



Exceptional service in the national interest

ADVANCEMENTS IN MACHINE LEARNING TECHNOLOGIES

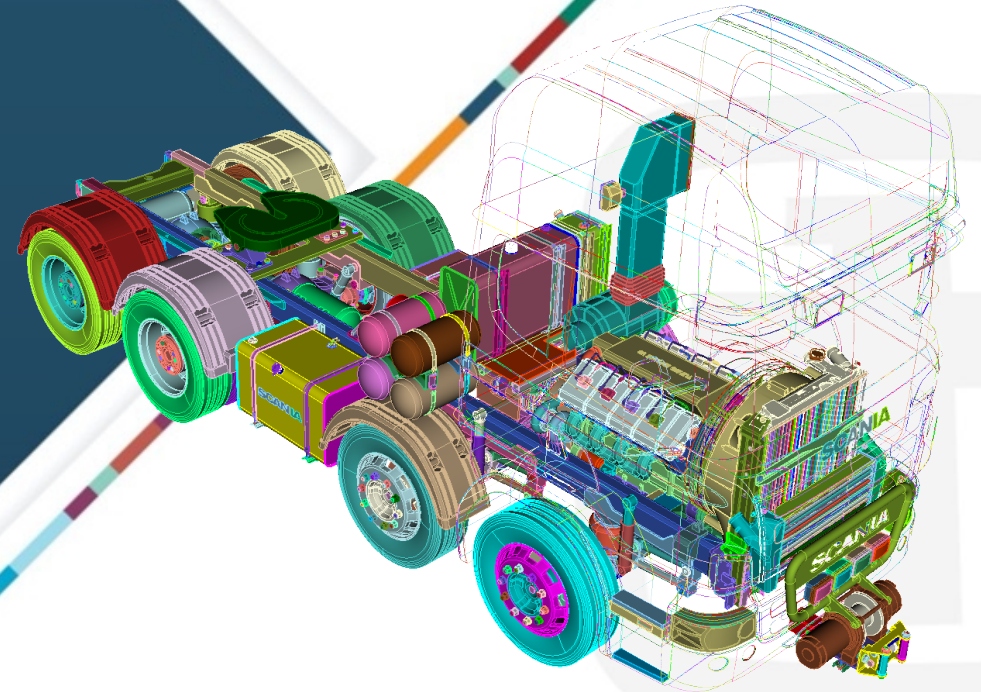
For CAD-to-Simulation

Steven Owen

CEA/NNSA Workshop

June 20th 2023

Ashville, North Carolina



RAPID CAD TO SIMULATION WITH MACHINE LEARNING



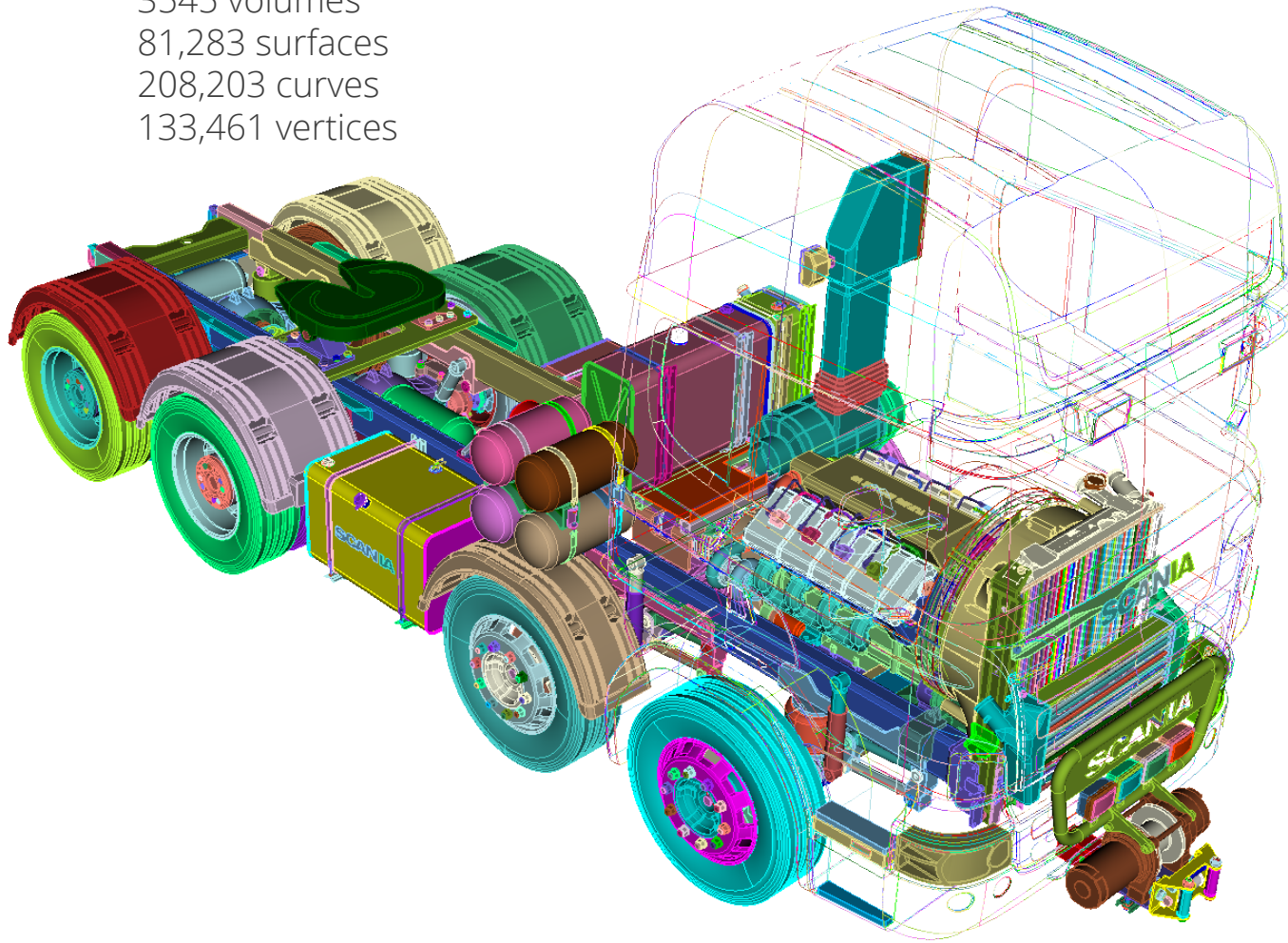
Commercial Truck CAD Model

3545 volumes

81,283 surfaces

208,203 curves

133,461 vertices



Example workflow

- Break into subsystems for teaming and/or avoid large model size
- Remove parts that are irrelevant and not normally modeled for a specific physics
- Fix bad geometry
- Remove small features
- Remove gaps, overlaps, misalignments
- Decompose for Hex Meshing
- Tet mesh/Hex Mesh
- Identify and prepare specific categories of mechanisms (Bolts, Springs, Bearings, etc.)
- Reduce Dimension: Model Thin Volumes with Shells and Beams
- Compute preloads on bolts, springs, etc.
- Prepare input deck

RAPID CAD TO SIMULATION WITH MACHINE LEARNING



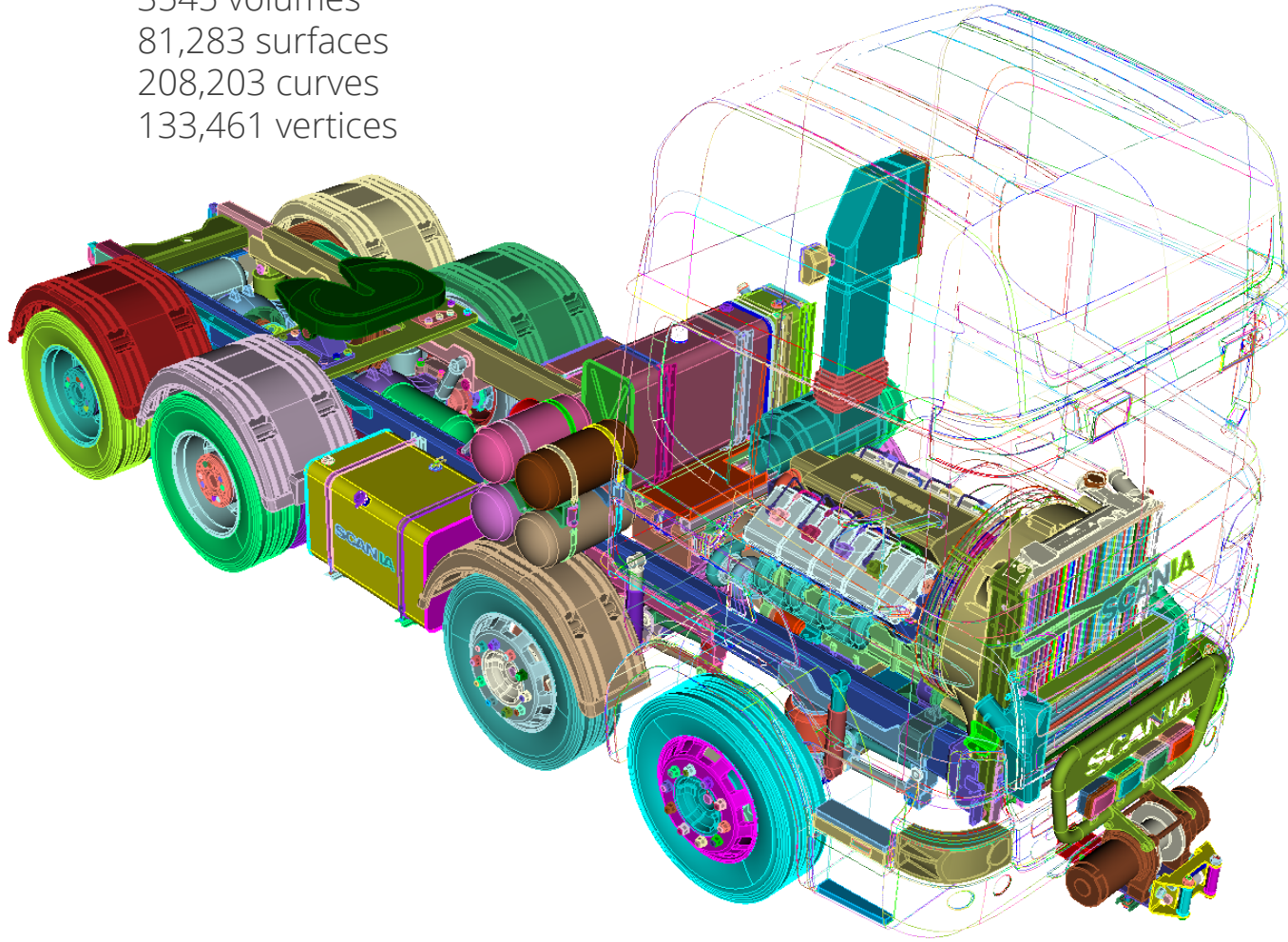
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Machine Learning for Analysis Preparation:

- Reduce/Eliminate most tedious tasks
- Guide user to next step
- Present user with smart options
- User validates ML-solutions
- Standardization between analysts



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① Defeaturing for Meshing

④ Decomposition for Hex Meshing

② Classification and Reduction

③ Reduce Thin Volumes to Shells

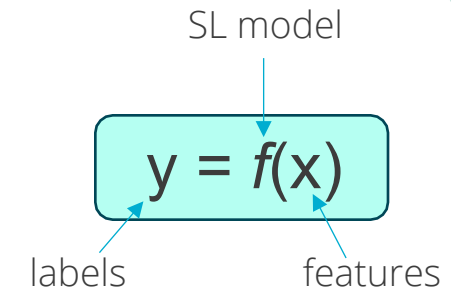
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MACHINE LEARNING APPROACHES

1. Supervised Learning

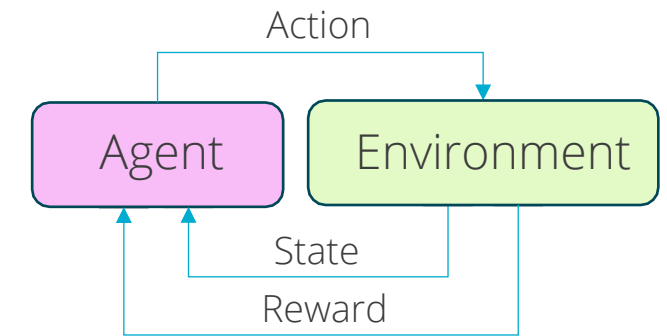
- Operates using predefined labels during training
- Processes known input-output pairs (features, labels) for learning
- Encounters limitations when addressing new, unseen data scenarios
- Provides a single prediction based on established input-output correlations



Supervised Learning

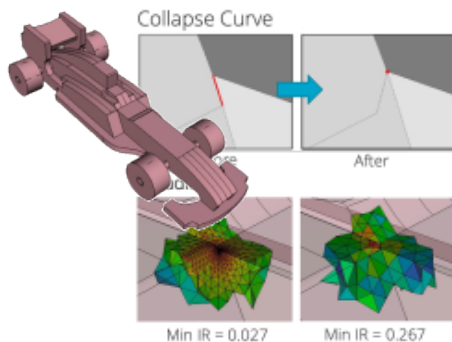
2. Reinforcement Learning

- Operates under a reward system instead of explicit correct answers
- Employs a trial-and-error methodology, aiming to maximize long-term rewards
- Balances exploration and exploitation for optimal learning
- Produces a procedure or series of steps to execute a task, guided by the reward system

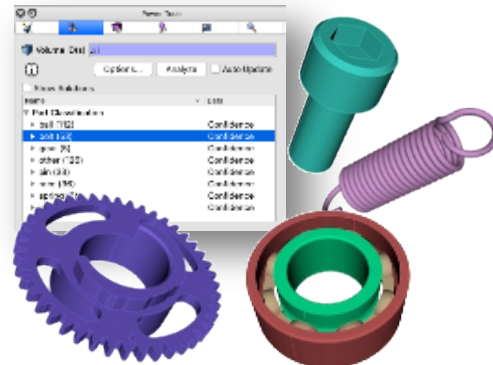


Reinforcement Learning

Supervised Learning

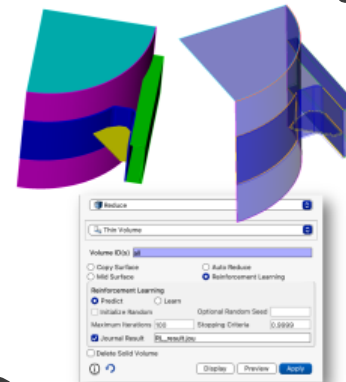


① Defeaturing for Meshing

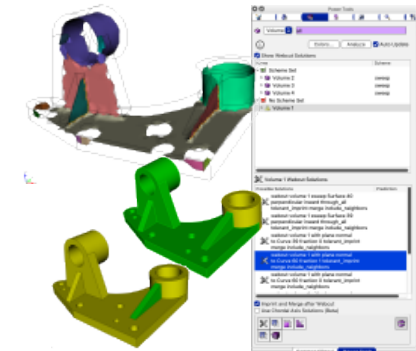


② Part Classification

Reinforcement Learning

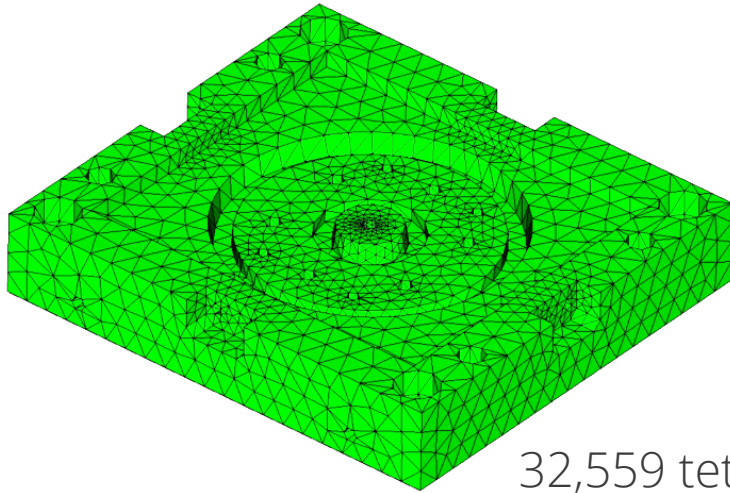


③ Dimension Reduction



④ Geometry Decomposition

MACHINE LEARNING FOR DEFEATURING



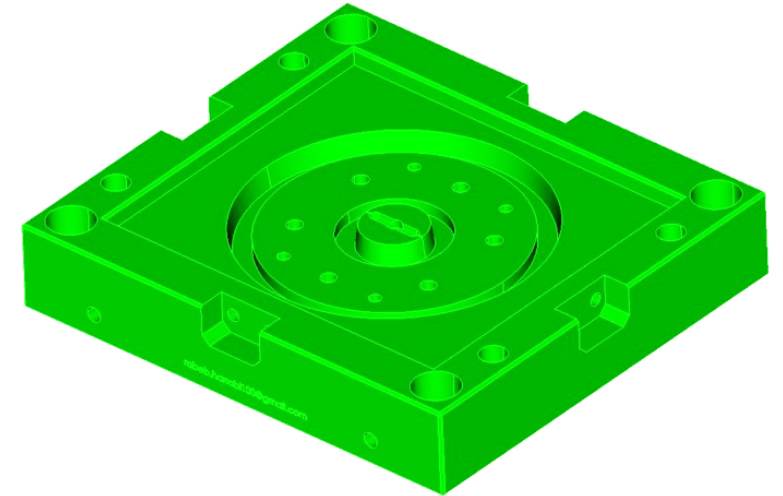
32,559 tets

Machine Learning

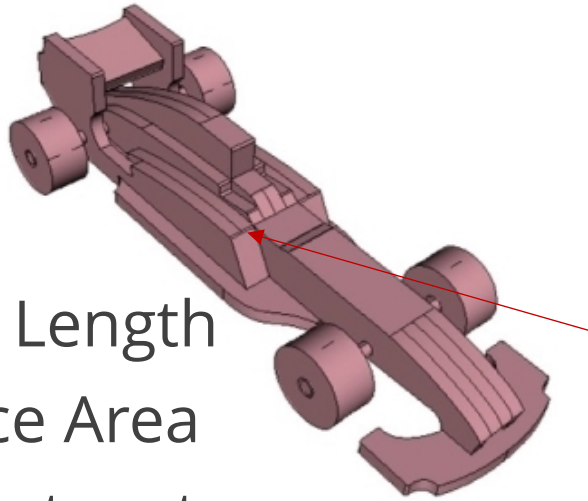
$$y = f(x)$$

Output: Mesh
quality metrics
"labels"

Input: CAD Model
Local geometry/topology
"features"



TRAINING DATA FEATURES



Curve Length

Surface Area

Angle at vertex

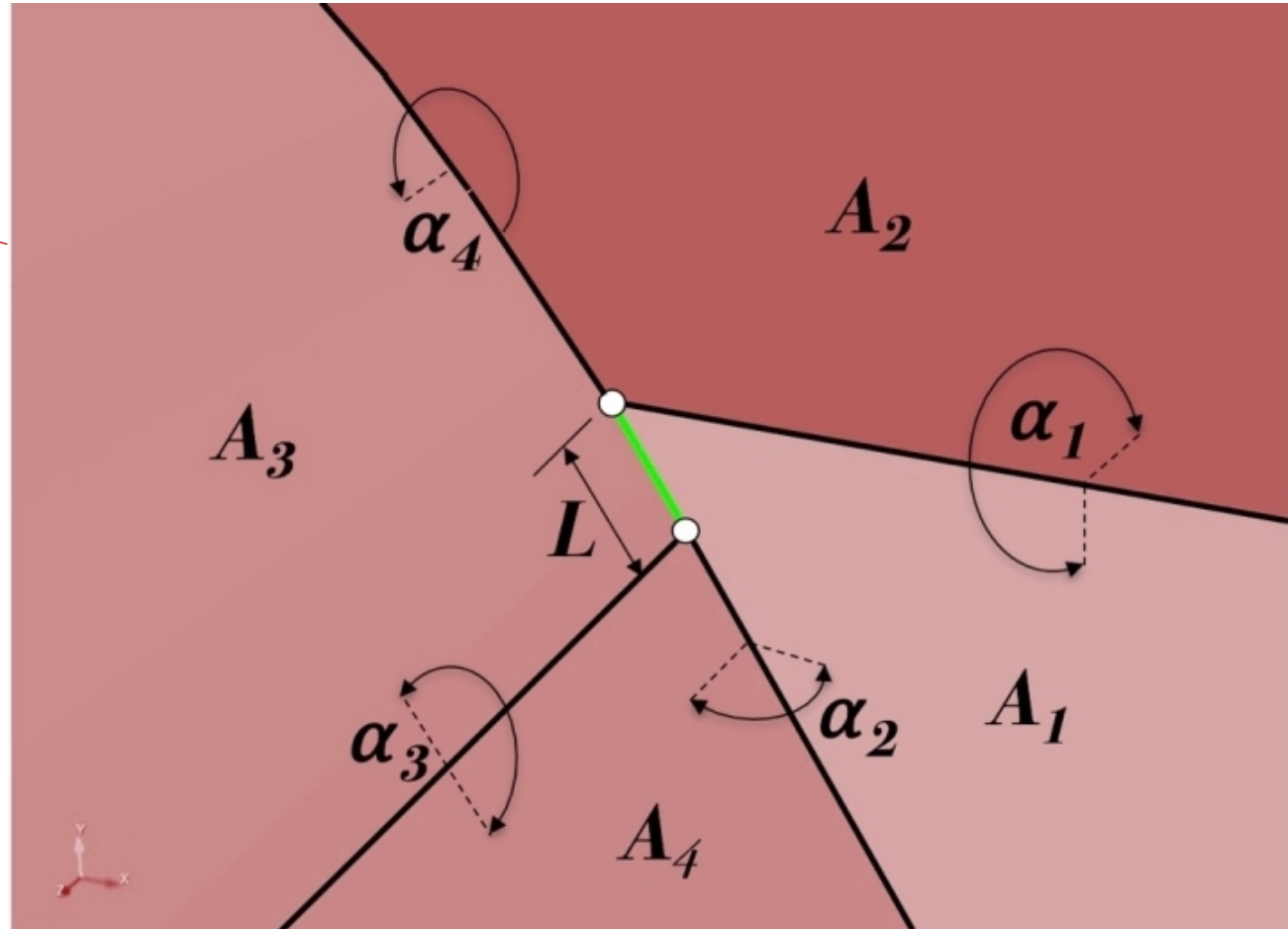
Angle at curves

Valence at vertex

Number of loops

Hydraulic Radius

Etc...



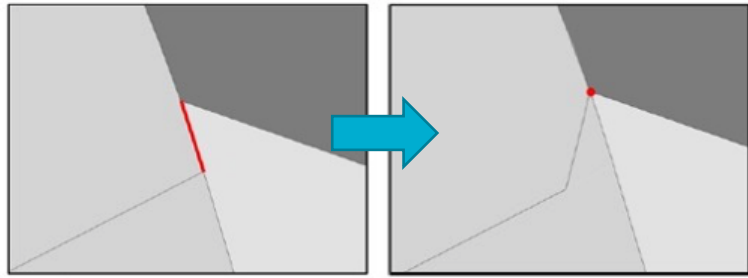
Topology-Based Features

TRAINING DATA LABELS



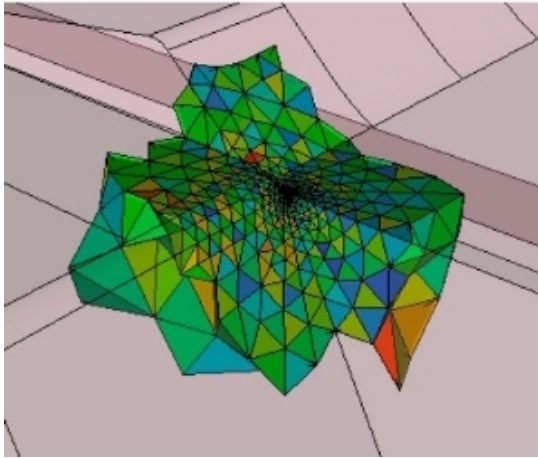
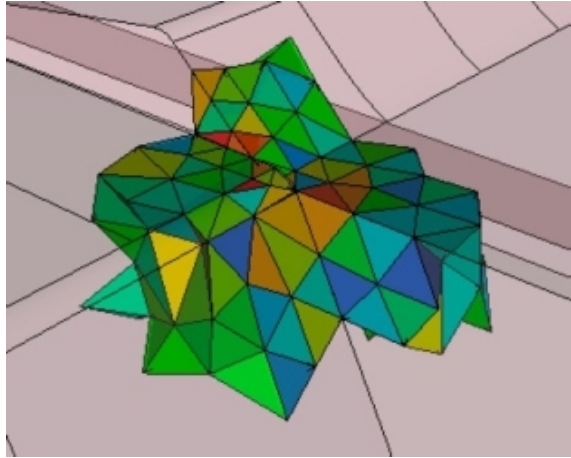
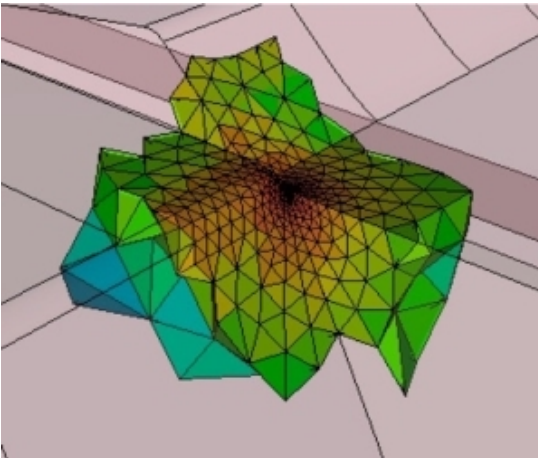
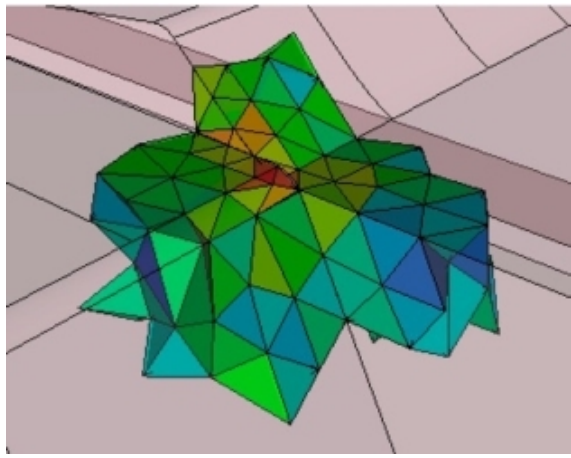
Collapse Curve

Collapse Curve

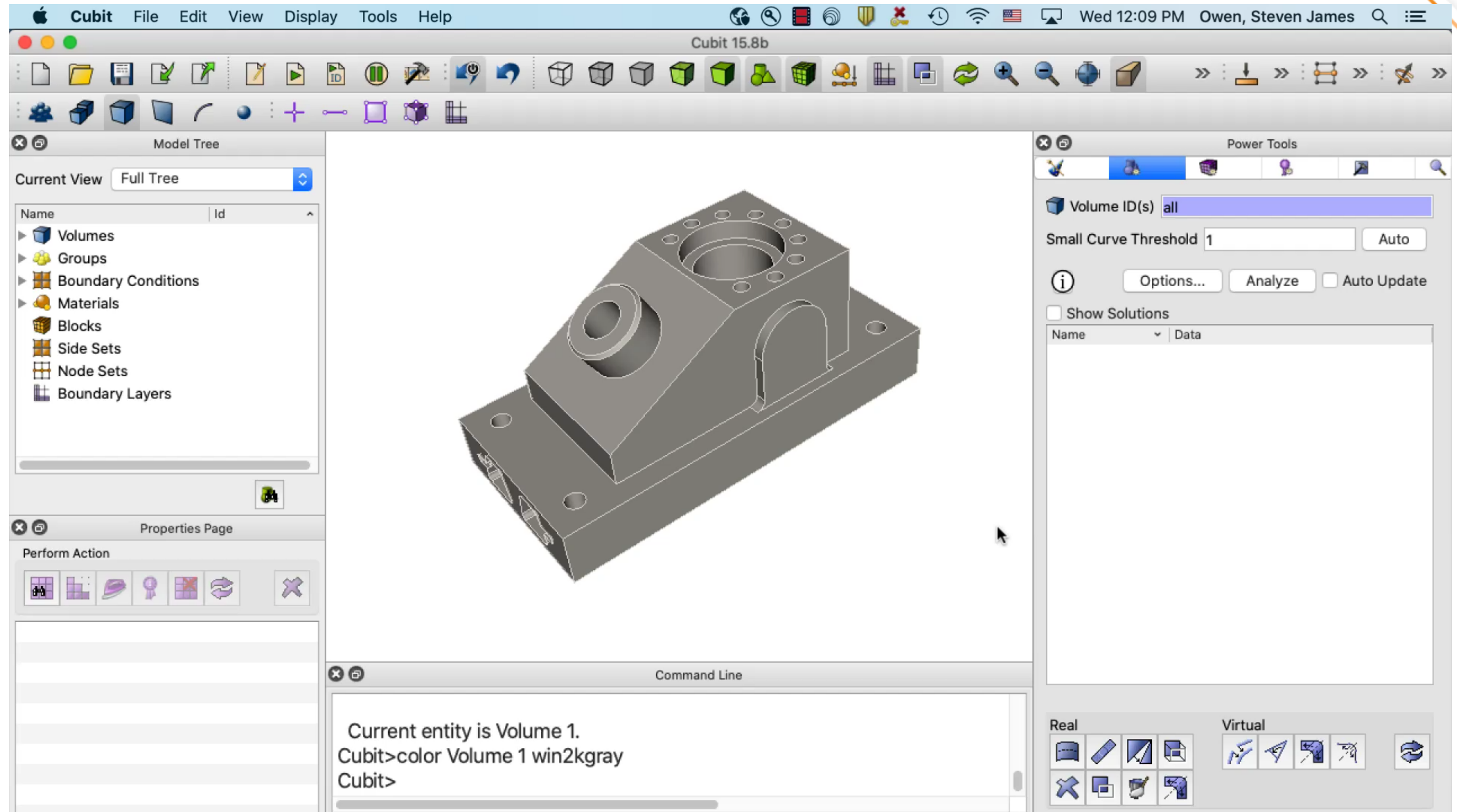


Before

After

	Before	After
Scaled Jacobian	 Min SJ = 0.250	 Min SJ = 0.227
In-radius	 Min IR = 0.027	 Min IR = 0.267

DEFEATURING FOR MESHING EXAMPLE



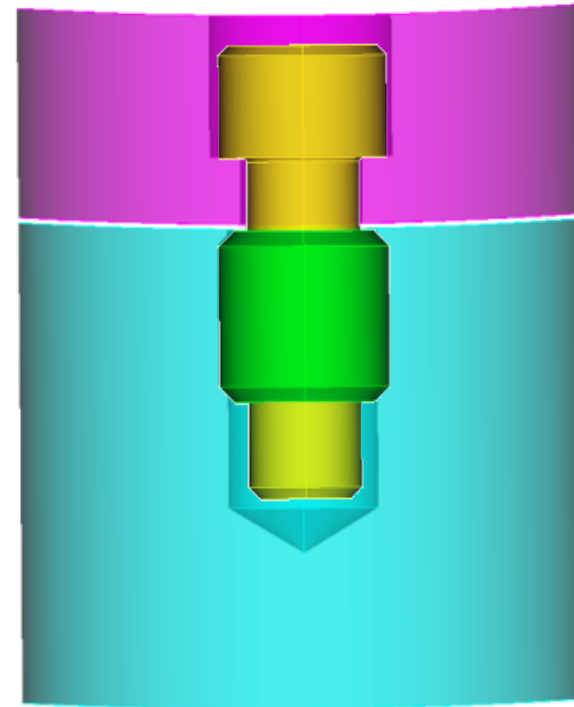
MACHINE LEARNING CLASSIFICATION FOR RAPID CAD-TO-SIMULATION



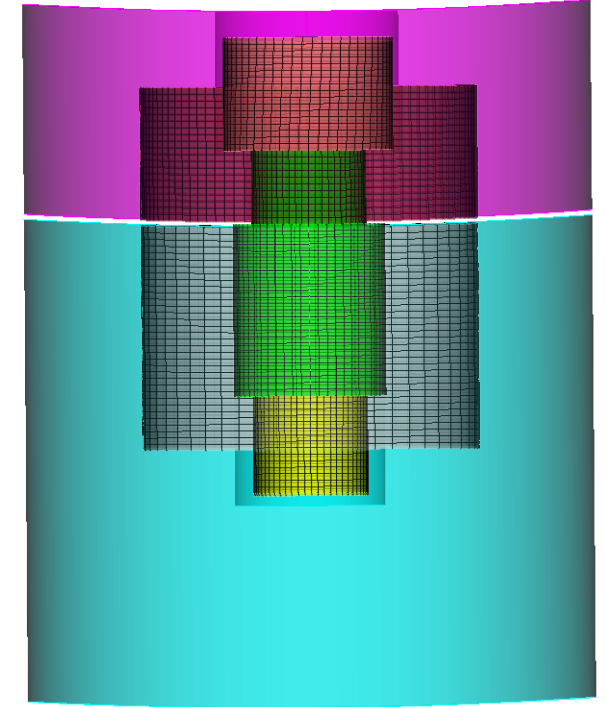
Classify Common Mechanisms



Rapidly Prepare for Analysis

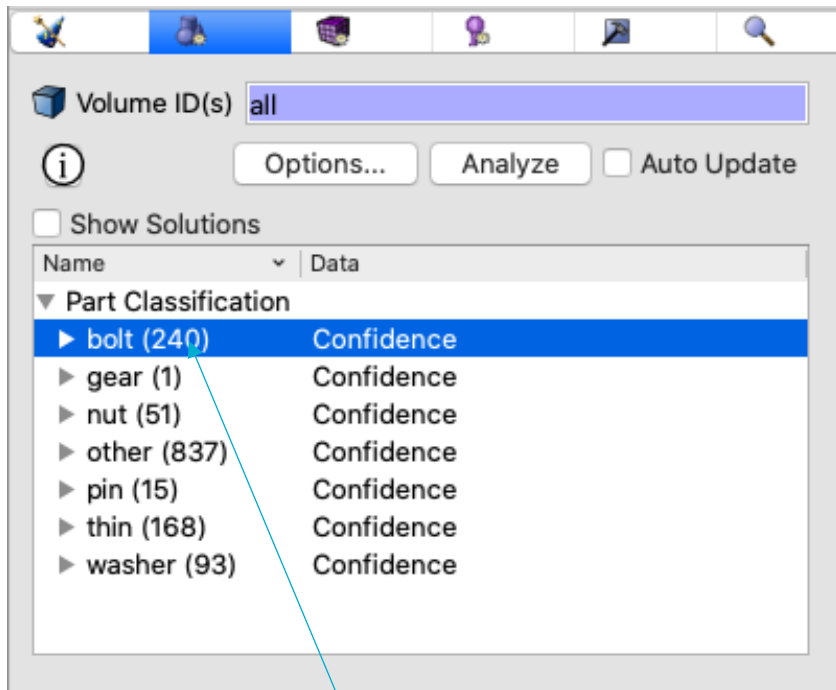


Bolt in CAD assembly before preparation

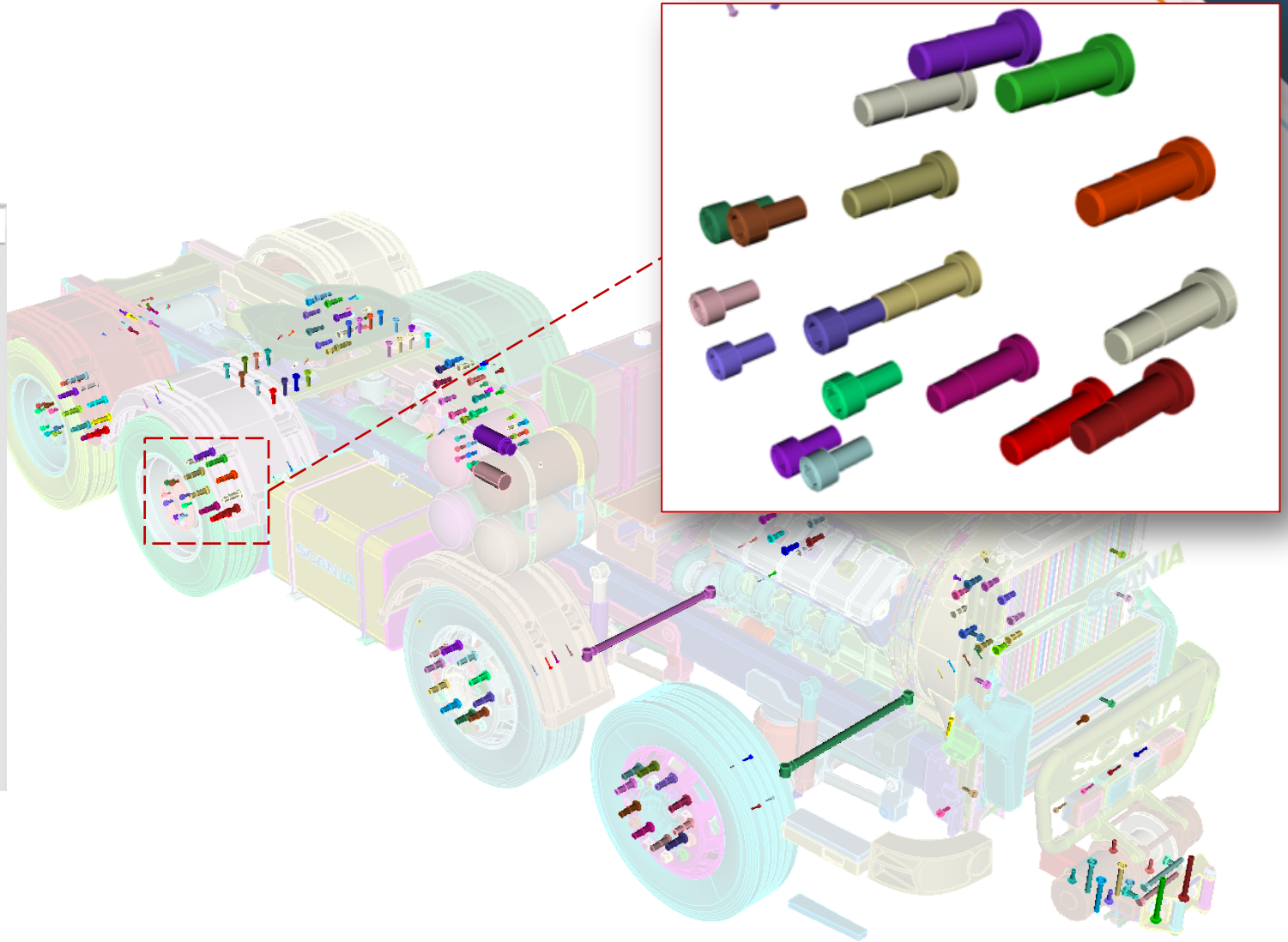


Bolt ready for analysis

MACHINE LEARNING CLASSIFICATION FOR RAPID CAD-TO-SIMULATION



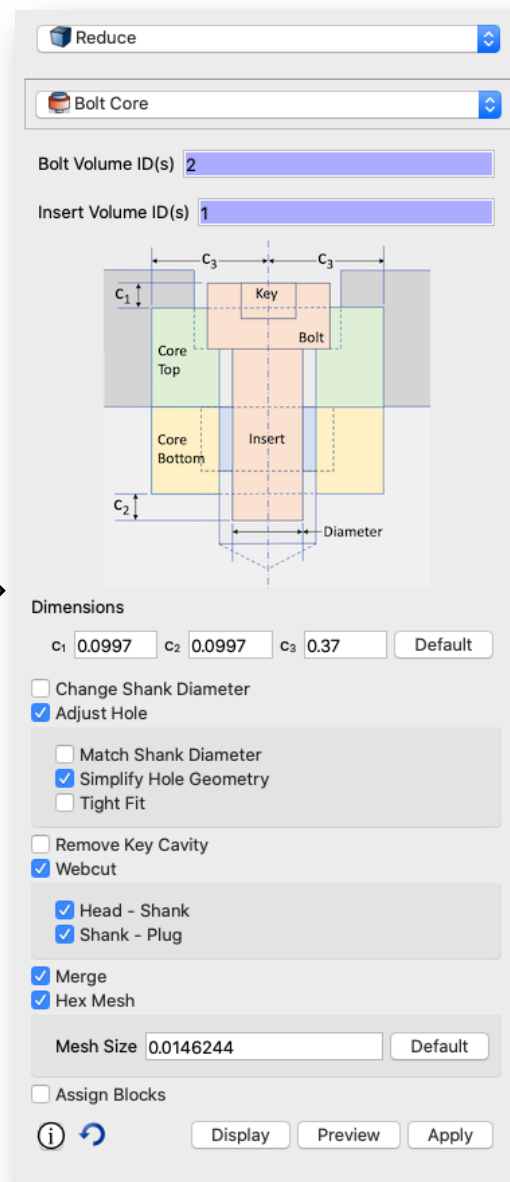
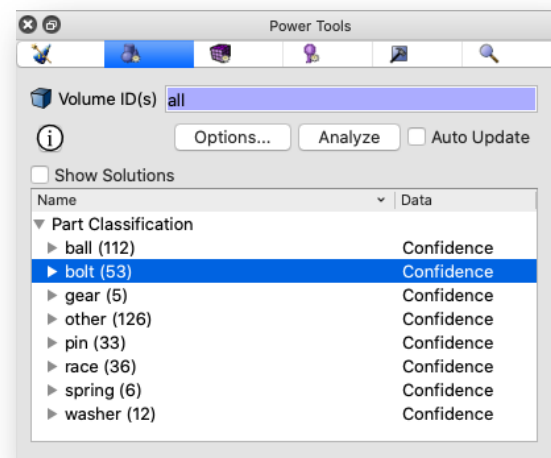
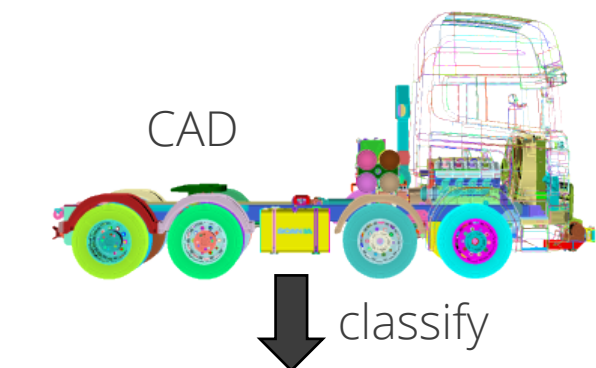
Existing “bolt” category
Classified 240 bolts



3D Solid Model: “Bolt” Volumes Only
(240 Volumes)



REDUCE FOR SIMULATION (FASTENERS)

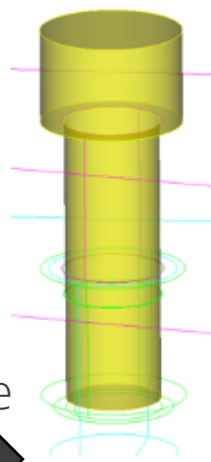


reduce

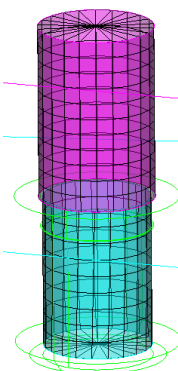


simulation-ready

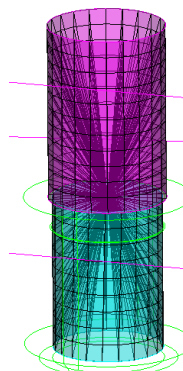
simple reduce



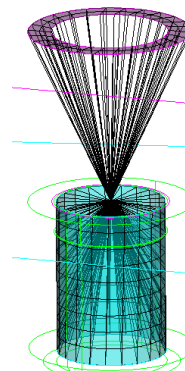
spider wagon wheel



spider j2g



spider countersink



tweak hole diameter to shaft; webcut head, shank, plug

Hex meshed

Include insert and tweak to hole, shaft

core from surrounding volumes



THIN VOLUME REDUCTION WITH REINFORCEMENT LEARNING

Reduce

Thin Volume

Volume ID(s)

☐ Copy Surface ☐ Auto Reduce
☐ Mid Surface ☒ Reinforcement Learning

Reinforcement Learning

☒ Predict ☐ Learn

☐ Initialize Random

Maximum Iterations Stopping Criteria

☒ Journal Result

☐ Delete Solid Volume

Reinforcement Learning Command Panel

```
reduce {volume <ids>} thin RL  
[number iterations <value>] [initialize random [<value>]]  
[stopping criteria <value>] [journal result <string>]  
[delete] [preview]
```

RL Command Syntax

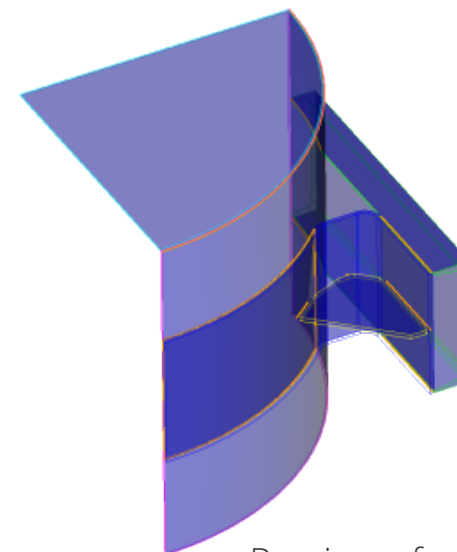
Initial 3D
Solid
Model



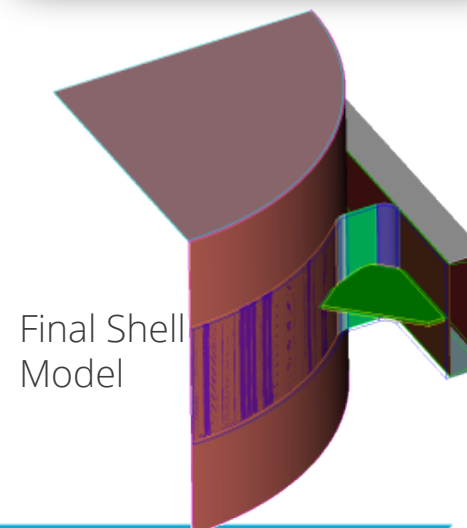
Journal File
of Best RL
iteration

RL_result.jou - Journal Editor

1
2 # Reinforcement Learning for Volumes 1 to 5
3
4
5 # Completed after 1 iterations
6 # Maximum Reward: 1.000 (Iteration 0)
7 # 5 Reduce Thin Actions
8
9
10 # Volume 1 [Reward = 1.000]
11 reduce volume 1 thin copy surface 7 12 13 loft factor 0 0 0 thickness 0
12
13 # Volume 2 [Reward = 1.000]
14 reduce volume 2 thin midsurface surface 15 23 loft factor 0.5 thickness
15
16 # Volume 3 [Reward = 1.000]
17 reduce volume 3 thin copy surface 28 loft factor 0 thickness 0.012
18
19 # Volume 4 [Reward = 1.000]
20 reduce volume 4 thin midsurface surface 31 33 loft factor 0.5 thickness
21
22 # Volume 5 [Reward = 1.000]
23 reduce volume 5 thin copy surface 36 40 41 42 43 loft factor 0 0 0 0
24
25 # 9 Connections
26
27 # [9] Volume 1 to 3 [connected]
28 imprint volume 6 10
29 merge curve in volume 6 with curve in volume 10
30 imprint volume 6 7 10
31 merge curve in volume 6 with curve in volume 7 10
32 imprint volume 6 7 8 10
33 merge curve in volume 6 7 with curve in volume 8 10
34
35 # [10] Volume 1 to 3 [connected]
36
37 # [16] Volume 2 to 5 [connected]
38 imprint volume 12 13 14 15 16
39 merge volume 12 13 14 15 16
40 tweak curve 129 target surface 57
41 imprint volume 14 with curve 129
42 merge volume 14 9
43
44 # [10] Volume 2 to 5 [connected]

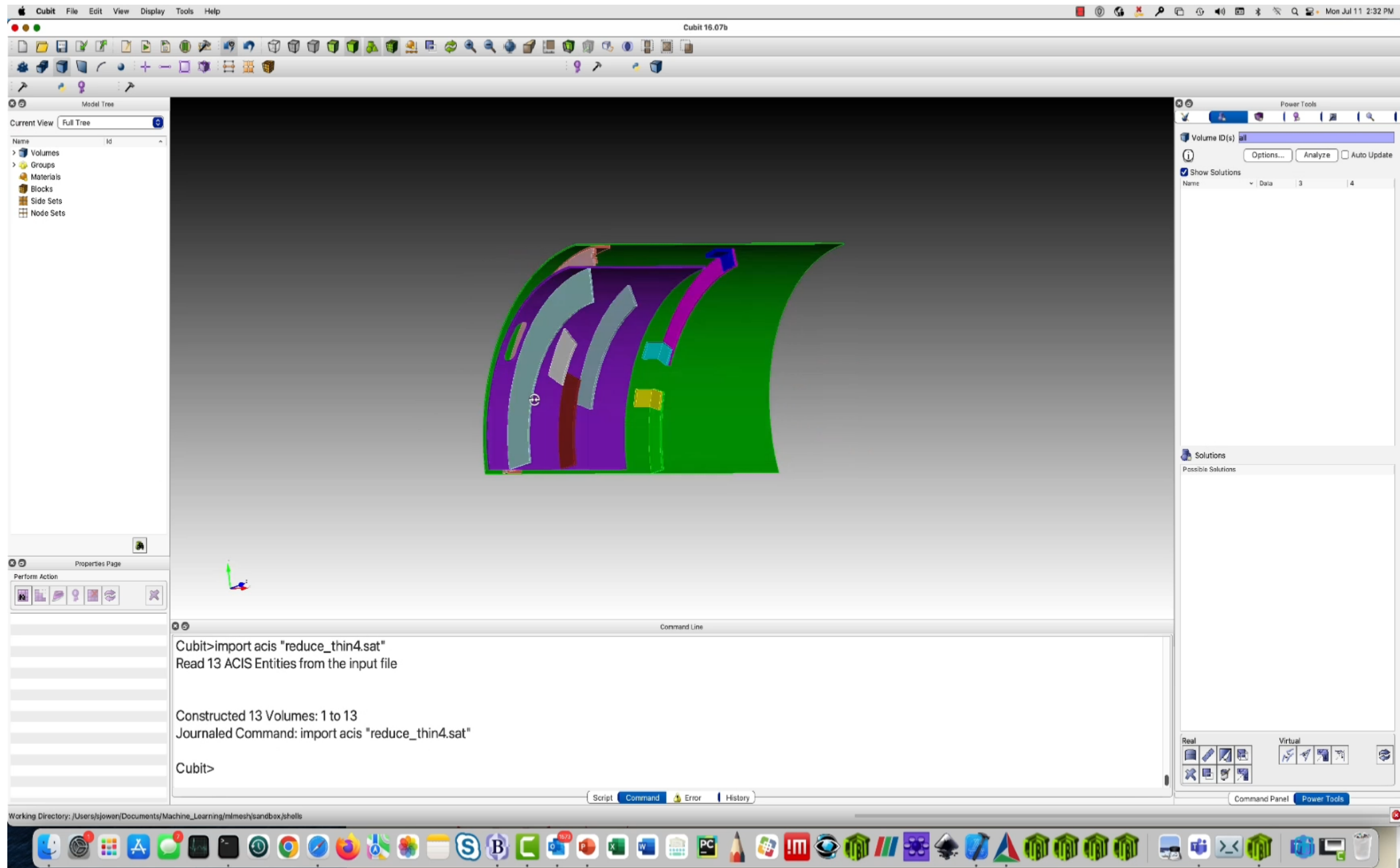


Preview of
Reduction



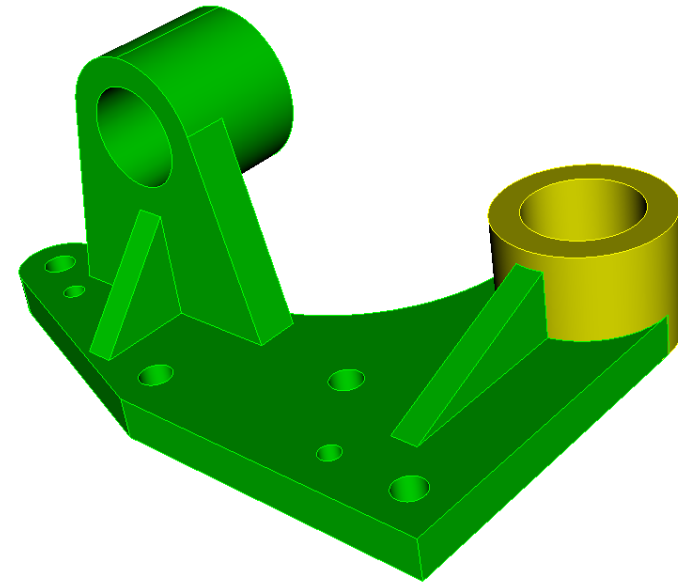
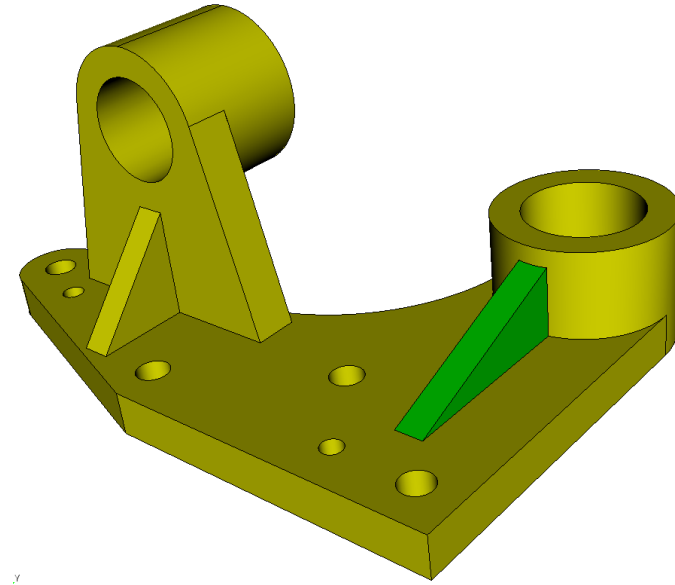
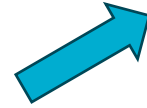
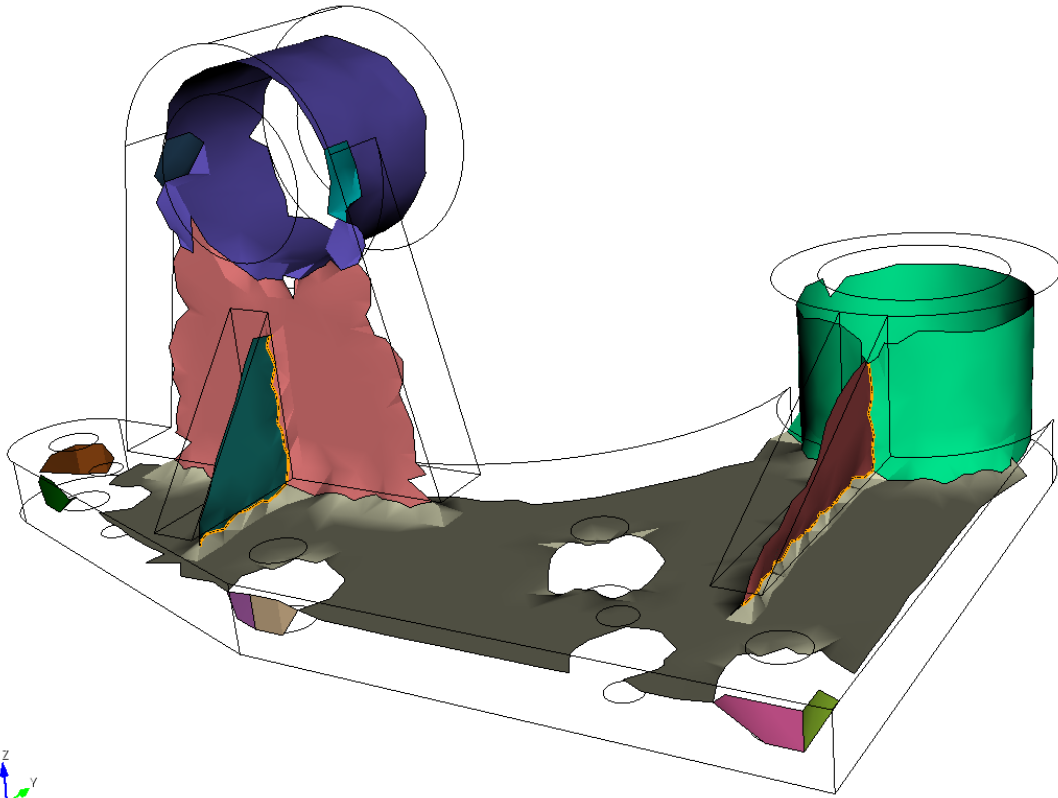
Final Shell
Model

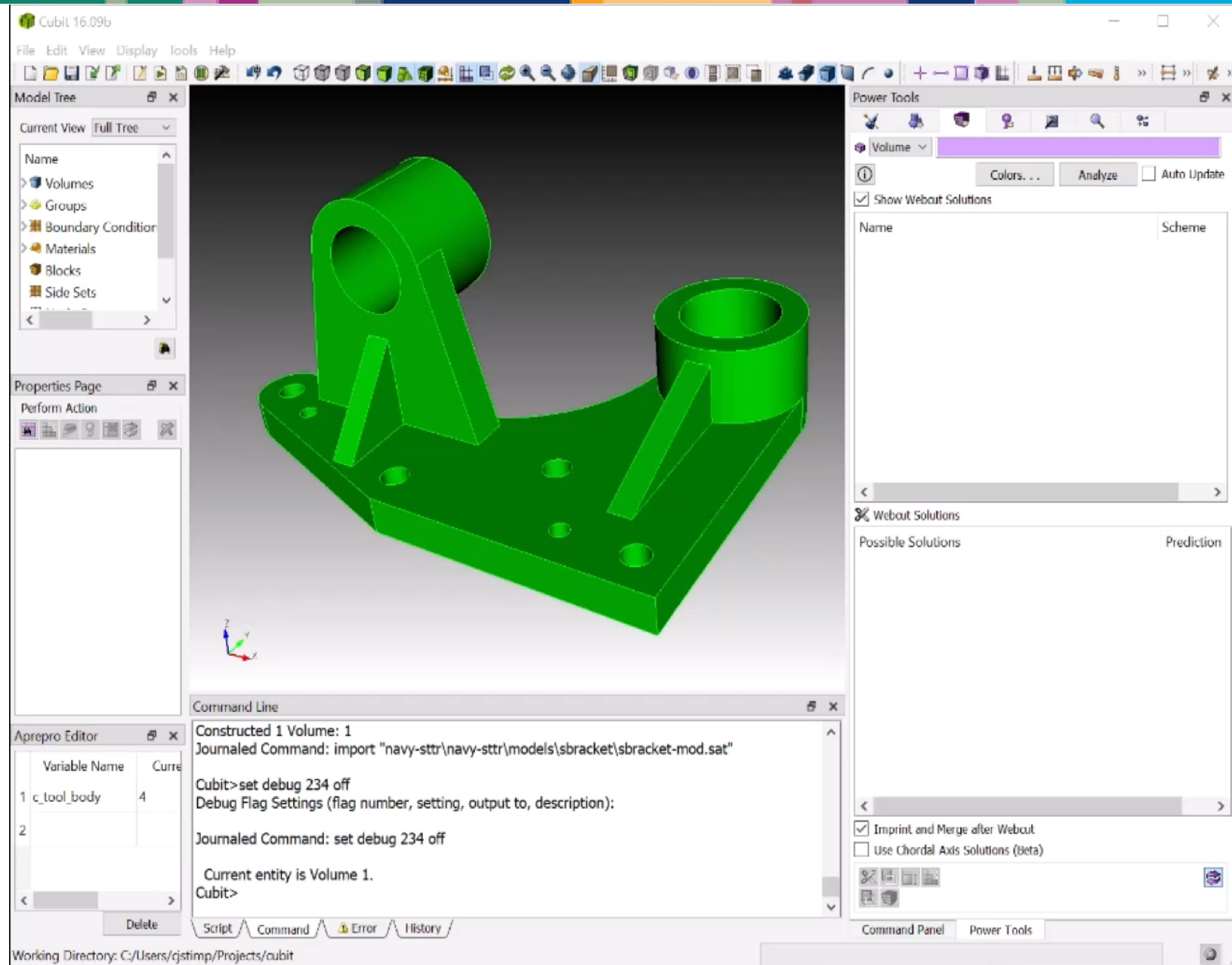
THIN VOLUME REDUCTION WITH REINFORCEMENT LEARNING



Chordal Axis Extraction

(mid-surfaces created from tetmesh)







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