

# **Mesh Generation for Geological Applications**

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**Earth & Environmental Sciences Division**

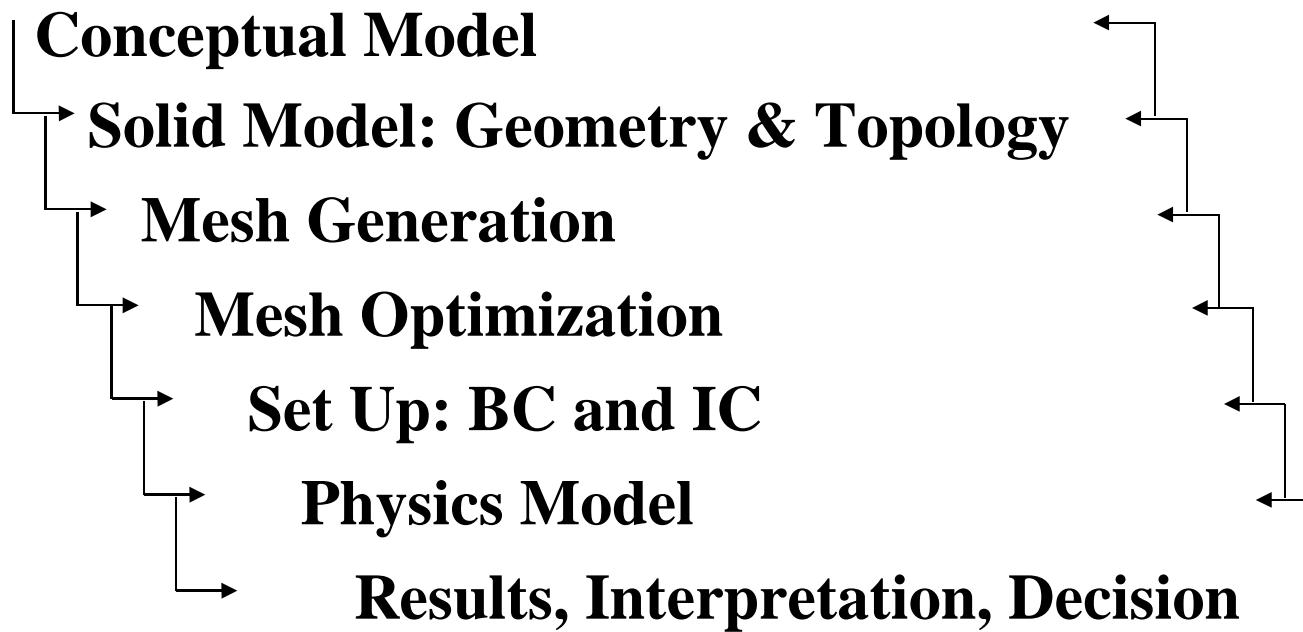
**<http://meshing.lanl.gov>**

**<http://lagrit.lanl.gov>**

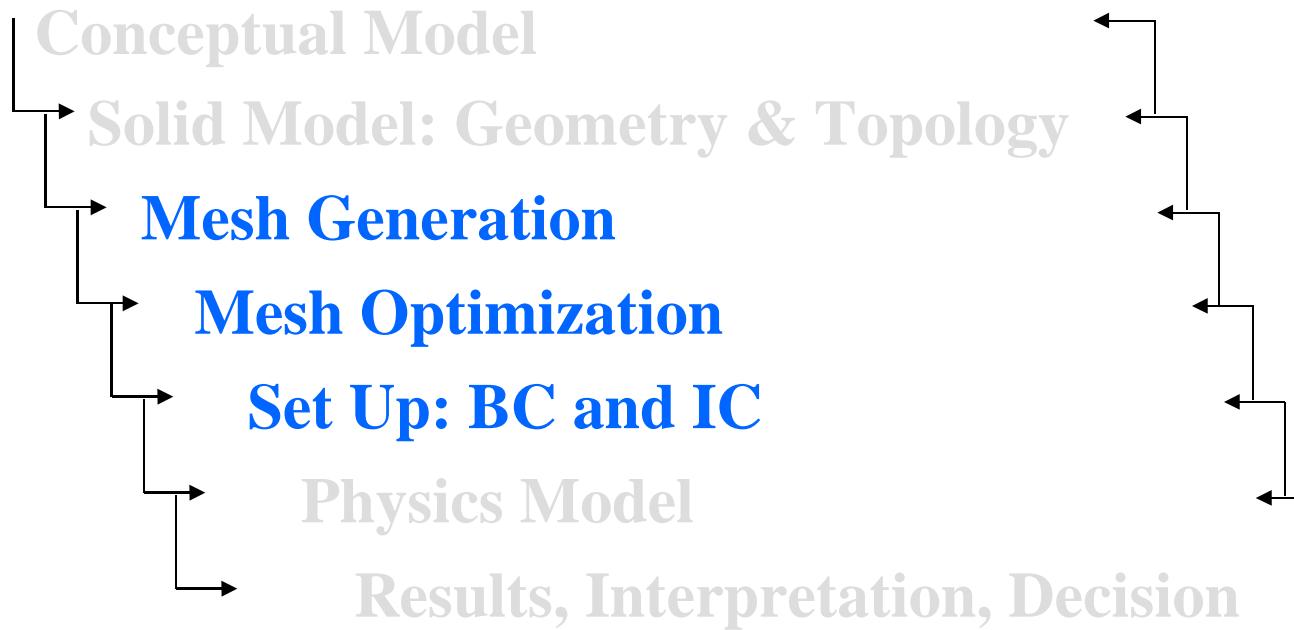
**Numerical Modeling of Crustal Deformation and Earthquake Faulting**

**Golden CO June 23-27**

# Modeling and Simulation Workflow



# Modeling and Simulation Workflow

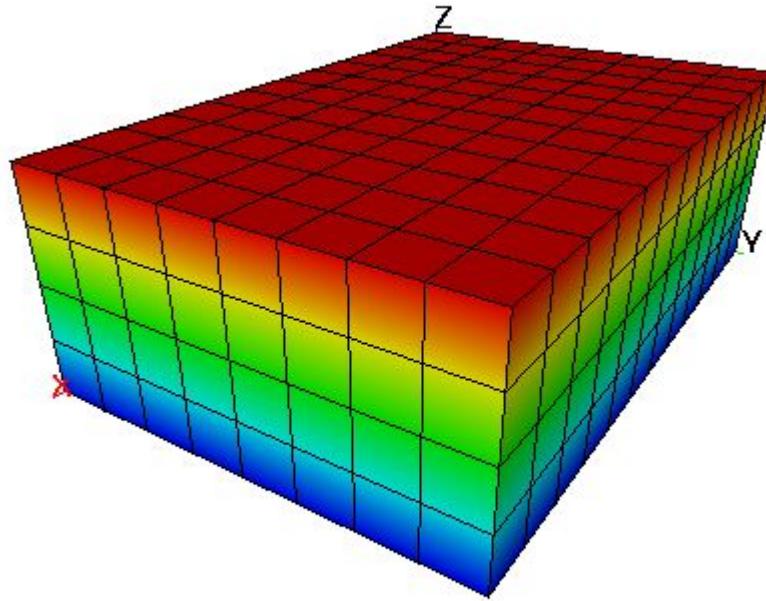


# Earth Science Related Mesh Generation

- Flow and Transport in Porous Media
- Tectonics, Stress and Strain, Faulting, Earthquake Studies
- Yucca Mountain Project (YMP)
- Heat & Mass Transport Studies of Nuclear Fuel In Salt Repository (GNEP)
- Nevada Test Site Underground Test Area (UGTA)
- Los Alamos Environmental Programs (LANL EP)
- Oil Shale and Water Resources
- Hard and Deeply Buried Targets (HDBT)
- WFO
  - Navy Coso Hydrothermal
  - Southern California Earthquake Center (SCEC)
  - Rhine Valley Fault Systems (NSF)

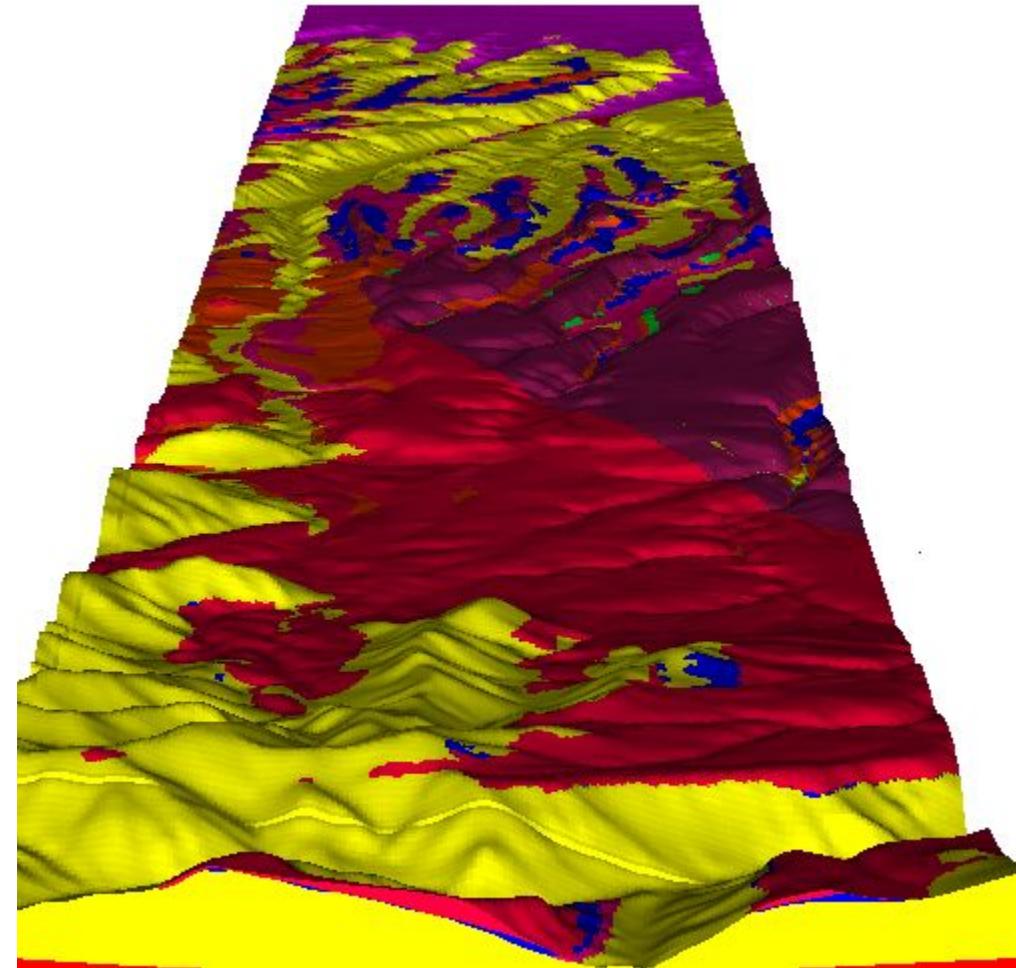
# Conceptual Model

- Imagine a Spherical Cow



# Conceptual Model

- Imagine a Spherical Cow



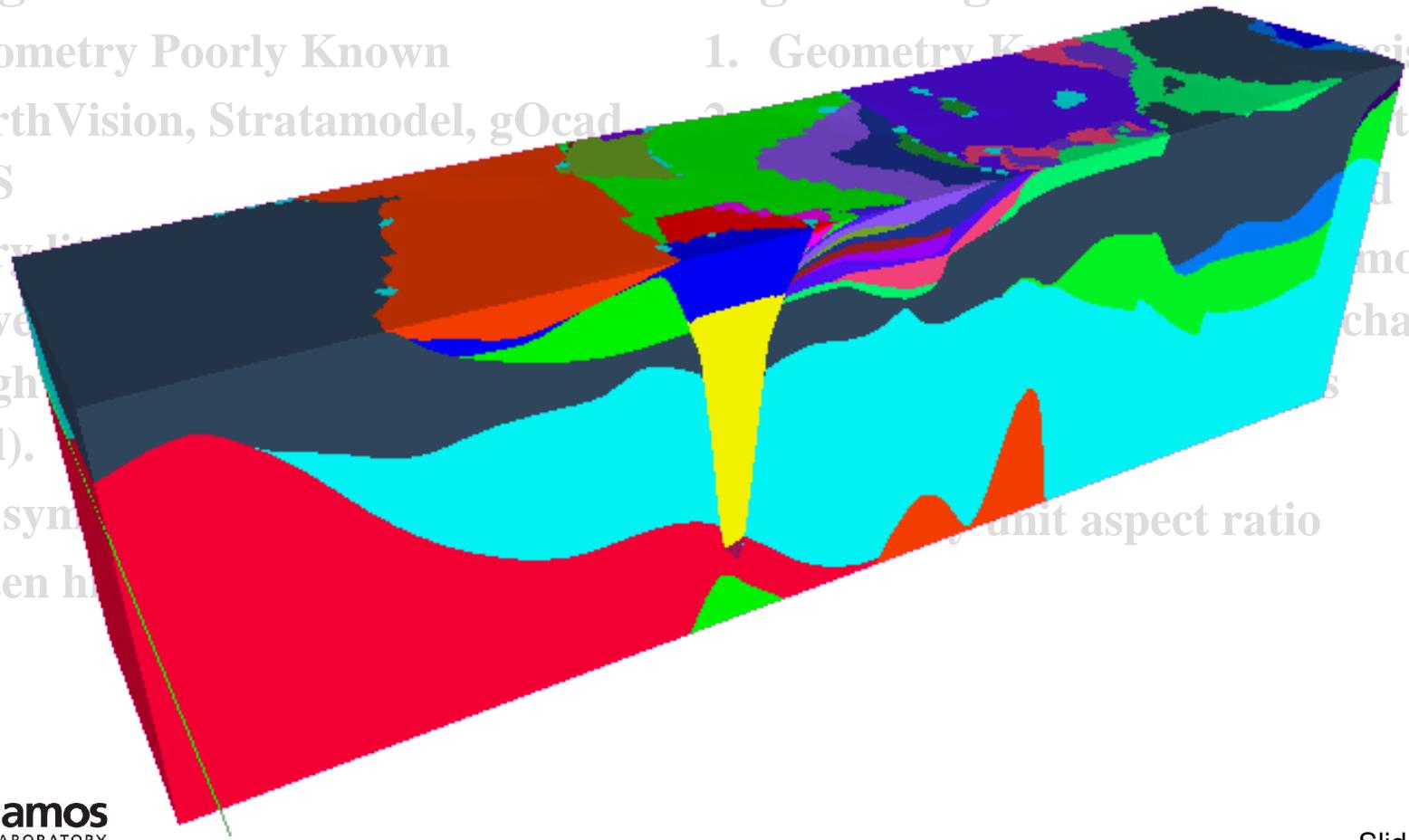
# Solid Model: Geometry and Topology

## Geologic

1. Geometry Poorly Known
2. EarthVision, Stratamodel, gOcad
3. Very little automation
4. Development slow (high end).
5. No symmetry
6. Often highly irregular

## Engineering

- 1. Geometry Known
- 2. CAD (AutoCAD)
- 3. Lots of automation
- 4. Motive, Mechanical, SolidWorks
- 5. Symmetry
- 6. Unit aspect ratio



# Solid Model: Geometry and Topology

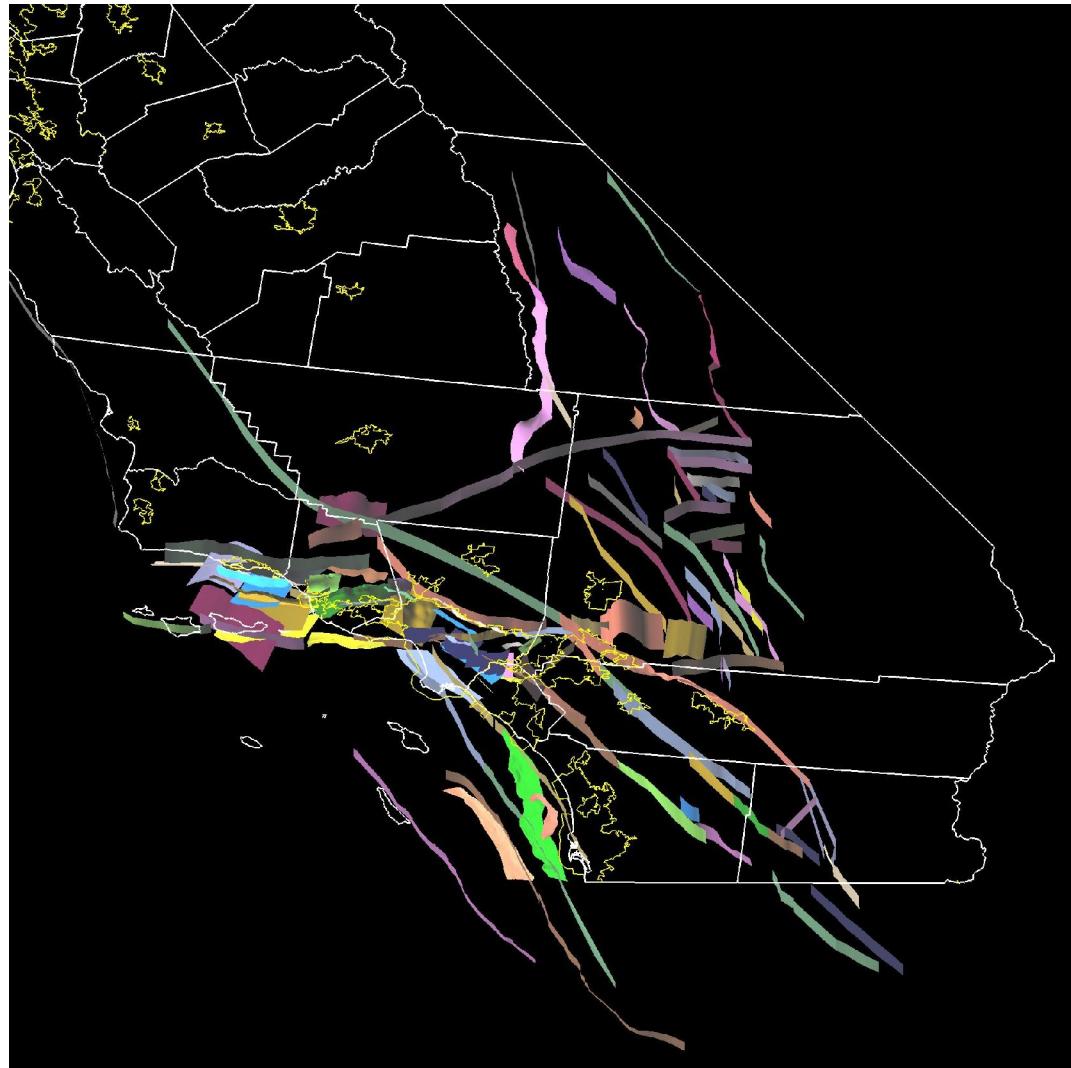
## Geologic

1. Geometry Poorly Known
2. EarthVision, Stratamodel, gOcad, GIS
3. Very little FE integration
4. Development driven by oil patch (high end), environmental (low end).
5. No symmetry
6. Often high aspect ratio

## Engineering

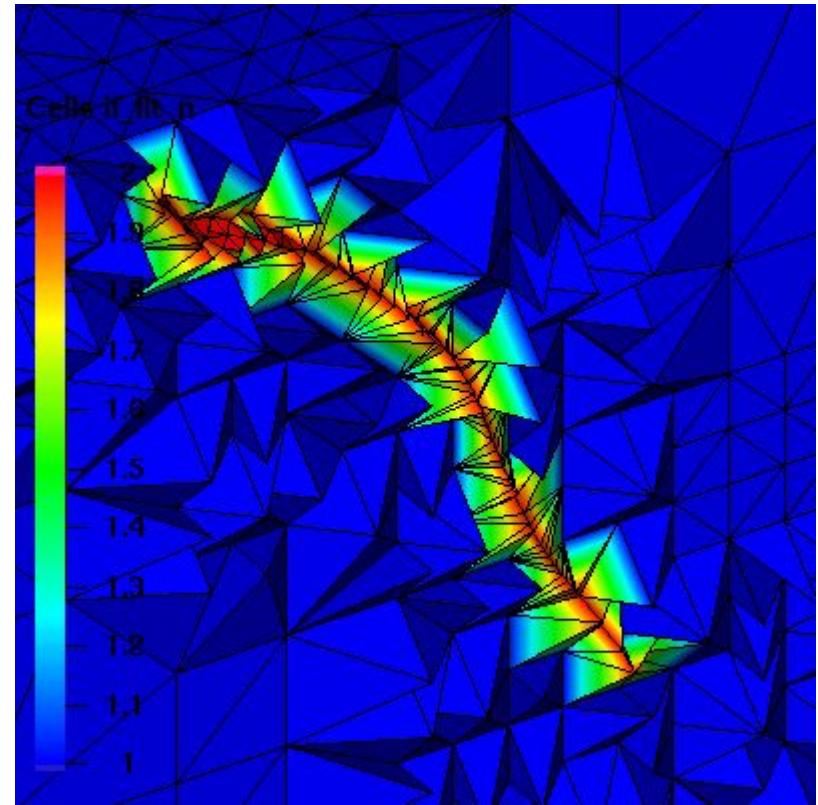
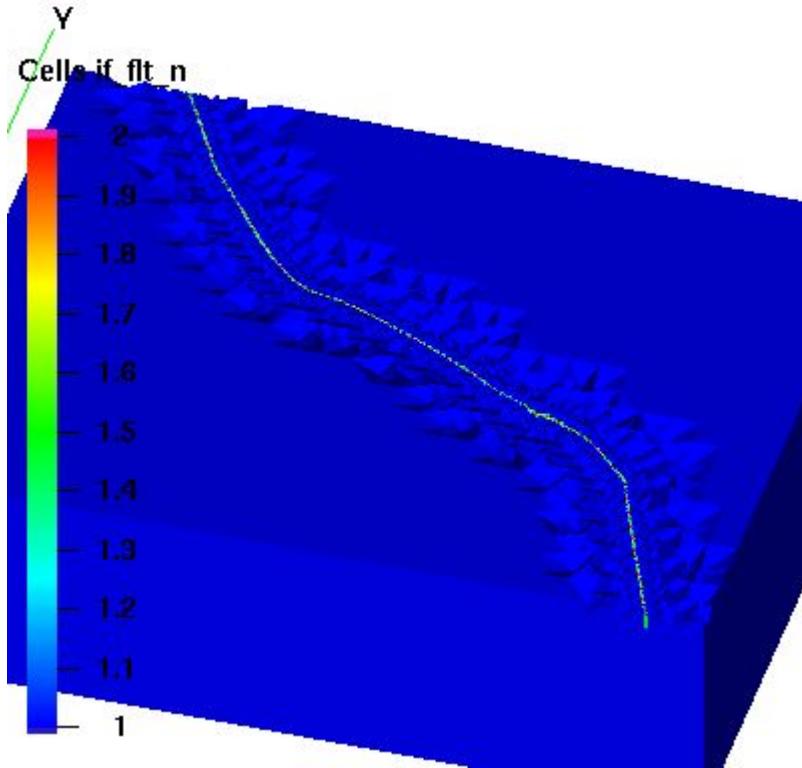
1. Geometry Know w/ High Precision
2. CAD Model (ACIS, Pro/E, Autocad)
3. FE application well integrated
4. Development driven by automotive, aircraft, semiconductor, mechanical engineering, fluid dynamics
5. Often symmetry
6. Generally unit aspect ratio

# Model: Geometry, No Topology



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# San Andreas Fault



# What do we do if the geologic framework model is not in CAD format?

## Option 1

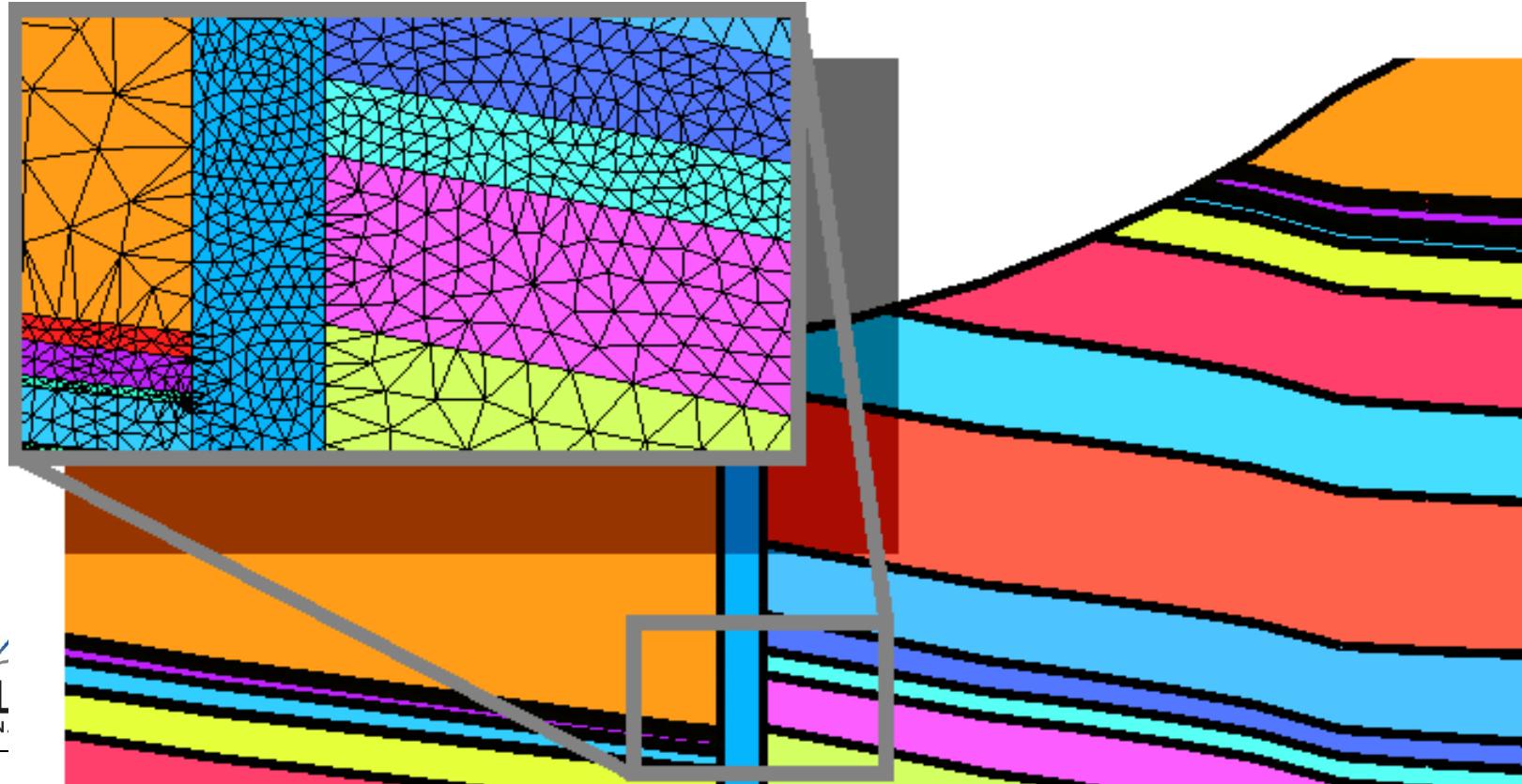
1. Derive CAD solid model (ACIS, Pro/E, etc.) from geologic framework model (EarthVision, gOcad, Stratamodel, ...).
2. Use mesh generation tools that require CAD solid model input.

## Option 2

5. Use mesh generation tools that do not require CAD solid model input.

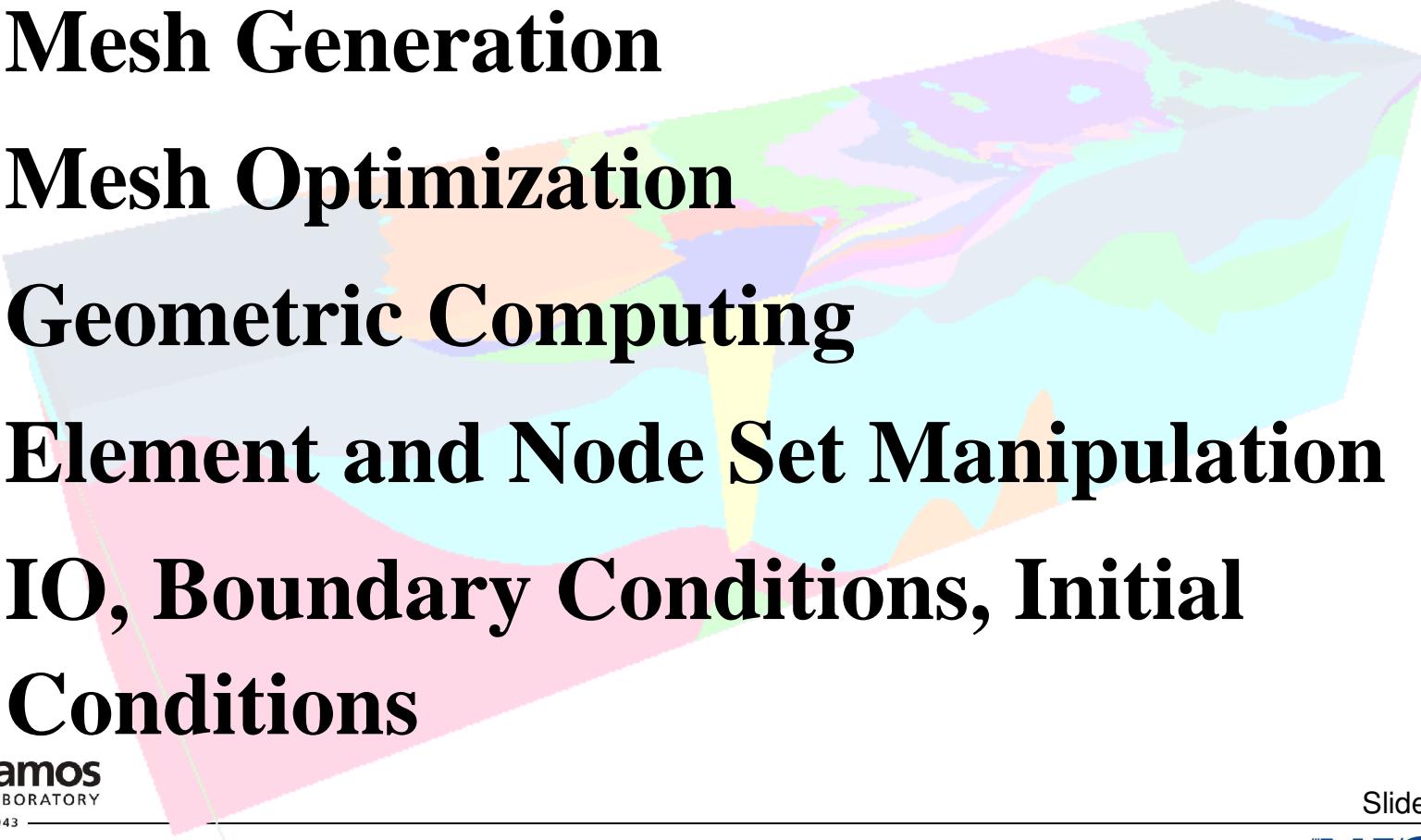
# LaGriT: Los Alamos Grid Toolbox

**meshing.lanl.gov**      **lagrit.lanl.gov**



side 12

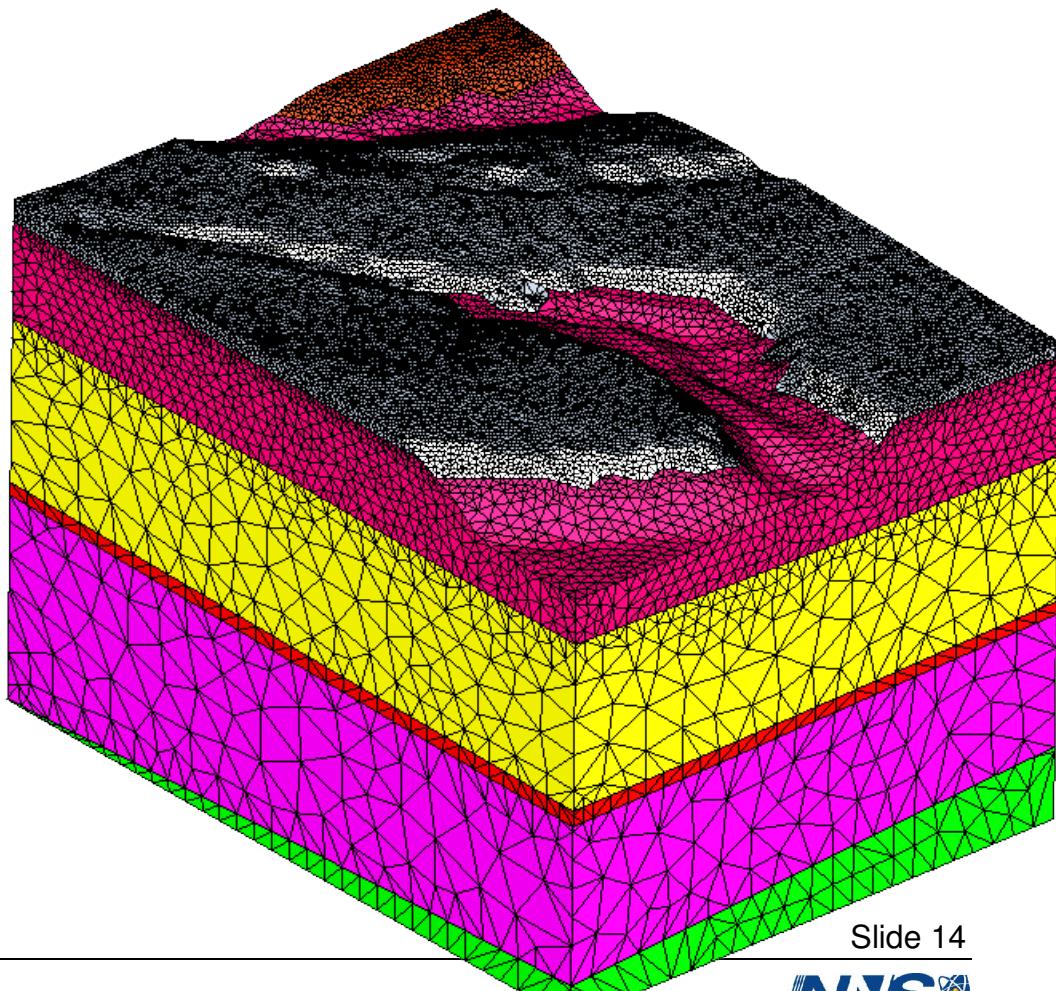
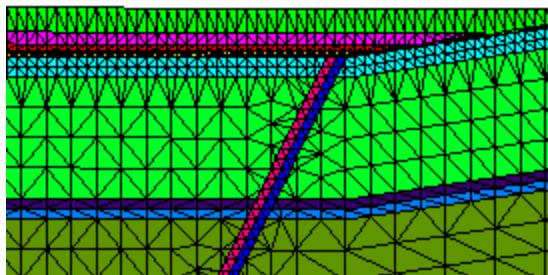
# LaGriT

- Mesh Generation
  - Mesh Optimization
  - Geometric Computing
  - Element and Node Set Manipulation
  - IO, Boundary Conditions, Initial Conditions
- 

# LaGriT: Mesh Generation

## Delaunay point connection

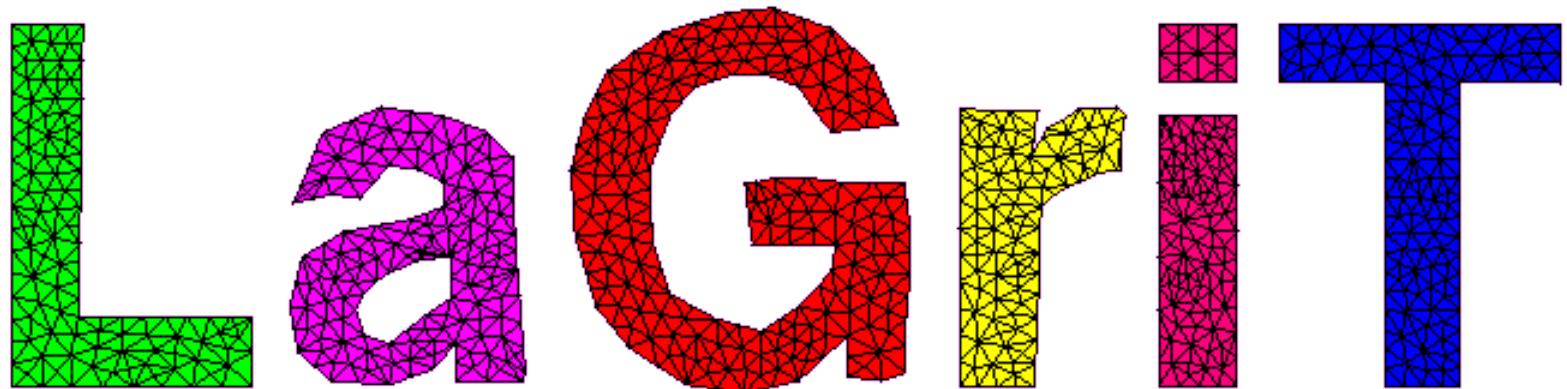
- 2D triangulation
- 3D tetrahedralization



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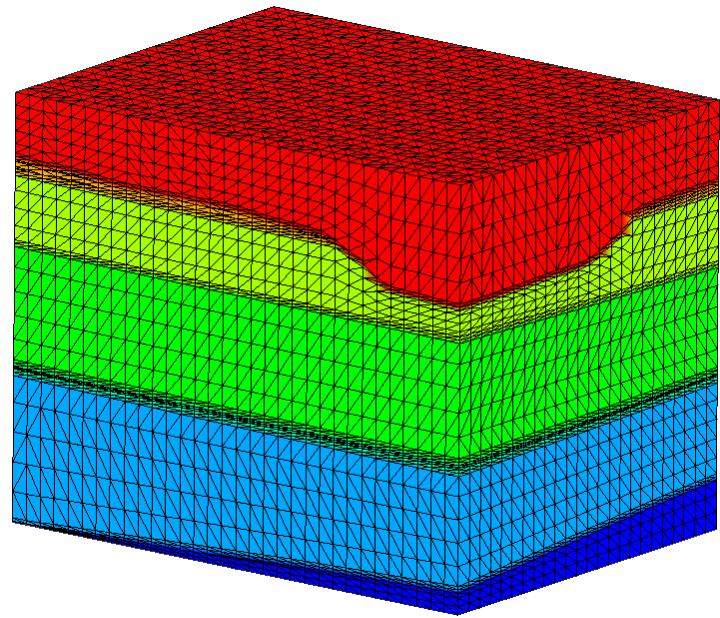
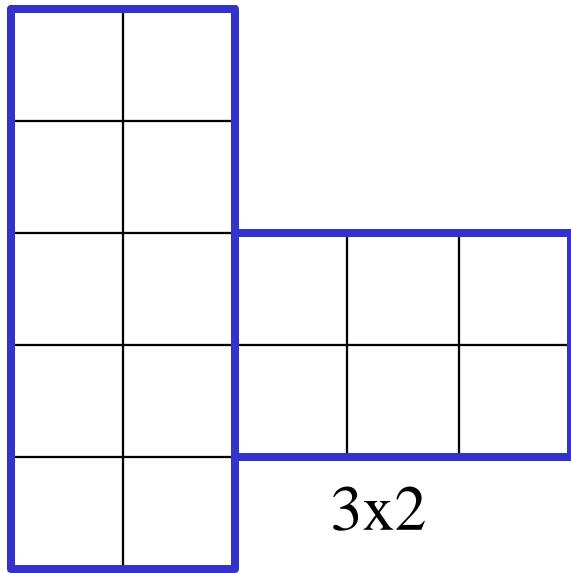
# LaGriT: Mesh Generation

- 2D arbitrary (concave) polygon triangulation



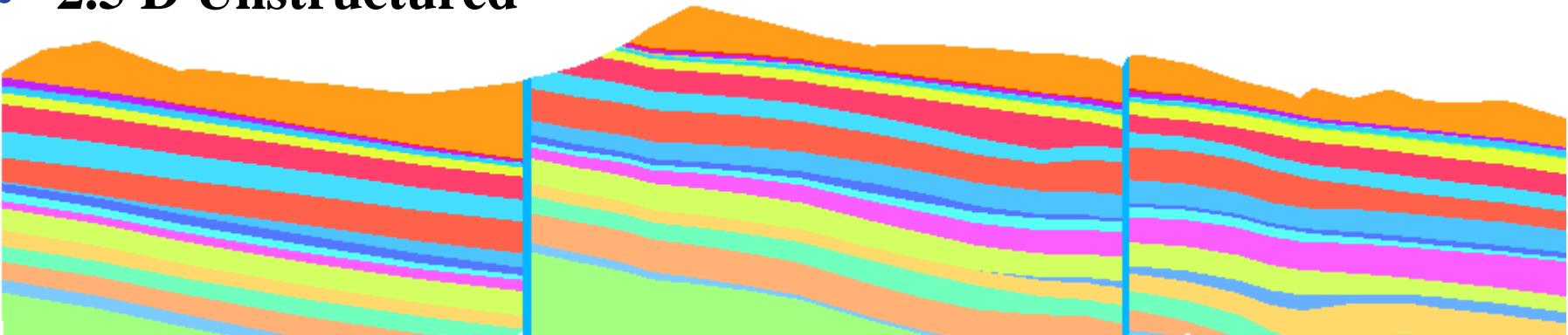
# LaGriT: Mesh Generation

- Block structured  $i,j,k$  connectivity
- 2.5D Stacking of  $z(x,y)$  surfaces



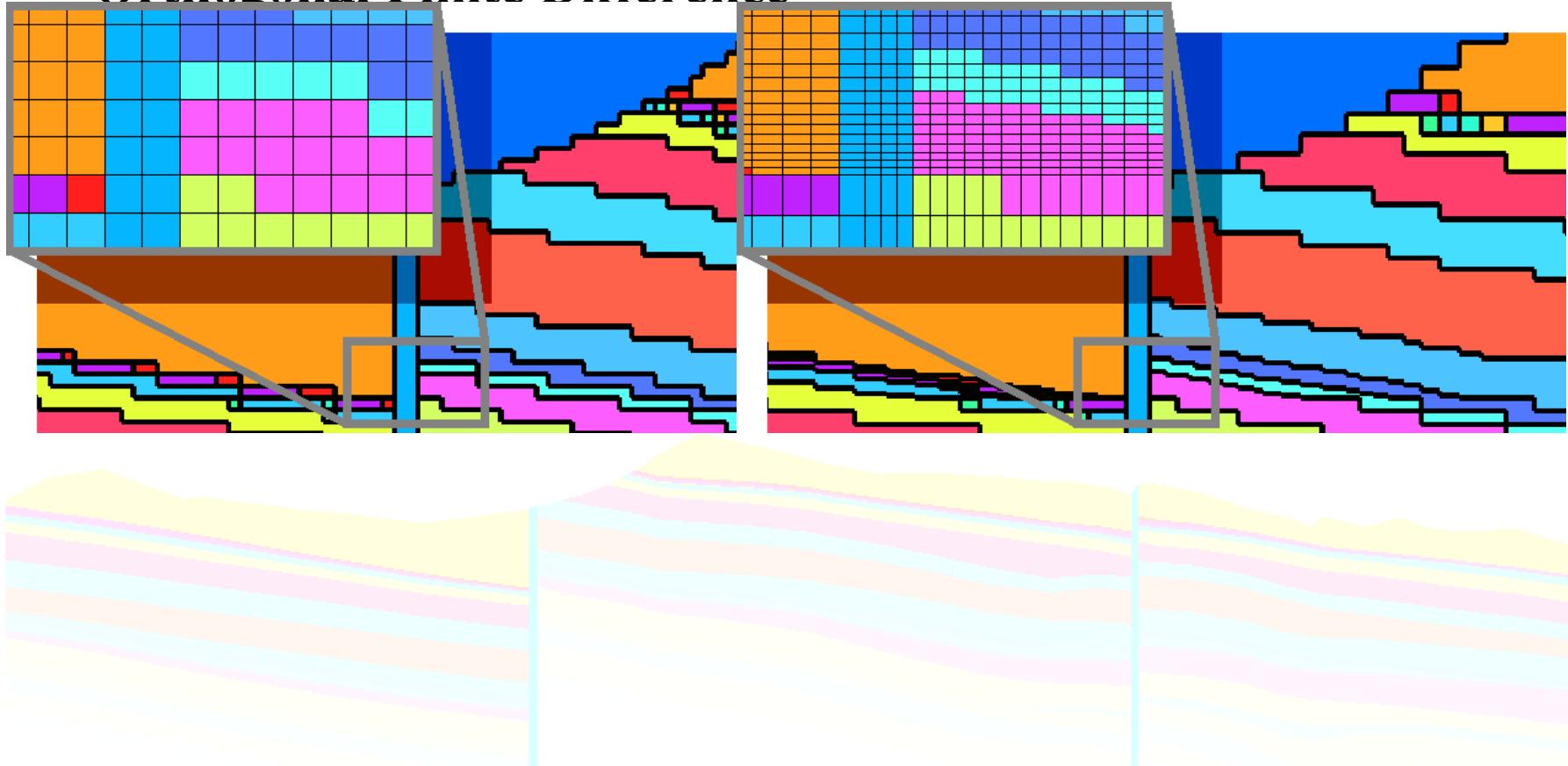
# Mesh Generation Depends on the Solver and Physics

- Orthogonal Finite Difference
- Logical Structured
- Block Structured
- Quadtree, Octree
- Unstructured (quad, tri, hex, tet, prism, pyramid, polyhedra)
- 2.5 D Unstructured



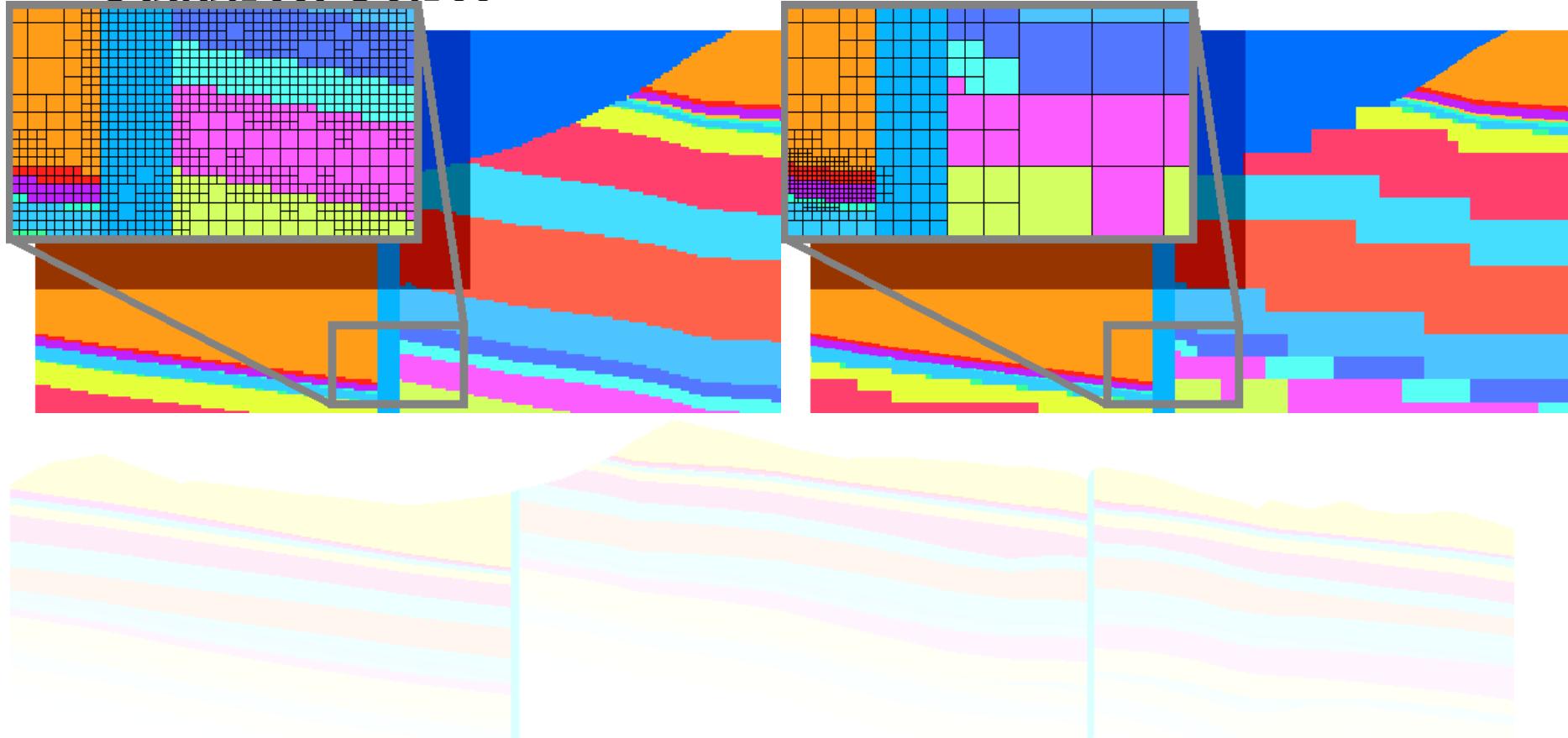
# Mesh Generation Depends on the Solver and Physics

- Orthogonal Finite Difference



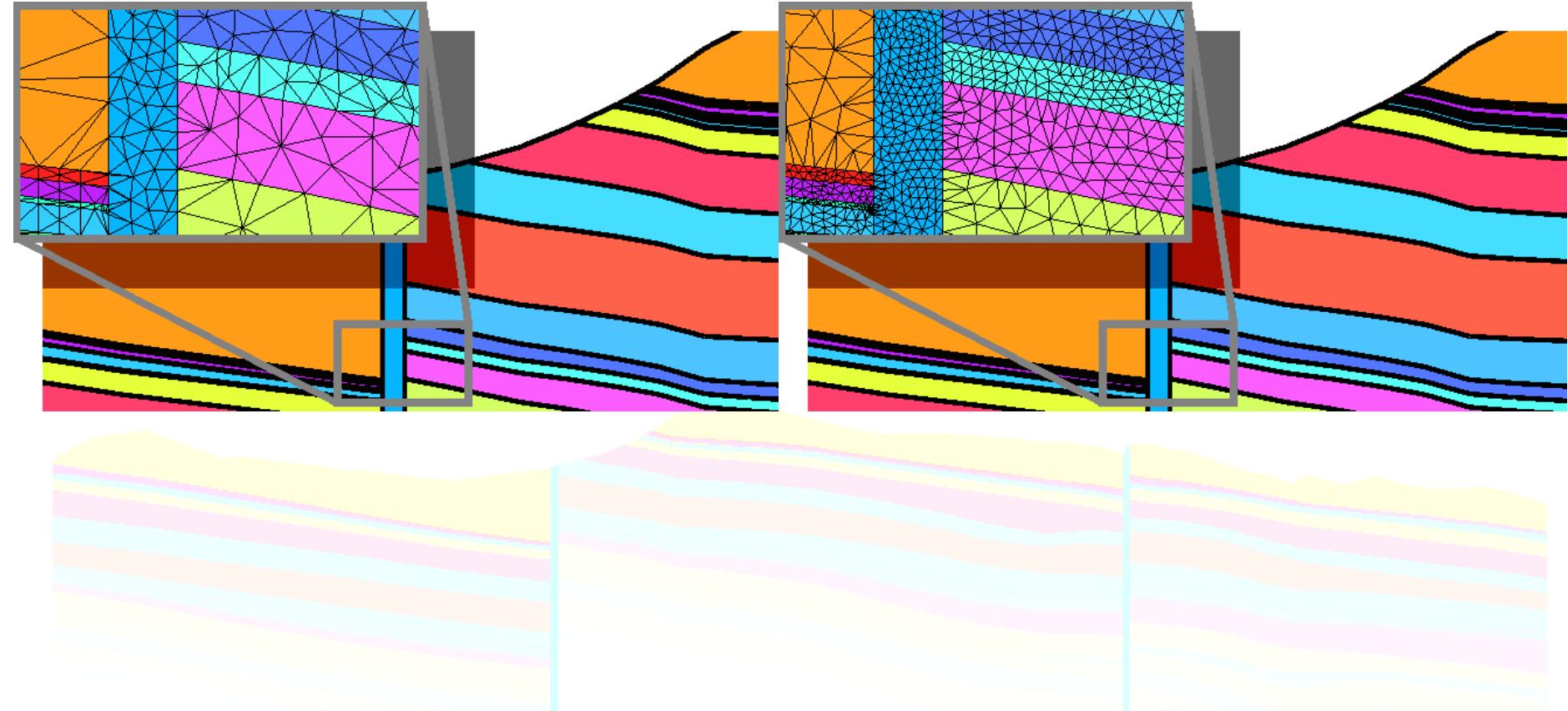
# Mesh Generation Depends on the Solver and Physics

- Quadtree, Octree

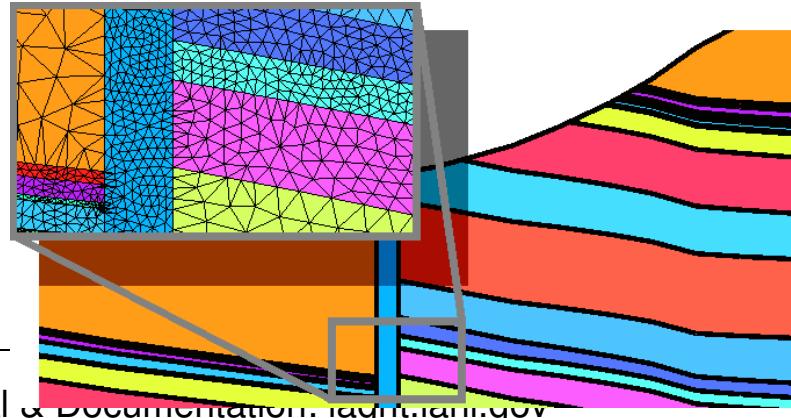
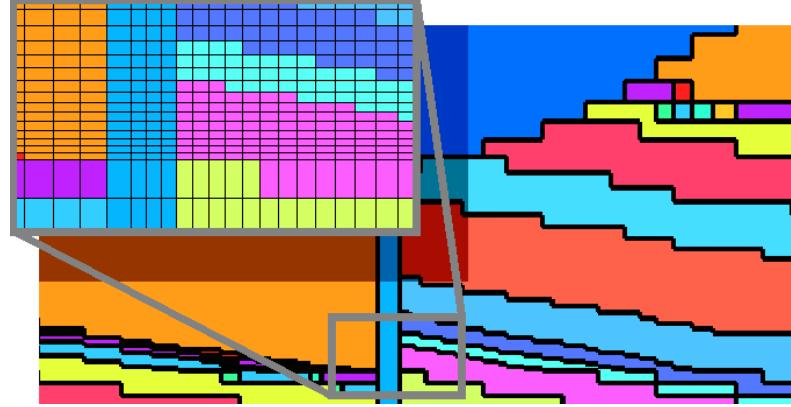
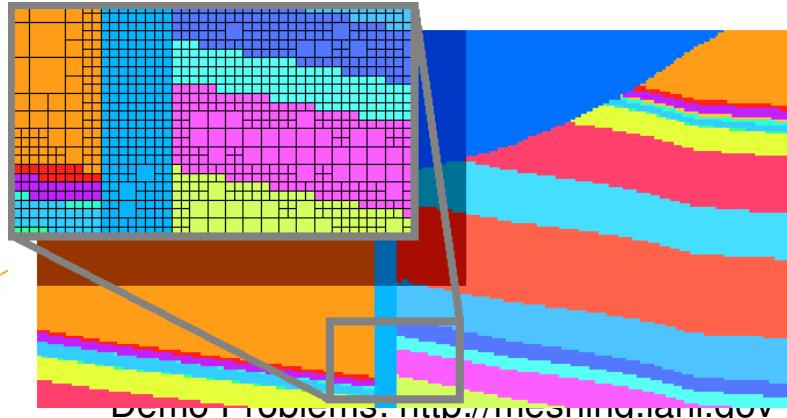
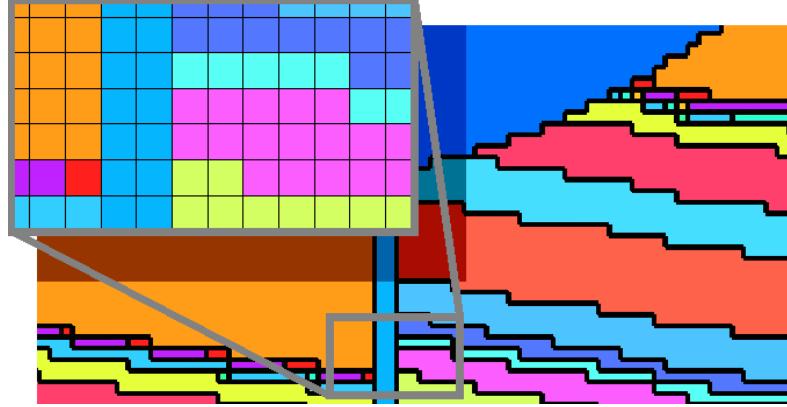
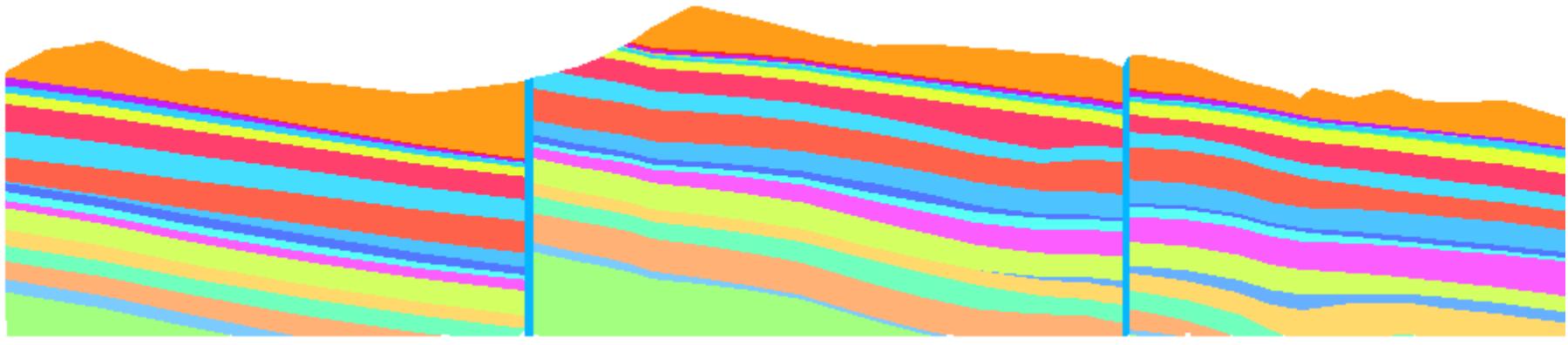


# Mesh Generation Depends on the Solver and Physics

- Unstructured (quad, tri, hex, tet, prism, pyramid, polyhedra)

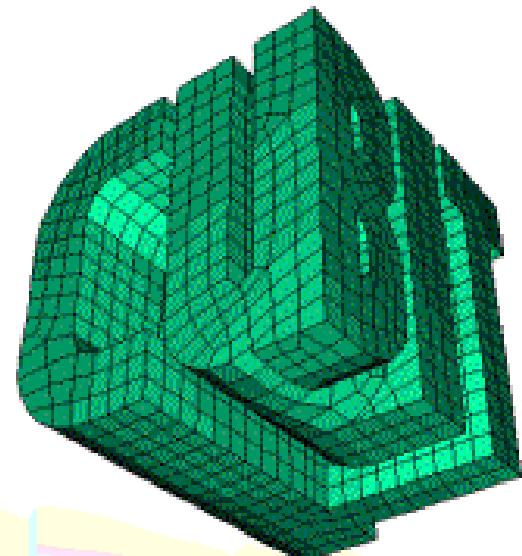
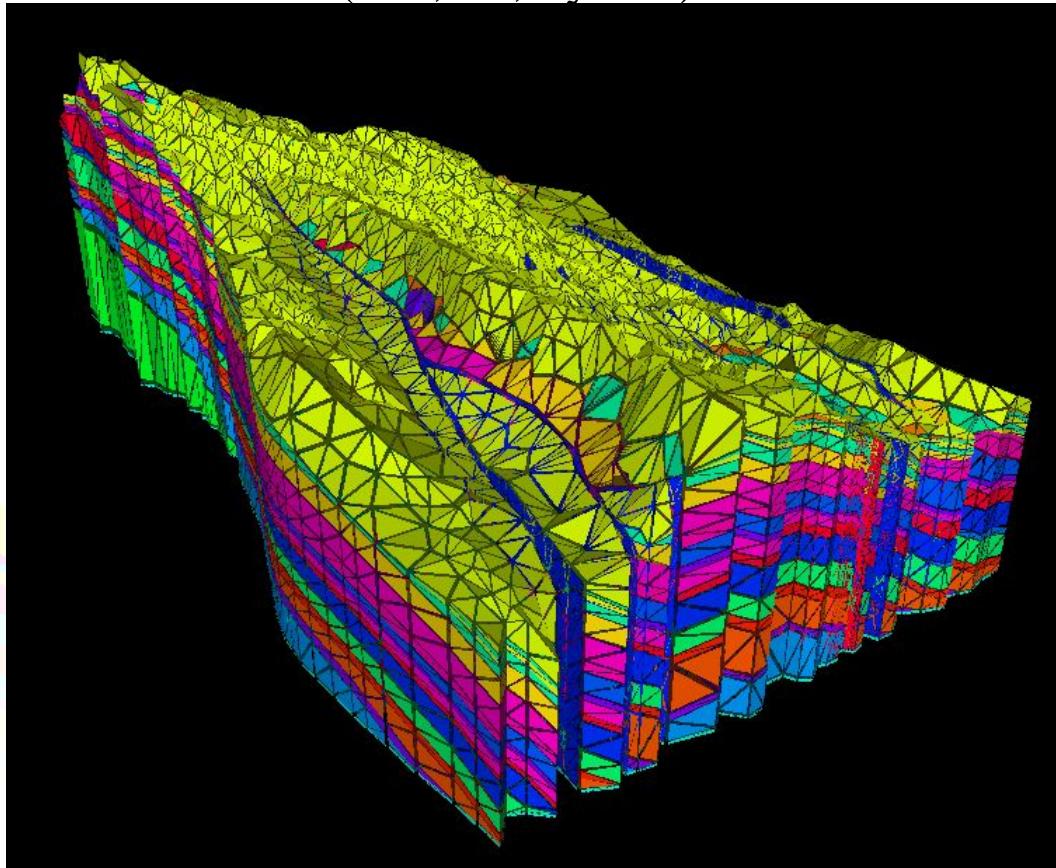


# Same Geometry, Different Mesh Method



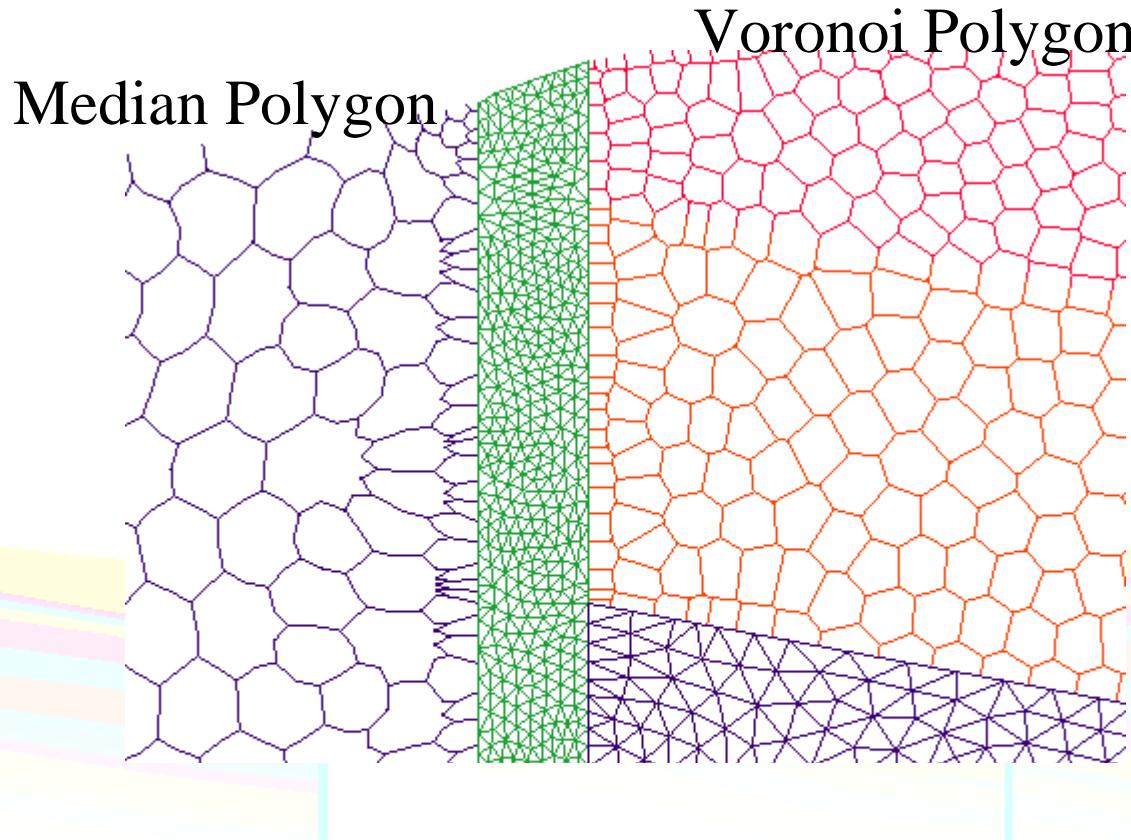
# Mesh Generation Depends on the Solver and Physics

- Unstructured 3D (hex, tet, hybrid)



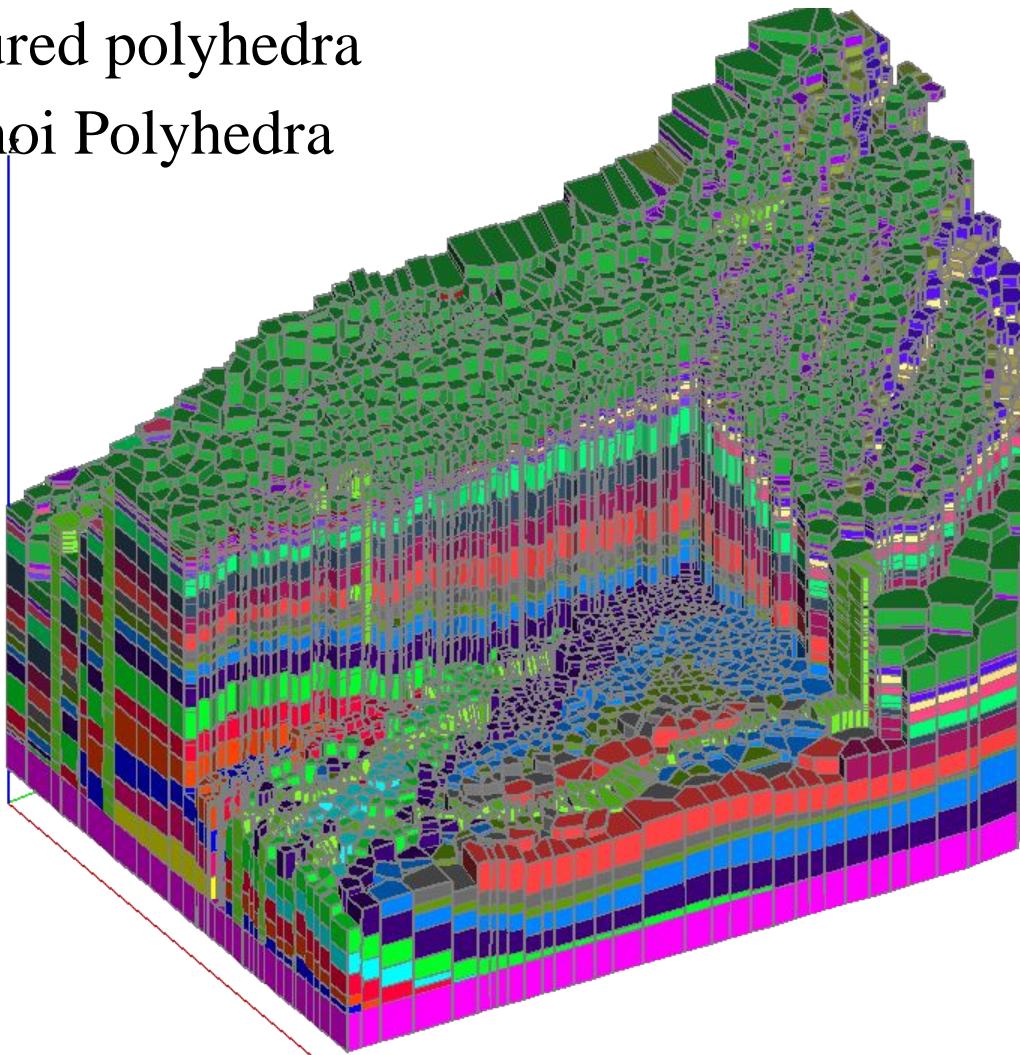
# Mesh Generation Depends on the Solver and Physics

- Unstructured polyhedra (control volume methods)

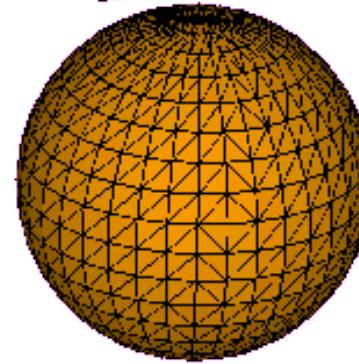
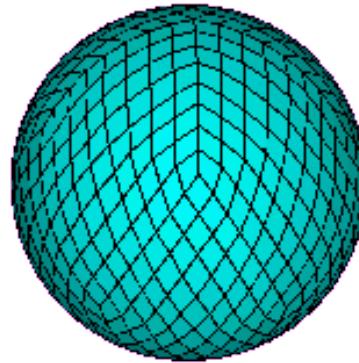
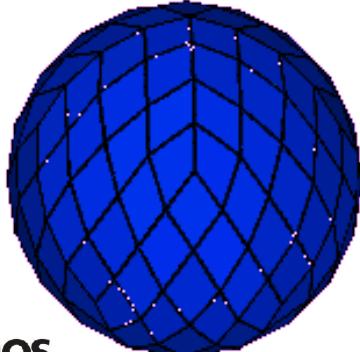
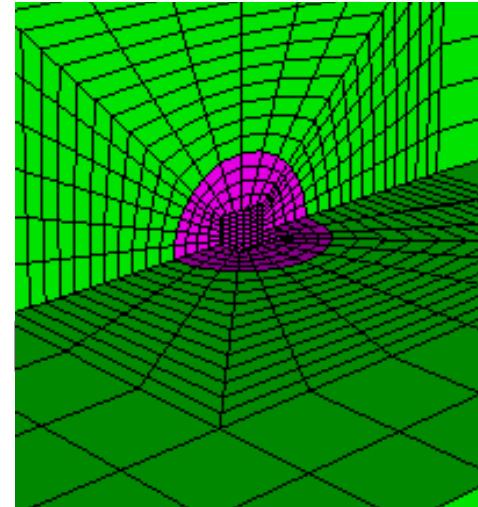
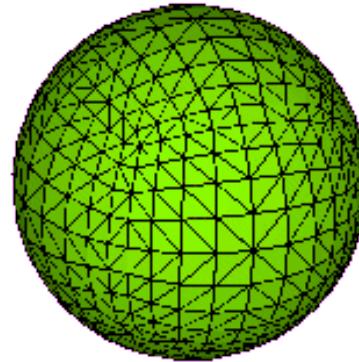
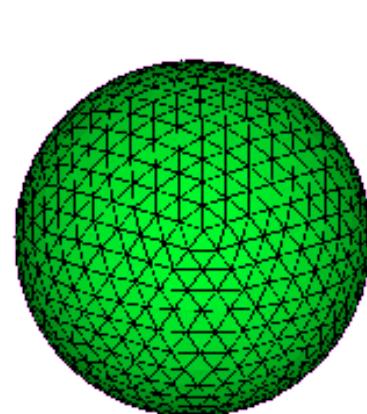


# Mesh Generation Depends on the Solver and Physics

- Unstructured polyhedra  
3D Voronoi Polyhedra



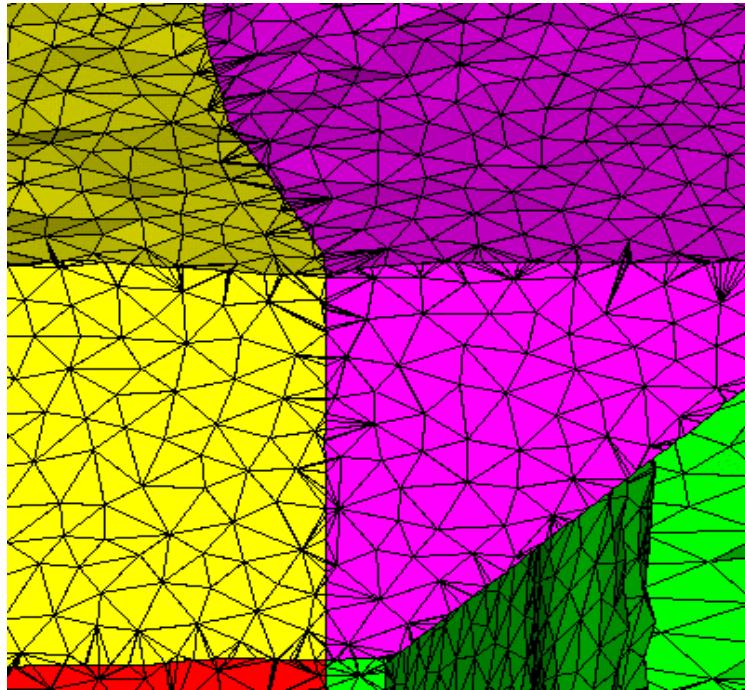
# Mesh Generation Depends on the Solver and Physics



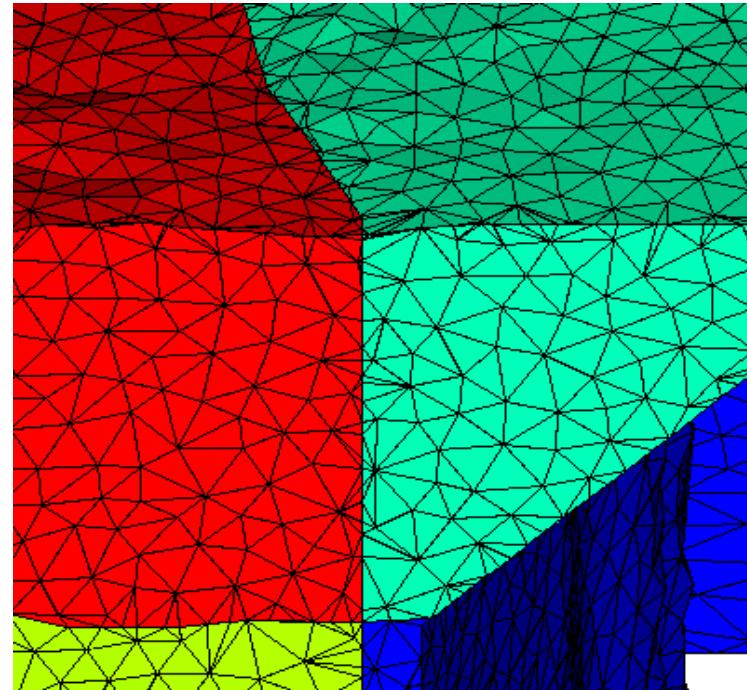
# Mesh Optimization

- **Quality:** *good* and *bad* is application dependent.
- **Flexible tools to characterize and improve mesh quality**
  - Volume, area, length
  - Gradient of volume, area, length
  - Aspect Ratio
  - Angle, min/max angle, angle ratio, solid angle, dihedral angle
  - Error estimate
  - Solution value, solution gradient ( $d/dx$ ,  $d/dx^2$  ), solution error
  - User defined

# Optimize: Refine, Derefine, Smooth

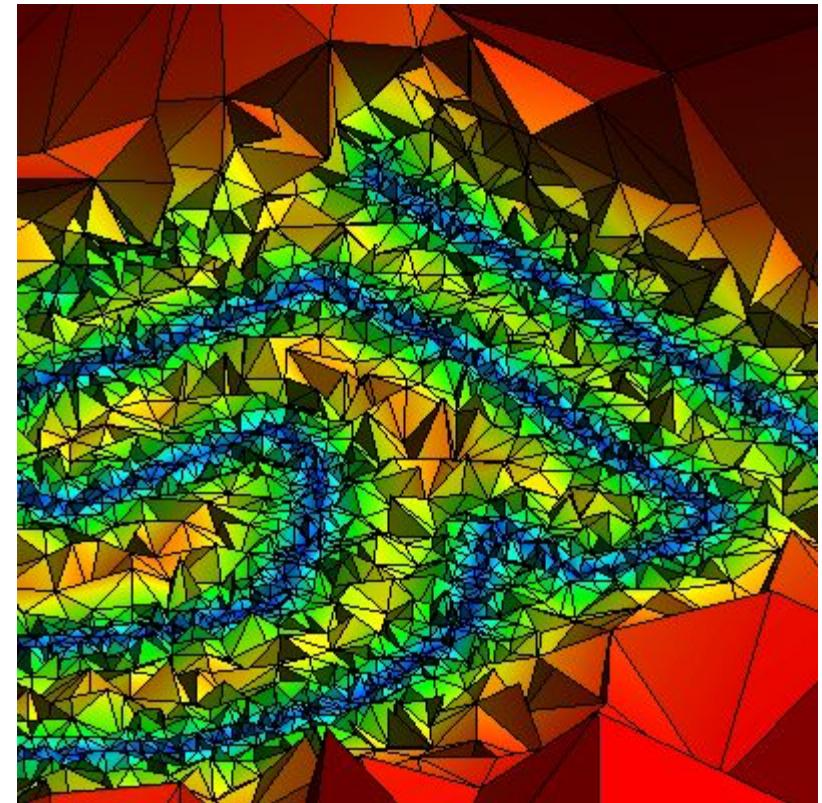


Original Block Triangles



**Filtered Block Triangles:**  
**Remove small area and high aspect ratio elements while maintaining geometry.**

# Optimize: Adapt mesh to user defined function

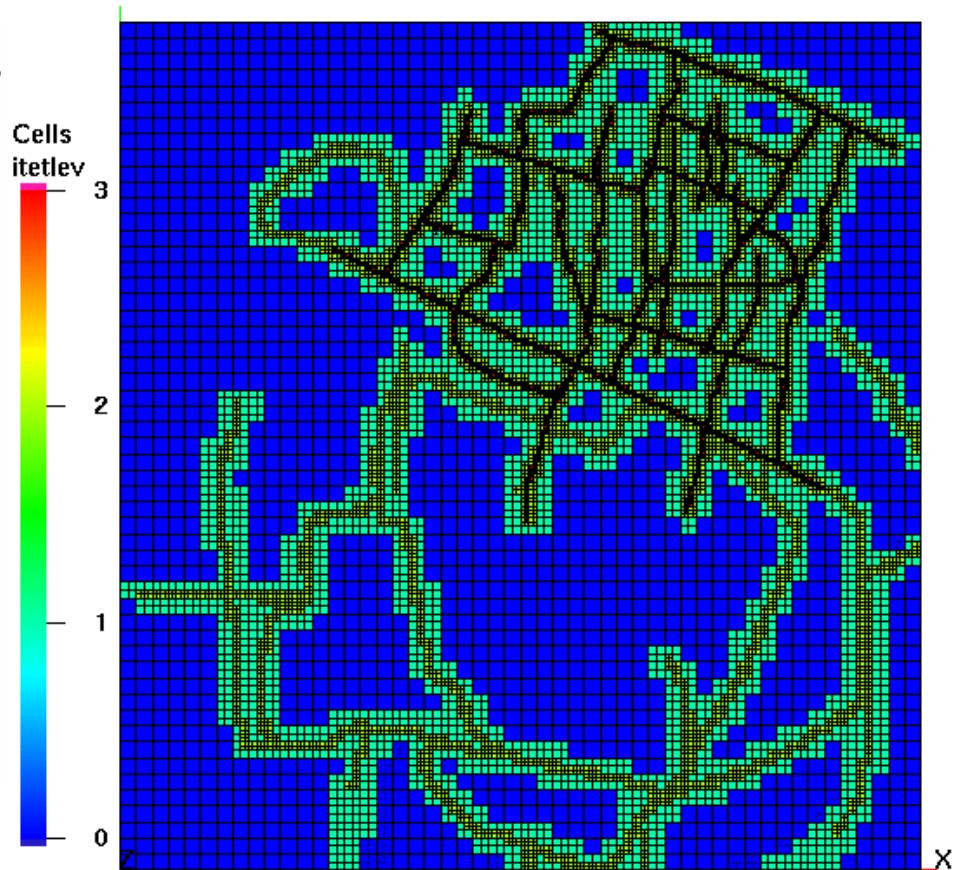
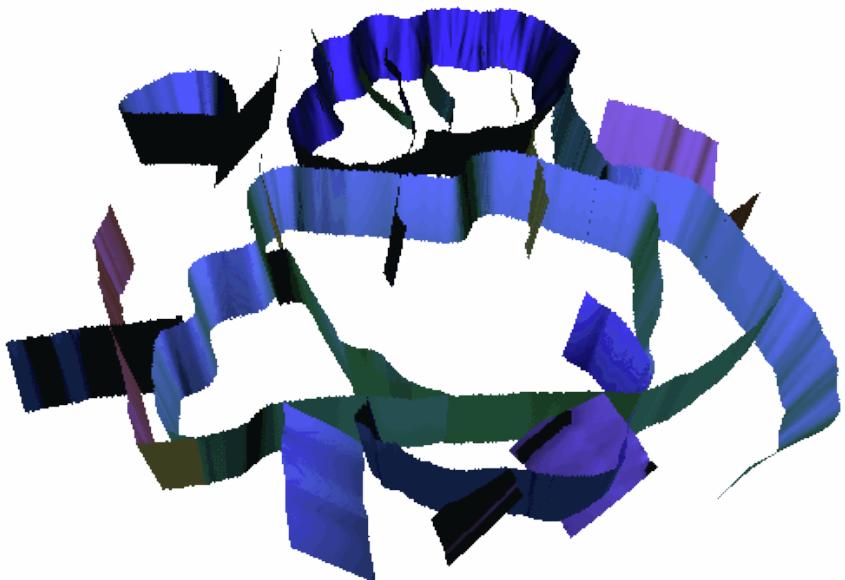


# Boundary and Initial Conditions

- **Mesh to Mesh Interpolation**
  - Set material properties to nodes and/or elements (*e.g.* density)
  - Set boundary conditions from another model (*e.g.* boundary flux)
- **Mesh-Object Intersections**
  - Point (injection), line (well bore), surface (fault), volume (tunnel)
- **Point, Element, Face Set Operations (Intersection, Union, Complement)**

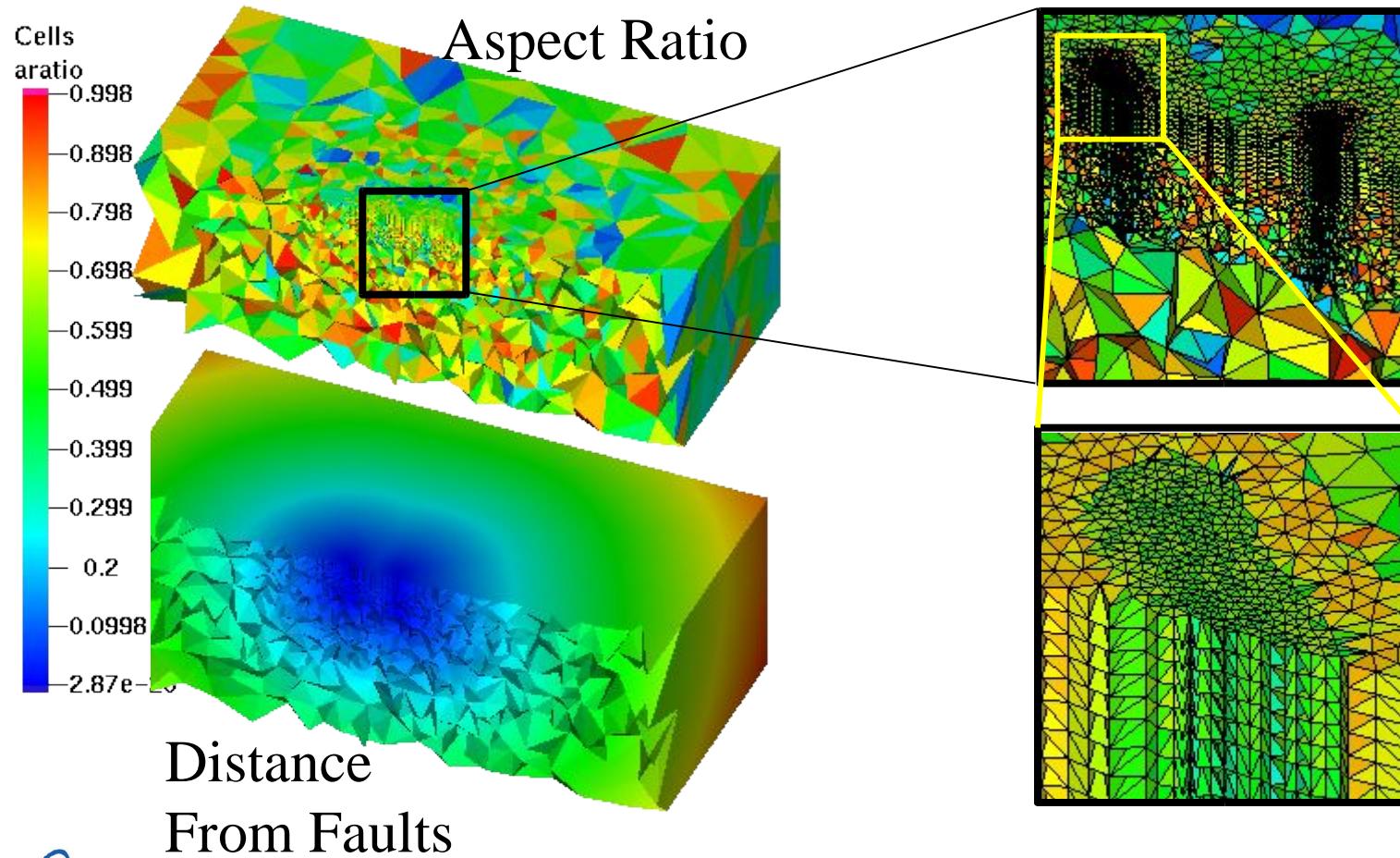
# Boundary and Initial Conditions

## Mesh to Object Intersections



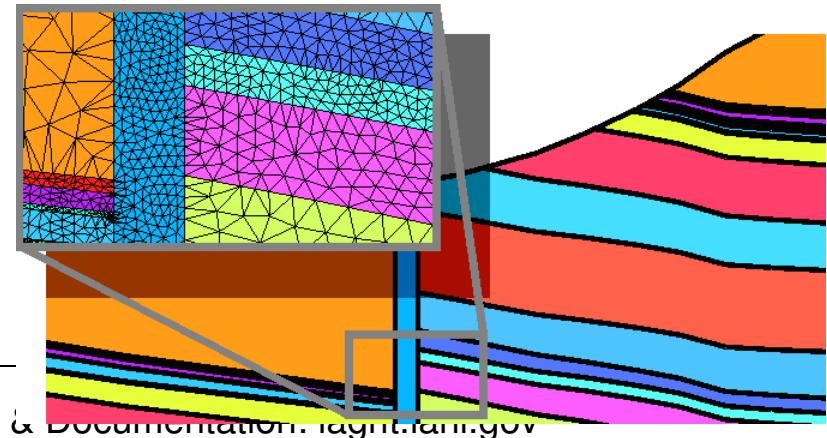
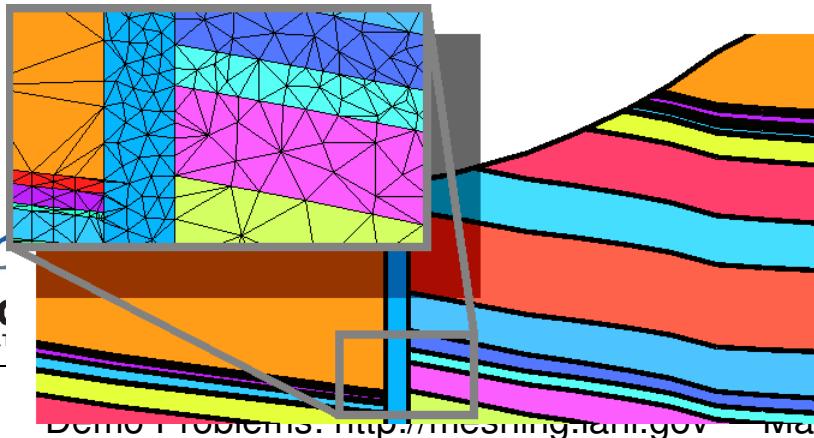
Intersect fault surfaces with mesh to select elements to be refined with quadtree type mesh refinement.

# Landers/Hector Mine, Cut Away View



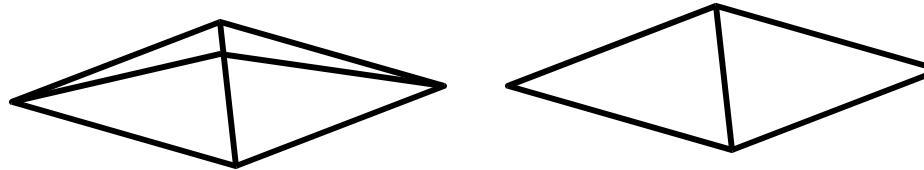
# LaGriT Mesh Optimization

- Refine
  - edge, face, element
  - Rivara
- Refine
  - field value, field gradient, aspect ratio, volume, arbitrary point

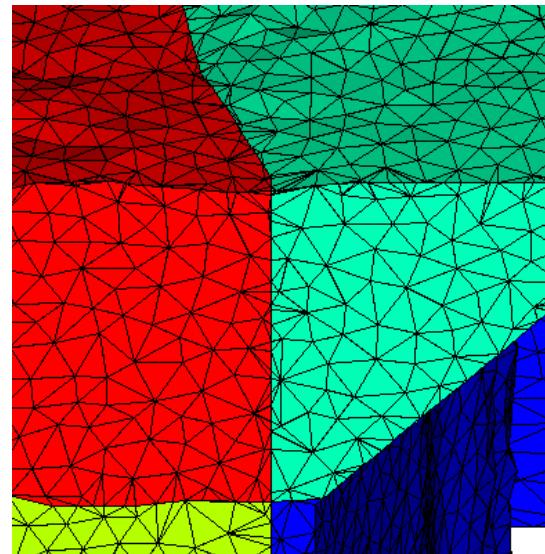
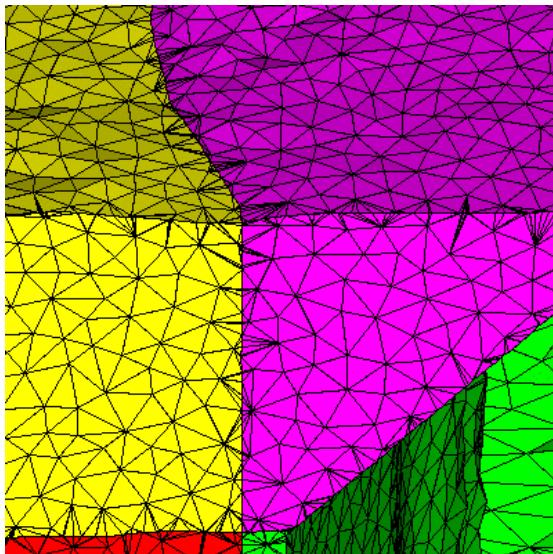


# LaGriT Mesh Optimization

- Derefine



- edge length, volume, aspect

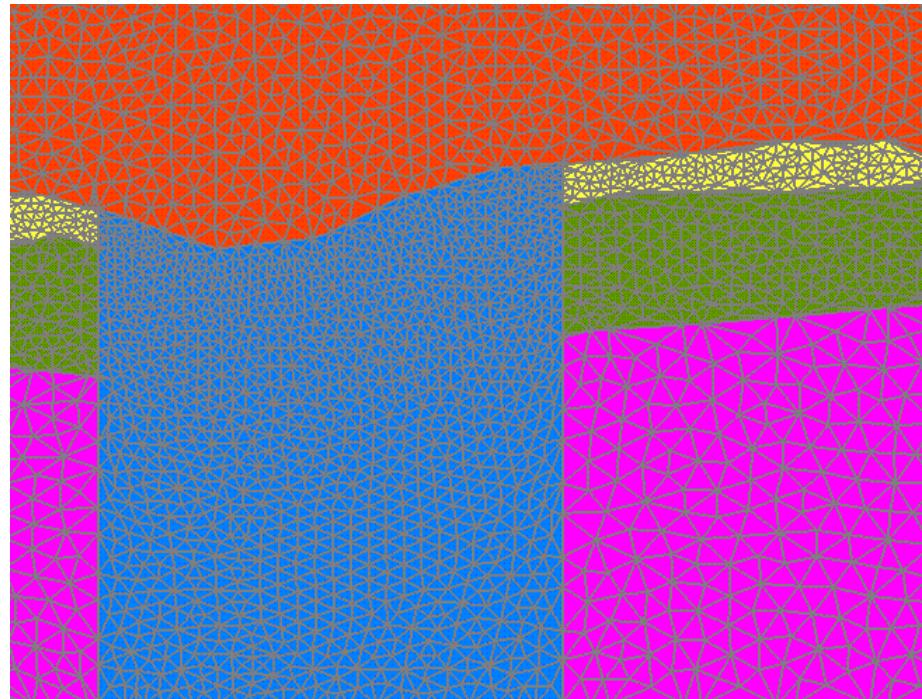
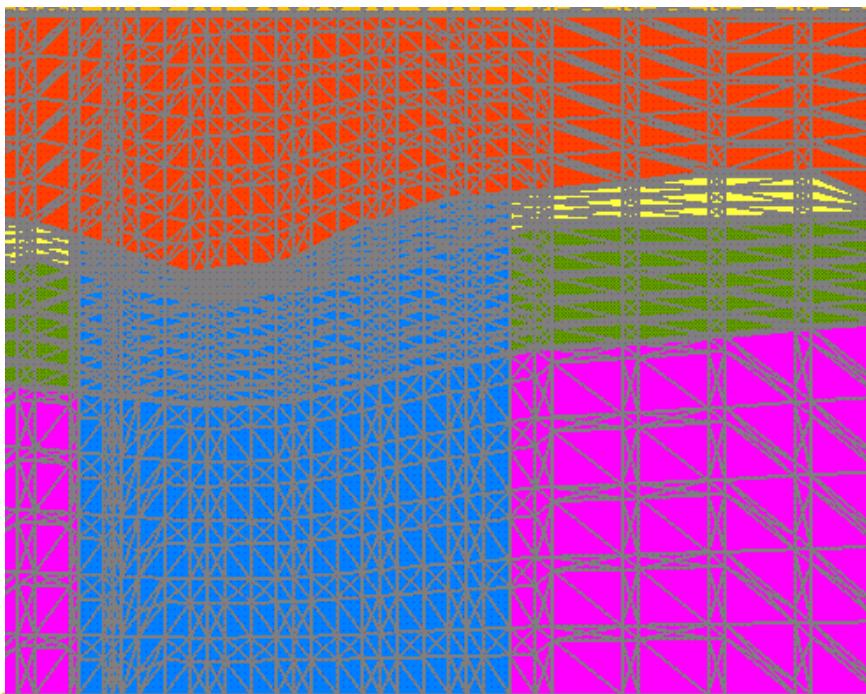


Original Elements

Filter: Remove small area and  
high aspect ratio elements while  
maintaining geometry.

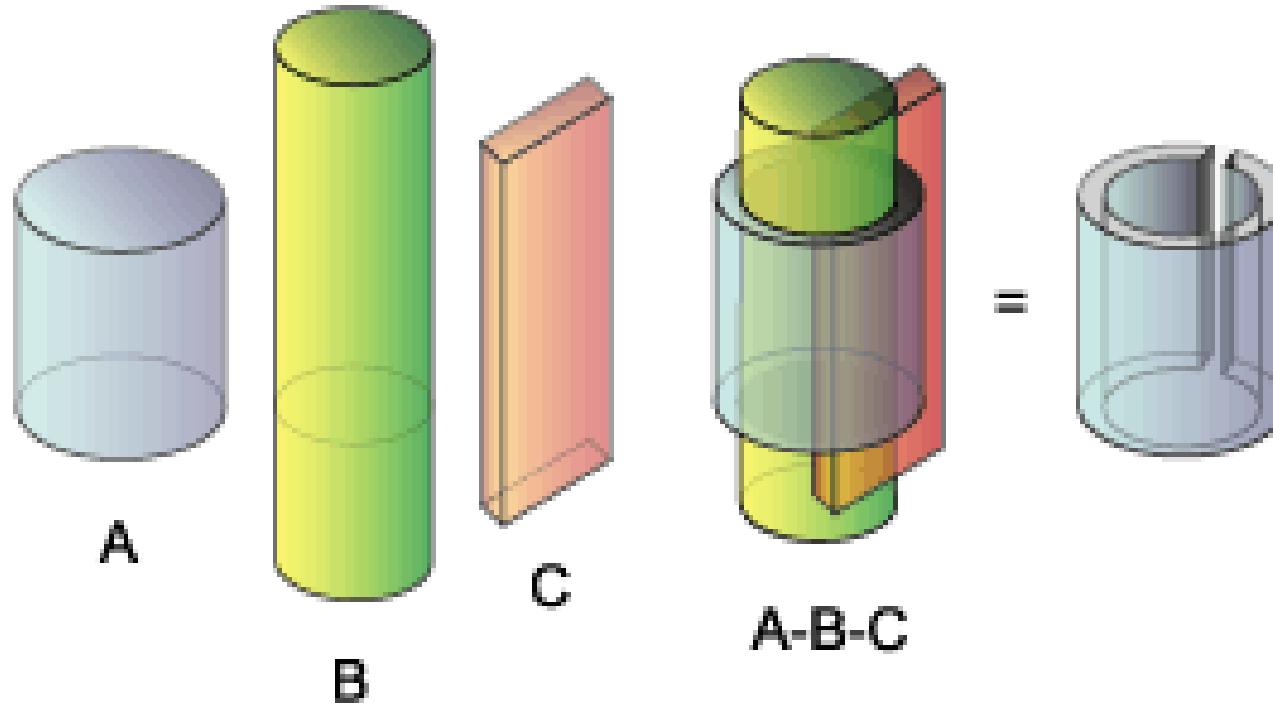
# LaGrit Mesh Optimization

- Smooth
  - elliptic, laplace, random
- Massage - refine-derefine-smooth



# LaGriT Geometry

- Constructive Solid Geometry



```
surface/s_a/interface/cylinder/x1,y1,z1/x2,y2,z2/radius  
surface/s_b/interface/cylinder/x1,y1,z1/x2,y2,z2/radius  
surface/s_c/interface/box/xmin,ymin,zmin/xmax,ymax,zmax/  
surface/s_ring/gt s_c and gt s_b and le s_a
```

# LaGriT Element and Node Manipulation Commands

- **Translate**
- **Scale**
- **Rotate:** `rotatept`,  
`rotateln`
- **Filter**
- **Perturb**
- **Remove**
- **Multi-Key Sort**
- **Reorder**
- **KDTree Search**

# LaGriT Grid Attributes

- **Real and integer node and element attributes**
- **Element area, element volume**
- **aspect ratio, dihedral angle, solid angle, min/max edge length ratio**
- **Identify Sliver, Wedge, Needle, Cap**
- **Unit normal, area normal vector**
- **Synthetic normal to surface nodes**
- **Volume/Area integration of floating point node or cell attributes**
- **Dual mesh connectivity**
- **Voronoi and median volume and face area**

# LaGriT Output Options

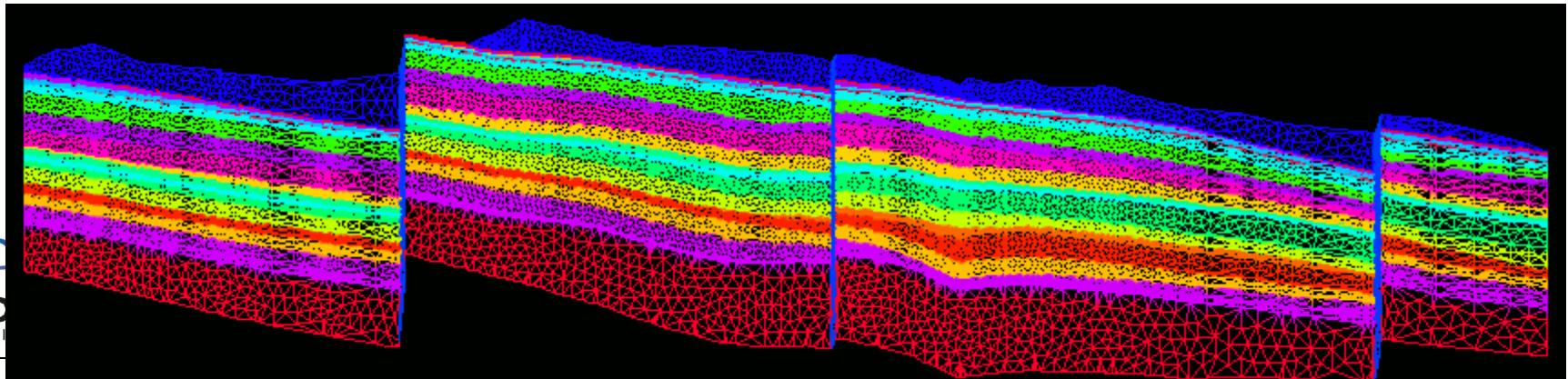
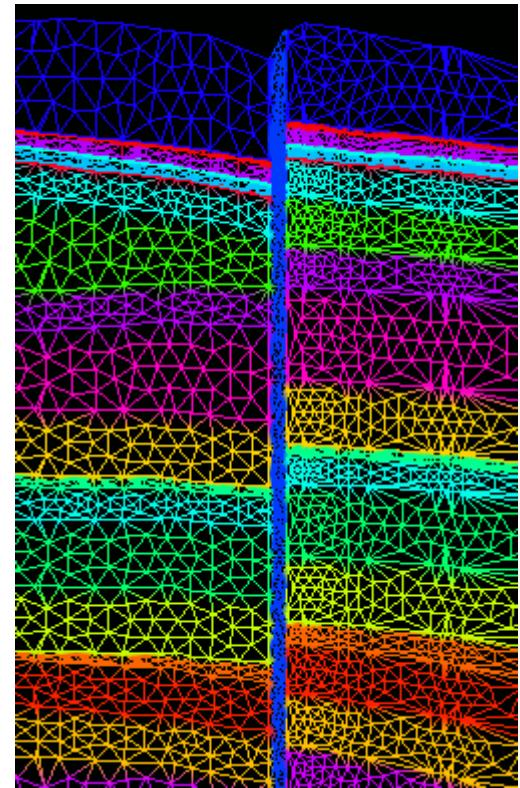
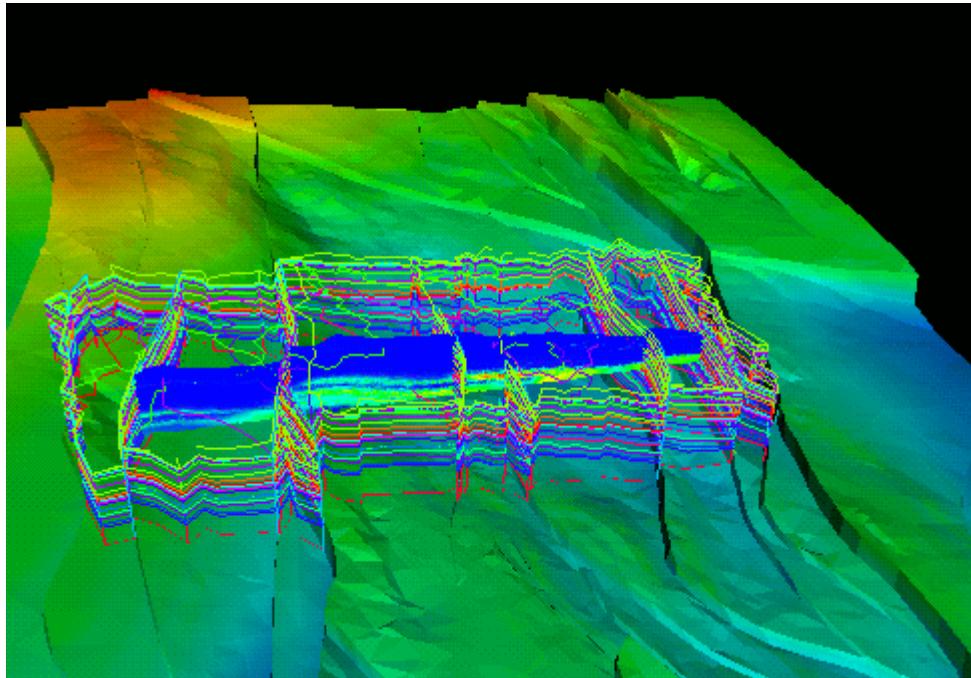
- PyLith
- GeoFEST
- FEHM
- AVS, GMV, Tecplot, (netCDF)
- STL, FLAG, X3D

# Mesh Manipulation

- Extract Lower D - 3D – 2D – 1D
  - Volume, Face, Line
- Extract 2D Surface (plane, isosurface, arbitrary triangulation) from 3D mesh
- Extract Line (well bore) from 3D mesh

# Mesh Manipulation

- Extract 2D Surface (plane) from 3D mesh.



# METIS Interface

- Supports METIS mesh partition algorithm calls

Partition:

```
metis /partition/ metis_partmeshnodal / node / 32  
metis /partition/ metis_partmeshdual / dual / 32
```

Reorder:

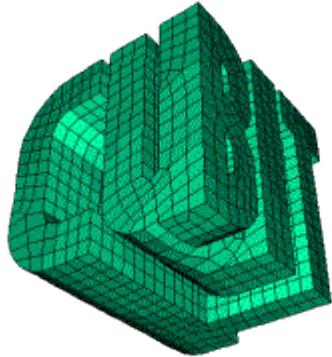
```
metis / reorder / metis_edgend / dual  
metis / reorder / metis_nodend / node
```

# What is the LaGriT Interface?

- **Command Line Driven**
- **Control File Driven**
- **Call from Fortran, C, C++**
- **Data structures can be accessed and manipulated by user code.**
- **Developer interface for extension and user modules**
- **Platforms: Linux, Mac, Sun, SGI**

## What LaGriT Is Not

- No GUI interface
- No advancing front algorithm
- No interface for ACIS, Autocad, ... CAD
- Not unstructured hex mesh (see Cubit)

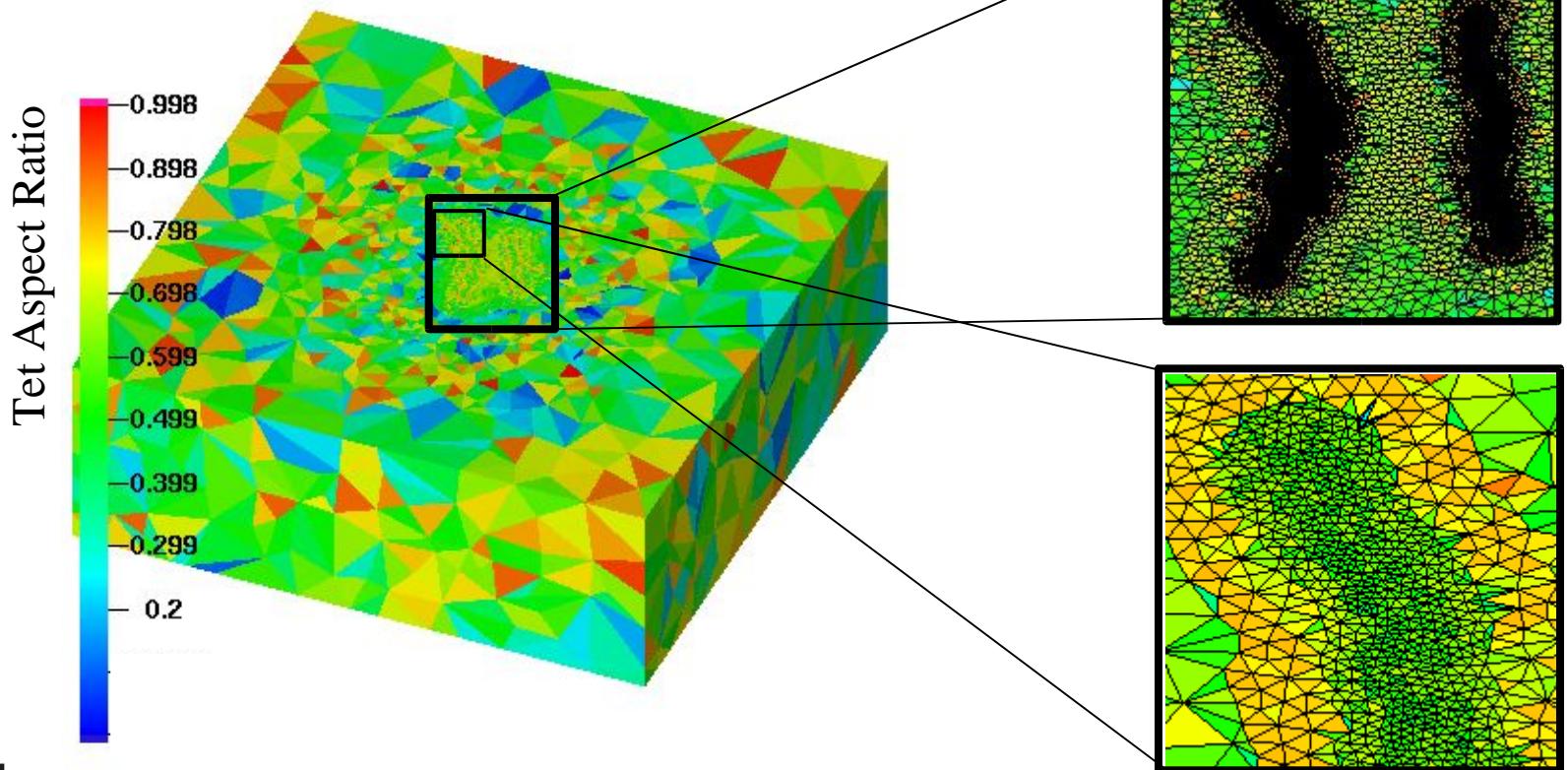


# Finite Element Mesh With CFM

## Landers & Hector Mine Faults

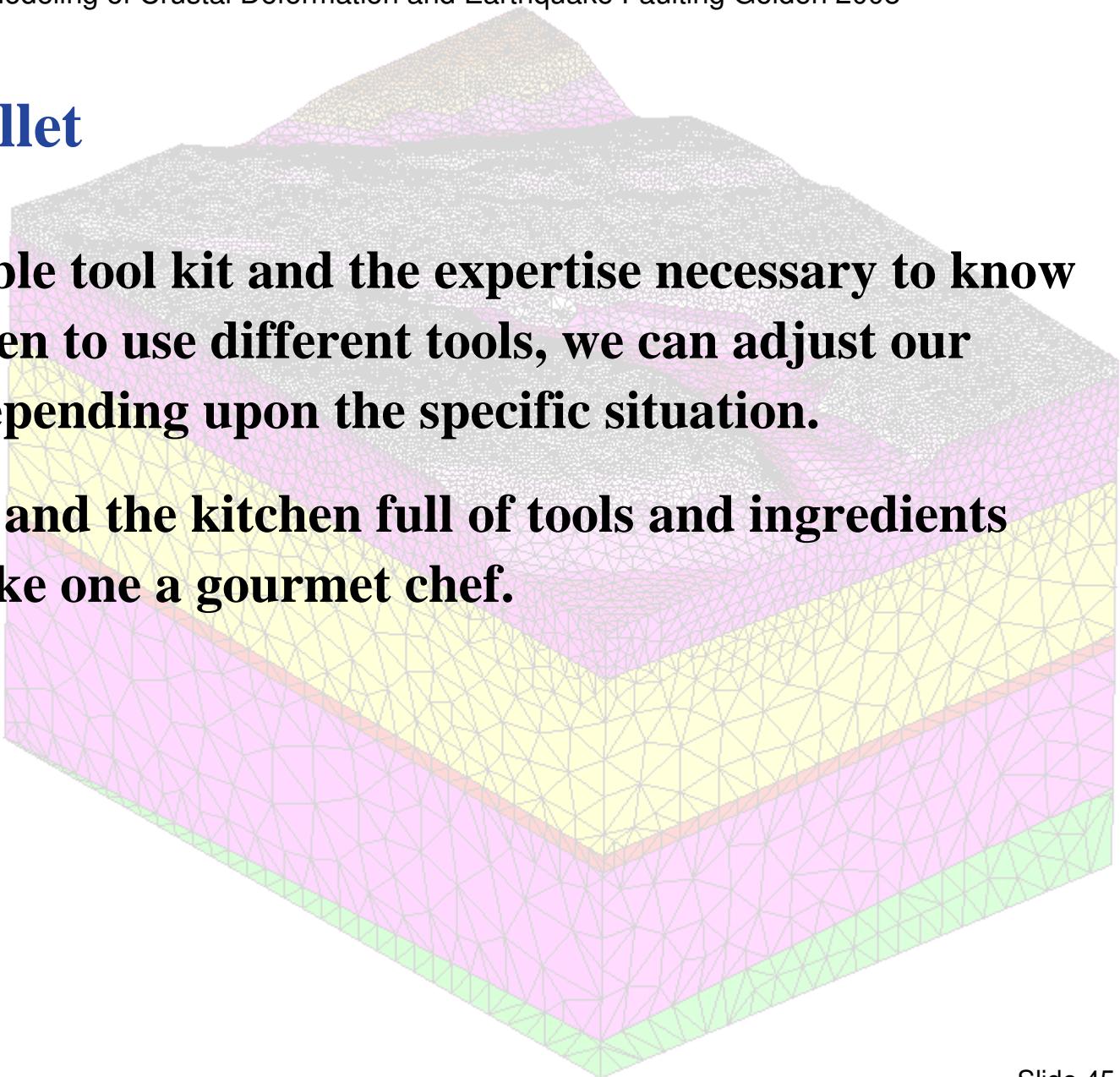
- Tetrahedral Finite Element Mesh
- 340km EW, 360km NS, 124km Z

- Element size ~50km far field
- Element size ~500m near faults

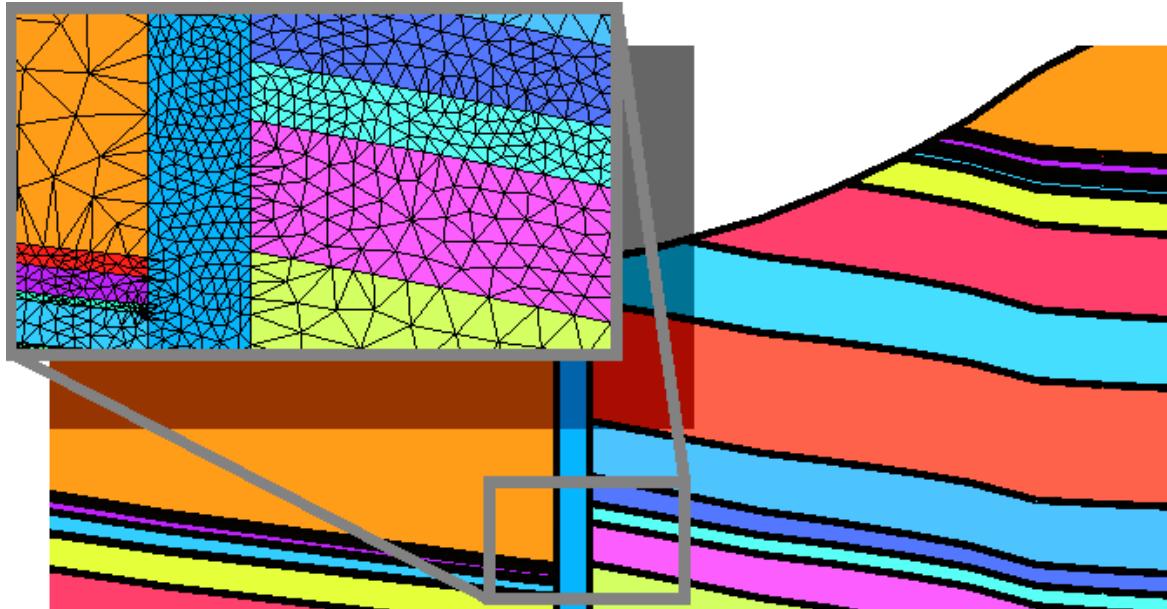


# No Silver Bullet

- With a **flexible tool kit** and the expertise necessary to know how and when to use different tools, we can **adjust our approach** depending upon the specific situation.
- A **cookbook** and the kitchen full of tools and ingredients does not make one a **gourmet chef**.



- **Demo problems with all input and LaGriT control files can be found at the URL  
<http://meshing.lanl.gov>**
- **Documentation and user manuals for LaGrit can be found at the URL <http://lagrit.lanl.gov>**



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