



CUBIT

Brett Clark

Sandia National Labs

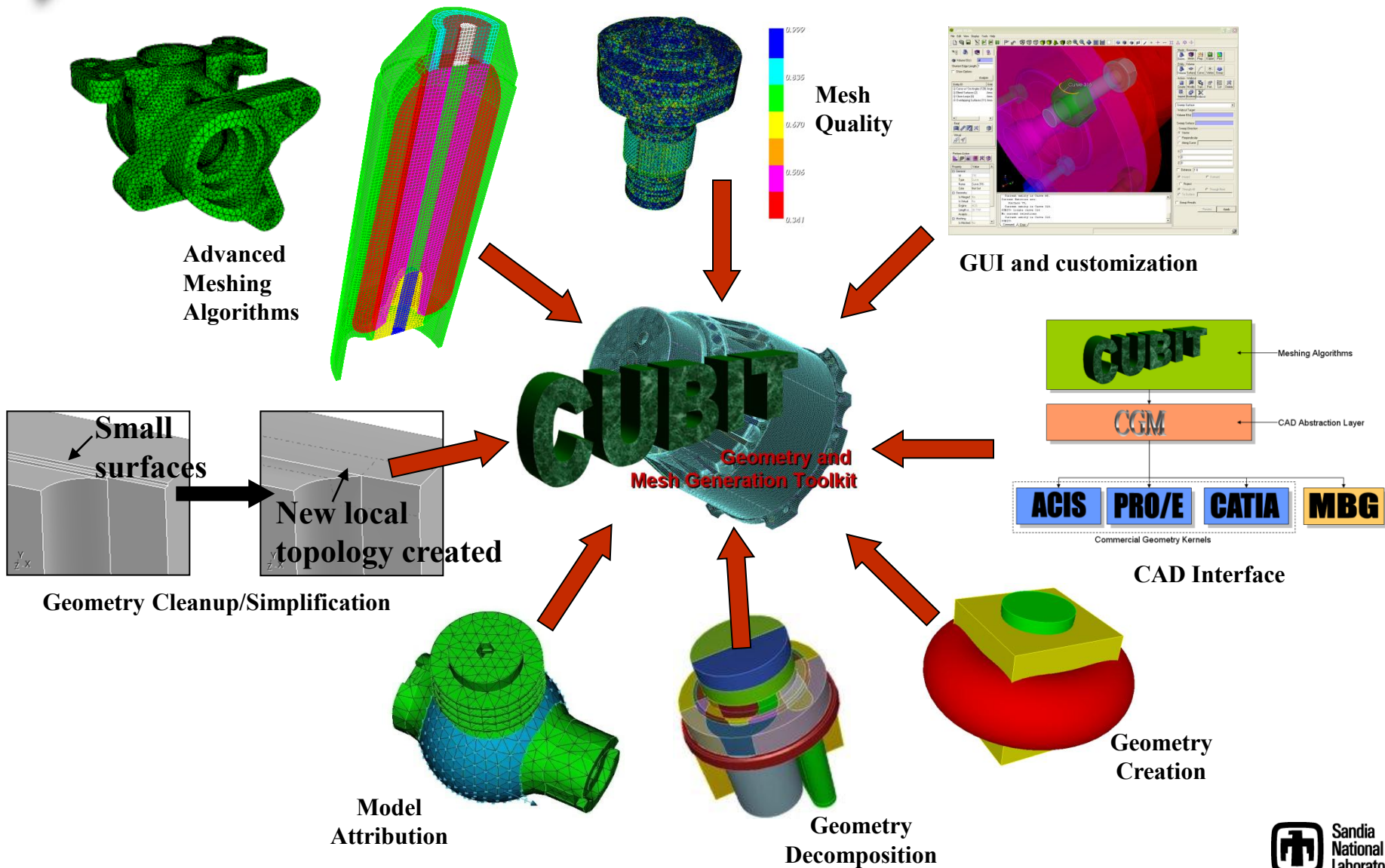
PHYSICS-BASED MODELING IN DESIGN & DEVELOPMENT

FOR U.S. DEFENSE CONFERENCE

Denver, Colorado

November, 2011

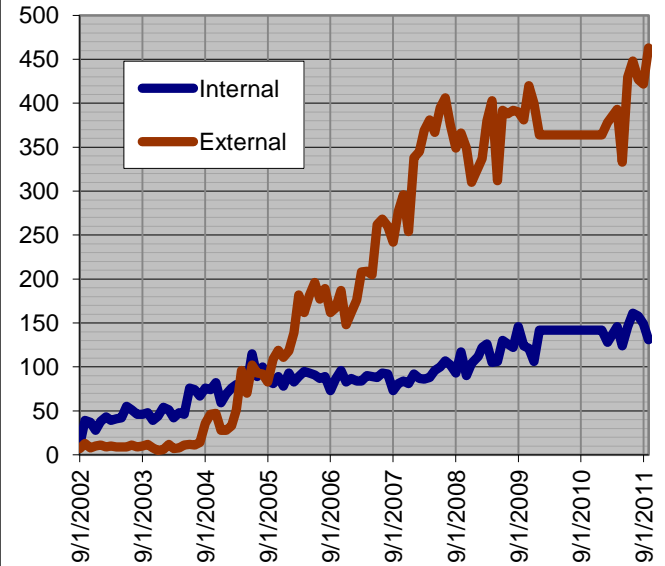
What is CUBIT?



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

CUBIT Repeat Users 2002-2011



Team Personnel

Sandia

Elemental Technologies, Inc.

Independent Contractors

Caterpillar

University Students

Technical Conferences



Past and Present

Collaborators

Industry



Universities



DoD



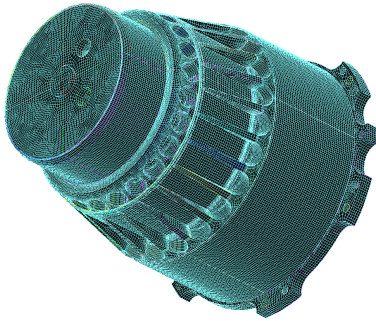
Sandia



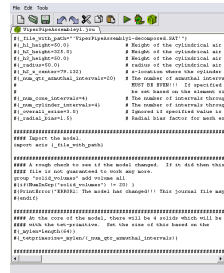
National Labs



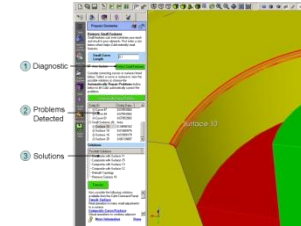
Some Distinguishing Strengths



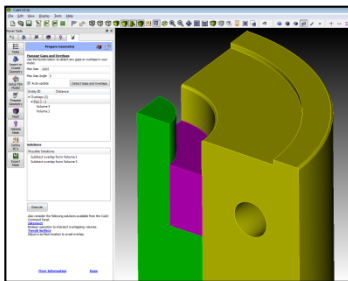
Complex Hex Meshing



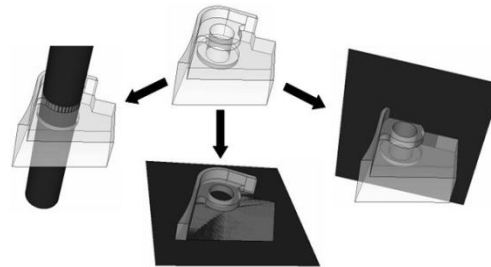
Scripting



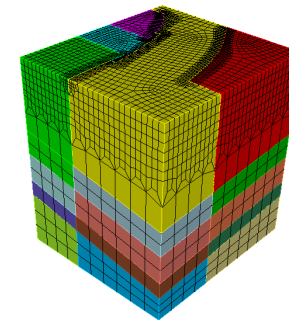
Geometry Clean-up & Defeaturing



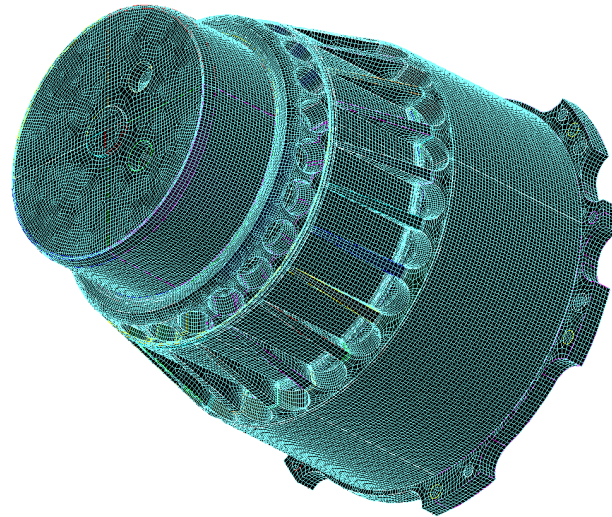
Contiguous Assembly Meshing



Decomposition Tools

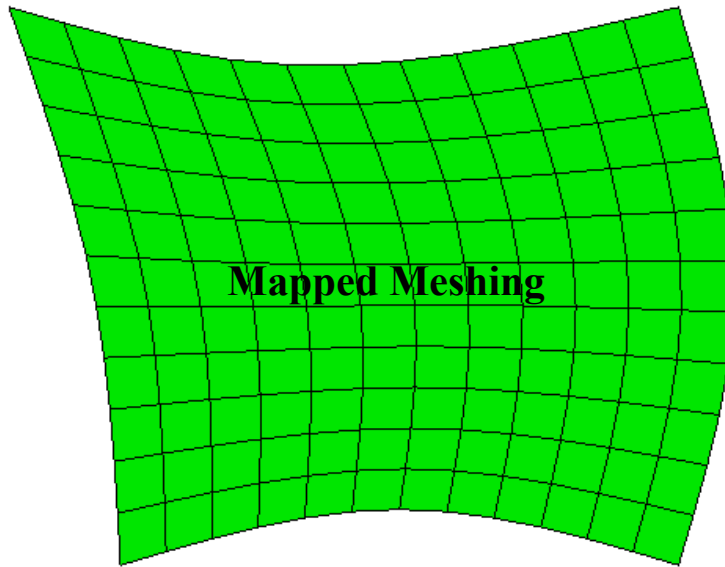


Local Hex Refinement



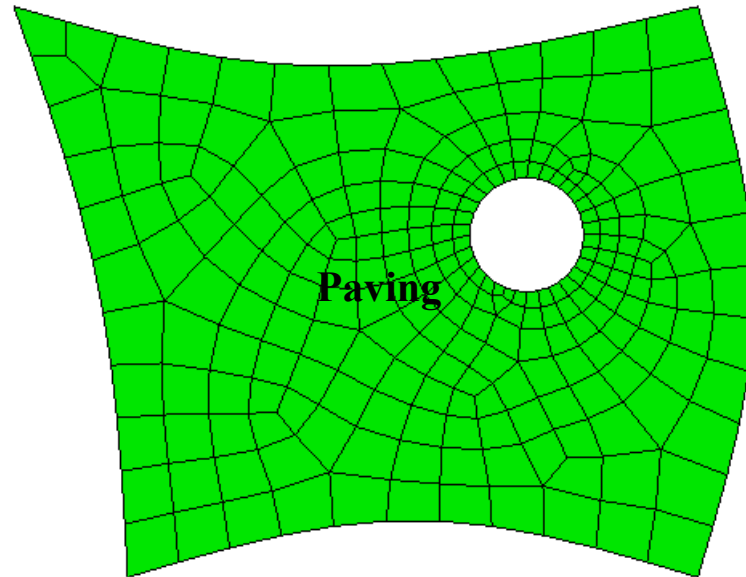
Complex Hex Meshing

Structured vs. Unstructured



Structured

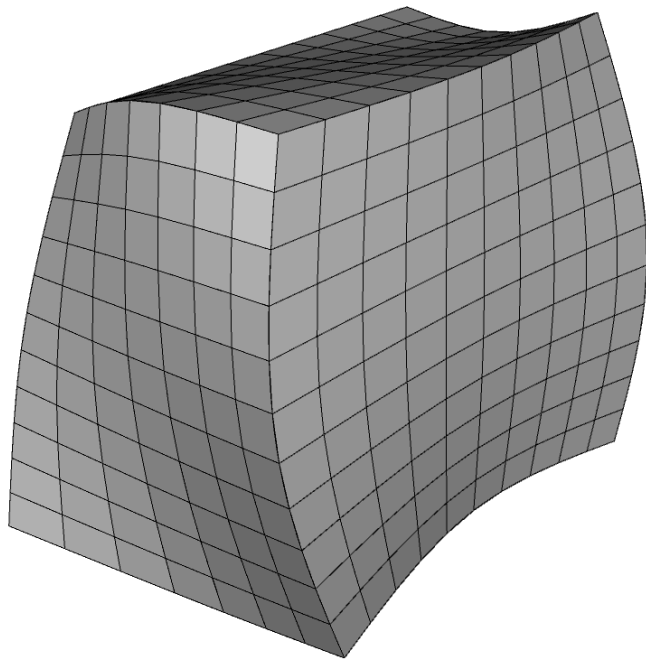
1. Interior node valence is constant.
ie. number of elements at each interior node=4
2. Meshing algorithm relies on specific topology constraints.
ie. number of sides=4



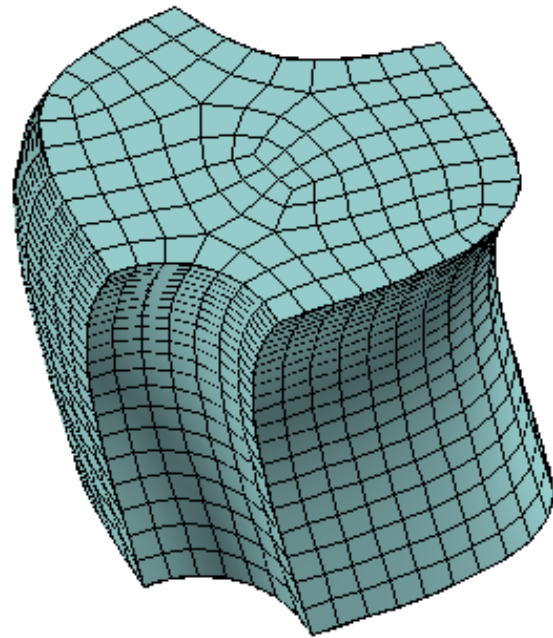
Unstructured

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?

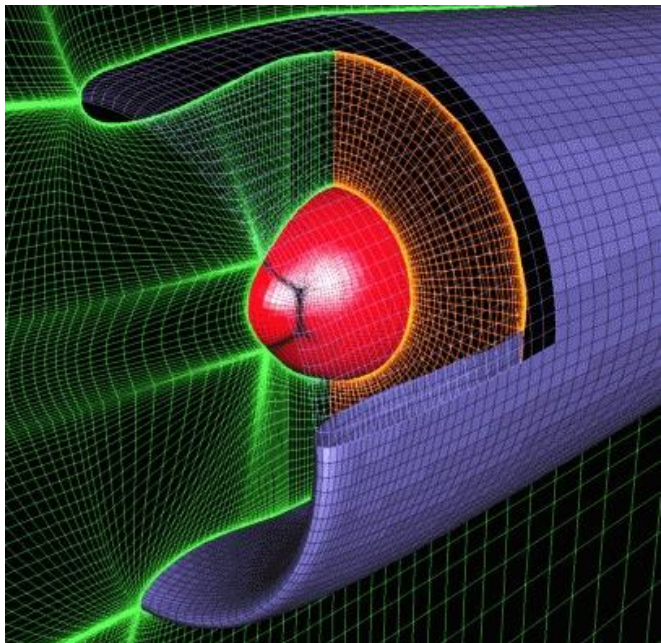


Mapped Meshing

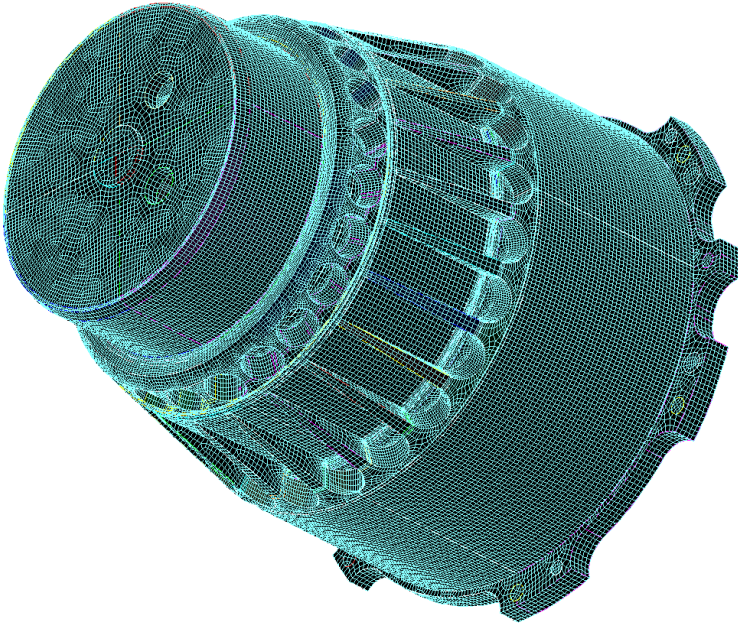


**Sweeping
(2.5 D)**

Complex 3D?



Block-Structured Meshing

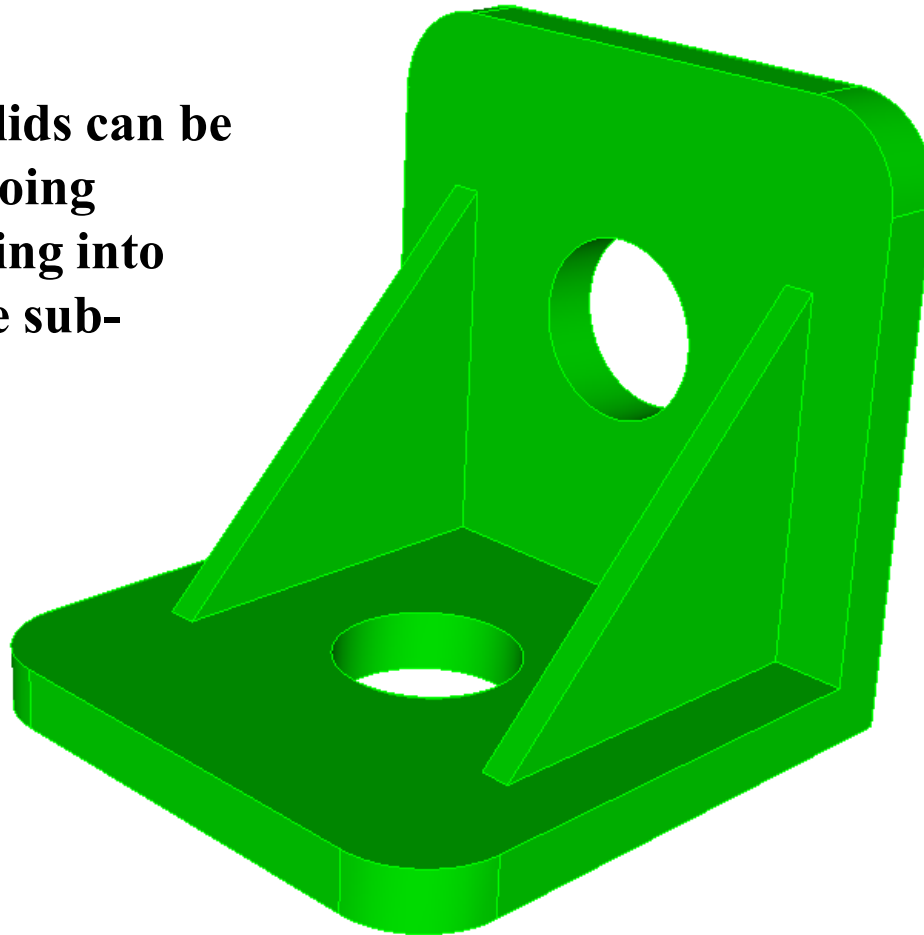


Partition & Sweeping



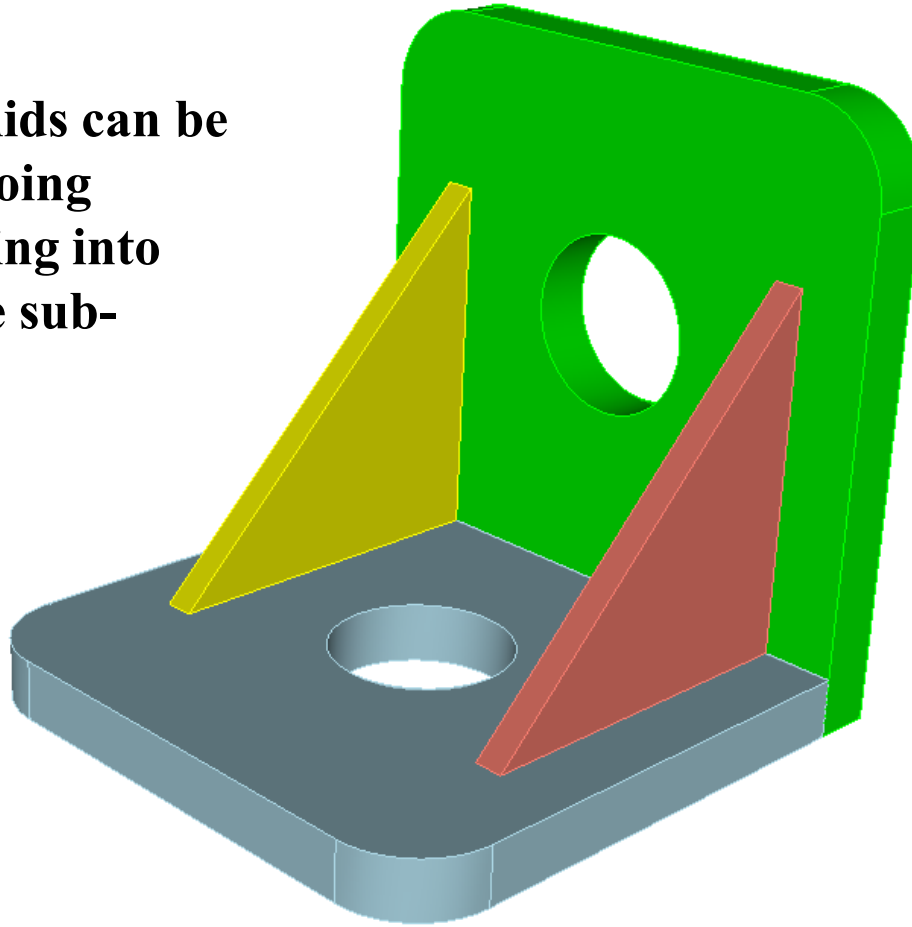
Partition & Sweeping

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



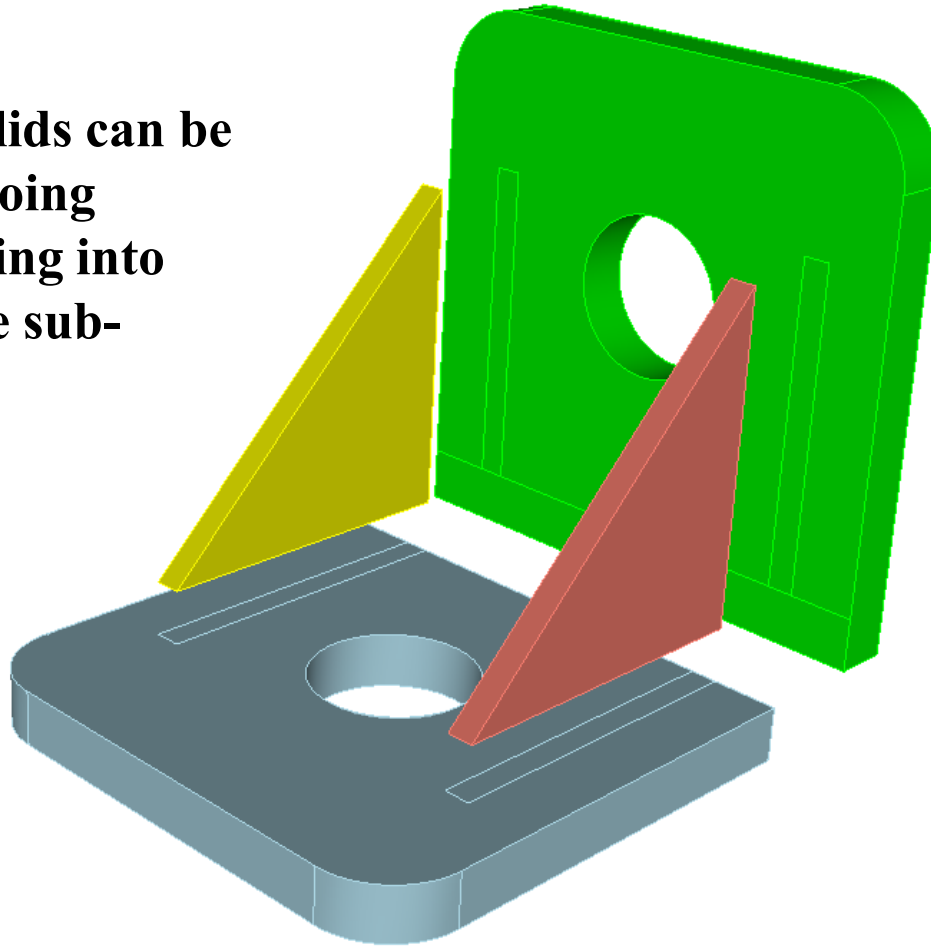
Partition & Sweeping

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



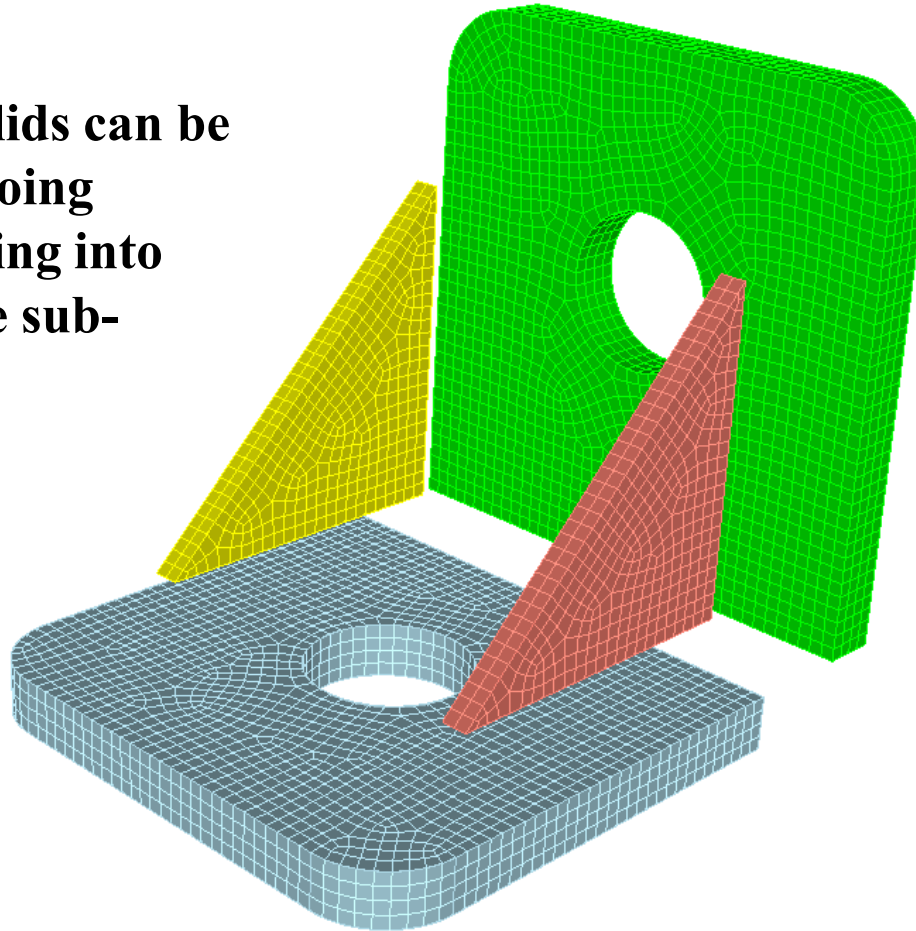
Partition & Sweeping

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Partition & Sweeping

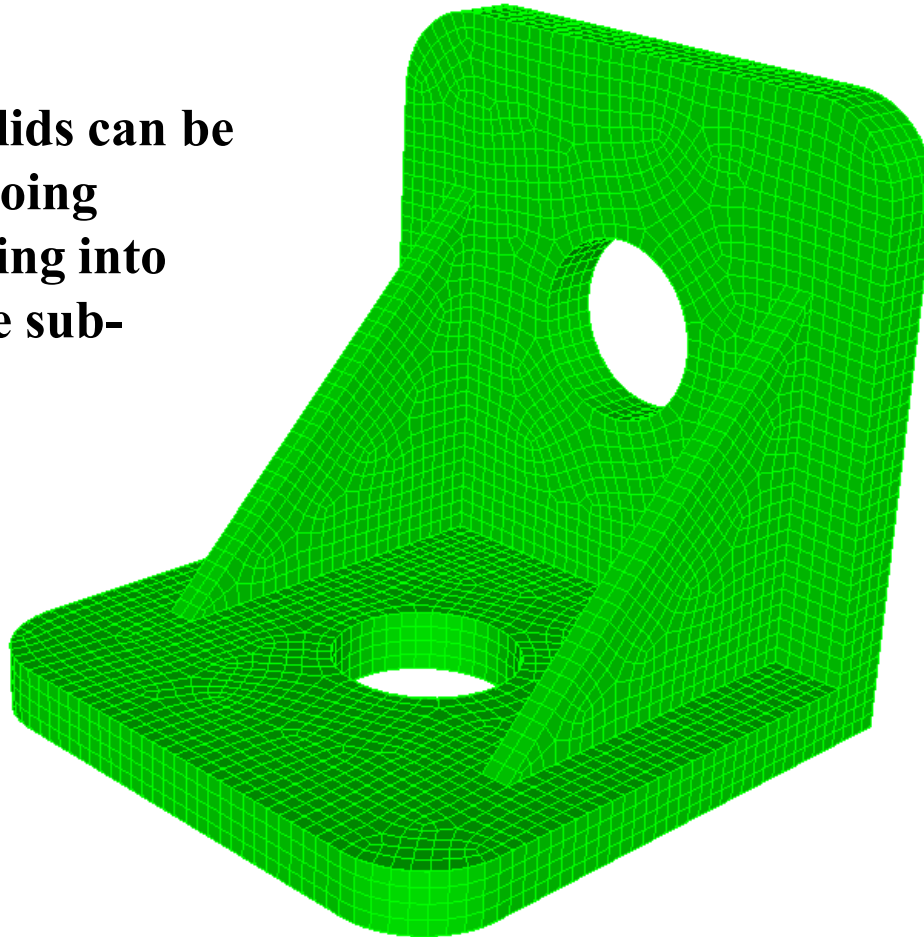
More complex solids can be meshed by first doing manual partitioning into several sweepable sub-solids.





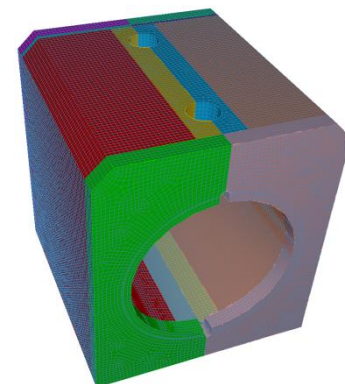
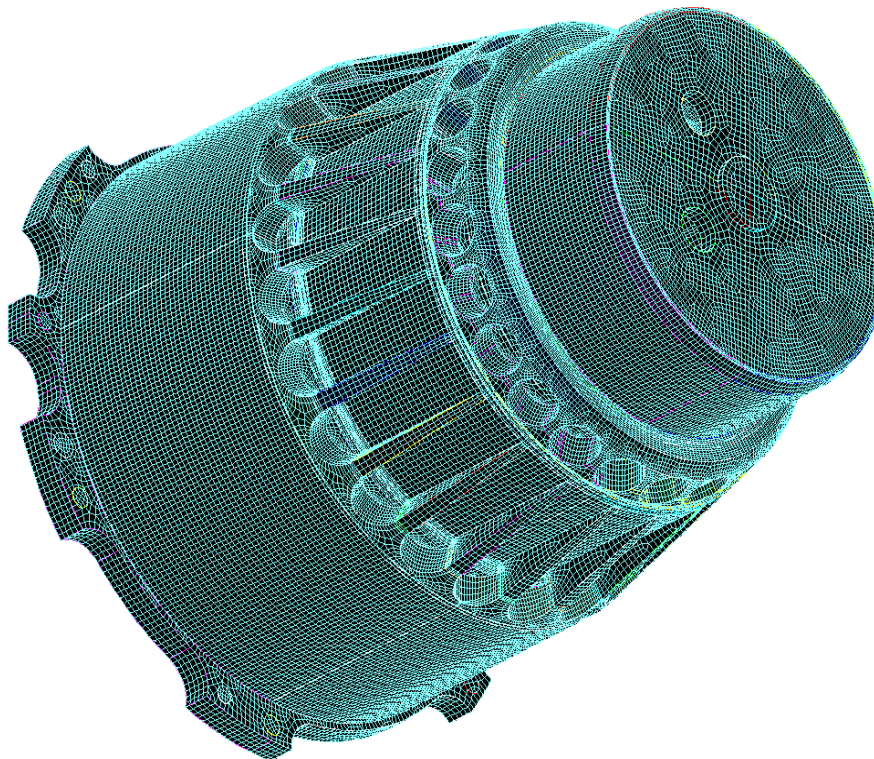
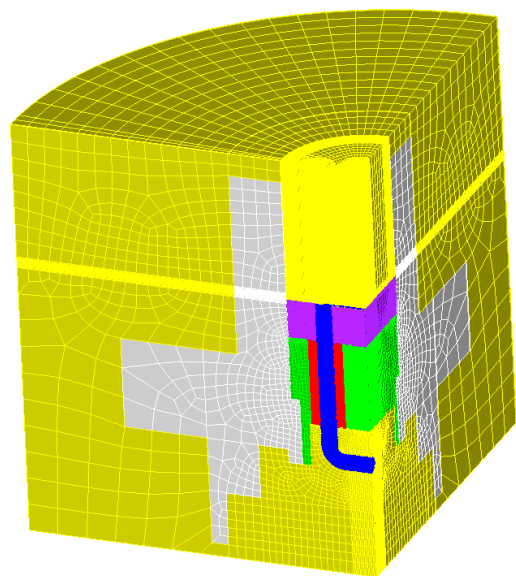
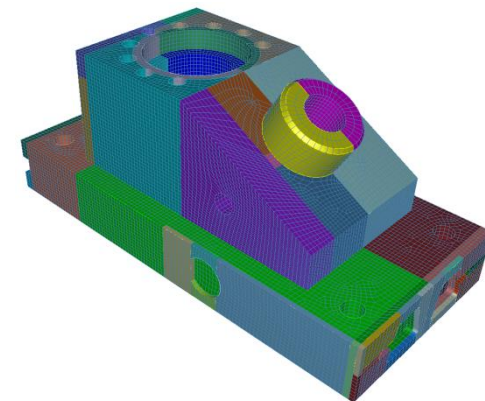
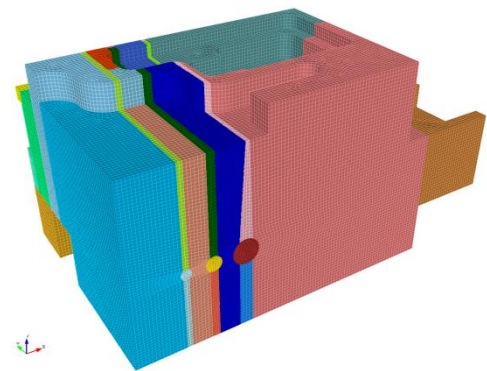
Partition & Sweeping

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

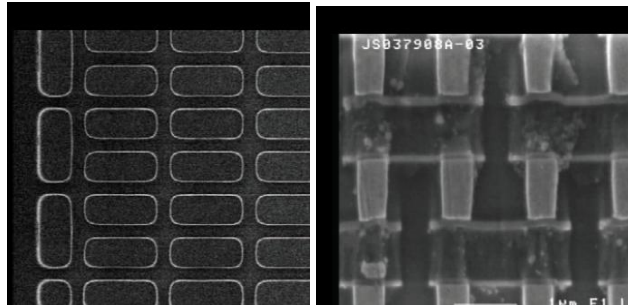


Partitioning & Sweeping Very Complex Solids

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.



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.

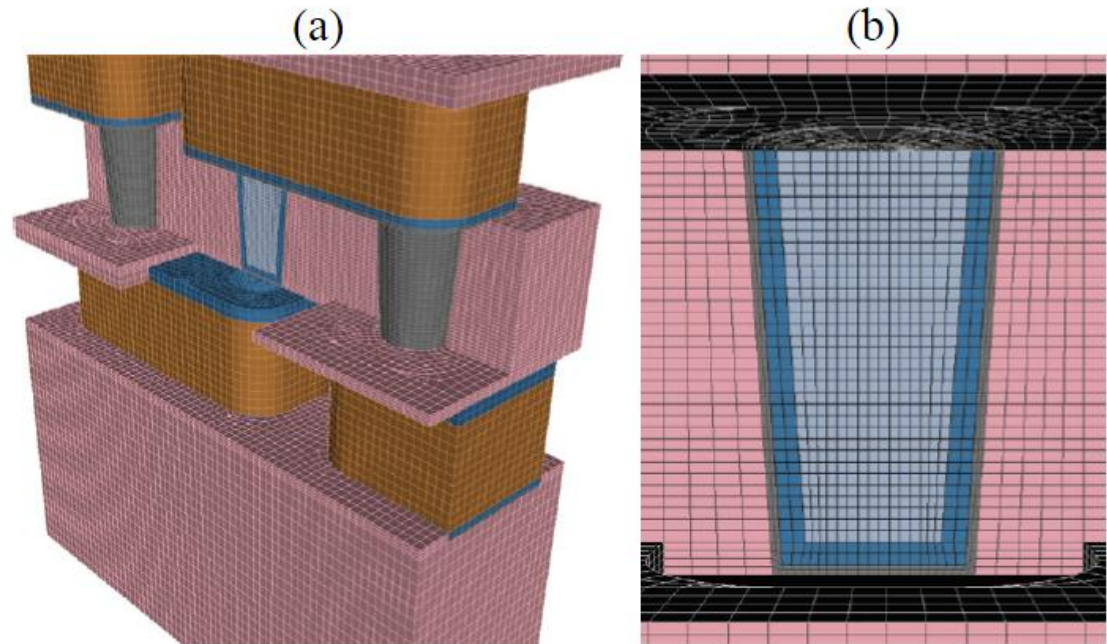
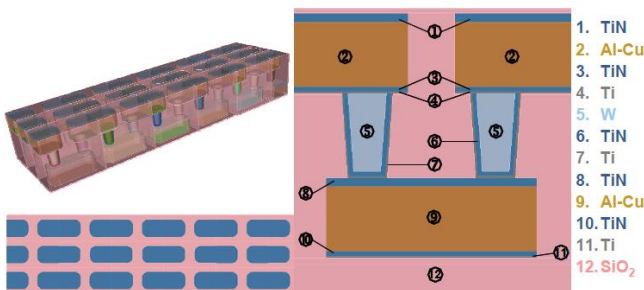
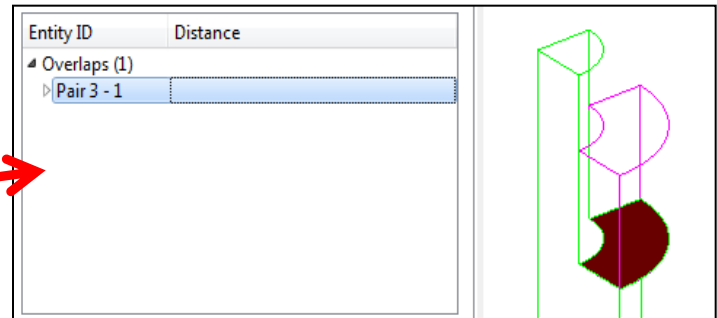
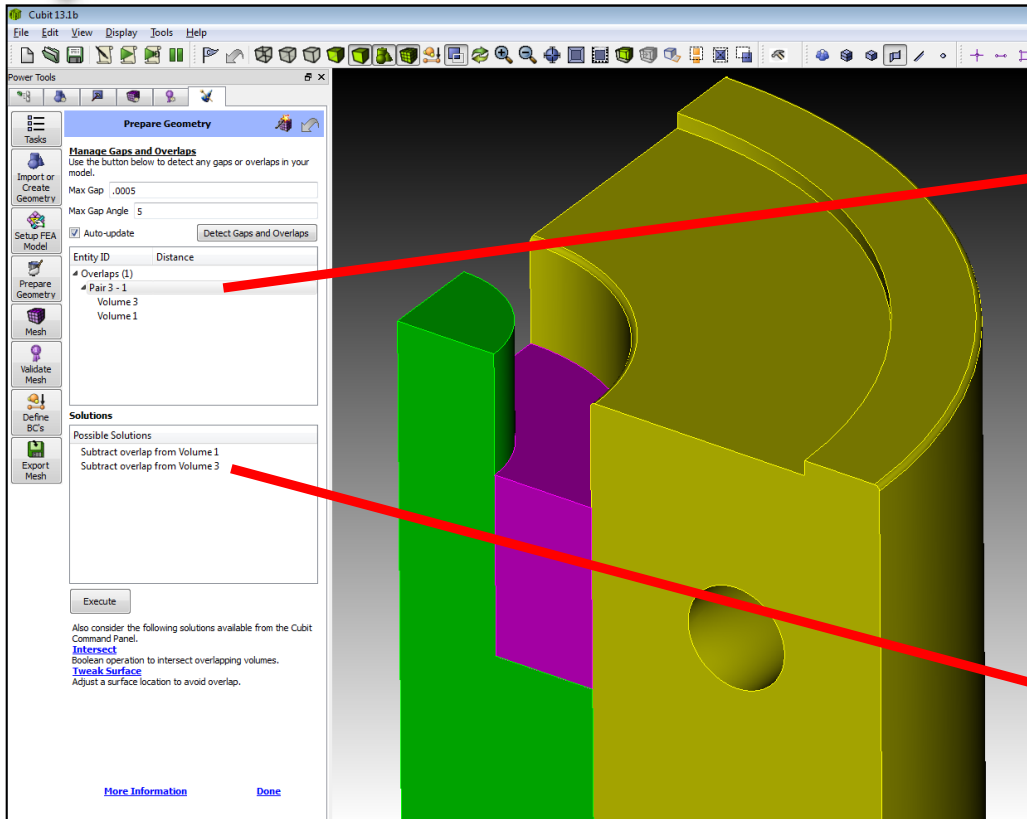


Figure 4: Mesh of a 3-link via chain; (a) isometric cutaway view, and (b) cross-section of W-filled via surrounded by Ti and TiN linings and SiO₂

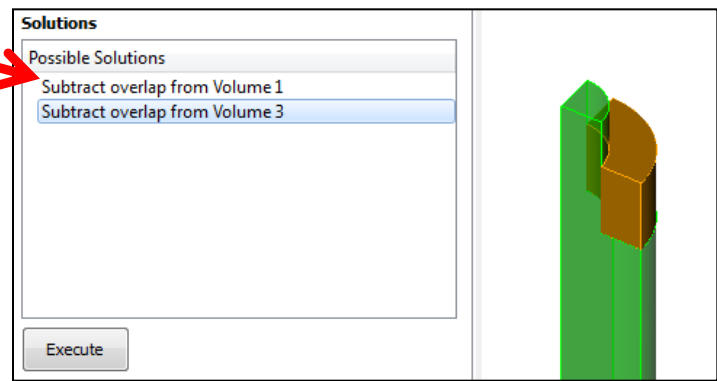


3D virtual geometry of a via chain. The as-drafted geometry is modified to resemble the fabricated geometry.

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.

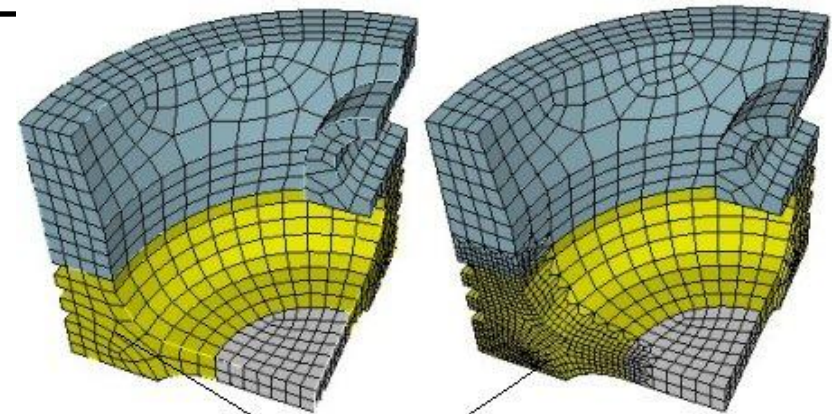


Selecting a solution will show the volume that the overlap region will be subtracted from and clicking “Execute” will do the subtraction.

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

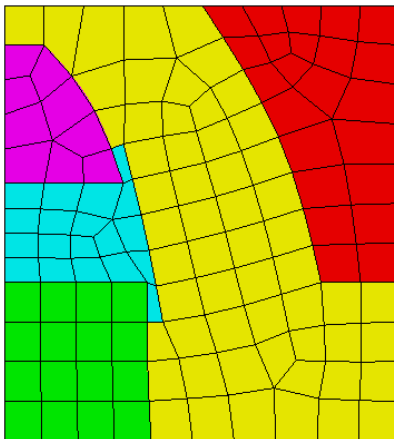
Local Hexahedral Refinement

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

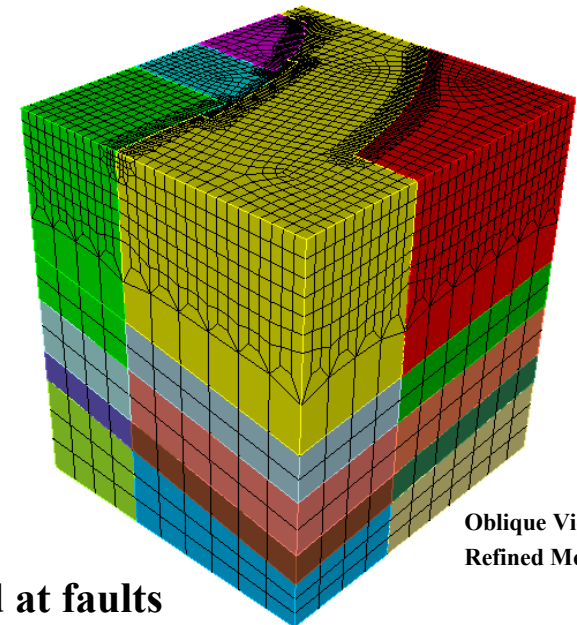
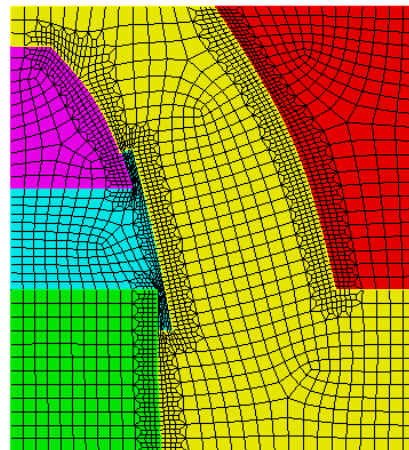


Before and after Hex refinement at a selected surface

Top View – Original Mesh



Top View – Refined Mesh



Oblique View – Refined Mesh

Geological model locally refined near surface and at faults

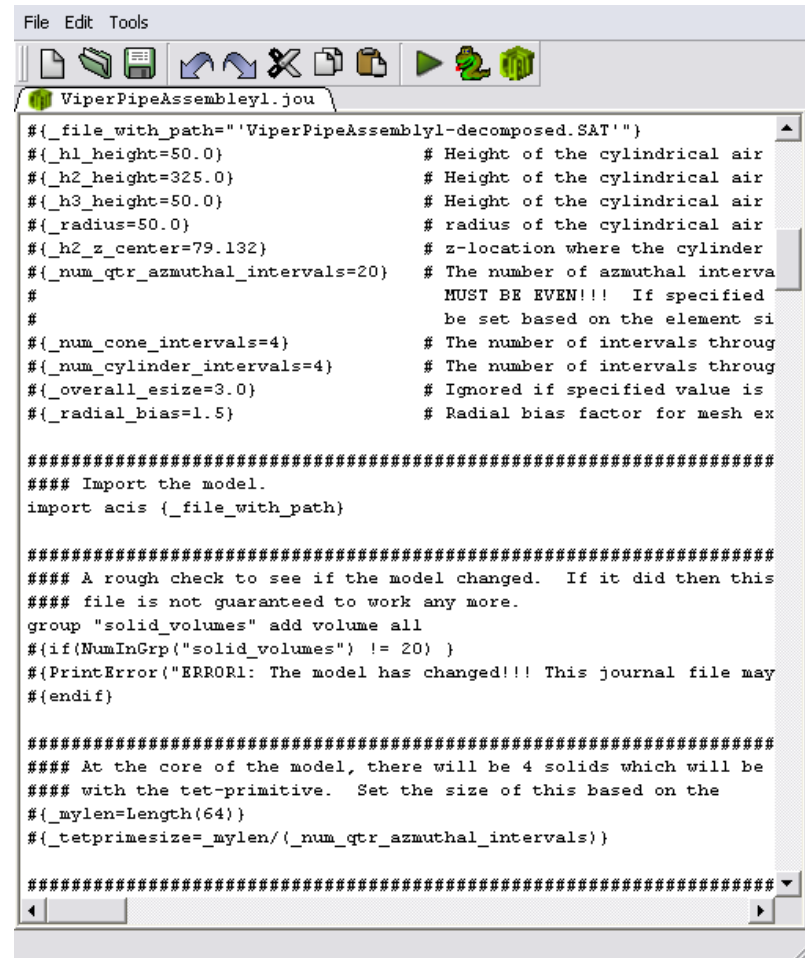
CUBIT Scripting Capability

- **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



```
File Edit Tools
ViperPipeAssembly1.jou
#{_file_with_path="ViperPipeAssembly1-decomposed.SAT"}
#{_h1_height=50.0} # Height of the cylindrical air
#{_h2_height=325.0} # Height of the cylindrical air
#{_h3_height=50.0} # Height of the cylindrical air
#{_radius=50.0} # radius of the cylindrical air
#{_h2_z_center=79.132} # z-location where the cylinder
#{_num_qtr_azimuthal_intervals=20} # The number of azimuthal intervals
# MUST BE EVEN!!! If specified
# be set based on the element size
#{_num_cone_intervals=4} # The number of intervals through
#{_num_cylinder_intervals=4} # The number of intervals through
#{_overall_esize=3.0} # Ignored if specified value is
#{_radial_bias=1.5} # Radial bias factor for mesh ex

#####
### Import the model.
import acis (_file_with_path)

#####
### A rough check to see if the model changed. If it did then this
### file is not guaranteed to work any more.
group "solid_volumes" add volume all
#{if(NumInGrp("solid_volumes") != 20) }
#{PrintError("ERROR! The model has changed!!! This journal file may
#{endif)

#####
### At the core of the model, there will be 4 solids which will be
### with the tet-primitive. Set the size of this based on the
#{_mylen=Length(64)}
#{_tetprimesize=_mylen/(_num_qtr_azimuthal_intervals)}

#####
```

Automated Geometry Defeaturing

Press “Detect Small Features” button to run diagnostics

① Diagnostic

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.

② Problems Detected

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)

③ Solutions

Prepare Geometry

Remove Small Features
Small features can over-constrain your mesh and result in poor elements. First enter a size below which helps Cubit identify small features.

Small Curve Length:

Auto Update

Consider correcting curves or surfaces listed below. Select a curve or surface to view the possible solutions or choose the **Automatically Repair Problems** button below to let Cubit automatically correct the problems.

Entity ID	Entity Data
Curve 47	0.07853982
Curve 49	0.07853982
Curve 51	0.07853982
Small Surfaces (4)	Area
Surface 10	0.24898162
Surface 18	0.61460876
Surface 16	0.61909179
Surface 35	0.86134887

Solutions

- Composite with Surface 11
- Composite with Surface 15
- Composite with Surface 13
- Composite with Surface 12
- Rebuild Topology
- Remove Surface 10

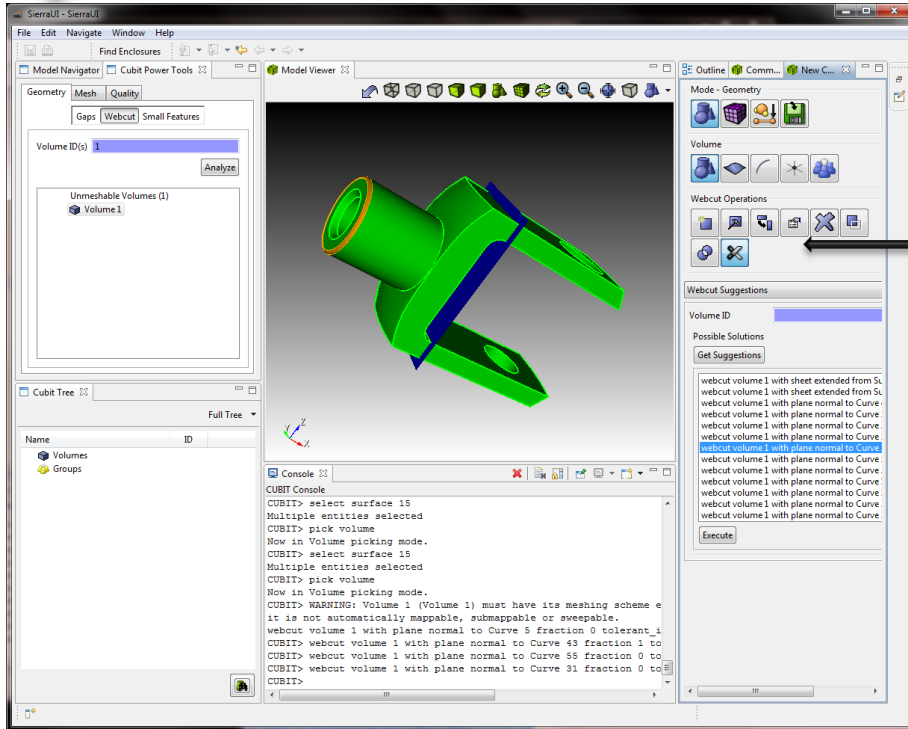
Also consider the following solutions available from the Cubit Command Panel.

[Tweak Surface](#)
Real operation to make small adjustments to a surface.

[Composite Curve/Surface](#)
Virtual operations to combine adjacent

[More Information](#) [Done](#)

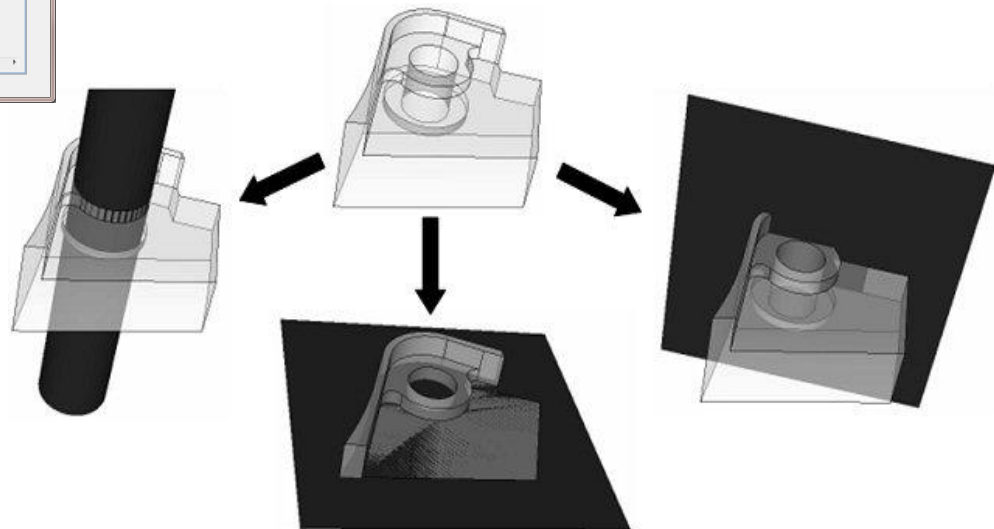
Tools for Decomposition



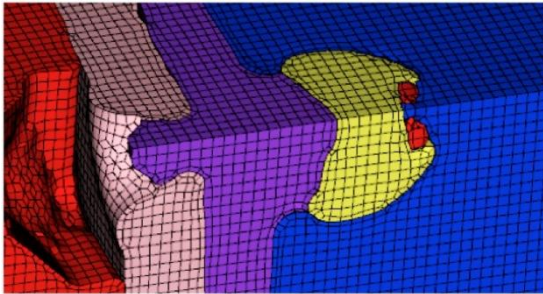
CUBIT provides multiple possible solutions and user selects the one they want

Types of Decomposition Cuts

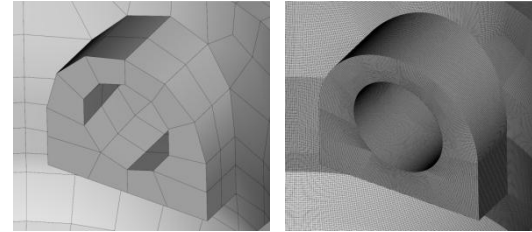
- Planar
- General Surface
- Tool Body
- Sweep Surface
- Sweep Curve



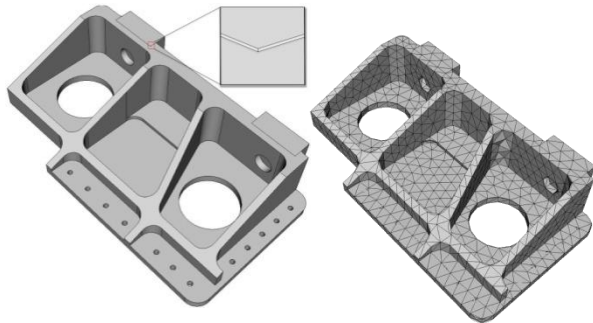
Current Technology Thrusts



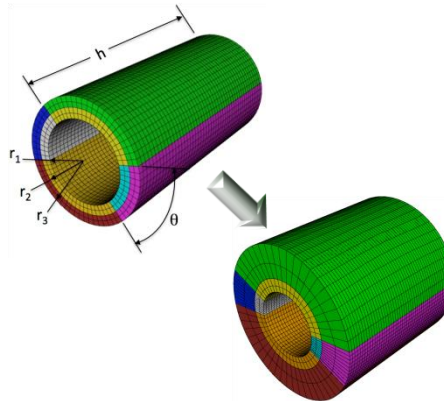
**Hex Meshing from
Volume Fractions**



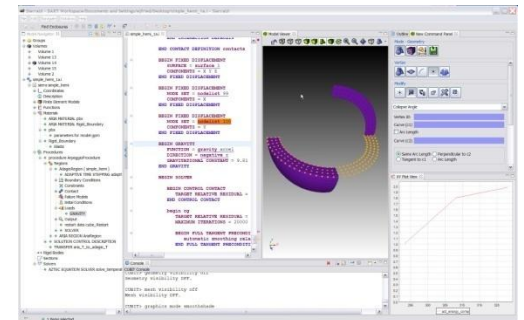
Parallel Refinement



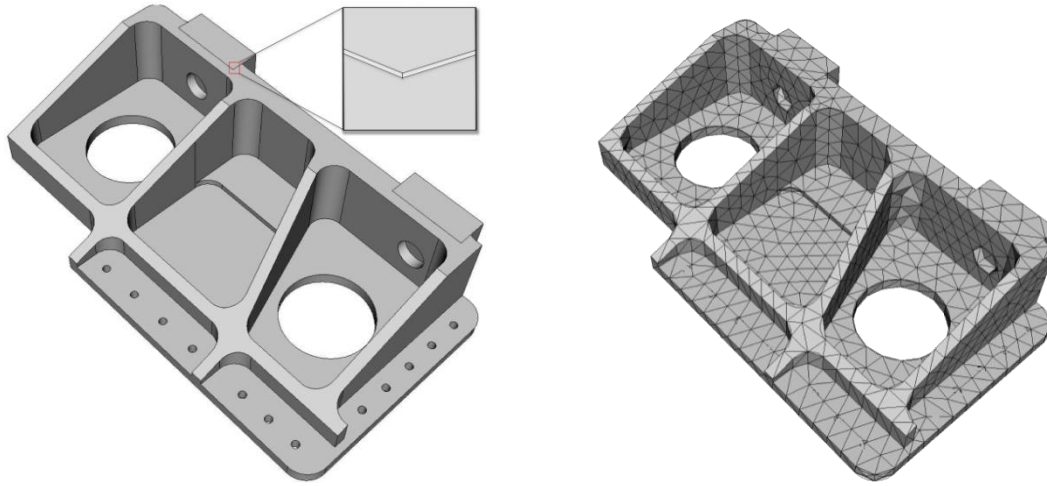
**Geometry Defeating
For Meshing**



**Moving Meshes,
Mesh Morphing**

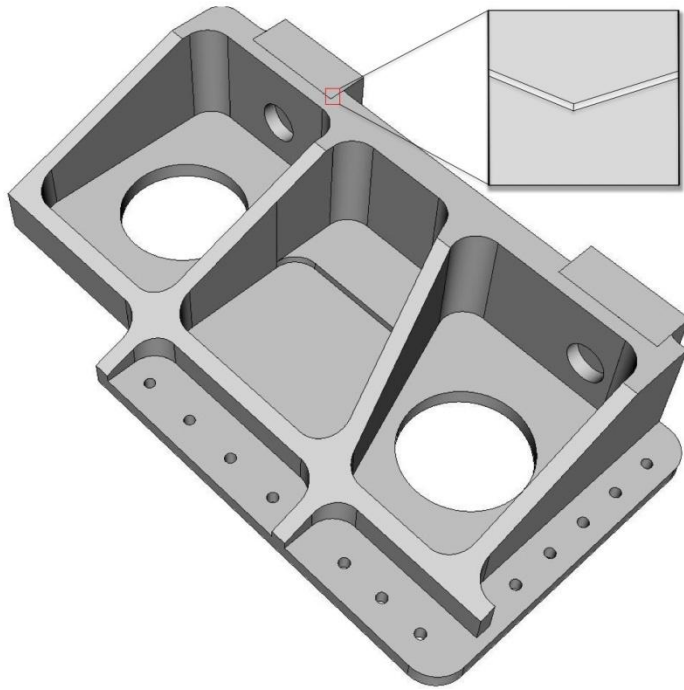


Integrated User Experience

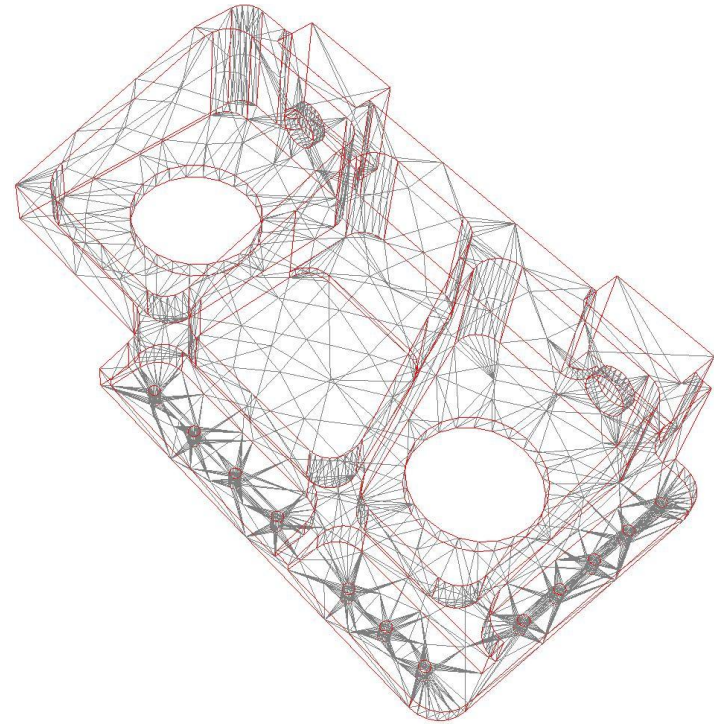


Geometry Defeaturing For Meshing

Automatic Geometry Defeaturing



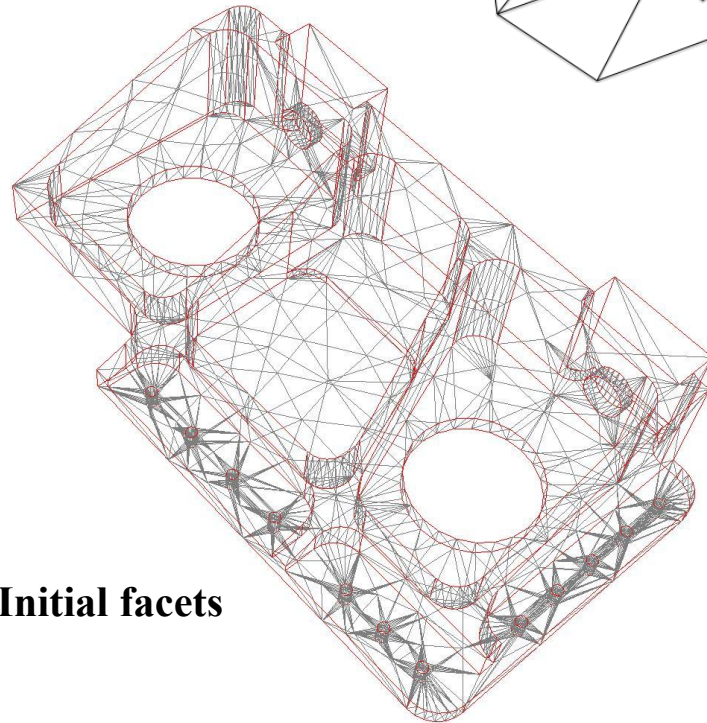
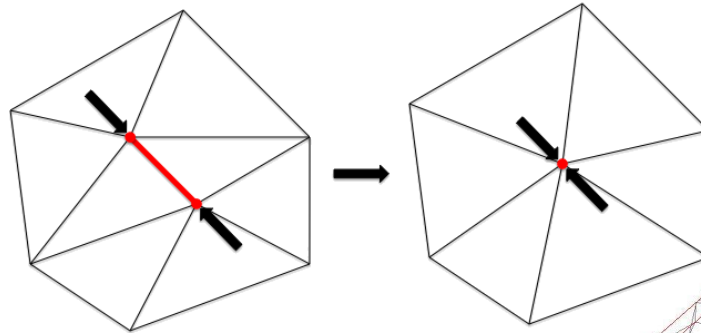
Solid Model



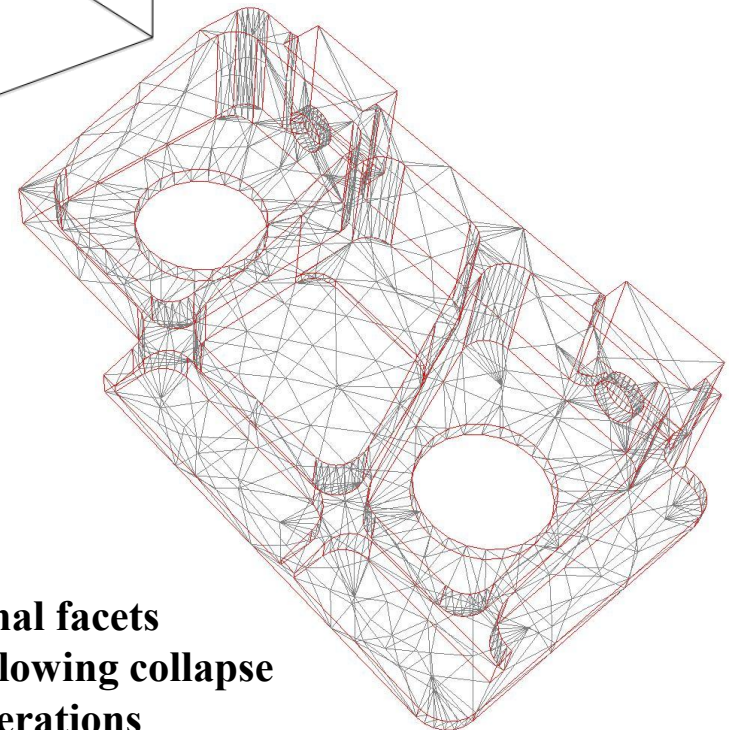
Facet Representation

Automatic Geometry Defeaturing

Basic Operation – Edge Collapse

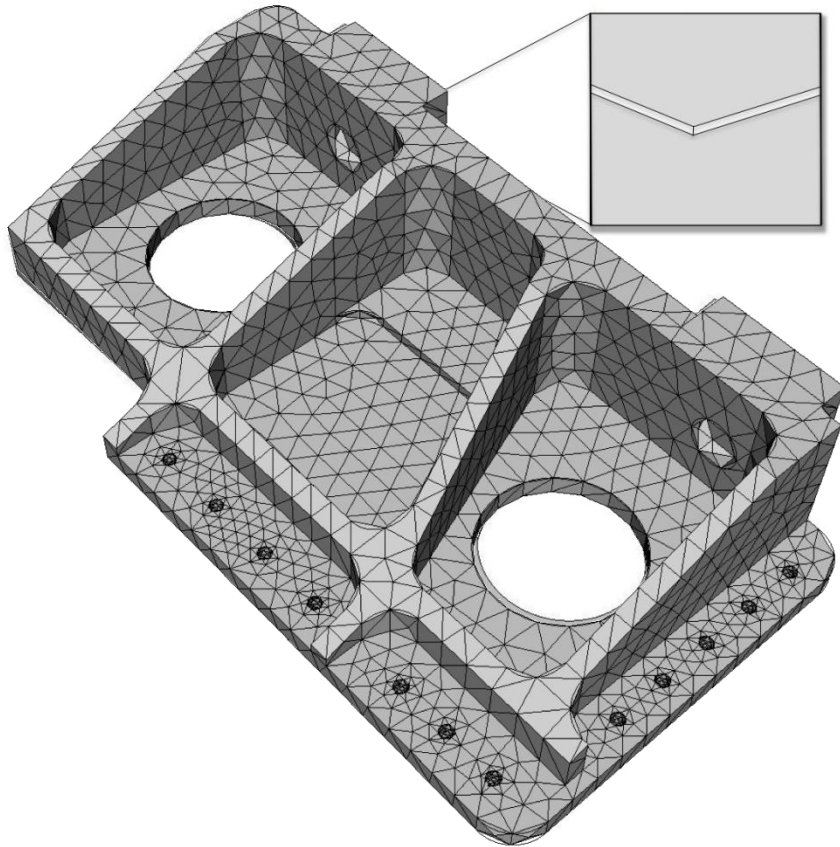


Initial facets



**Final facets
following collapse
operations**

Automatic Geometry Defetauring



**Original Solid Model
(ACIS-based representation)**



**Final Solid Model
(Facet-based representation)**

Defeaturing Tool

Cubit 13.1b

File Edit View Display Tools Help

Power Tools

Volume ID(s) all

Tolerance .01

Analyze

Entities to be Defeated

Item	Size
Small Curves (12)	Length
Curve 3977	0.00227721
Curve 3970	0.00227721
Curve 3969	0.00227721
Curve 3967	0.00227721
Curve 3935	0.00227721
Curve 3932	0.00227721
Curve 264	0.00227721
Curve 261	0.00227721
Curve 255	0.00227721
Curve 253	0.00227721
Curve 205	0.00227721
Curve 202	0.00227721
Narrow Surface Proximity (6)	Area
Surface 92	0.05205703
Surface 94	0.05205703
Surface 1421	0.05205703
Surface 1423	0.05205703
Surface 71	0.05205703
Surface 1401	0.05205703

Highlight Draw Locate Clear

Defeatured Group Name

defeature_group

Keep Originals

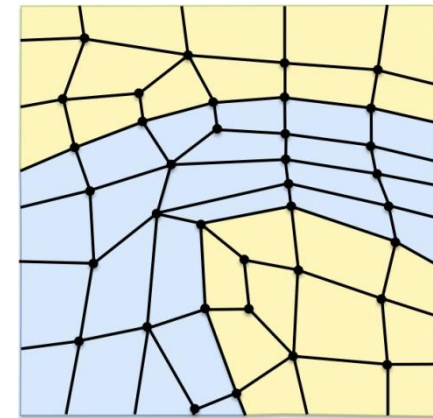
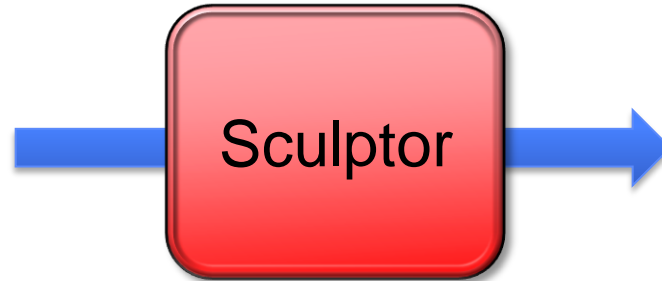
Execute

Surface 71

Eulerian to Lagrangian Meshing

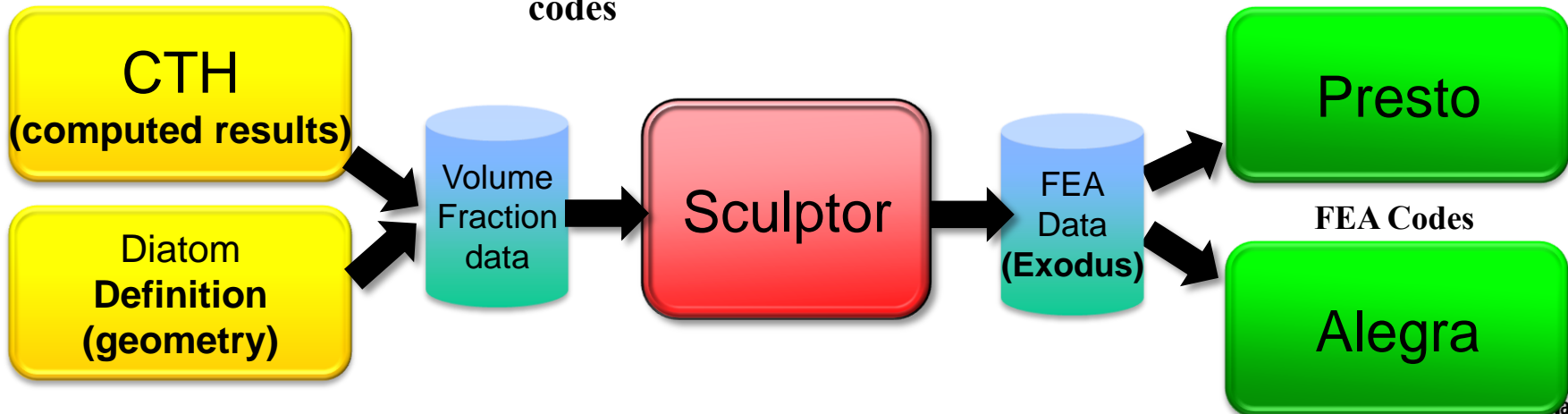
$v_A = 0.73$ $v_B = 0.27$	$v_A = 0.41$ $v_B = 0.59$	$v_A = 0.43$ $v_B = 0.57$
$v_A = 0.00$ $v_B = 1.00$	$v_A = 0.55$ $v_B = 0.45$	$v_A = 0.38$ $v_B = 0.62$
$v_A = 0.00$ $v_B = 1.00$	$v_A = 0.79$ $v_B = 0.21$	$v_A = 1.00$ $v_B = 0.00$

Eulerian

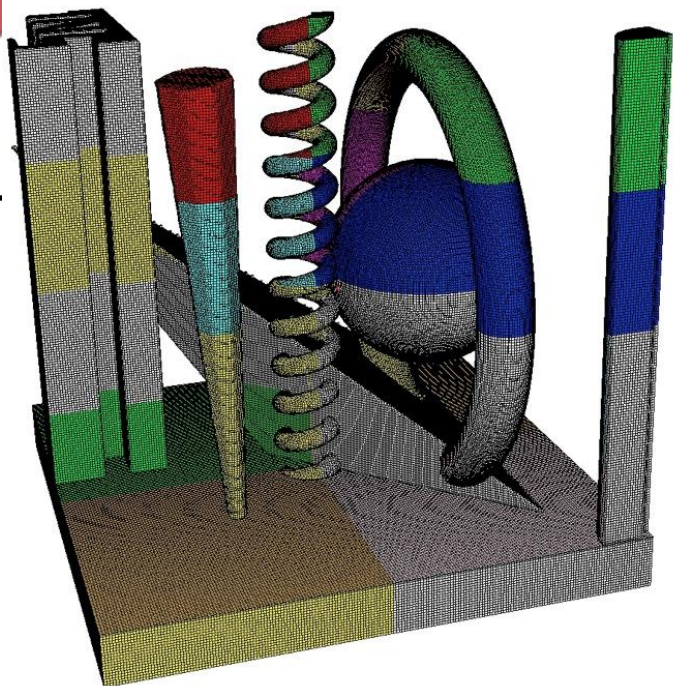


Lagrange

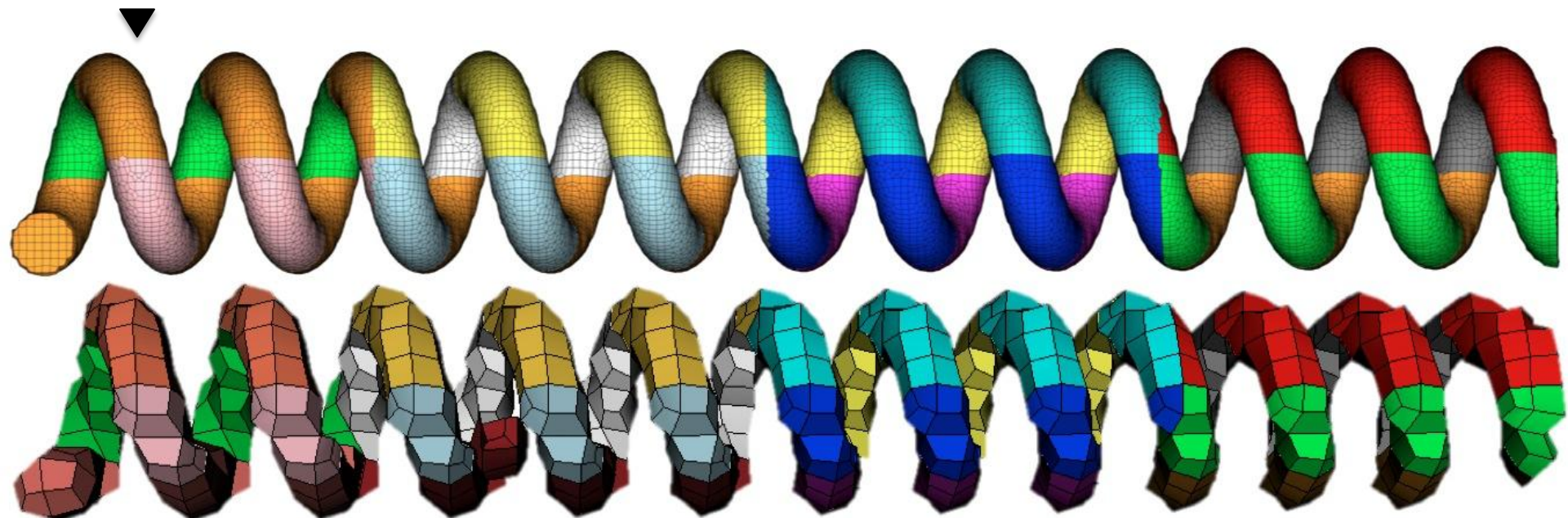
Sculptor is a new tool for generating meshes from volume fraction data generated from CTH for use in Sandia's FEA codes



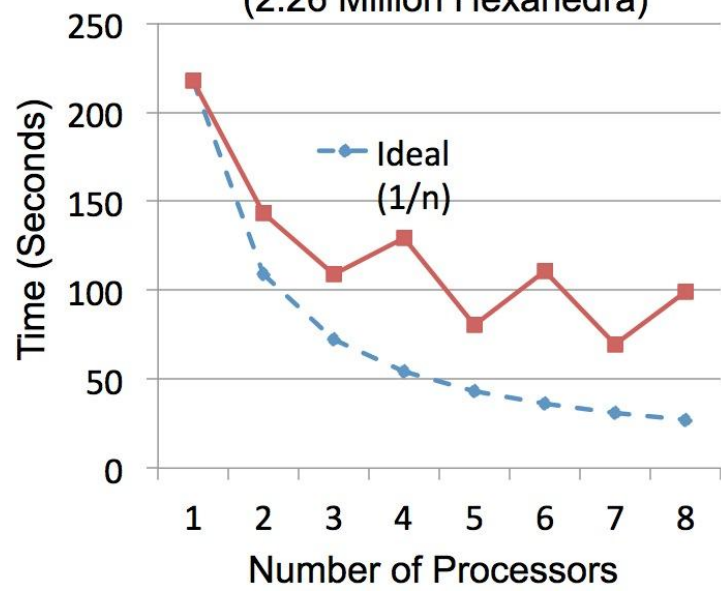
Hex mesh
constructed on
eight processors
and its timing
data

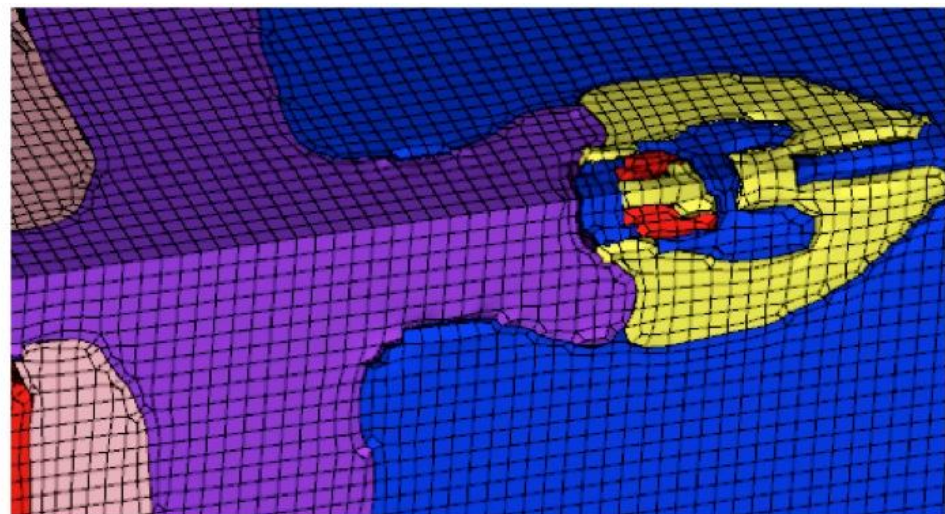
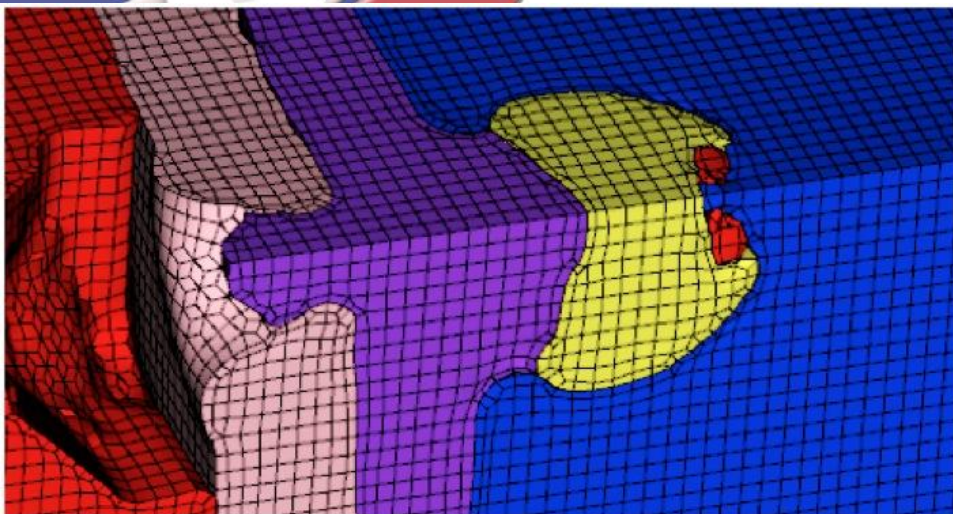


Detail from helix
meshed at 2
different
resolutions

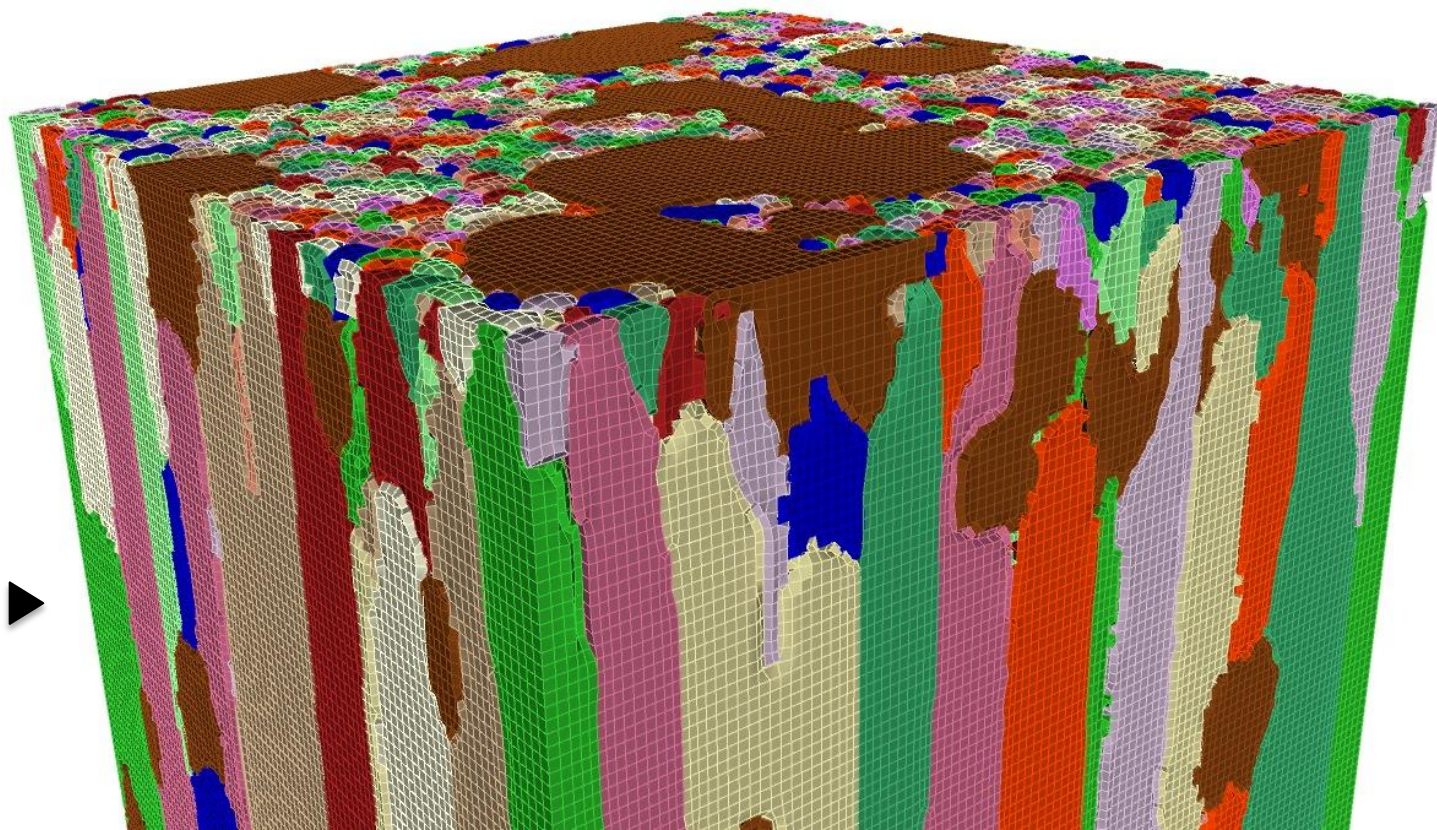


Scalability on fixed model size
Shapes Diatom
(2.26 Million Hexahedra)

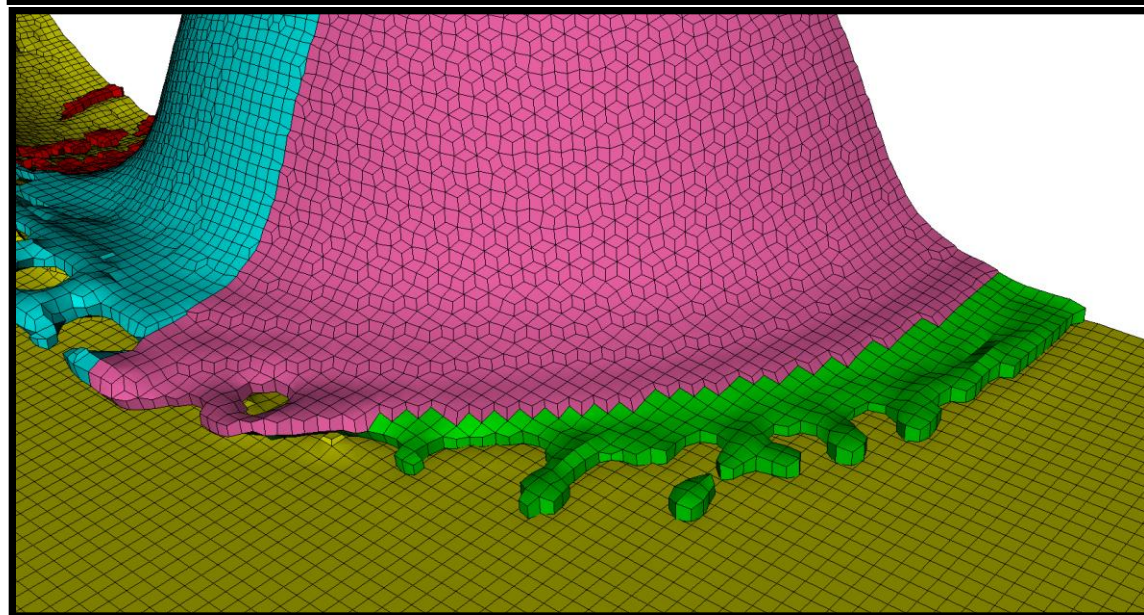
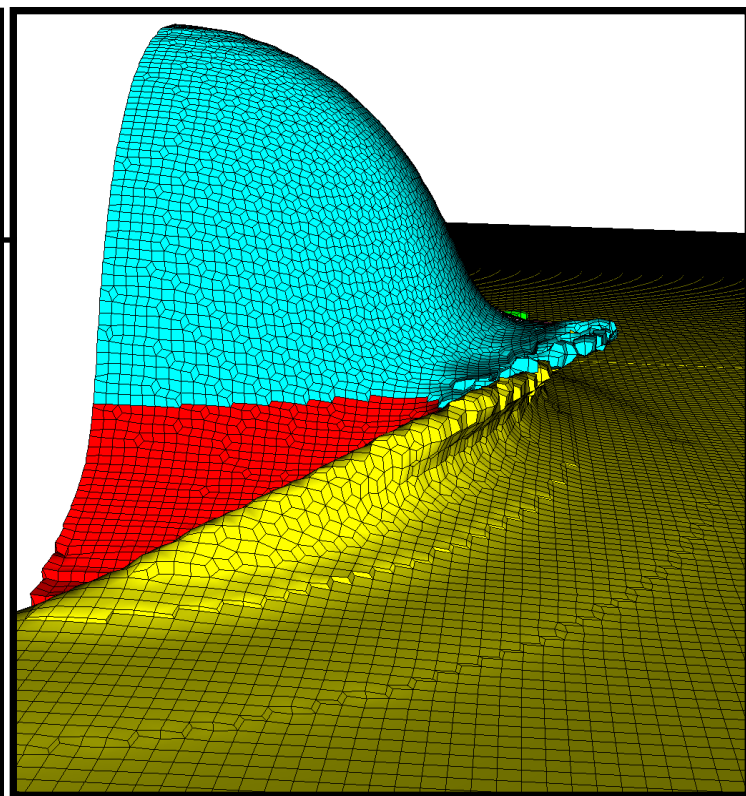
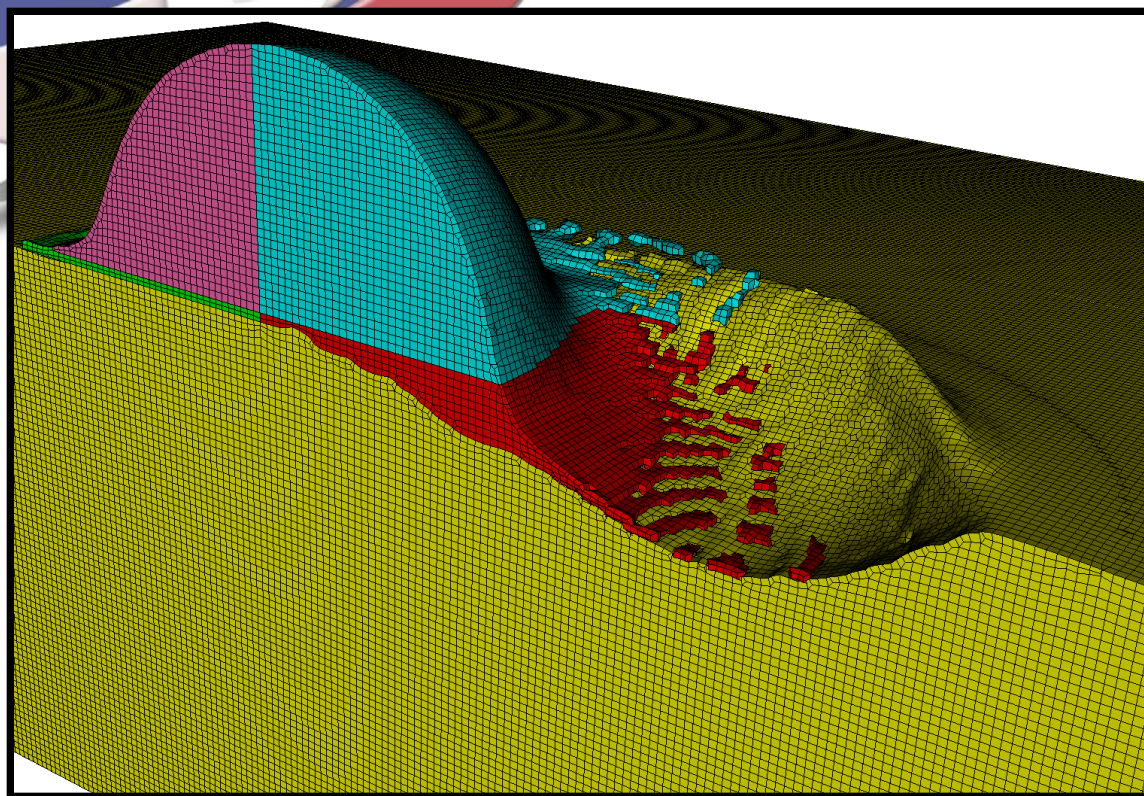




▲
Close-up view of hex
meshes generated at
two different time
steps of a simulated
pipe bomb explosion

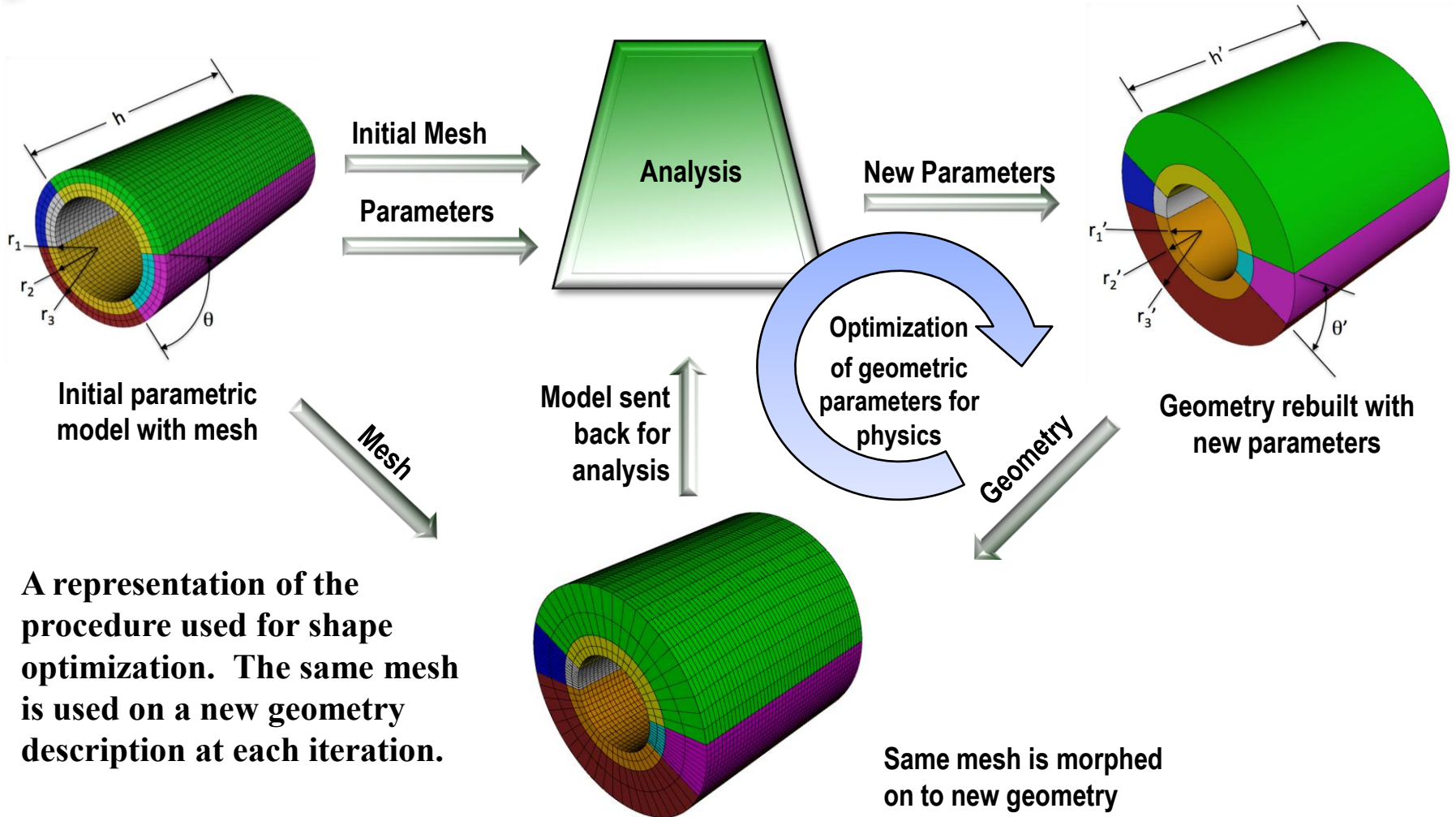


▶
Hex mesh of simulated
grain microstructure
with 15 different
materials



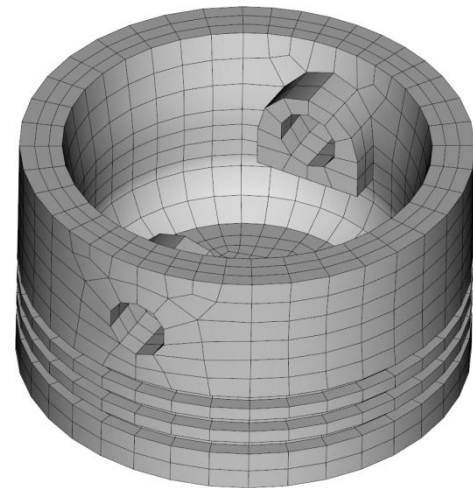
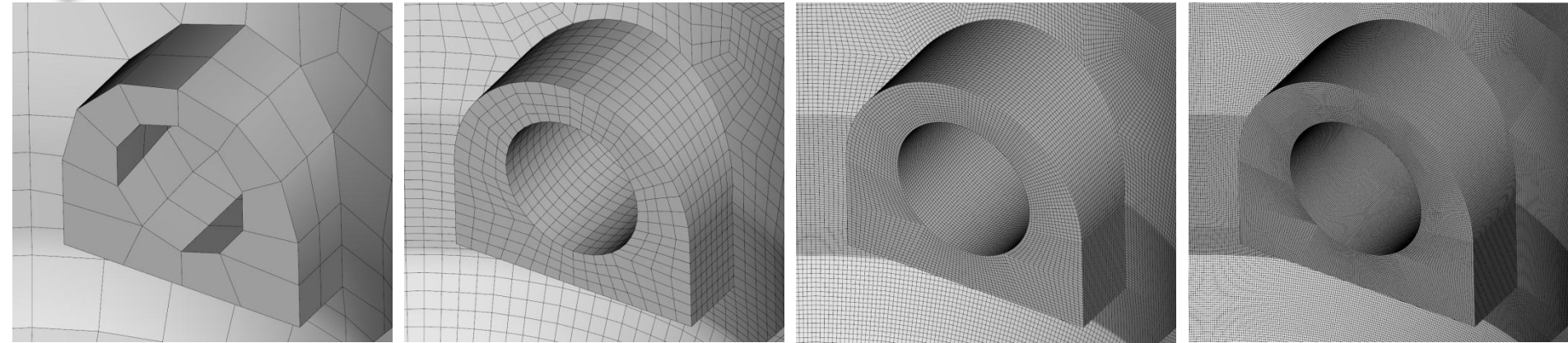
8 Processors, 4.19 million hexahedra. Hexes color-coded by processor

Mesh Morphing for CAD Parametric Shape Optimization

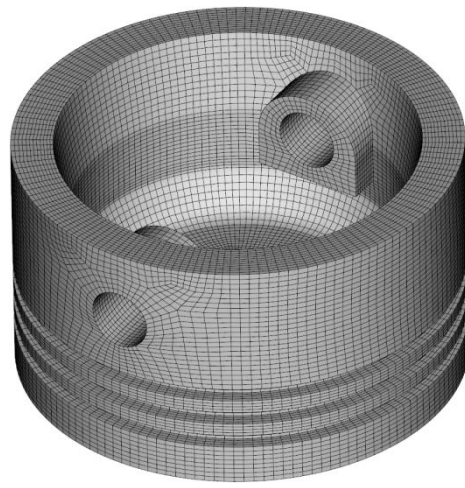


A representation of the procedure used for shape optimization. The same mesh is used on a new geometry description at each iteration.

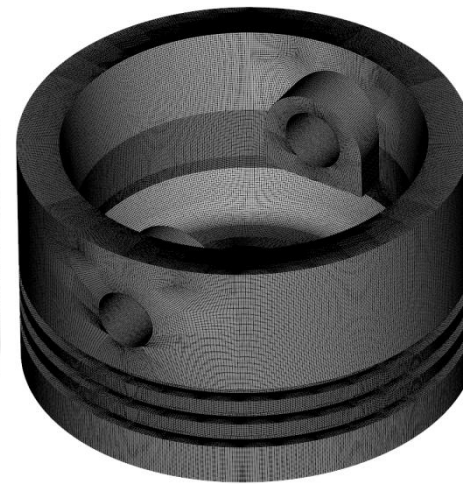
Parallel Refinement with Geometry



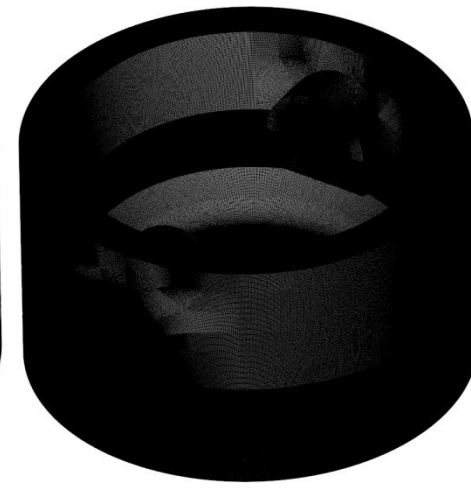
Input Mesh
1,936 Hex



2 levels refinement
124k Hex



4 levels refinement
7.93M Hex



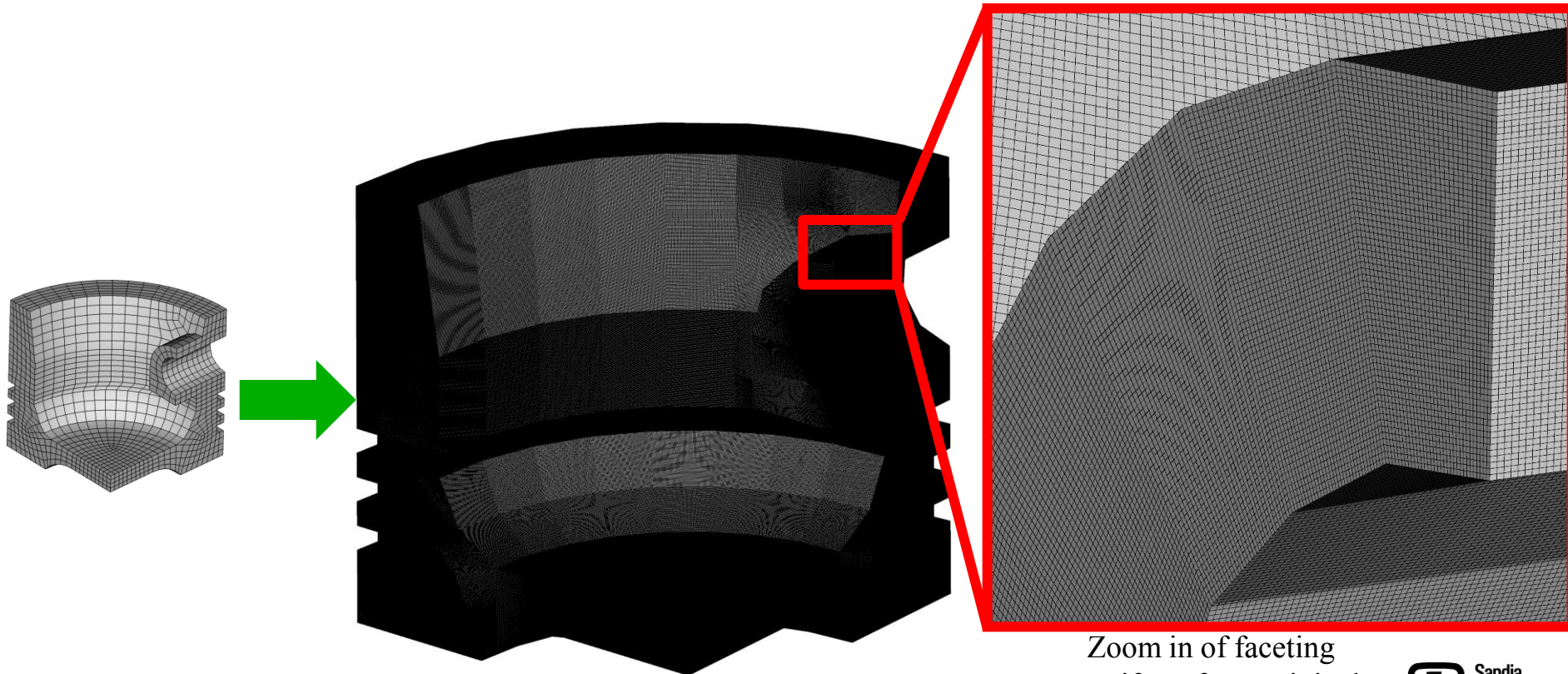
5 levels refinement
63.4M Hex

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.

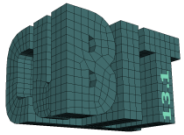
In previous releases, new nodes were positioned by evaluating element shape functions.



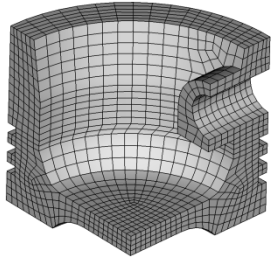
Zoom in of faceting artifacts from original mesh.

New Workflow

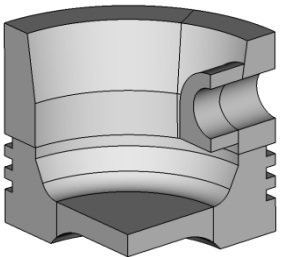
Step 1



Cubit exports:



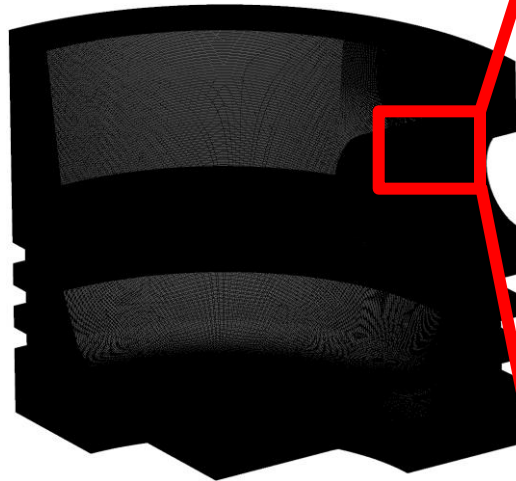
A coarse mesh (exo file) and:



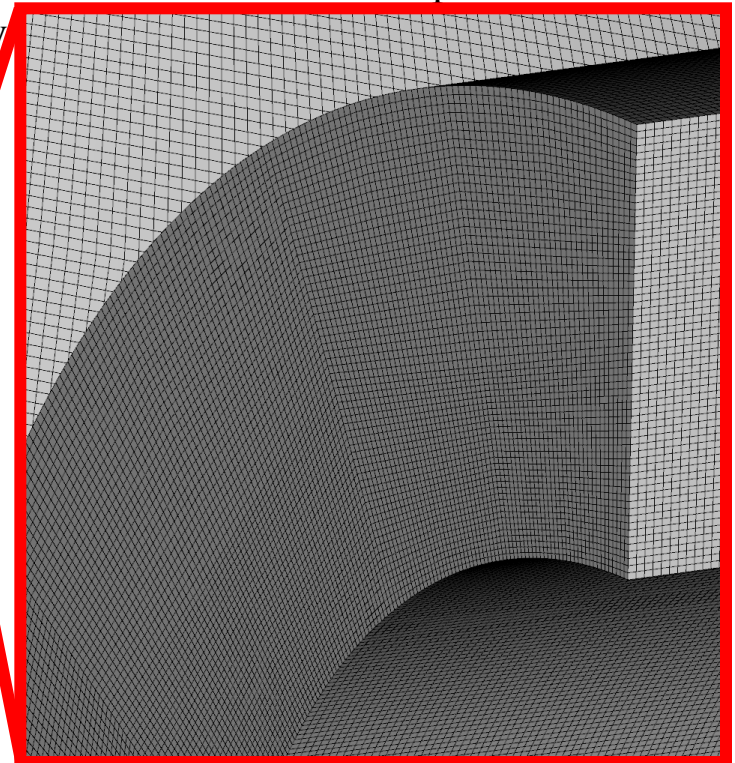
A geometry file
(3dm
OpenNURBS)

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.

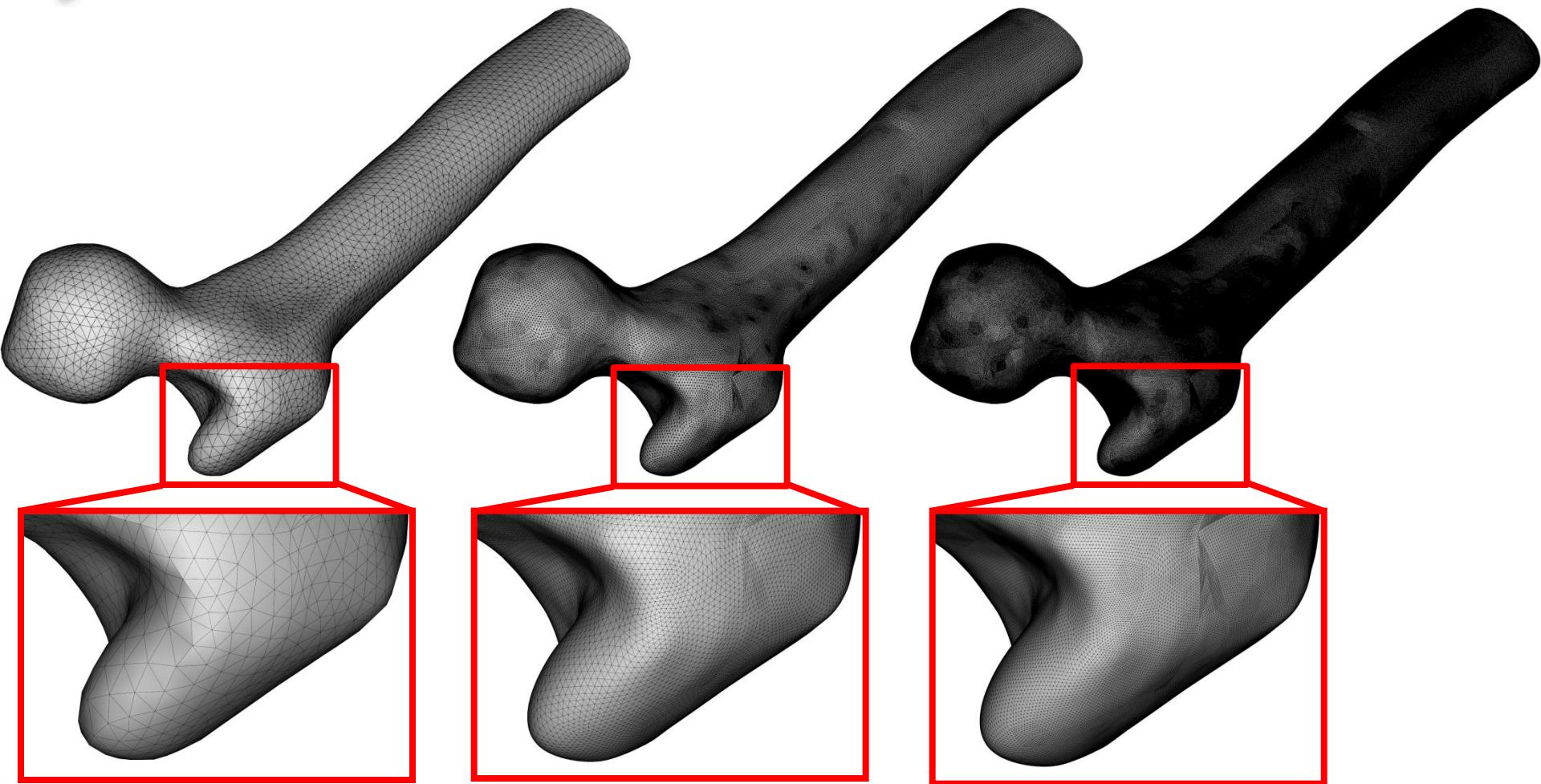


112 M hex elements
20 processors



Refined nodes are placed
on original CAD geometry.

Example - Bone



Input Mesh
86k Tet

Input Mesh
5.52M Tet

Input Mesh
44.2M Tet

Integrated User Experience

The screenshot displays the SierraUI software interface, which is used for finite element analysis. The interface is divided into several panels:

- Model Navigator:** A tree view on the left showing the project structure, including volumes (Volume 1, 13, 14, 15, 2), materials (ARIA MATERIAL pbx, Rigid_Boundary, Elastic), and procedures (AdagioRegion, Boundary Conditions, Constraints, Contact, Failure Models, Initial Conditions, Loads, Output, Solver).
- Command Window:** A central text area showing the input commands for the simulation, including:

```
END INTERSECTION DEFINITION contacts
END CONTACT DEFINITION contacts

BEGIN FIXED DISPLACEMENT
SURFACE = surface_1
COMPONENTS = X Y Z
END FIXED DISPLACEMENT

BEGIN FIXED DISPLACEMENT
NODE SET = nodelist_99
COMPONENTS = X
END FIXED DISPLACEMENT

BEGIN FIXED DISPLACEMENT
NODE SET = nodelist_100
COMPONENTS = Y
END FIXED DISPLACEMENT

BEGIN GRAVITY
FUNCTION = gravity_accel
DIRECTION = negative z
GRAVITATIONAL CONSTANT = 9.81
END GRAVITY

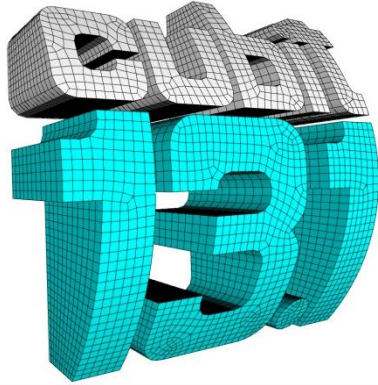
BEGIN SOLVER

BEGIN CONTROL CONTACT
TARGET RELATIVE RESIDUAL =
END CONTROL CONTACT

begin cg
TARGET RELATIVE RESIDUAL =
MAXIMUM ITERATIONS = 20000

BEGIN FULL TANGENT PRECONDI
automatic smoothing rela
END FULL TANGENT PRECONDI
```
- Model Viewer:** A 3D visualization of a curved, purple mesh structure with yellow nodes, representing a hemispherical cap.
- Outline / New Command Panel:** A panel on the right with various tool icons for geometry, vertex, and modify operations.
- XY Plot View:** A graph at the bottom right showing the energy component 'act_energy_comp' over time. The x-axis ranges from 295 to 320, and the y-axis ranges from 0.0 to 2.0. The plot shows a linear increase from approximately 1.0 at x=295 to 1.8 at x=305, followed by a slight increase to 2.0 at x=320.
- Console:** A window at the bottom showing the output of the CUBIT commands, such as 'geometry visibility off' and 'mesh visibility off'.

The Design Through Analysis Process



Cubit



DART Workbench

Integrated Product

Future

Geometry

Meshing

Model Attribution

Input Deck Creation

Job Submission

Sim Data Management

Post Processing

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.



<?xml?>



SAW

Sandia Analysis Workbench

The screenshot displays the SAW (Sandia Analysis Workbench) interface, showing a finite element model of a hemispherical shell. The interface is divided into several panels:

- Model Navigator:** Shows the hierarchical structure of the model, including Volumes (Volume 1, 13, 14, 15, 2), simple_hemi_1a.i, and various materials and procedures.
- Model Viewer:** Displays the 3D model of the hemispherical shell, rendered in purple and yellow. The shell is shown in a cutaway view, revealing the internal structure and the distribution of nodes and elements.
- Outline:** Shows the current mode (Geometry) and various tools for modifying the model, such as Vertex, Curve, and Arc Length.
- Console:** Displays the CUBIT console output, showing the execution of various commands and the resulting simulation parameters.

The simulation parameters shown in the console include:

```
END INTERACTION DEFINITION contacts
END CONTACT DEFINITION contacts

BEGIN FIXED DISPLACEMENT
SURFACE = surface_1
COMPONENTS = X Y Z
END FIXED DISPLACEMENT

BEGIN FIXED DISPLACEMENT
NODE SET = nodelist_99
COMPONENTS = X
END FIXED DISPLACEMENT

BEGIN FIXED DISPLACEMENT
NODE SET = nodelist_100
COMPONENTS = Y
END FIXED DISPLACEMENT

BEGIN GRAVITY
FUNCTION = gravity_accel
DIRECTION = negative_z
GRAVITATIONAL CONSTANT = 9.81
END GRAVITY

BEGIN SOLVER

BEGIN CONTROL CONTACT
TARGET RELATIVE RESIDUAL =
END CONTROL CONTACT

begin cg
TARGET RELATIVE RESIDUAL =
MAXIMUM ITERATIONS = 20000

BEGIN FULL TANGENT PRECONDI
automatic smoothing rela
END FULL TANGENT PRECONDI
```

The console output also shows the following commands and their results:

```
CUBIT Console
CUBIT> geometry visibility on
Geometry visibility OFF.

CUBIT> mesh visibility off
Mesh visibility OFF.

CUBIT> graphics mode smoothshade
```

The XY Plot View shows a graph of the act_energy_comp parameter, with the x-axis ranging from 285 to 320 and the y-axis ranging from 0.0 to 2.0. The plot shows a single curve that increases from approximately 1.0 at x=285 to 2.0 at x=320.

SAW

Sandia Analysis Workbench

The screenshot displays the SierraUI interface for the SAW (Sandia Analysis Workbench). The interface is divided into several key components:

- Cubit Geometry Navigation Tree:** Located on the left, it shows a hierarchical tree of the model's geometry, including volumes (Volume 1, 13, 14, 15, 2), materials, procedures, regions, and solvers.
- Cubit Interactive Graphics Window:** The central window displays a 3D model of a curved structure with a mesh. The model is rendered in purple and yellow, with a coordinate system (X, Y, Z) visible at the bottom left.
- Cubit Command Panel:** Located on the right, it provides a set of tools and options for interacting with the model, including buttons for geometry, vertex, and modify operations, as well as input fields for vertex ID, curve selection, and arc length options.
- Cubit Command Prompt:** Located at the bottom, it shows the command-line interface for Cubit, with the following commands and responses:

```
CUBIT Console
CUBIT> geometry visibility off
Geometry visibility OFF.

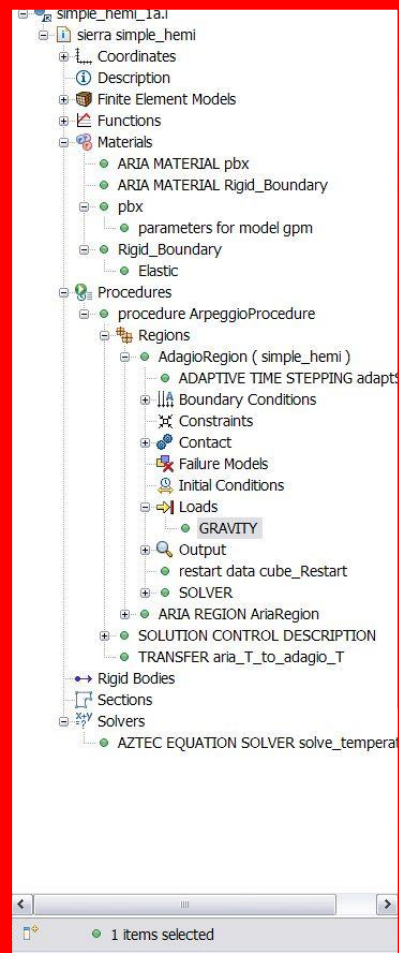
CUBIT> mesh visibility off
Mesh visibility OFF.

CUBIT> graphics mode smoothshade
```


SAW

Sandia Analysis Workbench

Workbench Model Navigation Tree



```
END INTERACTION DEFAULTS

END CONTACT DEFINITION contacts

BEGIN FIXED DISPLACEMENT
  SURFACE = surface 1
  COMPONENTS = X Y Z
END FIXED DISPLACEMENT

BEGIN FIXED DISPLACEMENT
  NODE SET = nodelist 99
  COMPONENTS = X
END FIXED DISPLACEMENT

BEGIN FIXED DISPLACEMENT
  NODE SET = nodelist 100
  COMPONENTS = Y
END FIXED DISPLACEMENT

BEGIN GRAVITY
  FUNCTION = gravity accel
  DIRECTION = negative z
  GRAVITATIONAL CONSTANT = 9.81
END GRAVITY

BEGIN SOLVER

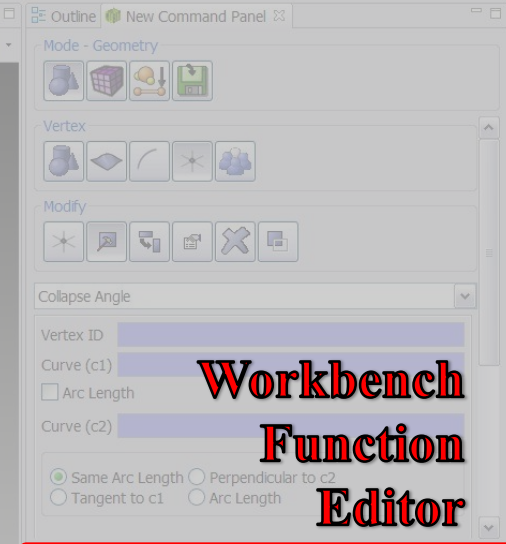
BEGIN CONTROL CONTACT
  TARGET RELATIVE RESIDUAL =
END CONTROL CONTACT

begin cg
  TARGET RELATIVE RESIDUAL =
  MAXIMUM ITERATIONS = 20000

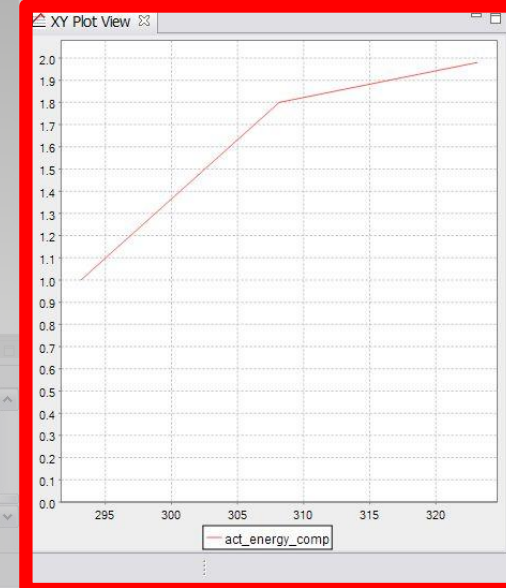
BEGIN FULL TANGENT PRECONDI
  automatic smoothing rela
END FULL TANGENT PRECONDI
```



Workbench Input Deck Editor

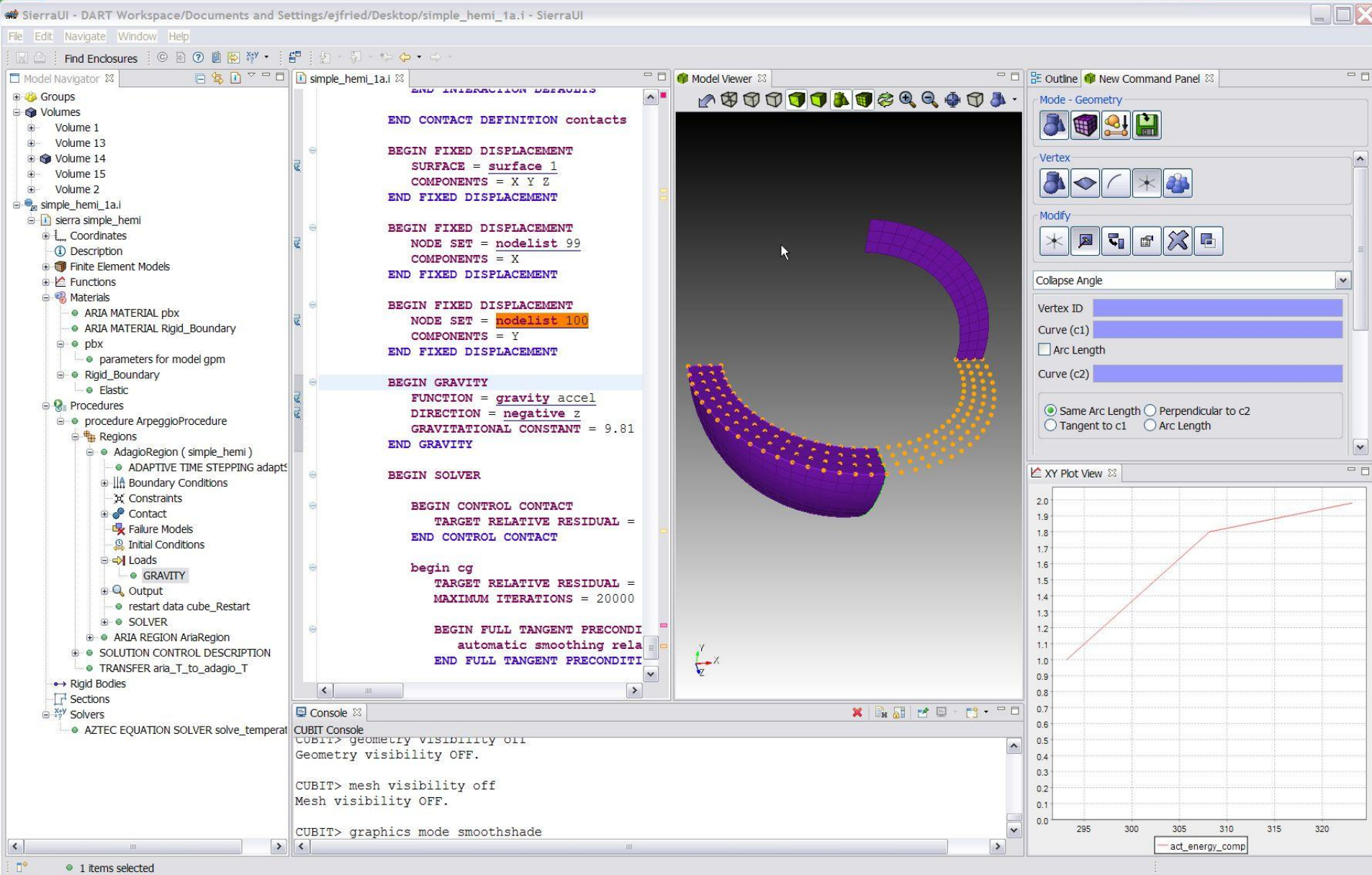


Workbench Function Editor



SAW

Sandia Analysis Workbench



The screenshot displays the SAW software interface with the following components:

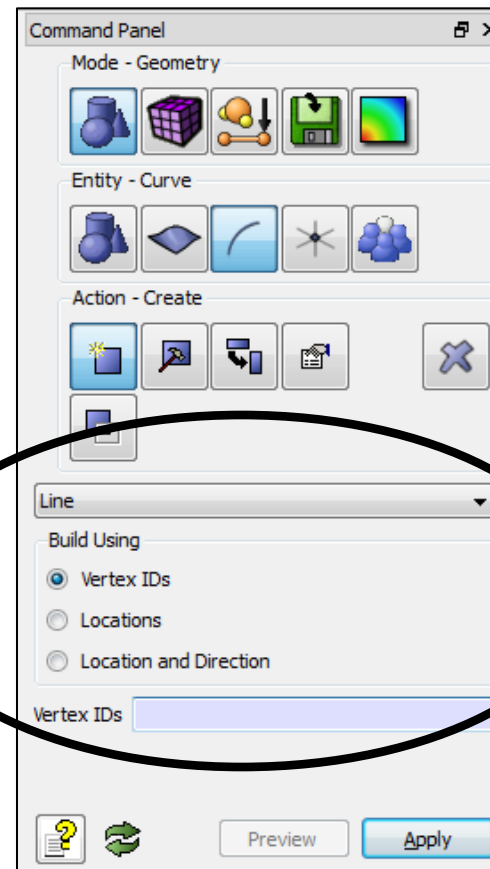
- Model Navigator:** A tree view on the left showing the project hierarchy, including Volumes (Volume 1, 13, 14, 15, Volume 2), Materials (ARIA MATERIAL pbx, Rigid_Boundary, Elastic), and Procedures (ArpeggioProcedure, Regions, Boundary Conditions, Constraints, Contact, Failure Models, Initial Conditions, Loads, Output, Solver).
- Code Editor:** A central window displaying the input script with sections for contact definitions, fixed displacements (e.g., `BEGIN FIXED DISPLACEMENT SURFACE = surface_1`), gravity application (`BEGIN GRAVITY FUNCTION = gravity accel`), and solver settings (`BEGIN SOLVER TARGET RELATIVE RESIDUAL = ...`).
- Model Viewer:** A 3D visualization of a purple curved structure with a mesh. A portion of the structure is highlighted with yellow dots, representing nodes or elements.
- Outline / Command Panel:** A panel on the right for geometry manipulation, including tools for vertex and curve selection, and options for arc length and tangency.
- XY Plot View:** A graph at the bottom right showing the relationship between `act_energy_comp` and a parameter ranging from 285 to 320. The plot shows a curve that increases from approximately 1.0 to 2.0.
- Console:** A window at the bottom showing the execution of CUBIT commands such as `geometry visibility off`, `mesh visibility off`, and `graphics mode smoothshade`.

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 are
    <!-- ** Type 'Help Direction' to see direction options **
    <!-- Create Curve Arc Center Vertex <center_id> <end1_id> <end2_id>
    <!-- ** Type 'Help Direction' to see direction options **
    <!-- Create Curve Arc Vertex <end1_id> <end2_id> Radius <value>
    <!-- ** Type 'Help Location/Direction' to see location/direction
    <!-- Create Curve Arc Radius <value> [Center <x=0> <y=0> <z=0>]
    <!-- ** 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 ID" />
        <Variable type="vertex-id" label="End Vertex ID" />
        <Variable token="radius" label="Radius" type="double" />
        <Variable type="direction_dialog" label="None" />
        <Option label="Full Circle">
          <Keyword token="full" />
        </Option>
        <Option label="Other Arc">
          <Keyword token="other_arc" />
        </Option>
      </Choice>
    </Choices>
  </CommandDefinition>
```

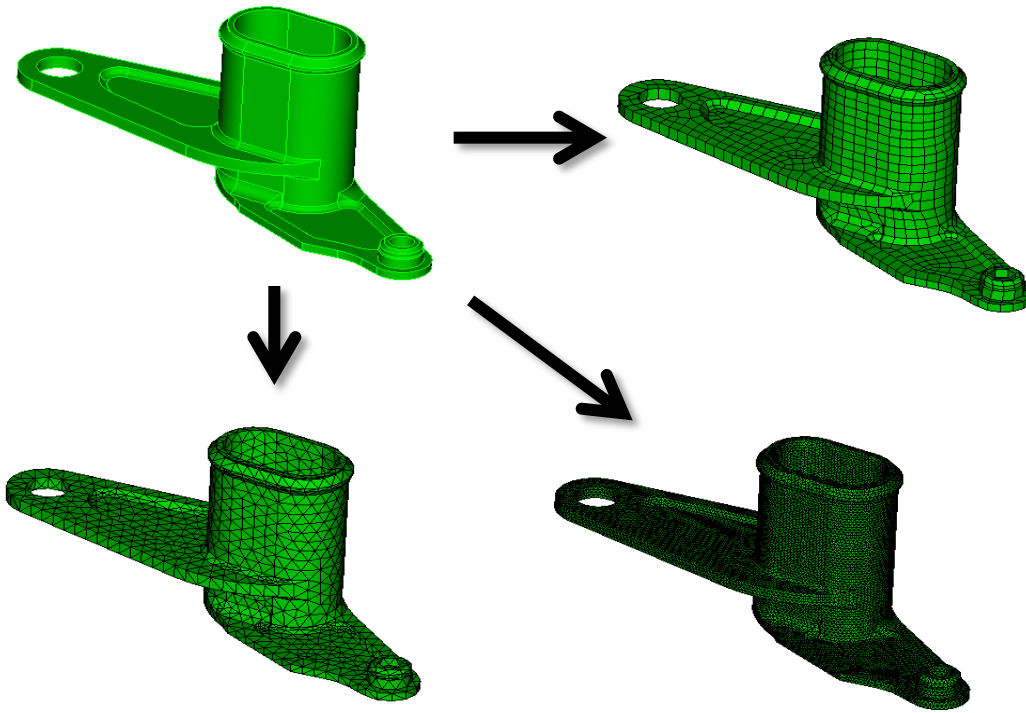
Cubit command defined with XML.



Automatically generated GUI from XML.

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.



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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