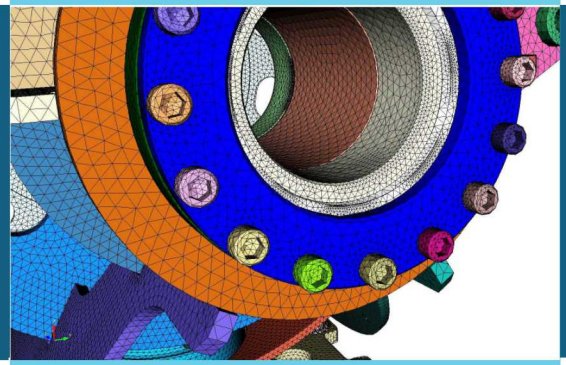
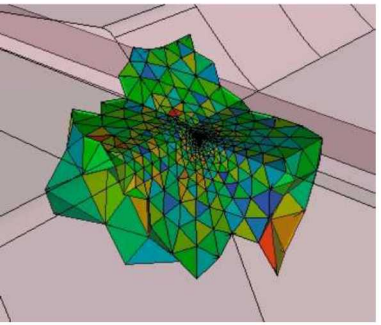
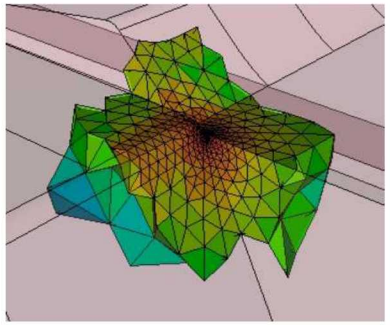
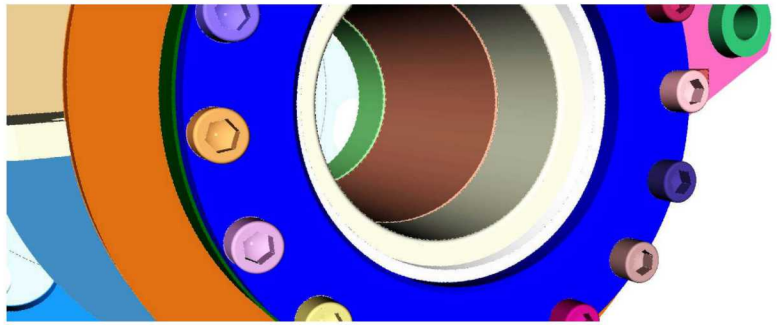
SAND2019-7240C

CAD Defeaturing with Machine Learning









PRESENTED BY

Steve Owen

Tim Shead, Shawn Martin

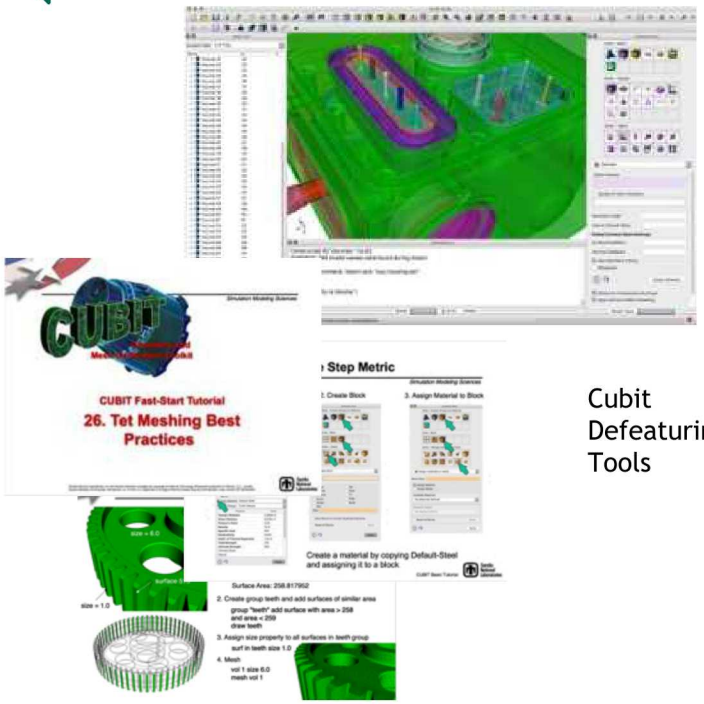
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Geometry Preparation for Tet Meshing

Manual
High User Control
High Expertise
Tedious

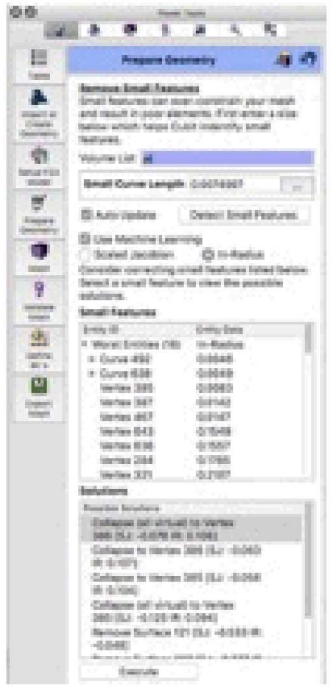
User Guided
Smart Solutions
Learn from
previous models

Fully Automatic
Loss of User Control
Low Expertise Needed
Fast



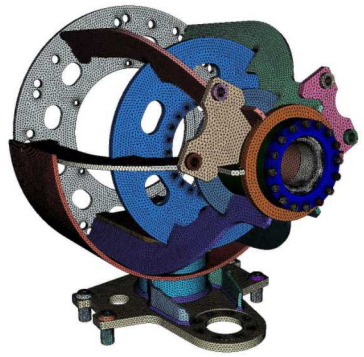
Tutorials and Workflows

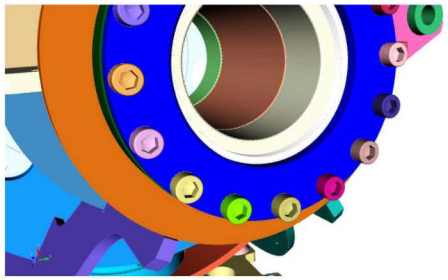
Cubit
Defeaturing
Tools

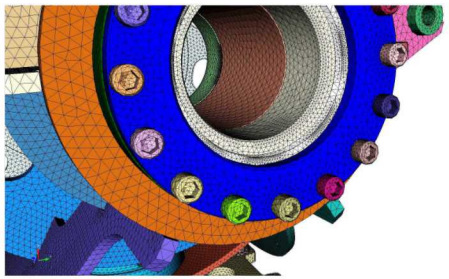


Machine Learning GUI
Environment

Mesh

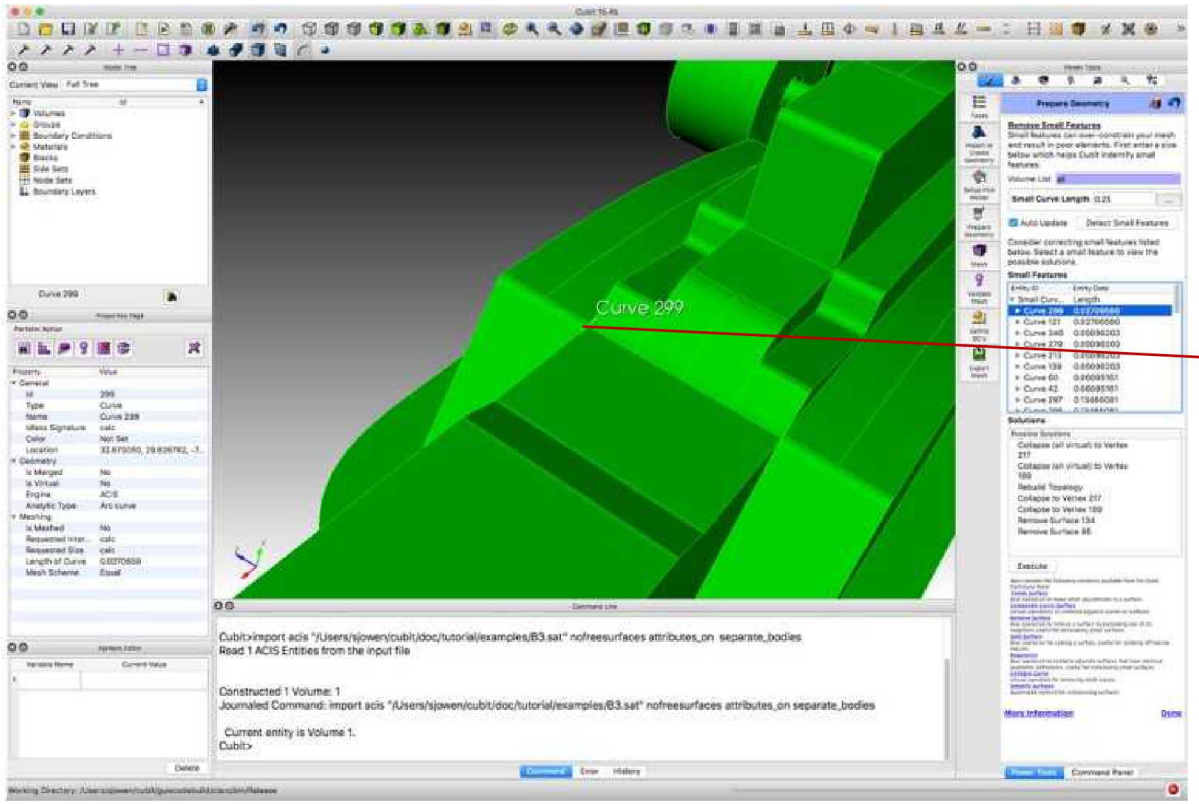


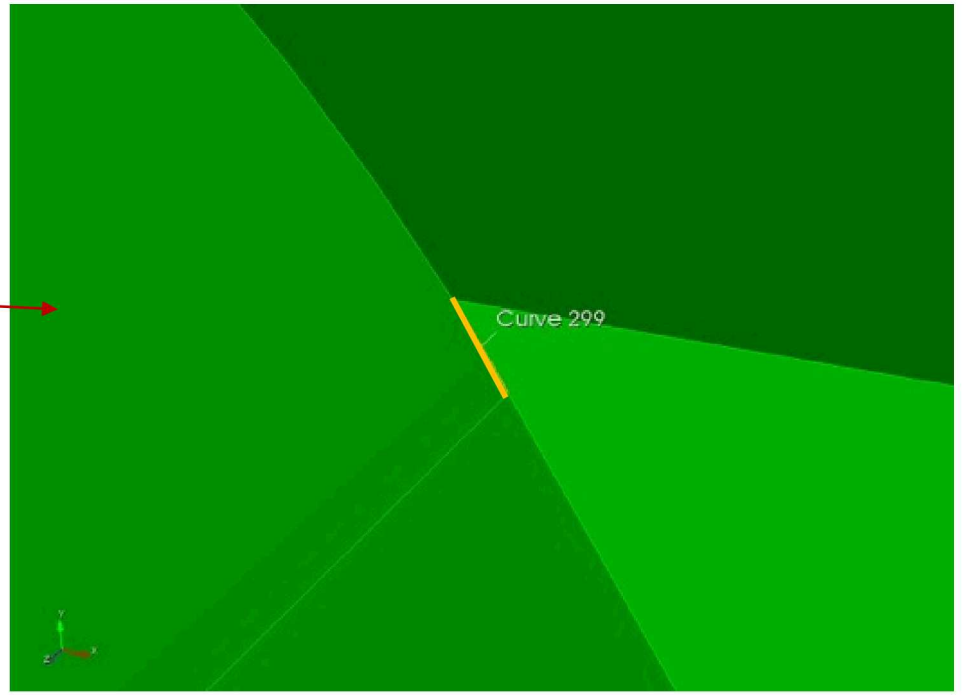




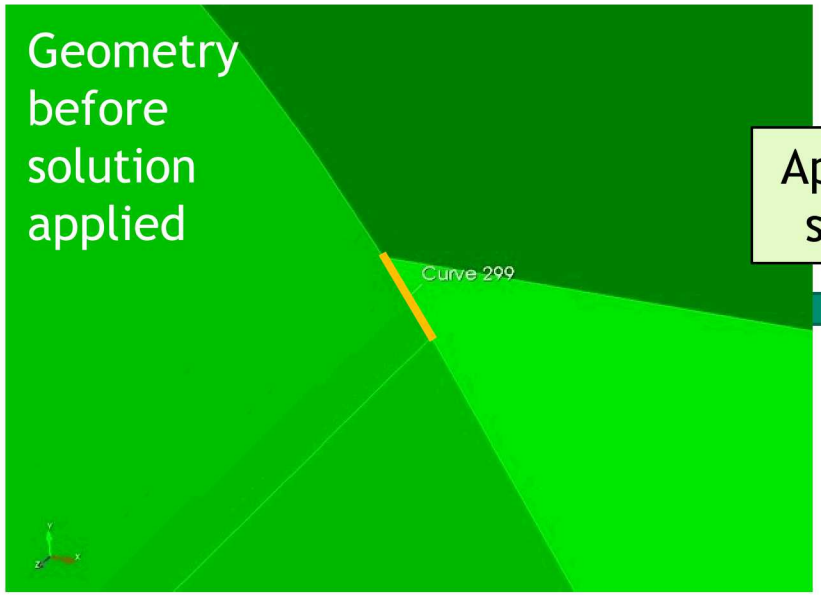
Cubit – Massive Compiste
Meshgems Mesher

Defeaturing

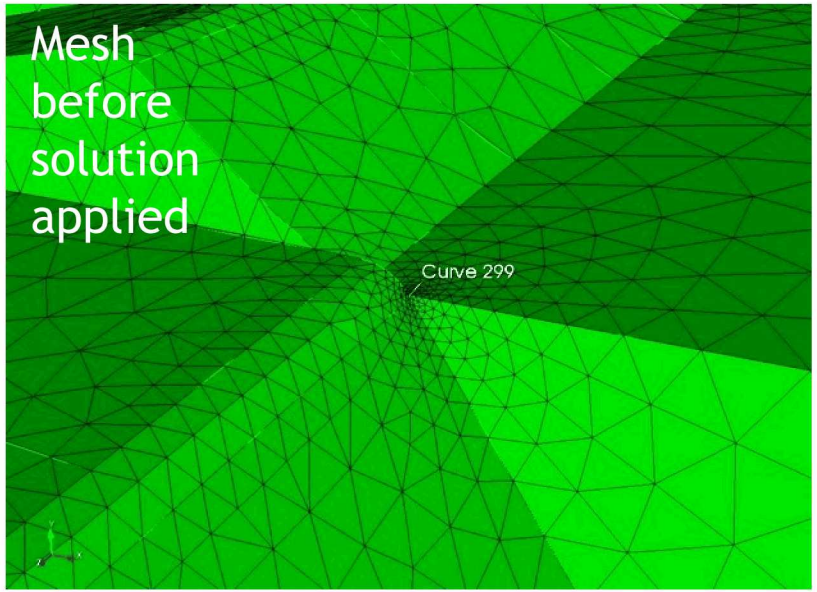




Defeaturing



Apply solution to selected curve



Objective: Guide the User

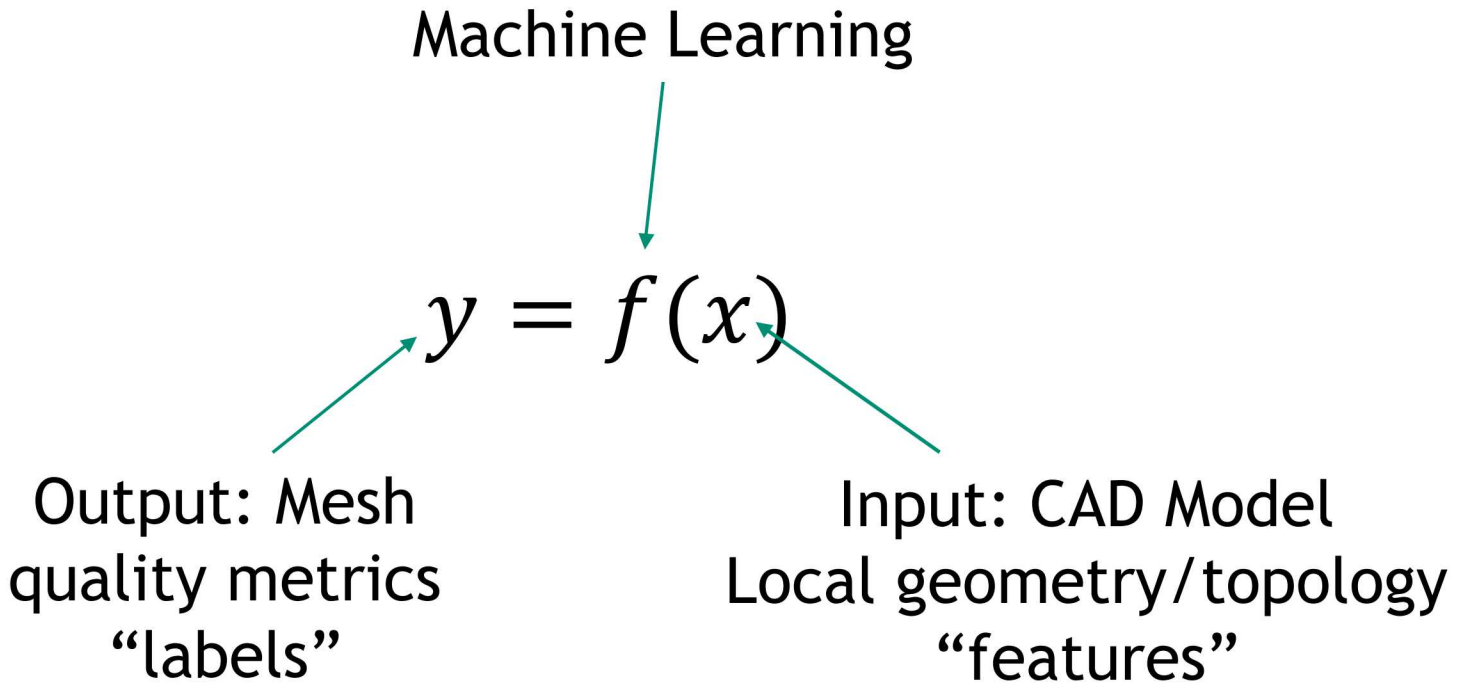
① Find the most problematic features in the CAD Model

- For a given local topology
  - Small Curve
  - Small Surface
  - Sharp Angle at Vertex
- Predict local mesh quality
  - Scaled Jacobian
  - In-Radius
  - Deviation

② Find solution that yields best mesh quality

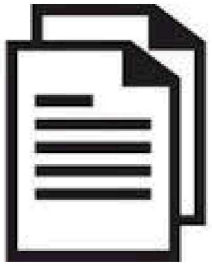
- For a given local geometry operation
  - Collapse Curve
  - Remove Surface
  - Blunt Tangency
  - Etc..
- Predict local mesh quality after operation
  - Scaled Jacobian
  - In-Radius
  - Deviation

Machine Learning



Machine Learning

x, y → f → $y = f(x)$



Training Data
.csv file

- Characterize *problems*
  - Features
  - Labels
- Python Script + Cubit
- Train many CAD models
- Diverse problems
- One row in .csv per *problem*
- Non-runtime

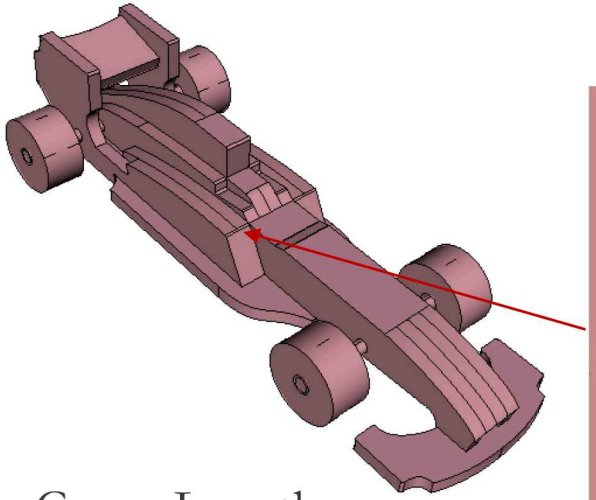
Machine Learning Methods

- scikit-learn
- Python open source
- Machine Learning libraries
- Many options and algorithms

Machine Learning Models

- Make predictions
- Small Binary
- Used Run-time in C++ Code
- Access via C-Python interface

Training Data Features



Curve Length

Surface Area

Angle at vertex

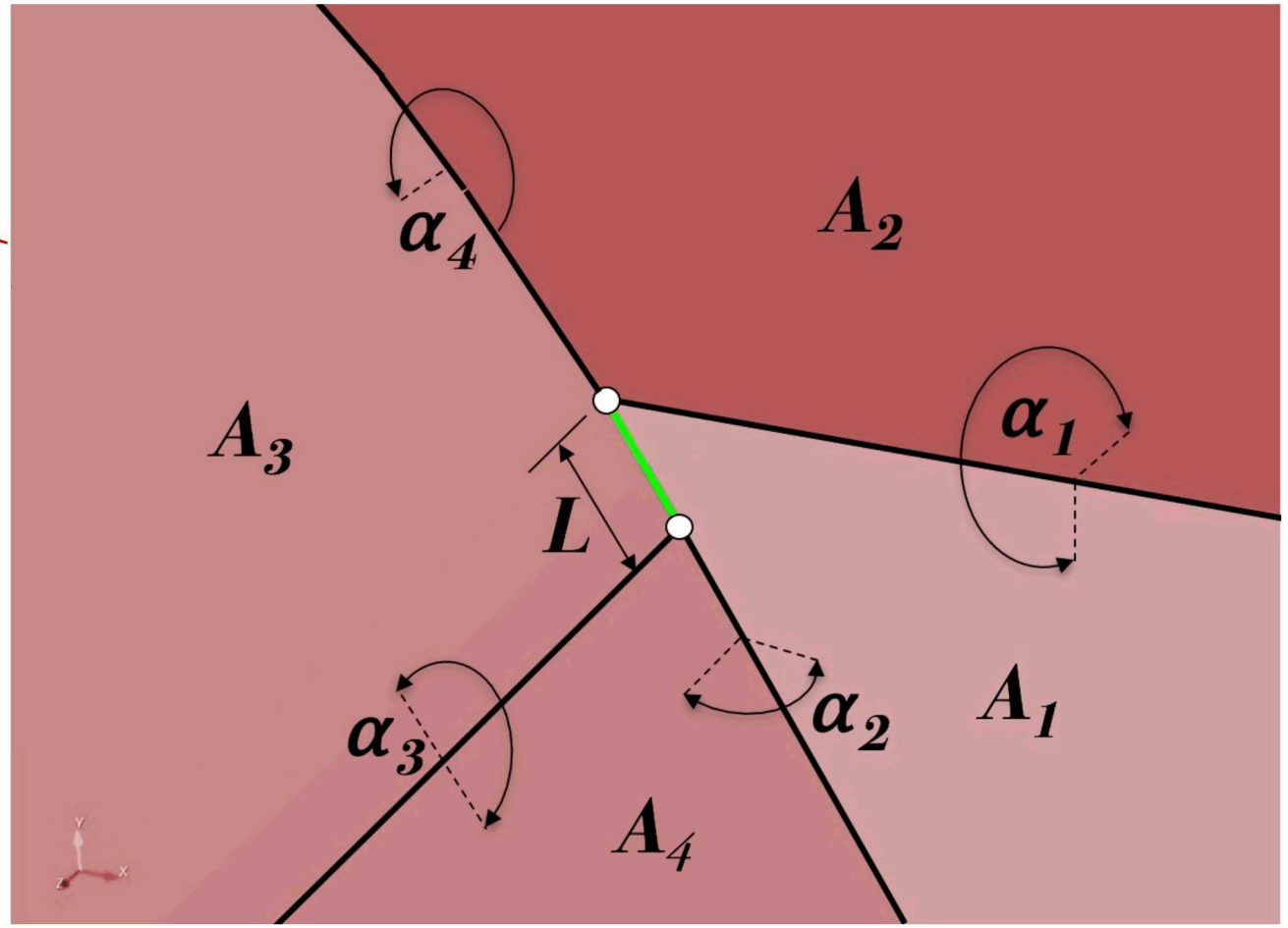
Angle at curves

Valence at vertex

Number of loops

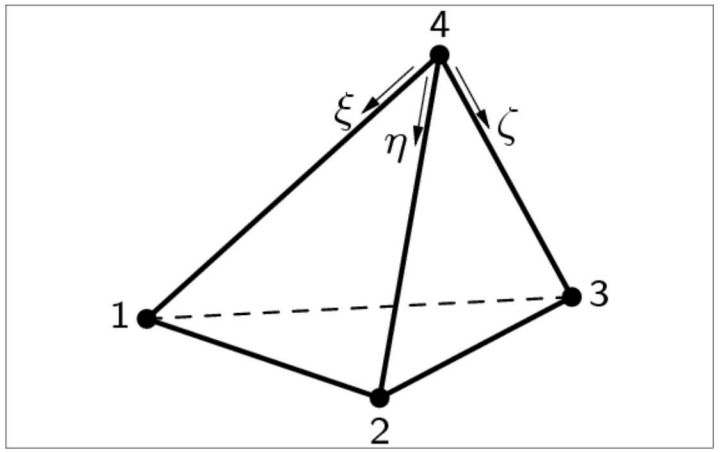
Hydraulic Radius

Etc…



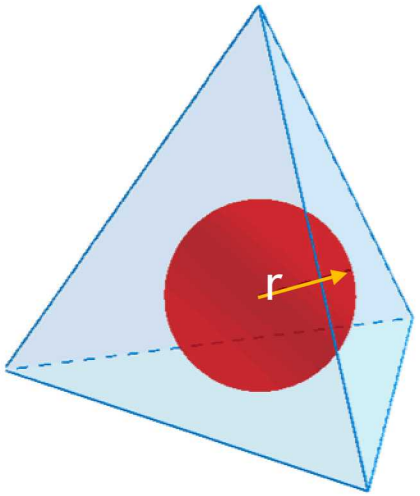
Topology-Based Features

Training Data Labels



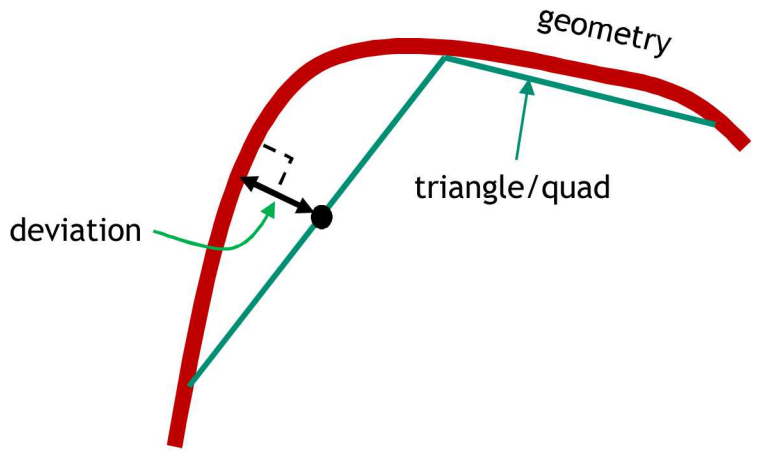
Scaled Jacobian

- Function of angles at vertices
- Scaled -1.0 to 1.0
- Independent of mesh size



In-Radius Ratio

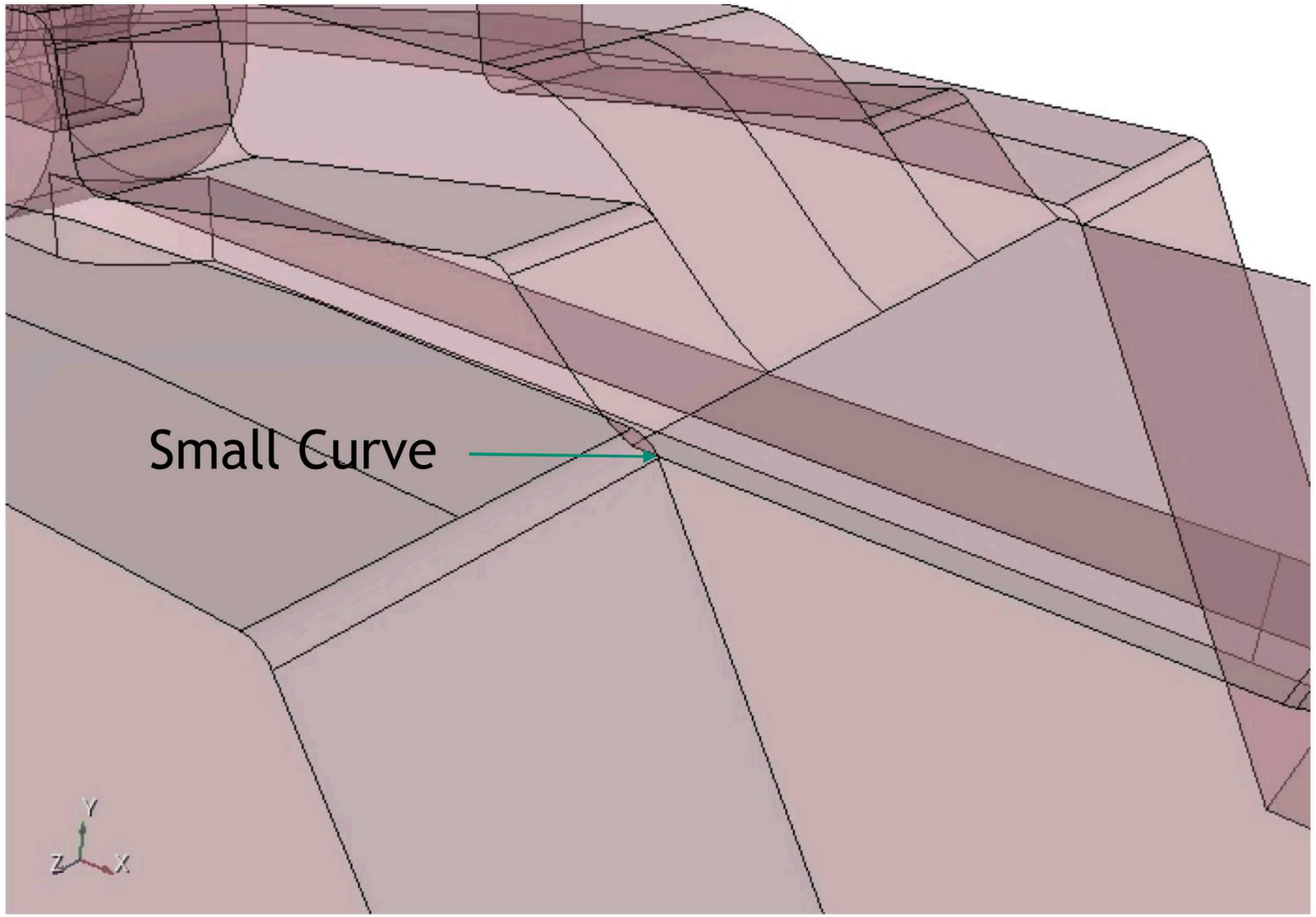
- Ratio with equilateral tet with target edge length
- Scaled 0.0 to 1.0
- Sensitive to mesh size



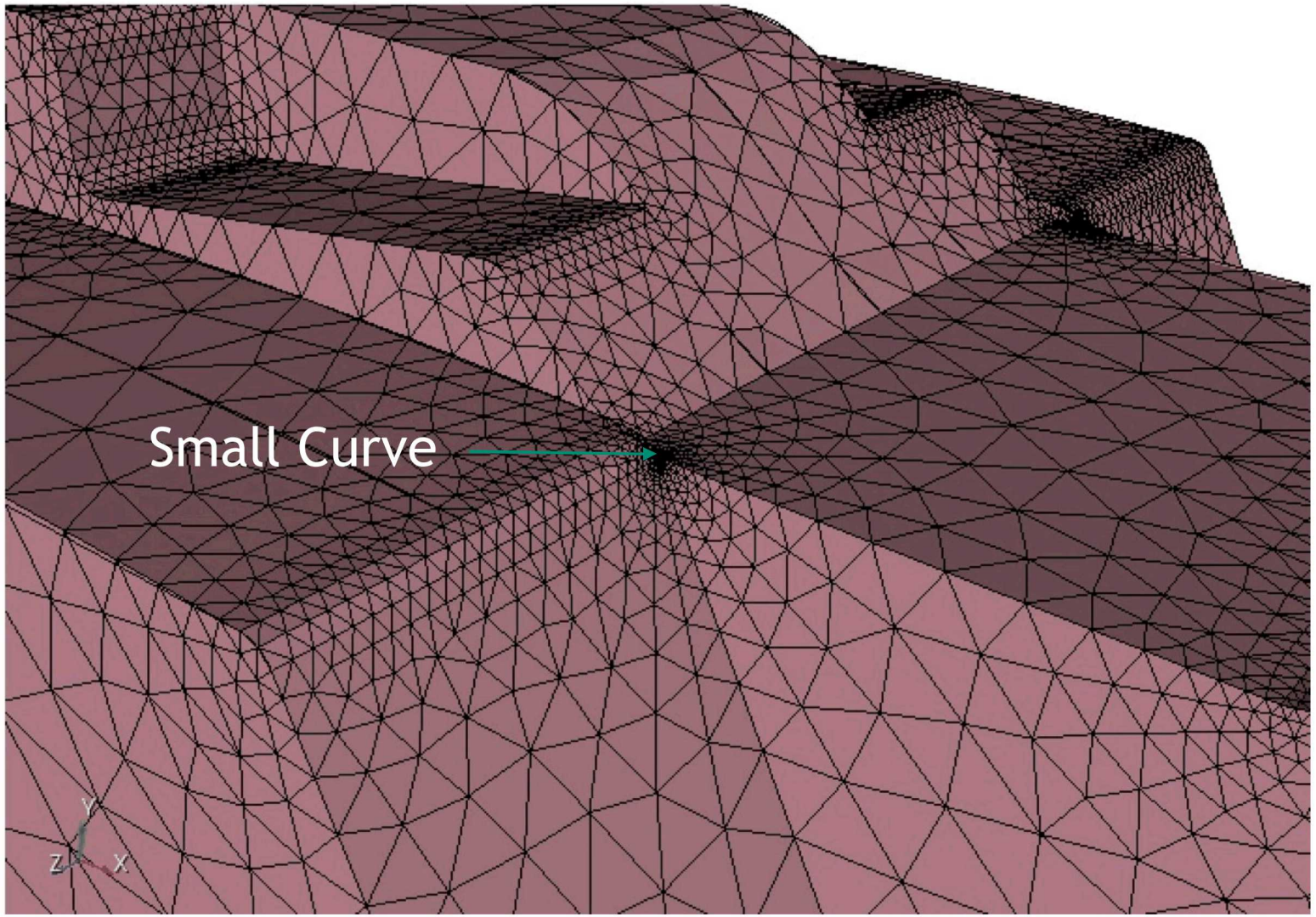
Deviation

- Distance from triangle centroid to closest point on geometry
- Scaled by target mesh size
- Ensure mesh "matches" geometry

Training Data Labels

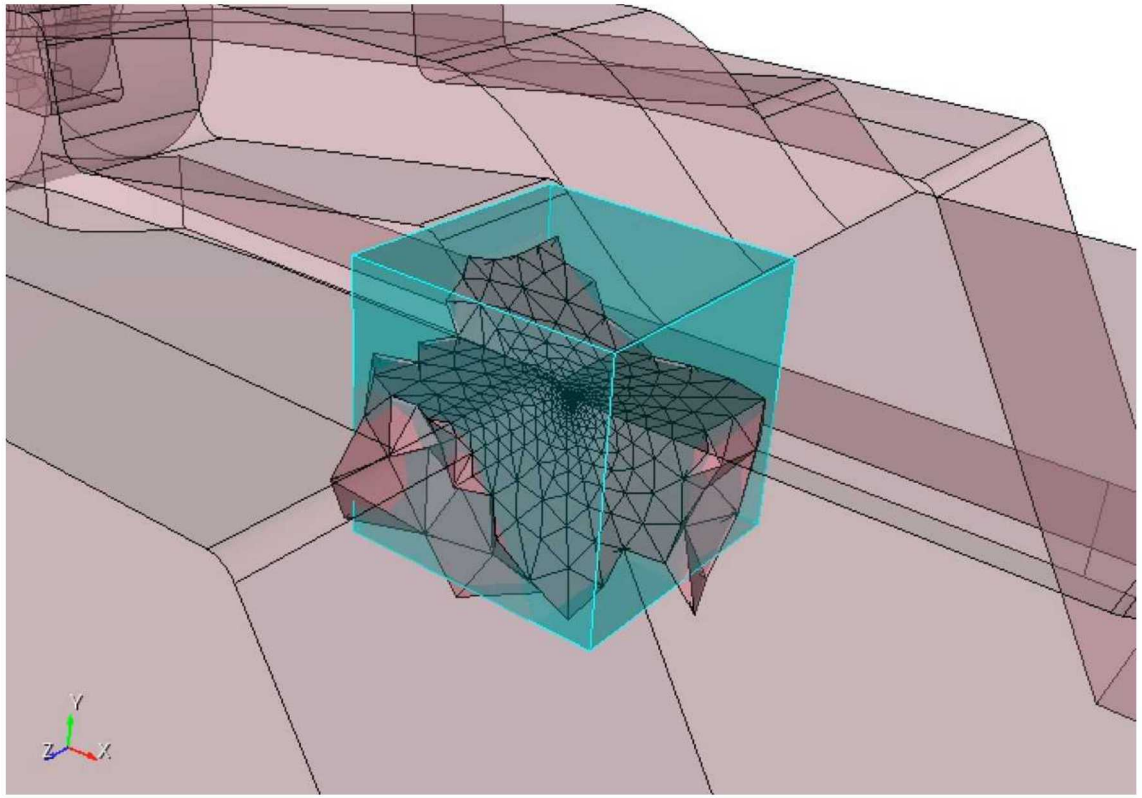


Training Data Labels

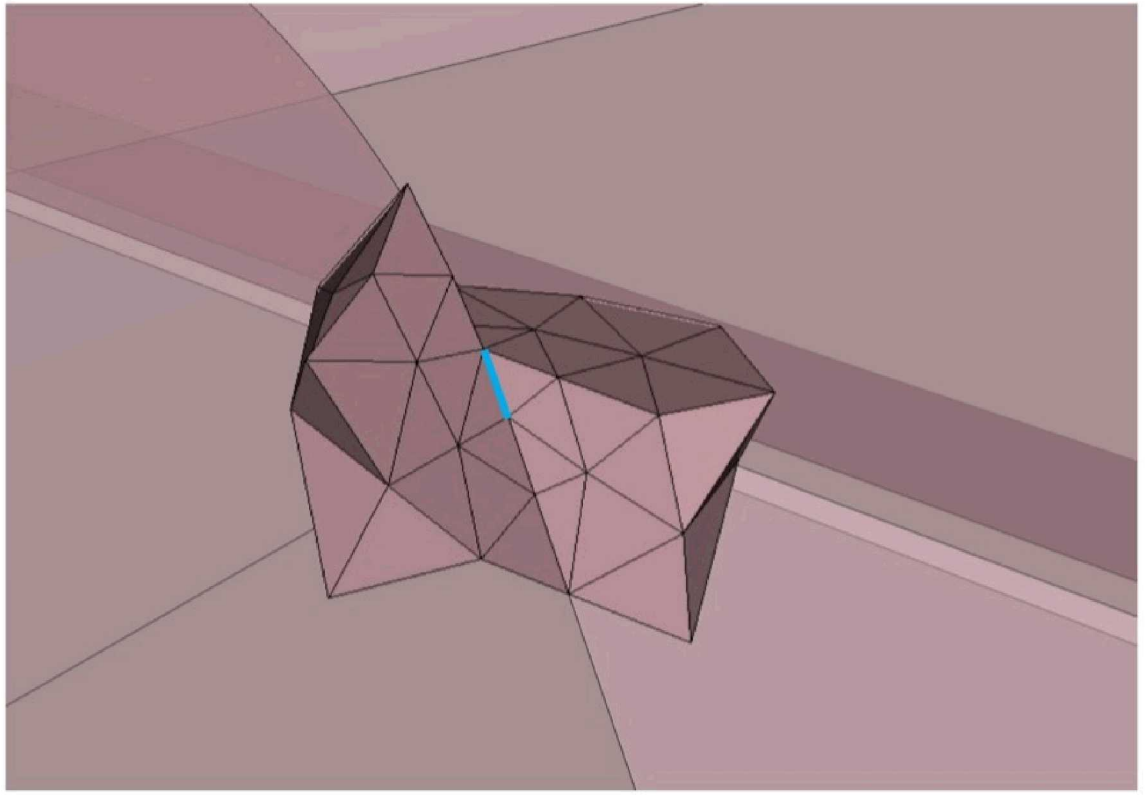


Training Data Labels

Local Tets at Geometric Curve



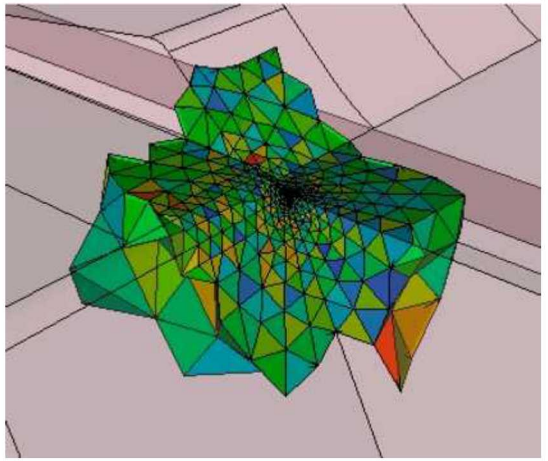
Bounding Box



Topology

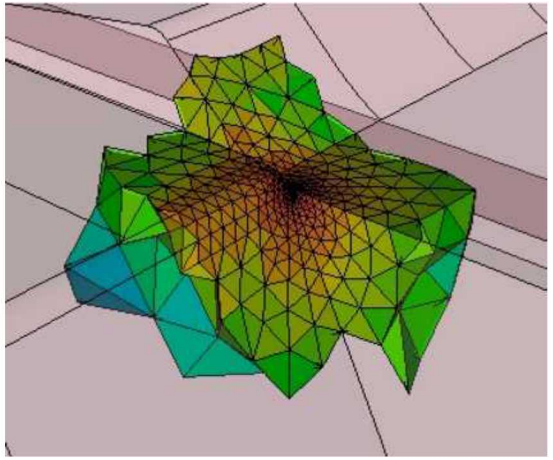
Training Data Labels

Before Curve Collapse Operation



Min SJ = 0.250

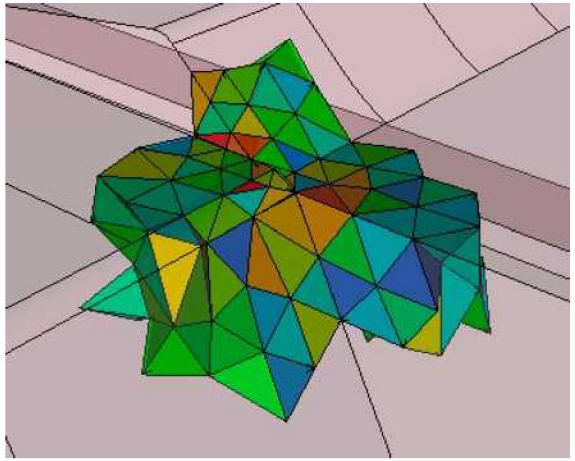
Scaled Jacobian



Min IR = 0.027

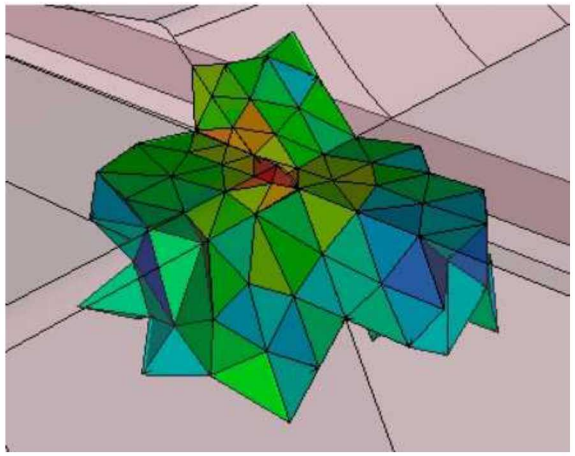
In-radius

After Curve Collapse Operation



Min SJ = 0.227

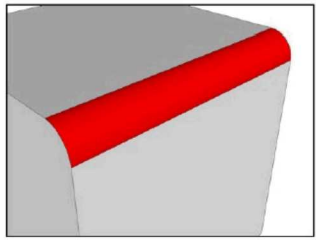
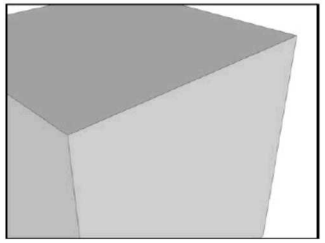
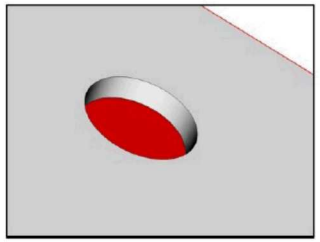
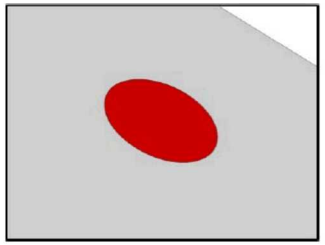
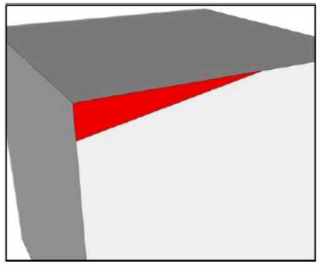
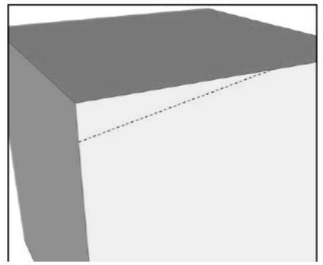
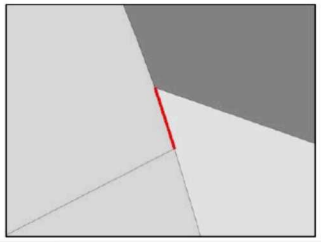
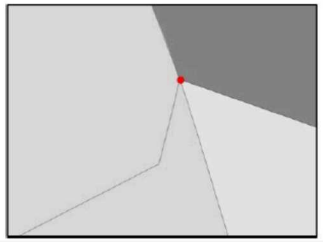
Scaled Jacobian

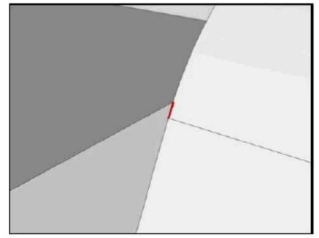
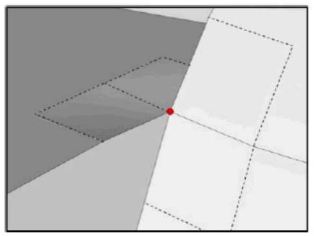
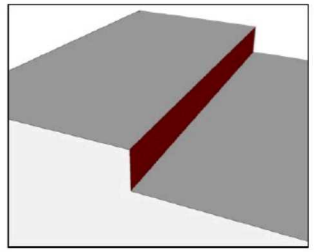
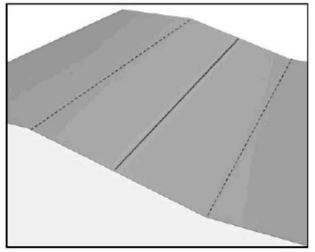
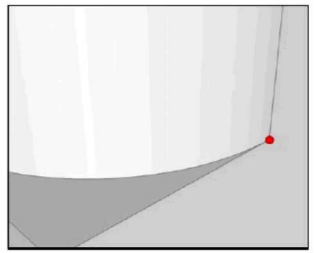
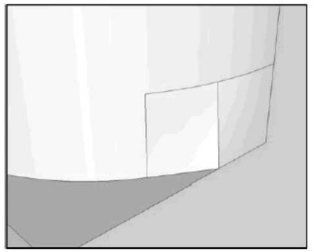
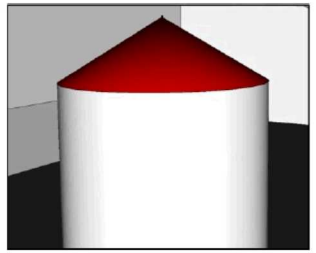
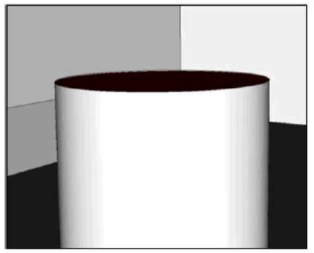


Min IR = 0.267

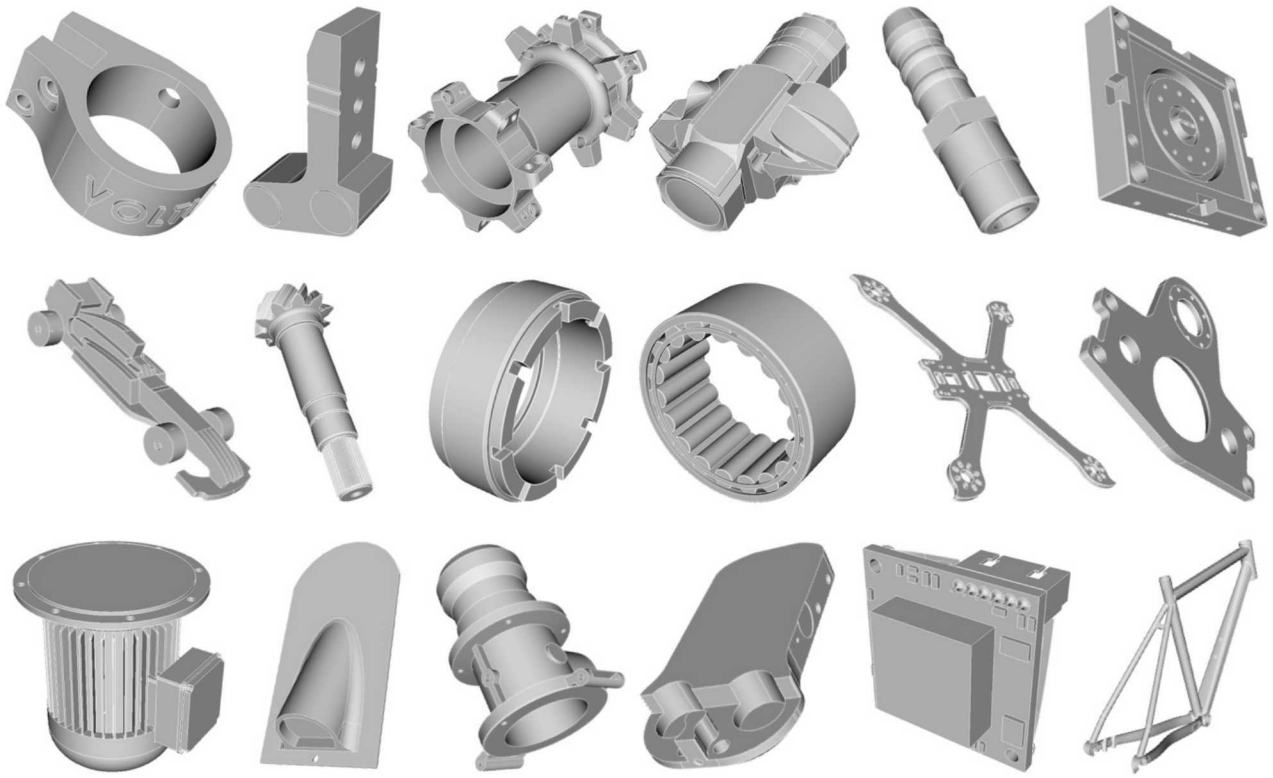
In-radius

Operations Trained

	begin state	end state
remove surface		
tweak replace surface		
composite surfaces		
collapse curve		

	begin state	end state
tweak remove topology curve		
tweak remove topology surface		
blunt tangency		
remove cone		

Machine Learning Study

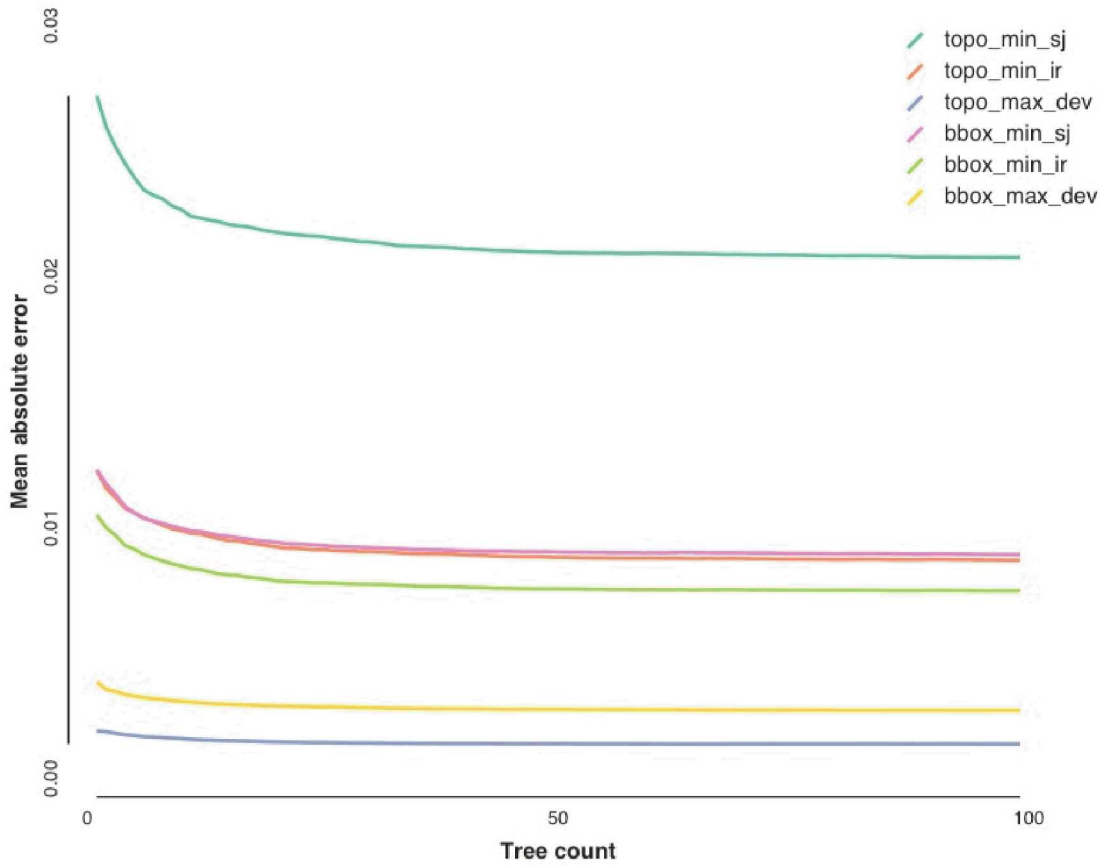


94 single-part
CAD models

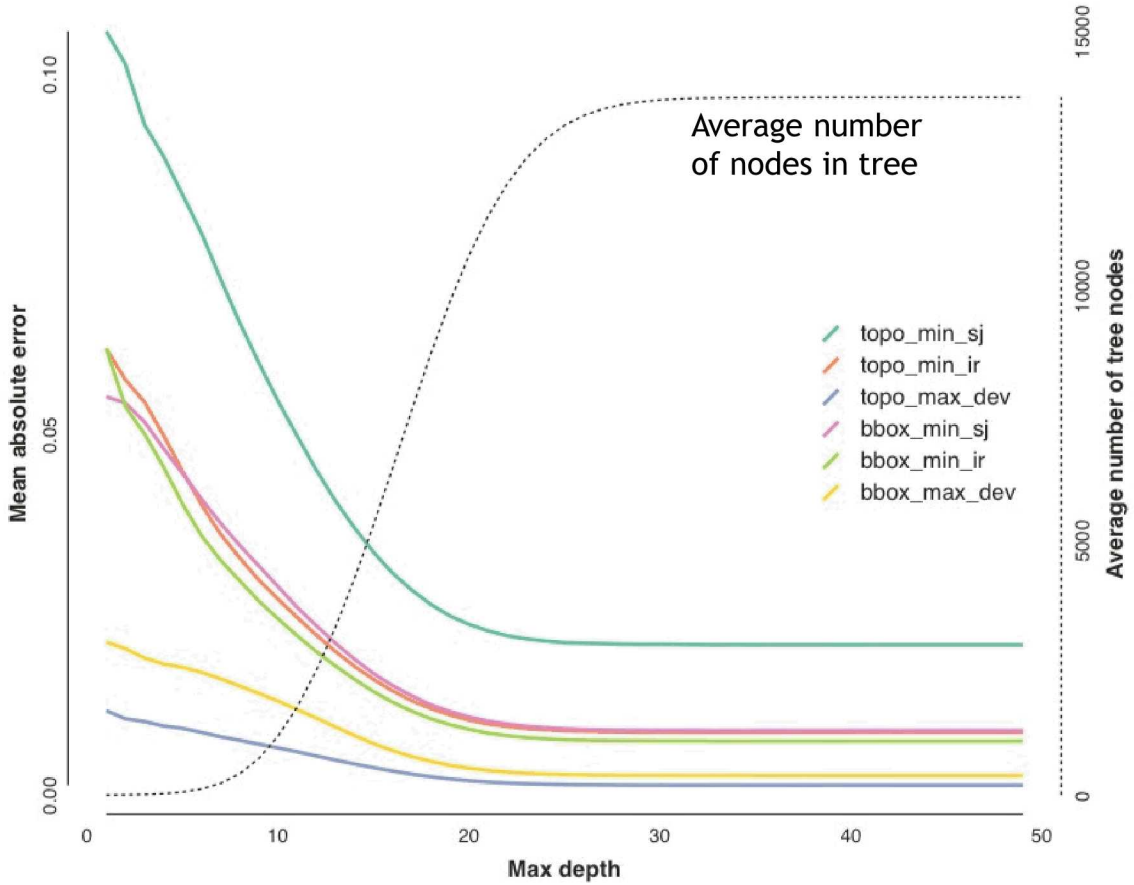
	Num Obs.	Num Failed	Num Trained
vertex_no_op	1348	0	1348
curve_no_op	9842	0	9892
surface_no_op	5842	0	5842
remove_surface	17,624	10,026	7598
tweak_replace_surface	2569	1152	1417
composite_surfaces	43,551	5020	38,531
collapse_curve	13,830	2113	11,717
virtual_collapse_curve	14,955	14,743	212
remove_topology_curve	7056	5175	1881
remove_topology_surface	3890	3102	788
blunt_tangency	8059	3982	4077
remove_cone	232	20	212
Totals	**128,484**	**45,333**	**83,515**

Machine Learning

Ensemble of Decision Trees (EDT)

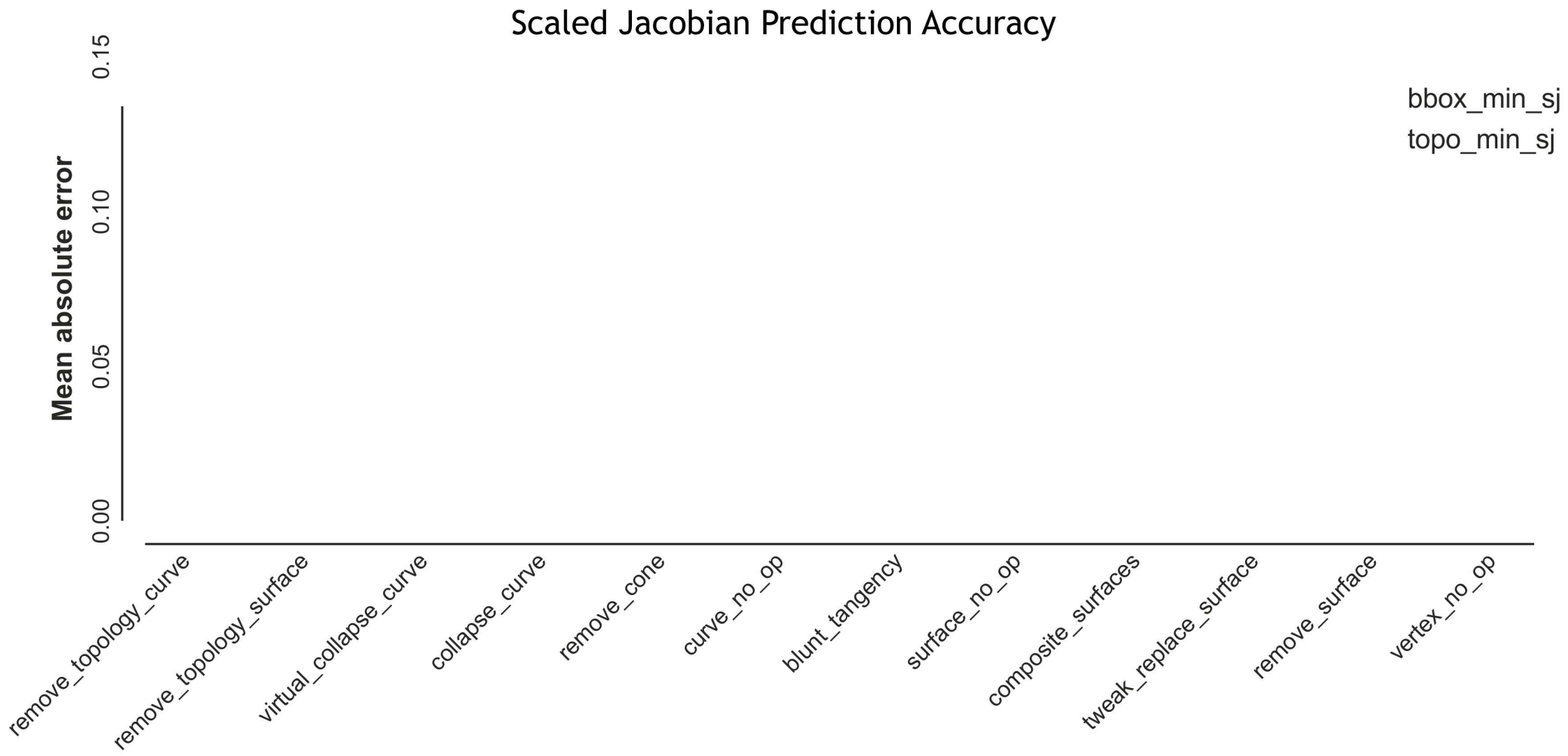


Performance of EDT model versus number of trees for six metrics

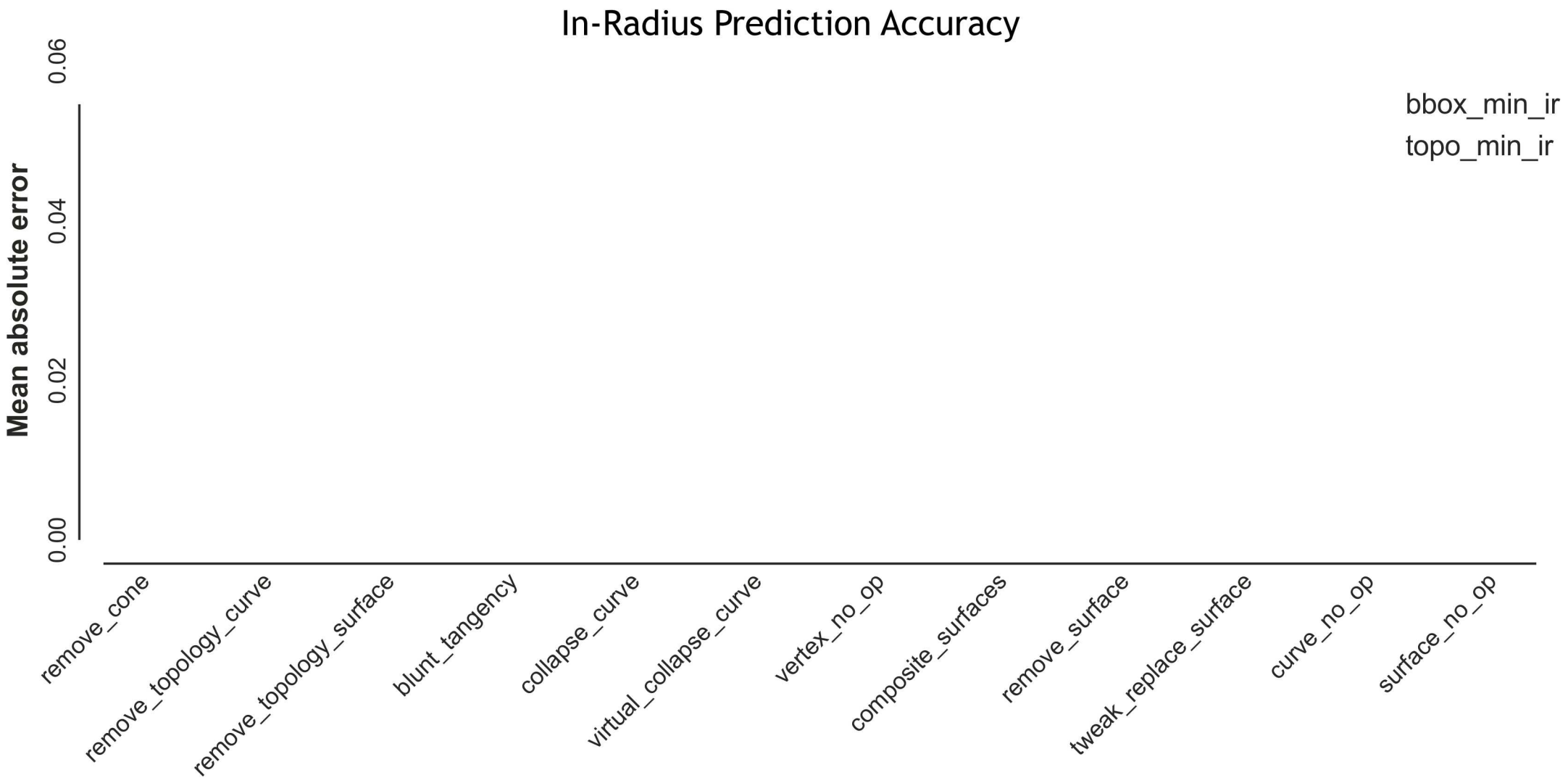


Performance of EDT model versus tree depth for six metrics

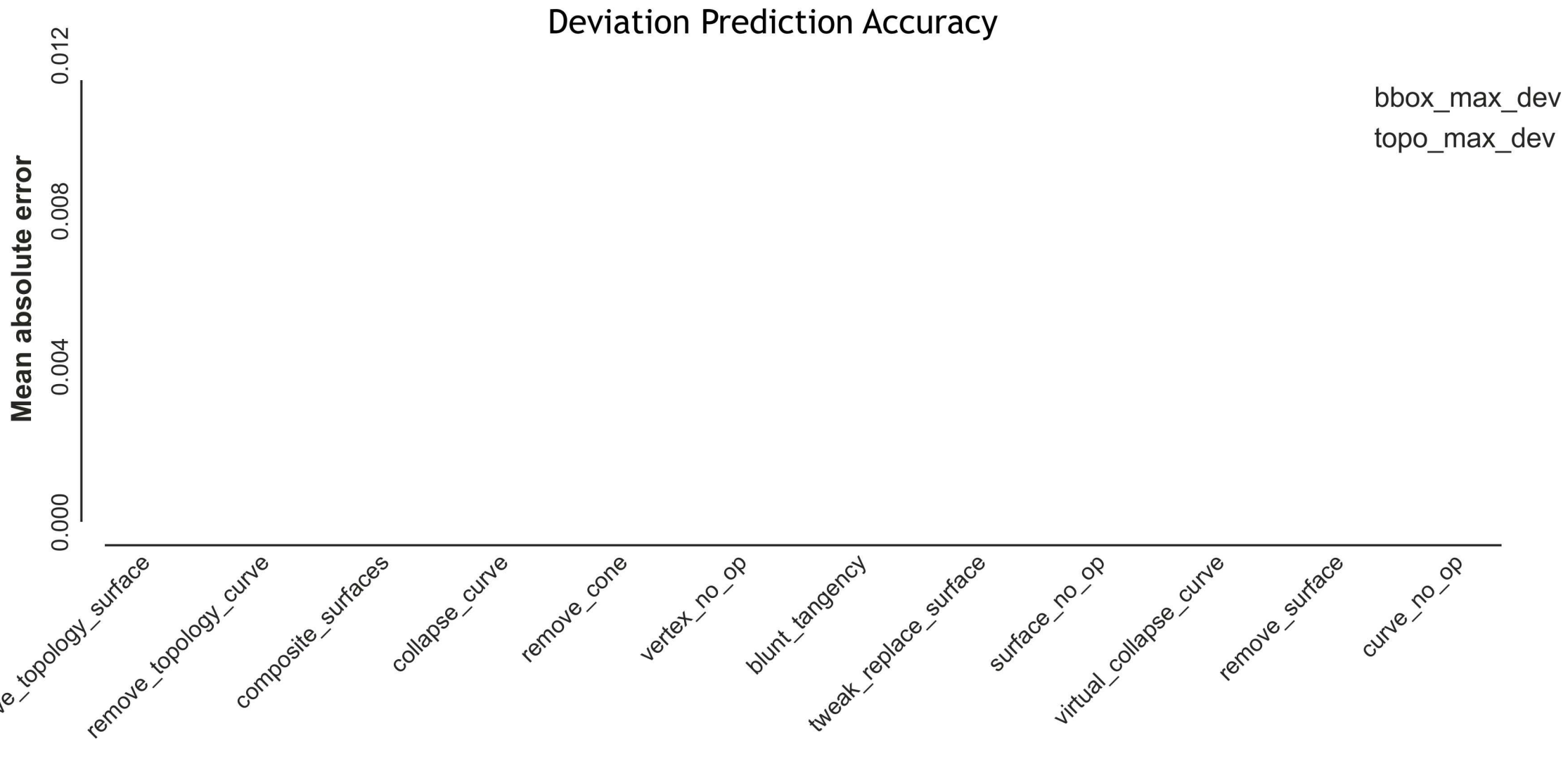
Results


Scaled Jacobian Prediction Accuracy
Mean absolute error
0.00
0.05
0.10
0.15
bbox_min_sj
topo_min_sj
remove_topology_curve
remove_topology_surface
virtual_collapse_curve
collapse_curve
remove_cone
curve_no_op
blunt_tangency
surface_no_op
composite_surfaces
tweak_replace_surface
remove_surface
vertex_no_op

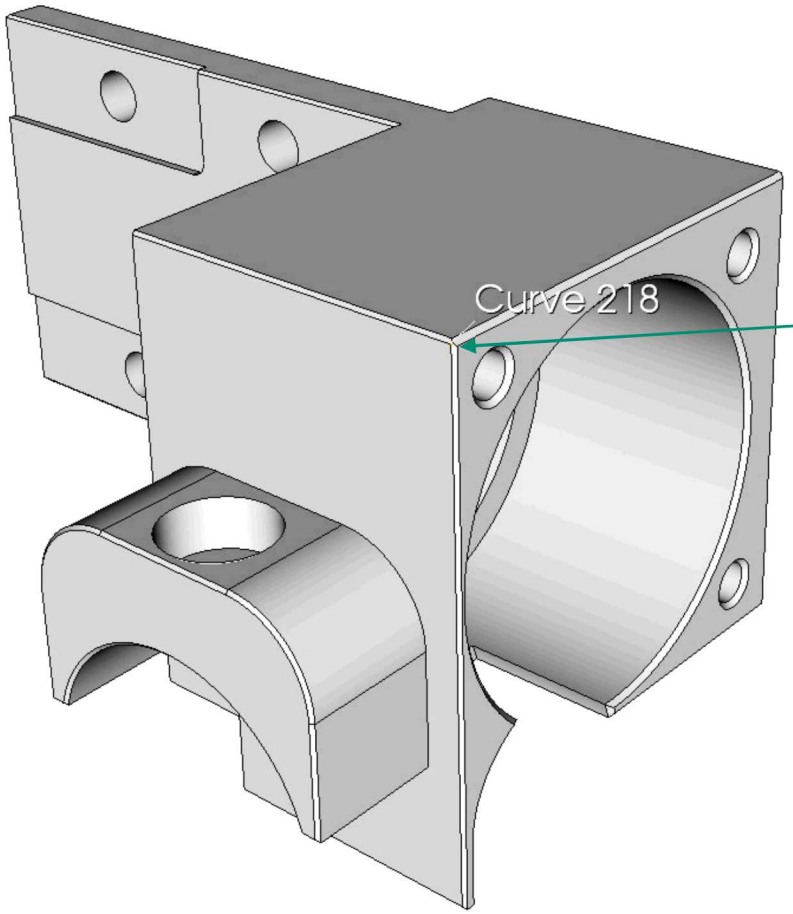
Results


In-Radius Prediction Accuracy
Mean absolute error
0.00
0.02
0.04
0.06
bbox_min_ir
topo_min_ir
remove_cone
remove_topology_curve
remove_topology_surface
blunt_tangency
collapse_curve
virtual_collapse_curve
vertex_no_op
composite_surfaces
remove_surface
tweak_replace_surface
curve_no_op
surface_no_op

Results


Deviation Prediction Accuracy
Mean absolute error
0.000
0.004
0.008
0.012
bbox_max_dev
topo_max_dev
remove_topology_surface
remove_topology_curve
composite_surfaces
collapse_curve
remove_cone
vertex_no_op
blunt_tangency
tweak_replace_surface
surface_no_op
virtual_collapse_curve
remove_surface
curve_no_op

Application



Volume List: all

Small Curve Length: 0.1 ...

Auto Update | Detect Small Features

Use Machine Learning

ML Metric Objective: In-Radius Ratio

Execute ML Solutions: 0.2

Consider correcting small features listed below. Select a small feature to view the possible solutions.

Small Features

Entity ID	Entity Data
Worst Entities (12)	In-Radius
Curve 218	0.1306
Curve 129	0.1306
Curve 131	0.1331
Curve 78	0.1331
Surface 24	0.2288
Surface 21	0.2289
Vertex 59	0.2297
Vertex 62	0.2306

Solutions

Possible Solutions

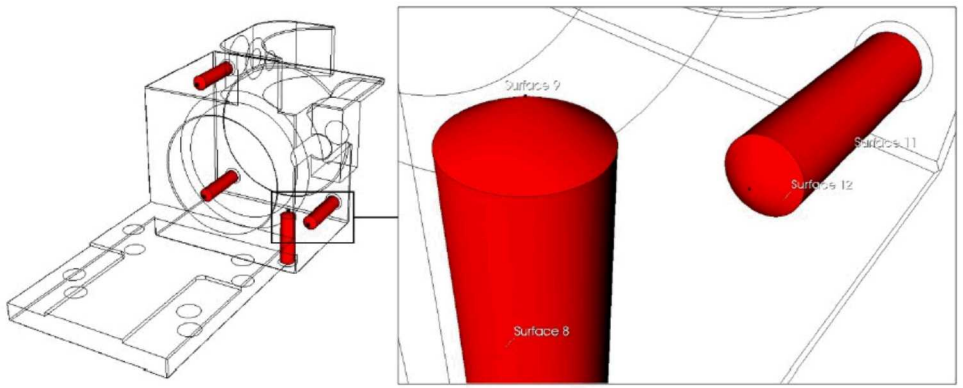
- Rebuild Topology [IR: 0.182315]
- Collapse to Vertex 12 [IR: 0.115744]
- Collapse to Vertex 75 [IR: 0.105005]
- Remove Surface 38 [IR: 0.06737]
- Remove Surface 41 [IR: 0.0653509]
- Collapse (all virtual) to Vertex 75 [IR: 0.0121588]
- Collapse (all virtual) to Vertex 12 [IR: 0.0106142]

List of poor quality entities ordered by predicted metric

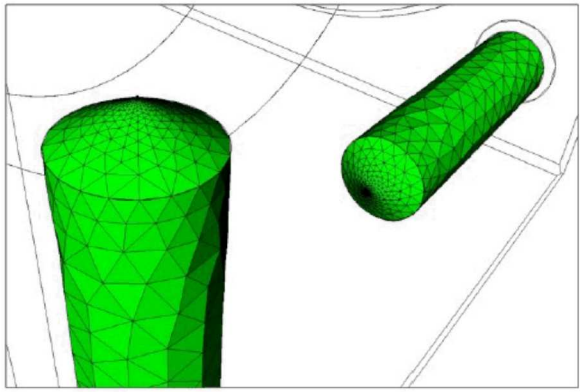
List of solutions ordered by predicted outcome

Application Example

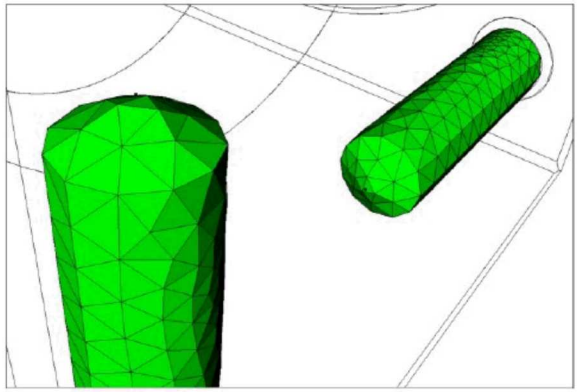
Operation	Num tets	Global min M_{sir}	Num tets $M_{sir} < 0.2$	Predicted no-op	Actual no-op	Predicted op	Actual op
Initial	269957	0.0078	10000+				
composite create surface 18 17	263957	0.0070	9477	0.0236	0.0086	0.4103	0.3139
composite create surface 15 14	256093	0.0072	5917	0.0236	0.0095	0.4103	0.2982
composite create surface 12 11	249603	0.0065	2020	0.0236	0.0080	0.4103	0.2962
composite create surface 9 8	245917	0.1069	54	0.0241	0.0065	0.4103	0.3147
tweak remove_topology curve 218	244754	0.1934	2	0.1039	0.1070	0.2935	0.2813
tweak remove_topology curve 176	244620	0.1628	4	0.1237	0.1935	0.2539	0.1628
tweak remove_topology curve 178	245172	0.1628	1	0.1352	0.1770	0.2381	0.1628



Surfaces predicted to have poor quality



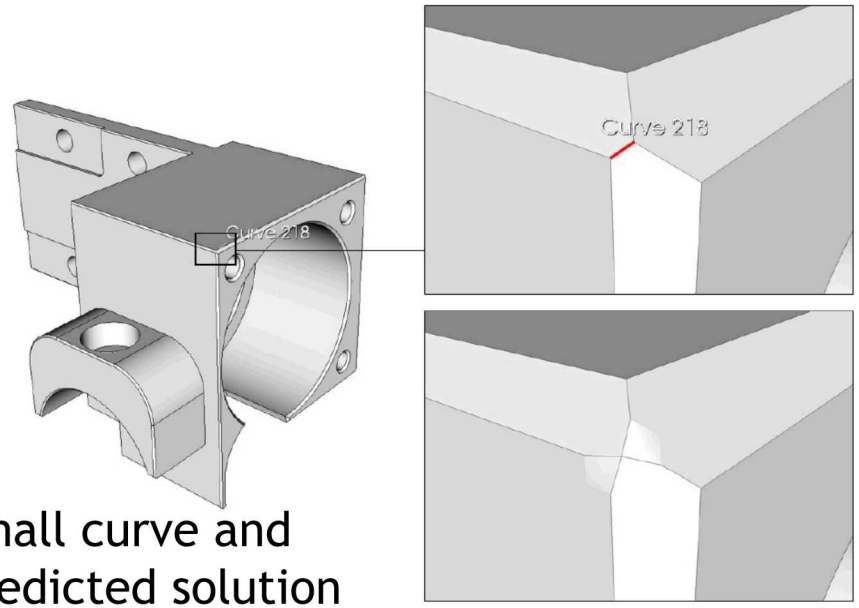
Mesh without defeaturing



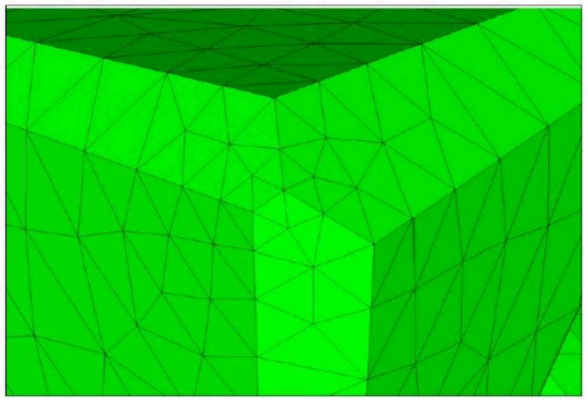
Mesh with best predicted solution

Application Example

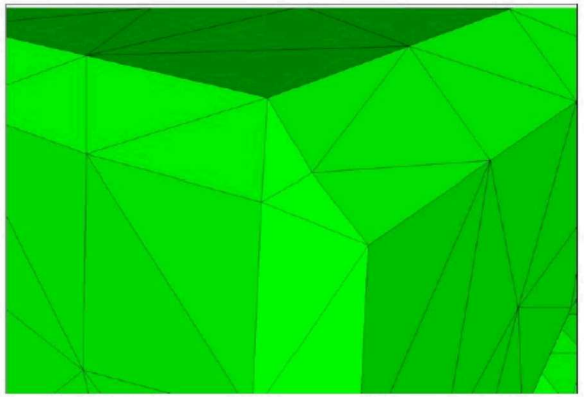
Operation	Num tets	Global min M_{sir}	Num tets $M_{sir} < 0.2$	Predicted no-op	Actual no-op	Predicted op	Actual op
Initial	269957	0.0078	10000+				
composite create surface 18 17	263957	0.0070	9477	0.0236	0.0086	0.4103	0.3139
composite create surface 15 14	256093	0.0072	5917	0.0236	0.0095	0.4103	0.2982
composite create surface 12 11	249603	0.0065	2020	0.0236	0.0080	0.4103	0.2962
composite create surface 9 8	245917	0.1069	54	0.0241	0.0065	0.4103	0.3147
tweak remove_topology curve 218	244754	0.1934	2	0.1039	0.1070	0.2935	0.2813
tweak remove_topology curve 176	244620	0.1628	4	0.1237	0.1935	0.2539	0.1628
tweak remove_topology curve 178	245172	0.1628	1	0.1352	0.1770	0.2381	0.1628



Small curve and predicted solution



Mesh without defeaturing



Mesh with best predicted solution

Conclusions

CAD Defeaturing with Machine Learning

1. Predict local mesh quality without meshing
2. Predict best CAD Operation without doing operation and meshing
3. Gives user best options but allows them to choose

Next Steps

1. Multiple Parts (Gaps, Overlaps)
2. Reinforcment Learning
3. Deploy and train on real user data