Mesh Generation for Geological Applications

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http://meshing.lanl.gov

http://lagrit.lanl.gov

Numerical Modeling of Crustal Deformation and Earthquake Faulting

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Modeling and Simulation Workflow

Conceptual Model
→ Solid Model: Geometry & Topology
→ Mesh Generation
→ Mesh Optimization
→ Set Up: BC and IC
→ Physics Model
→ Results, Interpretation, Decision
Modeling and Simulation Workflow

- Conceptual Model
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    - Mesh Generation
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      - Physics Model
        - Results, Interpretation, Decision
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 FEM integration
4. Development driven by oil patch (high end), environmental (low end)
5. No symmetry
6. Often high aspect ratio

Engineering
1. Geometry Known with high precision
2. CAD Model (ACIS, Pro/E, AutoCAD)
3. FEM application well integrated
4. Development driven by automotive, aerospace, semiconductor, mechanical engineering, fluid dynamics
5. Often symmetric
6. Generally unit aspect ratio
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Model: Geometry, No Topology
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
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
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)

Median Polygon  Voronoi Polygon
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

Aspect Ratio

Distance From Faults

Cells

-0.998
-0.898
-0.798
-0.698
-0.599
-0.499
-0.399
-0.299
-0.199
-0.0998
-2.87e-03
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/intersect/cylinder/x1,y1,z1/x2,y2,z2/radius
surface/s_b/intersect/cylinder/x1,y1,z1/x2,y2,z2/radius
surface/s_c/intersect/box/xmin,ymin,zmin/xmax,ymax,zmax/
region/r_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