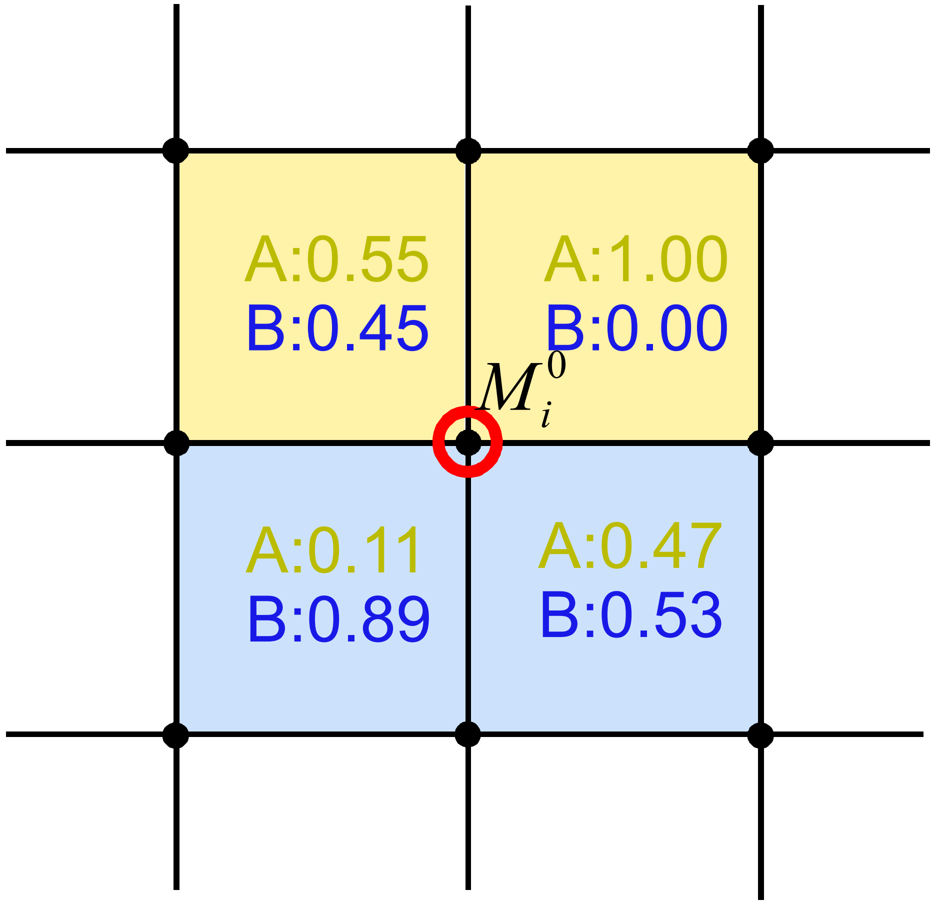
Interface Approximation



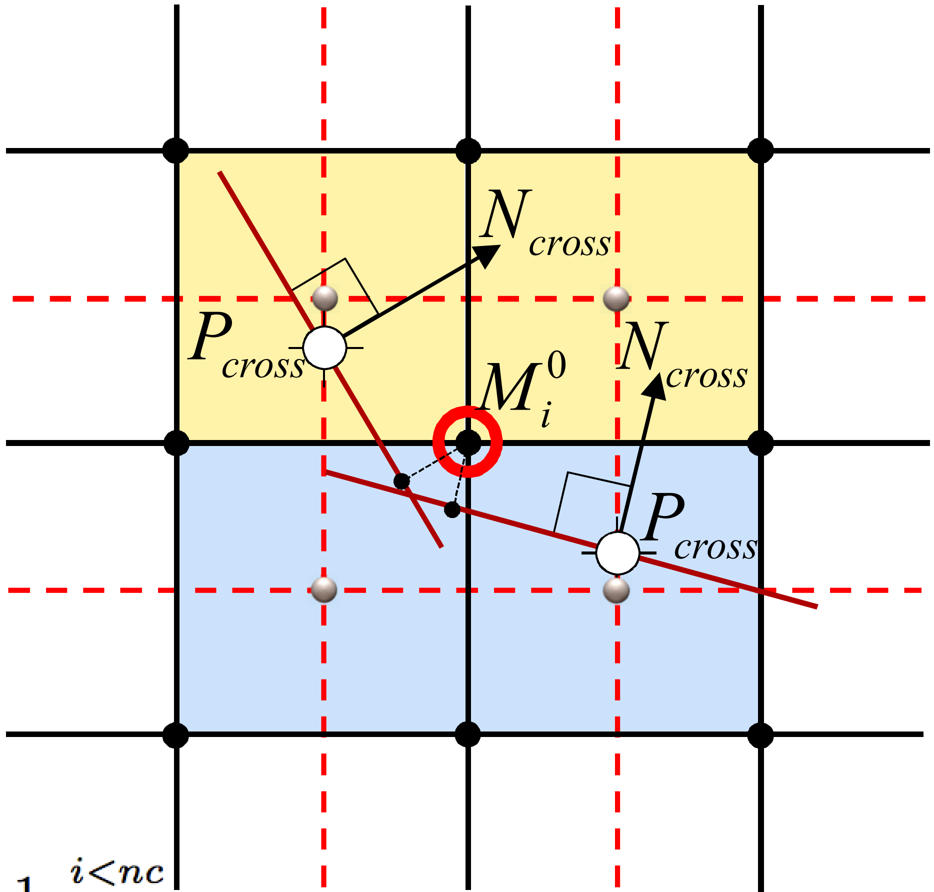
Interface Approximation



Interface Approximation



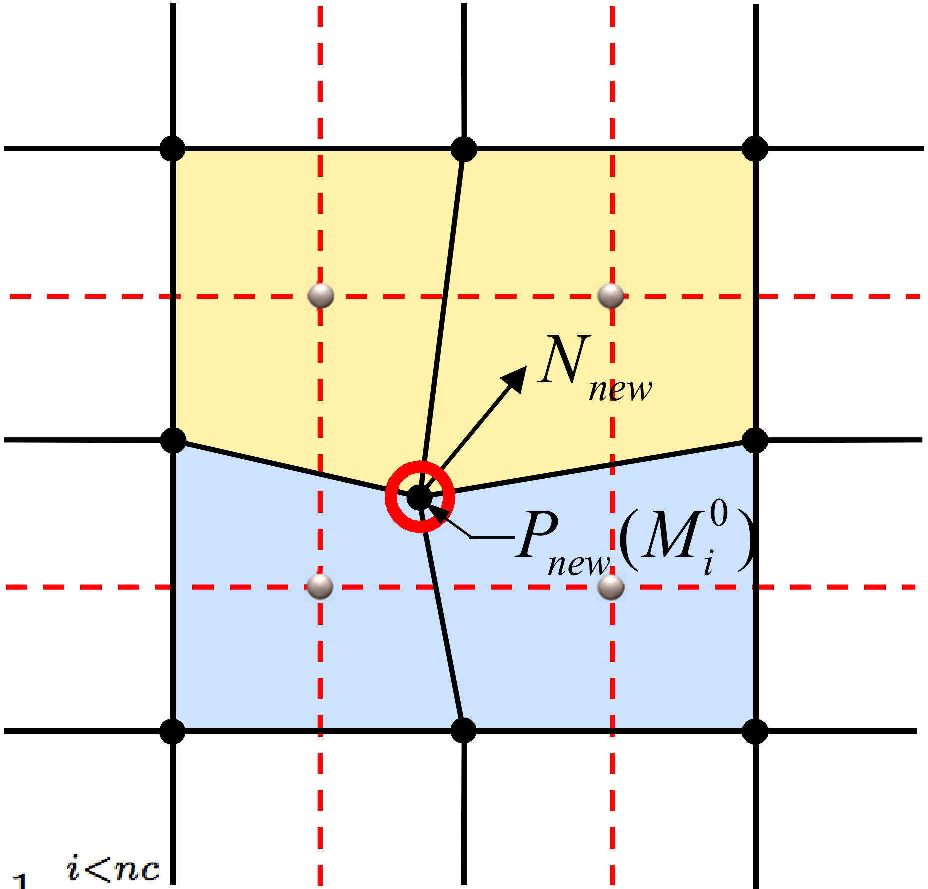
Interface Approximation



$$P_{new} = \frac{1}{nc} \sum_{i=0}^{i<nc} P_0 - (N_{cross})_i \cdot (P_0 - (P_{cross})_i) \times (N_{cross})_i$$

$$(N_{new})_n = \left| \sum_{i=0}^{i<nc_n} (N_{cross})_i \right|$$

Interface Approximation



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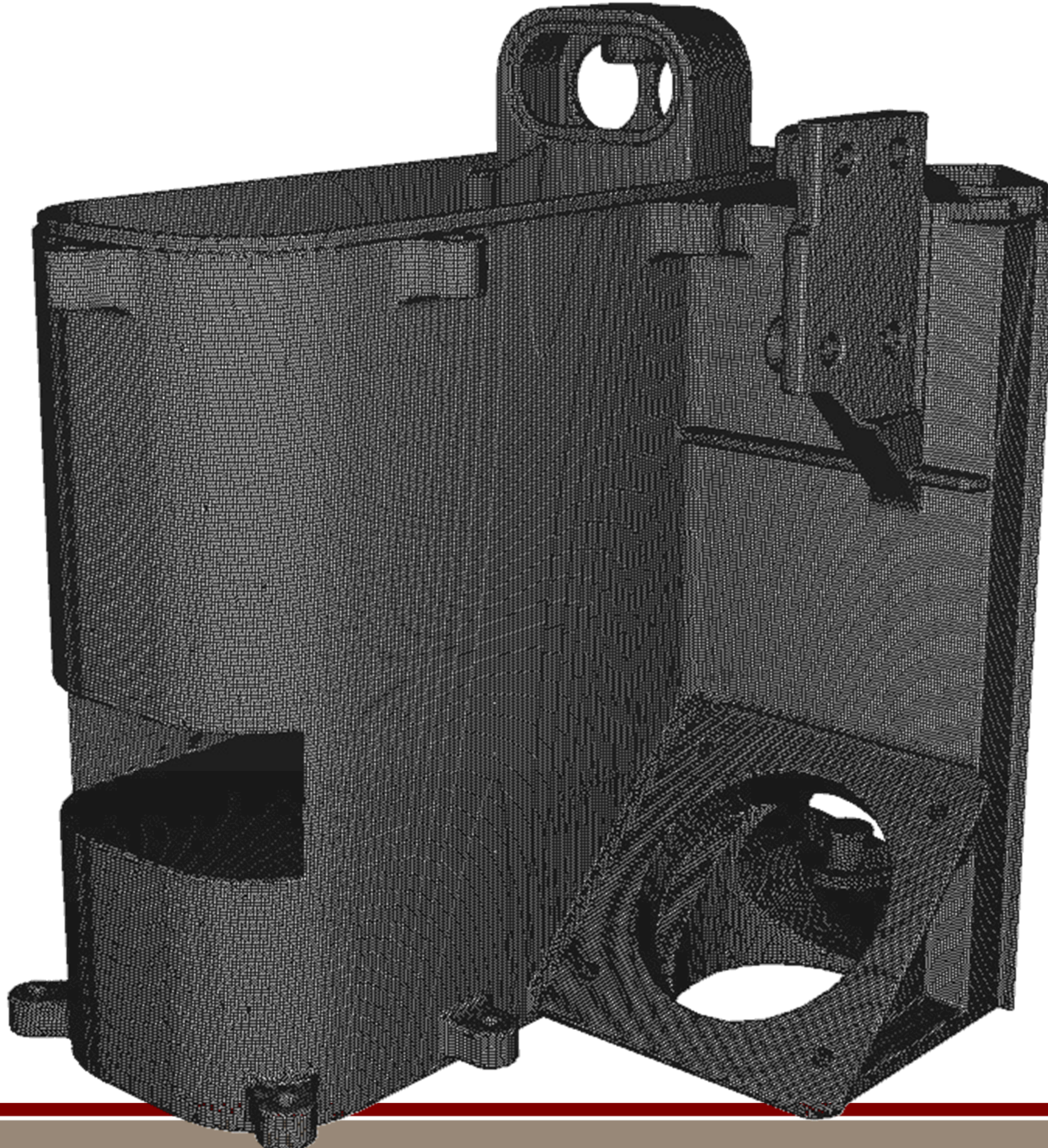

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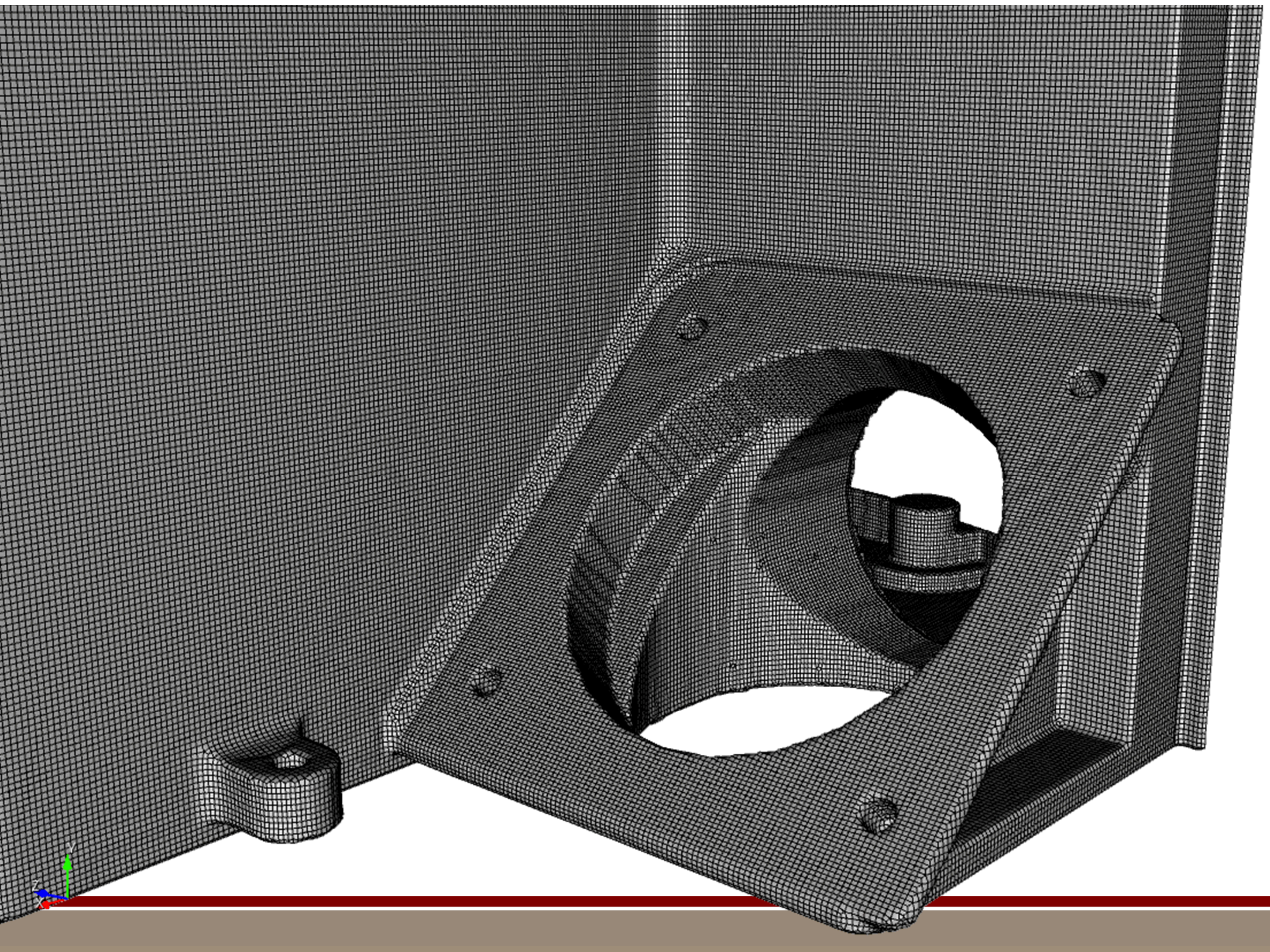

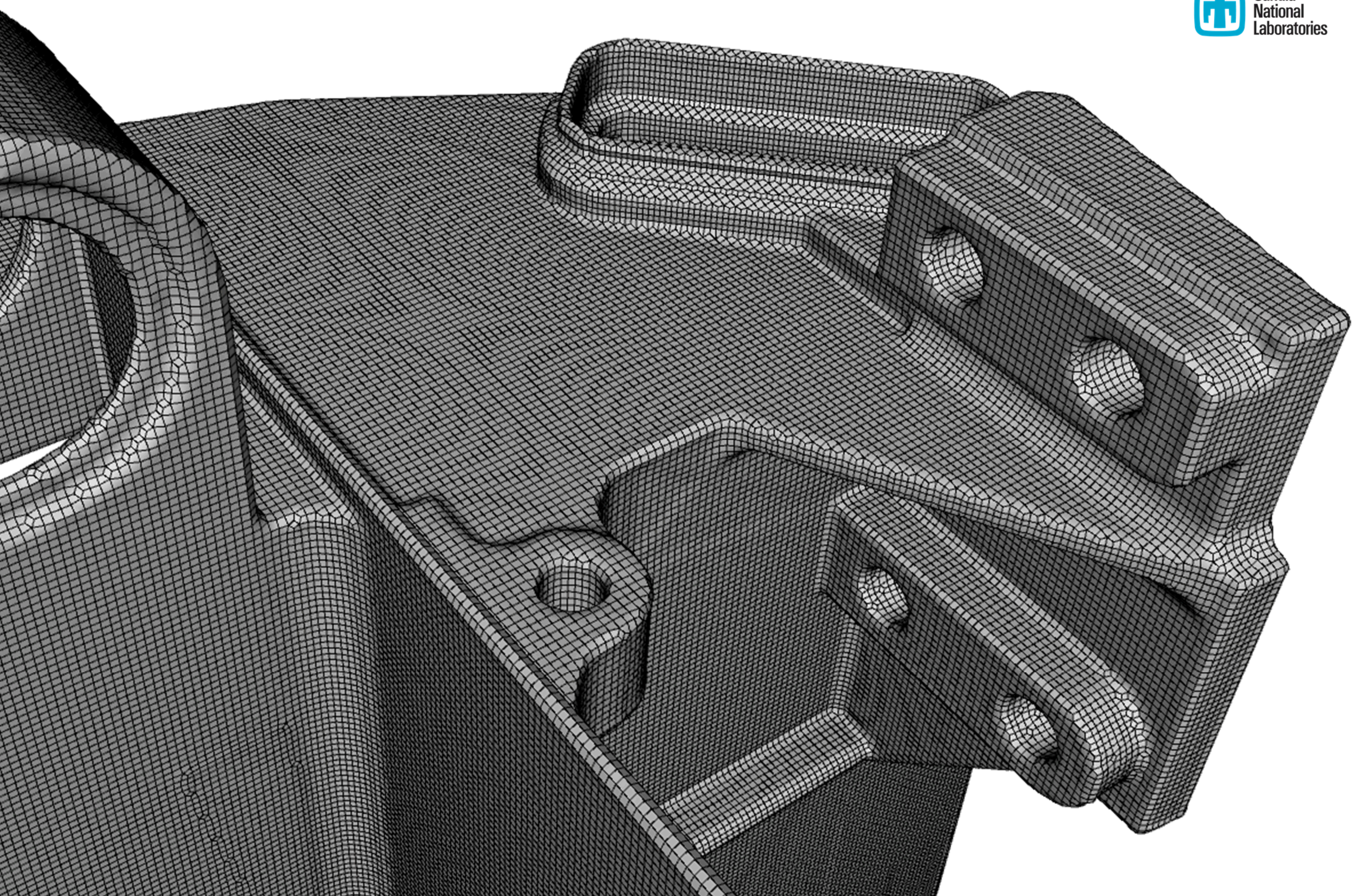

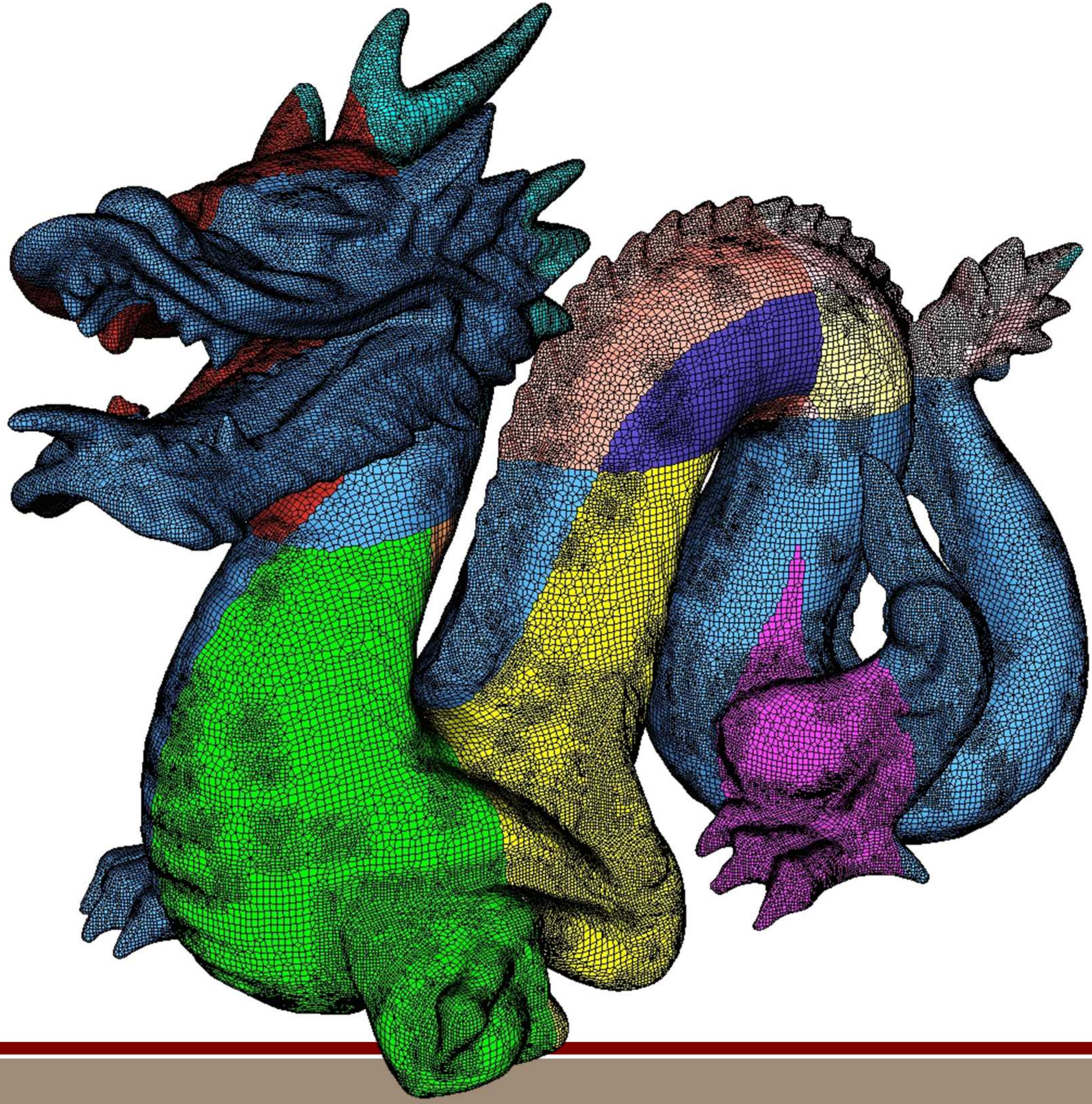

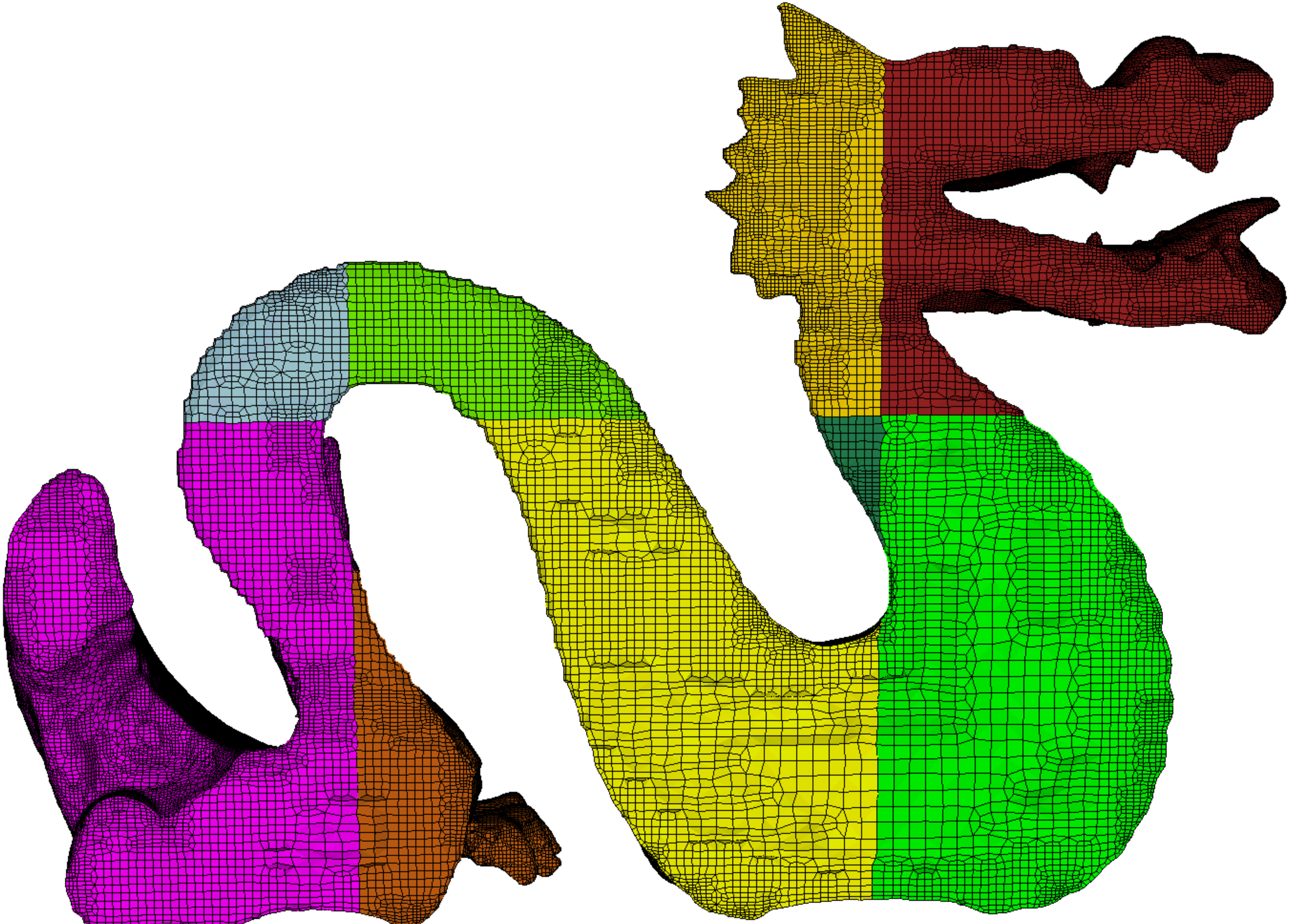

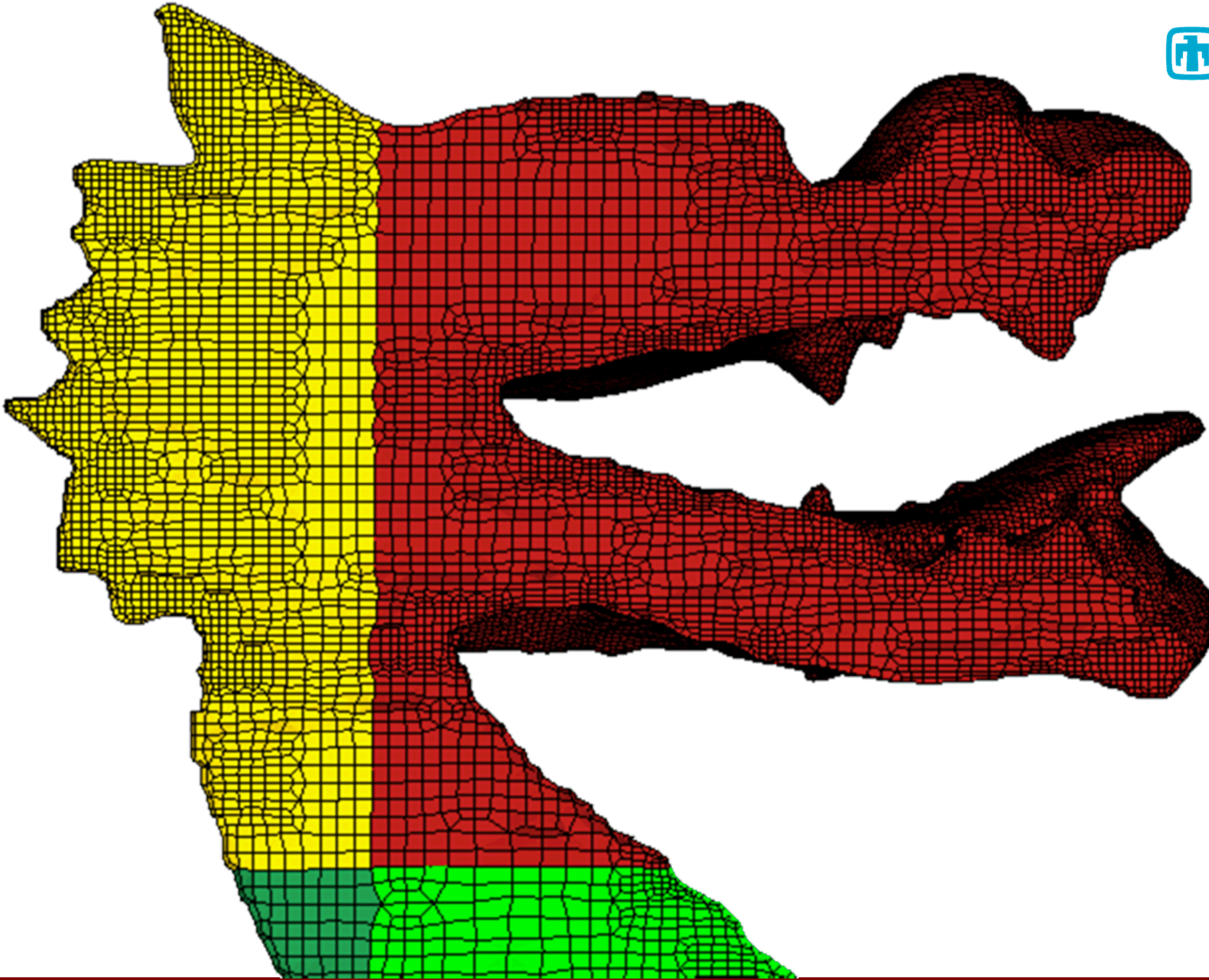

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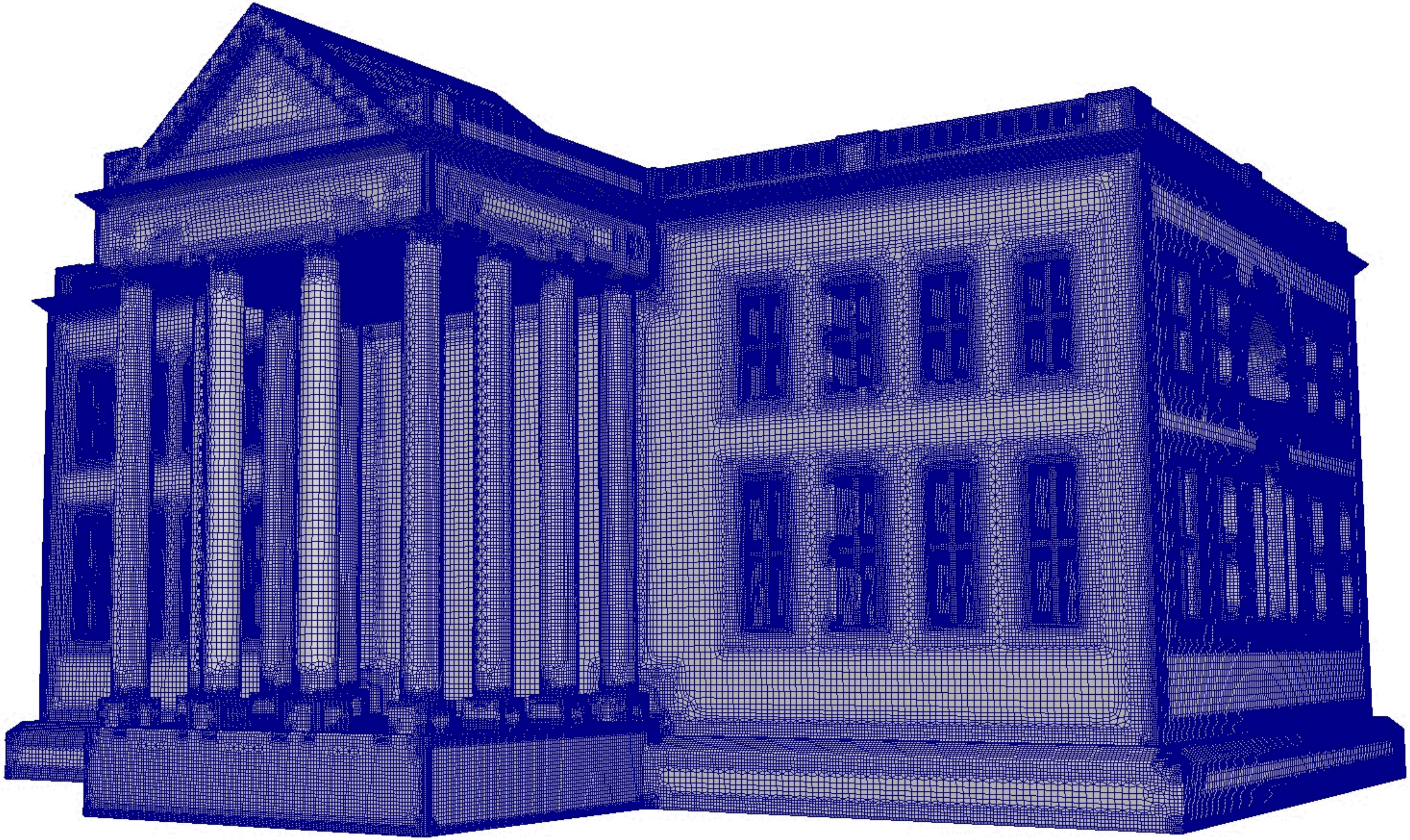
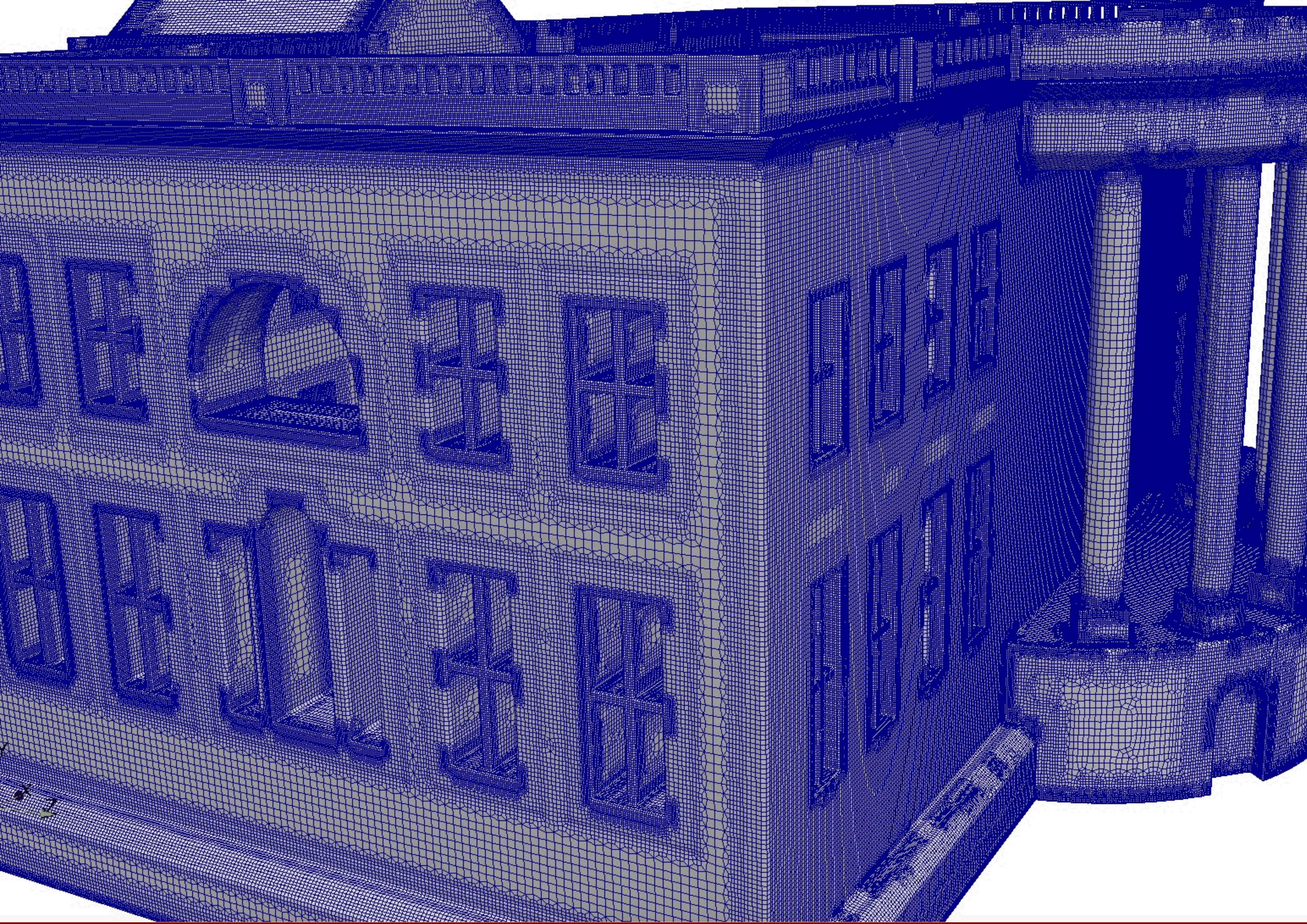
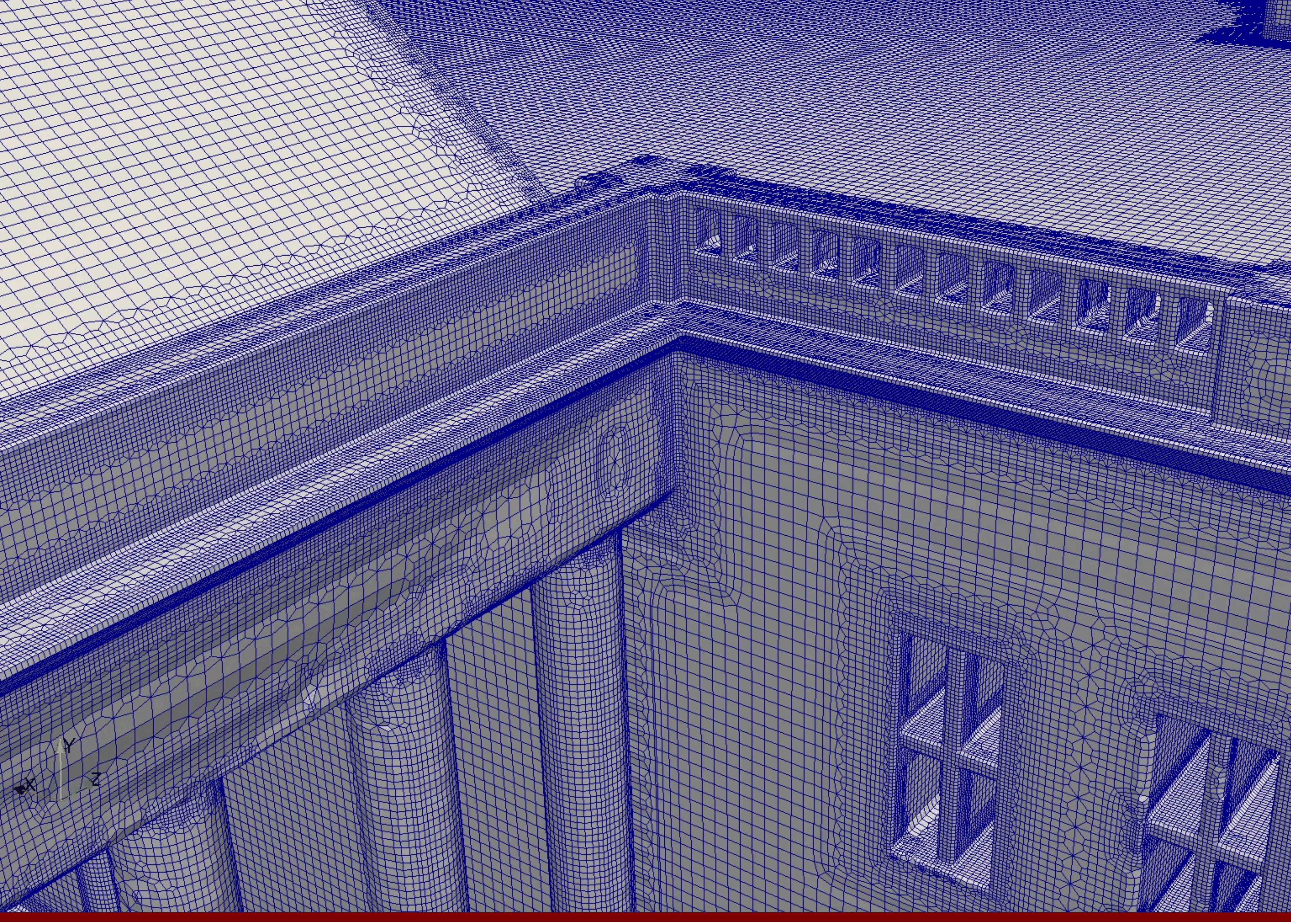
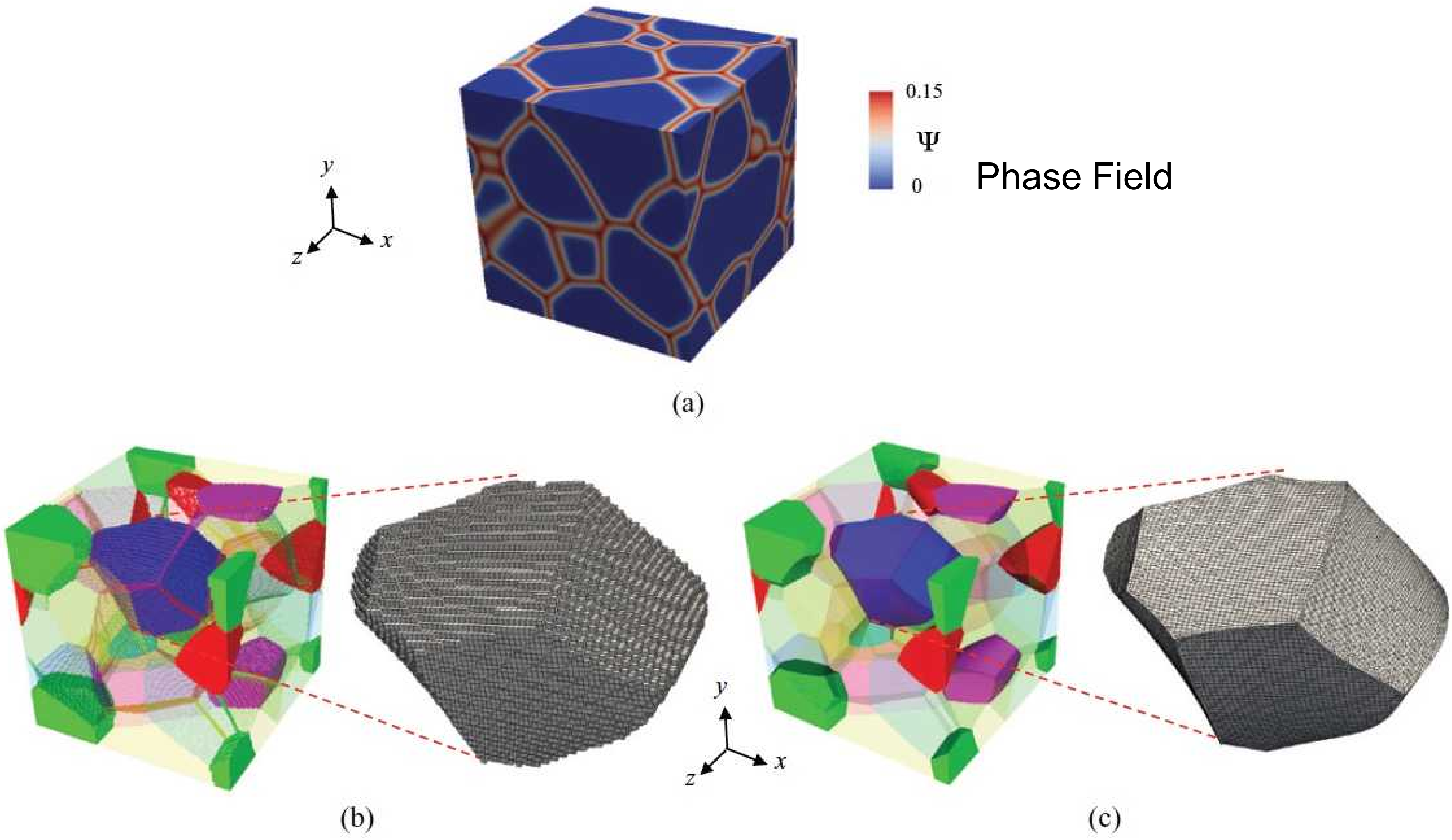






Hex Meshing Microstructures



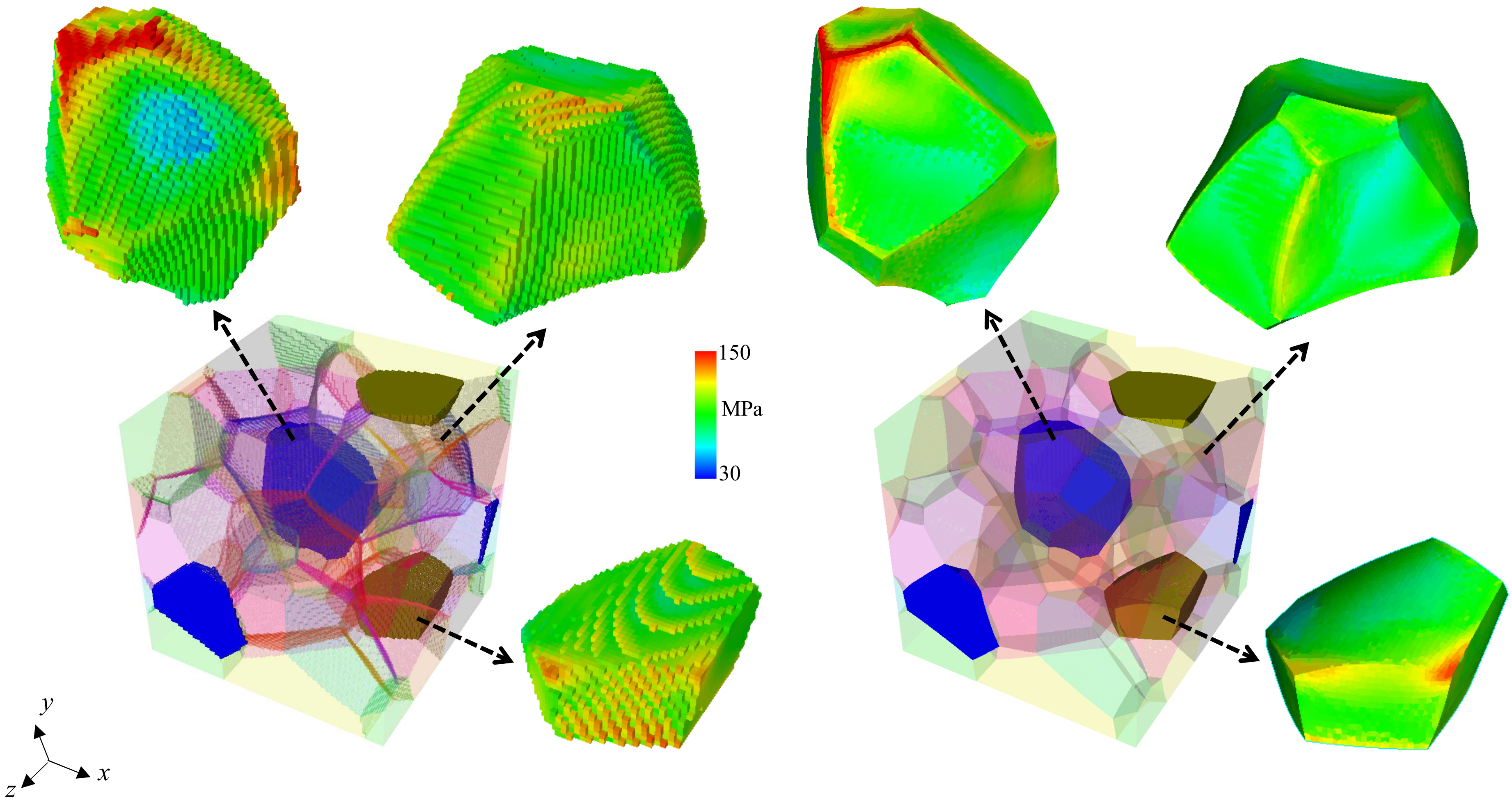
Phase Field

Voxelated Mesh

Sculpt Mesh

Hex Meshing Microstructures

Predicted von Mises stress fields



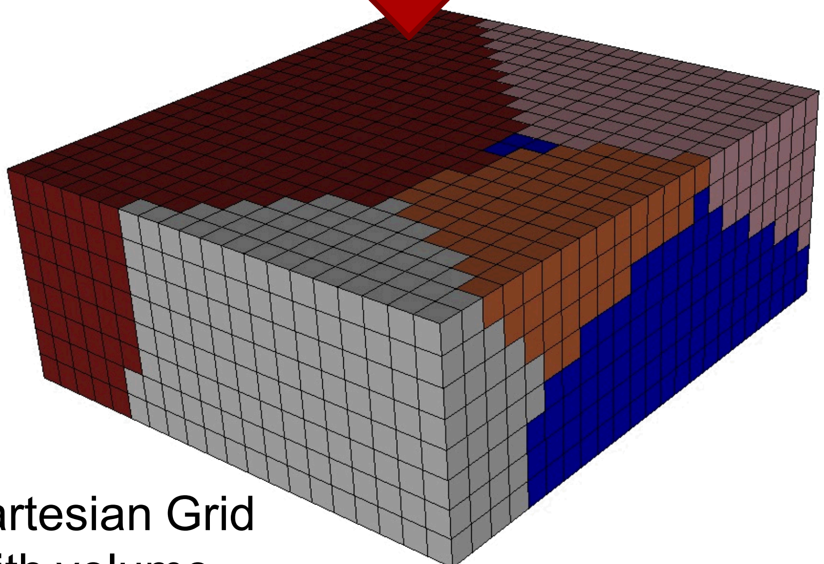
Voxelated Mesh

Sculpt Mesh

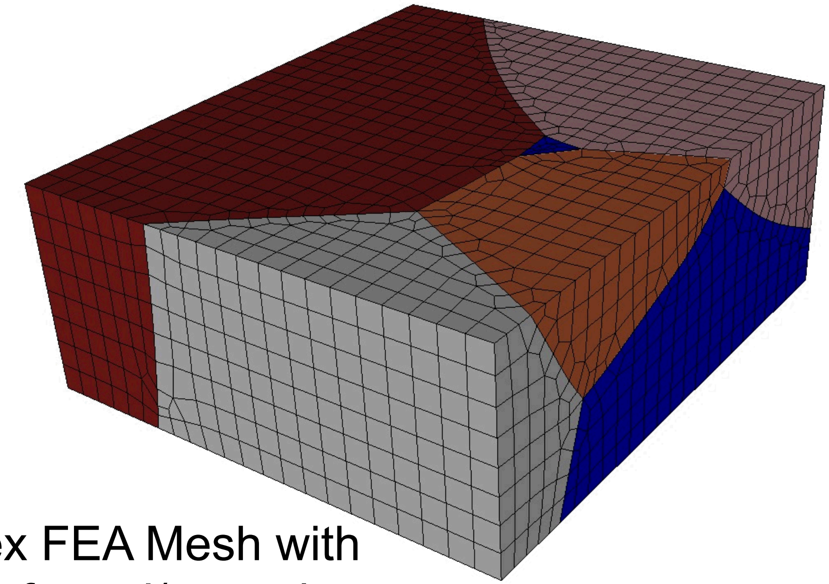
Hex Meshing Microstructures

```
TITLE = triple line system
VARIABLES = x y z, phi_1, phi_2, phi_3
ZONE i = 2 , j = 2 , k = 2
0.0000     0.0000     0.0000     0.5000     0.5000     0.0000
1.0000     0.0000     0.0000     0.3333     0.3333     0.3334
0.0000     1.0000     0.0000     1.0000     0.0000     0.0000
1.0000     1.0000     0.0000     0.0000     1.0000     0.0000
0.0000     0.0000     1.0000     0.2000     0.4000     0.4000
1.0000     0.0000     1.0000     0.6000     0.1000     0.3000
0.0000     1.0000     1.0000     0.0000     0.0000     1.0000
1.0000     1.0000     1.0000     0.9000     0.0000     0.1000
```

Microstructures volume fractions file (ascii)

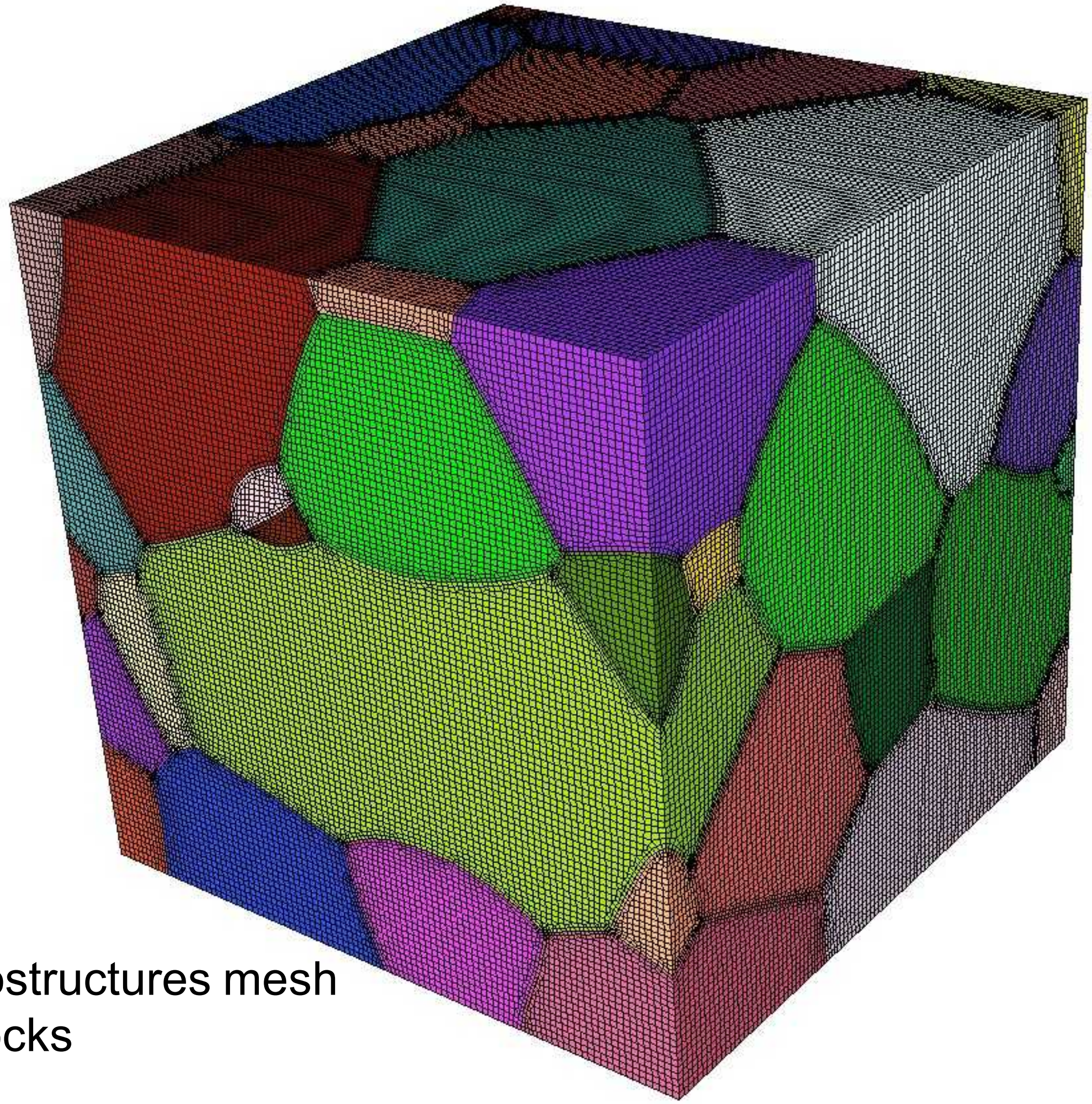


Cartesian Grid With volume fraction scalar fields



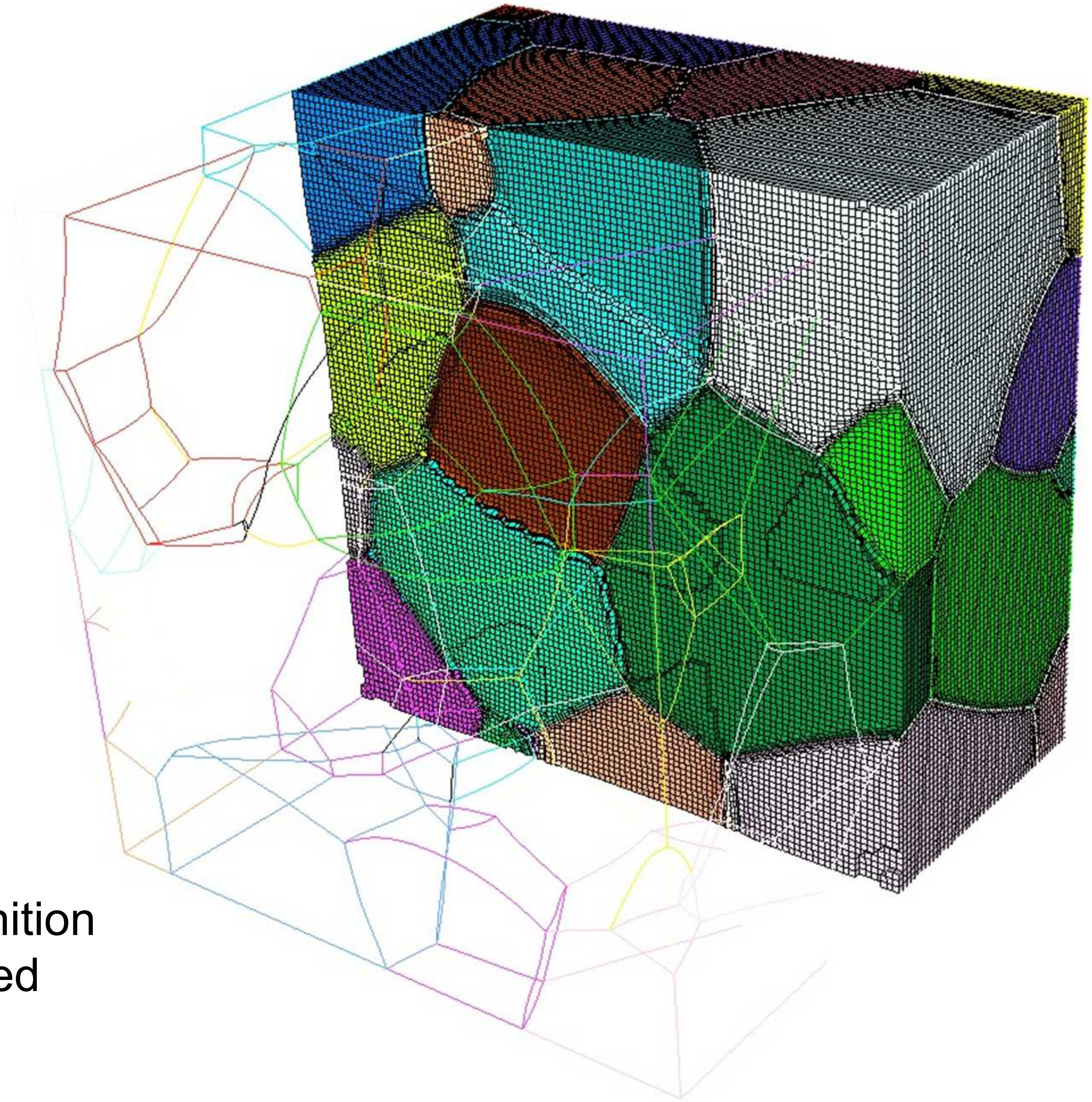
Hex FEA Mesh with conformal/smooth interfaces

Hex Meshing Microstructures



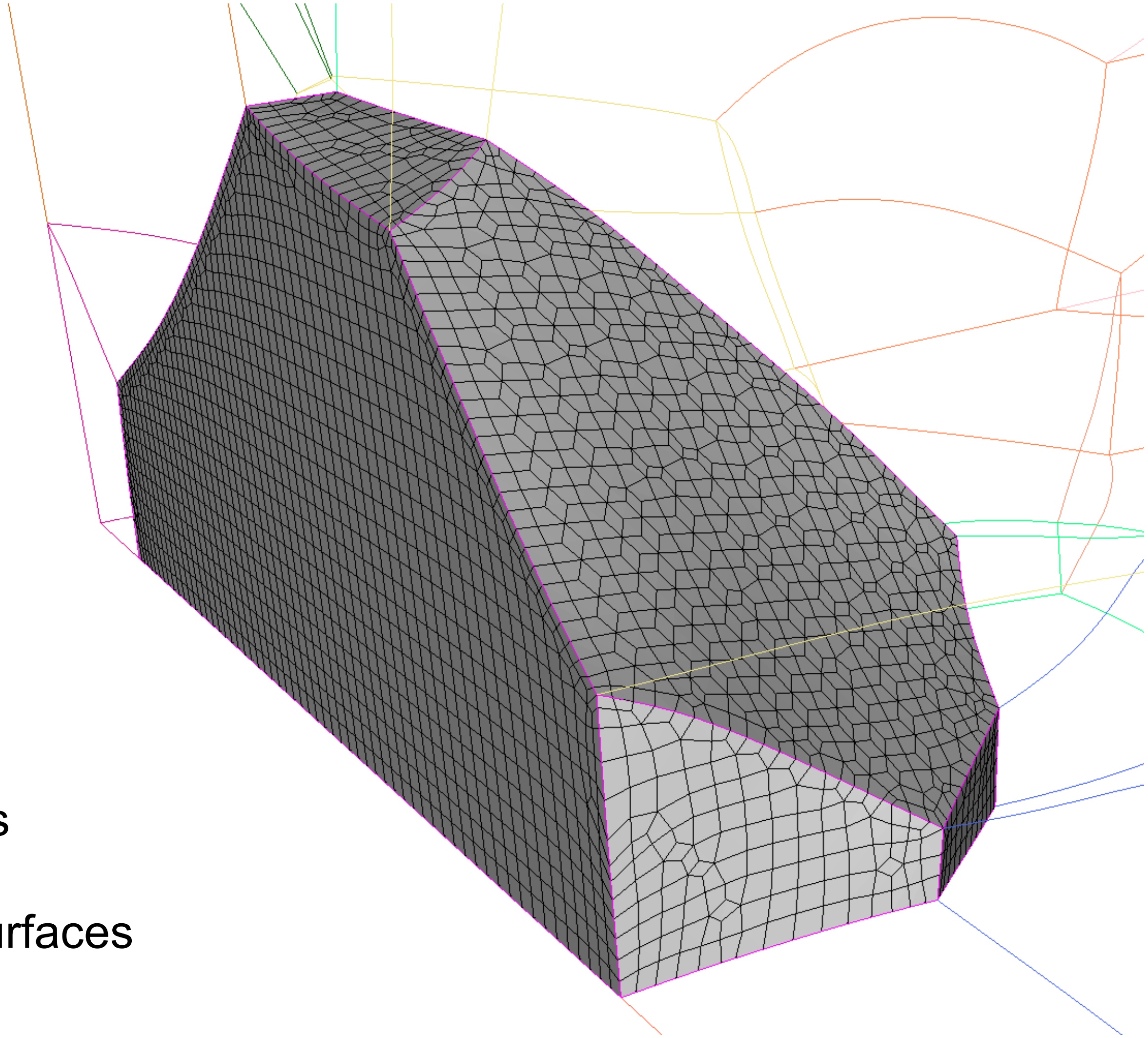
Example Microstructures mesh
16 material blocks
1.35M hexes

Hex Meshing Microstructures



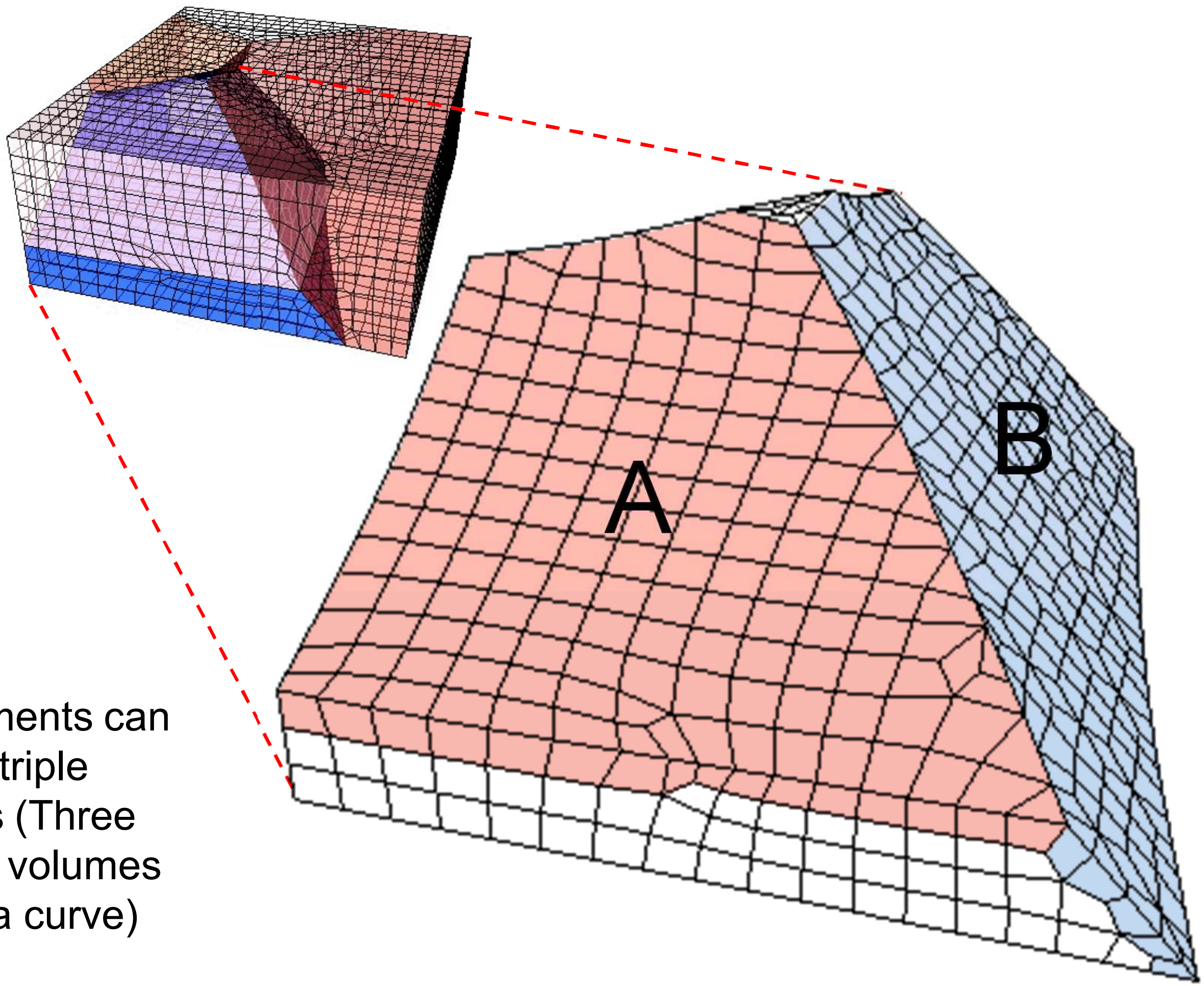
Geometry definition (B-rep) extracted from Interface reconstruction

Hex Meshing Microstructures



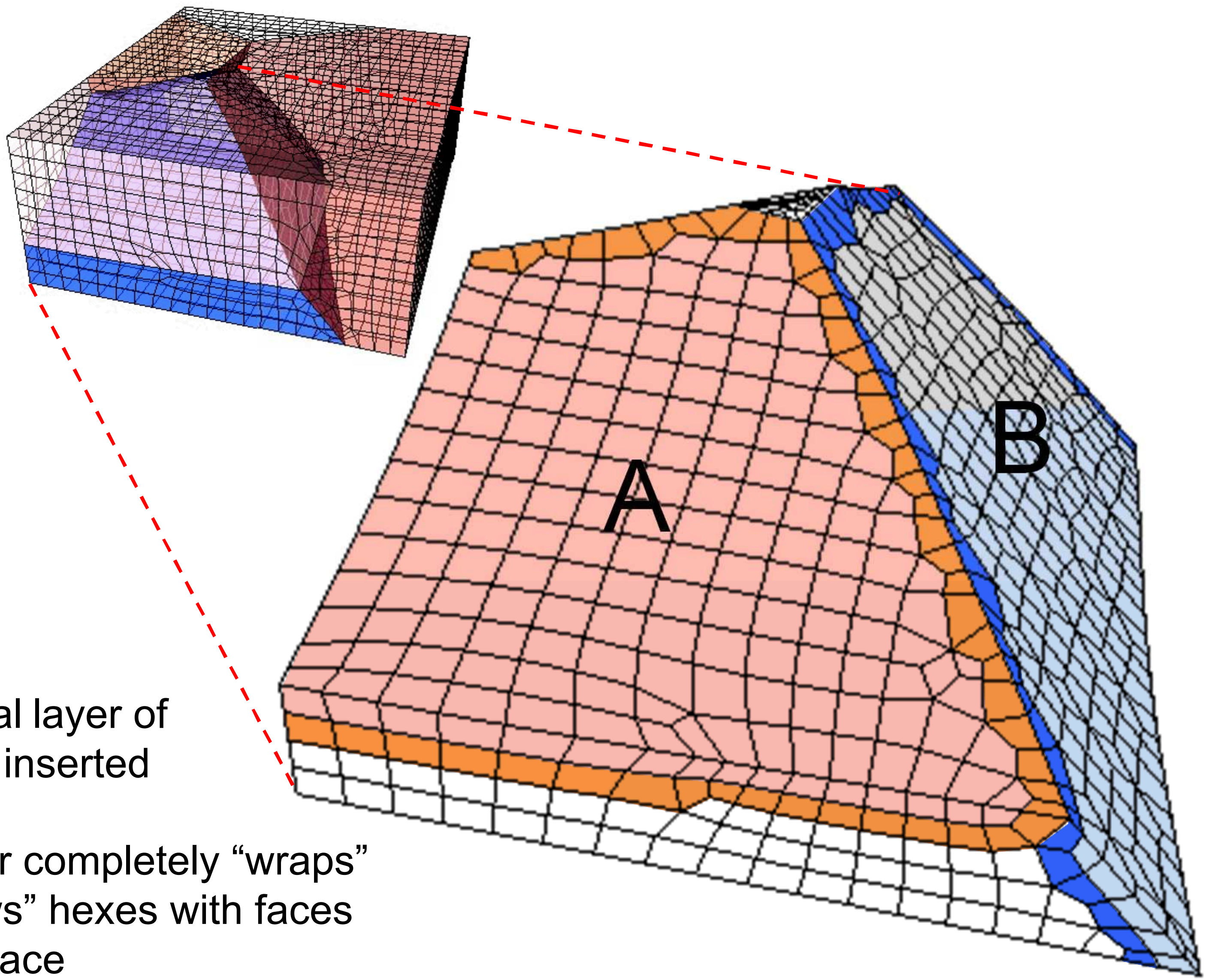
Boundary hexes inserted, nodes smoothed on surfaces and volumes

Hex Meshing Microstructures



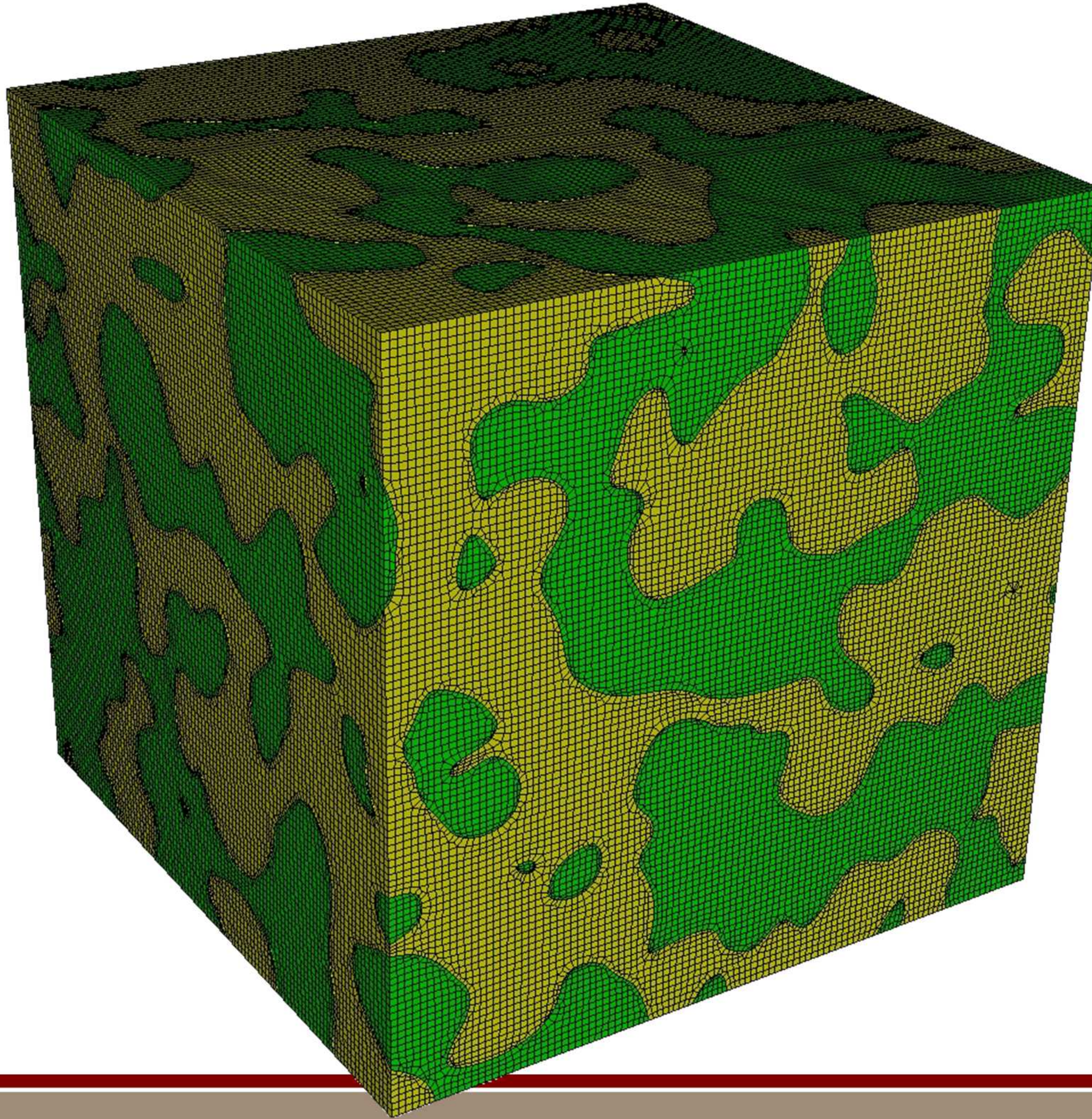
Bad elements can result at triple junctions (Three adjacent volumes meet at a curve)

Hex Meshing Microstructures



Additional layer of hexes is inserted

Hex layer completely "wraps" or "pillows" hexes with faces on a surface



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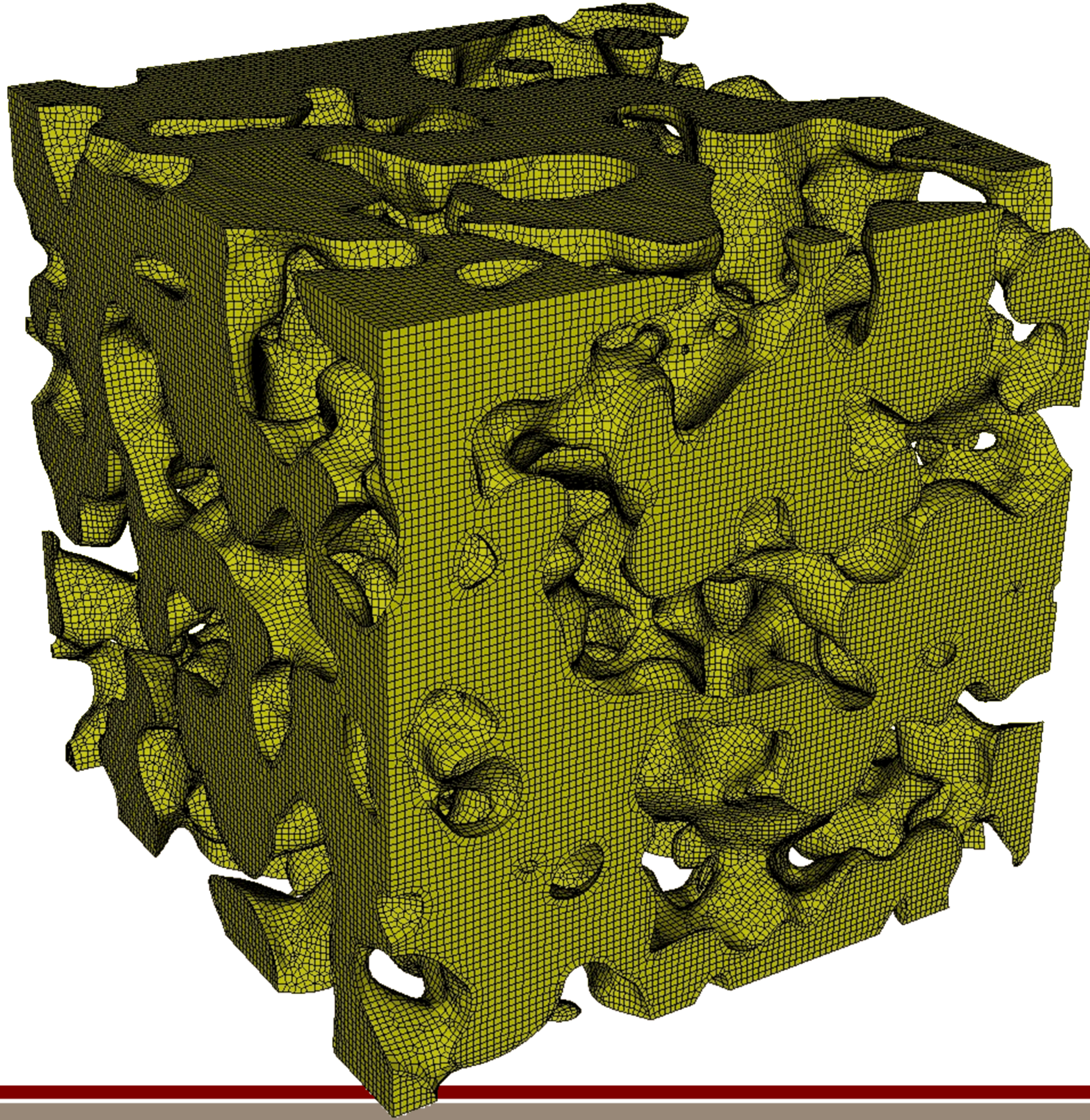
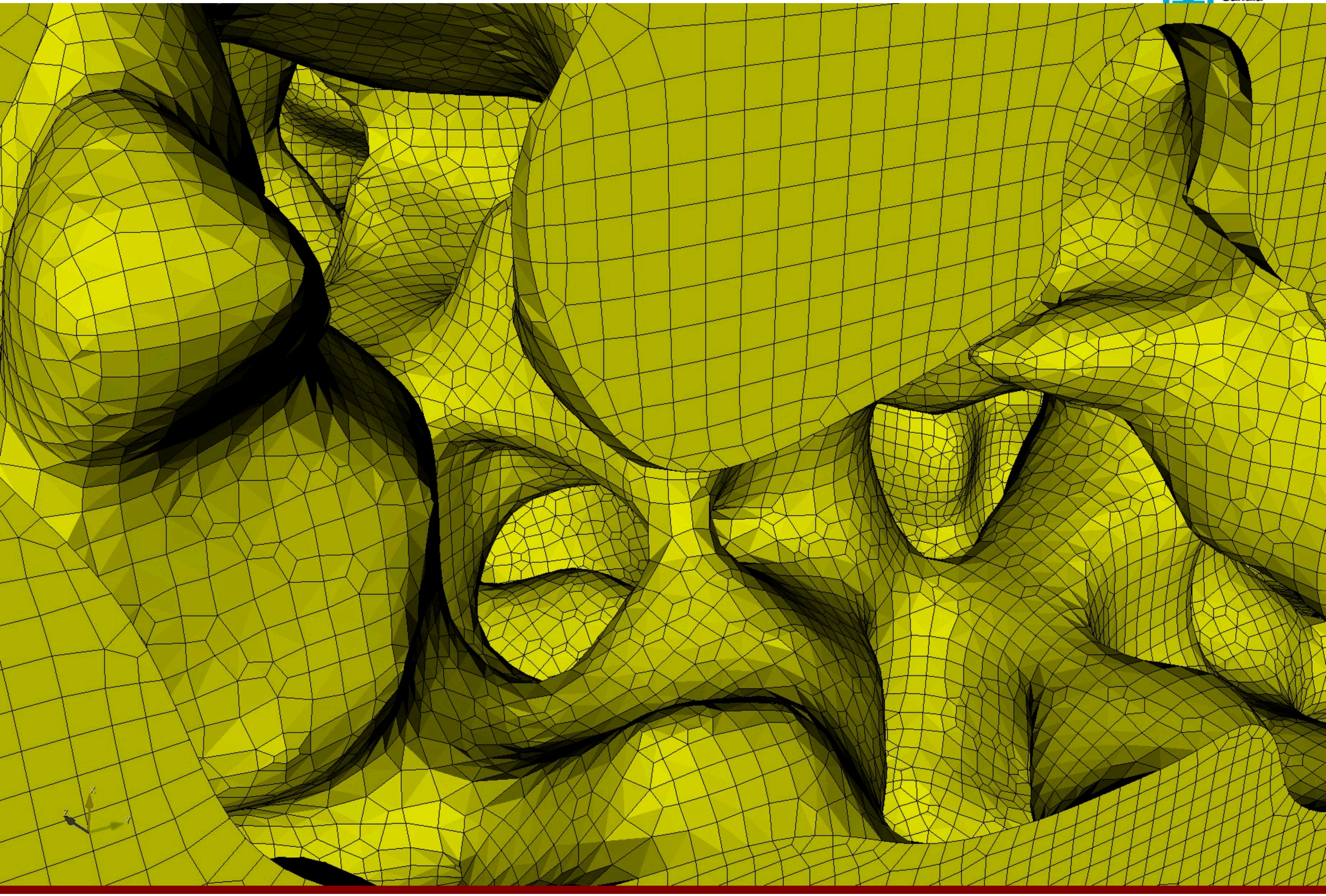
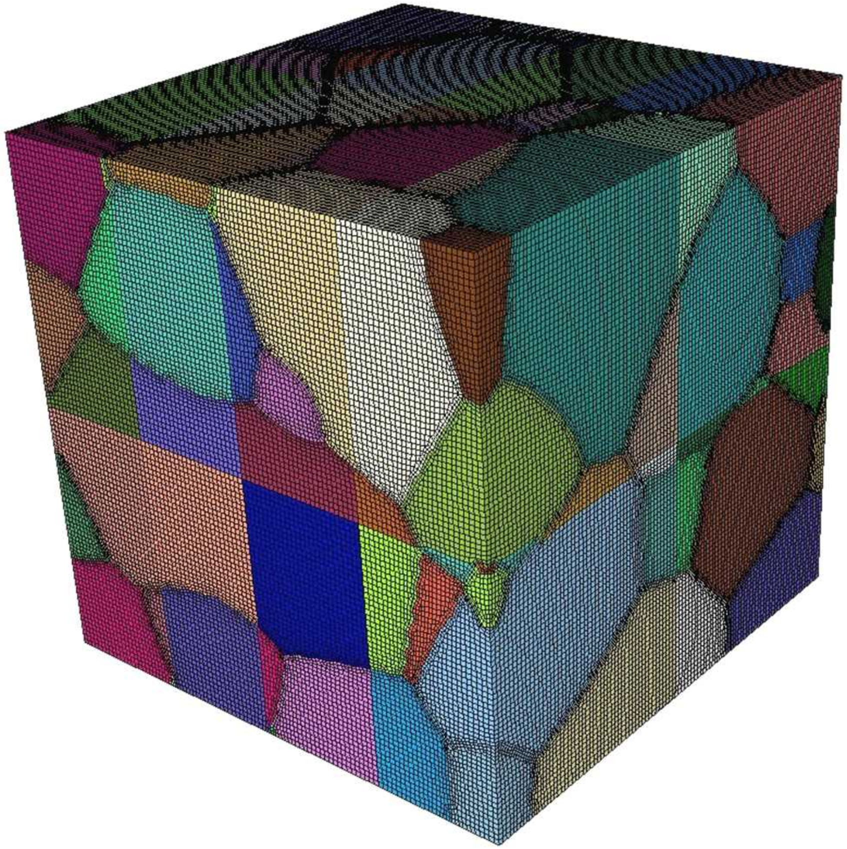


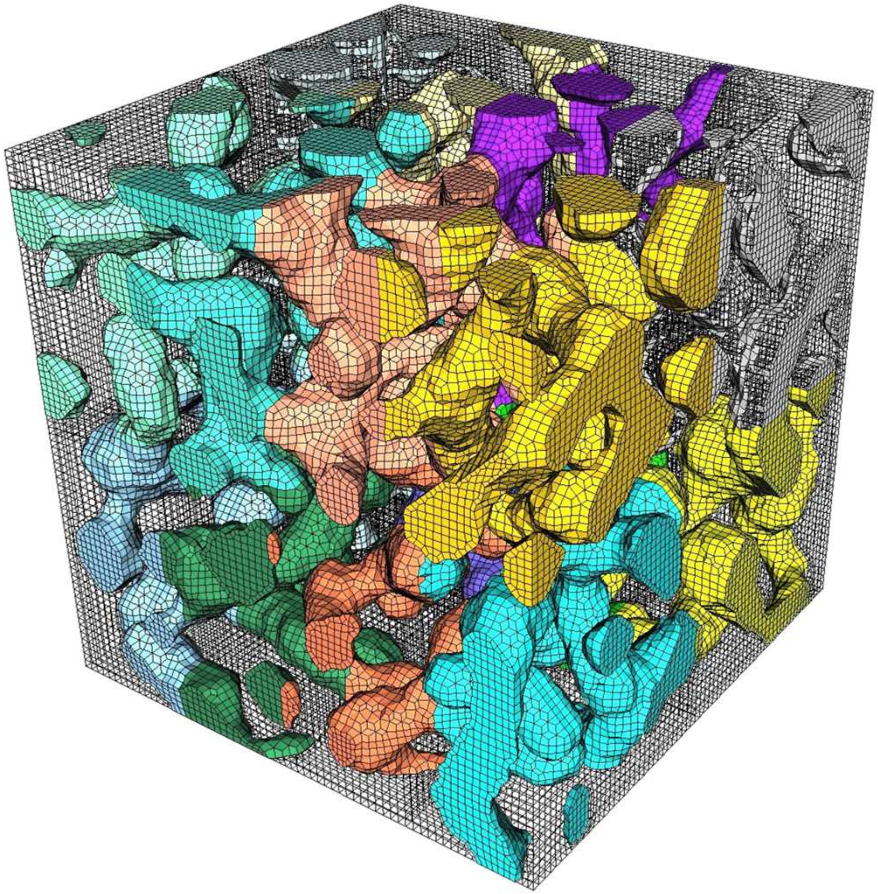


Hex Meshing Microstructures

Examples



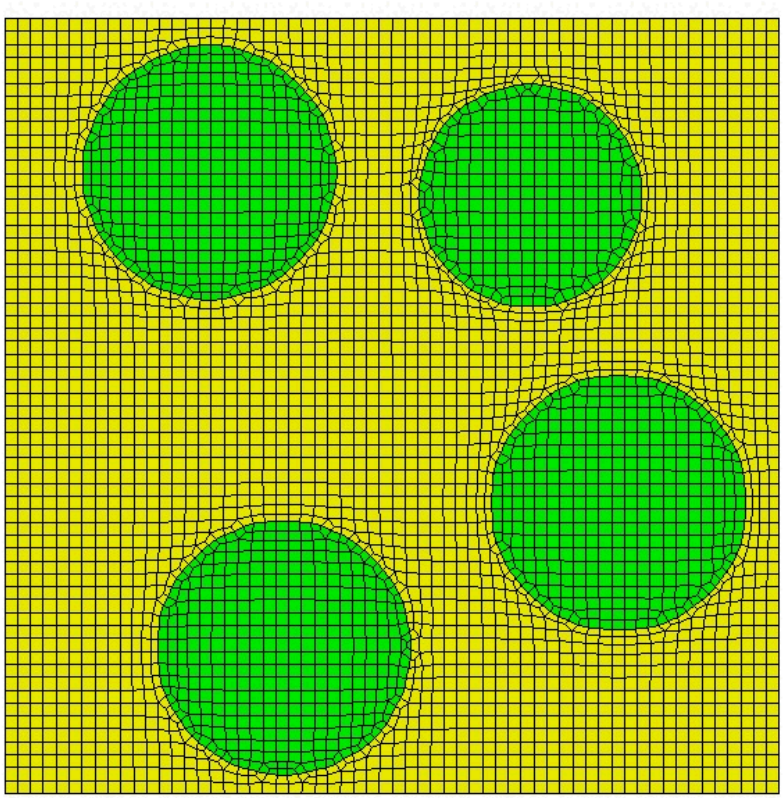
Microstructures with multiple unique volumes. 16 processors

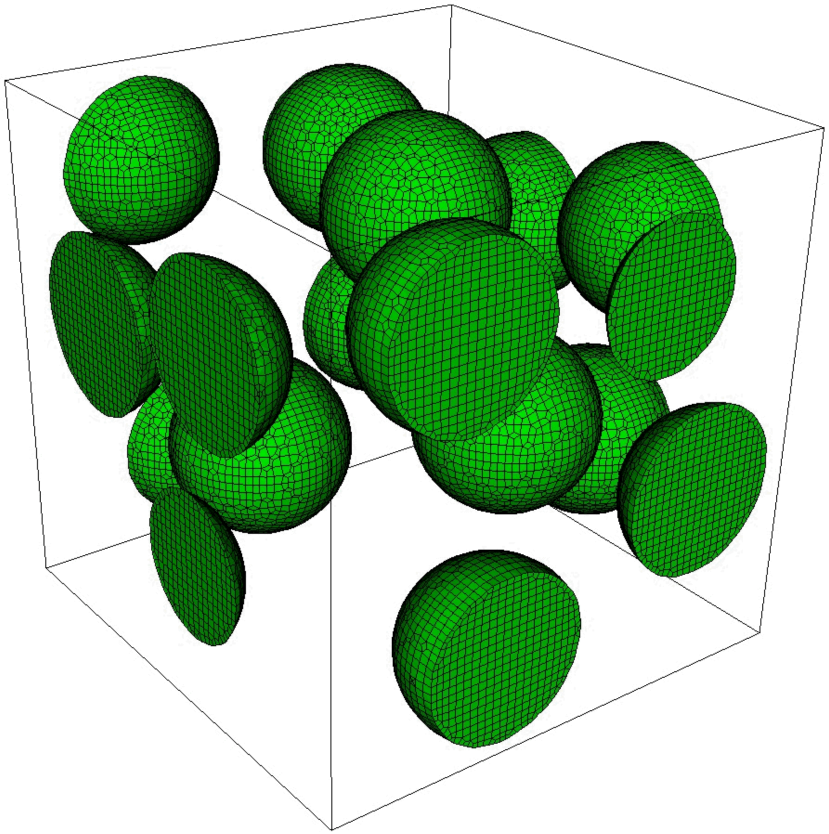


2 phase model. 16 processors

Example

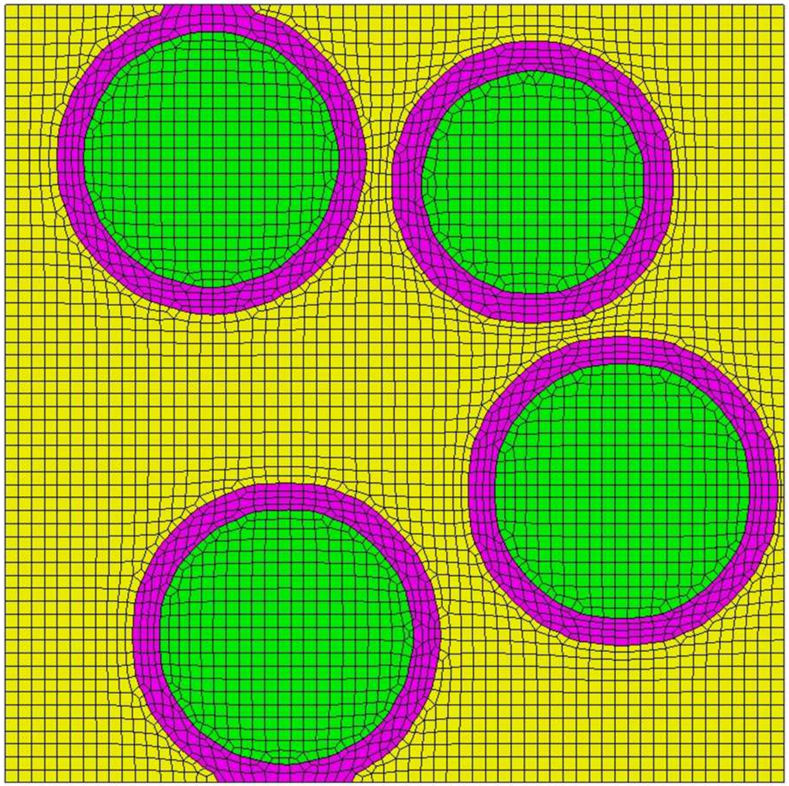
Spherical particles

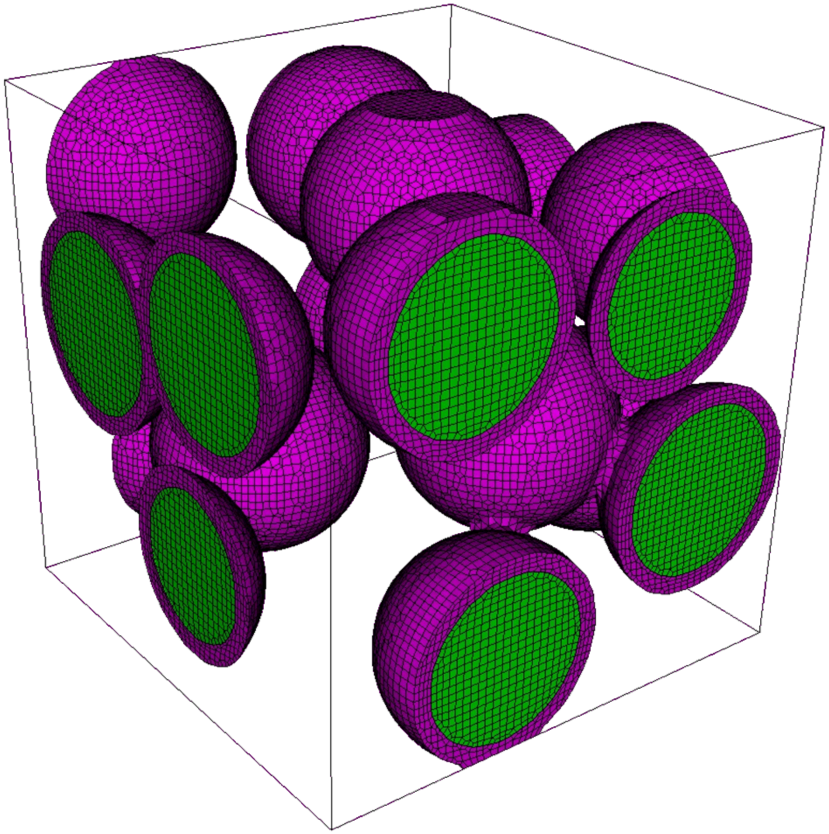




Example

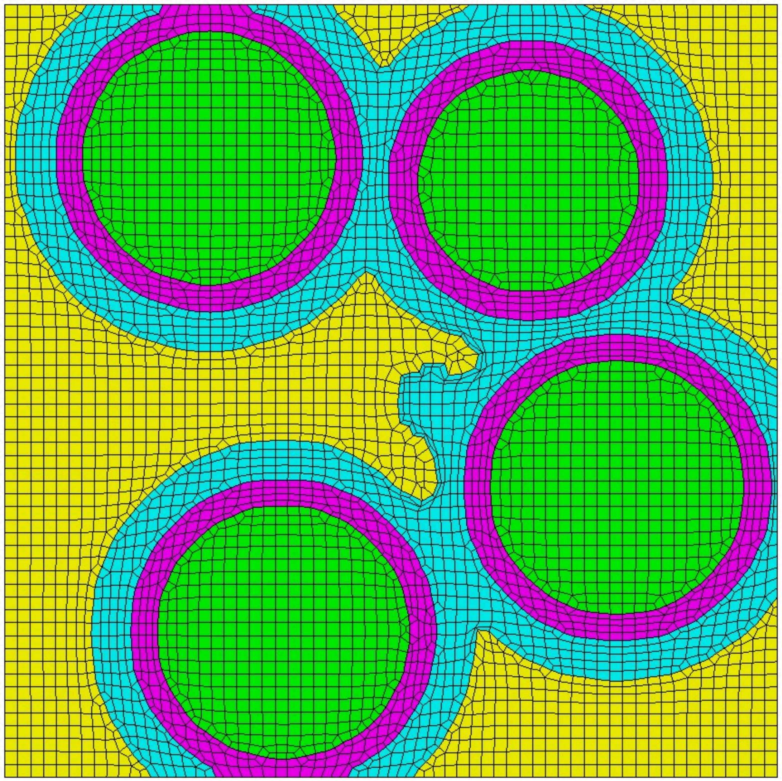
Spherical particles

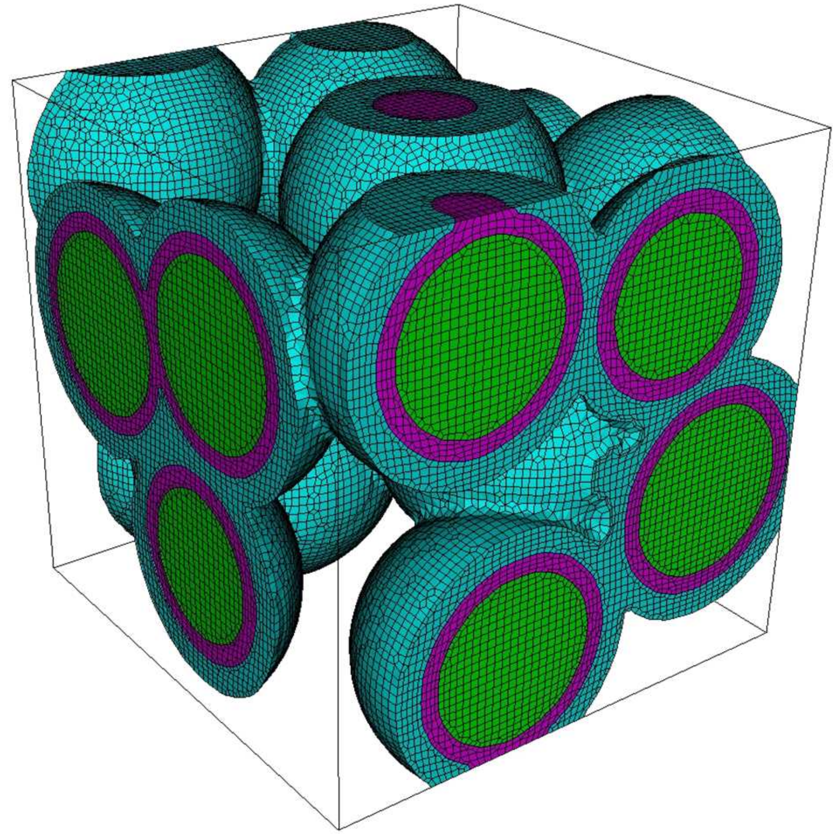




Example

Spherical particles





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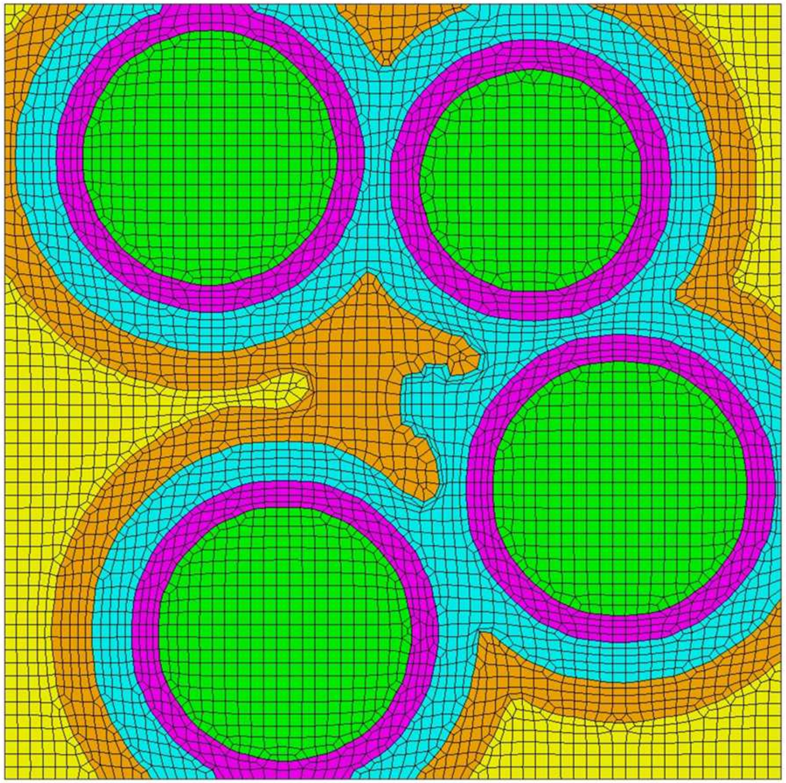

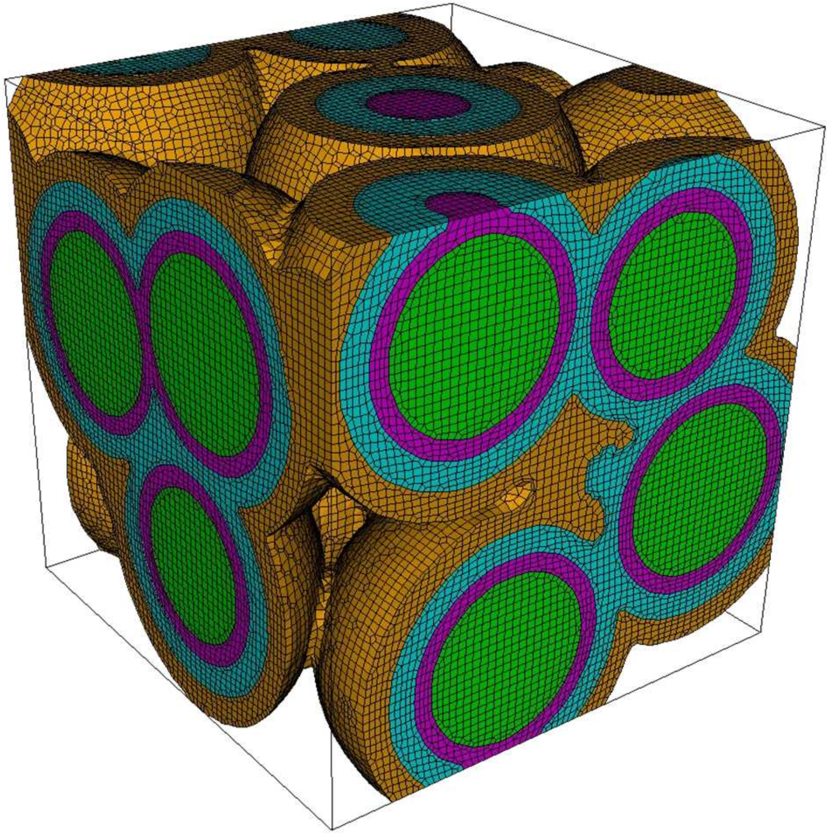

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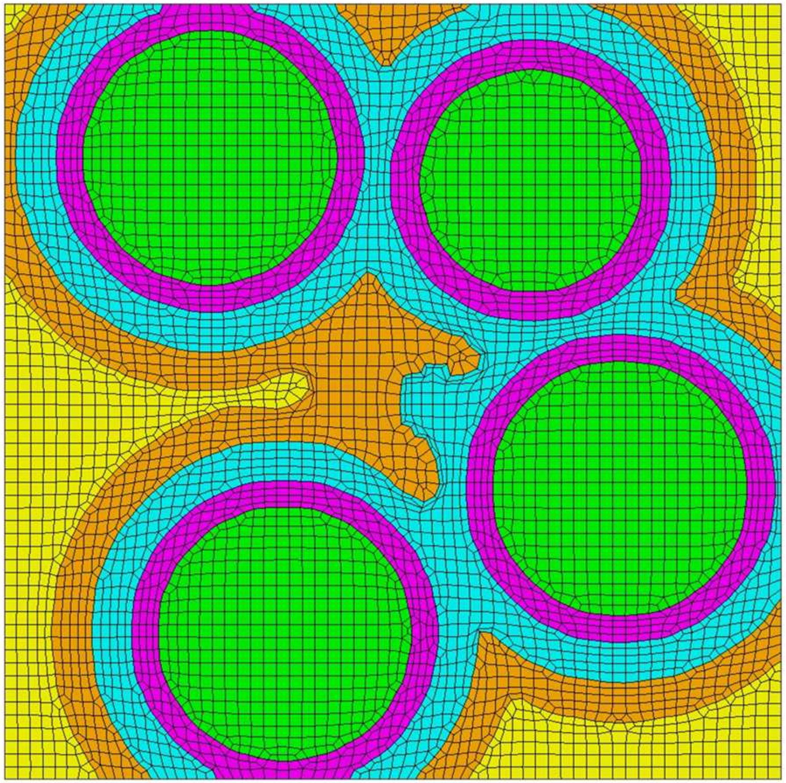
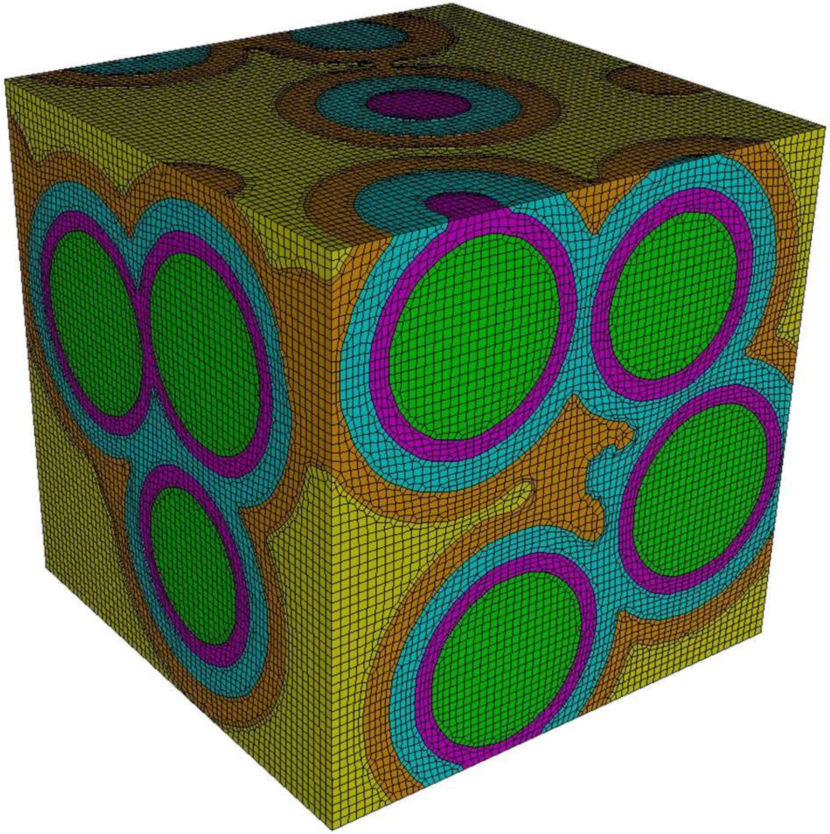
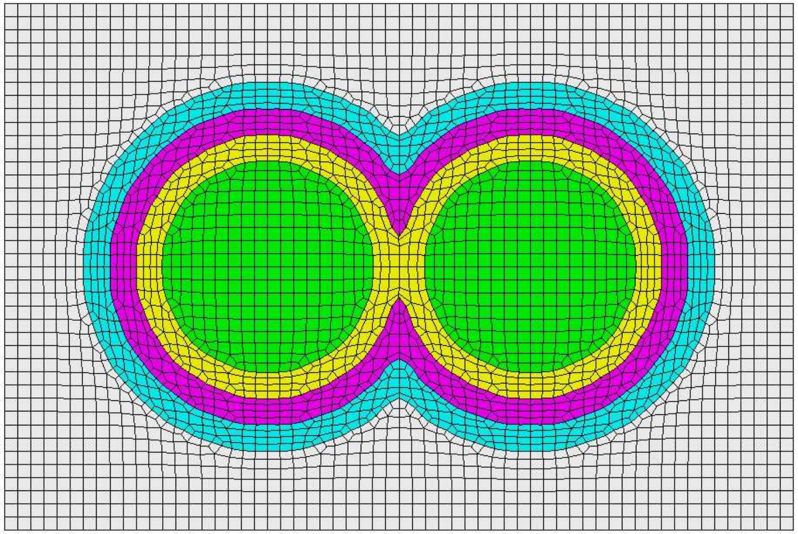
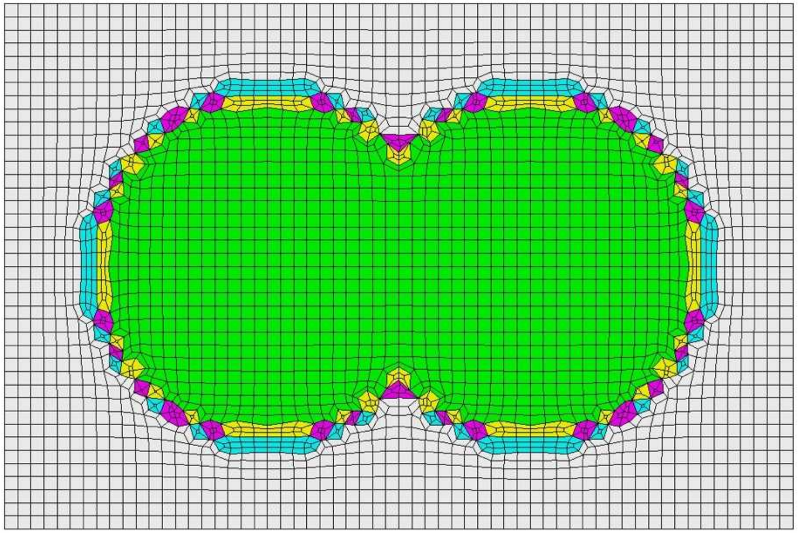




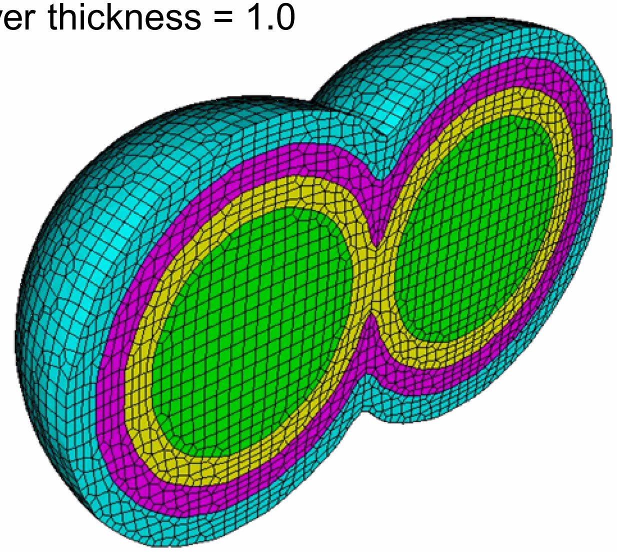
Resolving Features



Layer thickness = 1.0

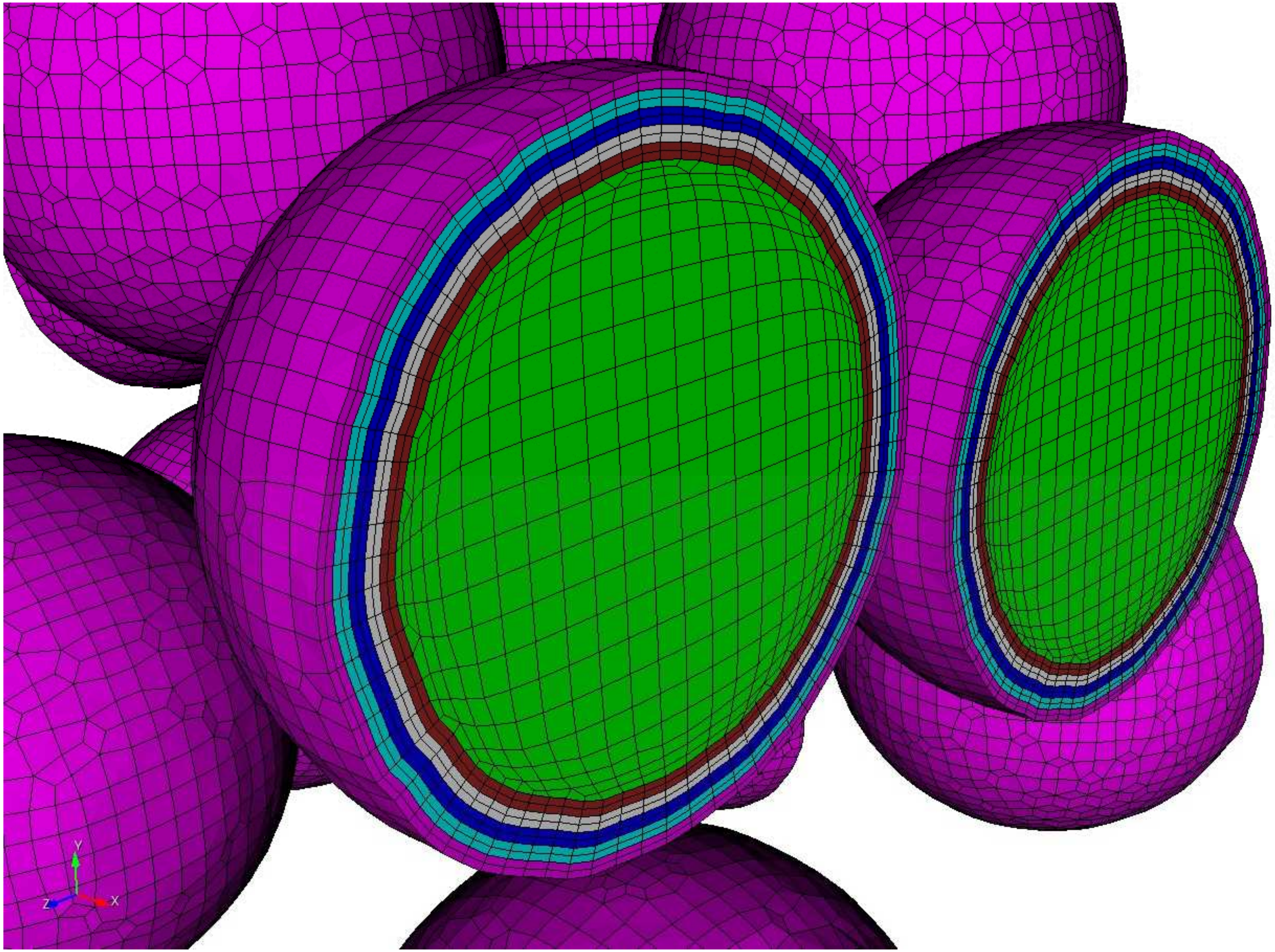


Layer thickness = 0.25



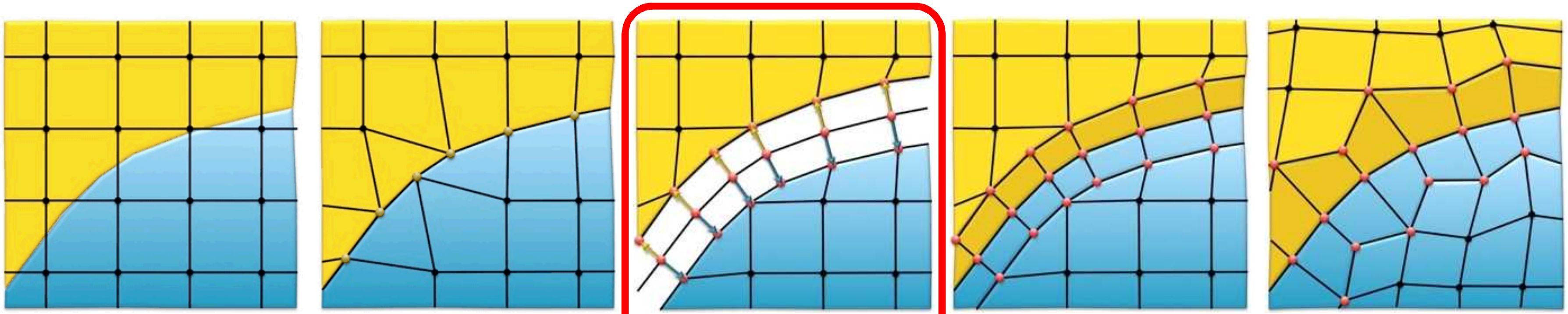
Features must be at least 2-3X the cell size or definition may be lost

Boundary Layer Insertion



Boundary Layer Insertion

Overlay Grid Procedure used by Sculpt



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Nearby nodes projected to boundaries

Mesh pulled away from the boundaries

And Layer of hexes inserted

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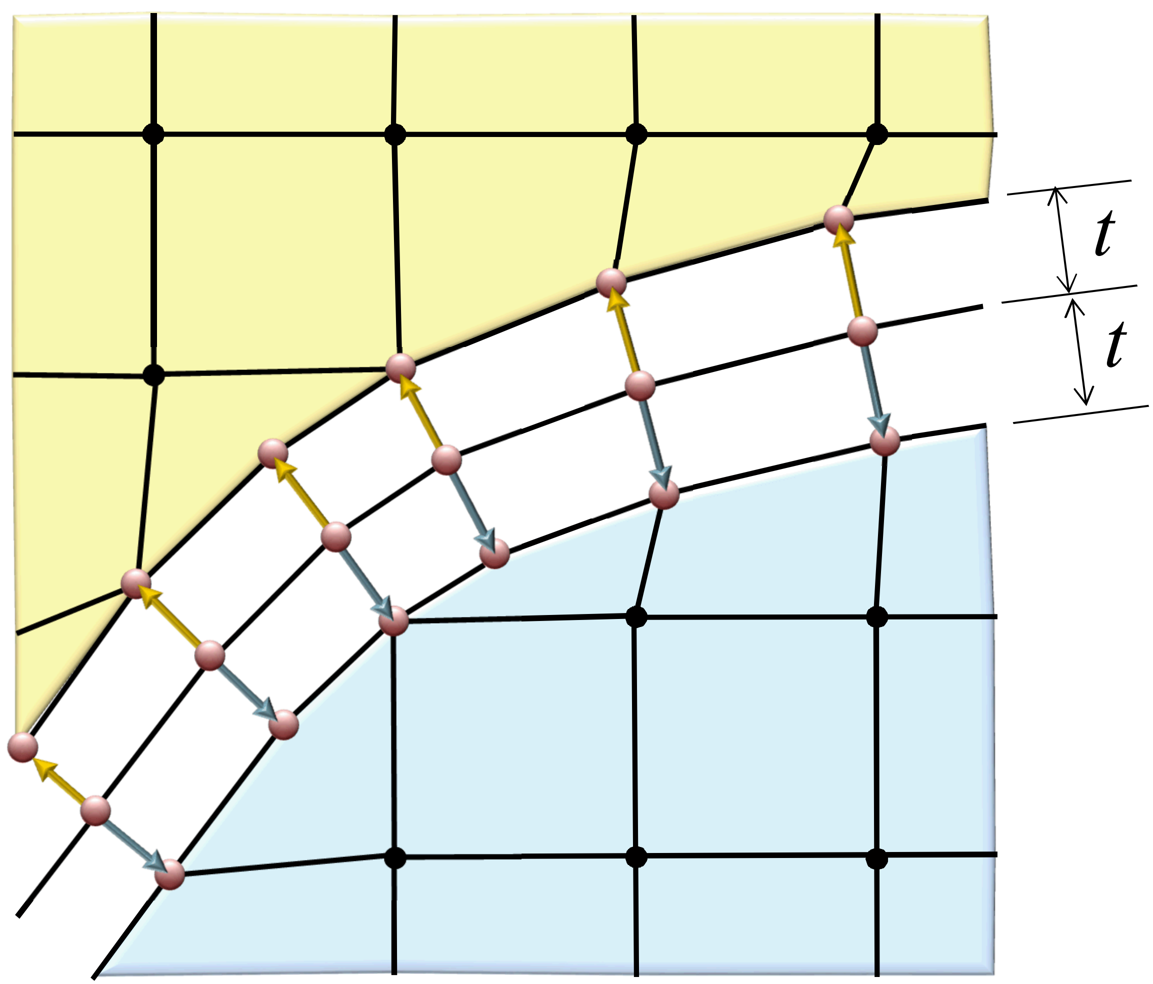
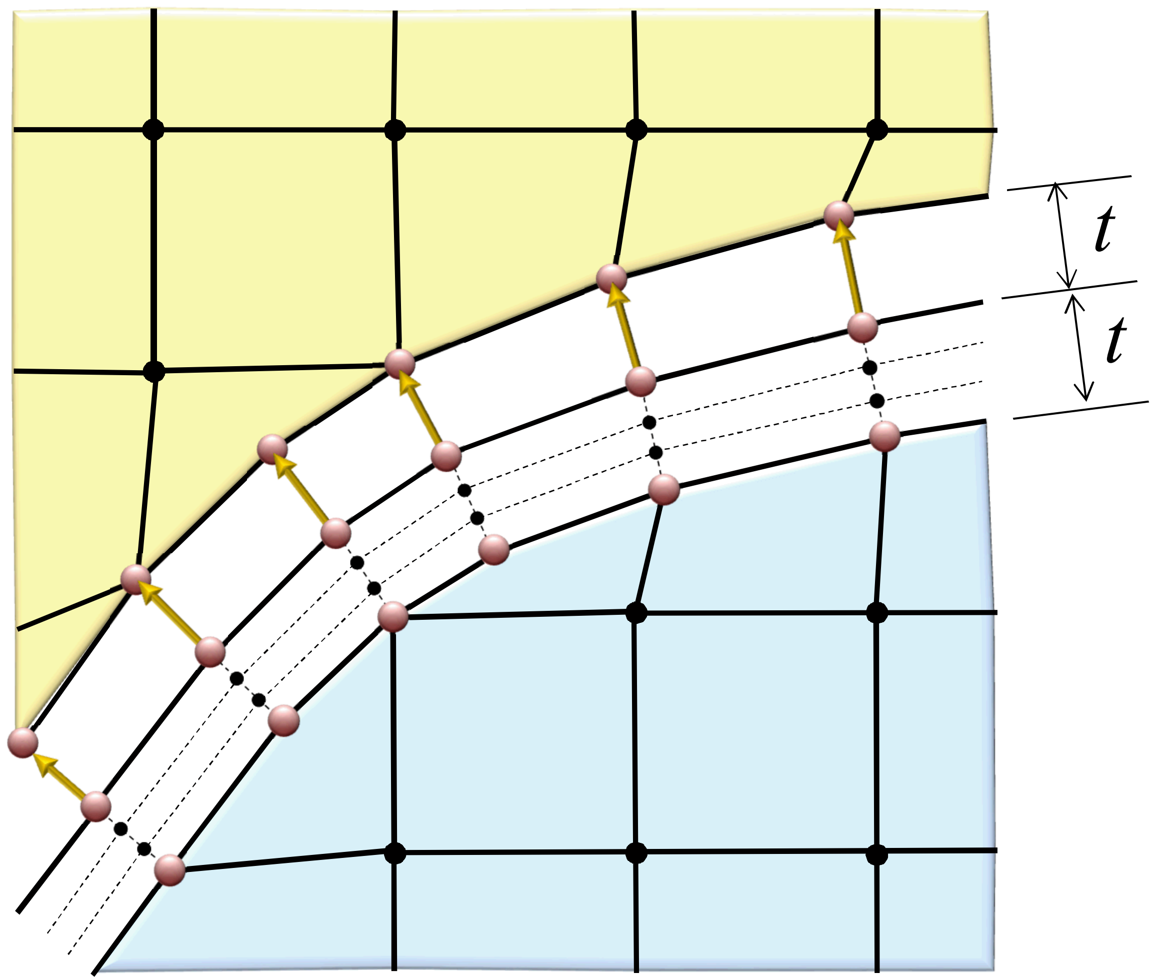


Boundary Layer Insertion



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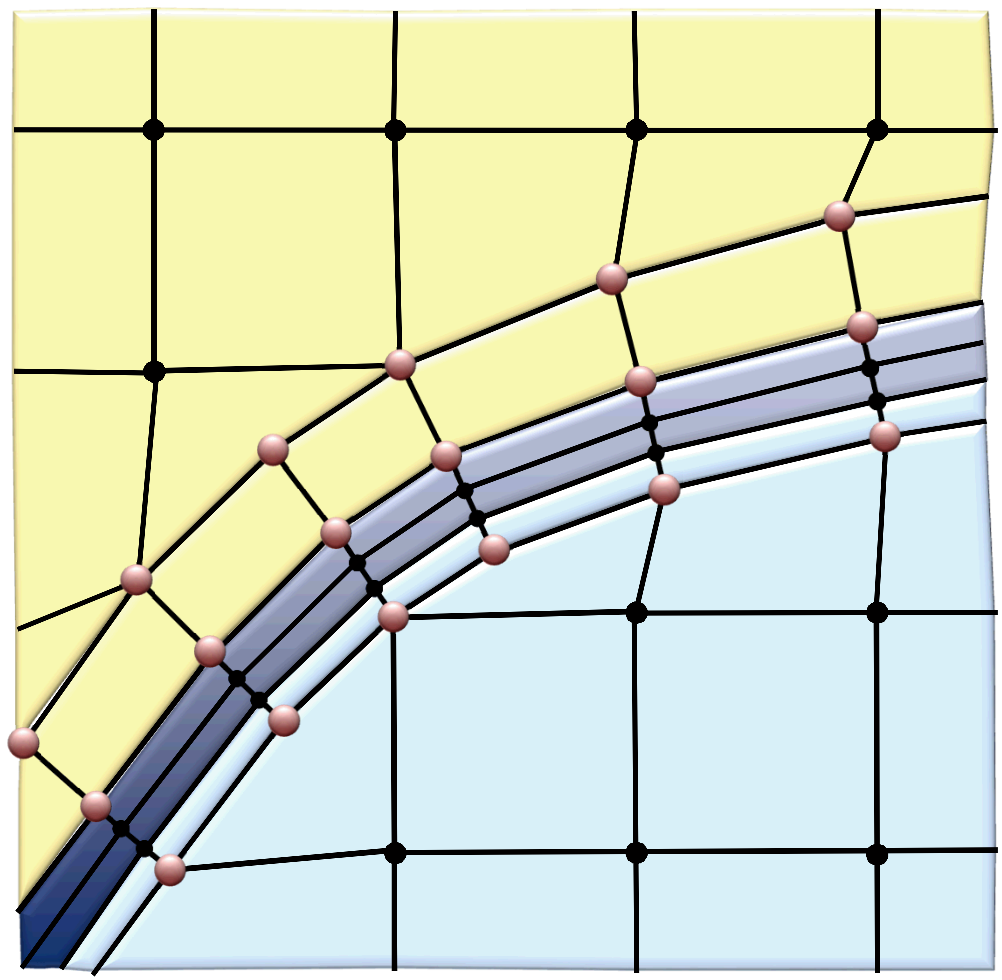

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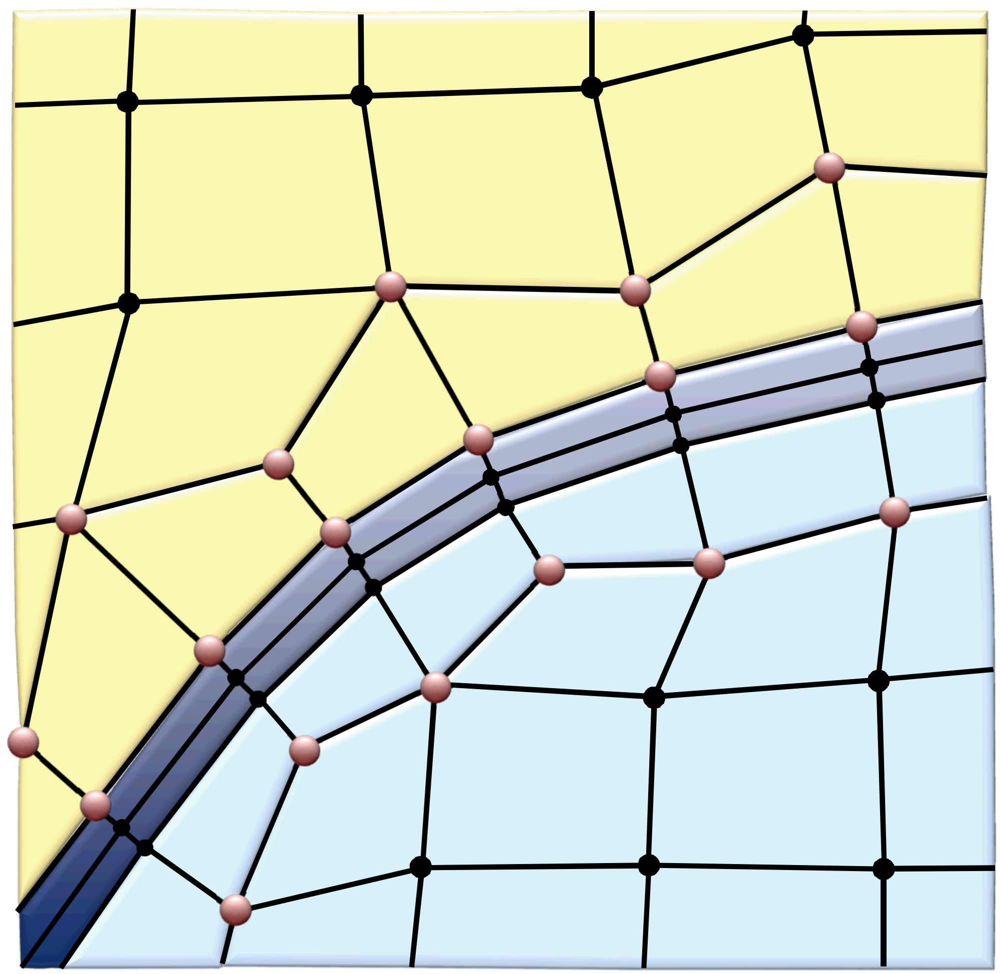
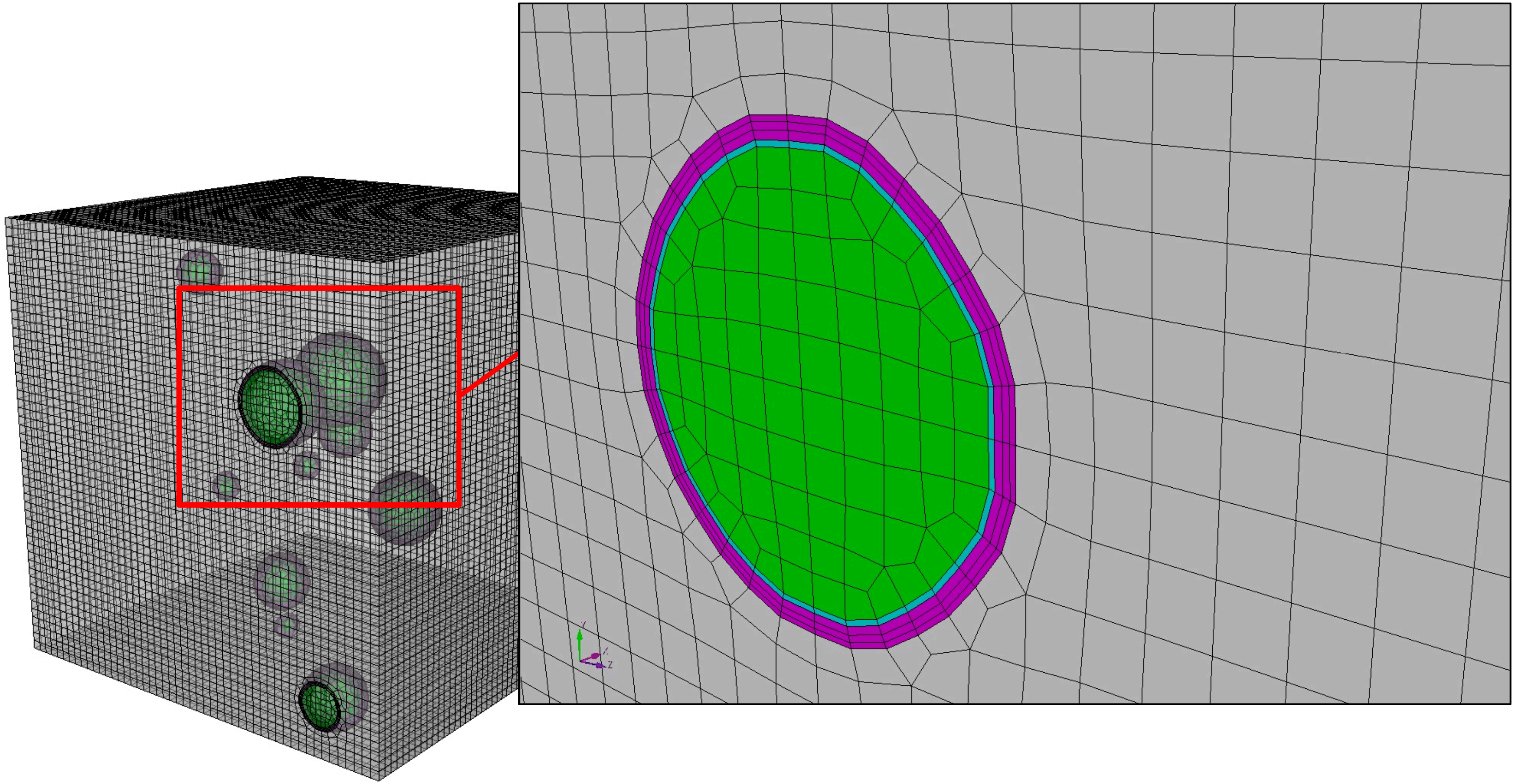
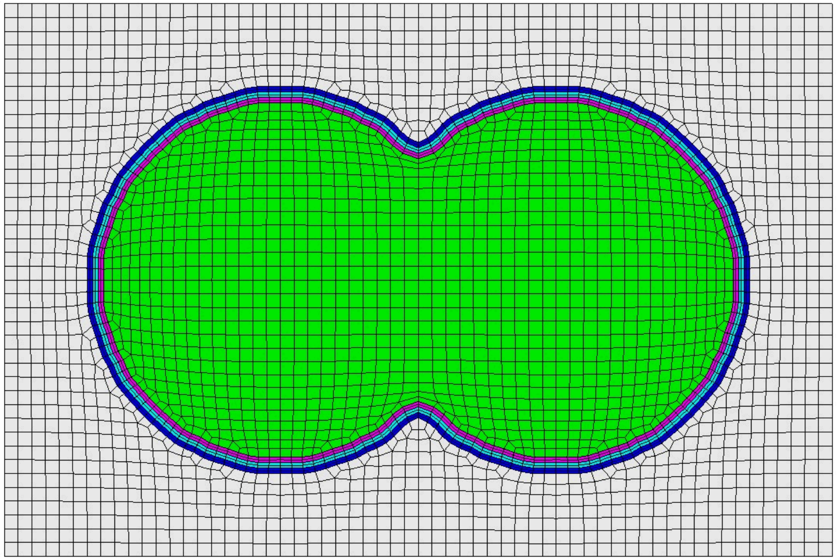


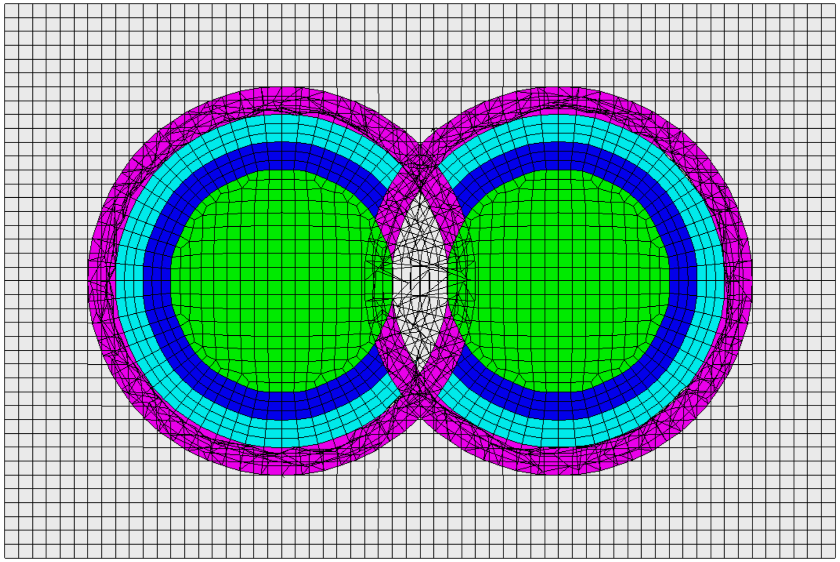
Boundary Layer Insertion



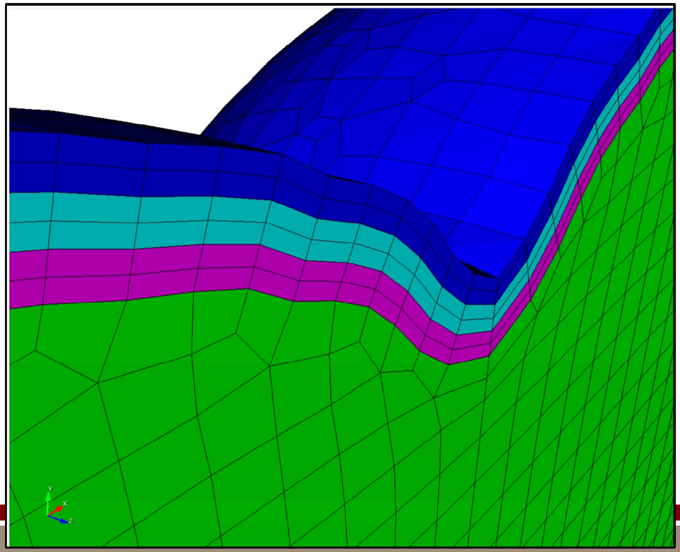
Boundary Layer Insertion



Valid mesh produced with multiple thin boundary layers



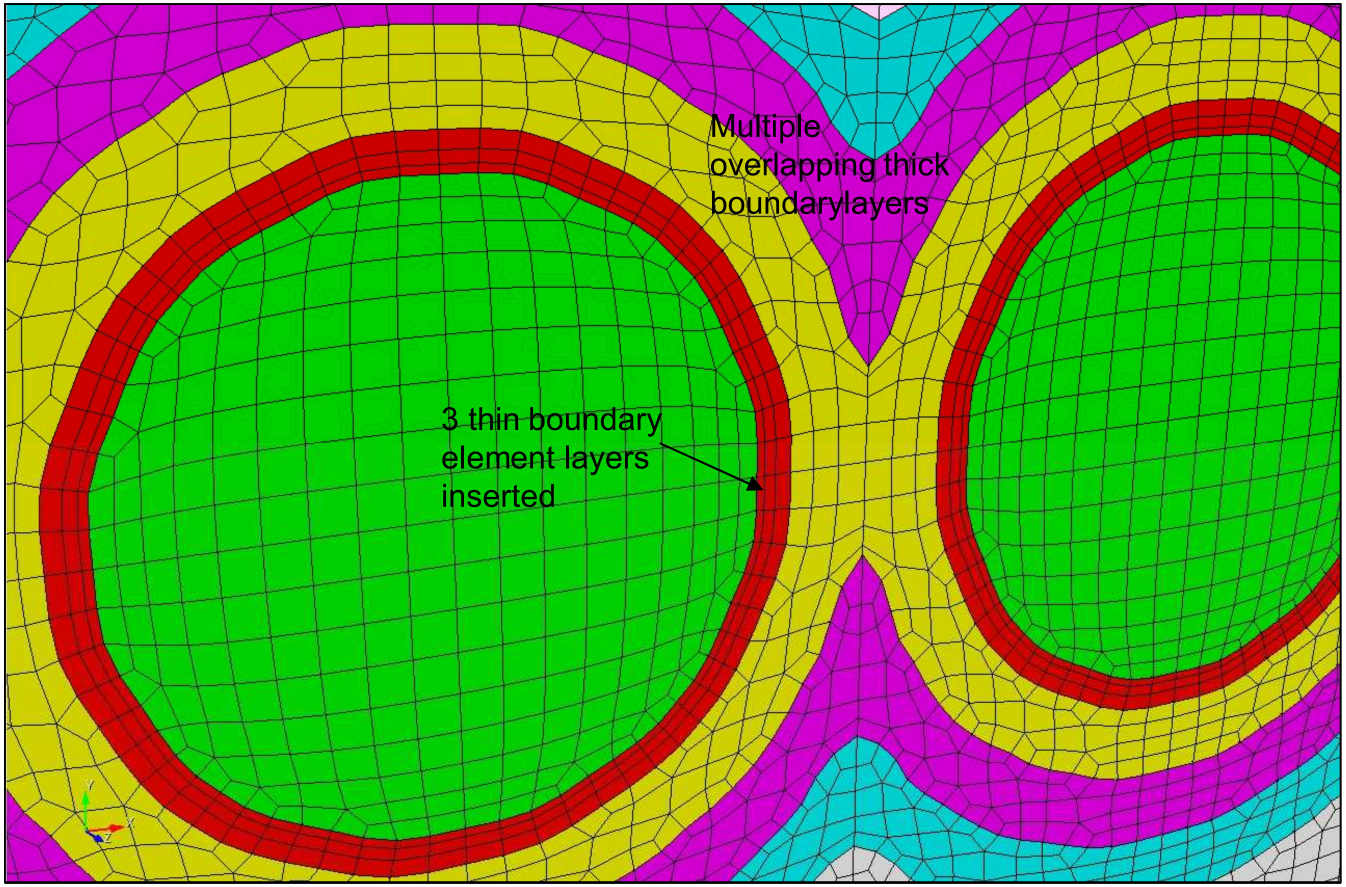
Invalid mesh shown with overlapping thick boundary layers



Not well suited to thick/overlapping layers

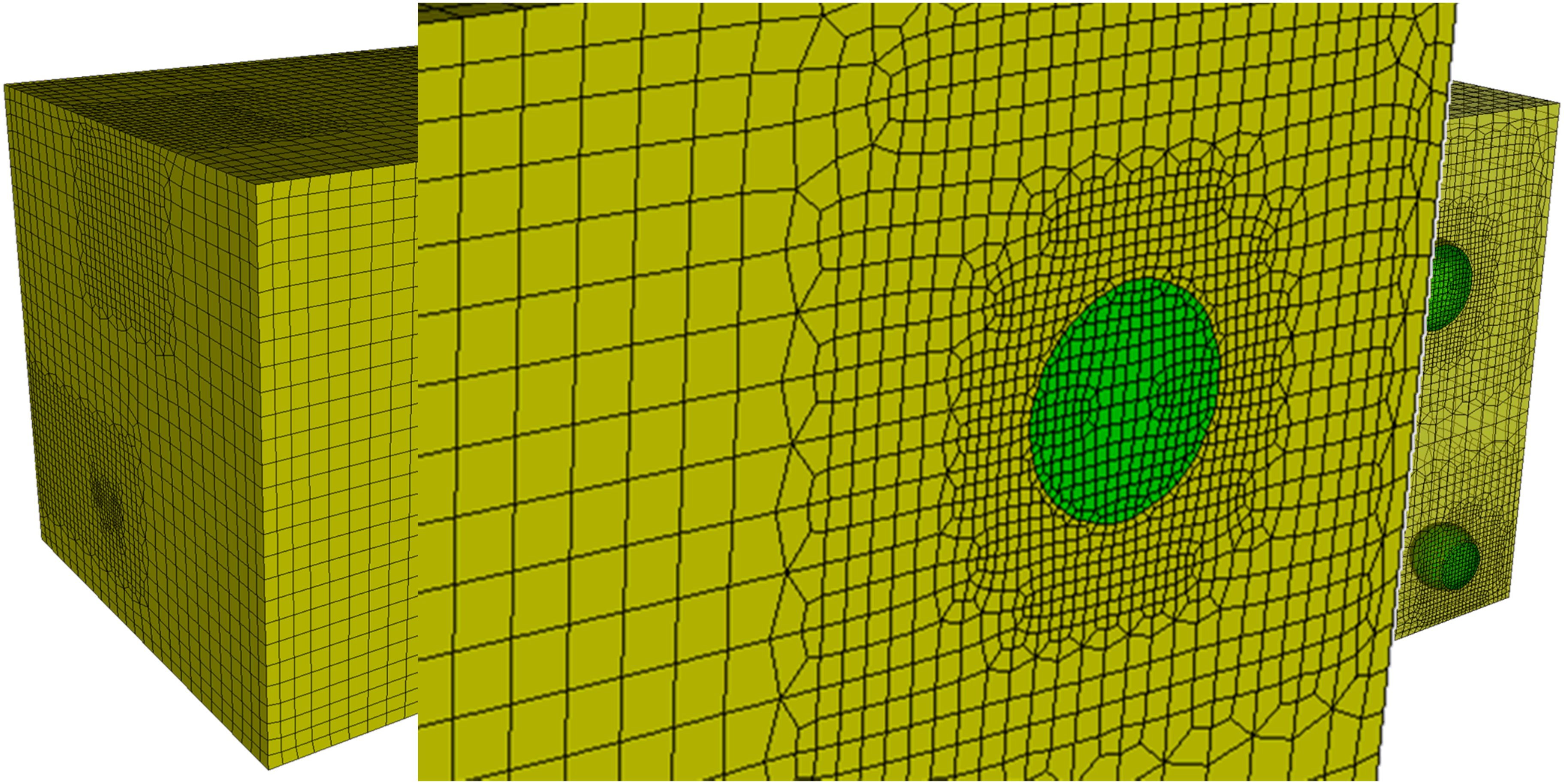
Requires significant smoothing to push away surrounding cells that are displaced by boundary layers

Boundary Layer Insertion

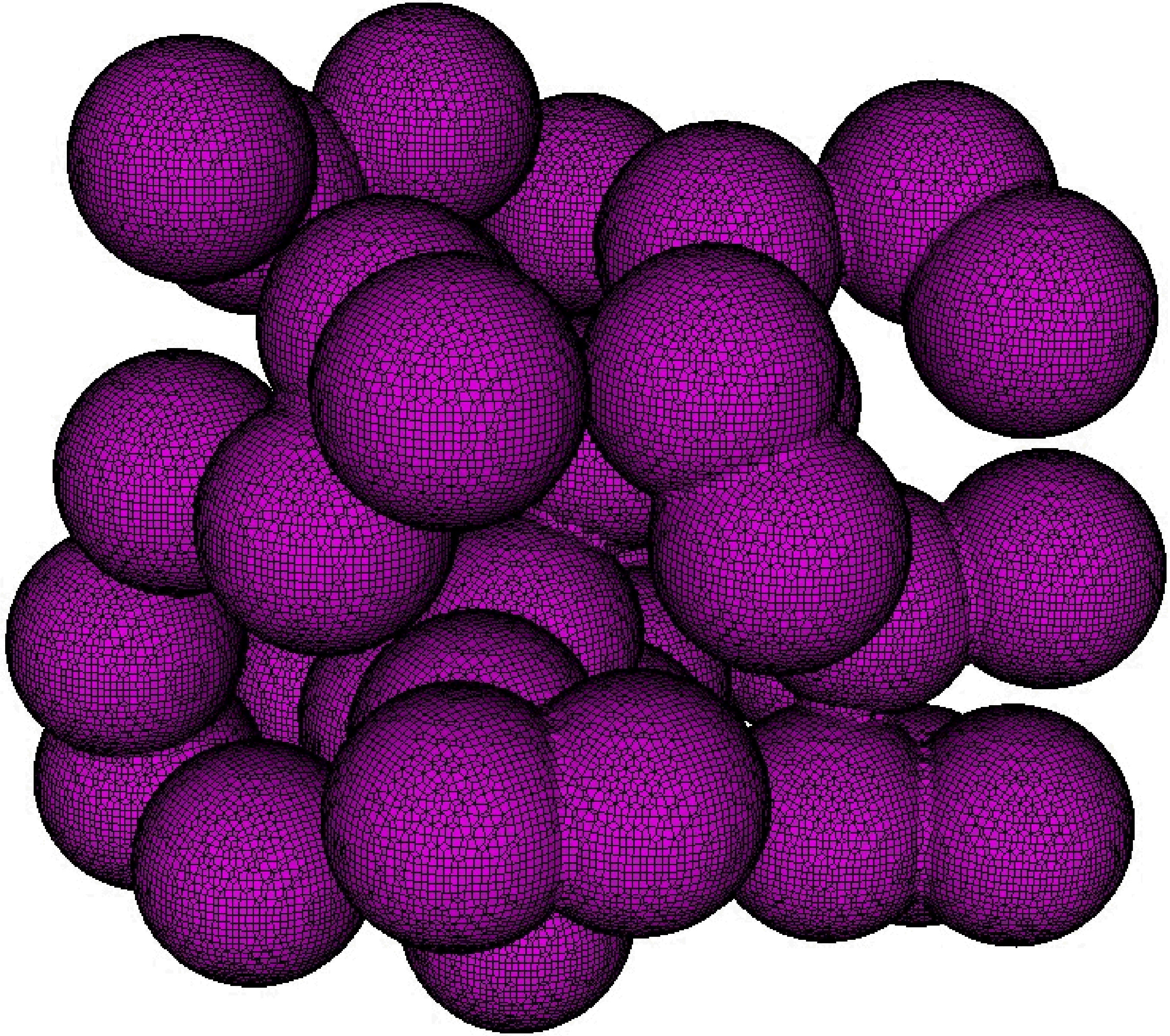


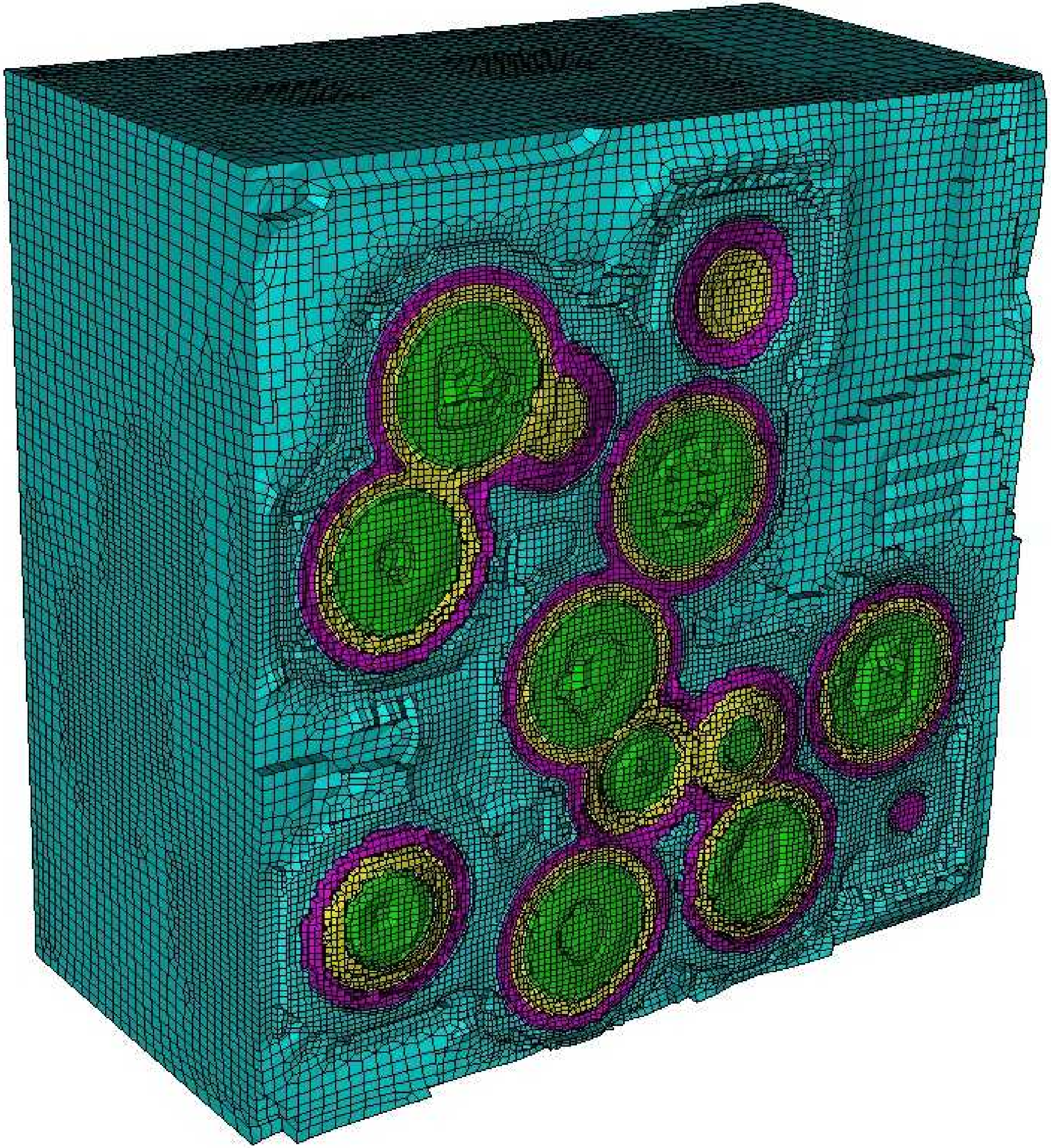
Thin boundary layers inserted with thicker layers built with interface reconstruction

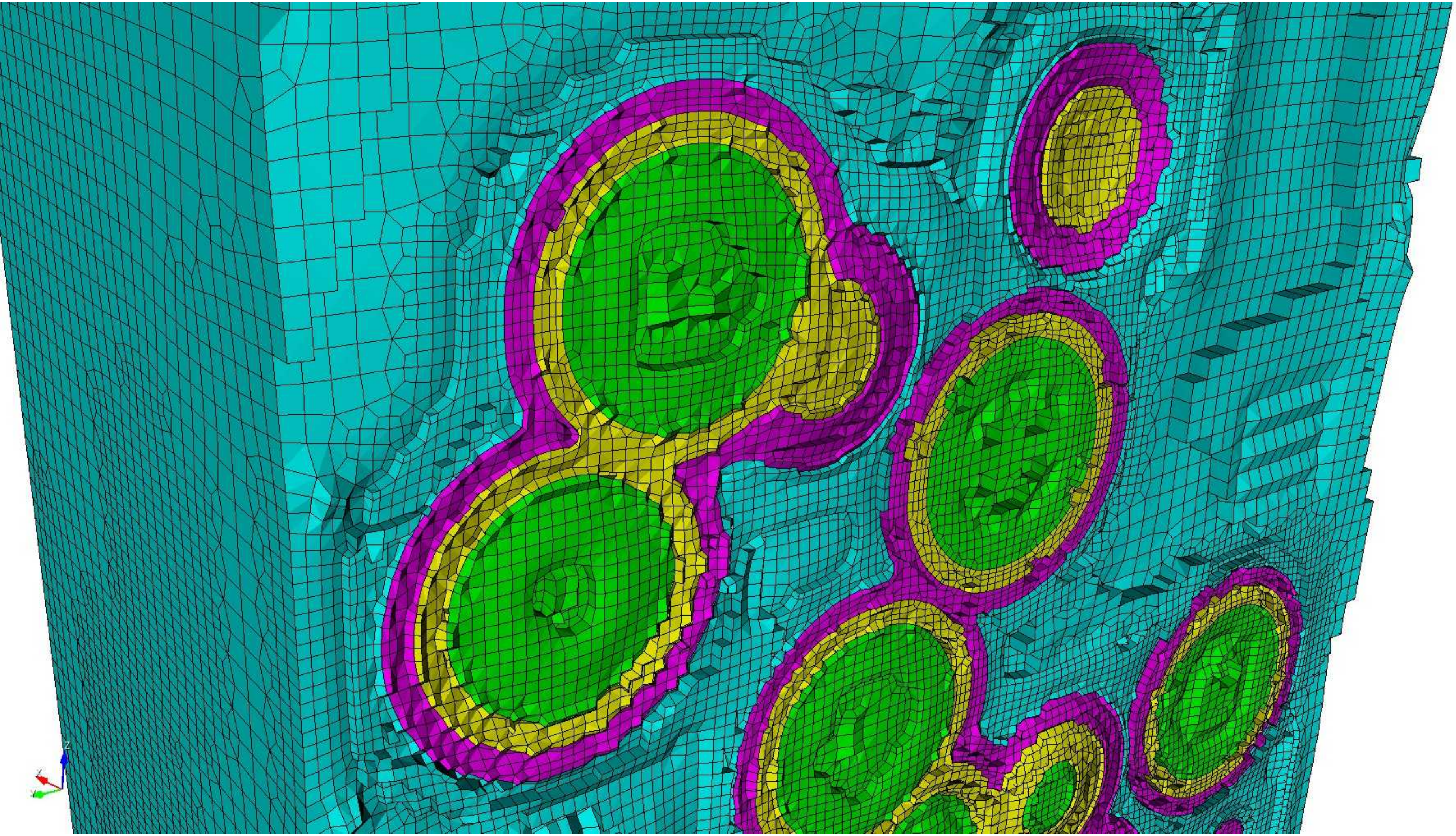
Adaptive Hex



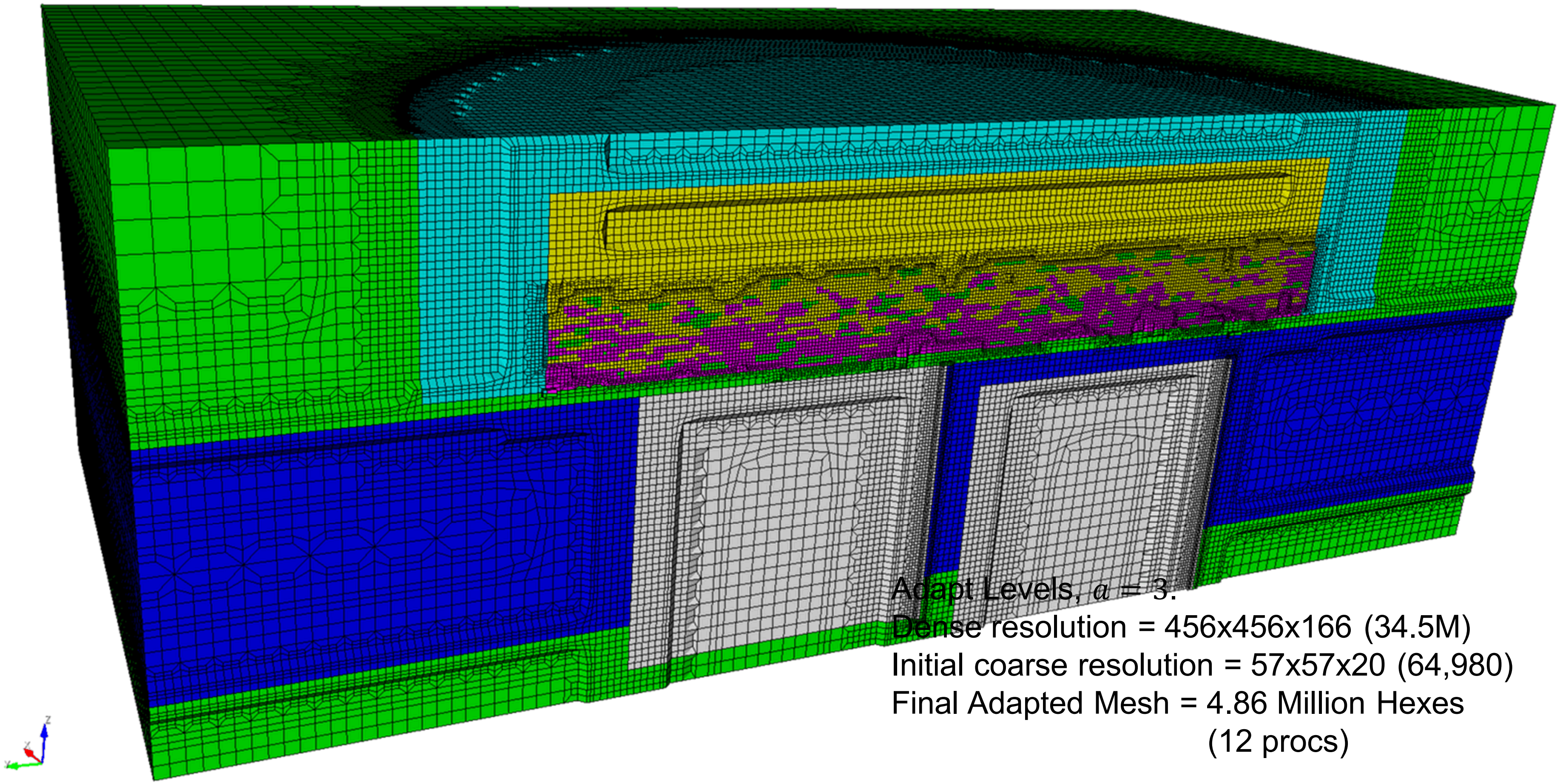
Base Cartesian grid is automatically refined to resolve geometric feaures





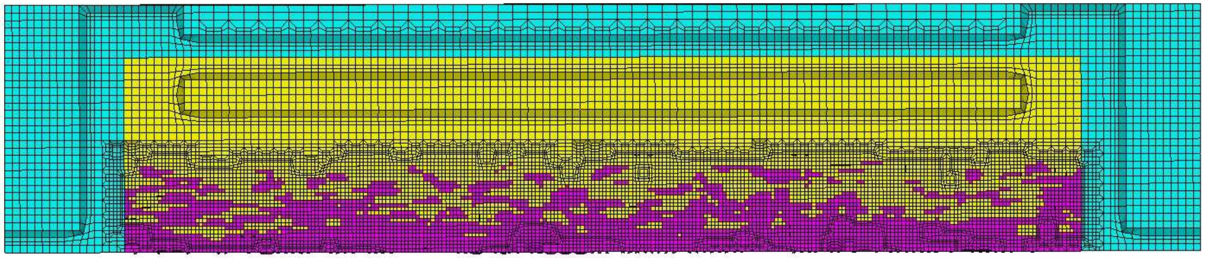


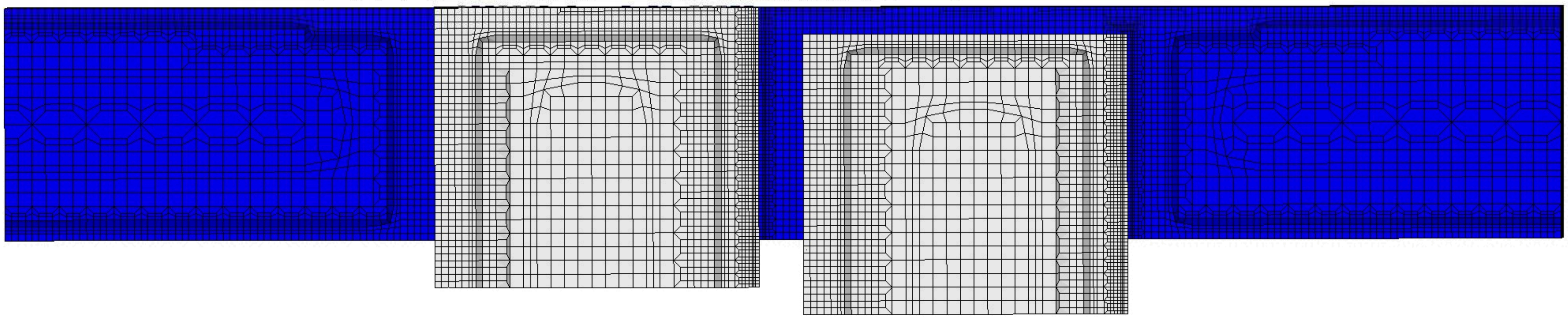
Adaptive Hex

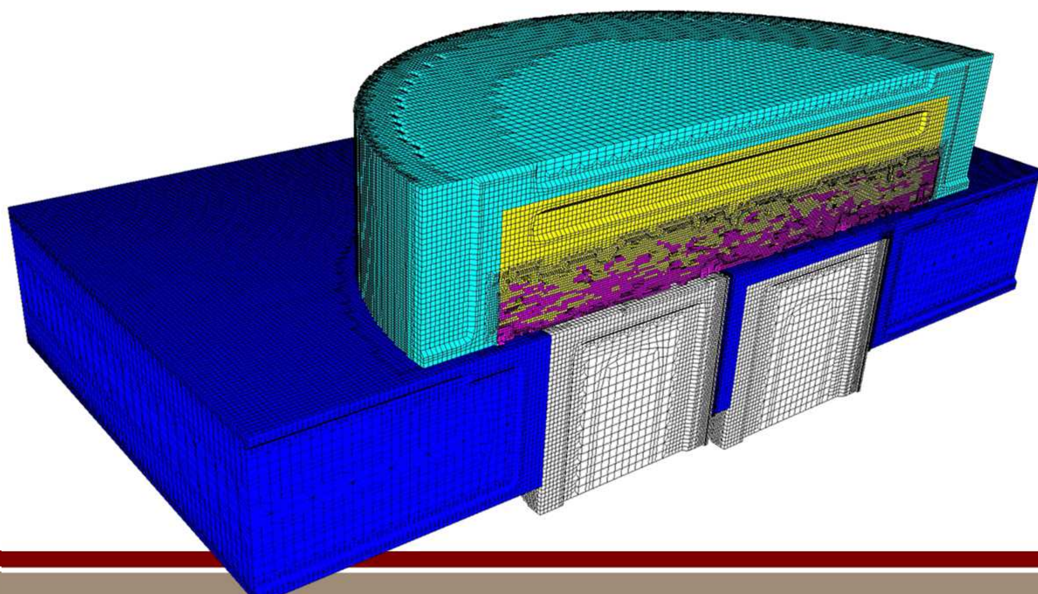


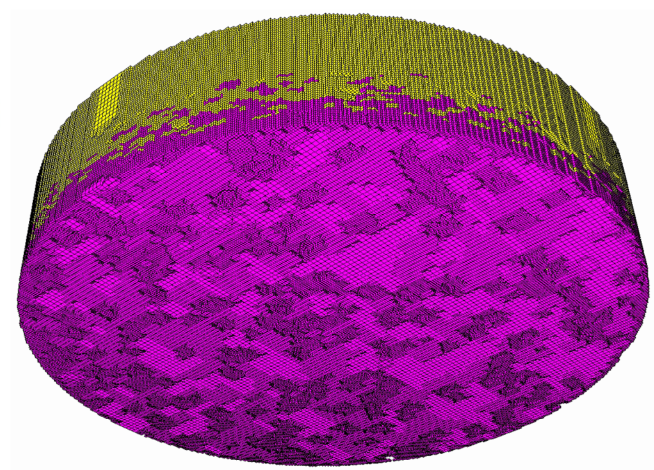
Adapt Levels, $a = 3$.
Dense resolution = 456x456x166 (34.5M)
Initial coarse resolution = 57x57x20 (64,980)
Final Adapted Mesh = 4.86 Million Hexes
(12 procs)

Adaptive Hex





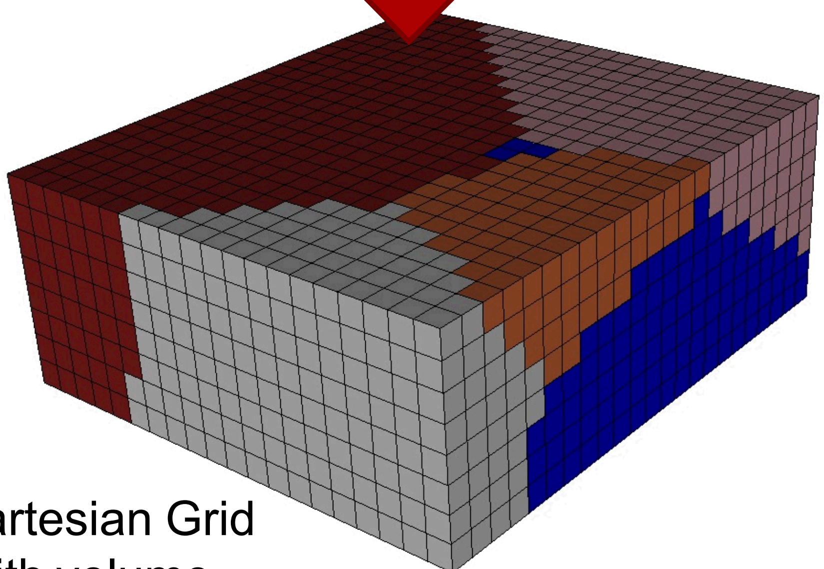




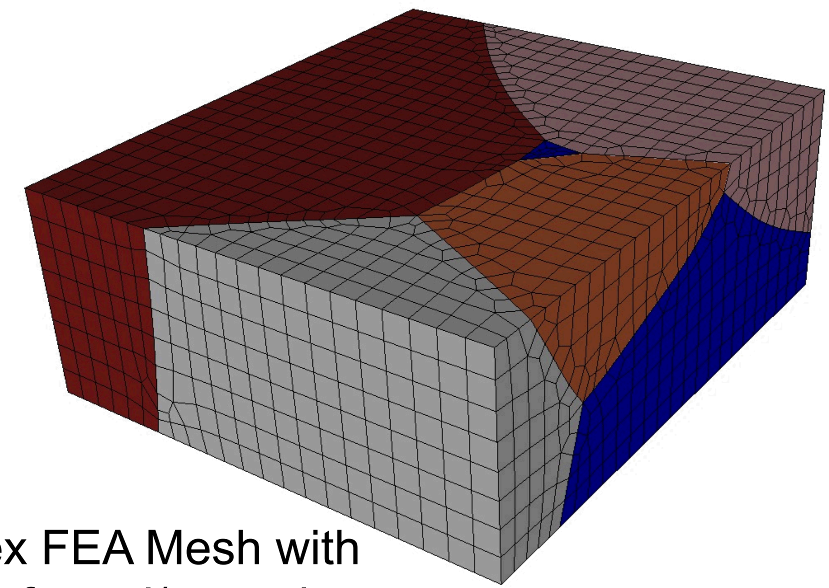
Tet Meshing Microstructures


```
TITLE = triple line system
VARIABLES = x y z, phi_1, phi_2, phi_3
ZONE i = 2 , j = 2 , k = 2
0.0000      0.0000      0.0000      0.5000      0.5000      0.0000
1.0000      0.0000      0.0000      0.3333      0.3333      0.3334
0.0000      1.0000      0.0000      1.0000      0.0000      0.0000
1.0000      1.0000      0.0000      0.0000      1.0000      0.0000
0.0000      0.0000      1.0000      0.2000      0.4000      0.4000
1.0000      0.0000      1.0000      0.6000      0.1000      0.3000
0.0000      1.0000      1.0000      0.0000      0.0000      1.0000
1.0000      1.0000      1.0000      0.9000      0.0000      0.1000
```

Microstructures volume fractions file (ascii)



Cartesian Grid With volume fraction scalar fields

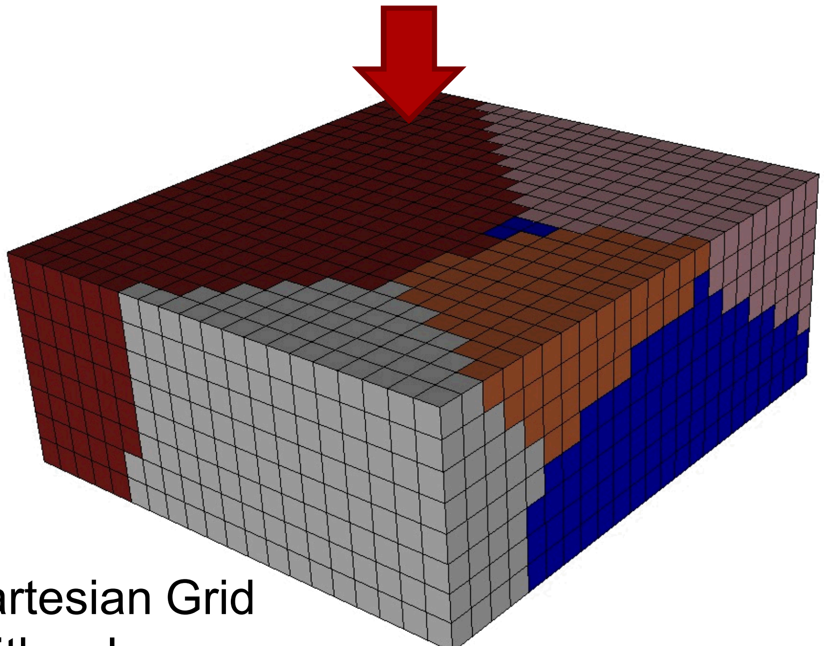


Hex FEA Mesh with conformal/smooth interfaces

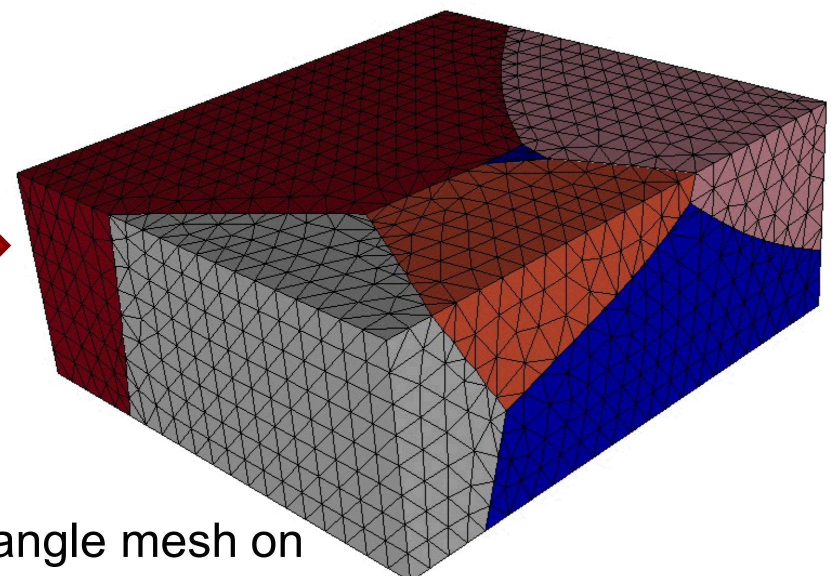
Tet Meshing Microstructures

```
TITLE = triple line system
VARIABLES = x y z, phi_1, phi_2, phi_3
ZONE i = 2 , j = 2 , k = 2
0.0000      0.0000      0.0000      0.5000      0.5000      0.0000
1.0000      0.0000      0.0000      0.3333      0.3333      0.3334
0.0000      1.0000      0.0000      1.0000      0.0000      0.0000
1.0000      1.0000      0.0000      0.0000      1.0000      0.0000
0.0000      0.0000      1.0000      0.2000      0.4000      0.4000
1.0000      0.0000      1.0000      0.6000      0.1000      0.3000
0.0000      1.0000      1.0000      0.0000      0.0000      1.0000
1.0000      1.0000      1.0000      0.9000      0.0000      0.1000
```

Microstructures volume fractions file (ascii)

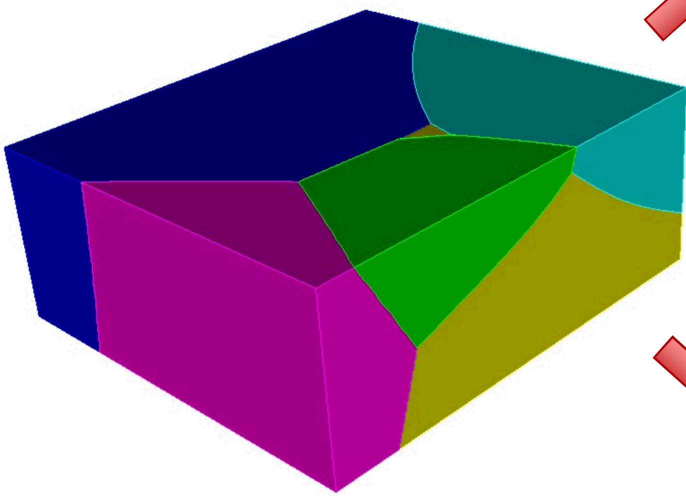


Cartesian Grid With volume fraction scalar fields

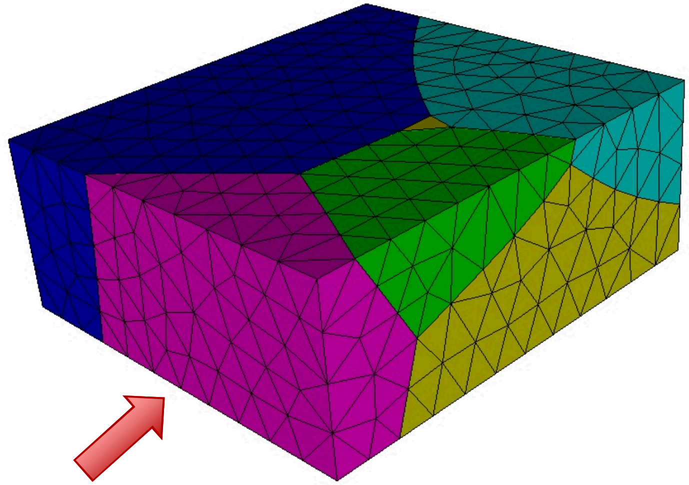


Triangle mesh on boundaries and interfaces

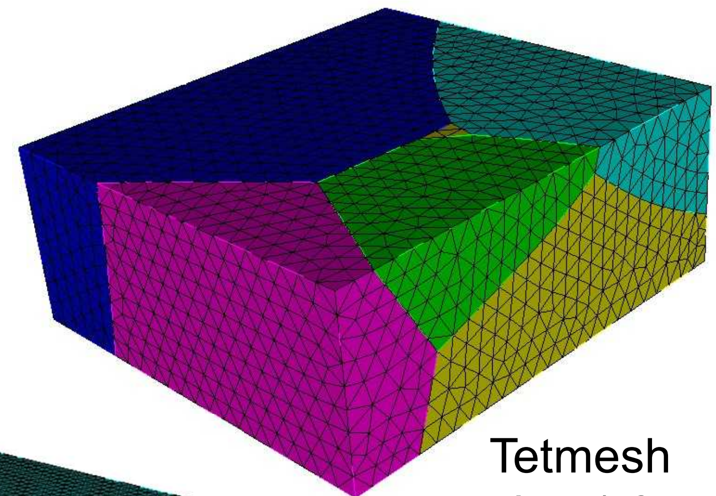
Objective: Generate tets at various resolutions from same geometry definition



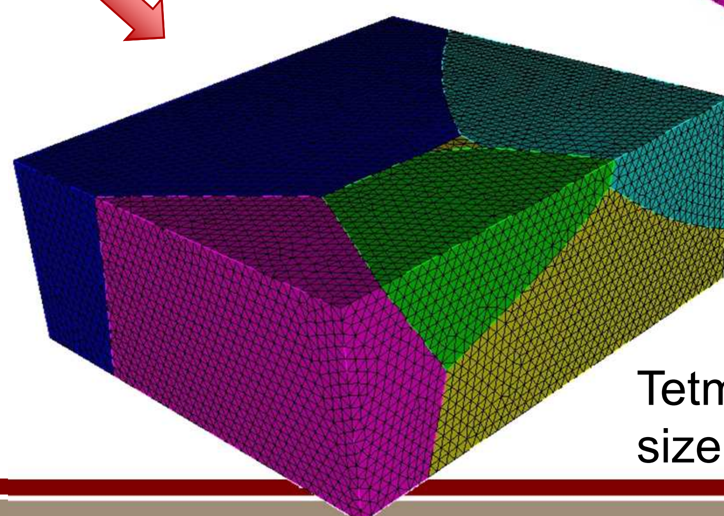
Mesh-Based Geometry



Tetmesh size 2.0

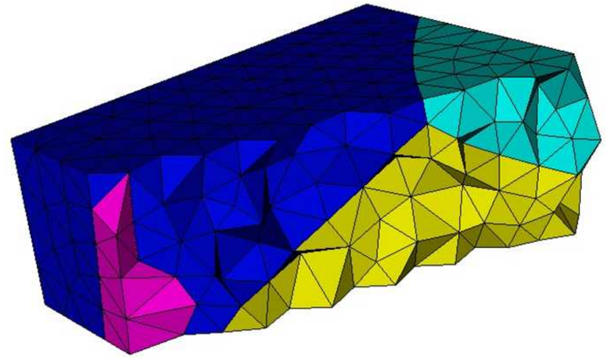


Tetmesh size 1.0

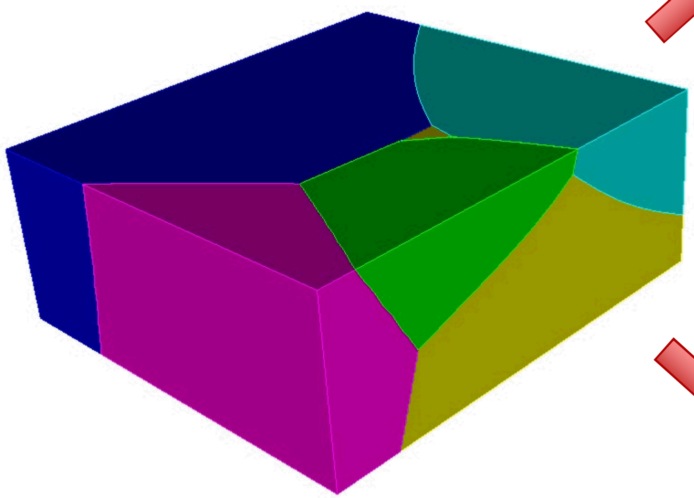


Tetmesh size 0.5

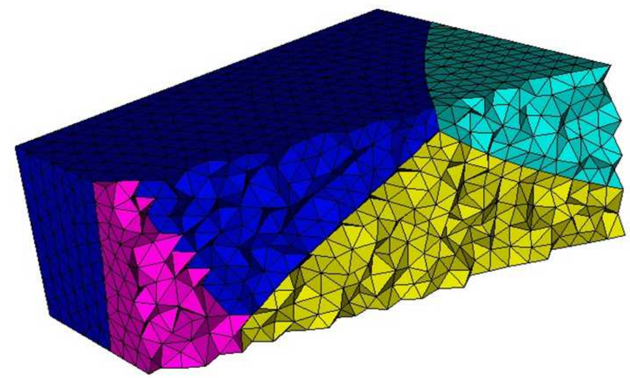
Objective: Generate tets at various resolutions from same geometry definition



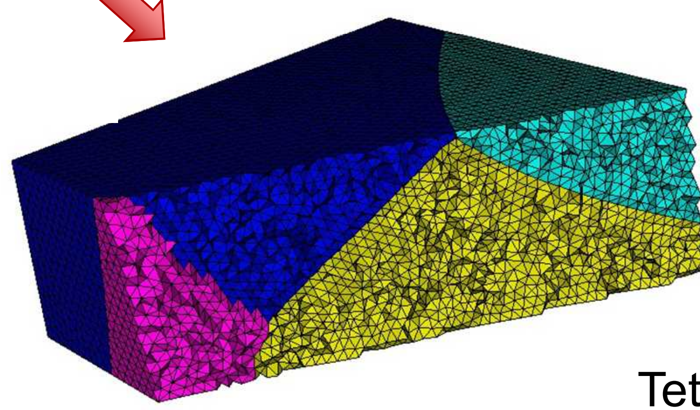
Tetmesh size 2.0



Mesh-Based Geometry



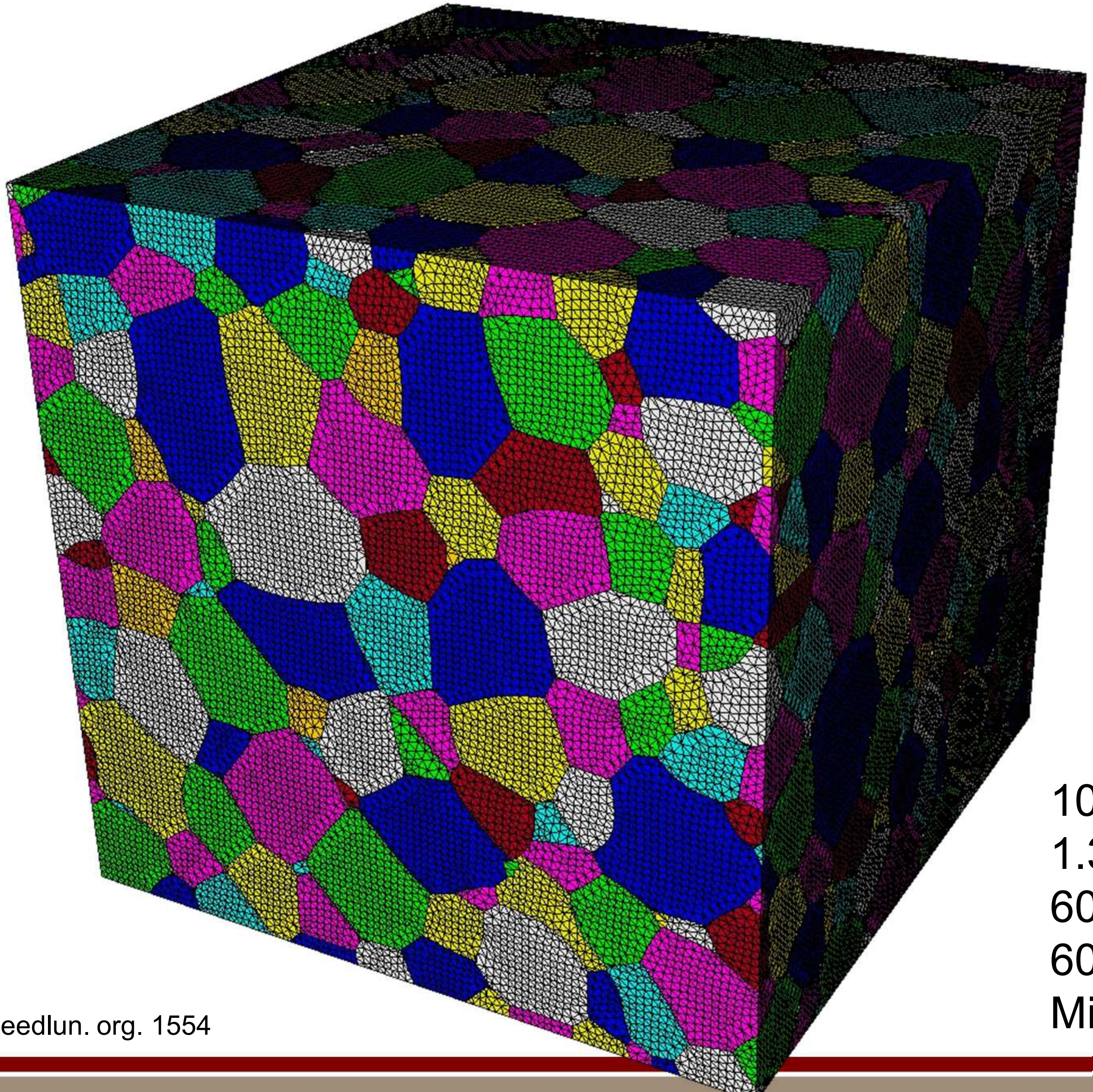
Tetmesh size 1.0



Tetmesh size 0.5

Tet Meshing Microstructures

Example

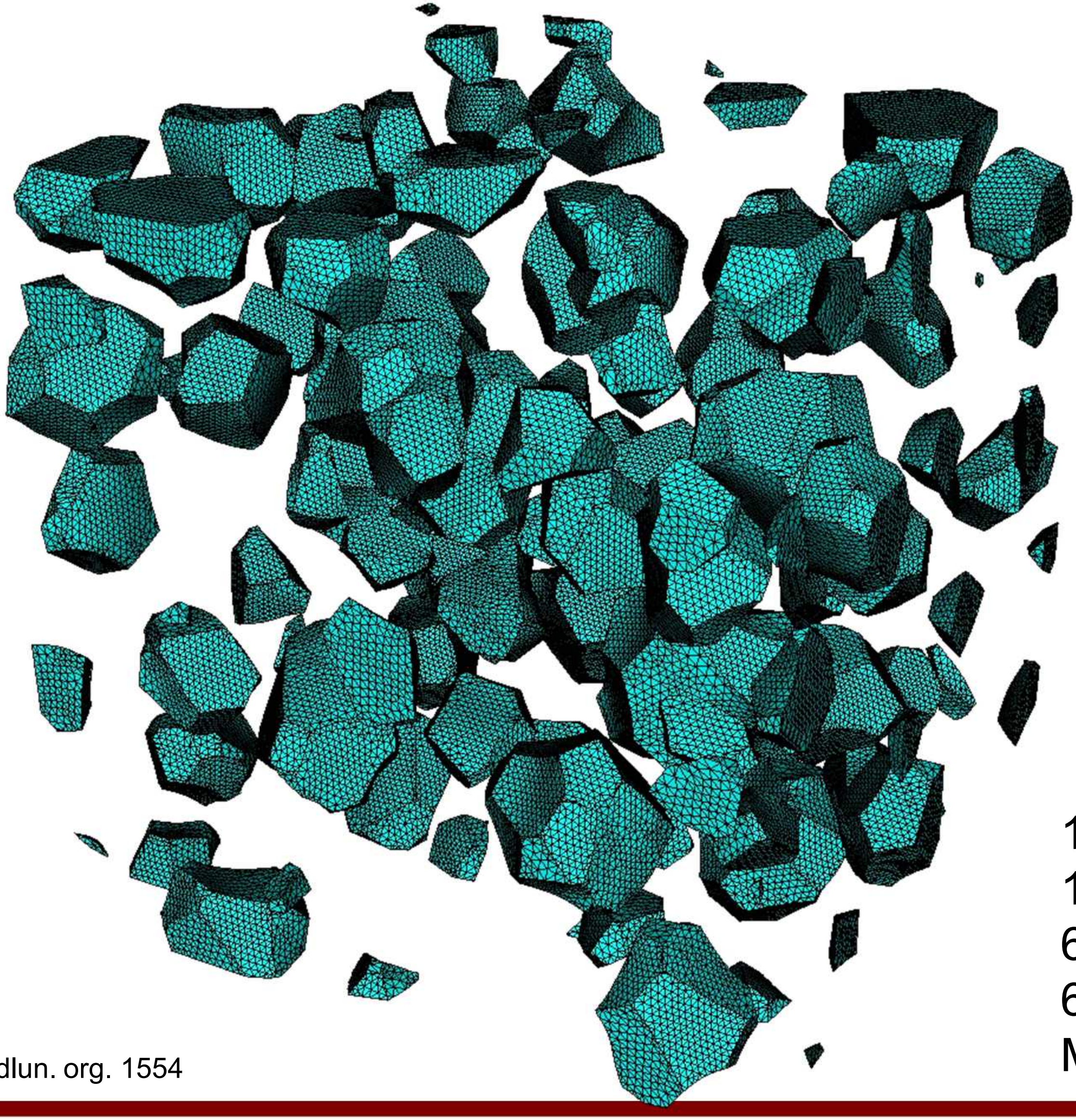


Model Courtesy Ben Reedlun. org. 1554

100x100x100 cells
1.35M Triangles
600+ volumes
60 sec. on 1 proc.
Min SJ = 0.0004

Tet Meshing Microstructures

Example

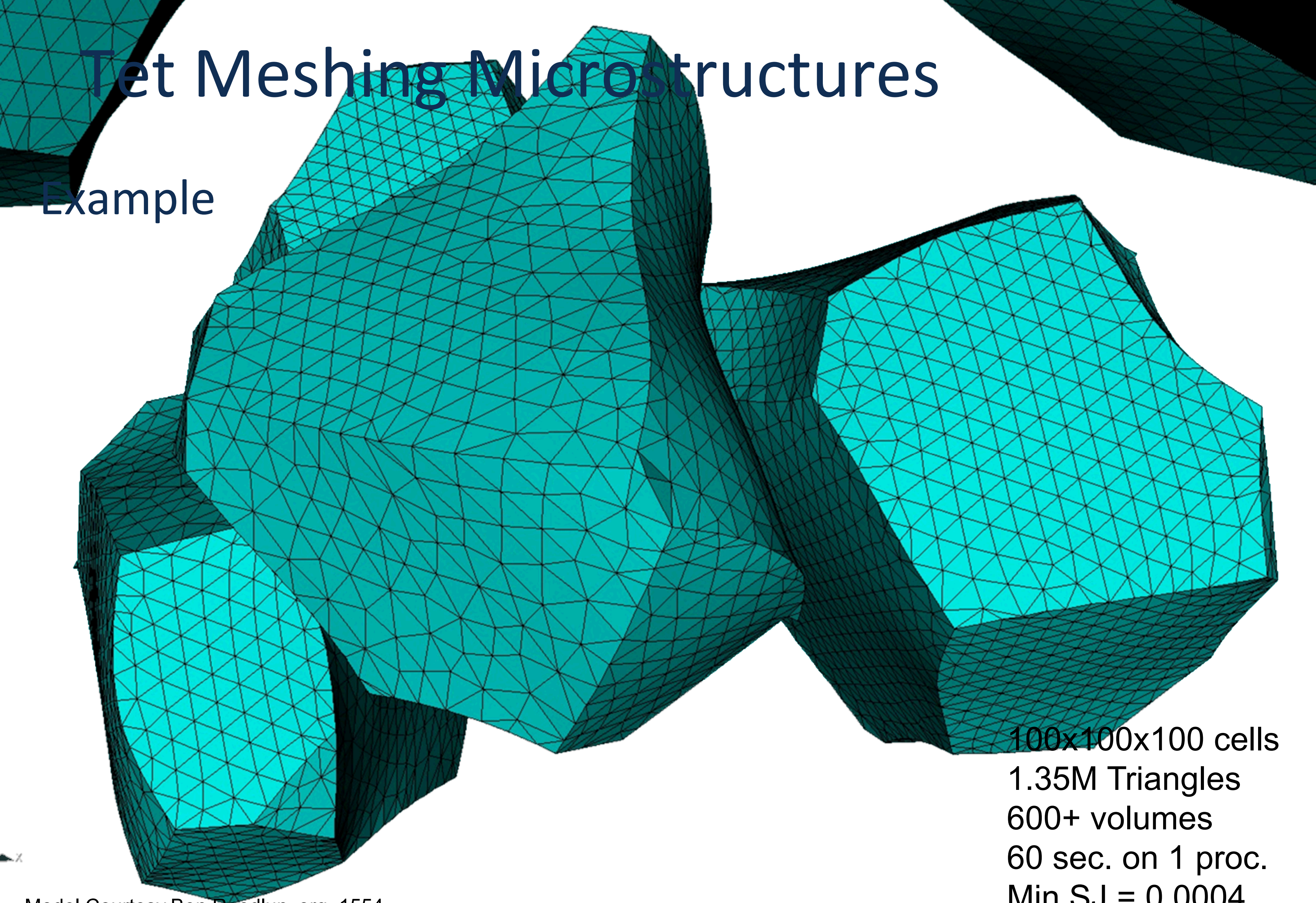


100x100x100 cells
1.35M Triangles
600+ volumes
60 sec. on 1 proc.
Min SJ = 0.0004

Model Courtesy Ben Reedlun. org. 1554

Tet Meshing Microstructures

Example

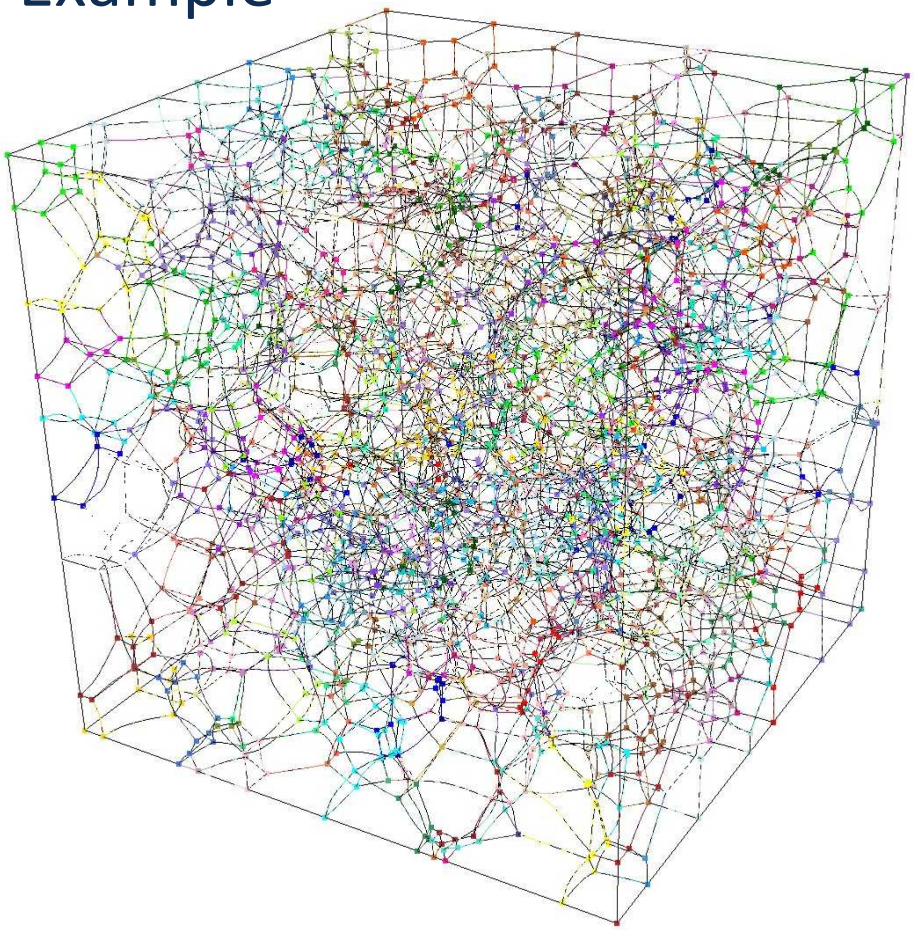


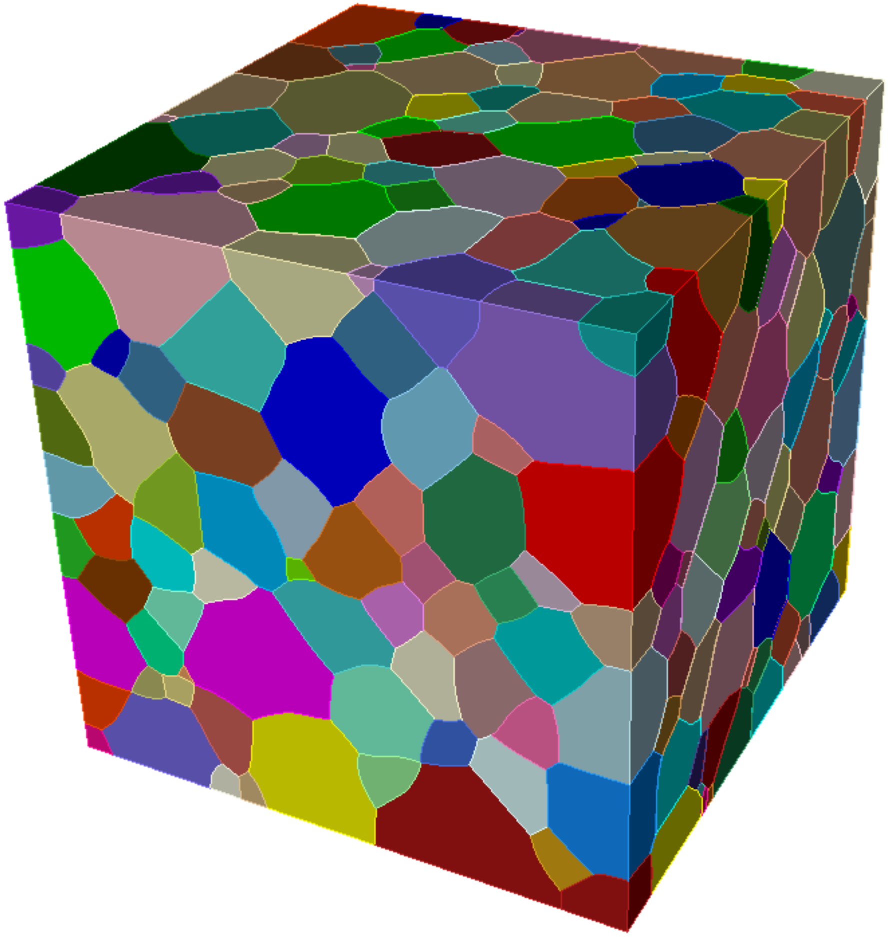
100x100x100 cells
1.35M Triangles
600+ volumes
60 sec. on 1 proc.
Min SJ = 0.0004

Model Courtesy Ben Reedlun. org. 1554

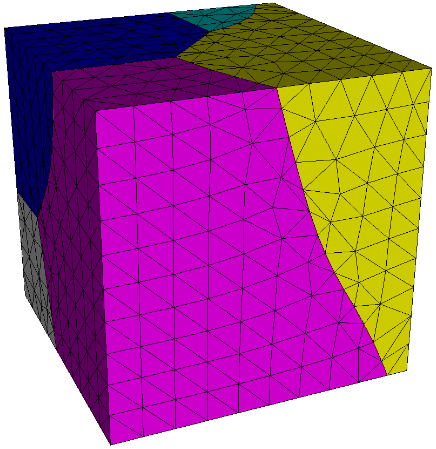
Tet Meshing Microstructures

Example

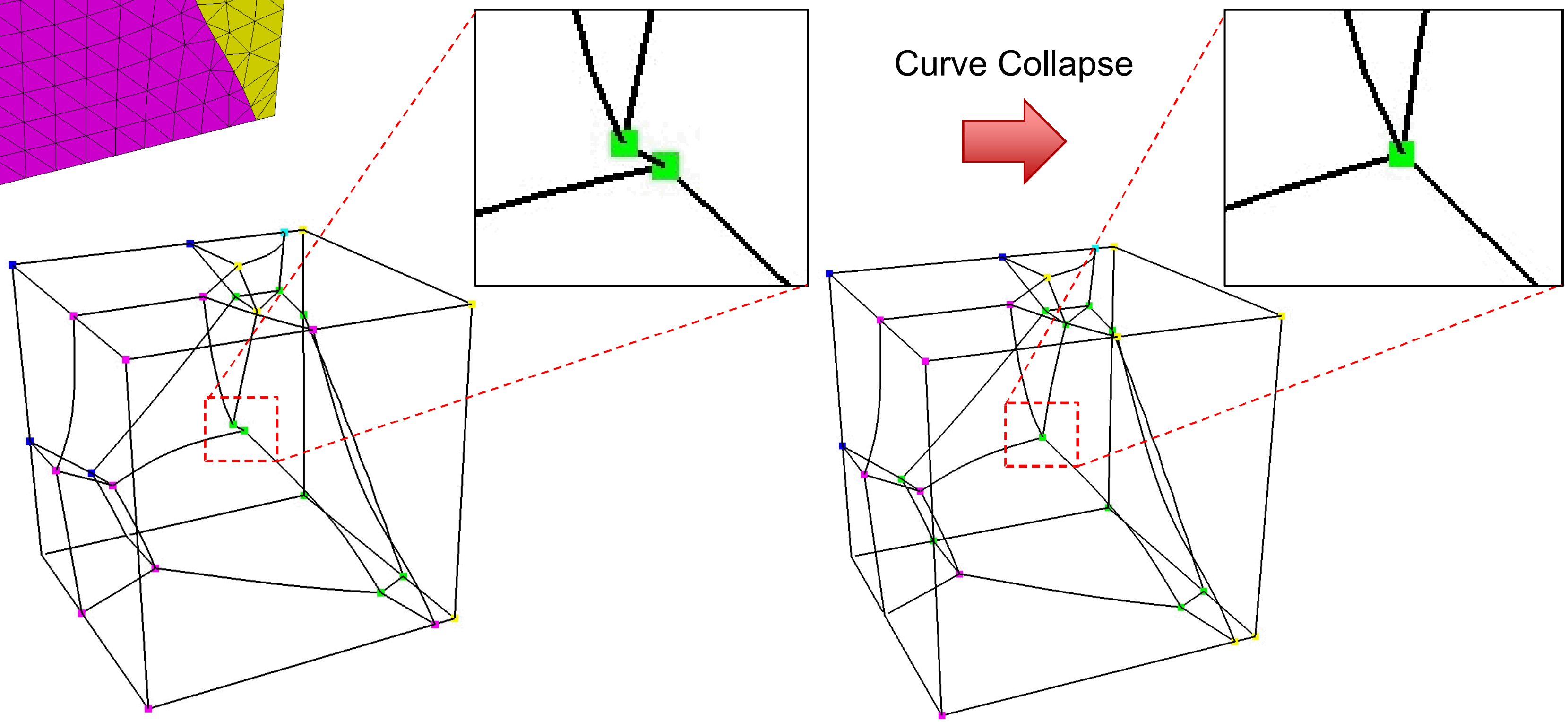




Curve/Surface Collapse



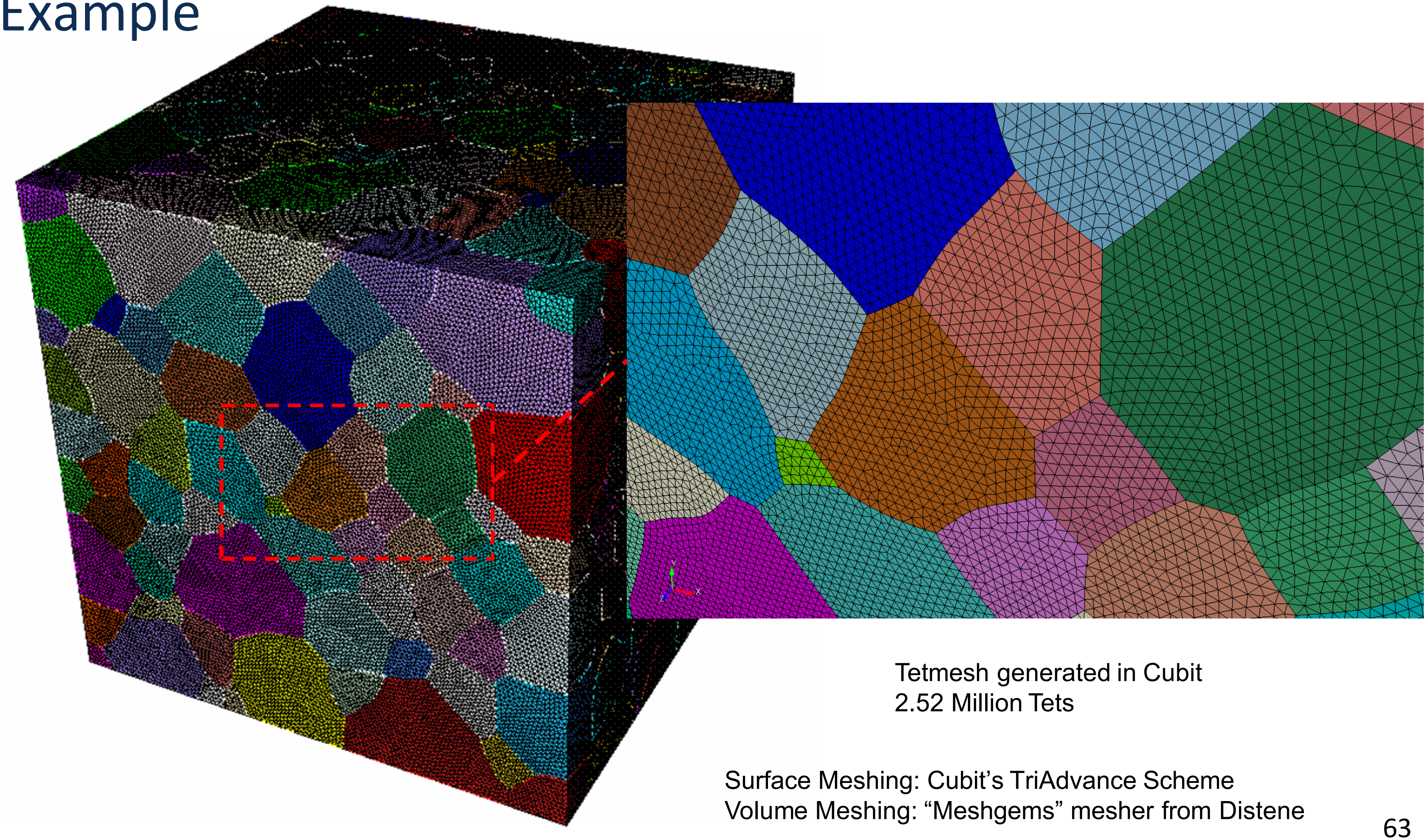
Collapses performed following geometry construction and triangle meshing



1. **Small curves**: exactly one triangle edge
2. **Small surfaces**: 2 curves each with 2 triangle edges

Tet Meshing Microstructures

Example



Tetmesh generated in Cubit
2.52 Million Tets

Surface Meshing: Cubit's TriAdvance Scheme
Volume Meshing: "Meshgems" mesher from Distene