CUBIT

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Sandia National Labs

PHYSICS-BASED MODELING IN DESIGN & DEVELOPMENT

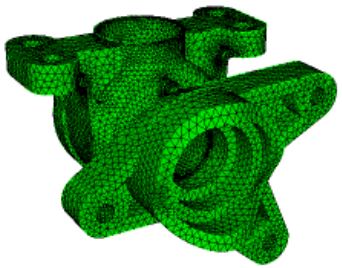
FOR U.S. DEFENSE CONFERENCE

Denver, Colorado

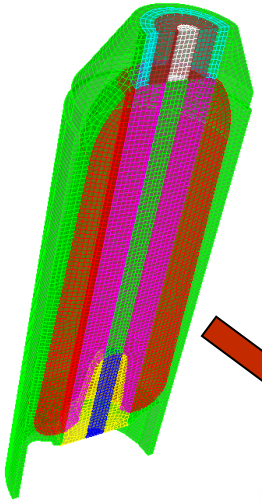
November, 2011

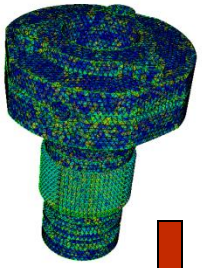
Sandia National Laboratories

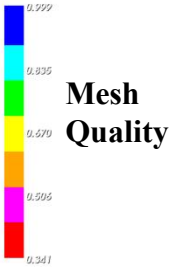
What is CUBIT?



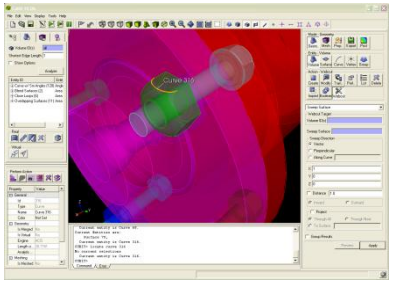
Advanced Meshing Algorithms



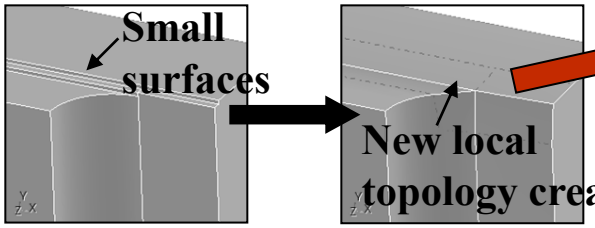




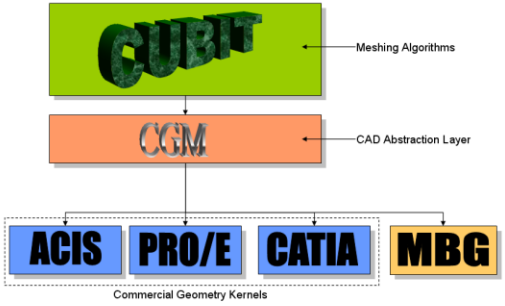
Mesh Quality



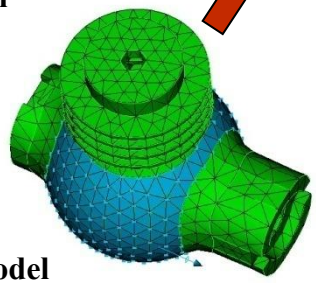
GUI and customization



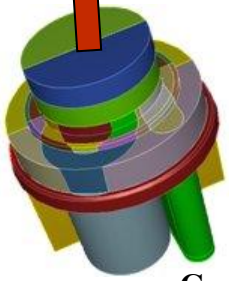
Geometry Cleanup/Simplification



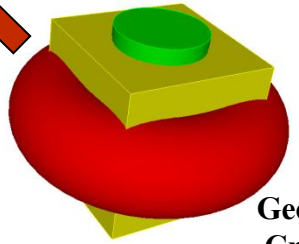
CAD Interface



Model Attribution



Geometry Decomposition



Geometry Creation

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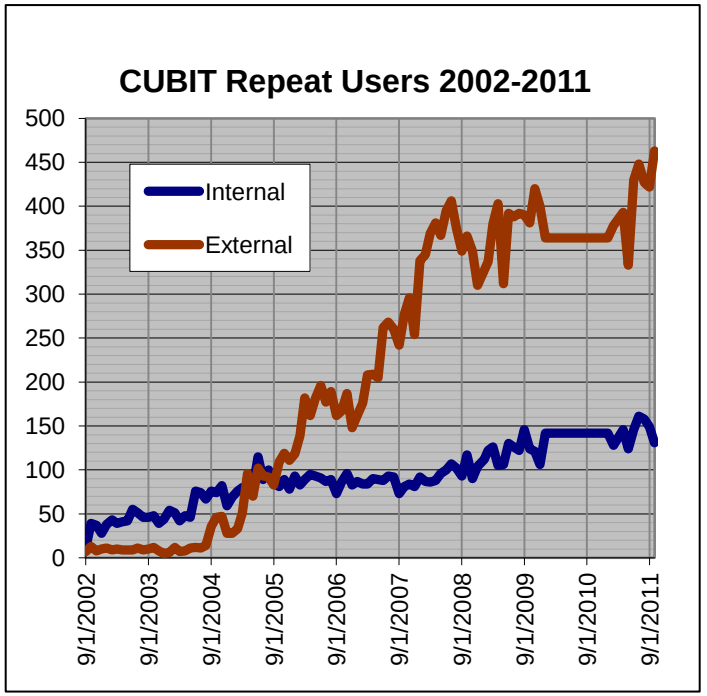
The CUBIT Project

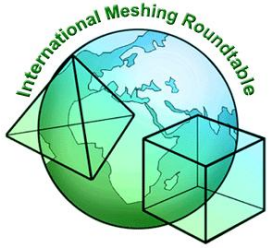
- CUBIT started as a research platform for unstructured quad and hex meshing in the early 90s
- late 90s GUI was added
- early 2000s product focus increased to improve robustness



Team Personnel

- Sandia
- Elemental Technologies, Inc.
- Independent Contractors
- Caterpillar
- University Students

Technical Conferences



Past and Present Collaborators

DoD

Office of Naval Research

HPC Modernization Program — Solving the Hard Problems

Sandia

DART

CEE

ALEGRA

National Labs

Los Alamos National Laboratory

Idaho National Laboratory

Lawrence Livermore National Laboratory — Science in the National Interest

Industry

Goodyear

Caterpillar

TechnoSoft Adaptive Modeling

MSC Software

Universities

Brigham Young University

Carnegie Mellon

The University of New Mexico

California Institute of Technology — Seismological Laboratory

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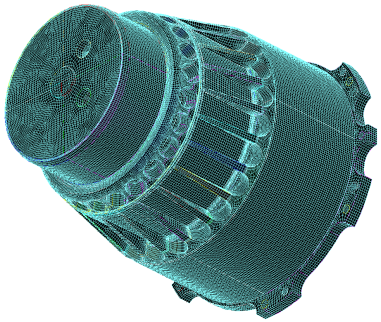
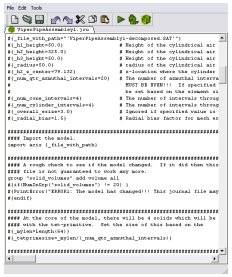
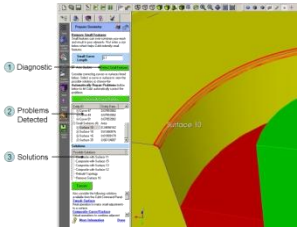
Some Distinguishing Strengths



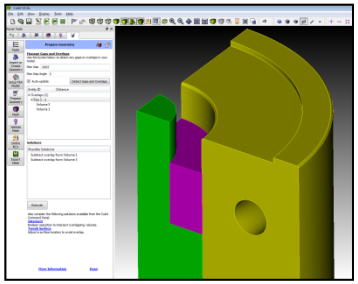
Complex Hex Meshing



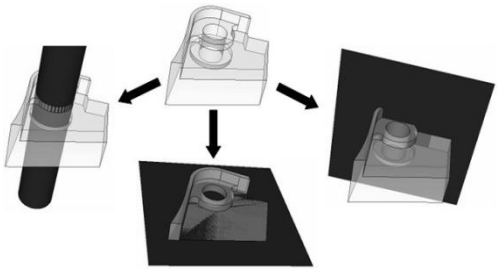
Scripting



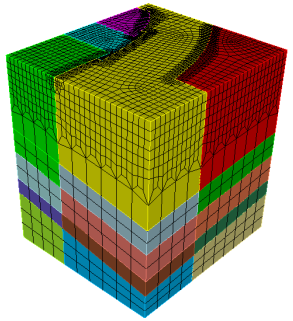
Geometry Clean-up & Defeaturing



Contiguous Assembly Meshing



Decomposition Tools



Local Hex Refinement

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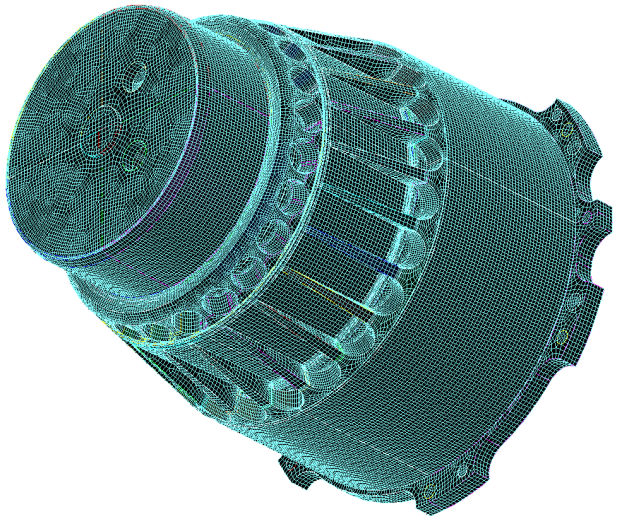
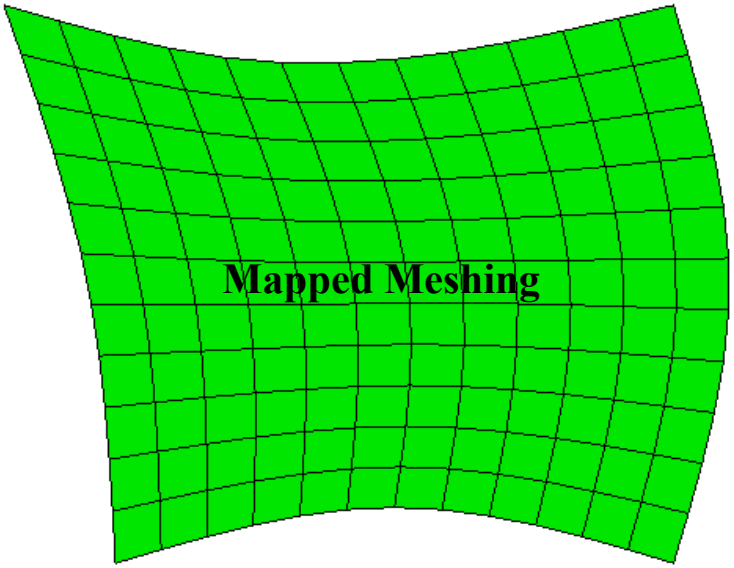
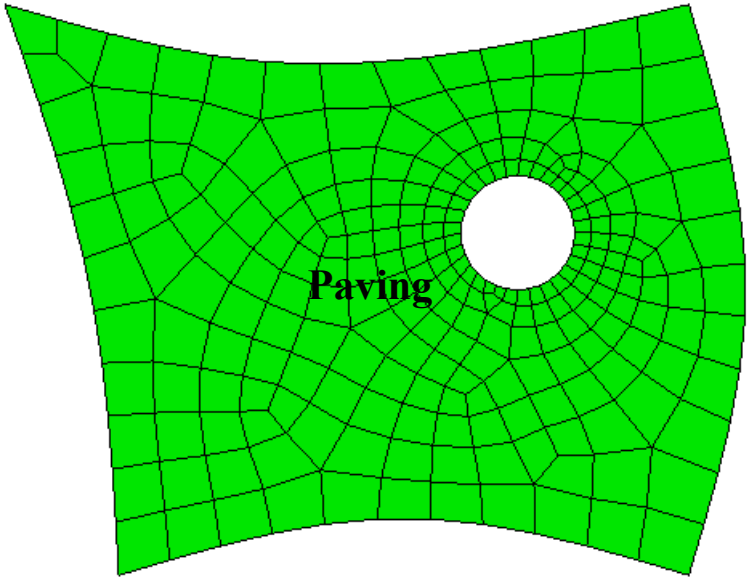


Complex Hex Meshing

Structured vs. Unstructured





Structured

1. Interior node valence is constant.

   ie. number of elements at each interior node=4

2. Meshing algorithm relies on specific topology constraints.

   ie. number of sides=4

Unstructured

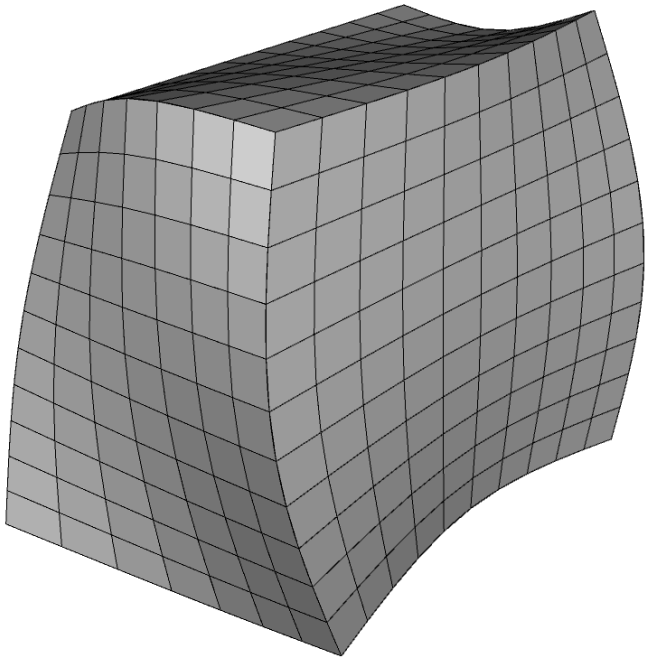
1. Interior node valence varies.

   ie. number of elements at each node=3,4,5…

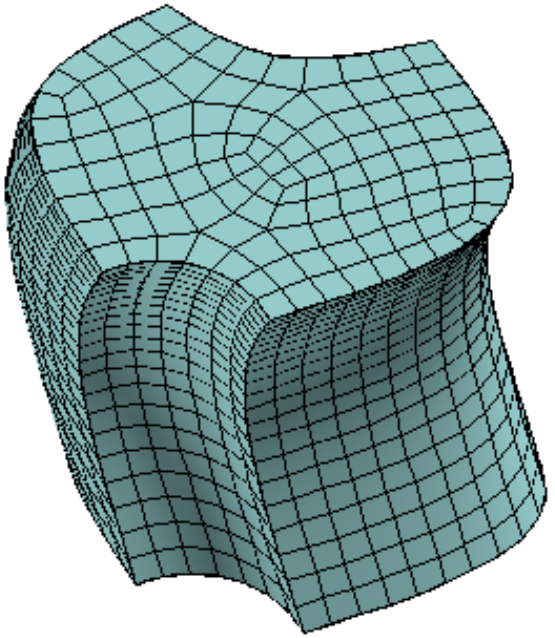
2. Meshing algorithm applies to arbitrary topology

   ie. number of sides is arbitrary

3D?

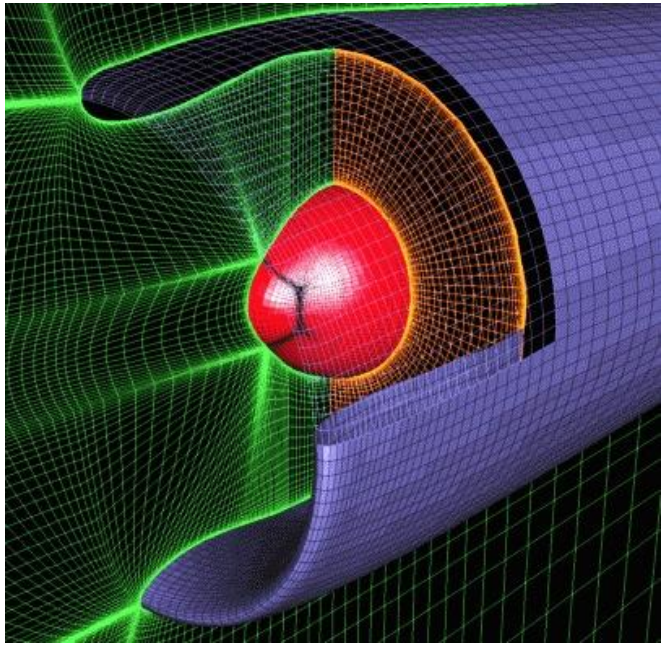


Mapped Meshing

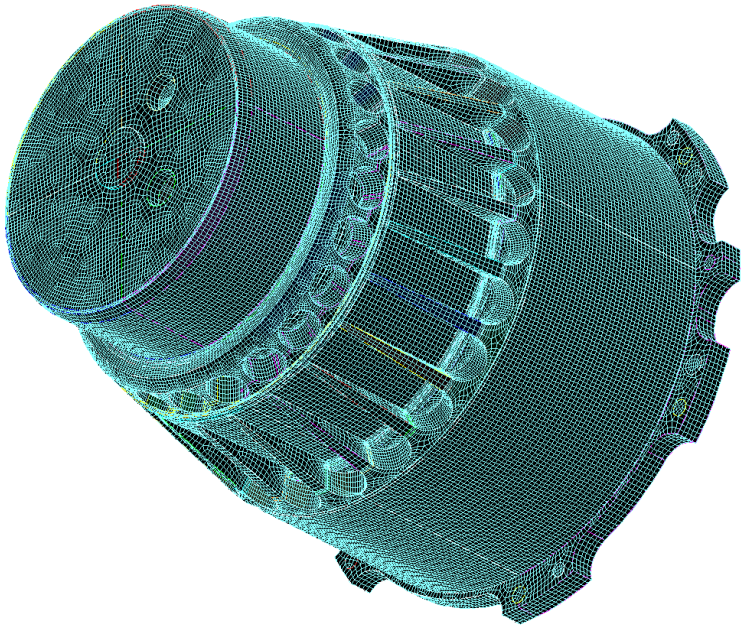


Sweeping
(2.5 D)

Complex 3D?



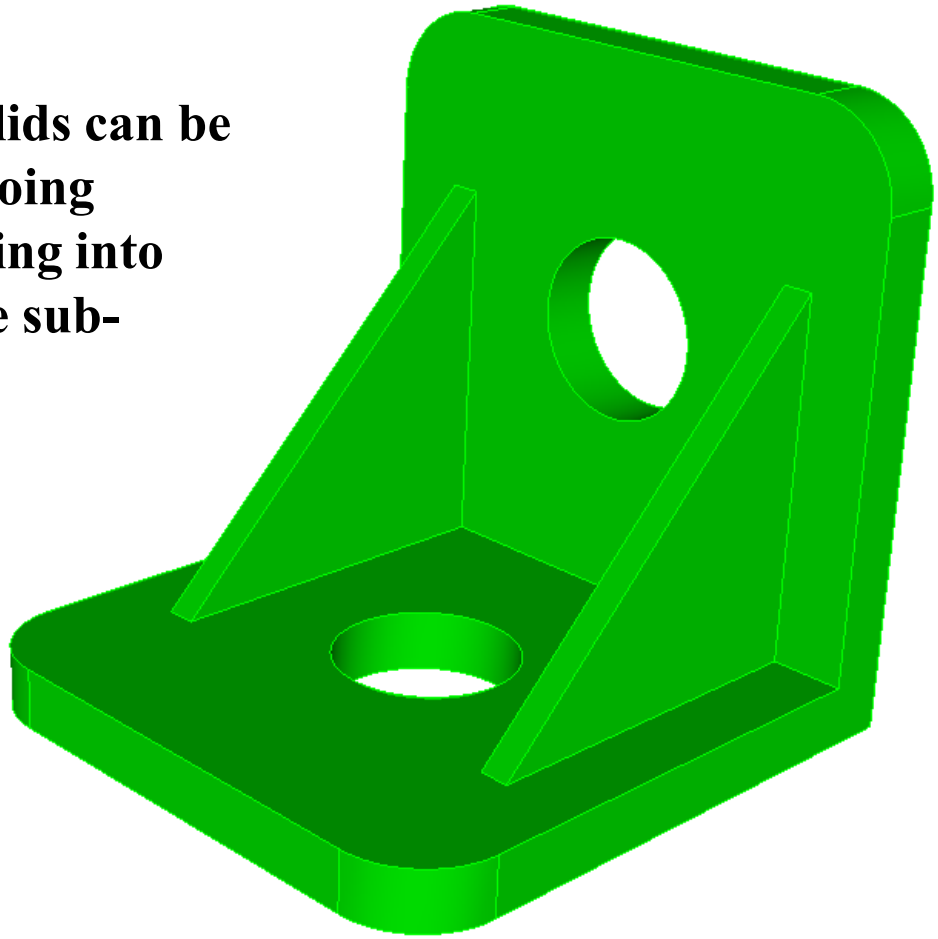
Block-Structured Meshing



Partition & Sweeping

Partition & Sweeping

More complex solids can be meshed by first doing manual partitioning into several sweepable sub-solids.



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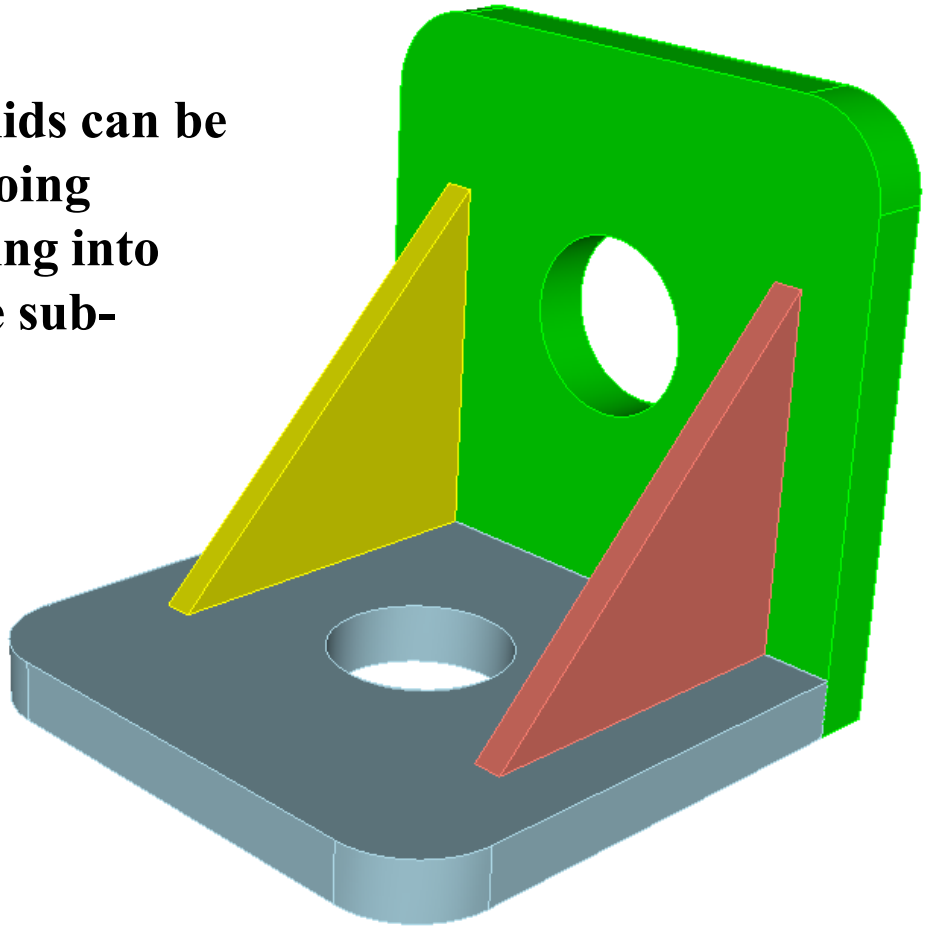

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Partition & Sweeping

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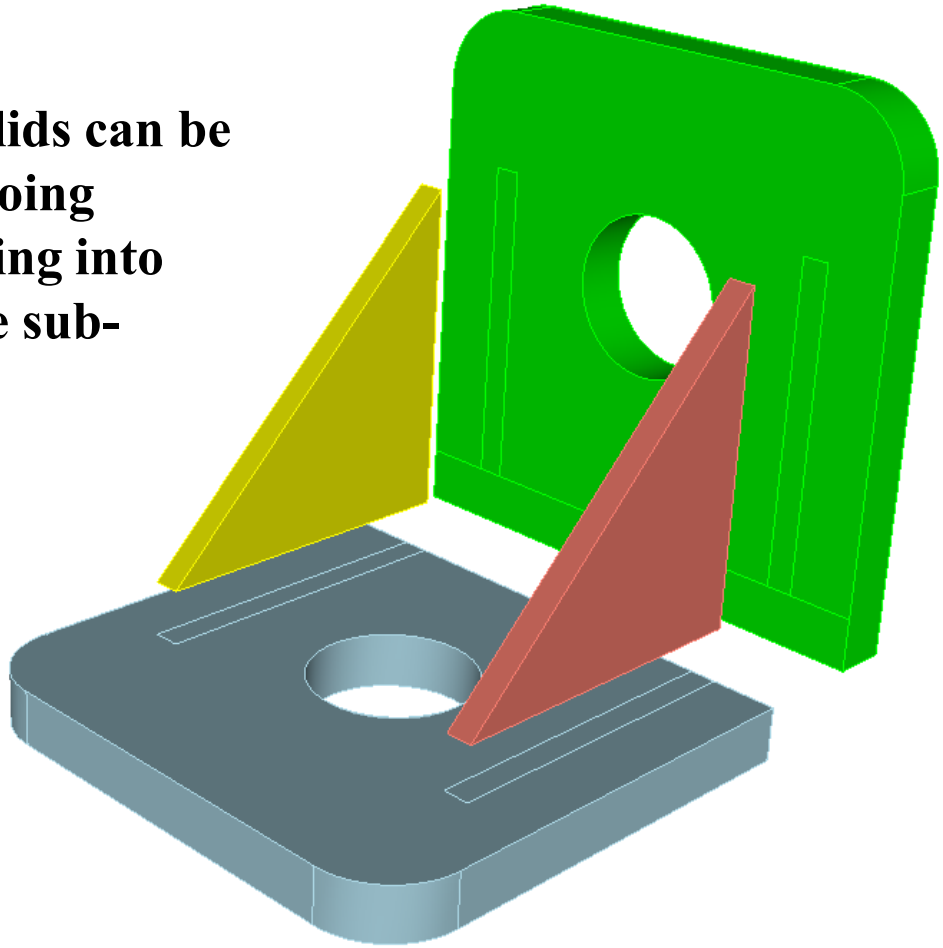

Partition & Sweeping

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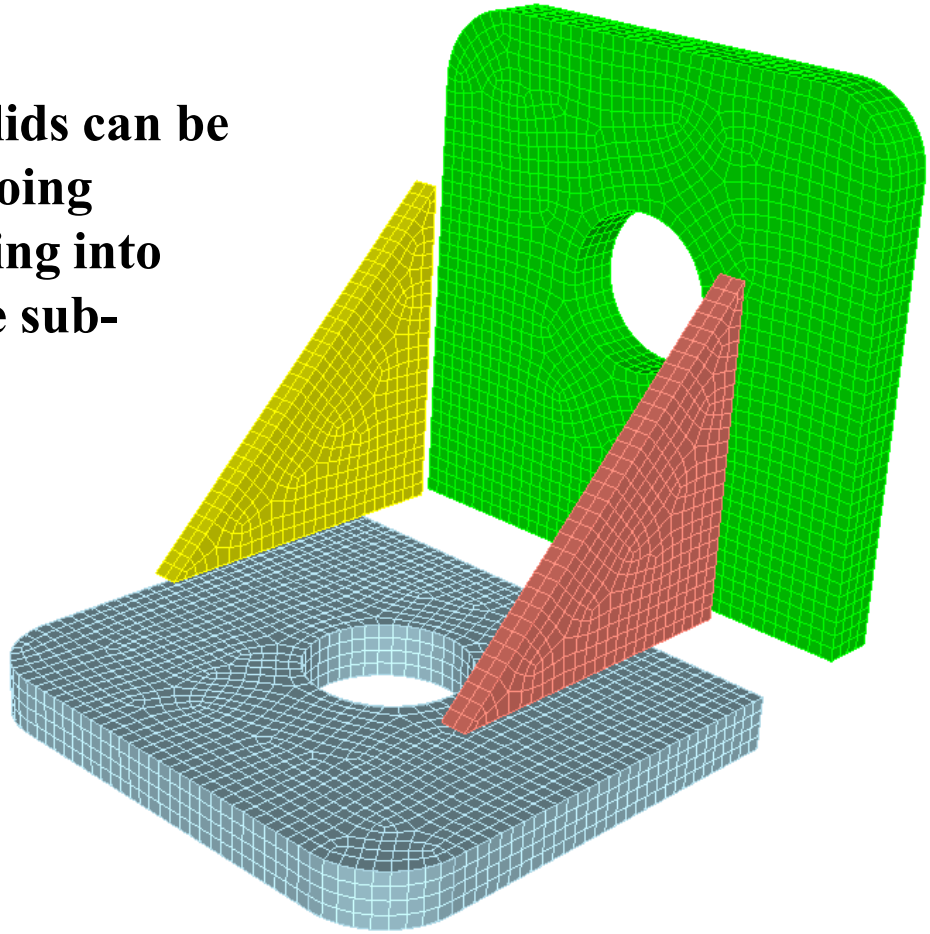

Partition & Sweeping

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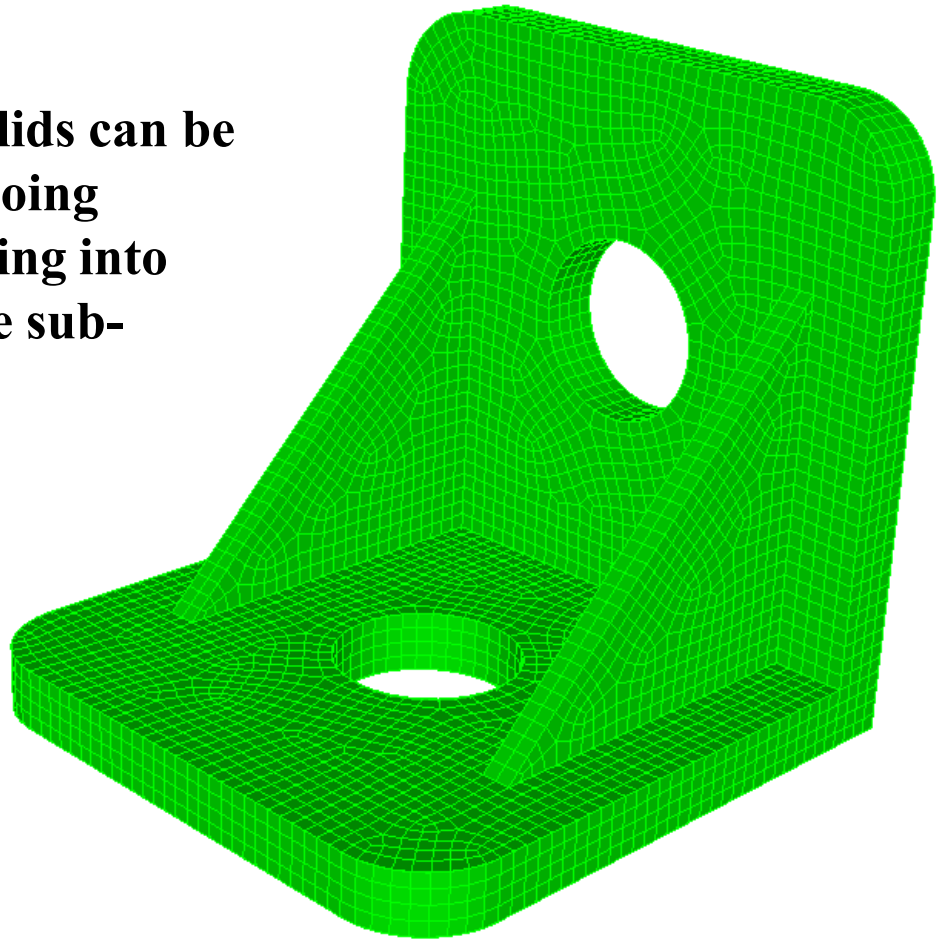
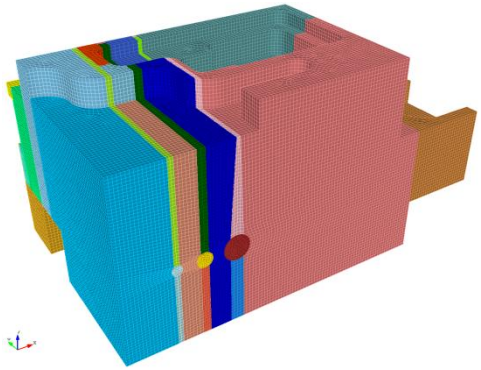
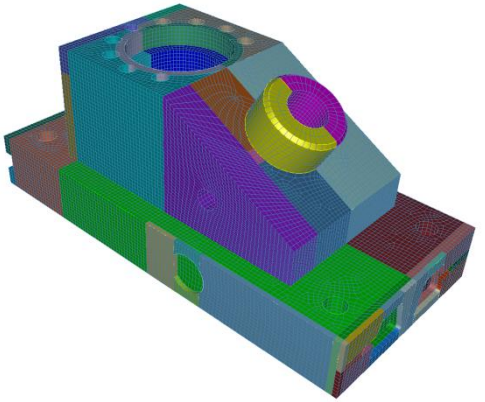
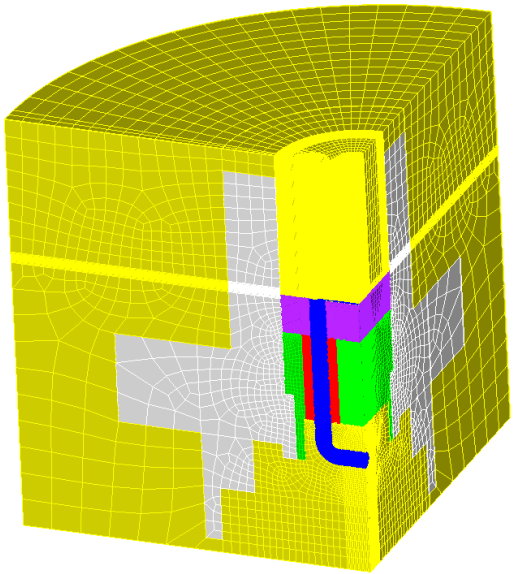


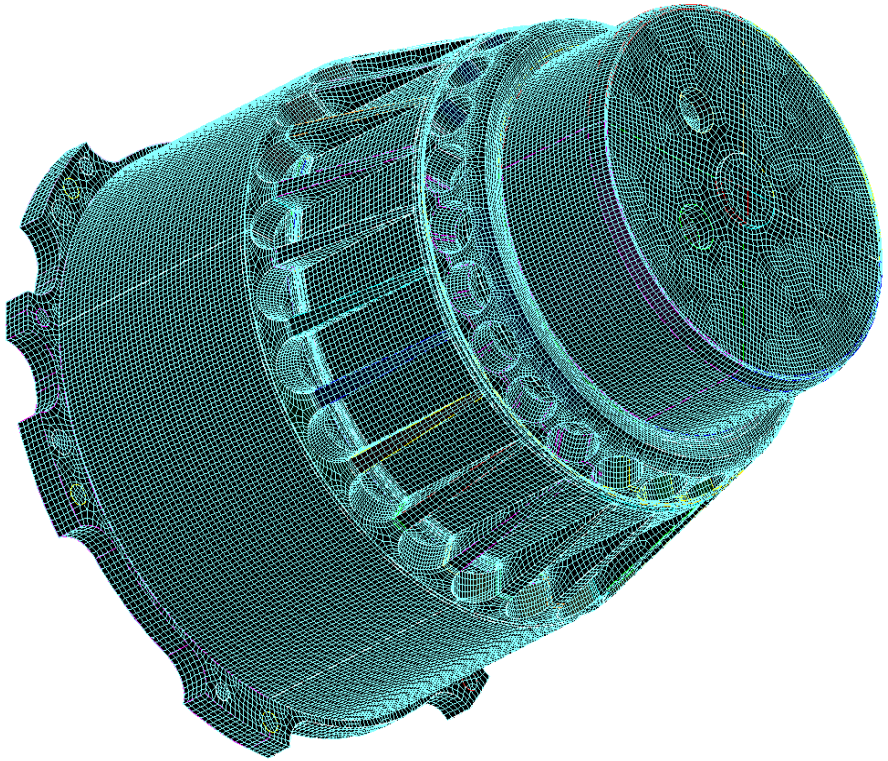
Partitioning & Sweeping Very Complex Solids

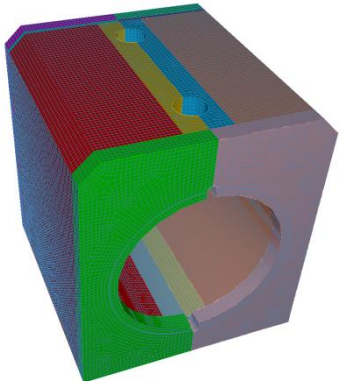


Any geometry, regardless of complexity, can be meshed by first decomposing it into sweepable sub-solids. Decomposition step of complex solids requires tedium, experience, and creativity and often lots of time.









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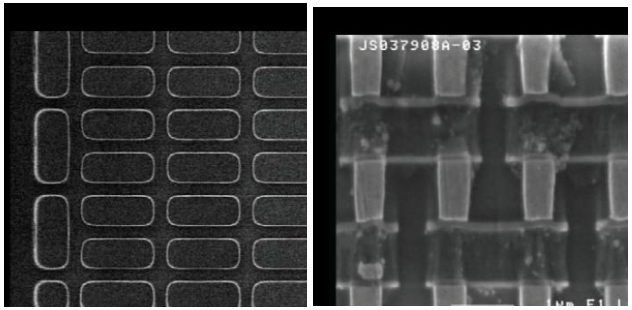
Hex Meshing Example: Thermomechanical Modeling of Back-End-of-the-Line 3D Interconnects



BEOL 3D via chain, (a) plan-view of exposed wires, and (b) cross section view of multi-layered chain.

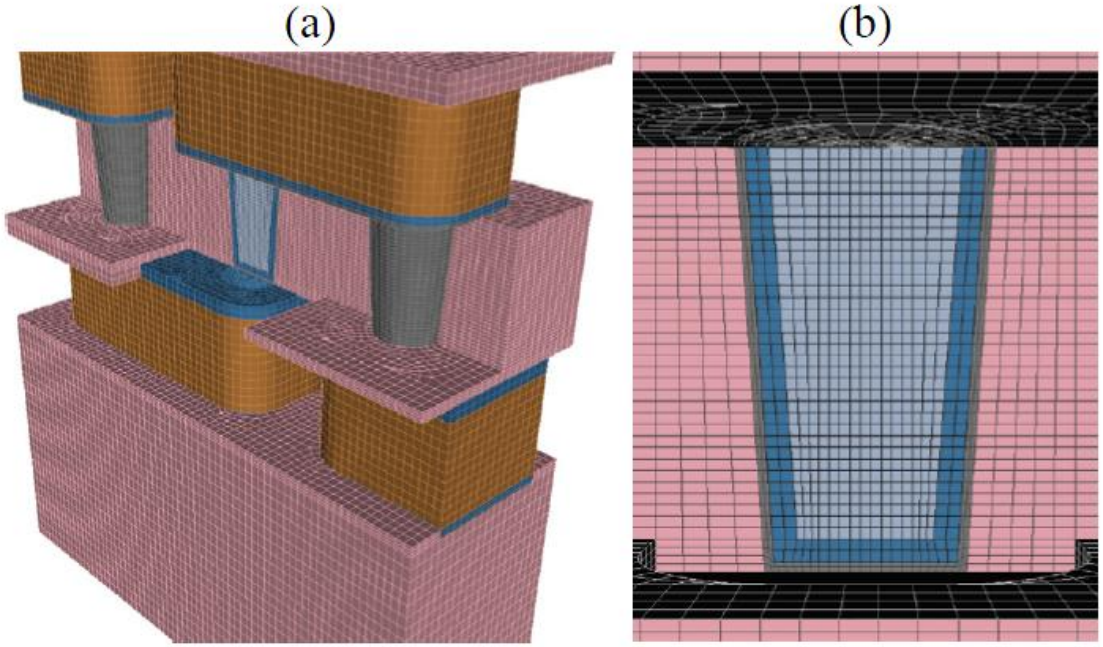
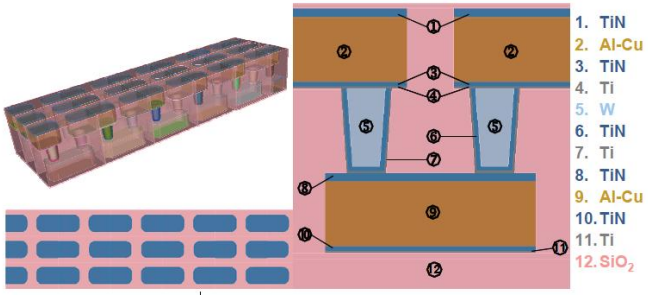


Figure 4: Mesh of a 3-link via chain; (a) isometric cutaway view, and (b) cross-section of W-filled via surrounded by Ti and TiN linings and SiO_2



3D virtual geometry of a via chain. The as-drafted geometry is modified to resemble the fabricated geometry.

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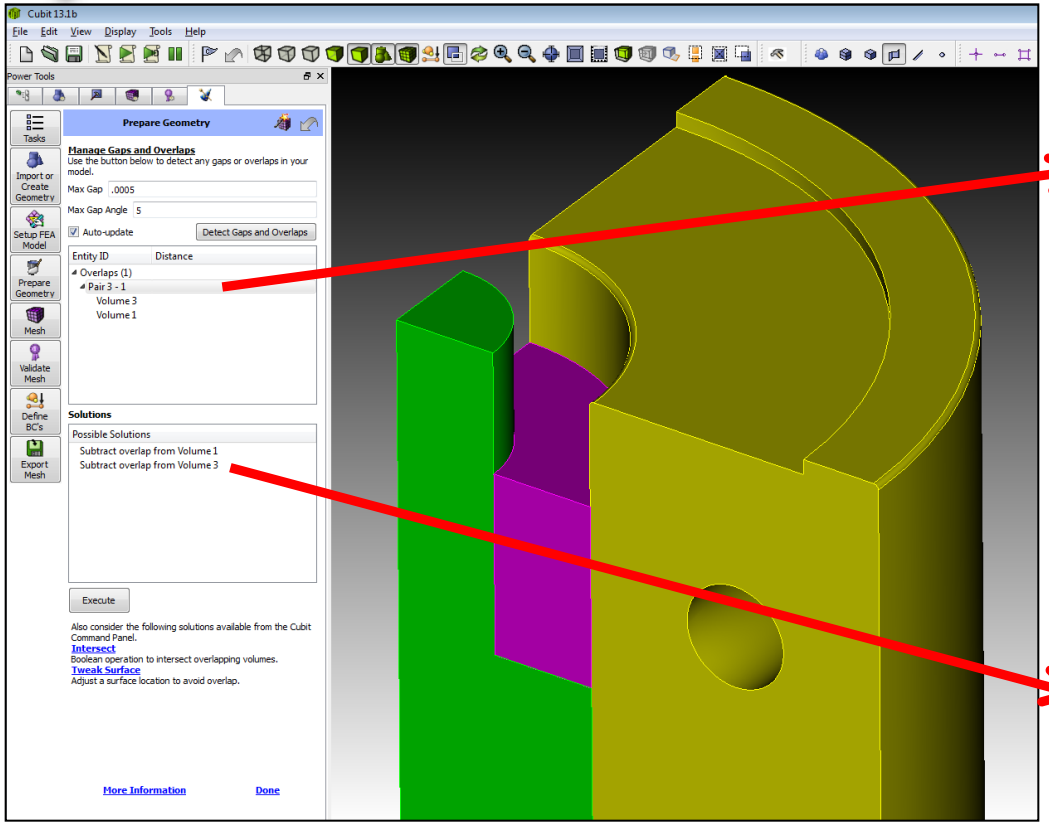
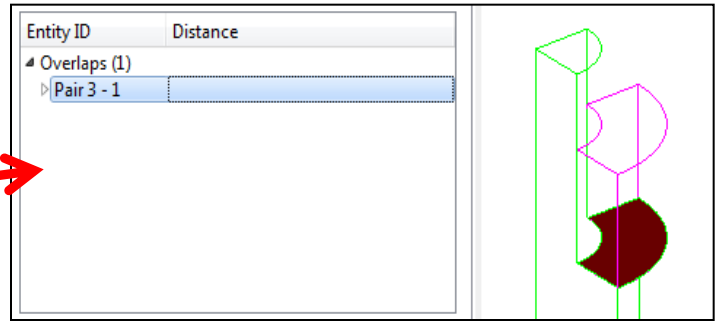
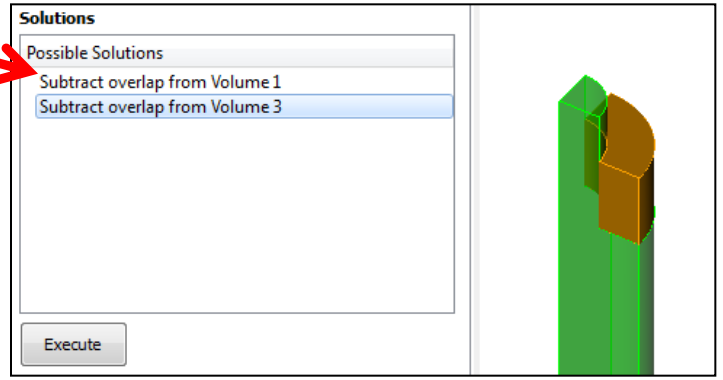
Assembly Meshing and Gaps/Overlaps/Misalignments





Right clicking on an overlap pair in the list and choosing "Draw Pair" will draw the two volumes with the overlap and shade the region of overlap.

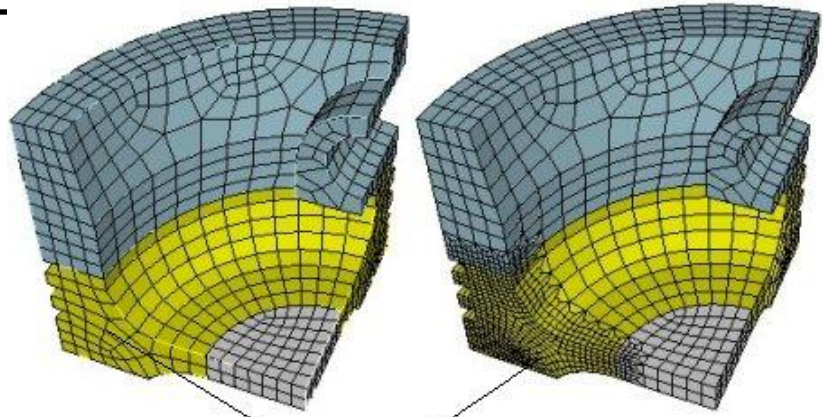


Selecting a solution will show the volume that the overlap region will be subtracted from and clicking "Execute" will do the subtraction.

Tool for quickly finding and fixing gaps, overlaps, and misalignments in CAD assembly models.

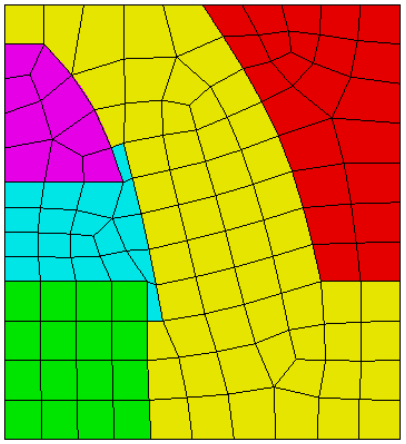
Local Hexahedral Refinement

- Fully conforming hexahedral refinement
- User selects target elements or geometry to refine
- CUBIT creates all-hex transitions between refined and coarse regions

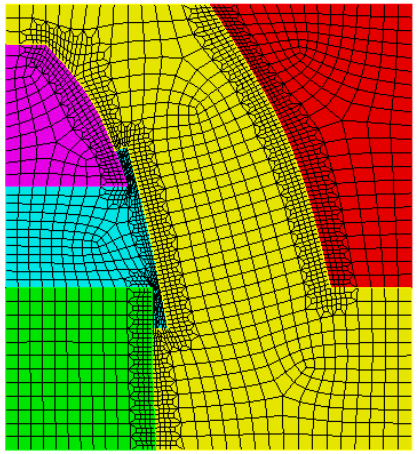


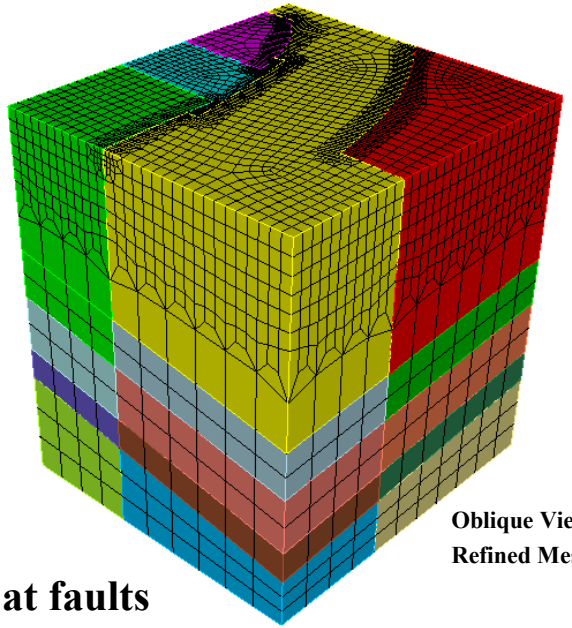
Before and after Hex refinement at a selected surface

Top View – Original Mesh



Top View – Refined Mesh





Oblique View – Refined Mesh

Geological model locally refined near surface and at faults

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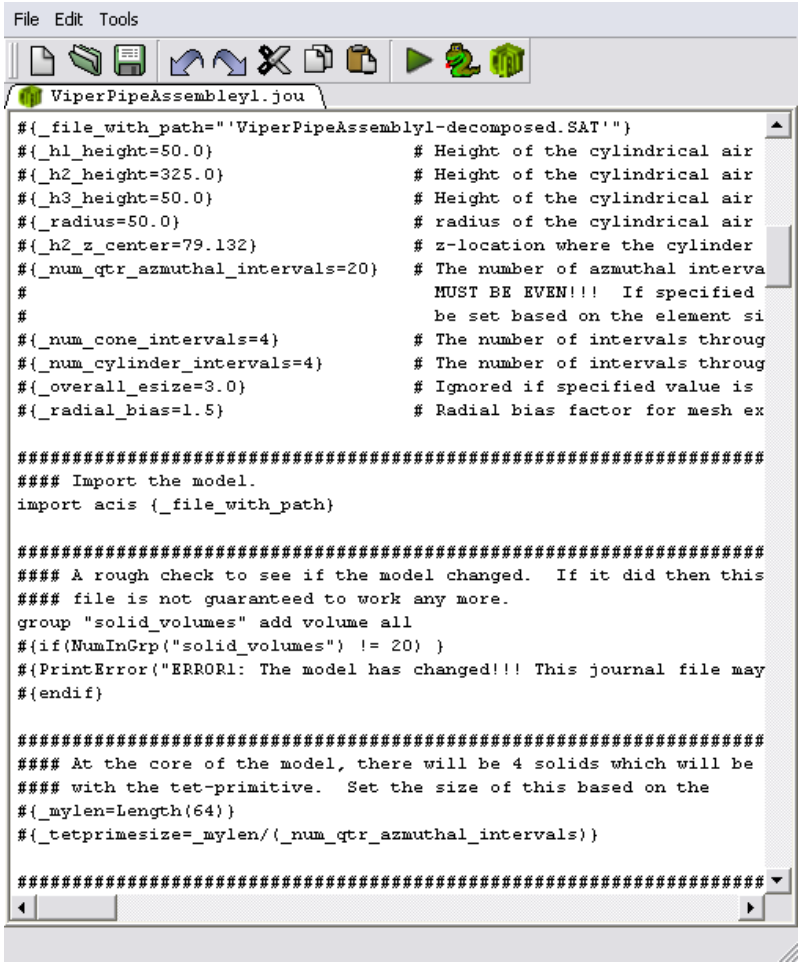
CUBIT Scripting Capability

- Journal Files
  - CUBIT Command Syntax
  - CUBIT Automatically echoes commands to create journal file
  - User can create and play journal files
  - APREPRO language permits basic programming and parameterization of variables
- Python Scripting
  - Full python interpreter included in CUBIT
  - More control than journal file
  - CUBIT Python Interface includes extensive API to CUBIT functions
  - Permits Custom GUI Creation with QT



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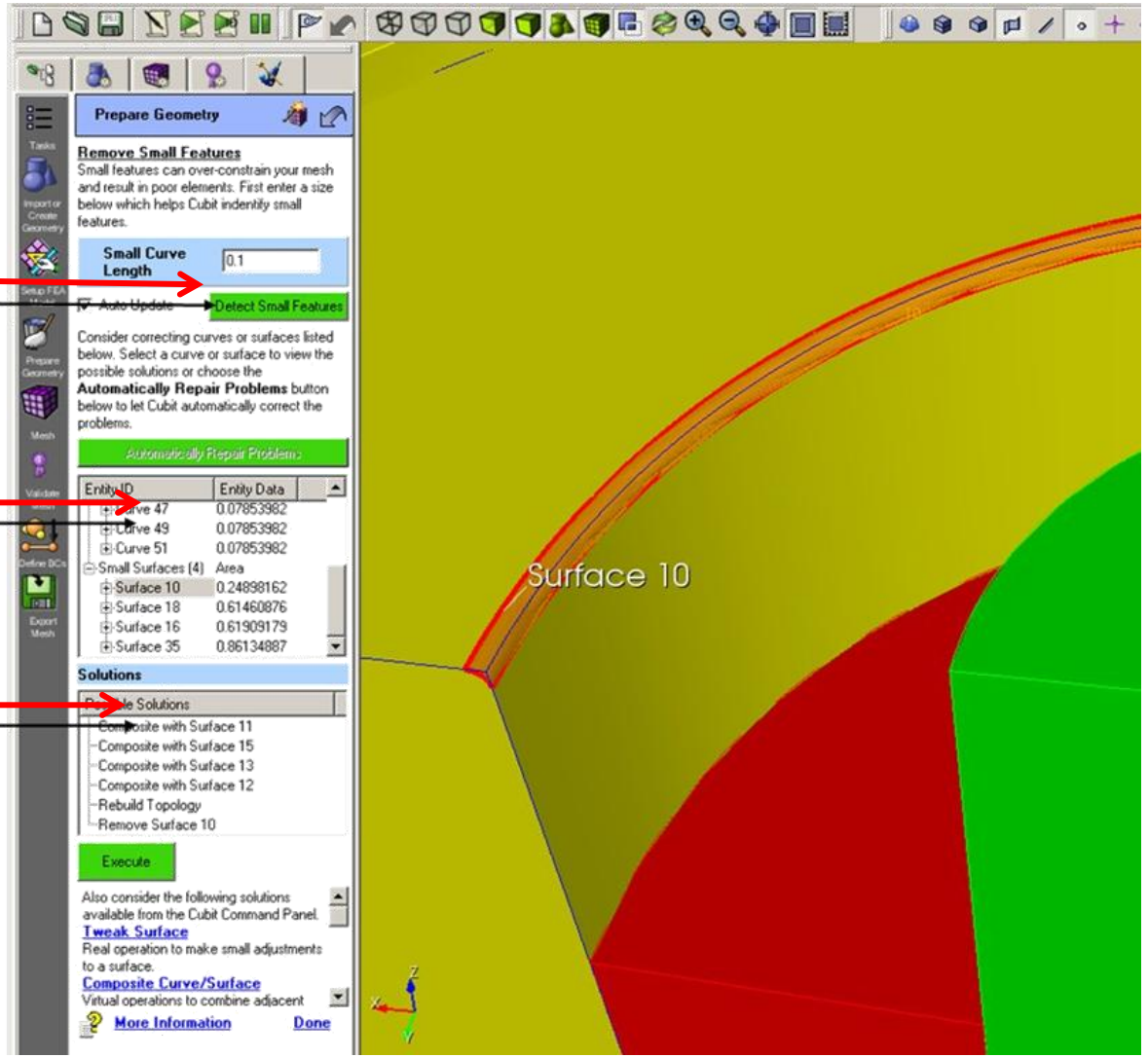
Automated Geometry Defeaturing

Press "Detect Small Features" button to run diagnostics

List of geometric entities that fail the diagnostic test. Left click to see solutions for an entity. Right click to zoom, point to, fly-in, etc.

List of specific solutions for selected entity. Left click to see a preview of the solution. Right click to get help or execute the solution (or press Execute button)



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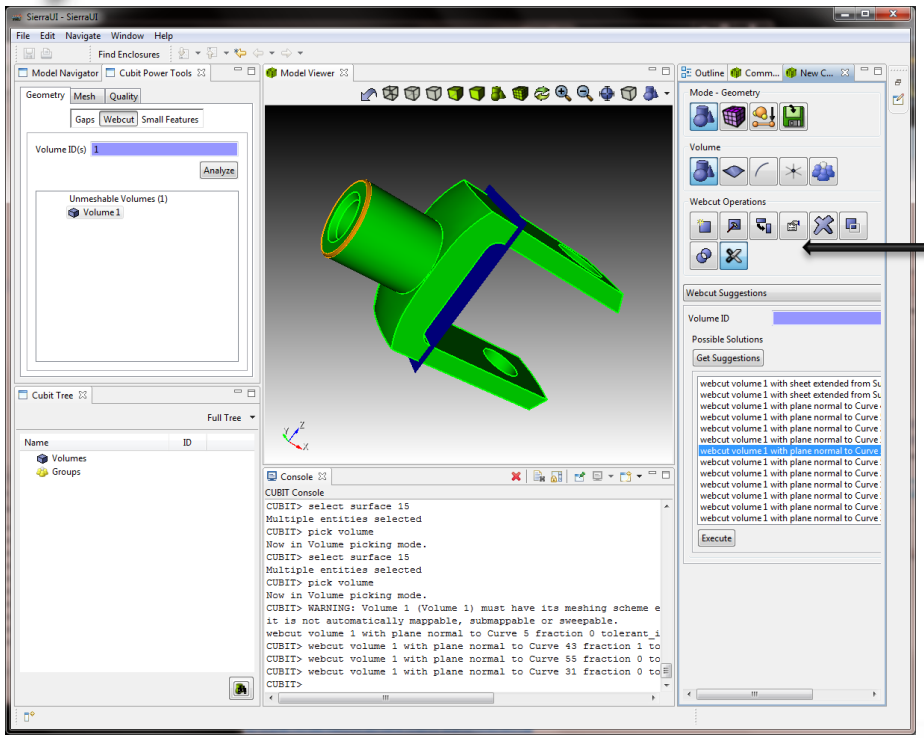
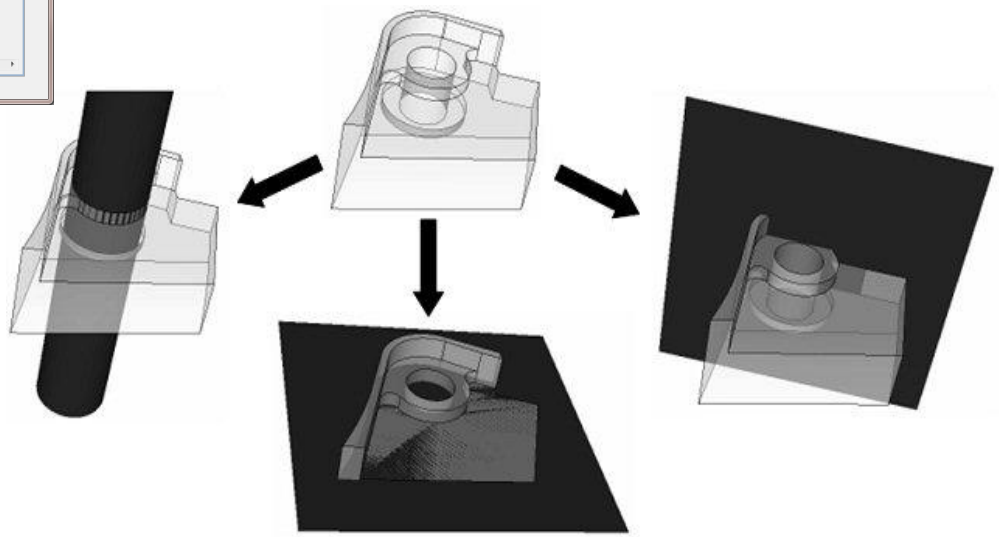
Tools for Decomposition



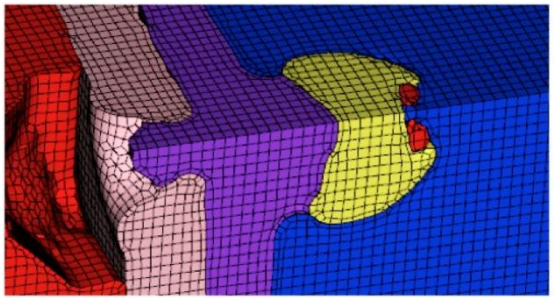
CUBIT provides multiple possible solutions and user selects the one they want

Types of Decomposition Cuts

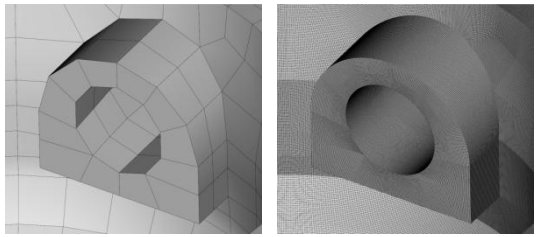
- **Planar**
- **General Surface**
- **Tool Body**
- **Sweep Surface**
- **Sweep Curve**



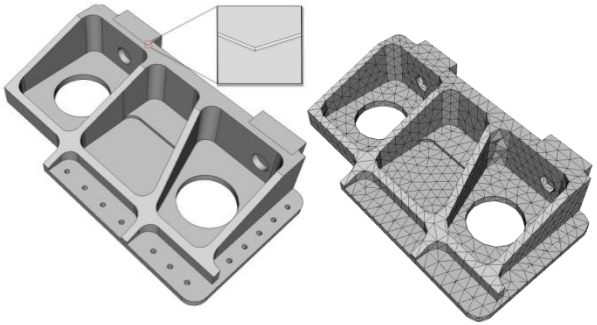
Current Technology Thrusts



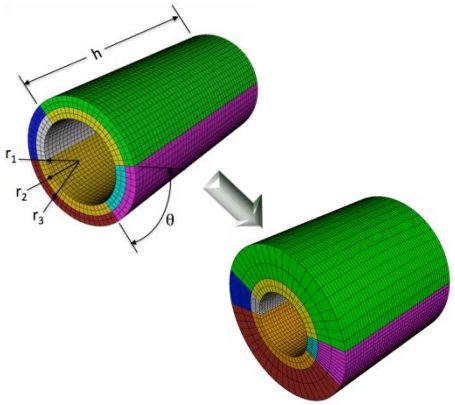
Hex Meshing from Volume Fractions



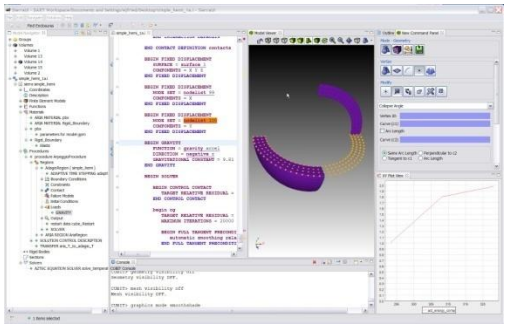
Parallel Refinement



Geometry Defeaturing For Meshing



Moving Meshes, Mesh Morphing



Integrated User Experience

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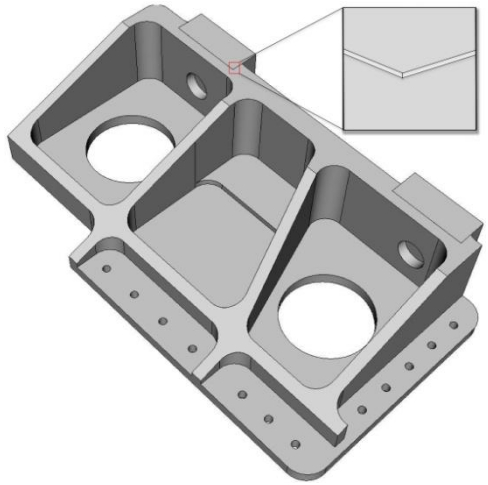
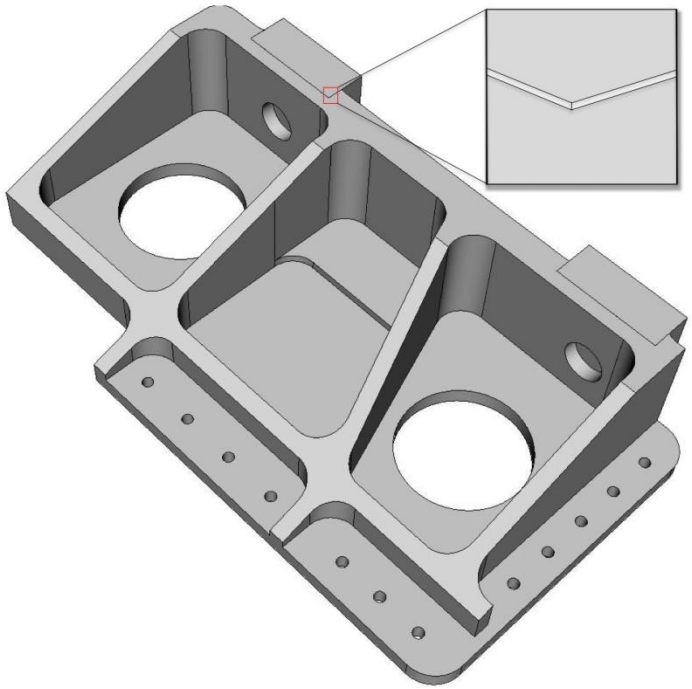
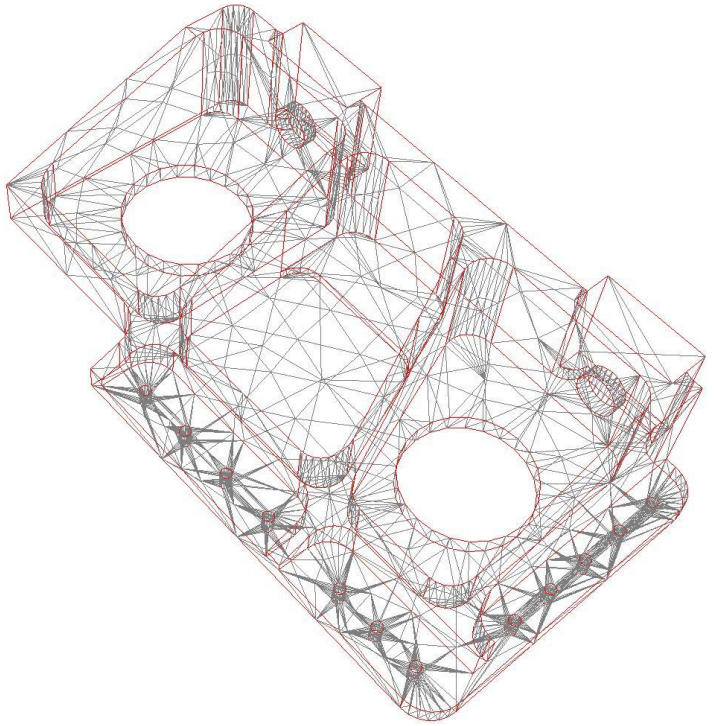


Geometry Defeaturing
For Meshing

Automatic Geometry Defeaturing



Solid Model



Facet Representation

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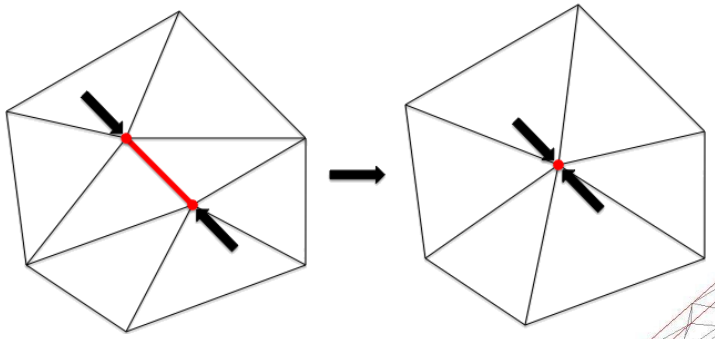
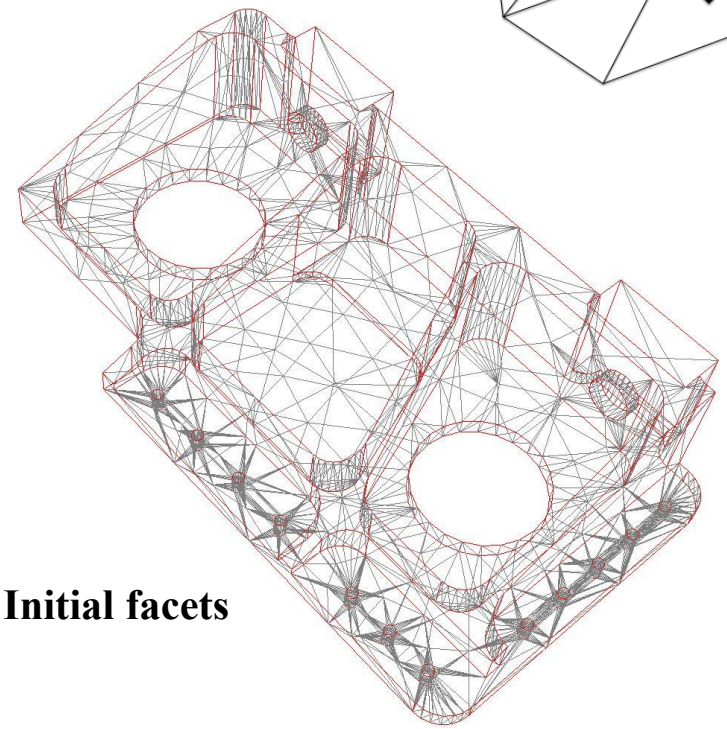
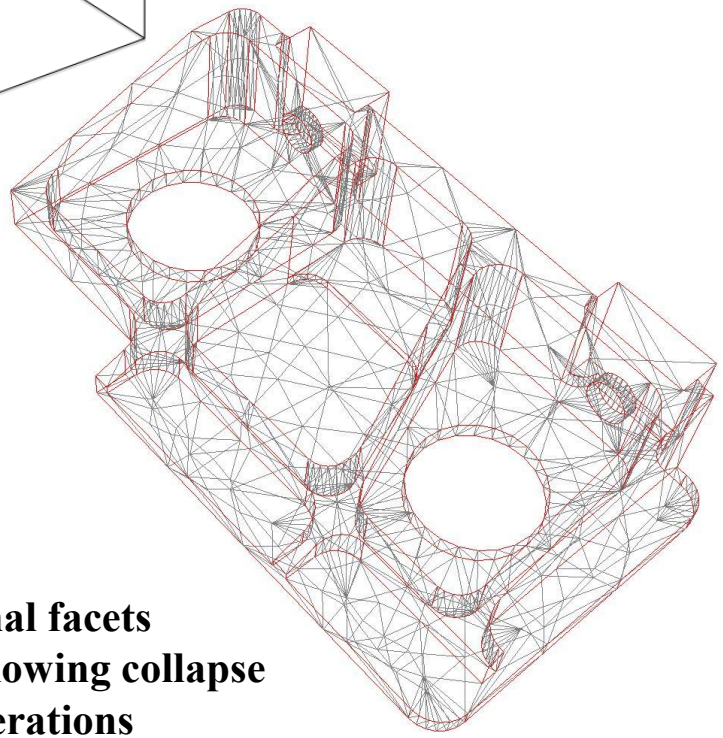
Automatic Geometry Defeaturing

Basic Operation – Edge Collapse





Initial facets



Final facets following collapse operations

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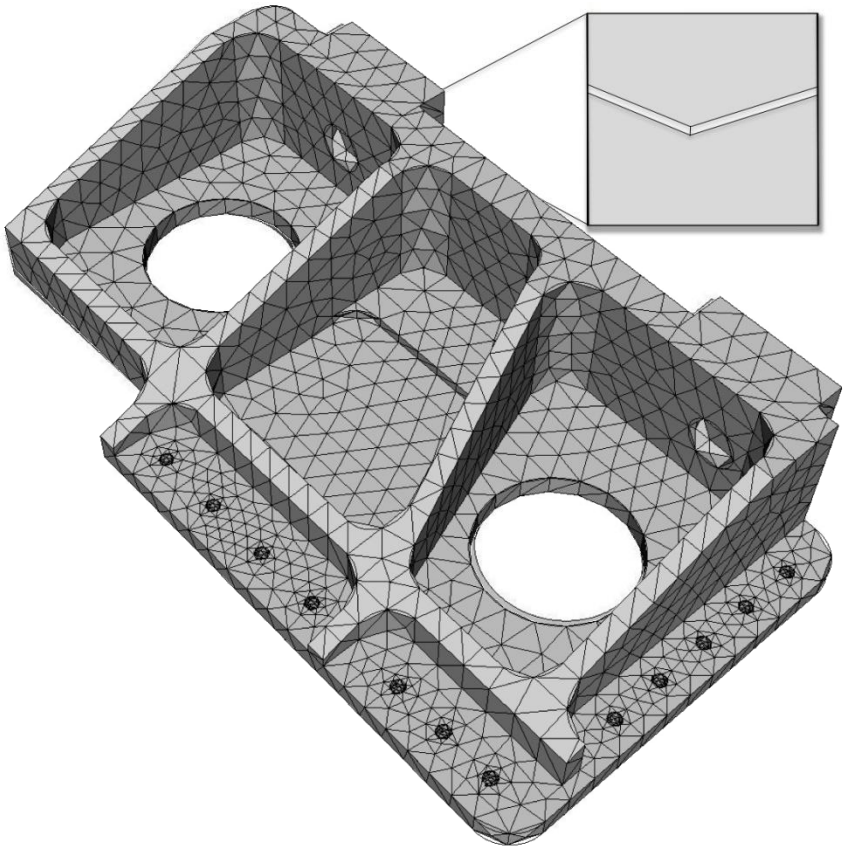
Automatic Geometry Defetauring



Original Solid Model
(ACIS-based representation)

Final Solid Model
(Facet-based representation)

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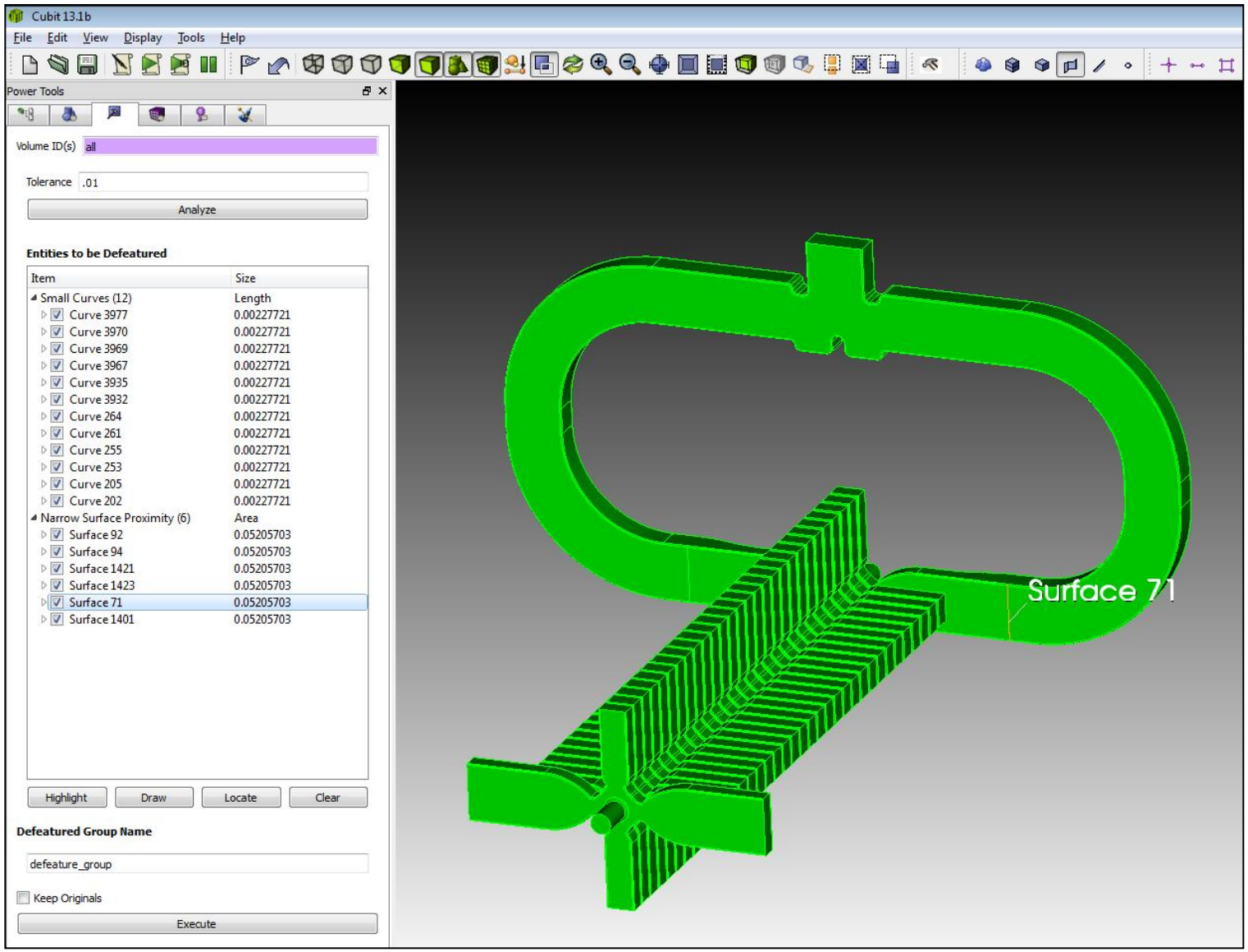
Defeaturing Tool



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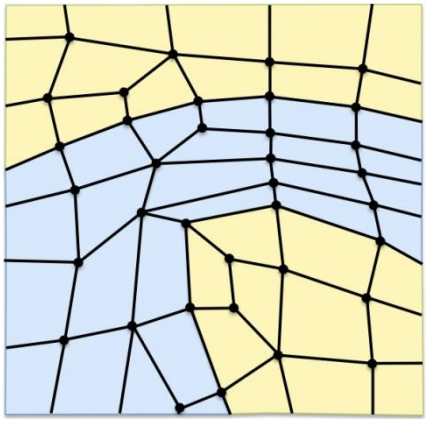
Eularian to Lagrangian Meshing

$v_A = 0.73$ $v_B = 0.27$	$v_A = 0.41$ $v_B = 0.59$	$v_A = 0.43$ $v_B = 0.57$
$v_A = 0.00$ $v_B = 1.00$	$v_A = 0.55$ $v_B = 0.45$	$v_A = 0.38$ $v_B = 0.62$
$v_A = 0.00$ $v_B = 1.00$	$v_A = 0.79$ $v_B = 0.21$	$v_A = 1.00$ $v_B = 0.00$

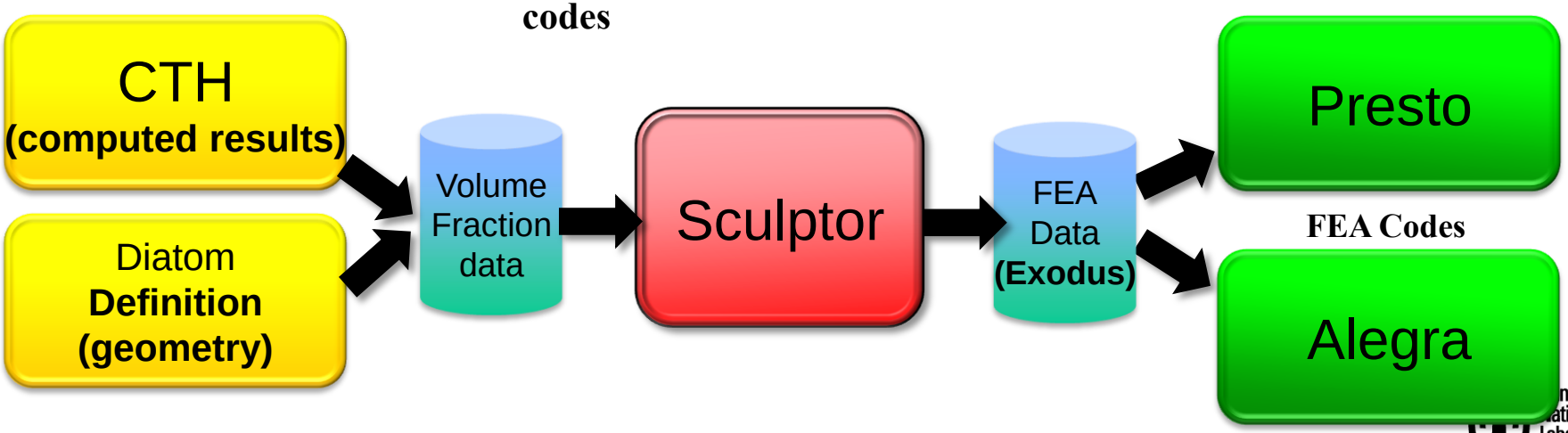
Eulerian

Sculptor

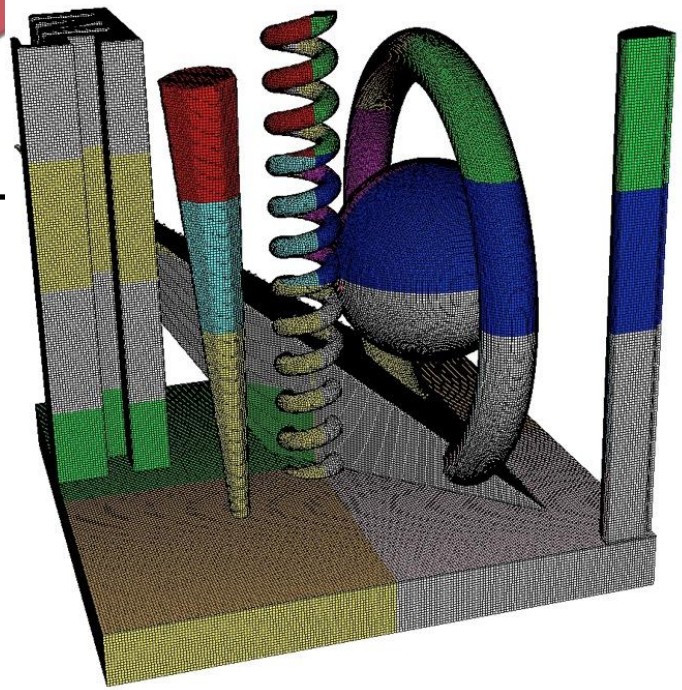


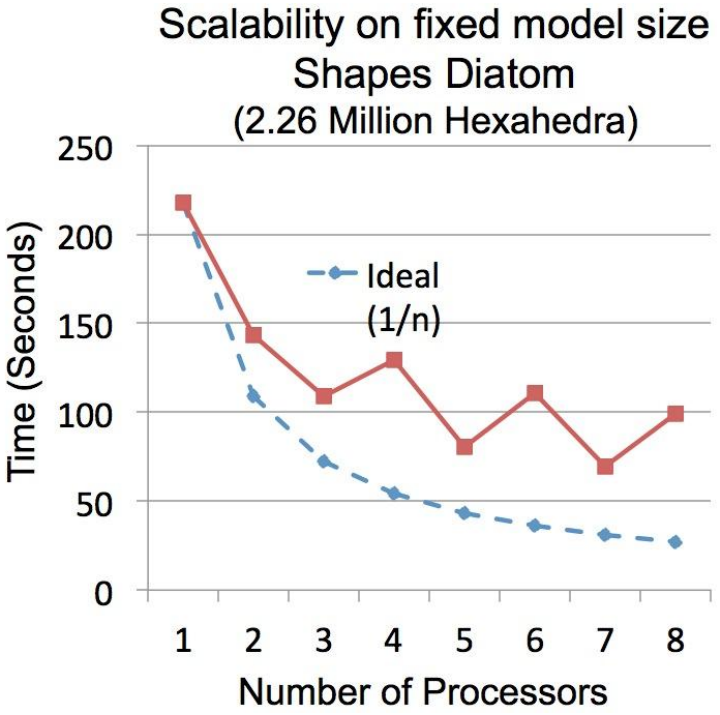
Lagrange

Sculptor is a new tool for generating meshes from volume fraction data generated from CTH for use in Sandia's FEA codes

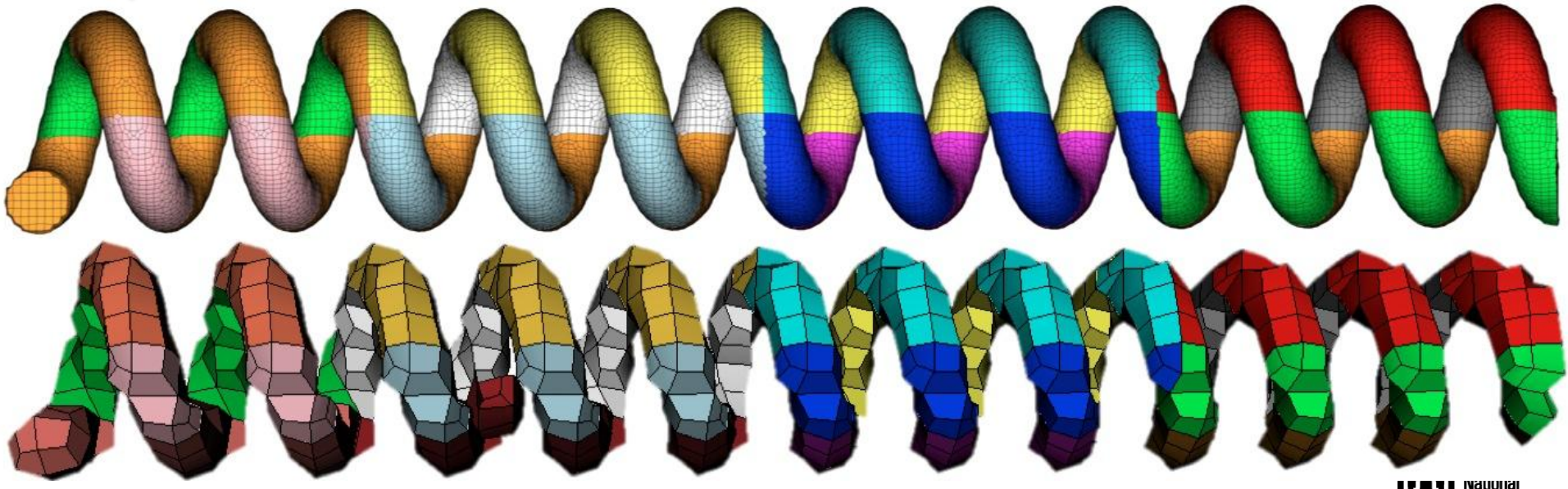


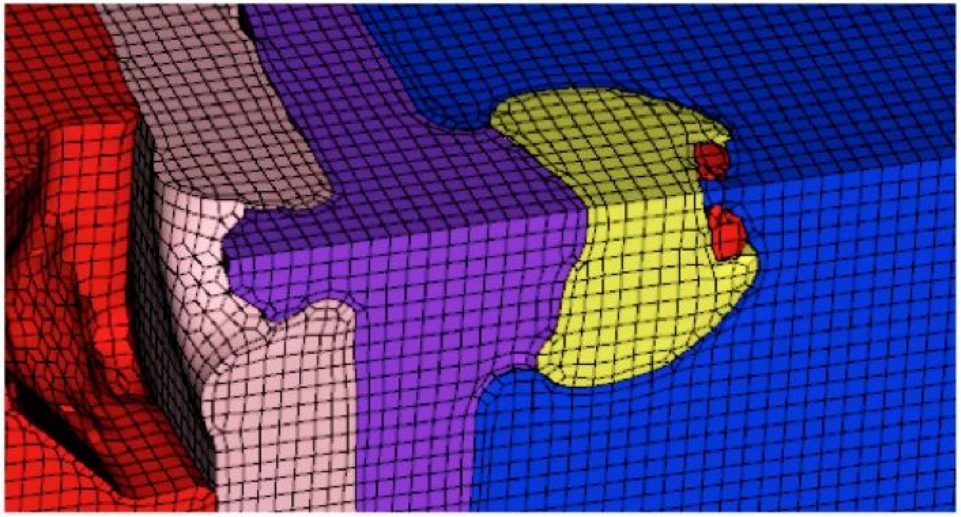
Hex mesh constructed on eight processors and its timing data

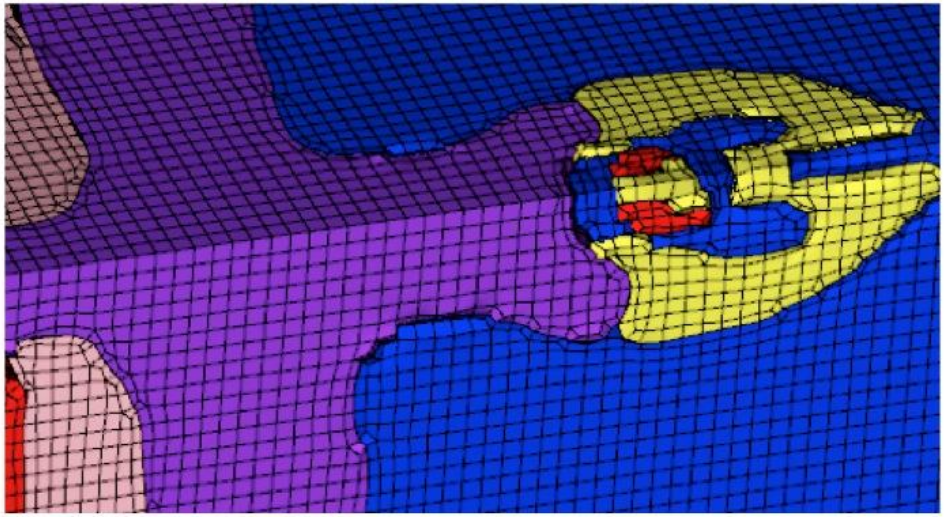




Detail from helix meshed at 2 different resolutions

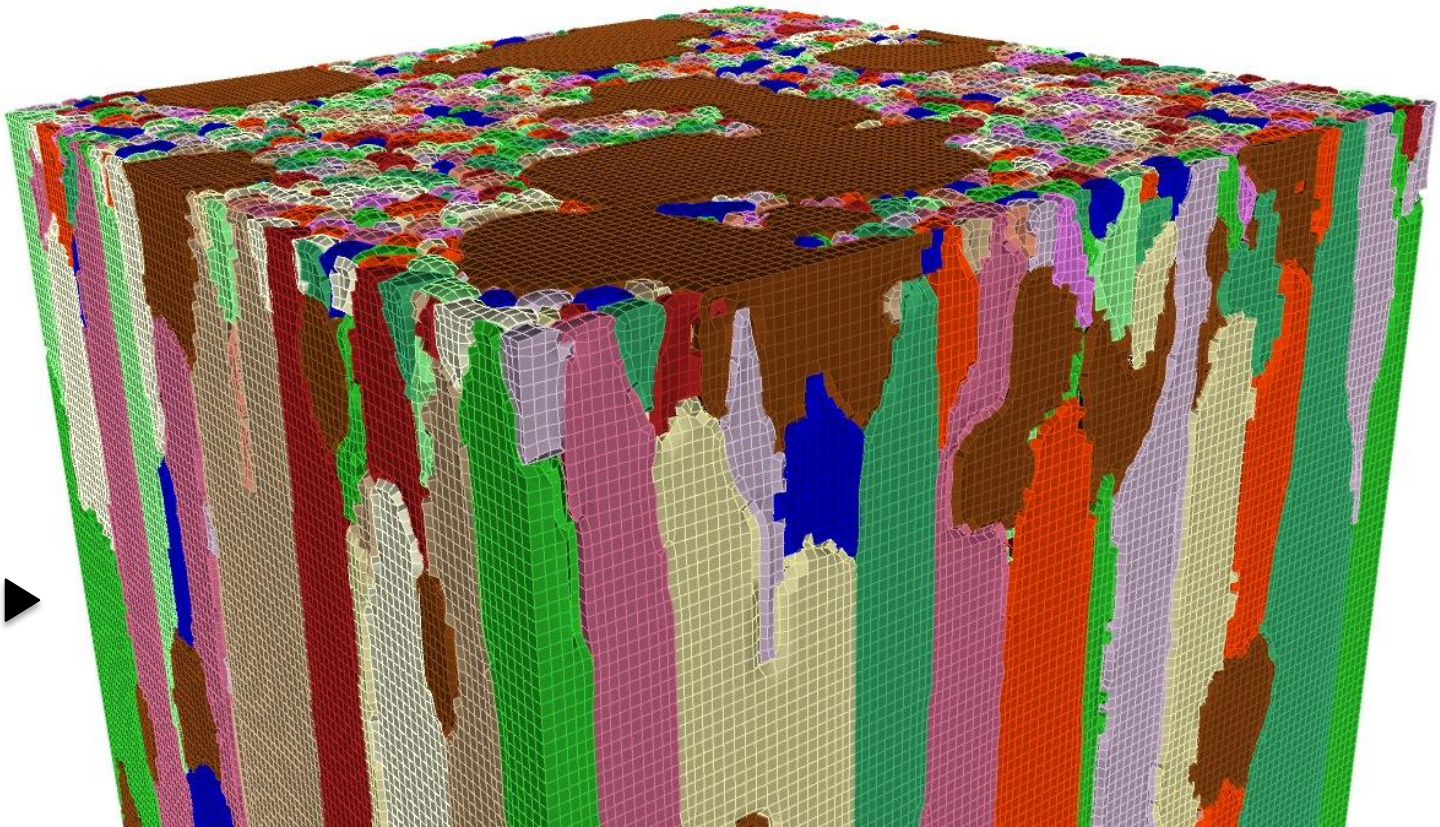


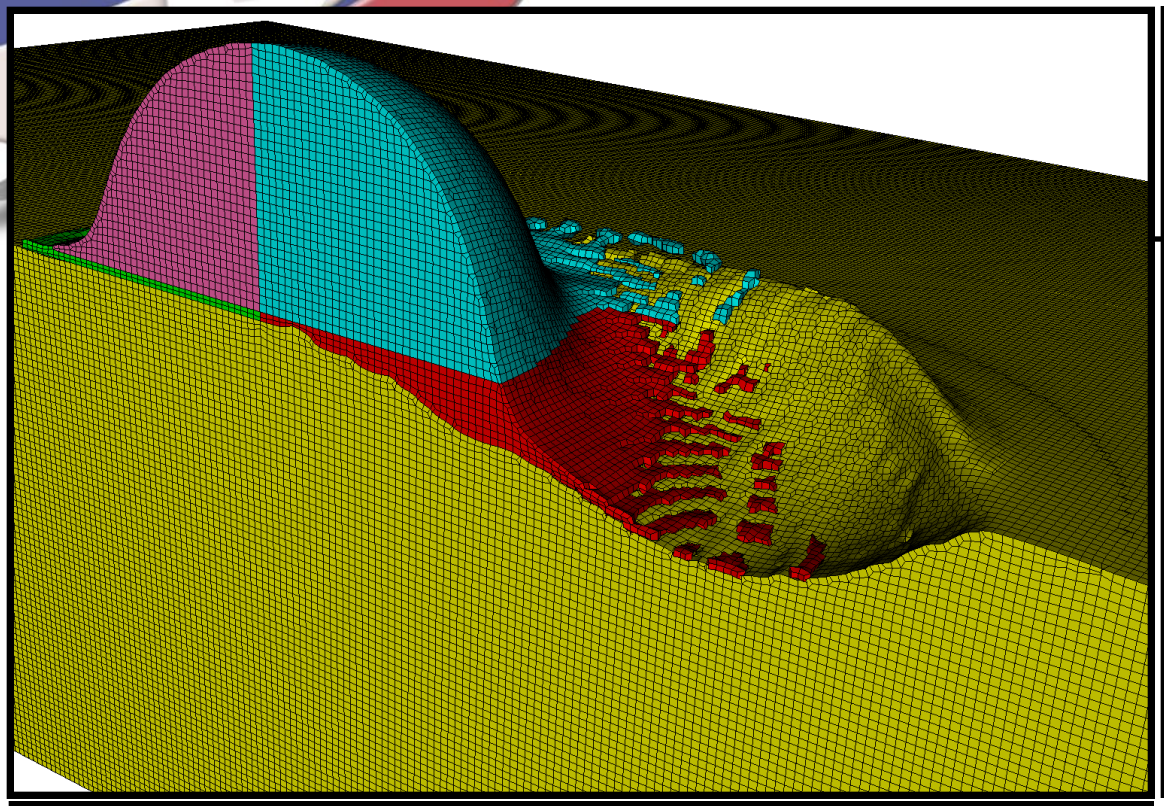


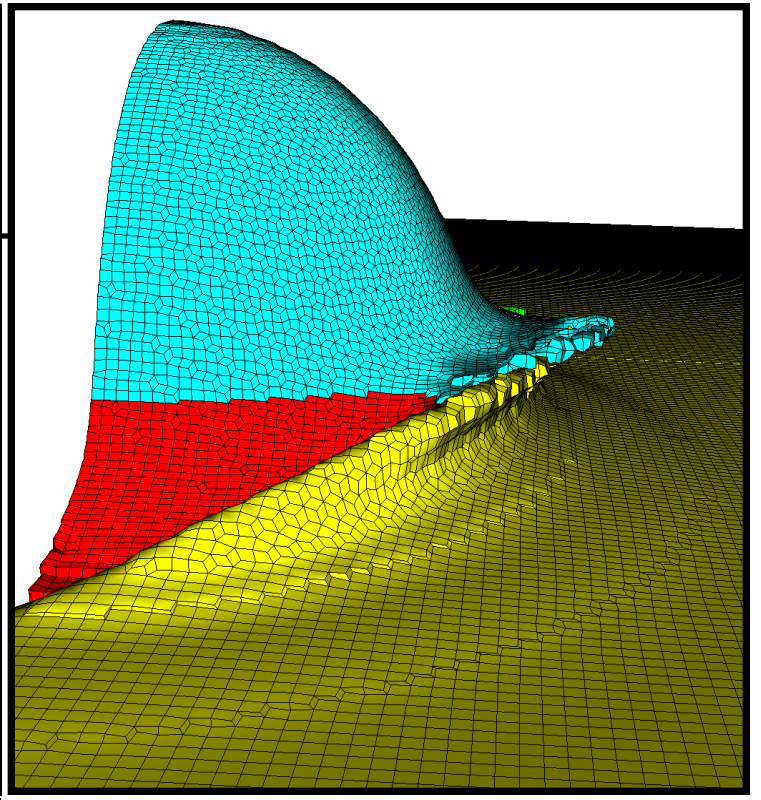


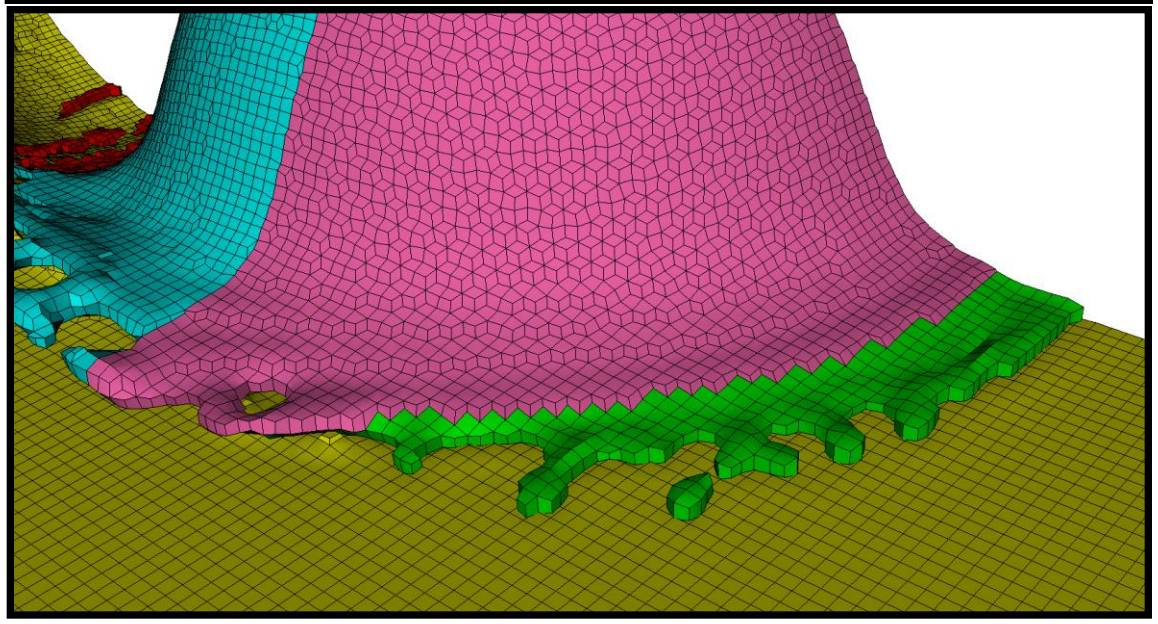
Close-up view of hex meshes generated at two different time steps of a simulated pipe bomb explosion

Hex mesh of simulated grain microstructure with 15 different materials









8 Processors, 4.19 million hexahedra. Hexes color-coded by processor

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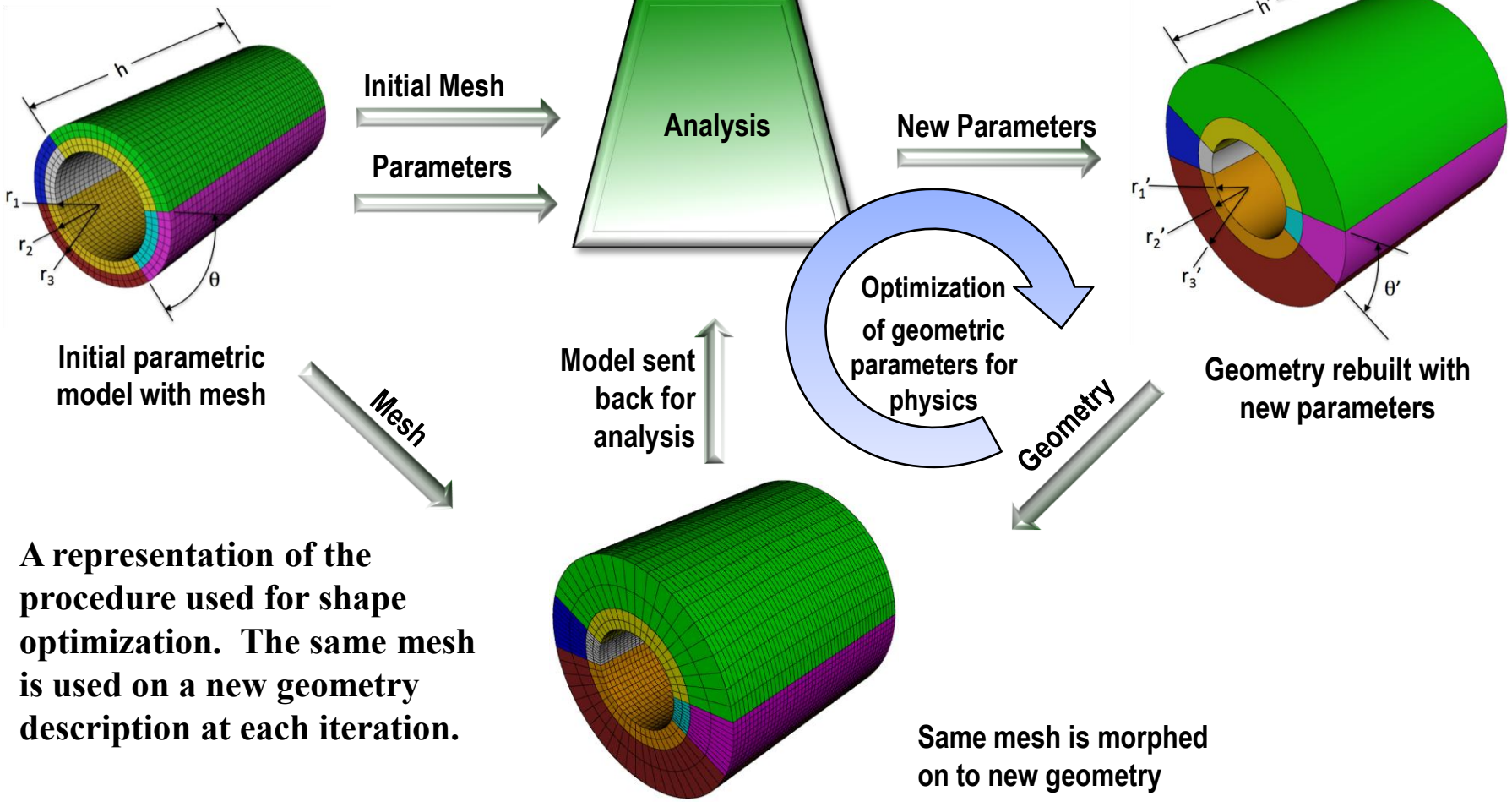
Mesh Morphing for CAD Parametric Shape Optimization



A representation of the procedure used for shape optimization. The same mesh is used on a new geometry description at each iteration.

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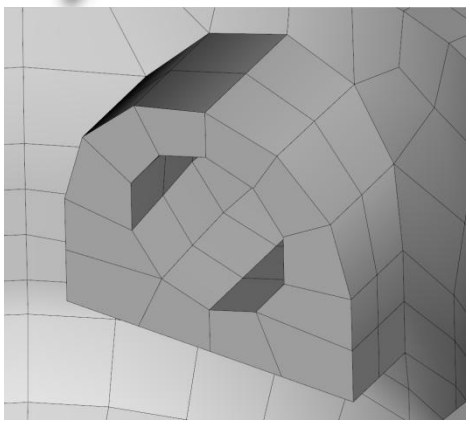
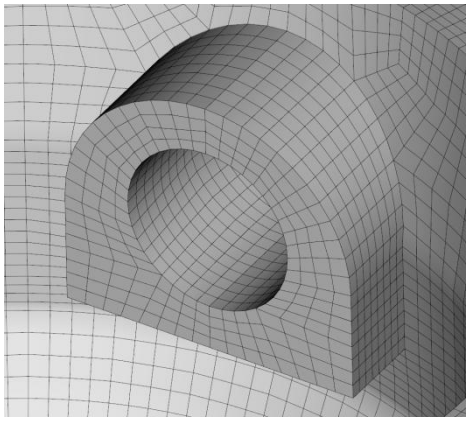
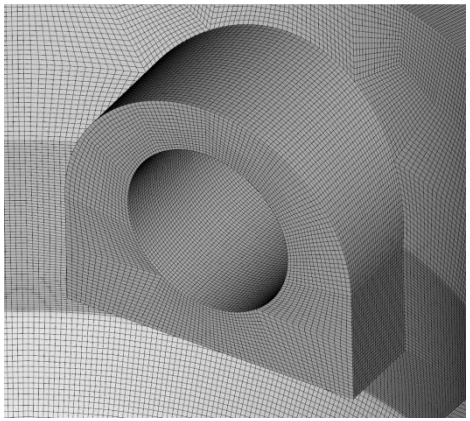
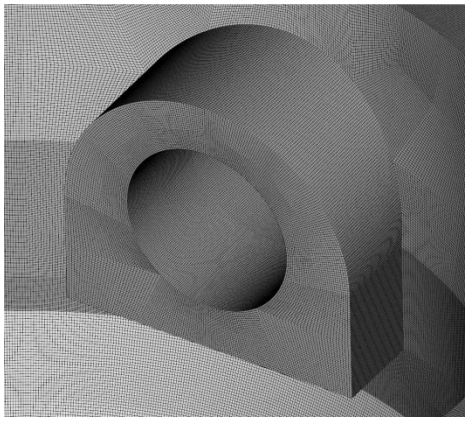
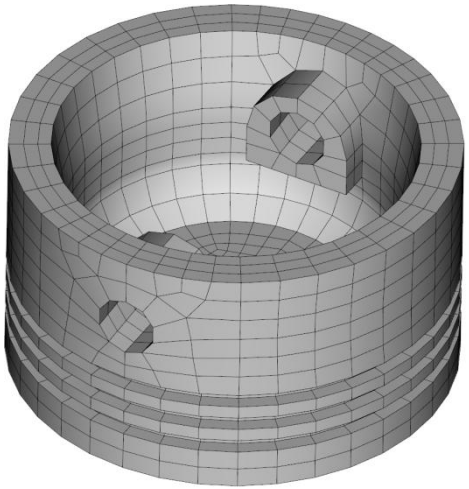
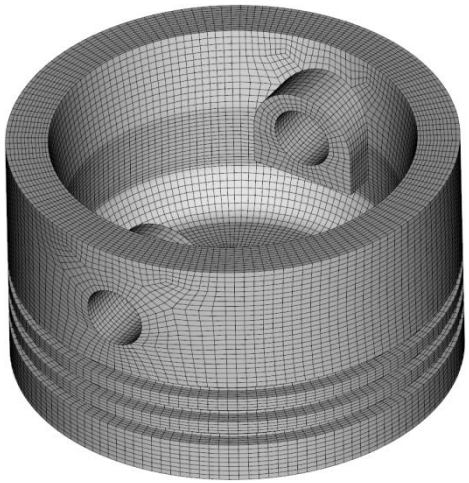
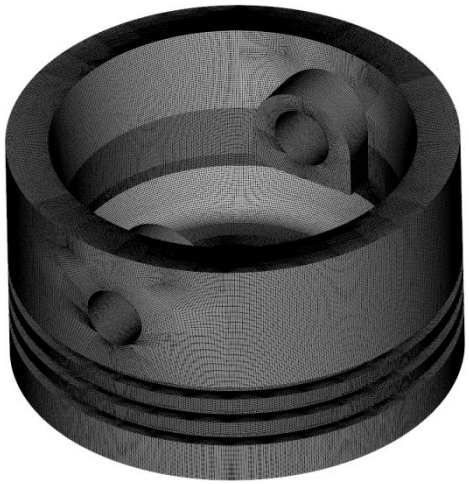
Parallel Refinment with Geometry


Input Mesh
1,936 Hex

2 levels refinement
124k Hex

4 levels refinement
7.93M Hex

5 levels refinement
63.4M Hex

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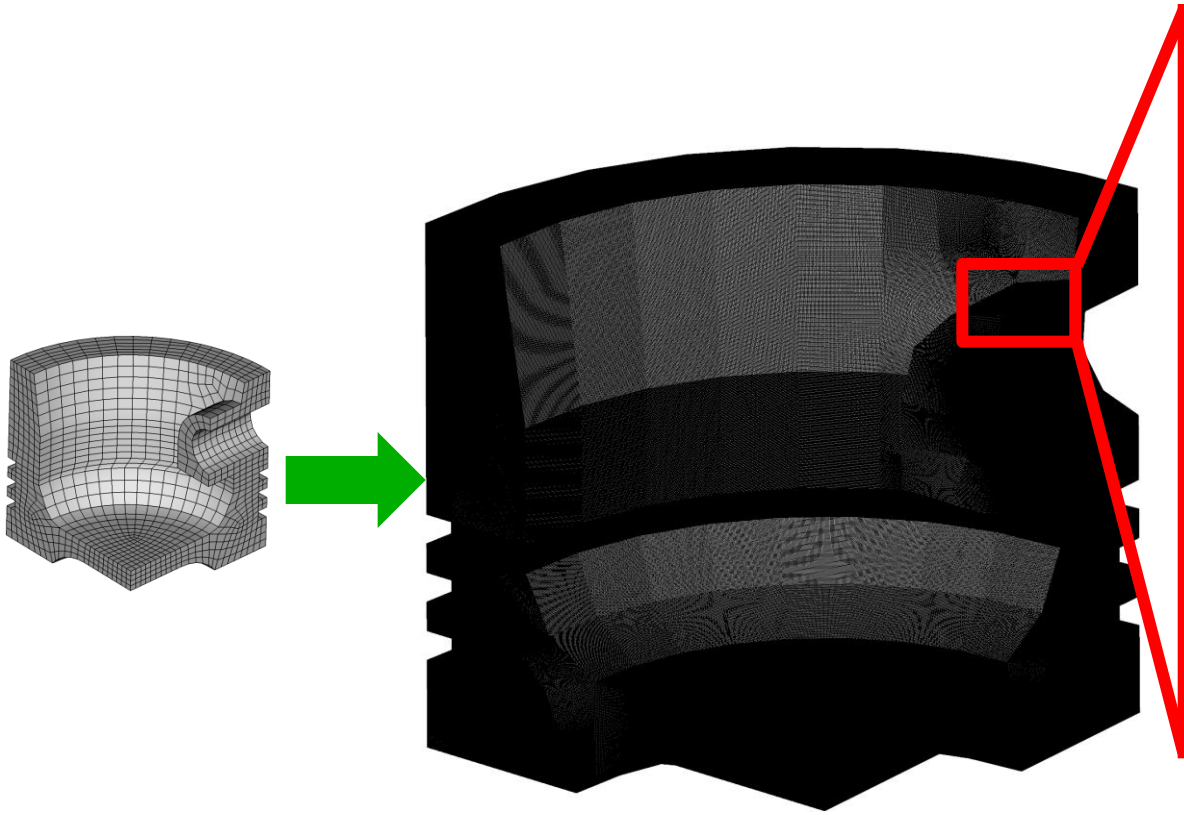
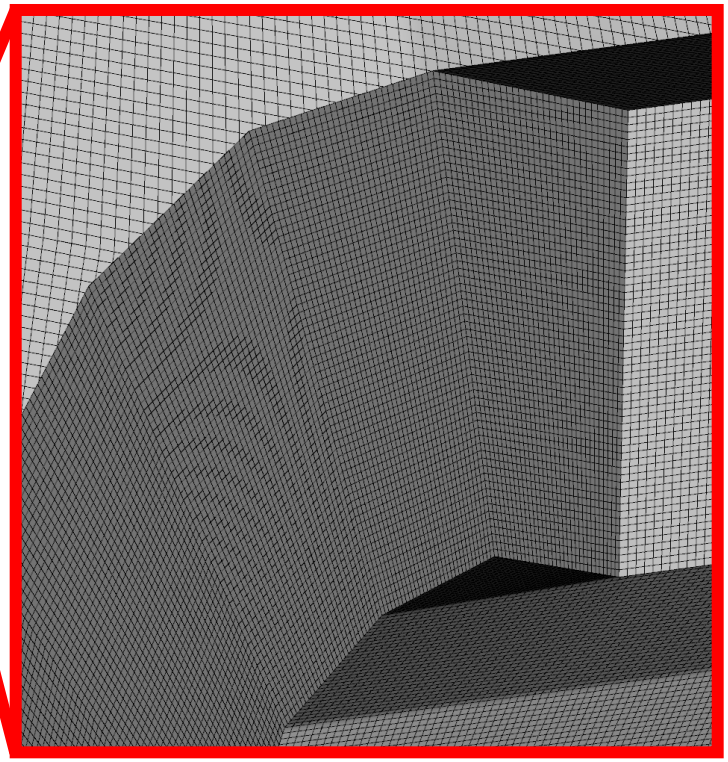
Previous Workflow

STK_Adapt is a Sandia (Trilinos) module which refines unstructured meshes.

Input mesh is an Exodus II file. Had no knowledge of CAD.

In previous releases, new nodes were positioned by evaluating element shape functions.





Zoom in of faceting artifacts from original mesh.

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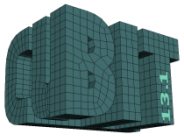
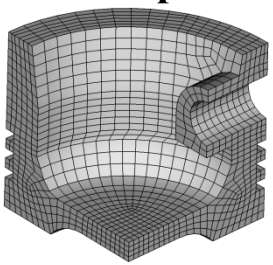
New Workflow

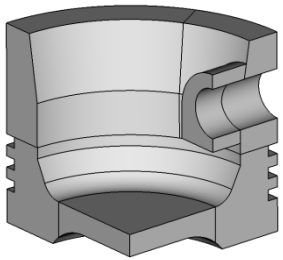
Step 1



Cubit exports:



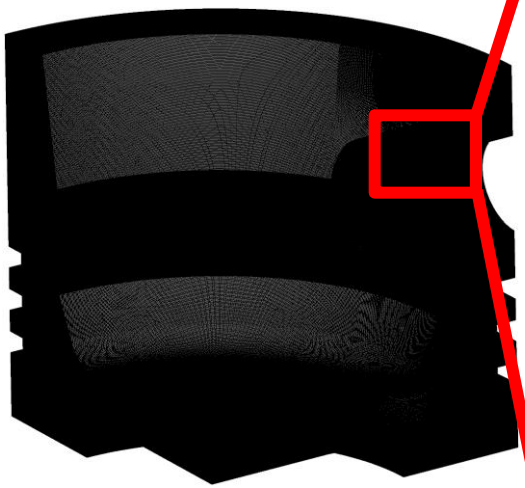
A coarse mesh (exo file) and:



A geometry file (3dm OpenNURBS)

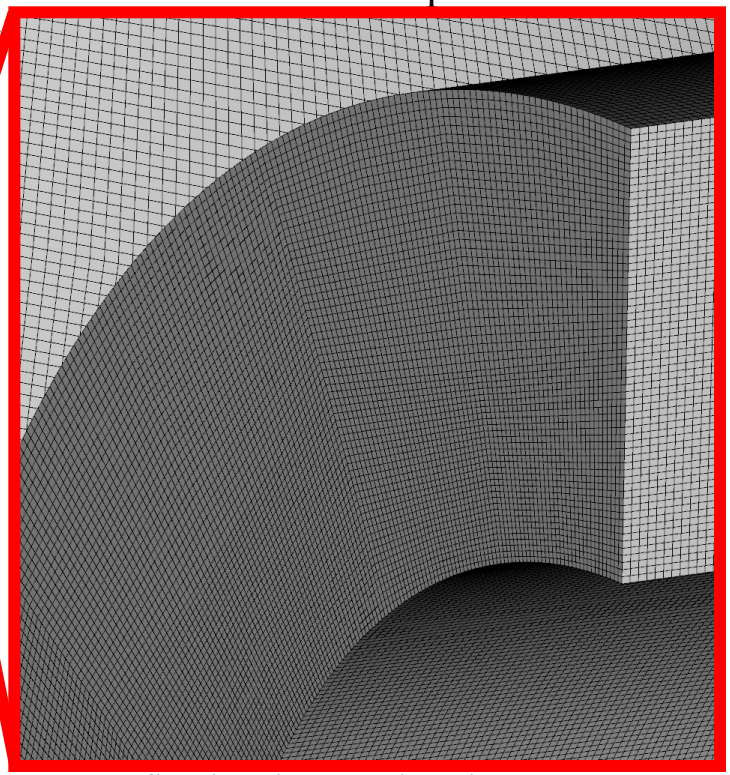
Step 2

Sierra STK_ADAPT imports the coarse exo file and 3dm files. The mesh is partitioned to *N* processors. The 3dm file is read into the OpenNURBS geometry evaluator kernel. Global uniform refinement is performed with new nodes projected to geometry



112 M hex elements

20 processors



Refined nodes are placed on original CAD geometry.

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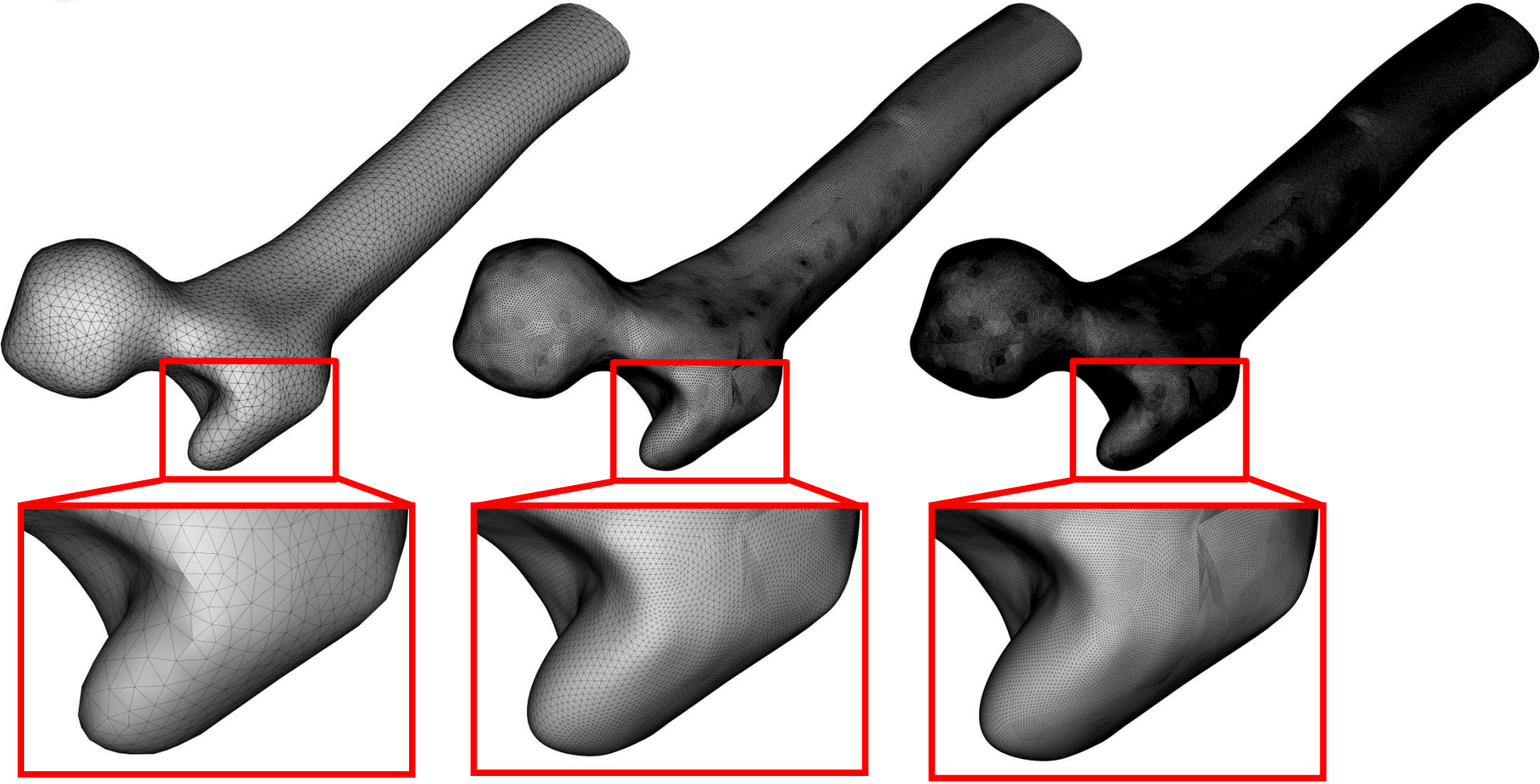
Example - Bone



Input Mesh
86k Tet

Input Mesh
5.52M Tet

Input Mesh
44.2M Tet

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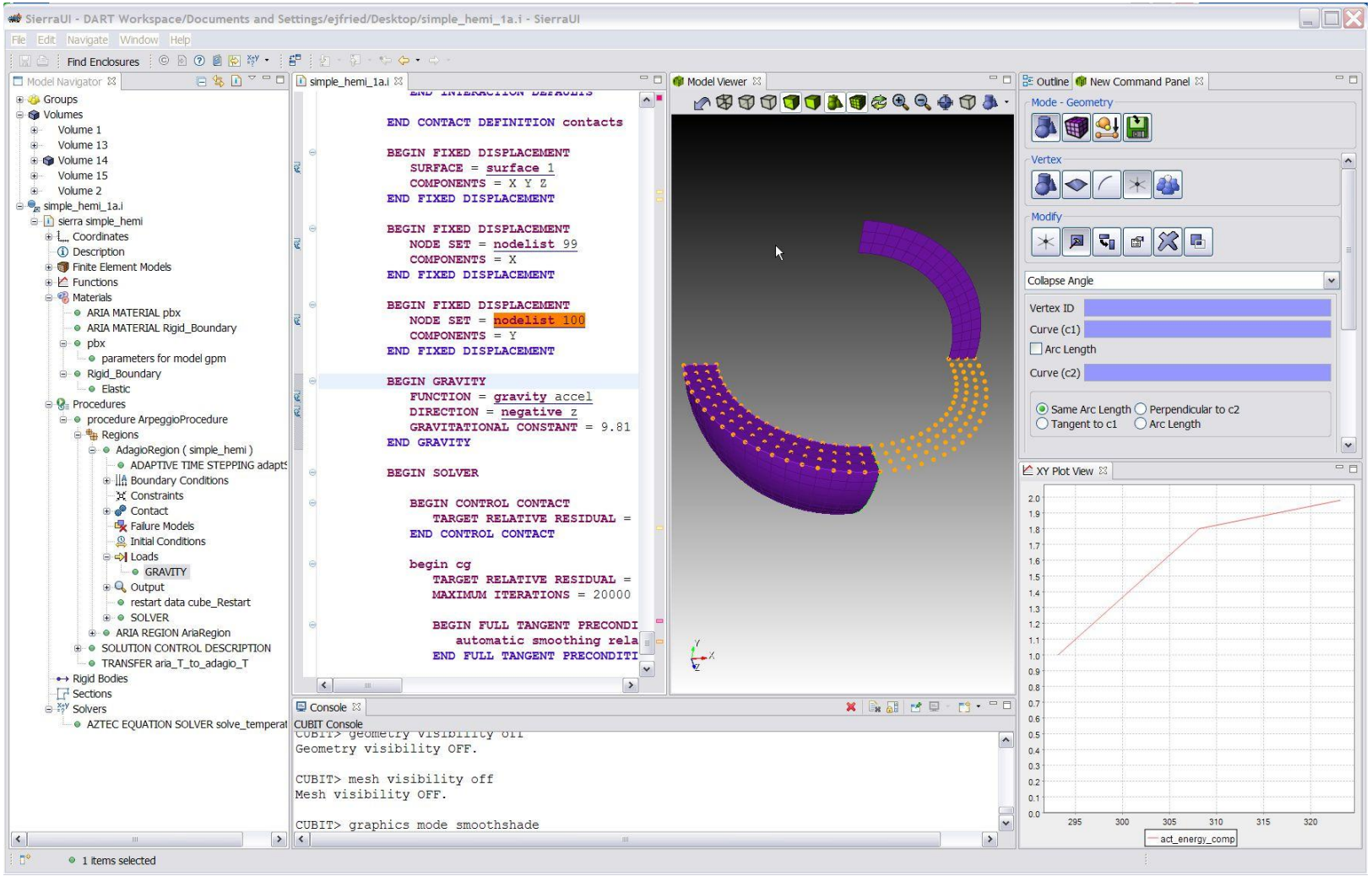
Integrated User Experience



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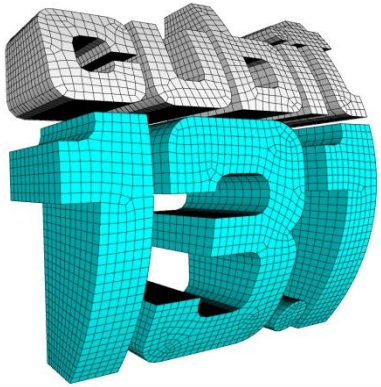
The Design Through Analysis Process



Cubit

DART

DART Workbench

Integrated Product

Future

Geometry

Meshing

Model Attribution

Input Deck Creation

Job Submission

Sim Data Management

Post Processing

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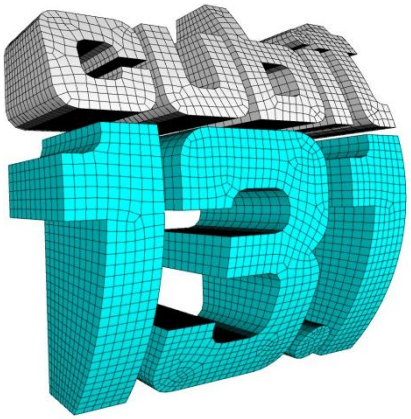
The Eclipse Framework

Eclipse was chosen as the environment in which Cubit and the DART Workbench are being integrated. Eclipse provides a powerful plug-in environment ideal for integrating different pieces of functionality. The DART Workbench was already developed within Eclipse. Cubit's GUI is built upon the Qt toolkit with Python as the glue between the Cubit GUI and the core functionality accessed through a command line interface. The Cubit GUI is being replicated within the new environment. During this process certain parts of the GUI are being redesigned and improved.



DART

<?xml?>

Java

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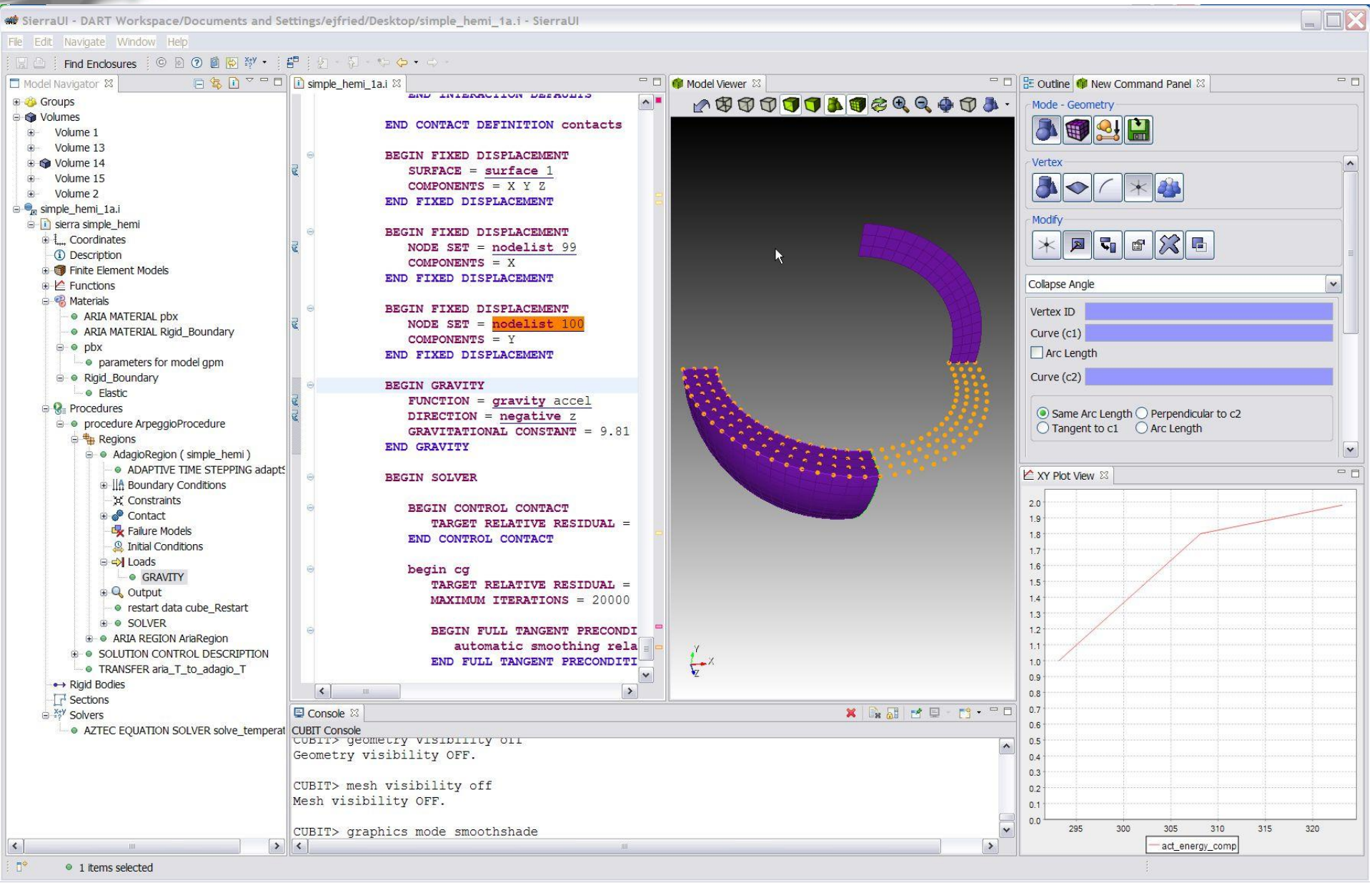
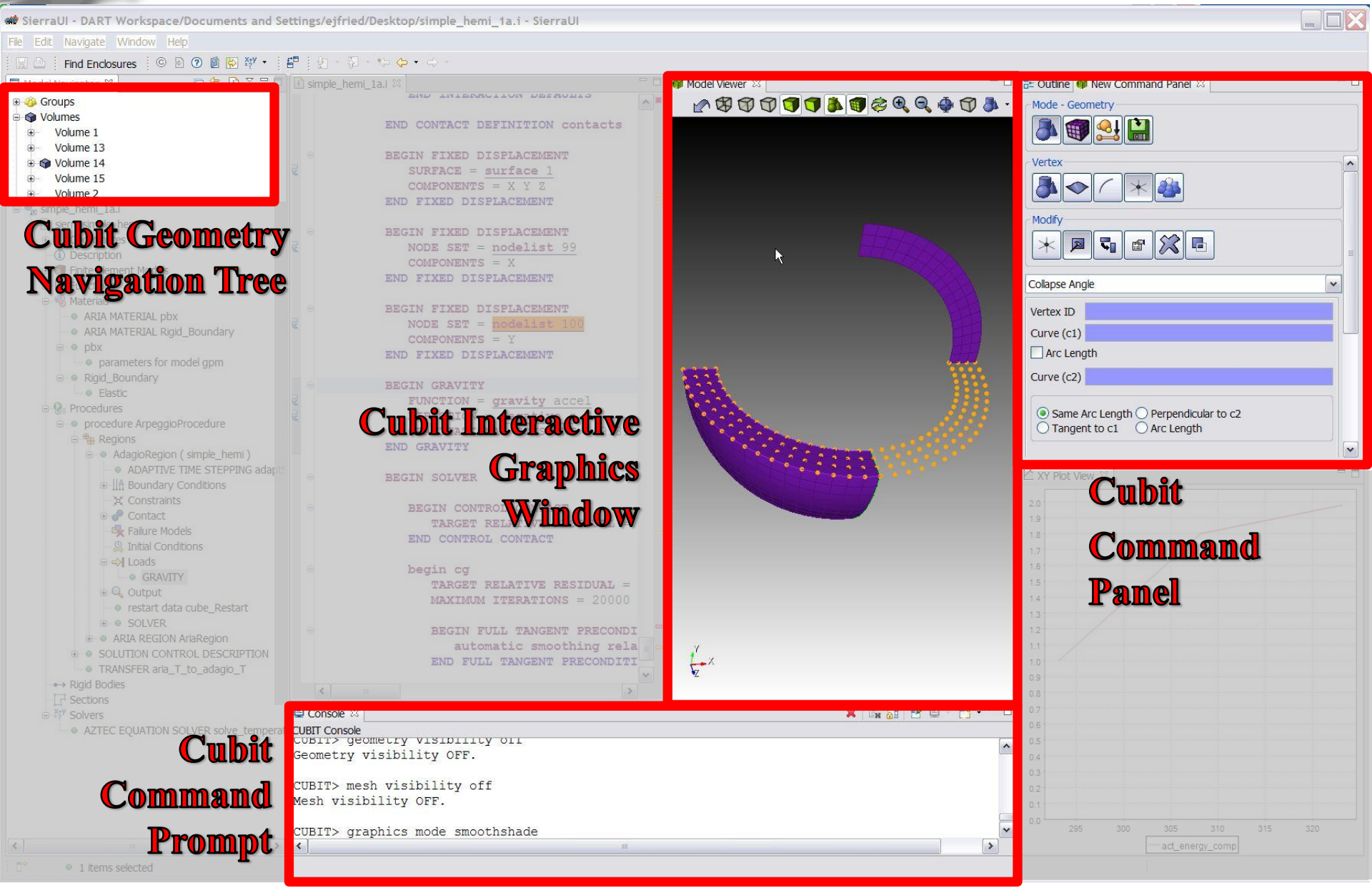
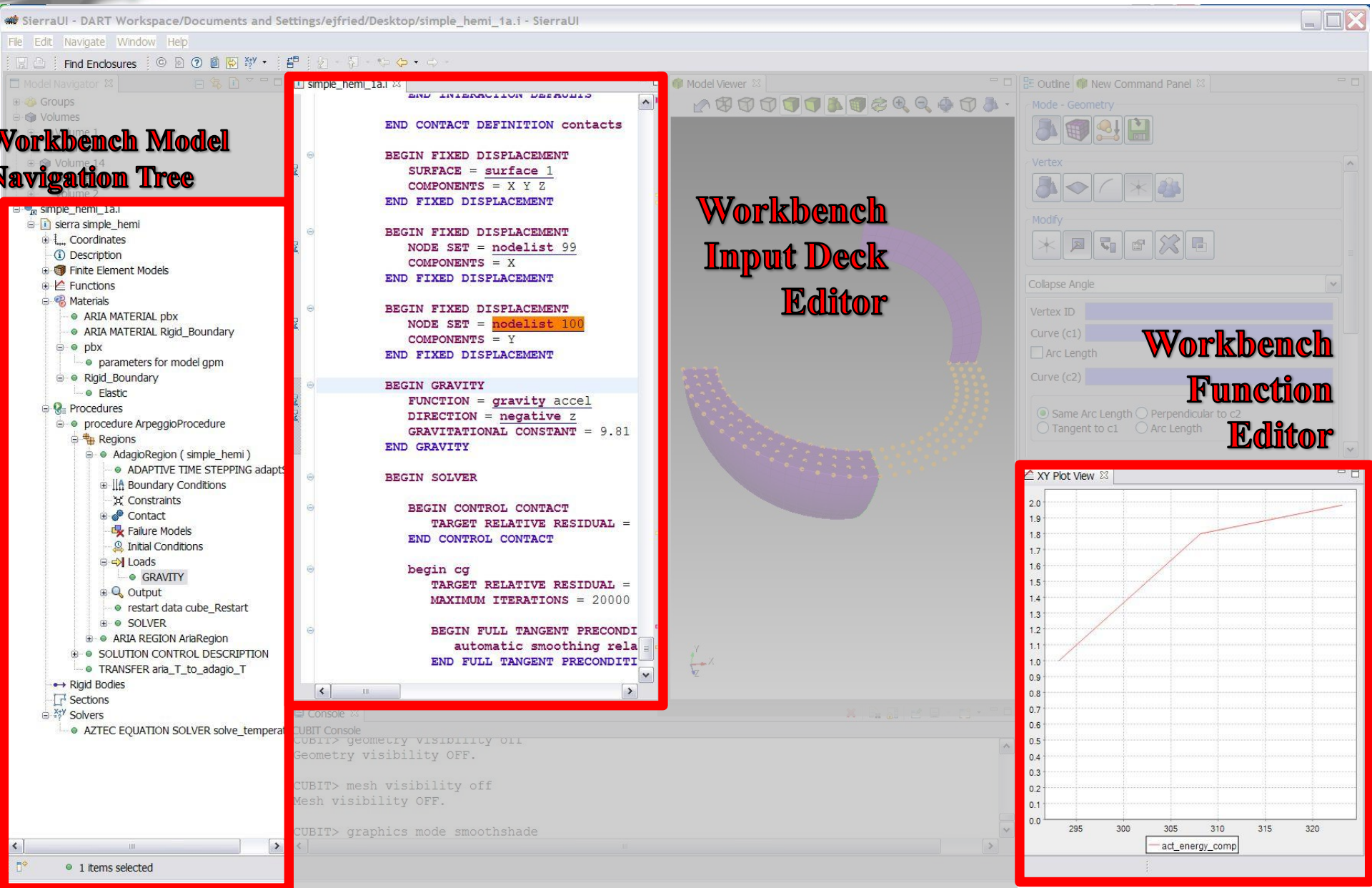
SAW
Sandia Analysis Workbench



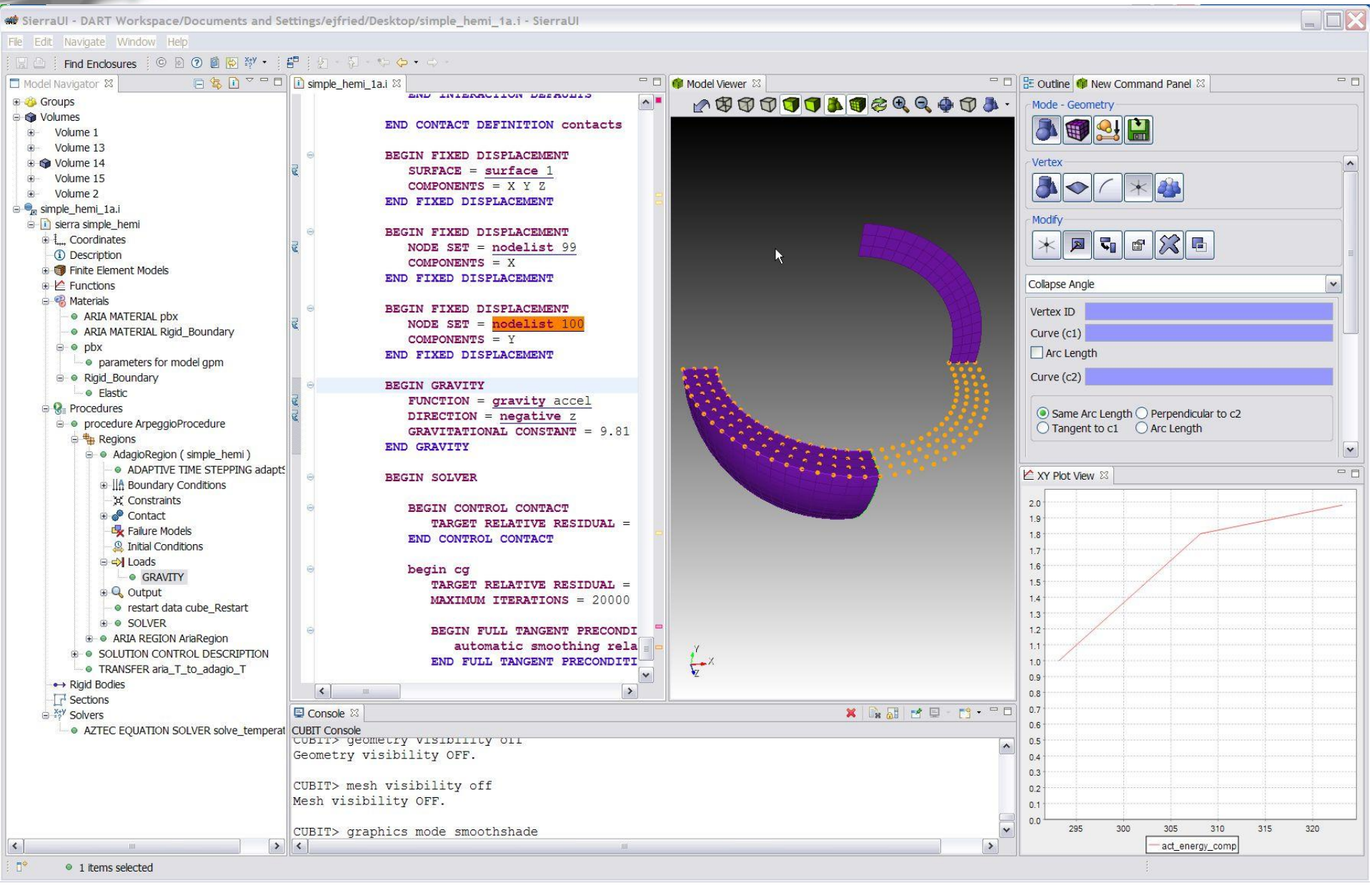
SAW
Sandia Analysis Workbench



SAW
Sandia Analysis Workbench



SAW
Sandia Analysis Workbench

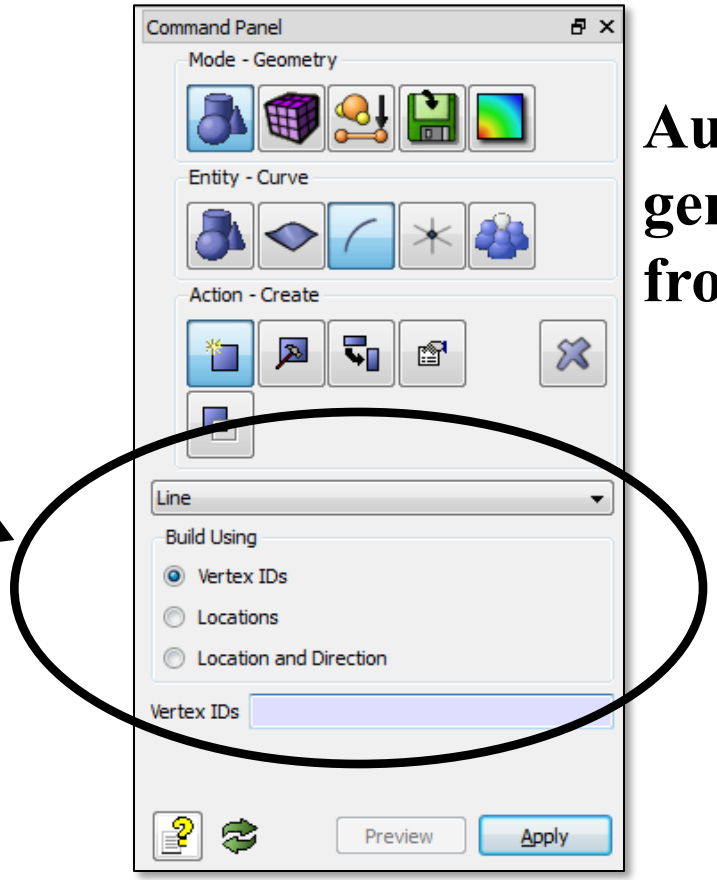


XML-Based GUI Definition

As the Cubit GUI has been replicated in the Eclipse environment powerful tools for automatically generating GUI panels from XML have been developed. This has greatly facilitated the GUI development process and will allow a user-modifiable architecture for GUI development and modification in the future.

```
<?xml version="1.0" encoding="UTF-8"?>
<sui:CommandDefinition xmlns:sui="http://www.example.org/sierra
    <Command name="CreateCurveArc">
    <!-- *** Requires 3 Vertices - all three are on the arc ***
    <!-- Create Curve Arc Three {Vertex|Curve} <id_list> [Full]
    <!-- *** Requires 3 Vertices - first is center, other two a
    <!-- *** Type 'Help Direction' to see direction options ***
    <!-- Create Curve Arc Center Vertex <center_id> <end1_id> <
    <!-- *** Type 'Help Direction' to see direction options ***
    <!-- Create Curve Arc Vertex <end1_id> <end2_id> Radius <va
    <!-- *** Type 'Help Location/Direction' to see location/dir
    <!-- Create Curve Arc Radius <value> [Center <x=0> <y=0> <z
    <!-- *** Type 'Help Axis' to see axis options *** -->
    <!-- Create Curve Axis (options) -->
        <Help></Help>
        <Keyword token="create curve arc" />
        <Choices label="Build Using">
            <Choice label="Vertices and Radius">
                <Variable type="vertex-id" label="Start Vertex
                <Variable type="vertex-id" label="End Vertex ID
                <Variable token="radius" label="Radius" type="d
                <Variable type="direction_dialog" label="Norm
                <Option label="Full Circle">
                    <Keyword token="full" />
                </Option>
                <Option label="Other Arc">
                    <Keyword token="other_arc" />
                </Option>
            </Choice>
            <Choice label="Center Angle">
```

Cubit command defined with XML.



Automatically generated GUI from XML.

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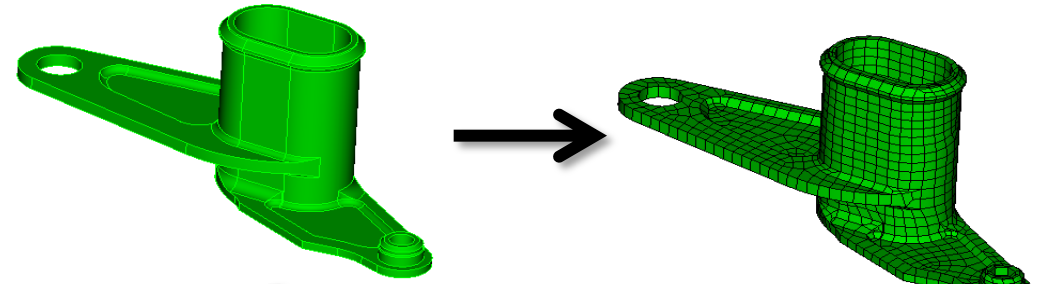
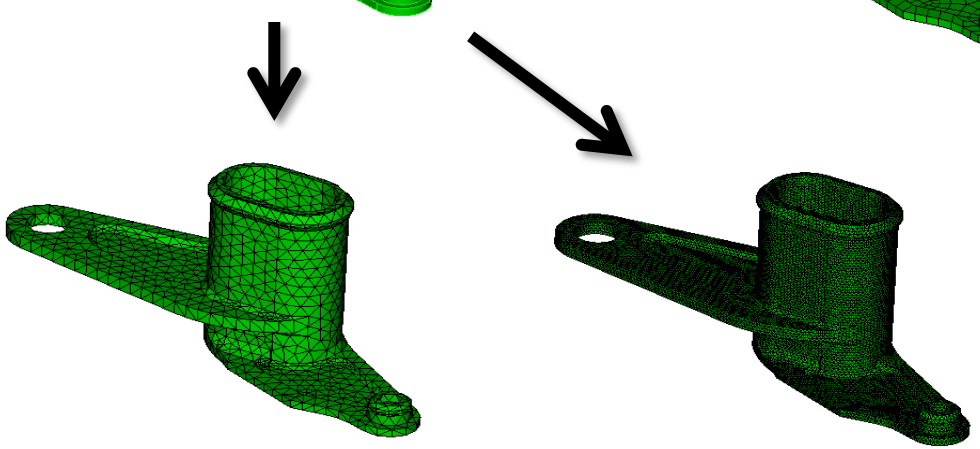
Multi-Model for V&V and Multi-Physics

Cubit has traditionally only supported a single model at a time. However, part of the integration effort will be to expand Cubit to use a client-server architecture which will facilitate working with multiple models at a time. This need has been identified for Verification and Validation studies as well as for multi-physics applications.



Multiple mesh types for multi-physics support.



Multiple mesh resolutions for a single CAD model for V&V studies.

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Vision Going Forward: Collaboration!

- Open Source
  - The CUBIT product will be going open source under a very unrestrictive license (target date: end of FY12)
- Integration with the DART Workbench under Eclipse plug-in environment
  - Ideal environment for future collaboration
  - Continue to modularize core CUBIT as plug-ins to facilitate sharing and collaboration

Contact Info

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