LaGriT Mesh Generation and Model Set Up: Introduction

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Los Alamos National Laboratory

http://meshing.lanl.gov http://lagrit.lanl.gov

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LaGriT Mesh Generation and Model Set Up

- LaGriT – Los Alamos Grid Toolkit
- General meshing and setup, pre & post processing package
- Present examples from various geological applications
- http://lagrit.lanl.gov

Geologic Modeling and Simulation Workflow

Conceptual Model

Geologic Framework Model (GFM)

Mesh Generation

Mesh Optimization

Set Up: BC and IC

Physics Model

Results, Interpretation, Decision

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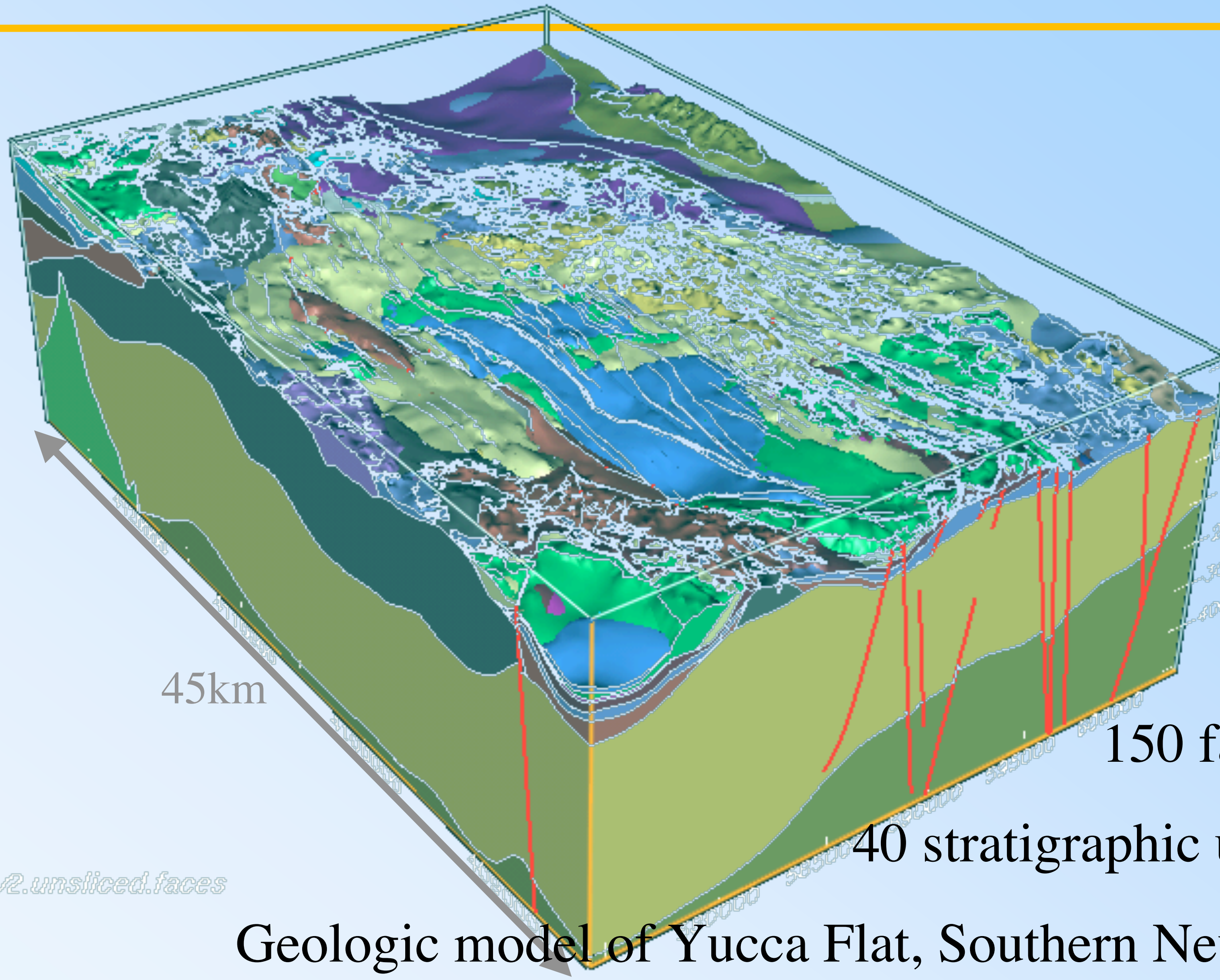
Geologic Framework Models (GFM) vs CAD



150 faults

40 stratigraphic units

Geologic model of Yucca Flat, Southern Nevada

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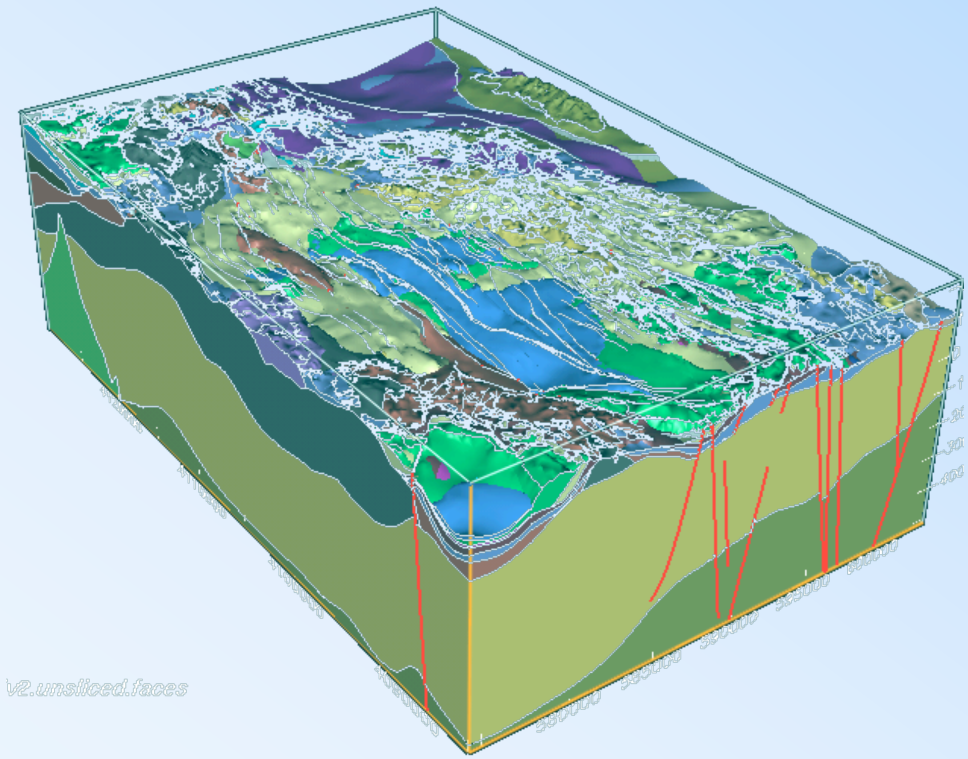

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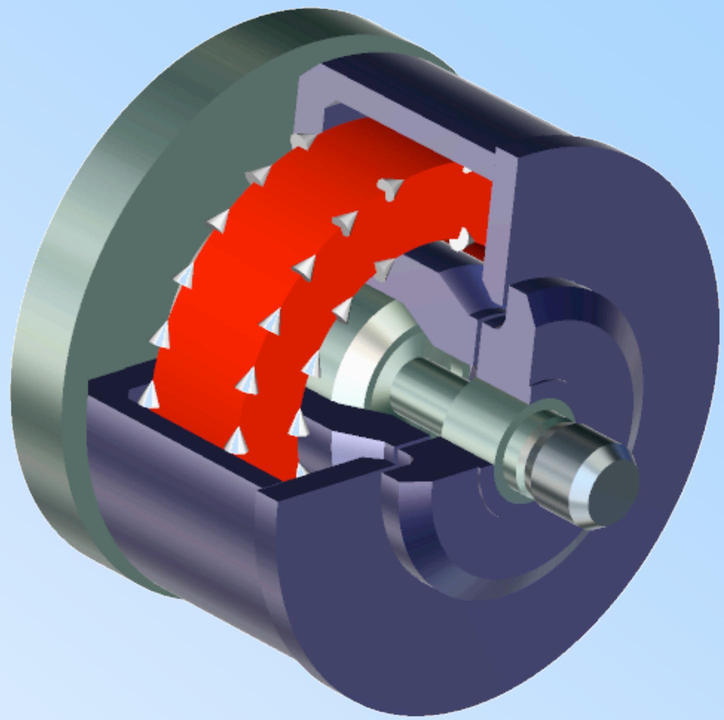

CAD Model

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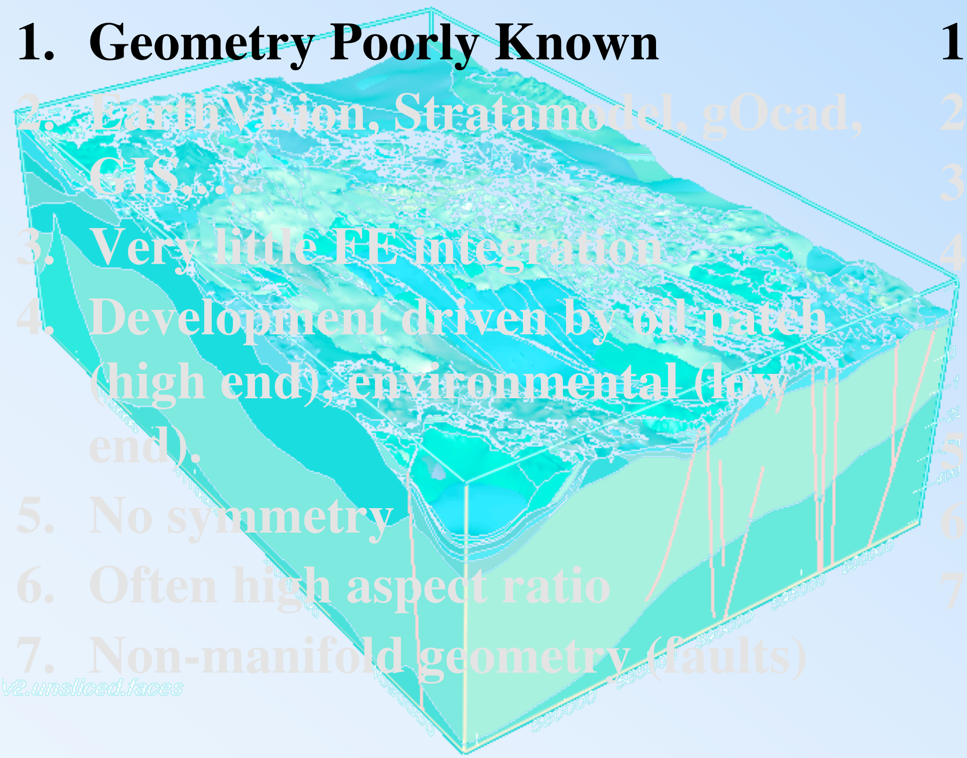
Comparison of GFM vs CAD

GFM 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
7. Non-manifold geometry (faults)



• CAD Engineering

1. Geometry Know to High Precision
2. CAD Model (ACIS, Pro/E, Autocad)
3. FE application well integrated
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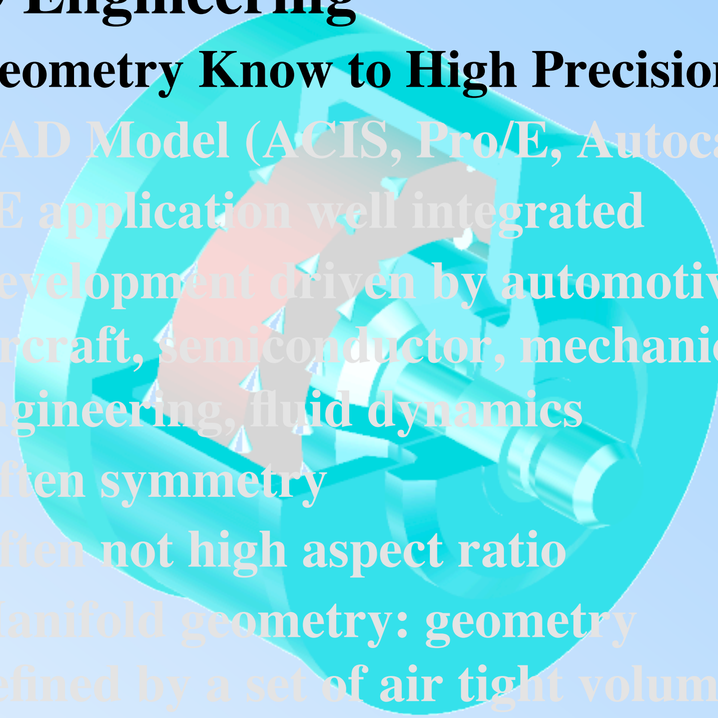

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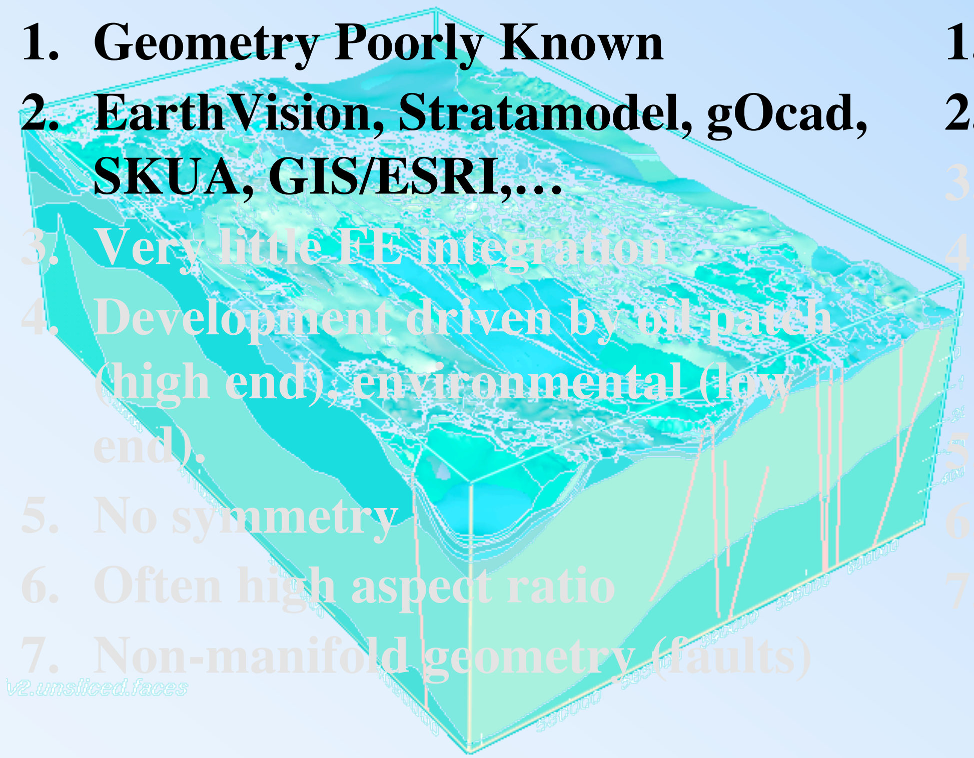

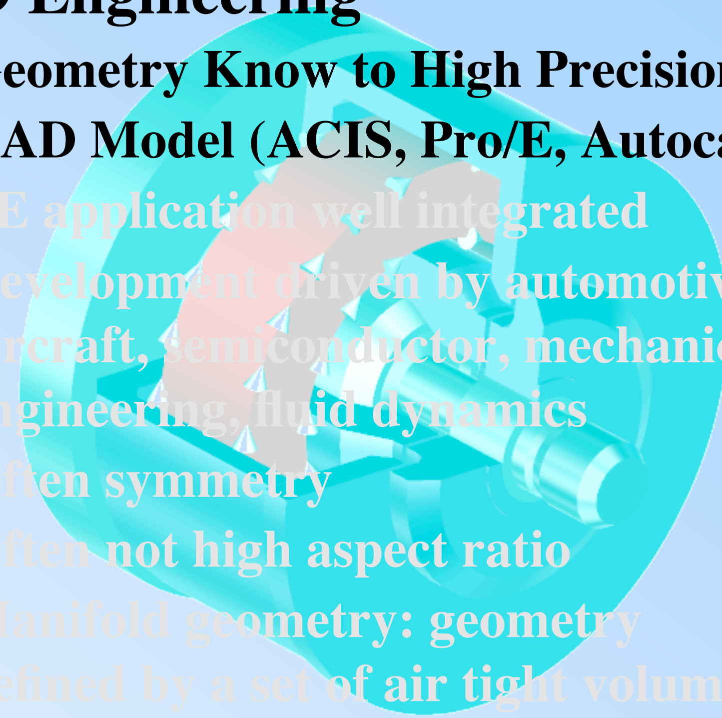

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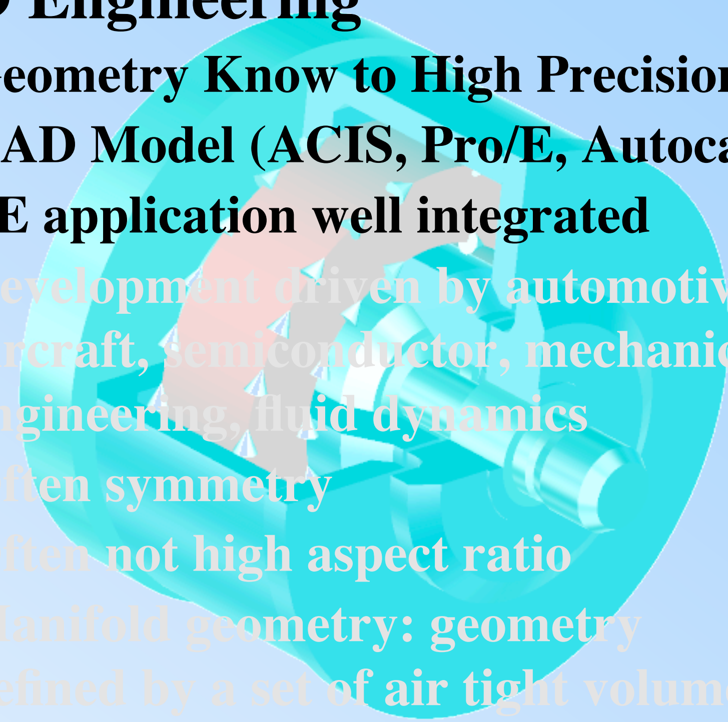

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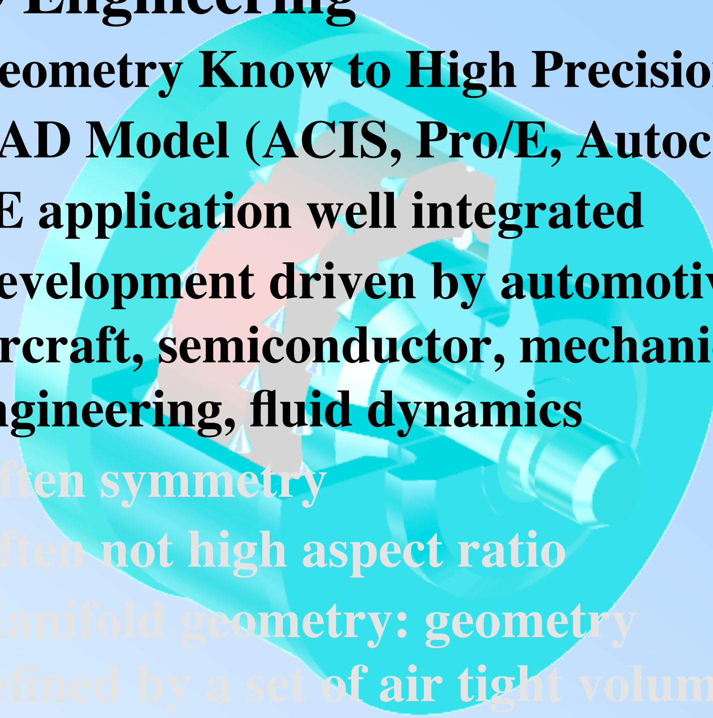

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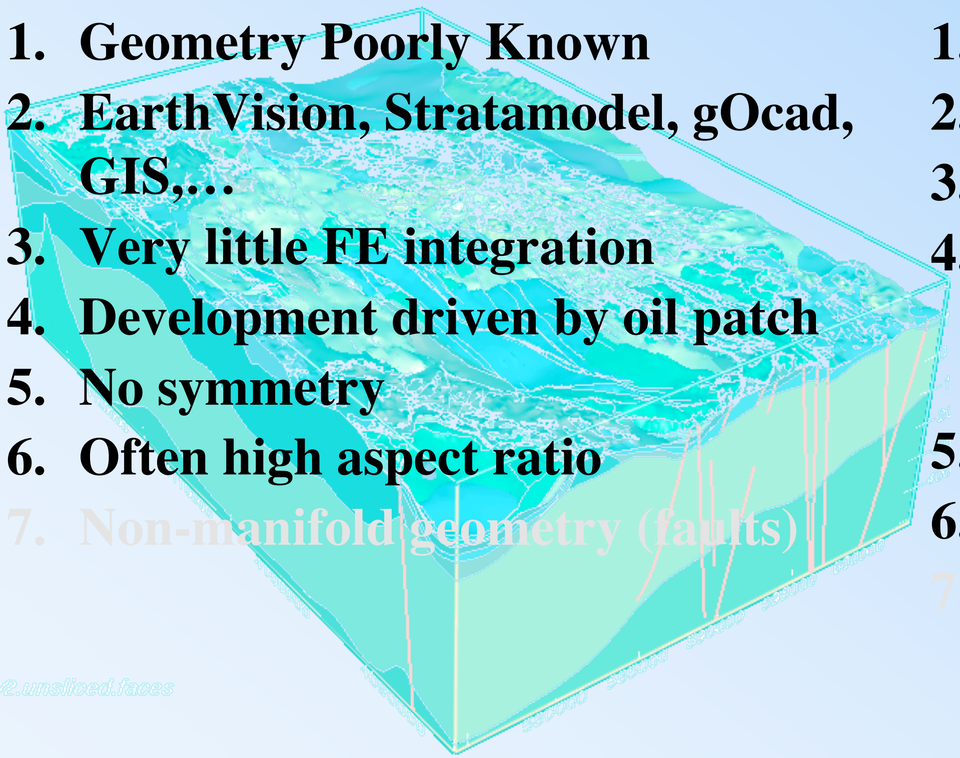

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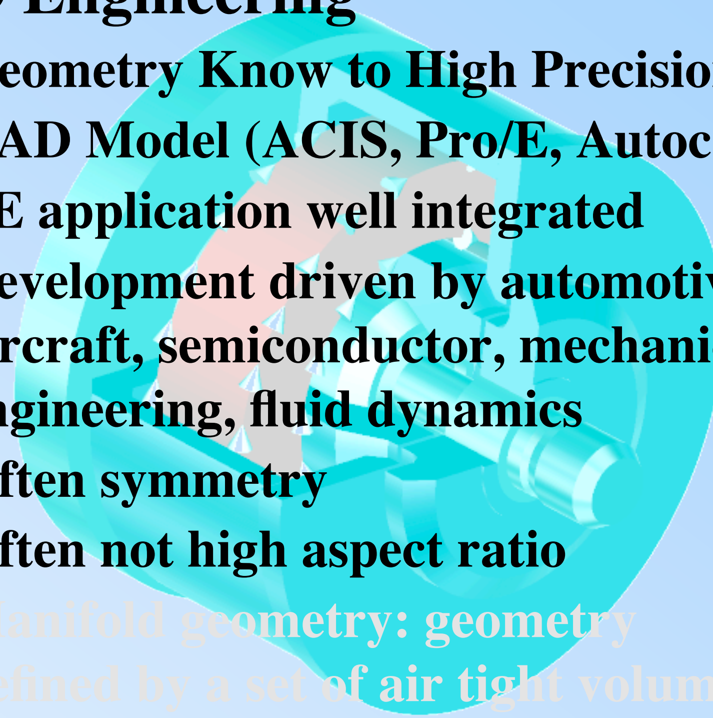

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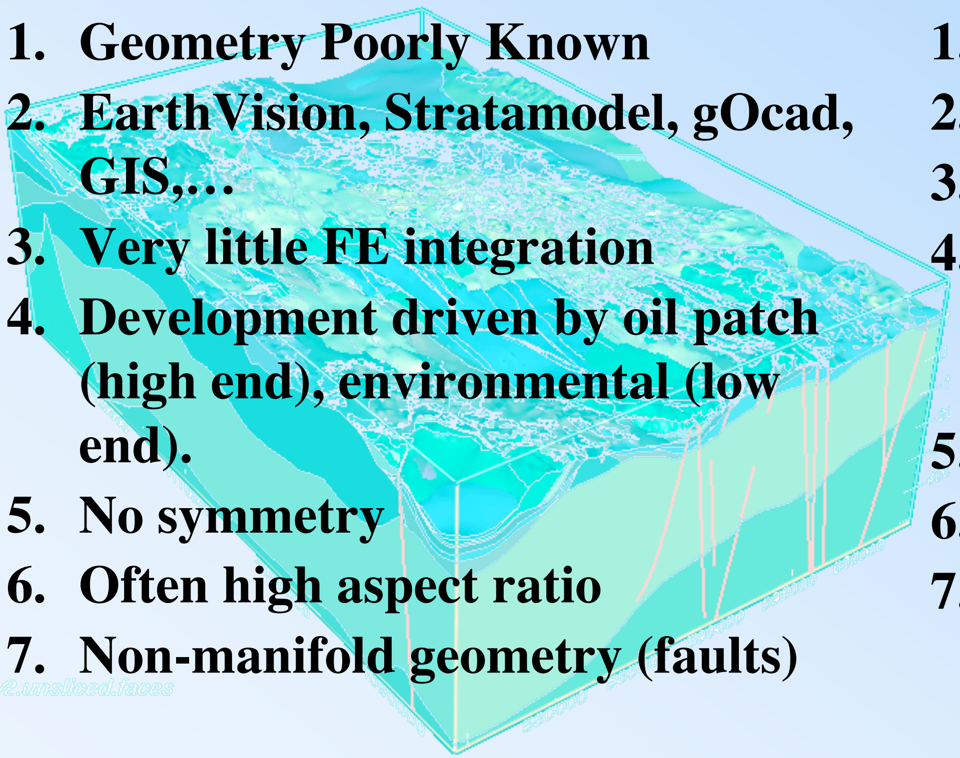

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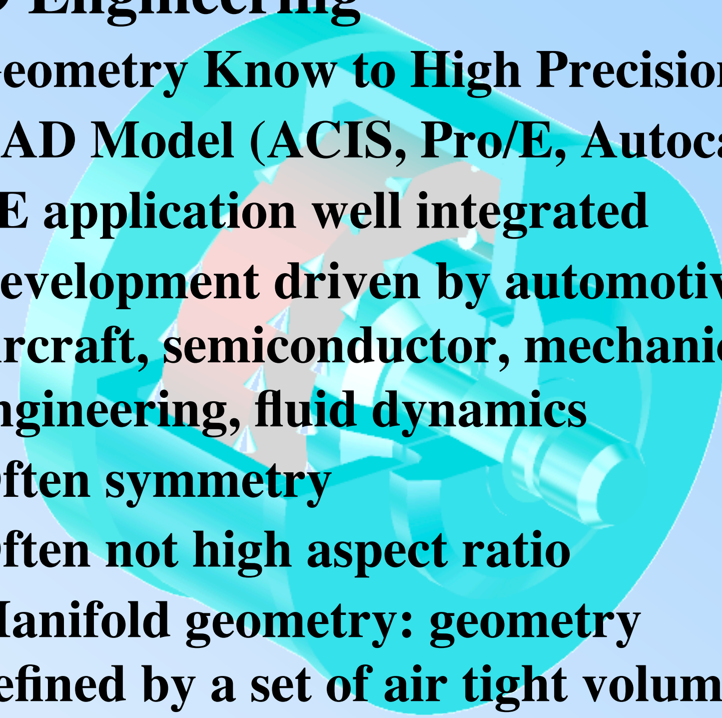

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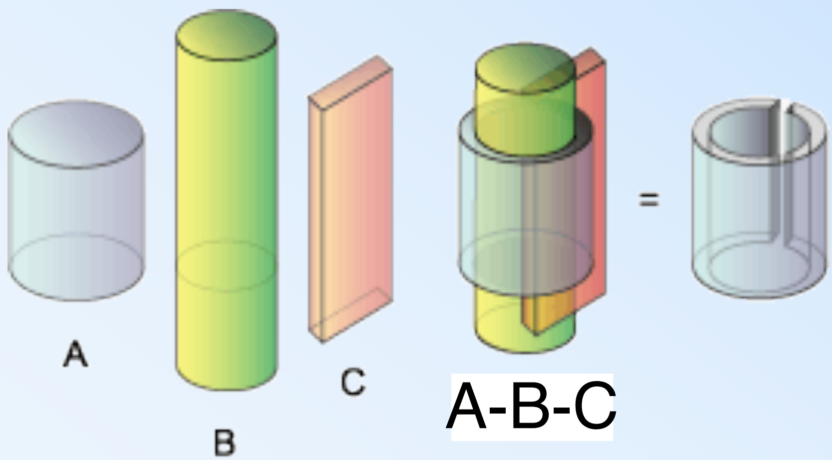
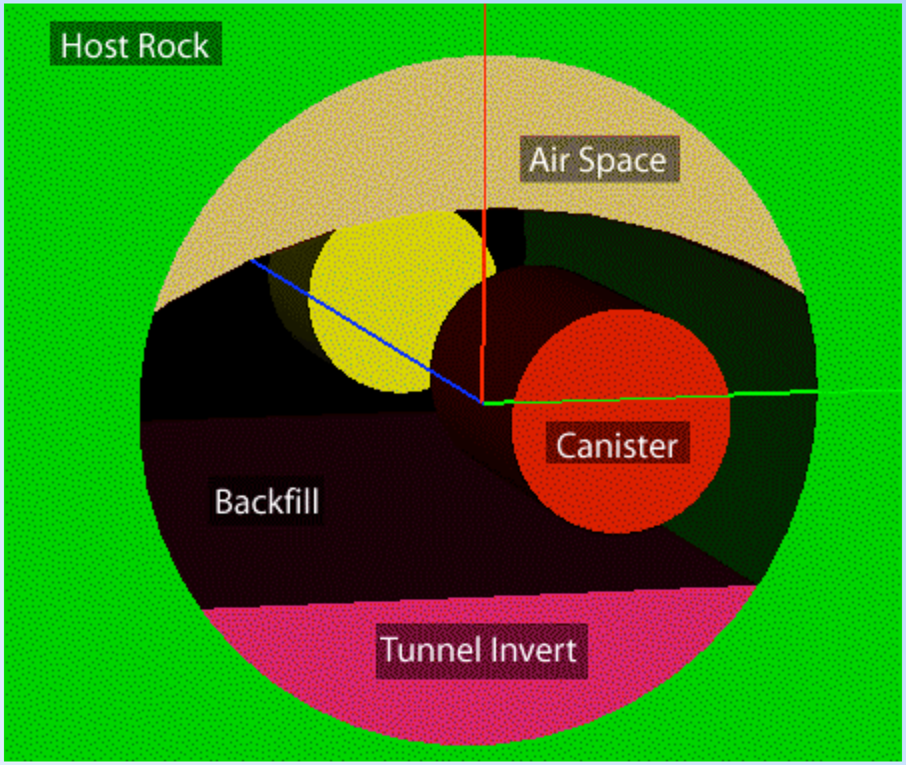
Forms of Geologic Framework Models (GFM)
Forms of Input to Meshing

- Picture
- Map
- Cross Section
- Collection of surfaces that bound volumes
- Non-manifold Geometry
- Cellular model of 2D or 3D space (triangle, quadrilateral, hexahedral, tetrahedral, prism, pyramid, polygon, polyhedral)
- CAD
- Geologic modeling software

Forms of GFMs

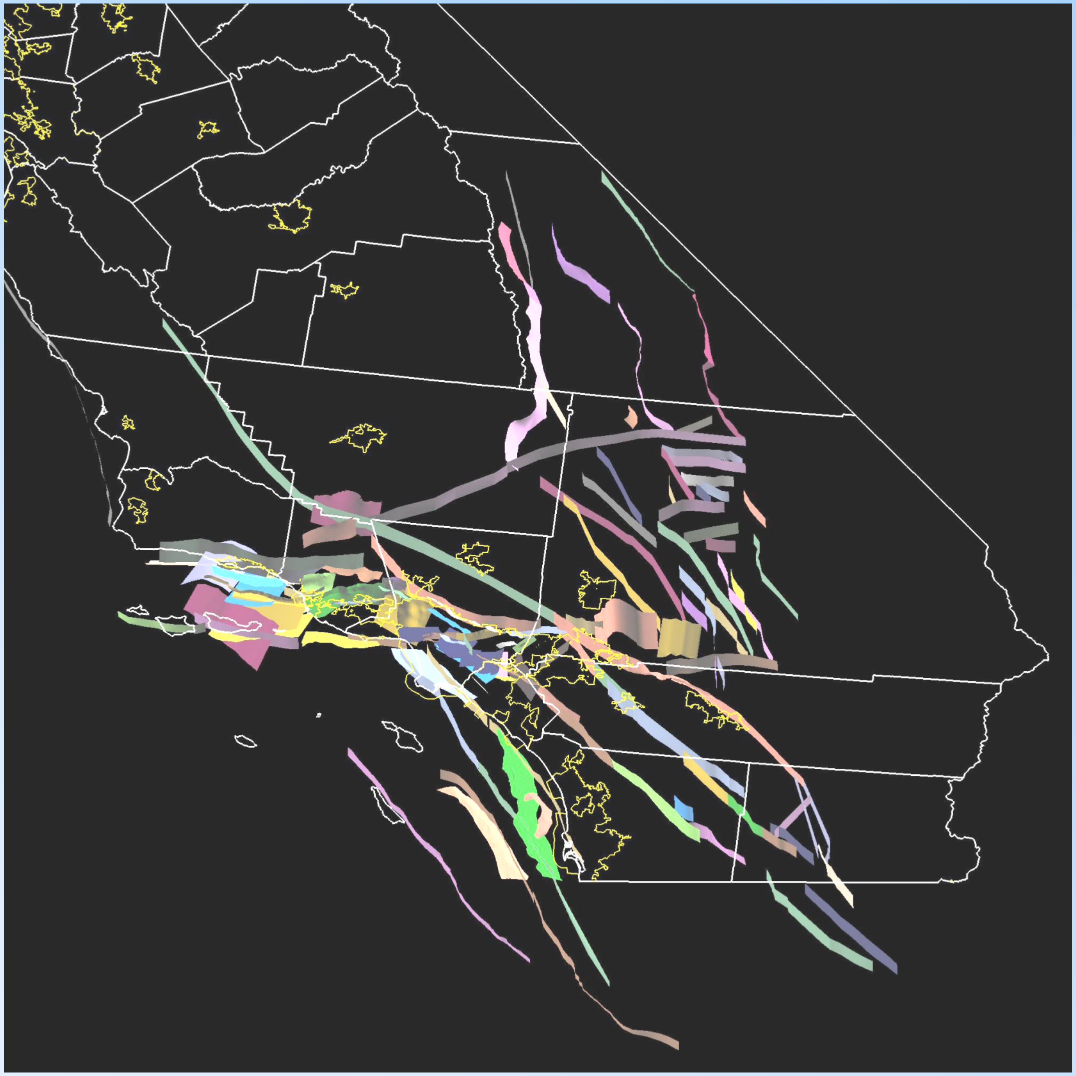
- Constructive Solid Geometry
- Collection of surfaces that bound volumes
- Can be used to define geometry, topology and attributes





Forms of GFMs

- Non-manifold Geometry
- Southern California Earthquake Center (SCEC) community fault model (CFM) of southern California
- Faults defined by triangulated surfaces
- Geometry of faults is well defined but topology is not defined



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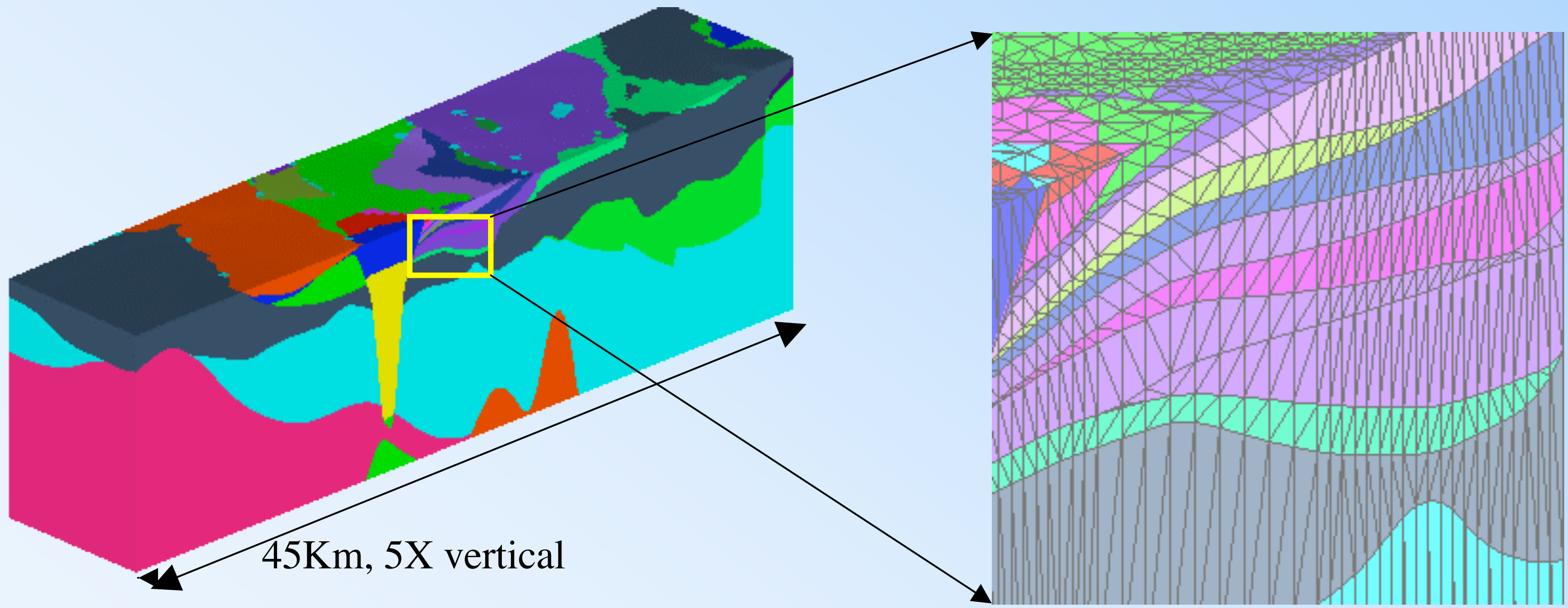
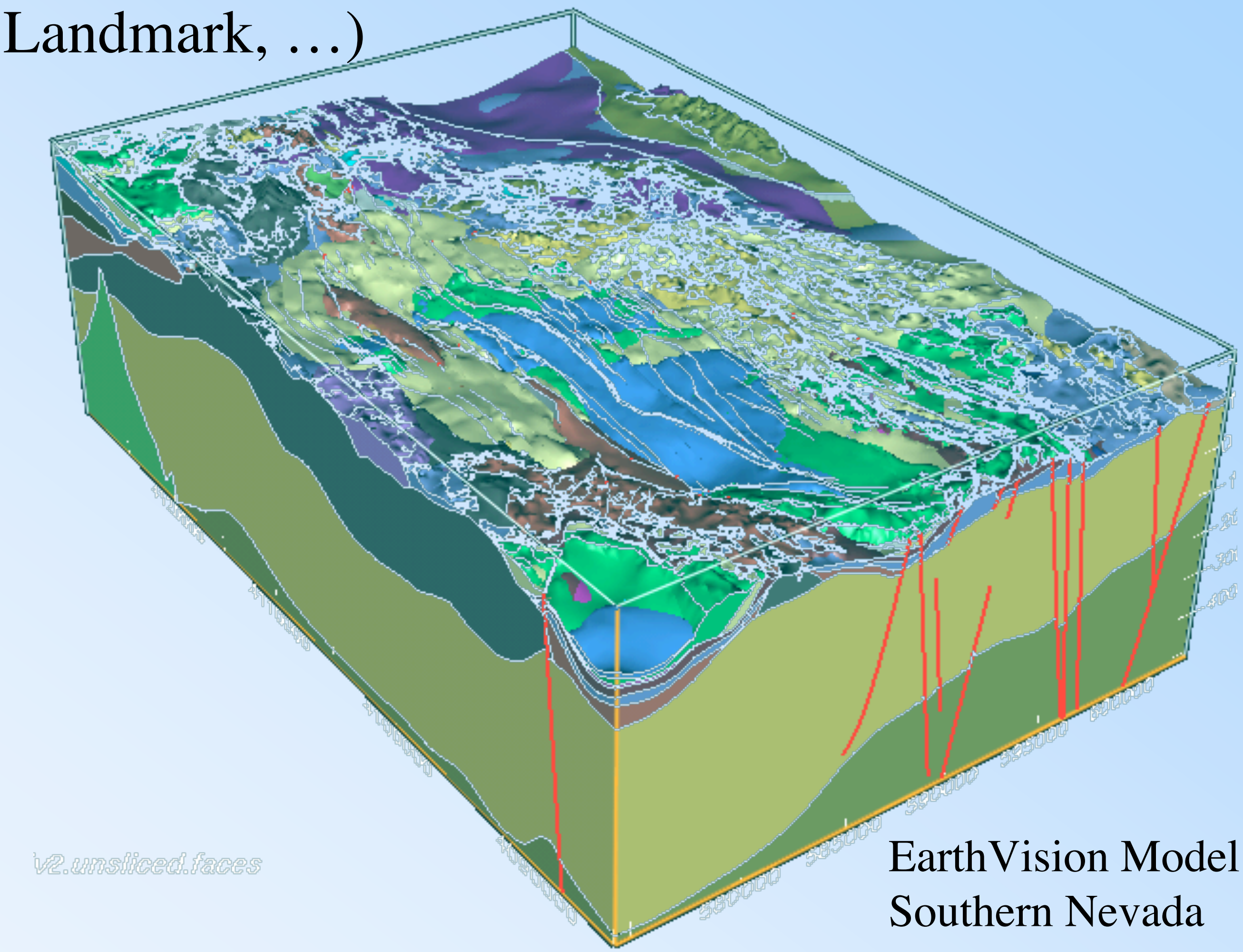
Forms of GFMs

- Cellular model of 2D or 3D space (triangle, quadrilateral, hexahedral, tetrahedral, prism, pyramid, polygon, polyhedral)
- 3D geologic framework defined by tetrahedral elements



Forms of GFMs

- Various Geologic Modeling Software Packages (EarthVision, gOcad/SKUA, Landmark, …)



EarthVision Model
Southern Nevada

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GFM Not in CAD Format

Option 1

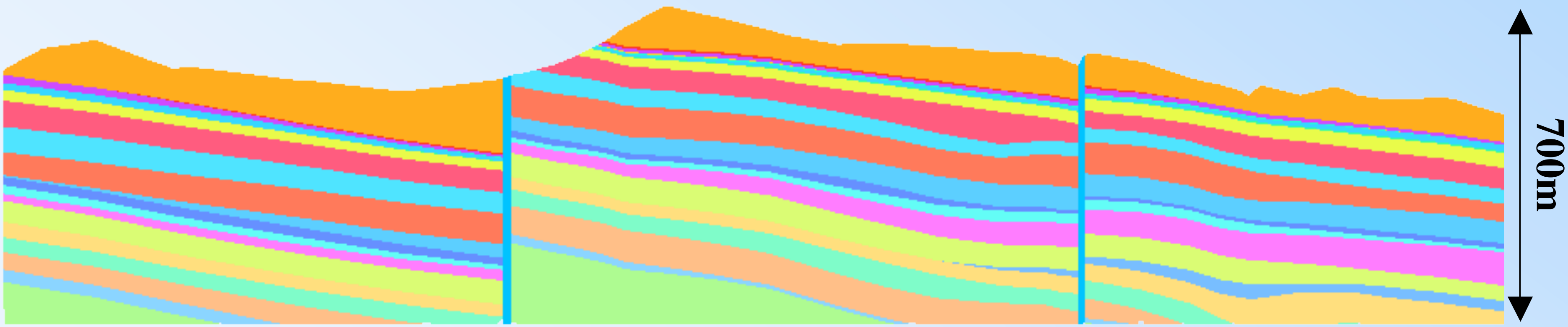
1. **Derive CAD solid model (ACIS, Pro/E, etc.) from geologic model (EarthVision, gOcad, Stratamodel, …).**
2. **Use mesh generation tools that utilize CAD solid model input.**

Option 2

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

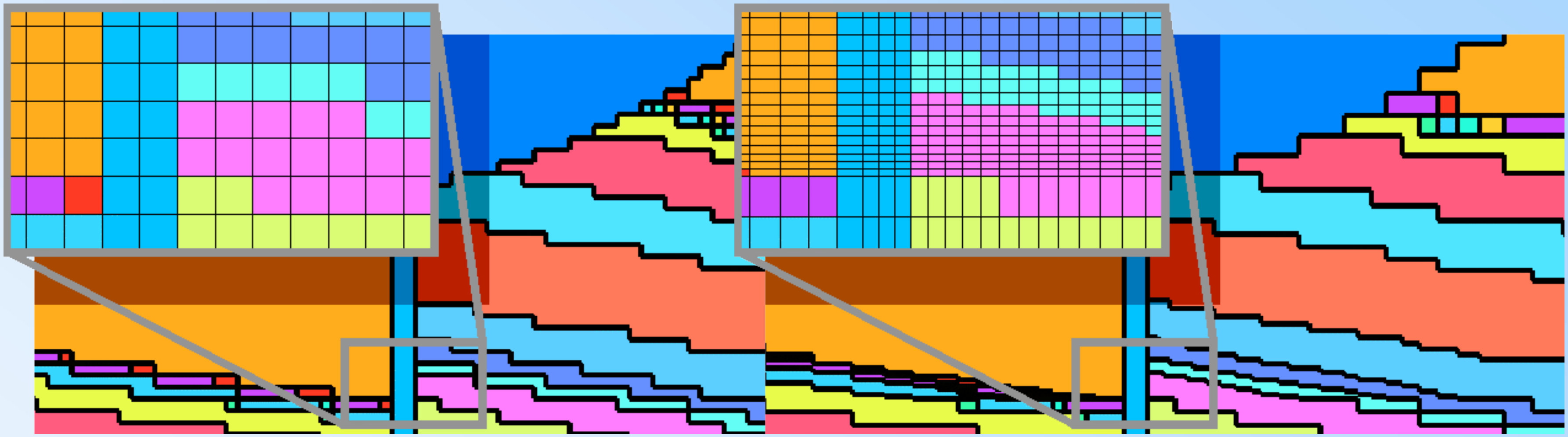
Mesh Generation Approach Depends on the Solver and Physics

- **Orthogonal Finite Difference, Logical Structured, Block Structured**
- **Quadtree, Octree**
- **2.5 D Unstructured (*e.g.* stacked triangles)**
- **Unstructured (quad, tri, hex, tet, prism, pyramid, polyhedral)**
- **Mesh quality (aspect ratio, volume variation, …)**



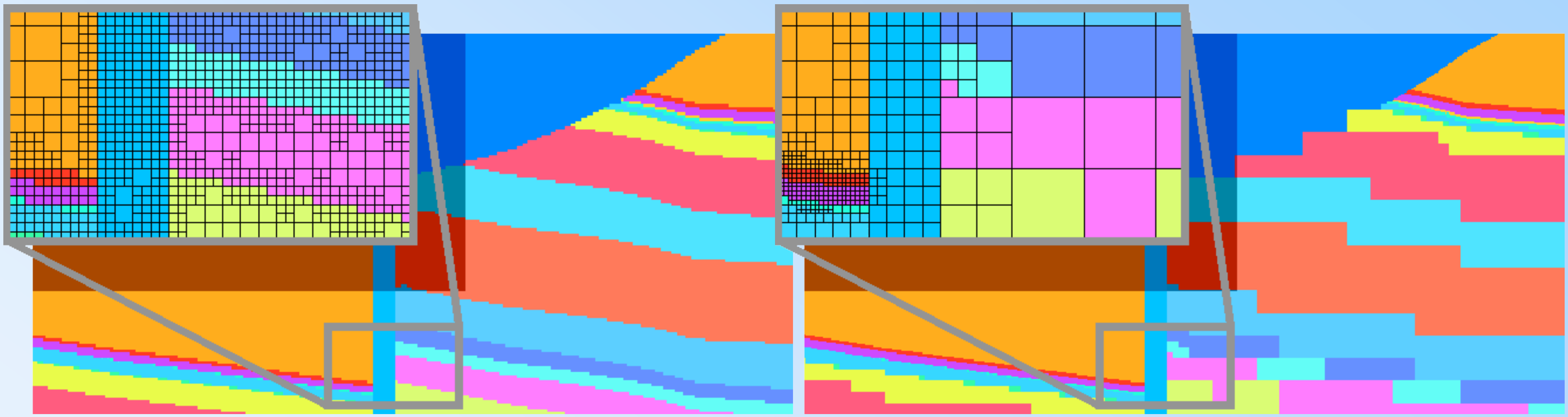
GFM, Yucca Mountain, Antler Ridge Cross Section

Mesh Generation: Orthogonal Finite Difference



- **Mesh node and element attributes are assigned from GFM but mesh resolution is not informed by GFM details**

Mesh Generation: Adaptive Quadtree(2d)



- **Mesh node and element attributes are assigned from GFM**
- **Mesh refinement is informed by GFM geometry**

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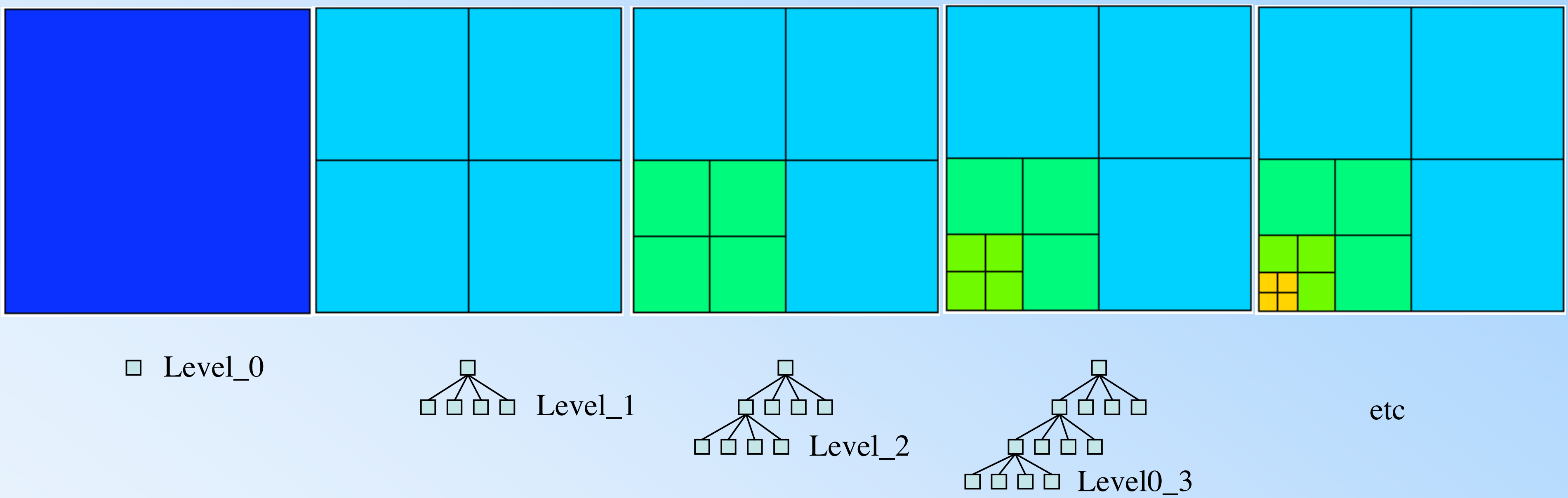
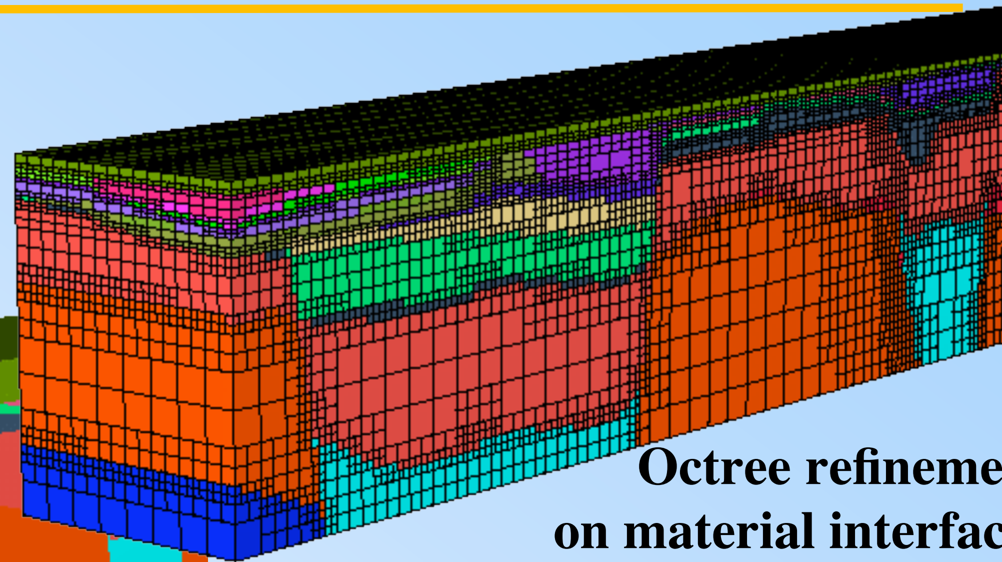
What is a 2D QUADTREE, 3D OCTREE mesh?

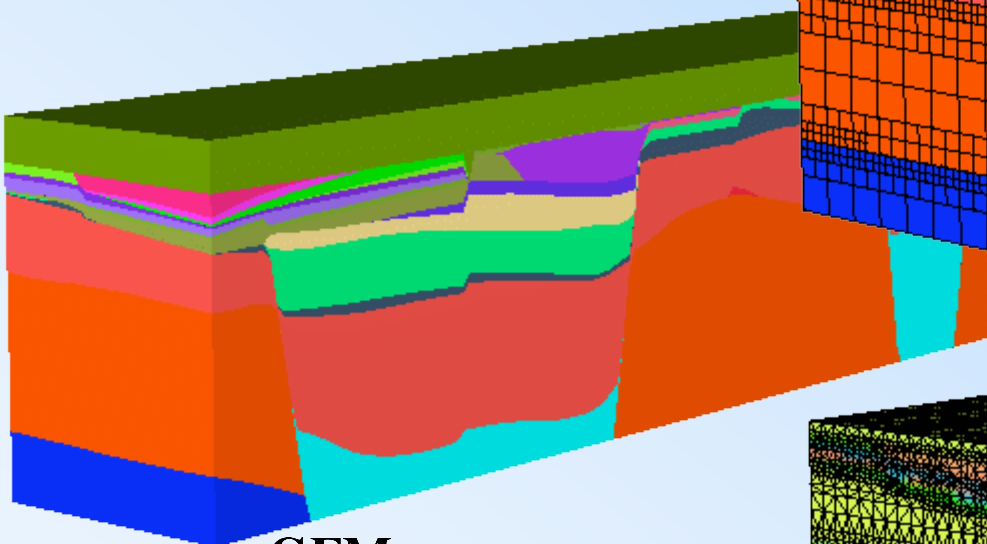


- Tree data structure, each branch has 4 leaves
- Balance tree = level n has neighbors of level n-1, n, n+1
- Octree is the 3D extension

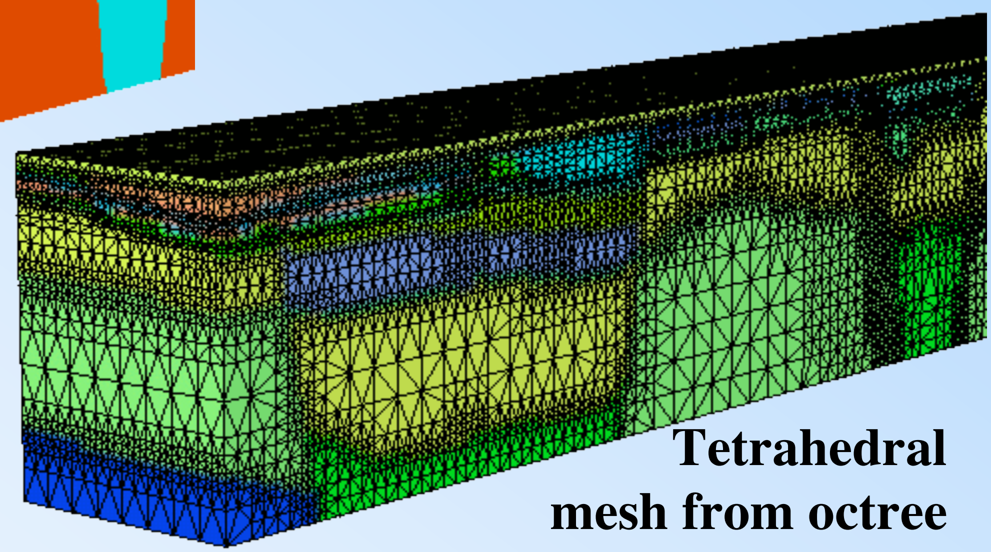
Mesh Generation: Adaptive Octree(3D)



Octree refinement on material interfaces



GFM



Tetrahedral mesh from octree

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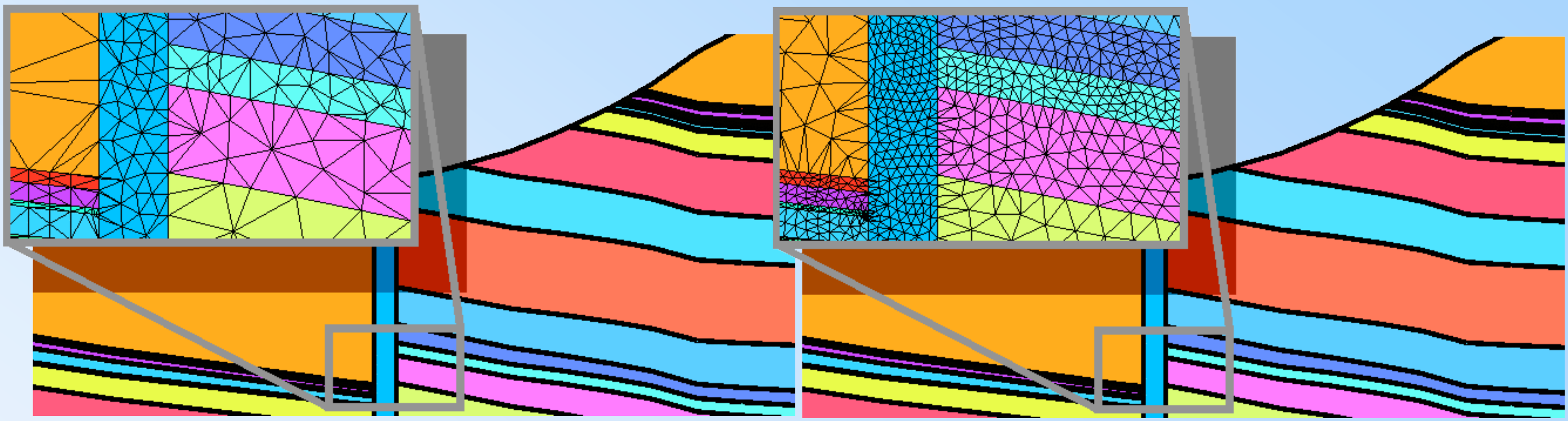
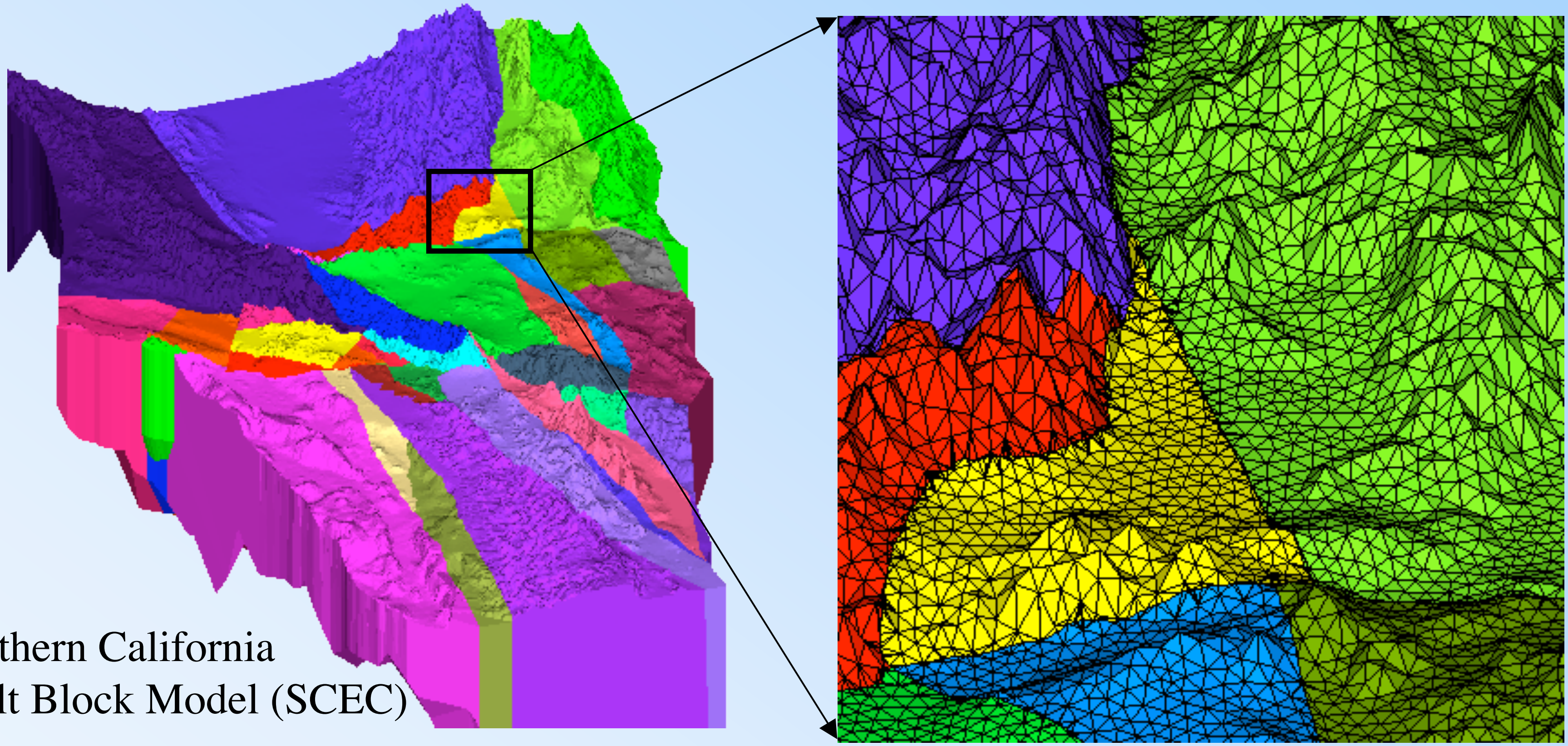
Mesh Generation: Unstructured Triangle/Tetrahedral



- Mesh node and element attributes are assigned from GFM
- Mesh reproduces geometry and topology of GFM
- Mesh resolution is informed by GFM

Mesh Generation: Unstructured Tetrahedral (3D)



Southern California
Fault Block Model (SCEC)

- Mesh node and element attributes are assigned from GFM
- Mesh reproduces geometry and topology of GFM
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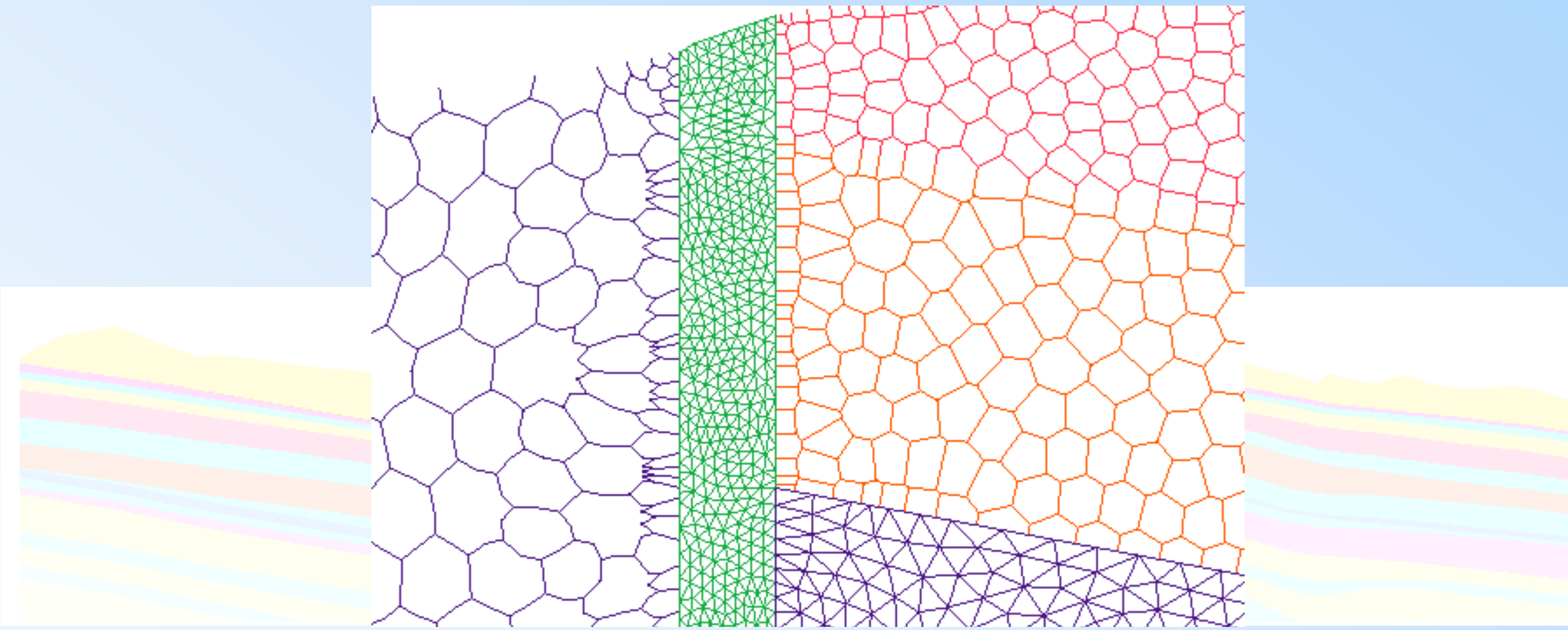
Mesh Generation Depends on the Solver and Physics

- Unstructured polyhedra (control volume methods)

Median Polygon Voronoi Polygon



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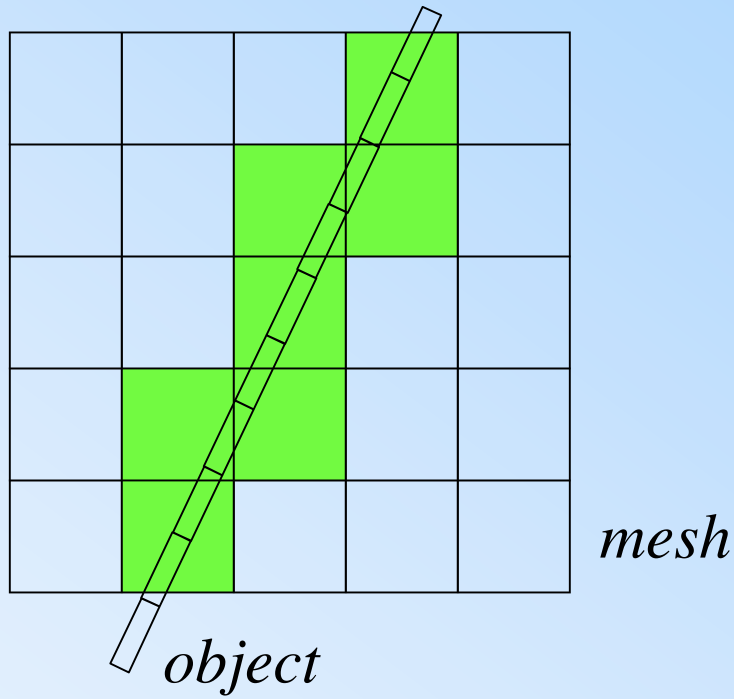
Model Setup: Attributes, Boundary and Initial Conditions

- **GFM to Mesh Interpolation**
  - **Set material properties to nodes and/or elements (*e.g*. density, permeability)**
  - **Set boundary conditions from GFM or another model (*e.g*. boundary flux)**
- **Upscale**
  - **Interpolate fine mesh properties onto a coarse mesh with various options for upscale function.**
- **Mesh-Object Intersections**
  - **Point (injection), line (well bore), surface (fault), volume (tunnel)**

Mesh-Object Intersection

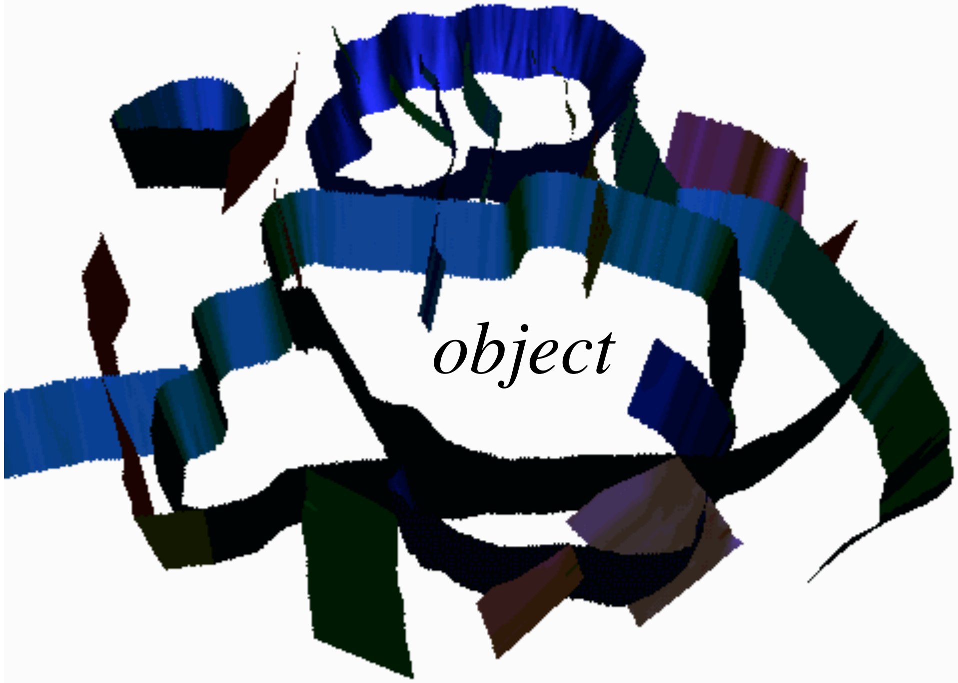
Compute intersection of *object* with *mesh*

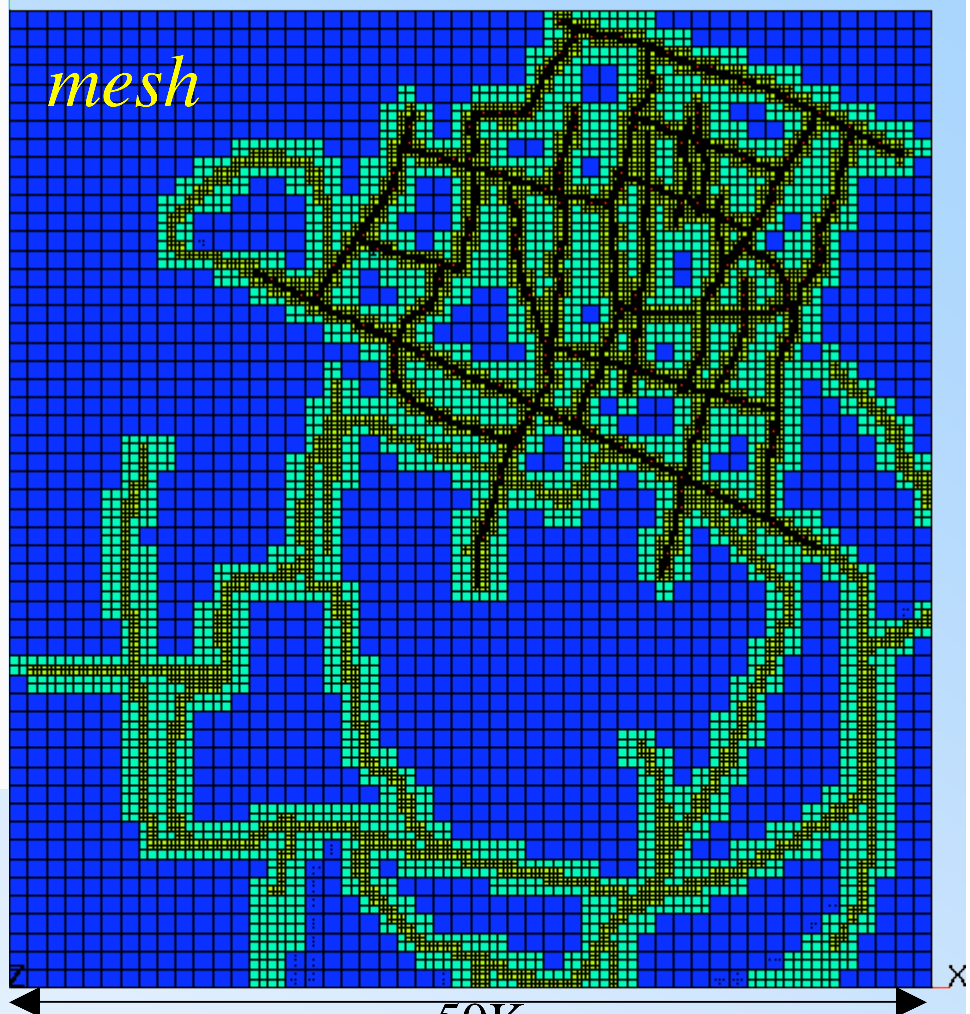


Mesh-Object Intersections: Point (injection), line (well bore), surface (fault, stratigraphic boundary), volume (tunnel, ore body, plume)

GFM Object - Computational Mesh Intersect/Refine

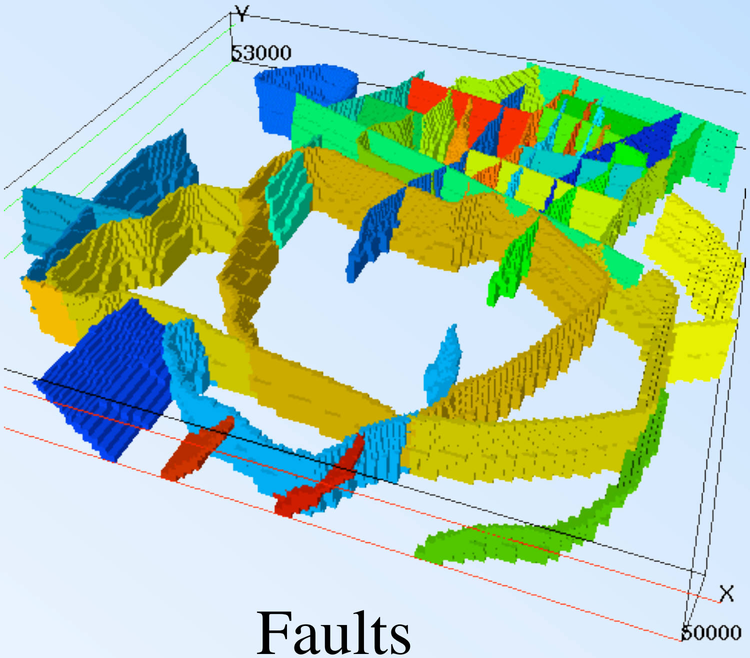
Compute intersection of *object* with *mesh,* refine mesh



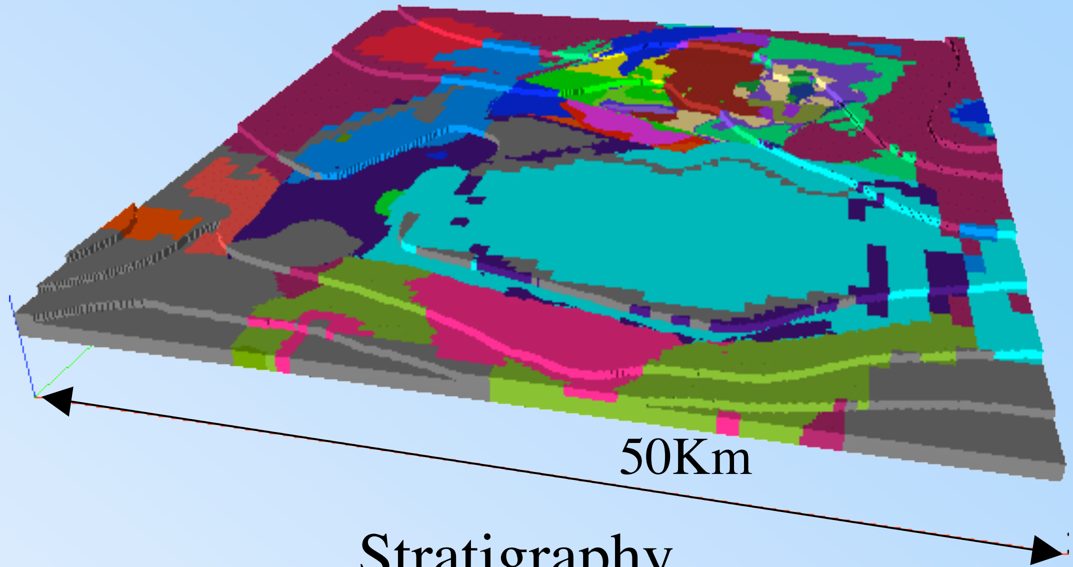


Intersect fault surfaces with mesh to select elements to be refined with quadtree type mesh refinement.

3D Octree Refined Mesh



Faults



Stratigraphy

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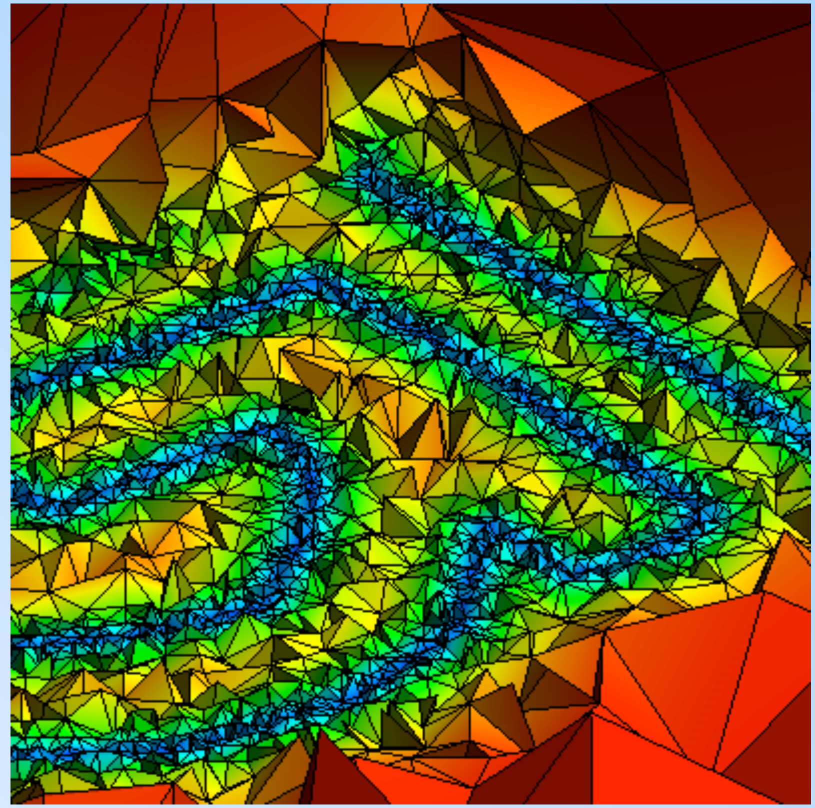
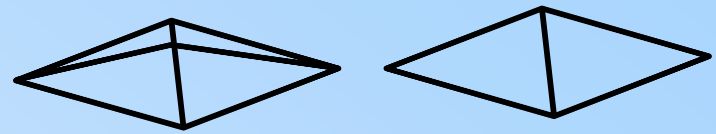
Mesh Optimization: Adaptive mesh refinement

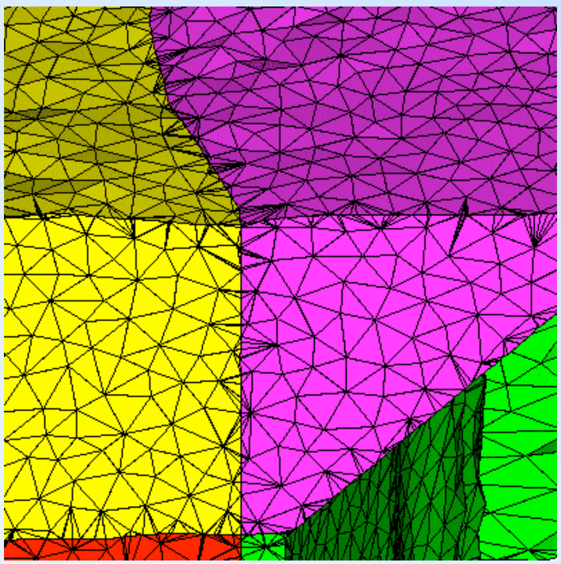
Mesh resolution depends on a field $f(\underline{\mathbf{x}})$, such as distance from model feature. Requires calculation of distance field $d = \mathit{dist}(\mathbf{q}, p_i)$, where d denotes the minimum distance from a point q to the nearest point on object p_i.



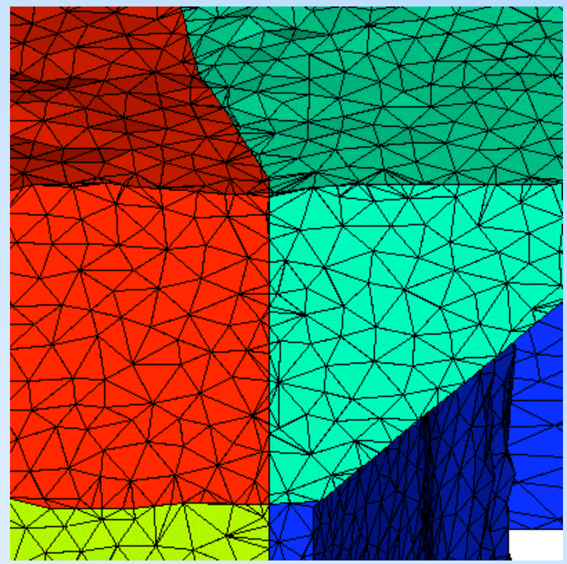
Mesh Optimization

- **Refine, Derefine, Smooth**
  - **edge length, volume, aspect**





Original Elements



Remove small area/volume and high aspect ratio elements while maintaining geometry.

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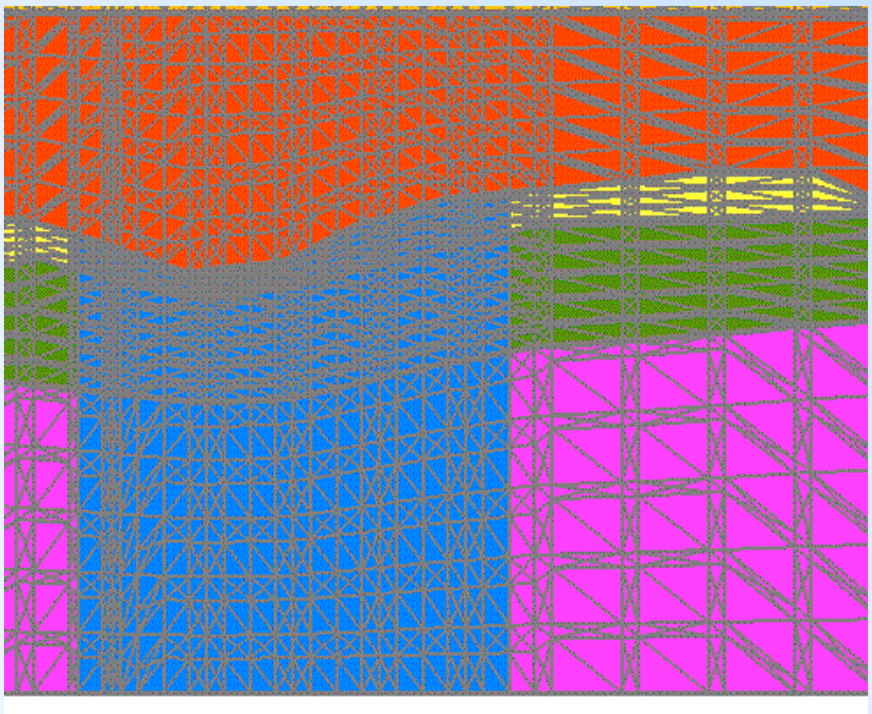
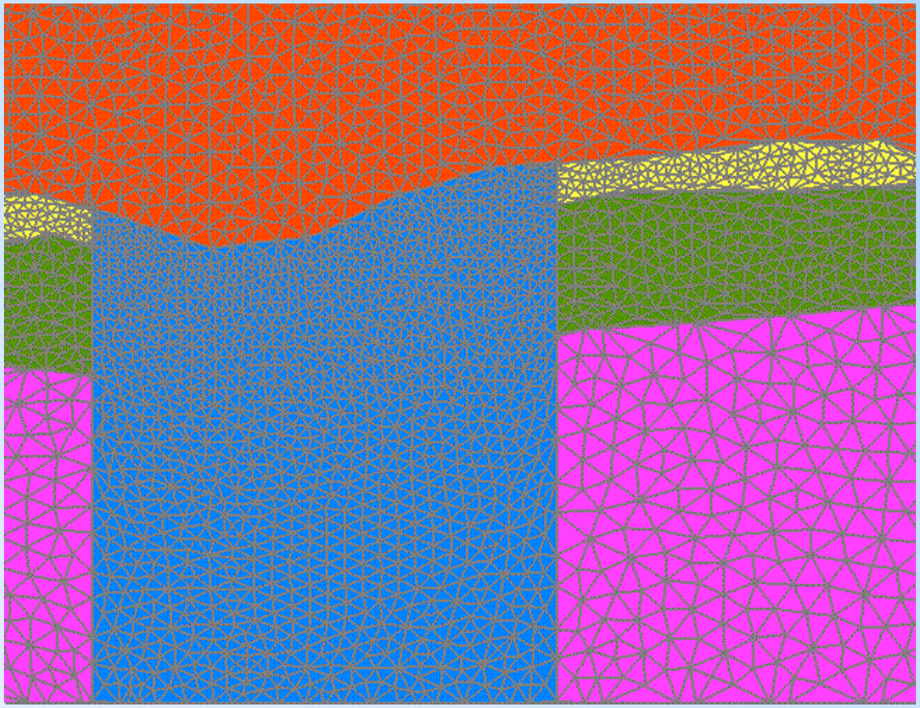
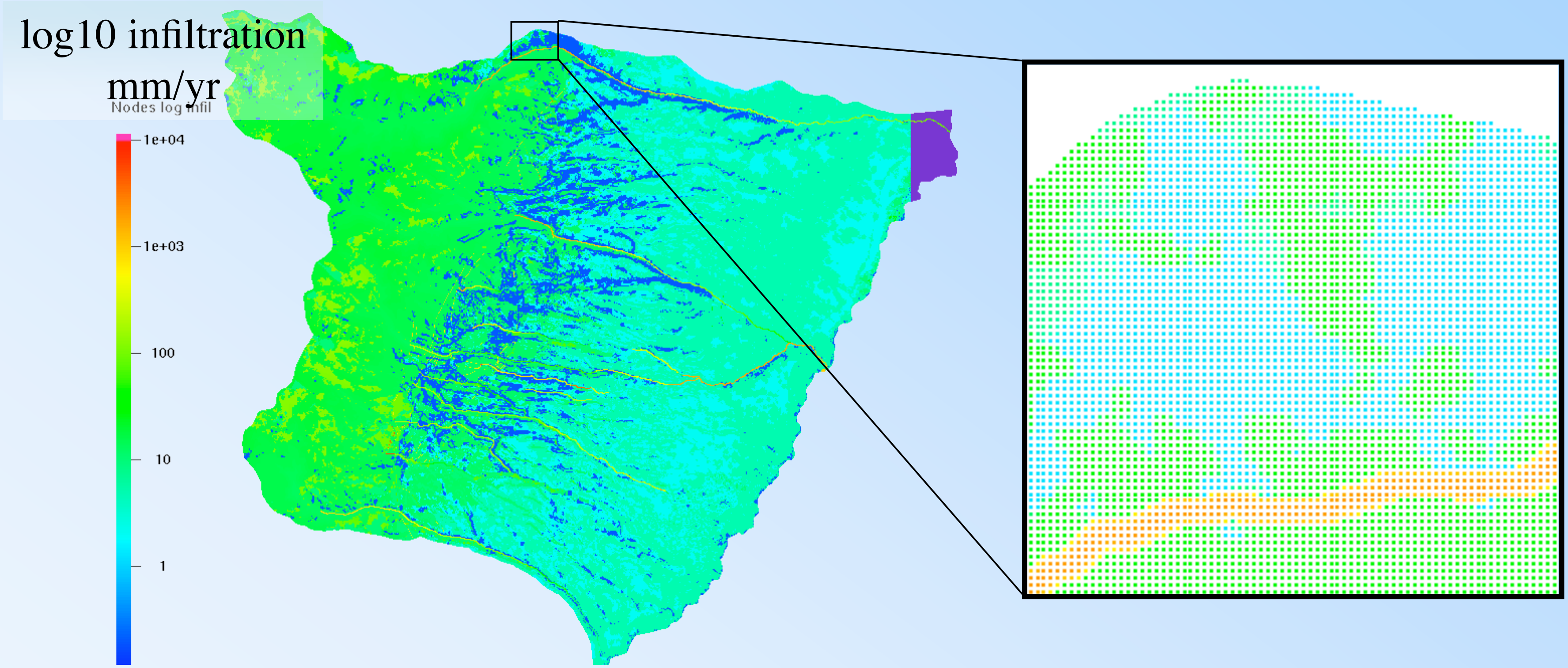
Mesh Smoothing

- **Smooth 2D and 3D**
  - **elliptic, laplace, aspect, …**



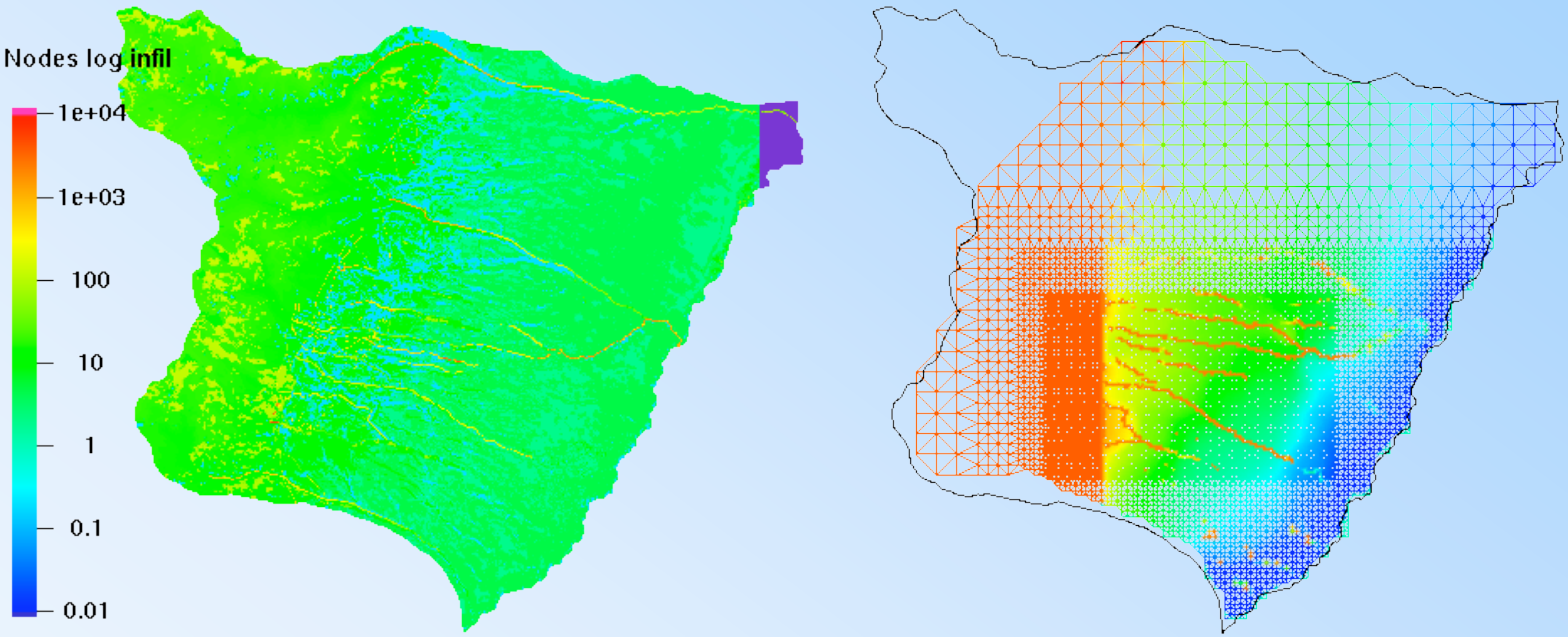


Mesh to Mesh Interpolation



- Infiltration (mm/yr) map on regular mesh.

Mesh to Mesh Interpolation



- Infiltration boundary condition (right) based on mass conserving interpolation from a high resolution mesh to a lower resolution computational mesh for flow model.

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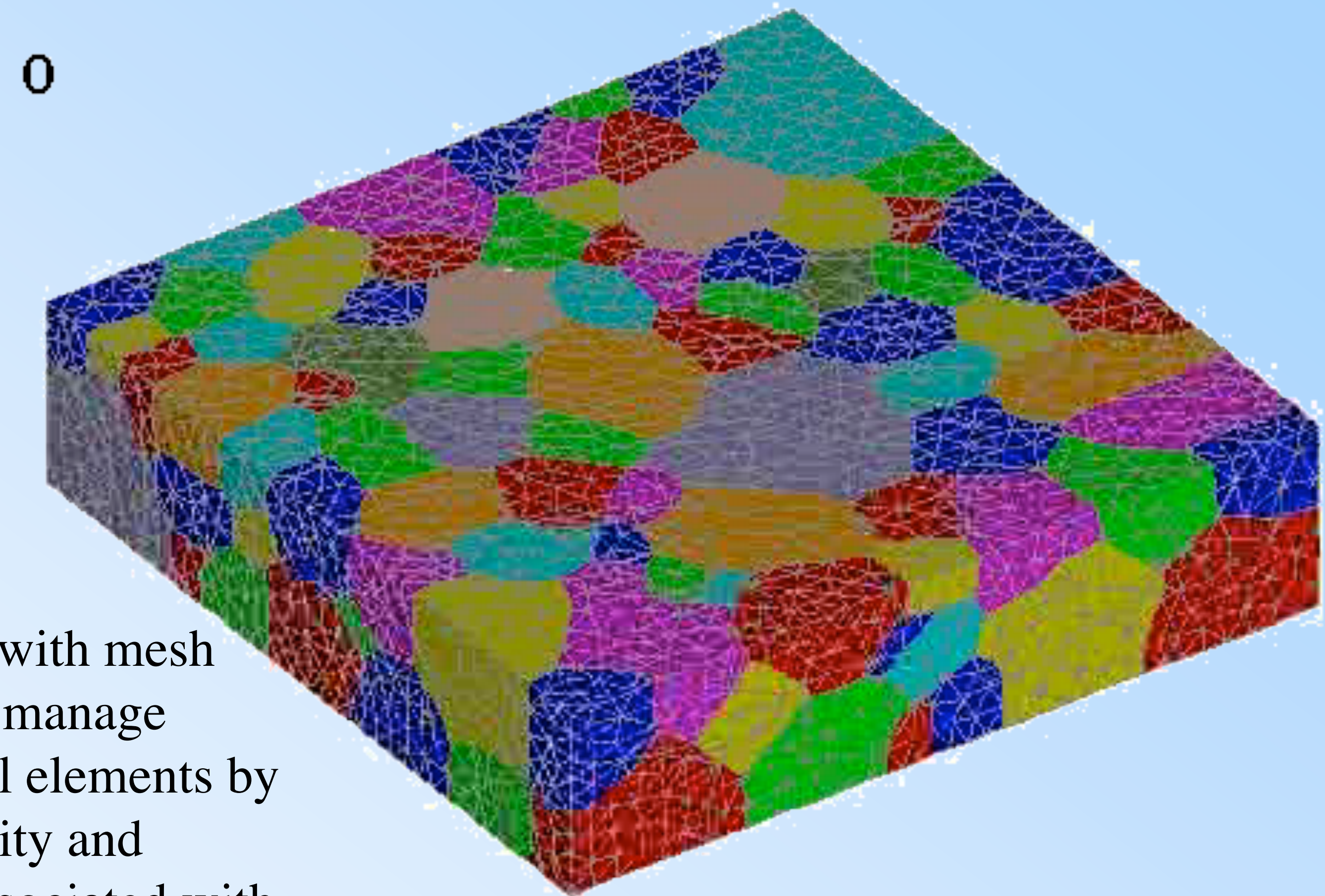
Moving Finite Element Simulation of Thermally Driven Grain Growth



Physics code interacts with mesh generation software to manage evolution of tetrahedral elements by maintaining mesh quality and topological changes associated with elimination of grains.

Calculation by Andrew Kuprat

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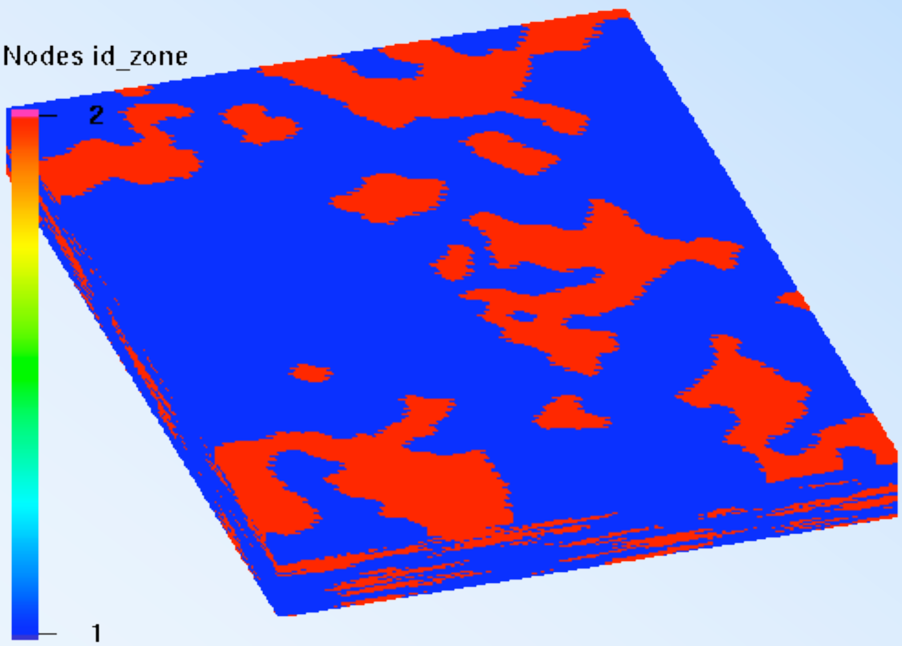
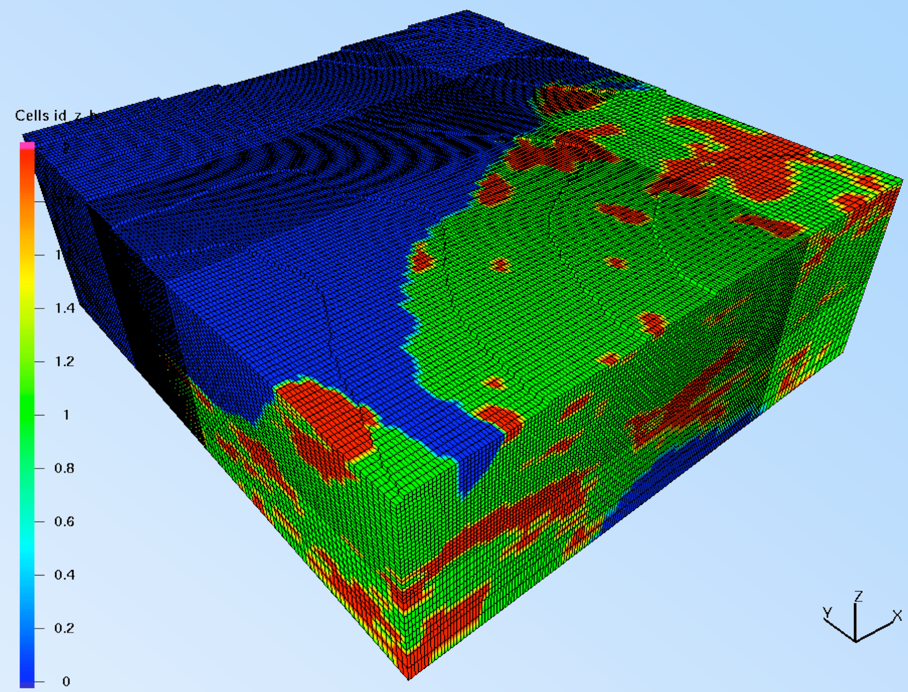
Model Setup

•Interpolate scalar quantity (head, concentration, geostatistical property distribution) from one mesh to another



Source



Sink

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LaGriT

- No GUI
- 3 Ways to Run LaGriT
  - Command line:

```
read / gmv / points.gmv / mo1
connect
dump / gmv / tets.gmv / mo1
```

  - Command File: `lagrit < input.lgi`
  - Call from C or Fortran Code:

```
string = 'read / gmv / points.gmv / mo1'
call dotask(string,error_flag)
```

LaGriT

Mesh Object: A data structure that contains geometry, topology and attributes

- Node geometry, x, y, z
- Mesh topology, connectivity of line, tri, quad, prism, pyramid, tet, hex elements
- Attributes (pressure, temperature, color): integer or real quantities on nodes or elements
- Point sets
- Element sets
- Neighbor Information
- Other book keeping…

LaGriT allows you to have many mesh objects simultaneously

LaGriT

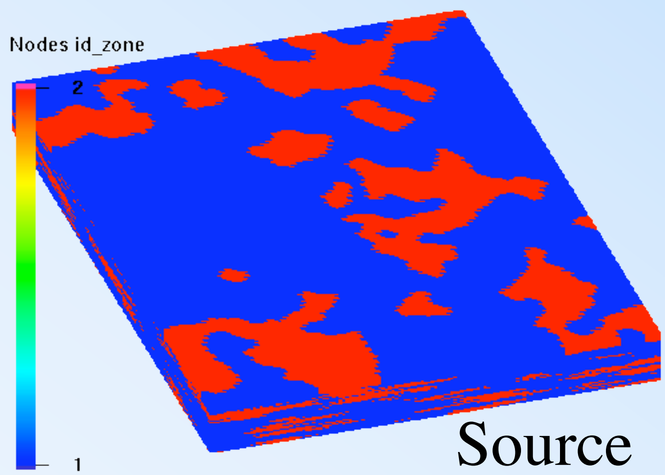
Command Line Syntax (http://lagrit.lanl.gov/docs/conventions.html)

•Lines are a maximum of 80 characters long
•Continuation lines are signaled by an "&" as the last character of a line to be continued. A command can be up to 1024 characters long.
•Delimiters are comma, slash, equal sign, or blank. (',' '/' '=" ').
•Commands should be typed in lower case, however names are case sensitive.
•To separate commands on the same line use a semicolon (;).
•Three coordinate systems are used, xyz, rtz, rtp.

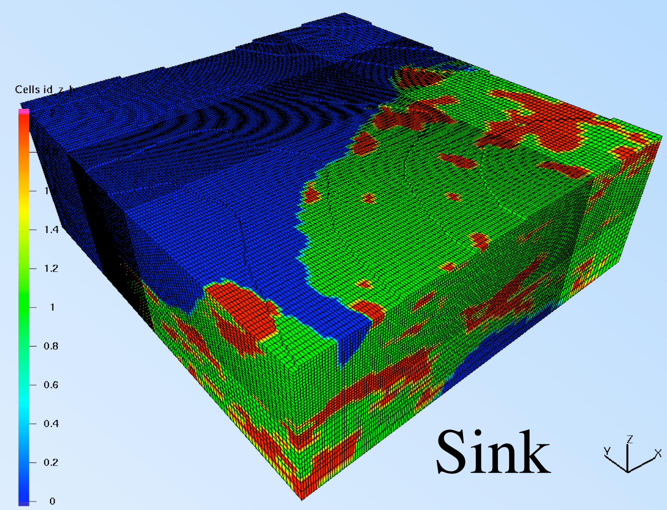
Model Setup

•Interpolate scalar quantity (head, concentration, geostatistical property distribution) from one mesh to another

```
cmo/readatt/source_mesh / xic yic zic id_zone id_elem /1,0,0 / file1
read / gmv / file2 / sink_mesh
pset /pinterp1/ attribute / imt / 1 0 0 / 10 / eq
interpolate / voronoi / sink_mesh / id_z_a / pset get pinterp1 /
source_mesh / id_zone
pset / pa_1 / attribute / id_z_a / 1 0 0 / 1 / eq
pset / pa_2 / attribute / id_z_a / 1 0 0 / 2 / eq
pset / pa_1 / zonn / outfile1.zonn / ascii
pset / pa_2 / zonn / outfile2.zonn / ascii
```



Source



Sink

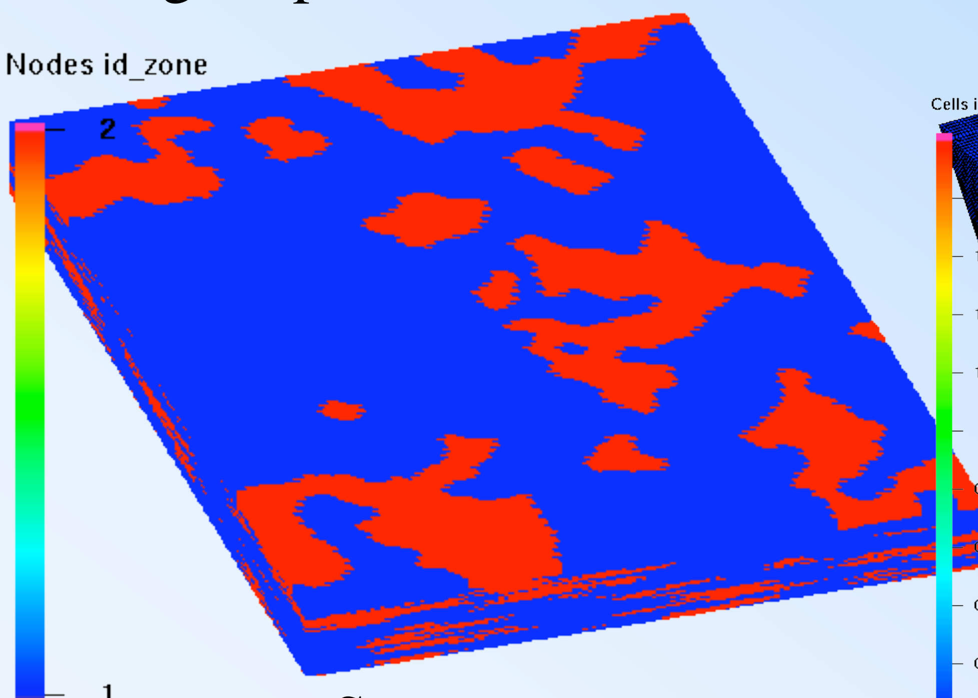
http://meshing.lanl.gov/proj

Los Alamos
NATIONAL LABORATORY
EST. 1943

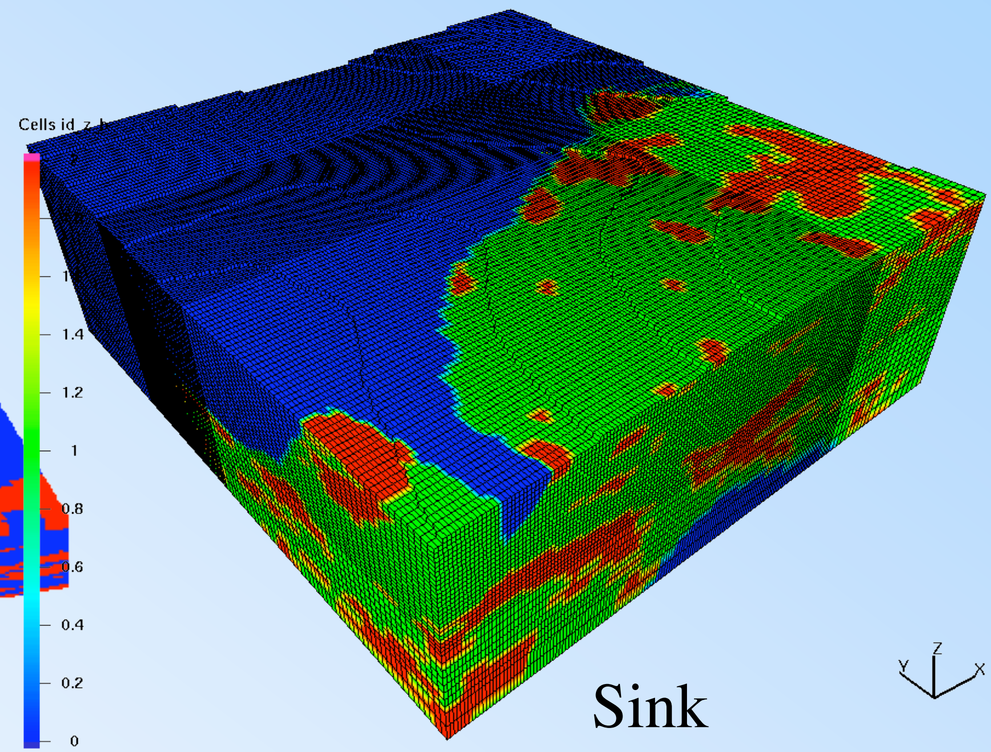
Model Setup

•Interpolate scalar quantity (head, concentration, geostatistical property distribution) from one mesh to another

•Accelerated implementation using a kd-tree search resulting in NlogM speed



Source



Sink

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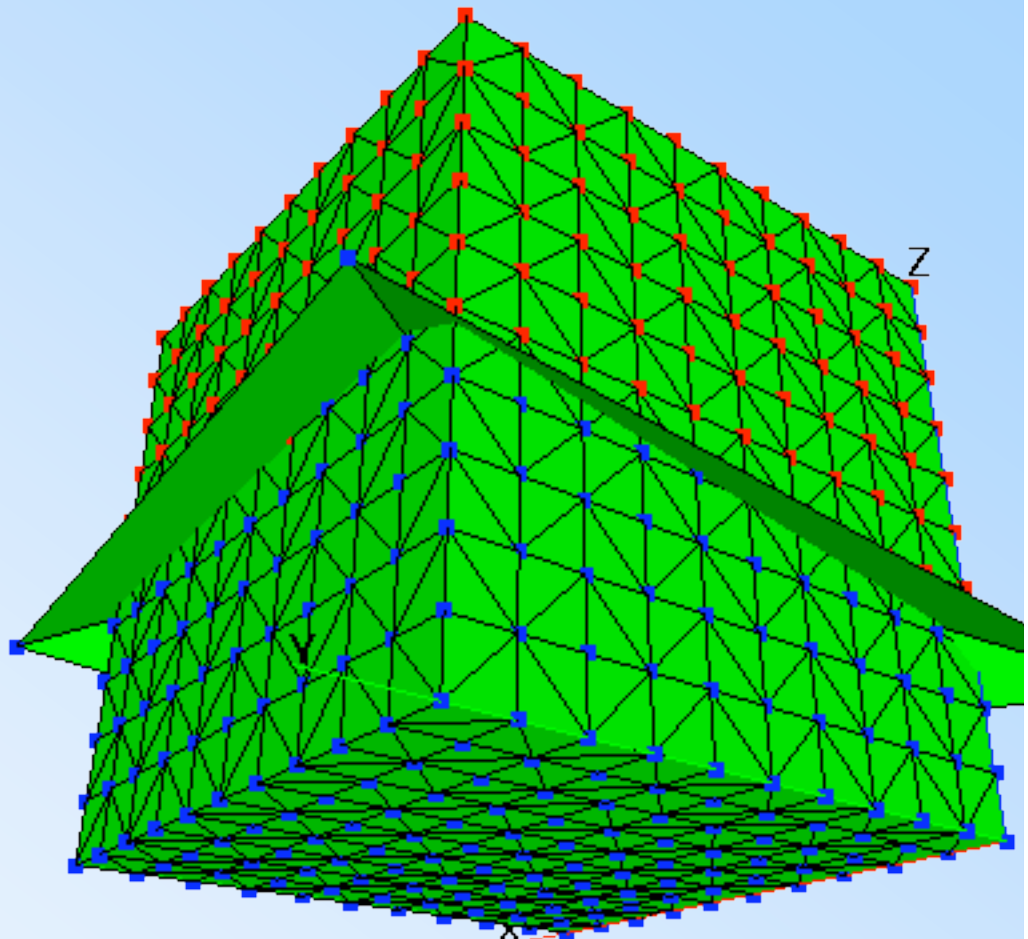
Model Setup

- Identify nodes above/below a surface (water table)

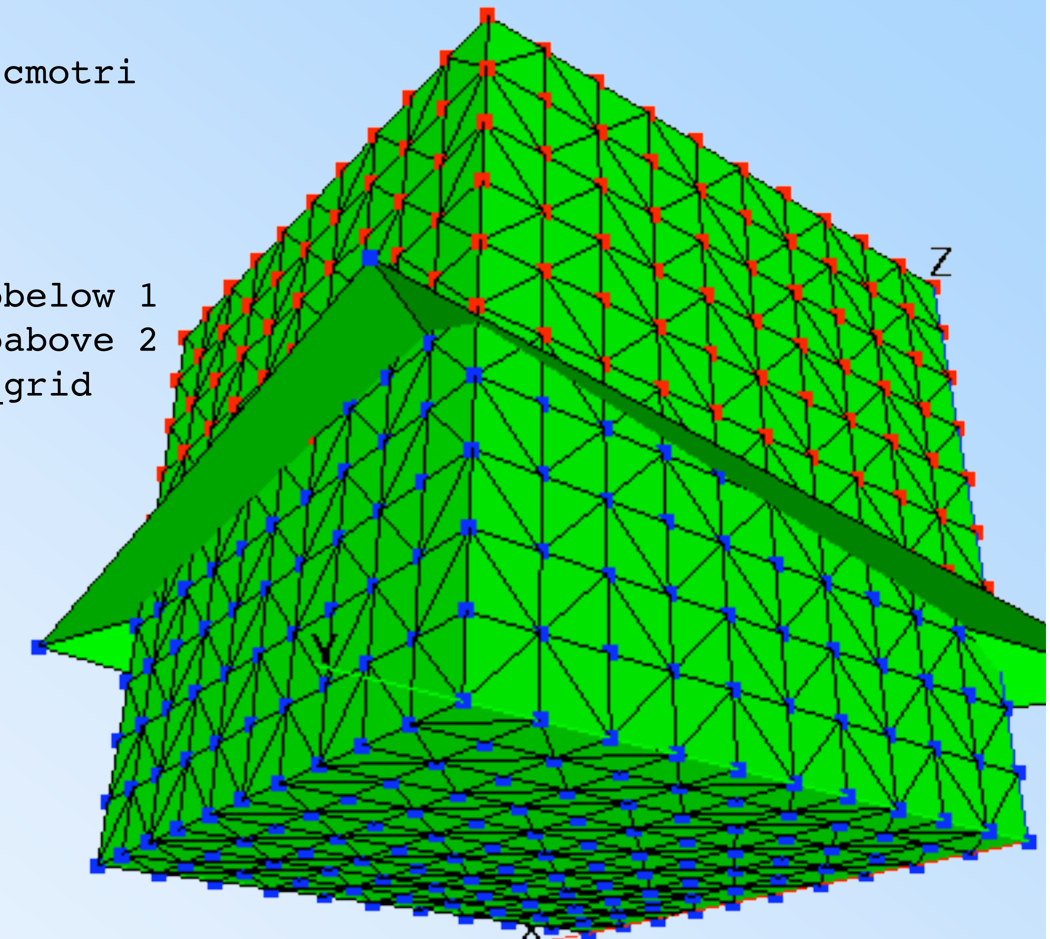


http://meshing.lanl.gov/proj

Model Setup

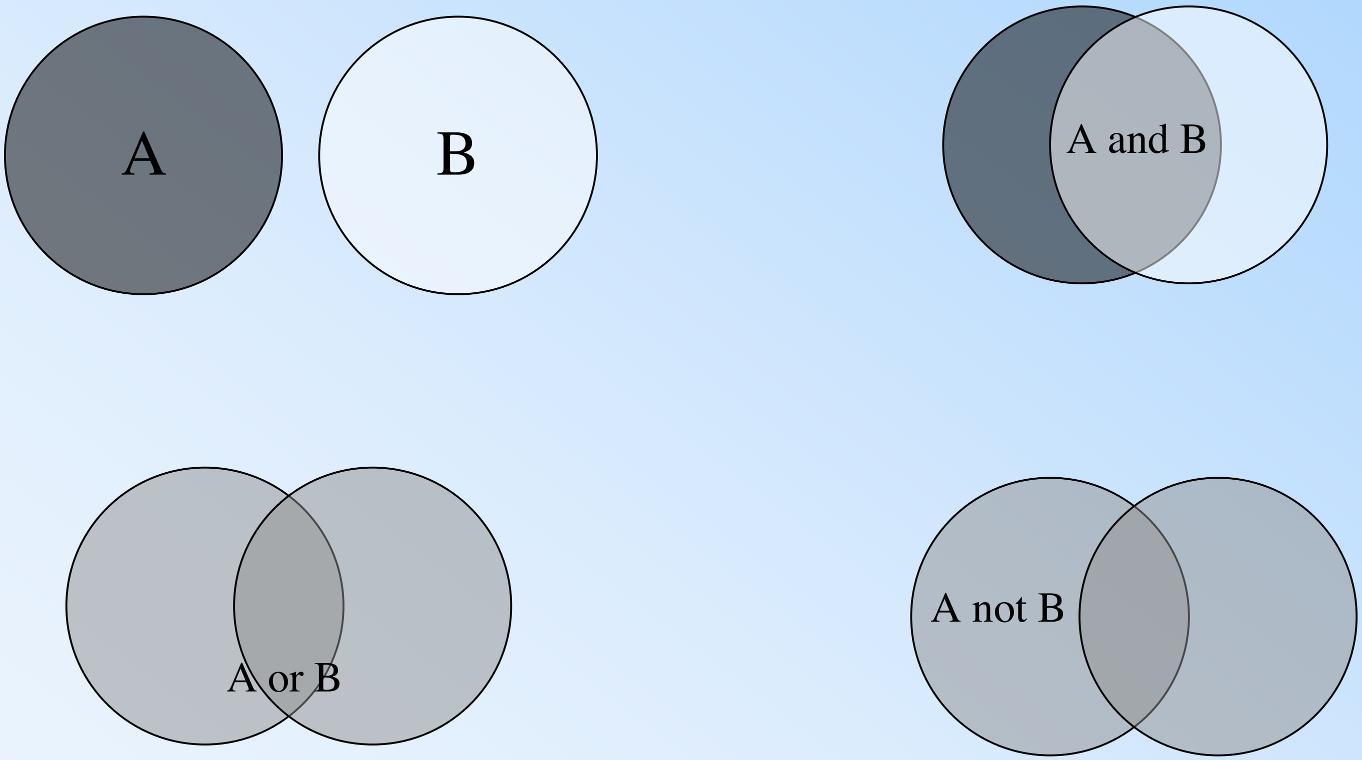
- Identify nodes above/below a surface (water table)

```
read / avs / WT_FILE / cmo_surf
read / avs / GRID_FILE / cmo_grid
surface / swt / reflect / sheet / cmotri
region / rwt / le swt
pset / pbelow / region rwt / 1 0 0
pset / pall / seq / 1 0 0
pset / pabove / not pall pbelow
cmo setatt cmo_grid imt pset get pbelow 1
cmo setatt cmo_grid imt pset get pabove 2
dump / zone_imt / ZONE_FILE / cmo_grid
```



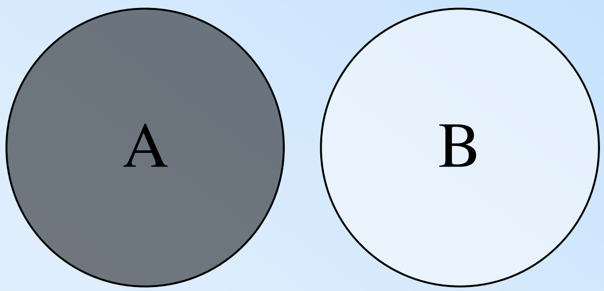
Model Setup

- Boolean operations on point sets (zone files)

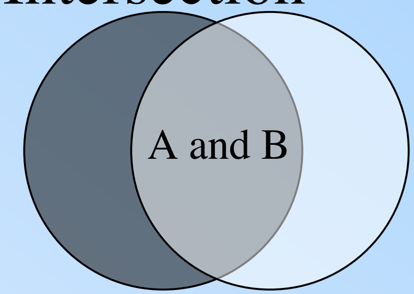


Model Setup

- Boolean operations on point sets (zone files)

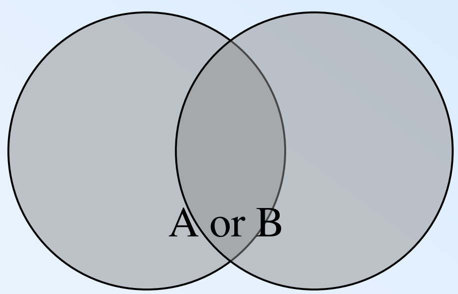


Intersection



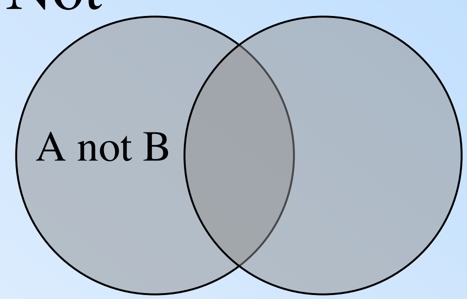

```
pset / p2 / inter / pa pb
```

Union




```
pset / p3 / union / pa pb
```

Not




```
pset / p4 / not pa pb
```

Model Setup

- Boolean operations on point sets (zone files)
- For Example:
  - Nodes that belong to material_4 and are below the water table and are within 5 km of fault_5
  - Nodes within 1 km of the topographic surface that are not within 1 km of a fault and are on the external boundary of the model

Meshing and Set Up Workflow

Problems and Challenges

•Automated (but not automatic)

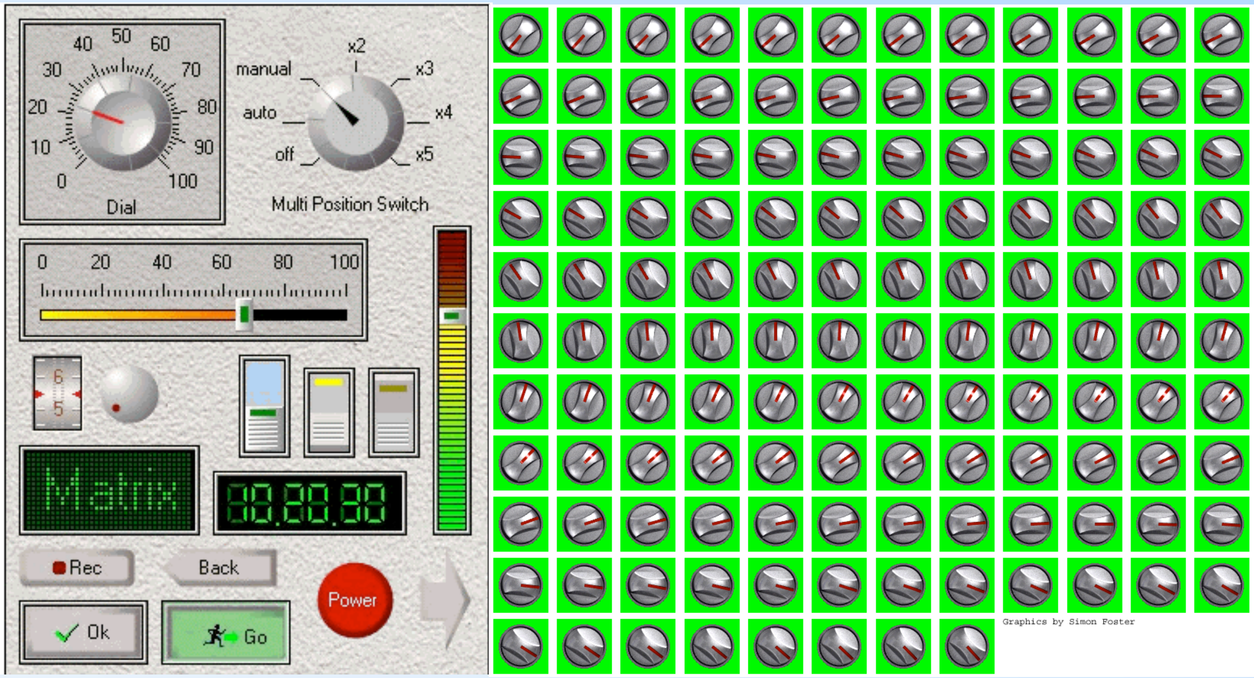
What users want.

http://meshing.lanl.gov/proj

Meshing and Set Up Workflow

Problems and Challenges

- **Automated (but not automatic)**



What users get.

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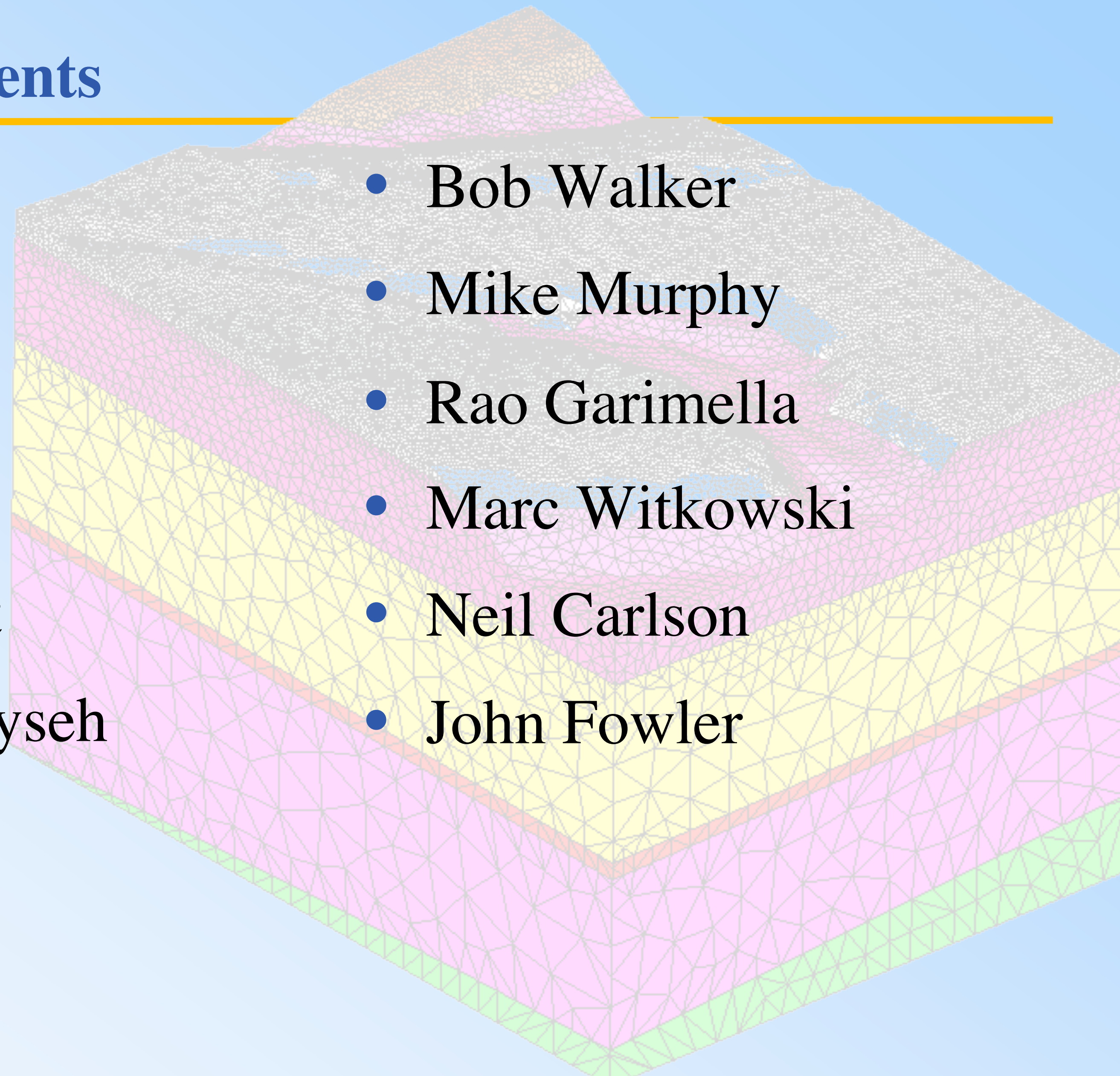
No Silver Bullet

- **A cookbook and the kitchen full of tools and ingredients does not make one a gourmet chef.**

- **What is required is a flexible tool kit and the expertise necessary to use the tools. One can then use expert knowledge to choose the right tool for the job depending upon the specific situation.**

Acknowledgements



- Harold Trease
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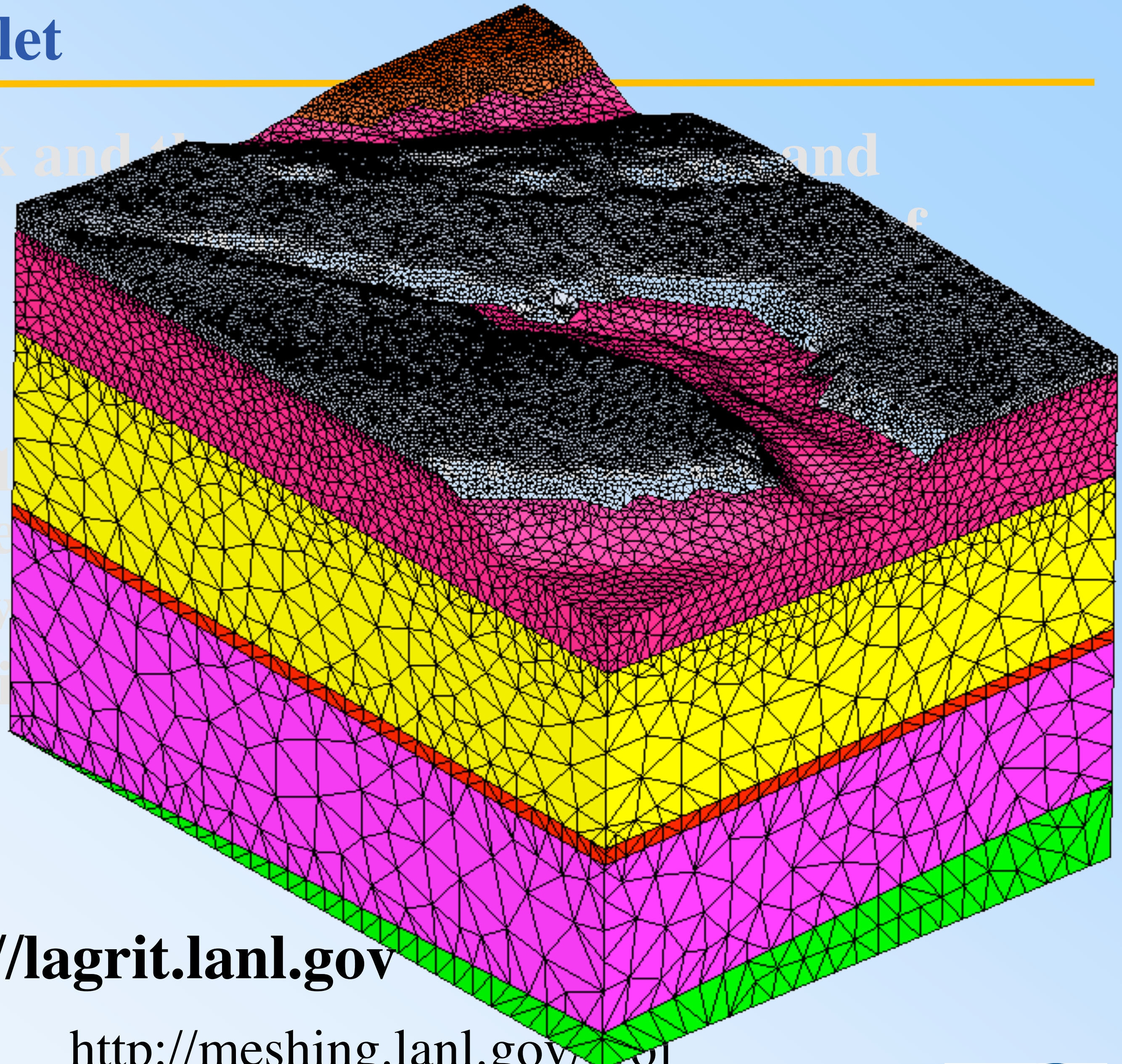
- Frank Ortega
- Jan Wills
- Bob Walker
- Mike Murphy
- Rao Garimella
- Marc Witkowski
- Neil Carlson
- John Fowler

No Silver Bullet

- A cookbook and th ... and ingredients ... f
- What is req ... expertise ne ... expert know ... job dependi

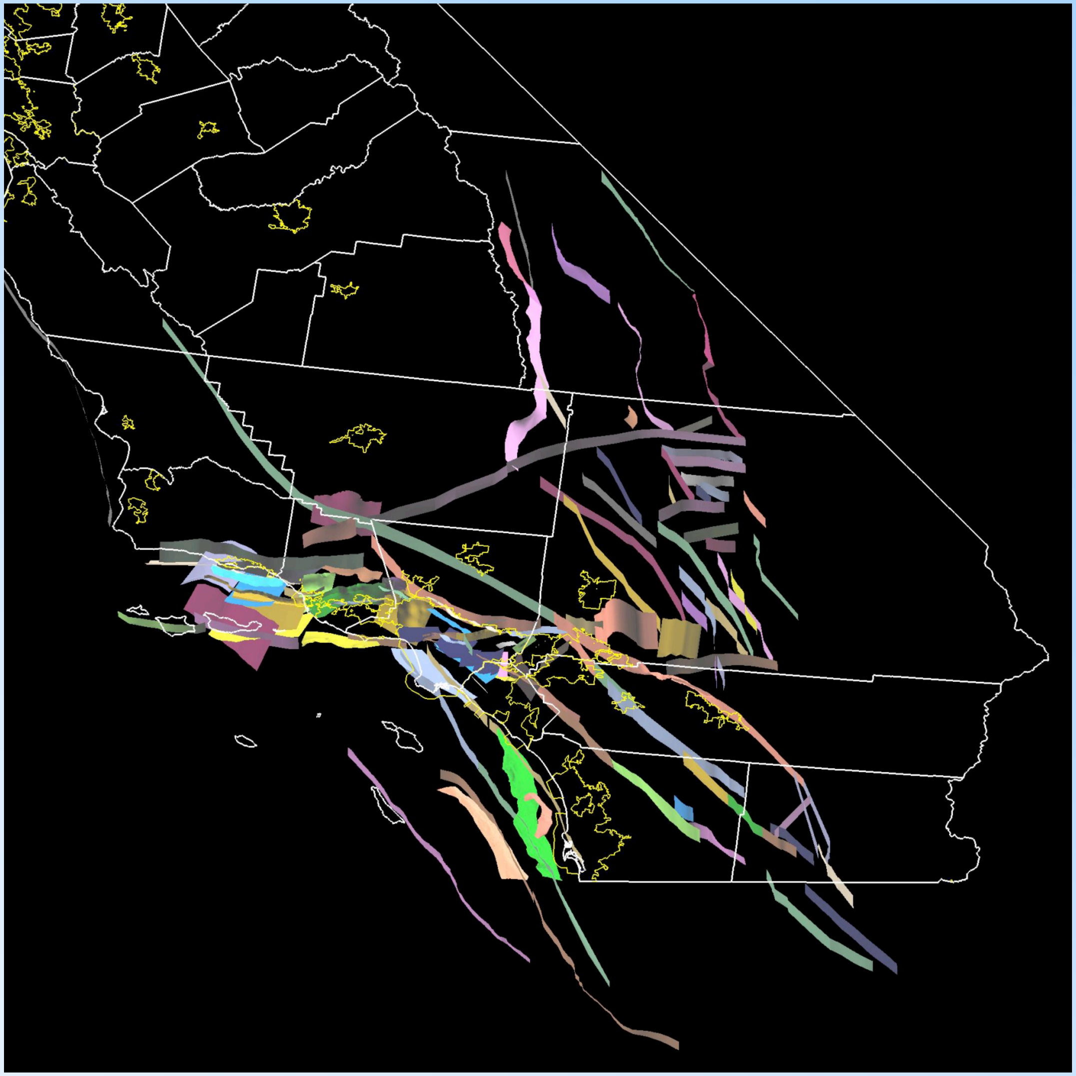


LaGriT – http://lagrit.lanl.gov

http://meshing.lanl.gov/proj

Meshing Non-manifold geometry

- Southern California Earthquake Center (SCEC) fault model for southern California
- 145 Faults defined by triangulated surfaces
- Surfaces have well defined normal (above and below surface) but since topology is not defined by closed volumes, a question such as, “Given an arbitrary location x,y,z, what material am I in?”, is ill defined.



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