# Determining Optimal Print Orientation Using GPU-Accelerated Convex Hull Analysis

**Charles Wade**, Breanne Crockett, Michael Borish, and Robert MacCurdy

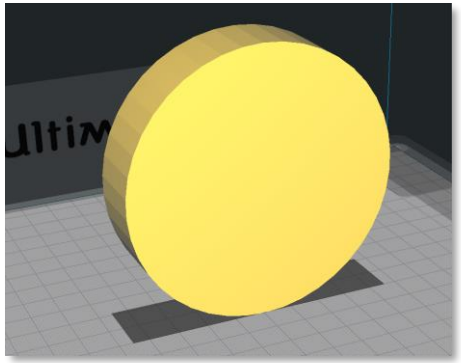
OAK RIDGE National Laboratory

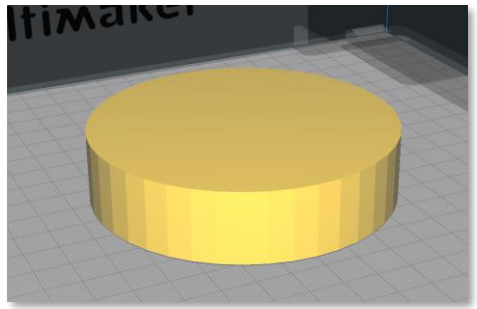
MAClab

University of Colorado **Boulder**

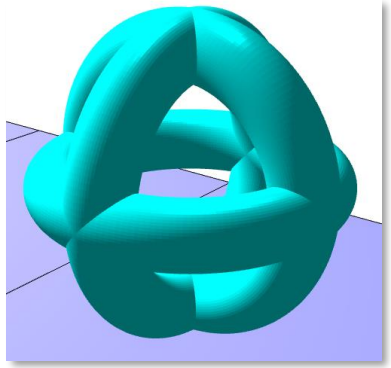
# How do we identify a “good” orientation for 3D printing?

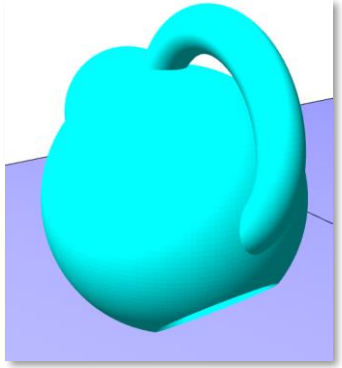
**Trivial Cases:**

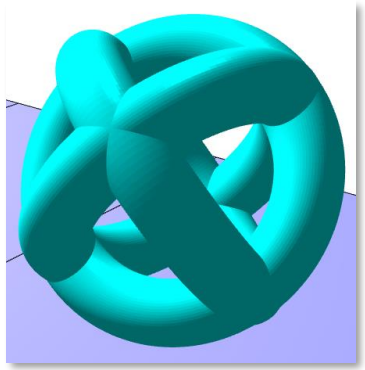


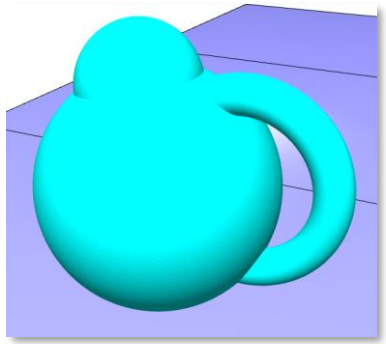


**Non-Trivial Cases:**



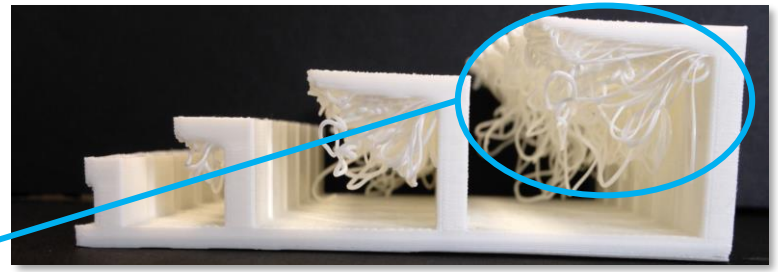


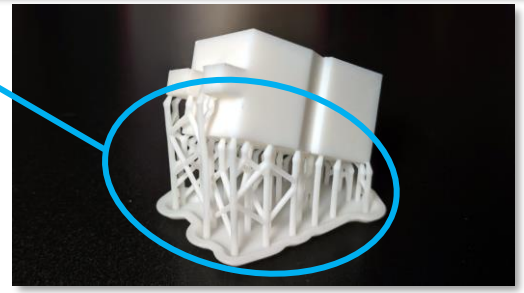




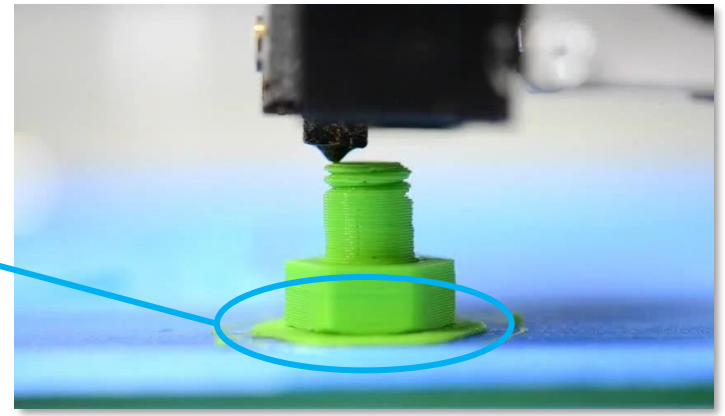
# What intuition are we using?

**Minimize**
(overhang/ supports)



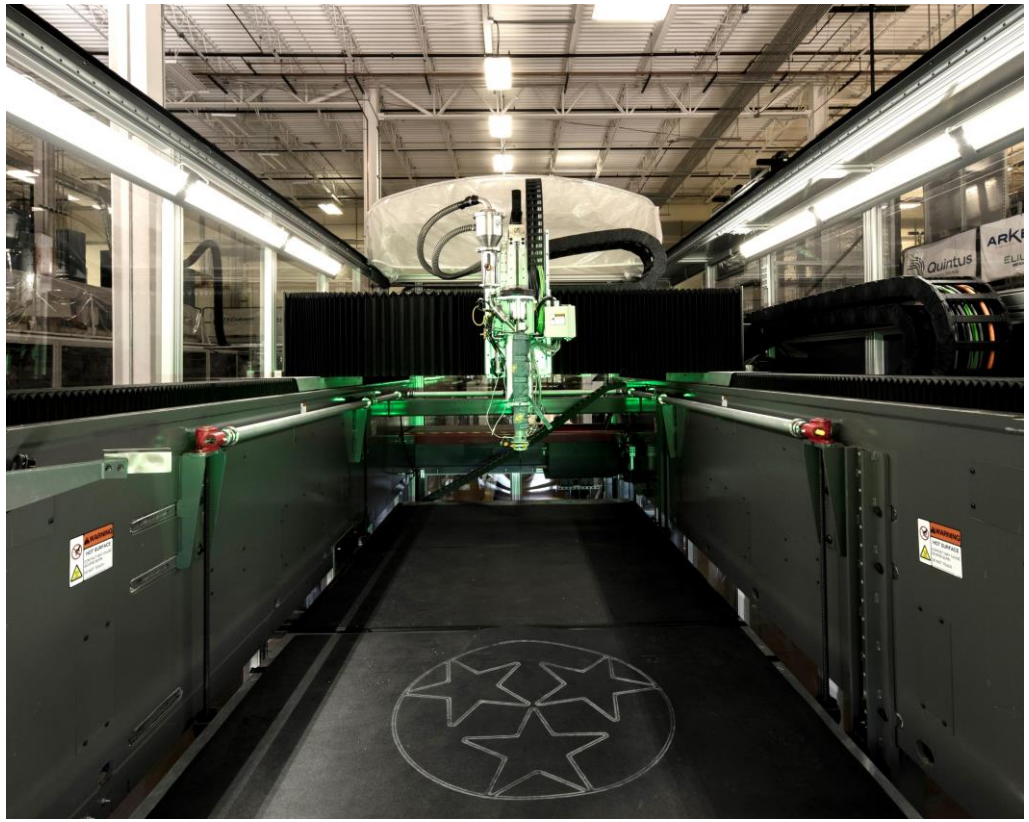


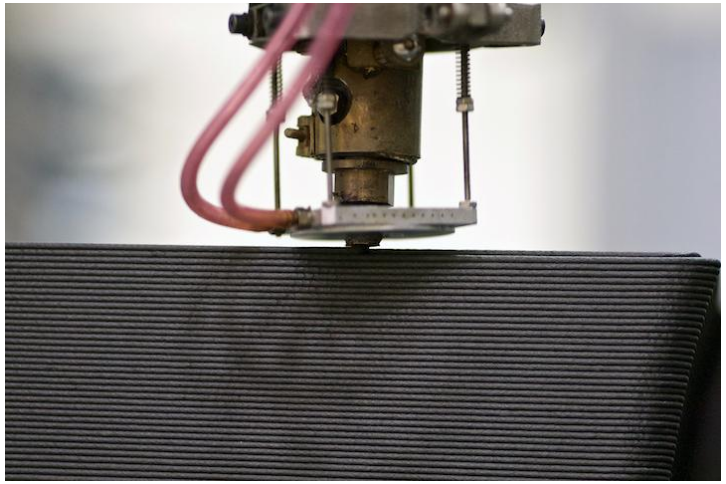
**Maximize**
(adhesion to build surface)



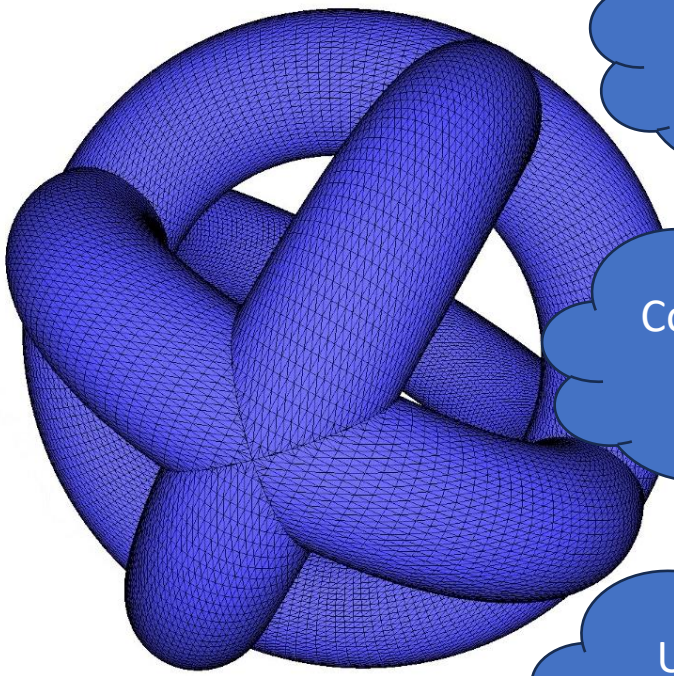
Result:
**Improve probability of a successful quality print**

# Our focus on large format FFF





# Existing Automated Approaches



Action space is too large

Computationally expensive

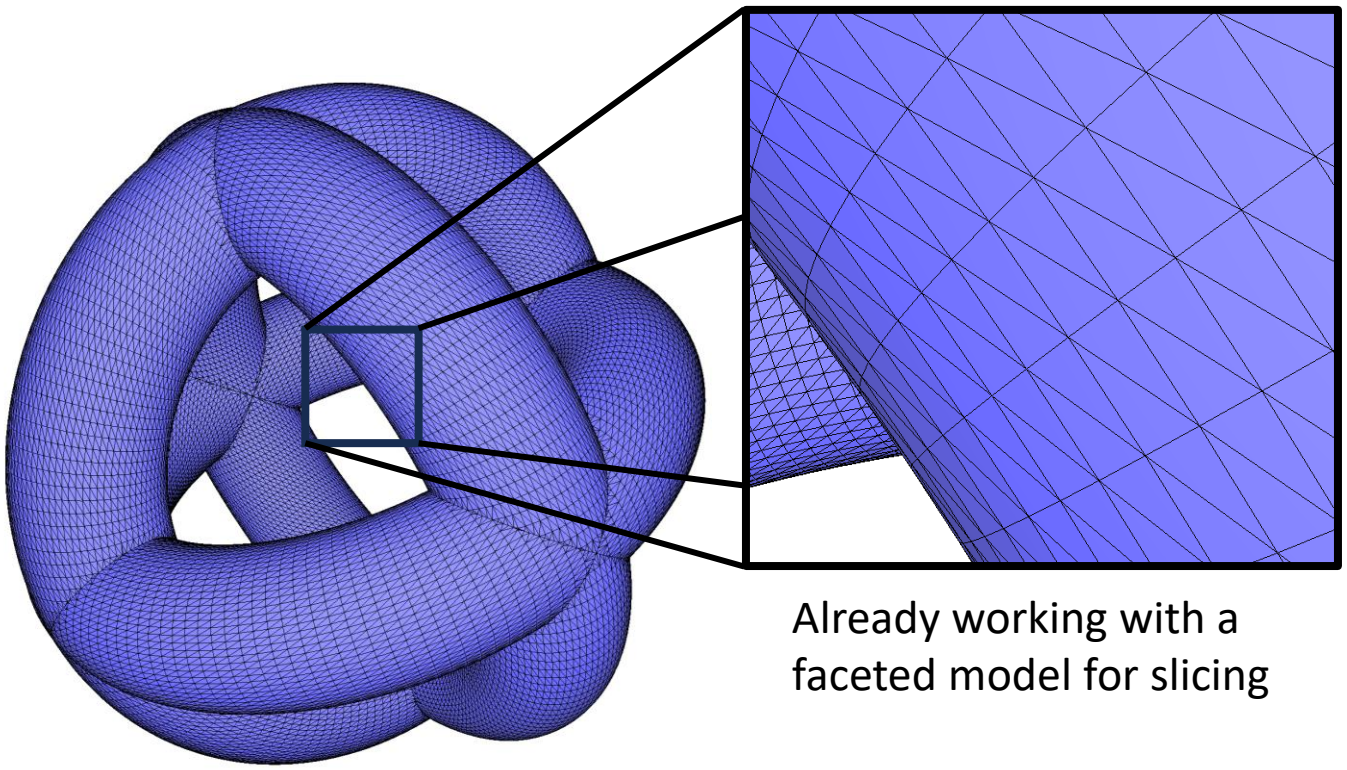
Unintuitive to users

**Actions:**
Rotate a part in **X** and **Y** at small increments

**Cost Functions:**
- *Support volume*
- *Bed adhesion*
- Aliasing
- Mechanical anisotropy

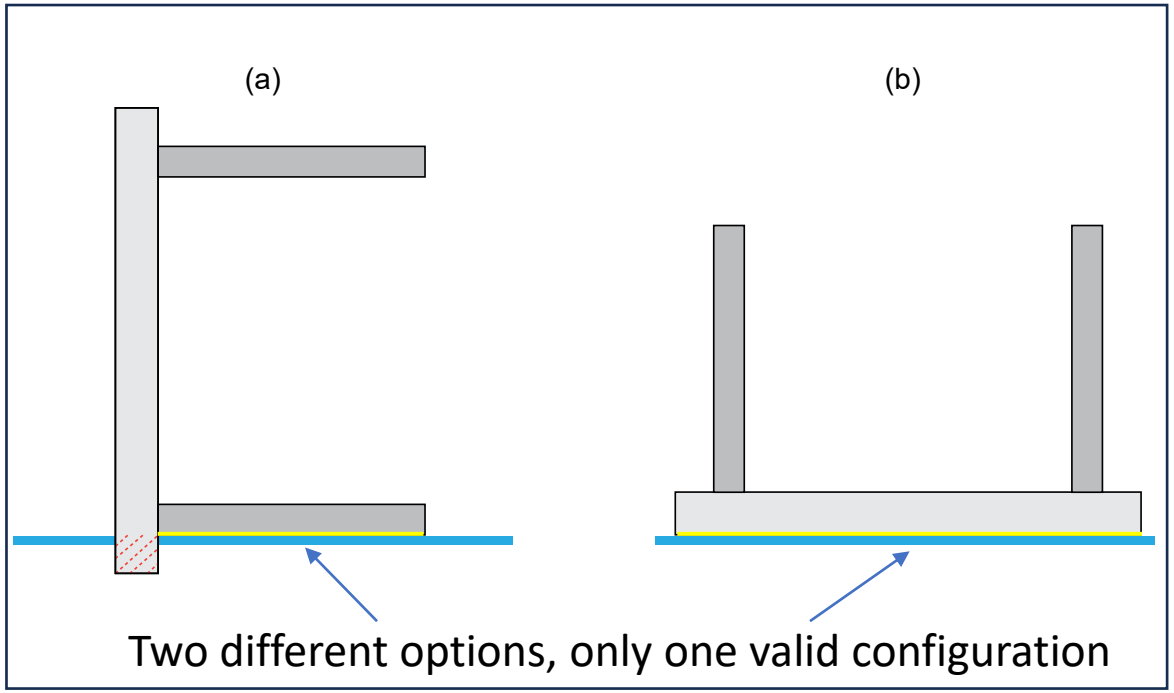
**Optimizers:**
- Brute-force
- Heuristics
- Machine learning
- …

# Reducing the action space



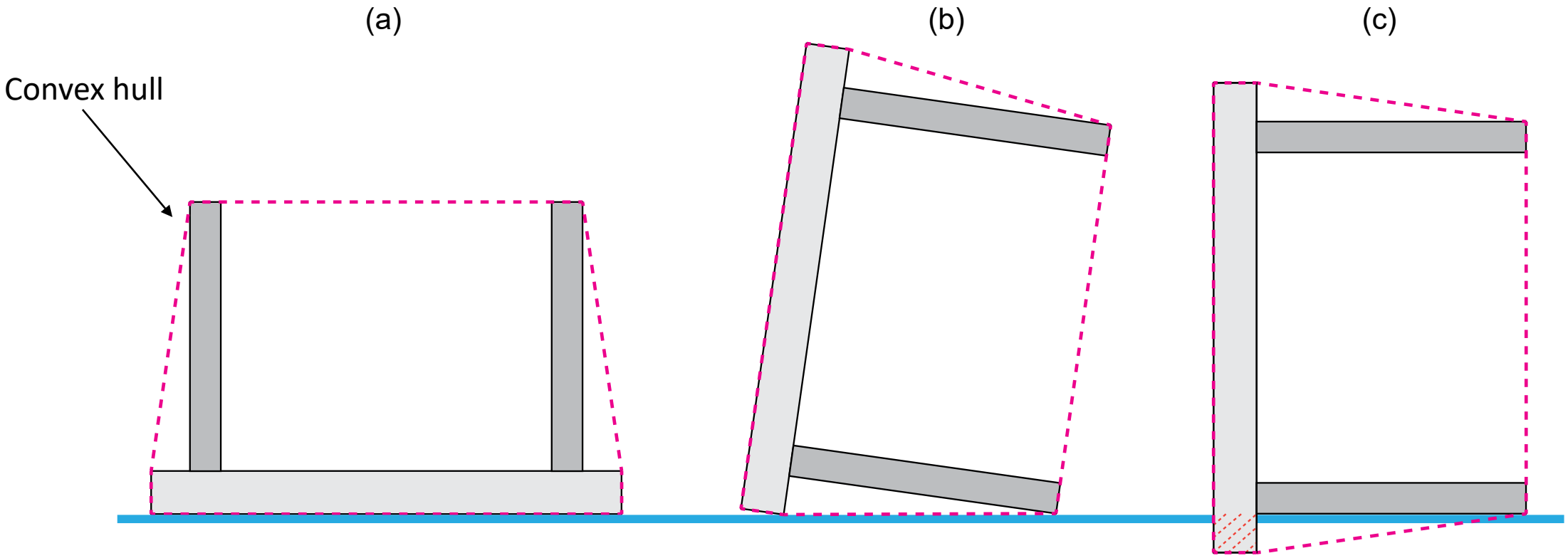
Already working with a faceted model for slicing

Why not pick a triangular face to lay on the bed?



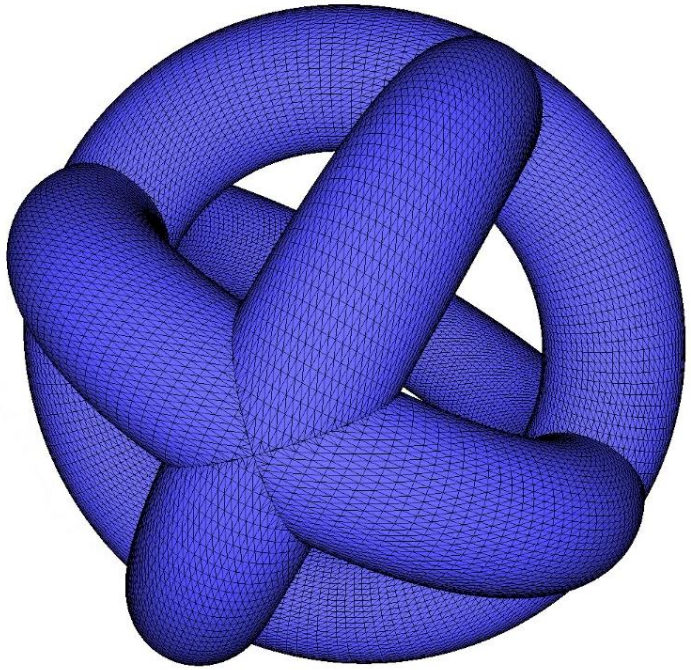

Two different options, only one valid configuration

# Picking only valid options

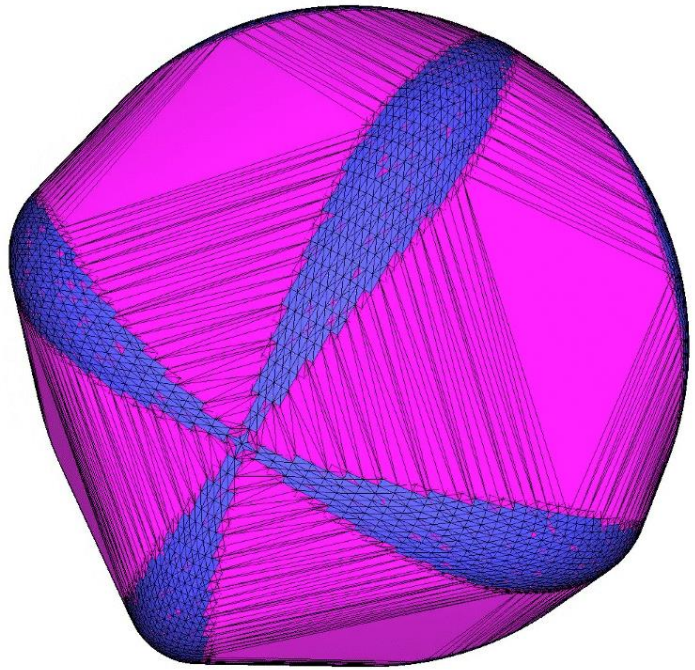



Lemma:
**Any face on the convex hull is a non-intersecting orientation**

# Convex hulls in 3D



Original



Convex Hull

**Compute hull using Quickhull algorithm:**
Average runtime is O(nlogn)

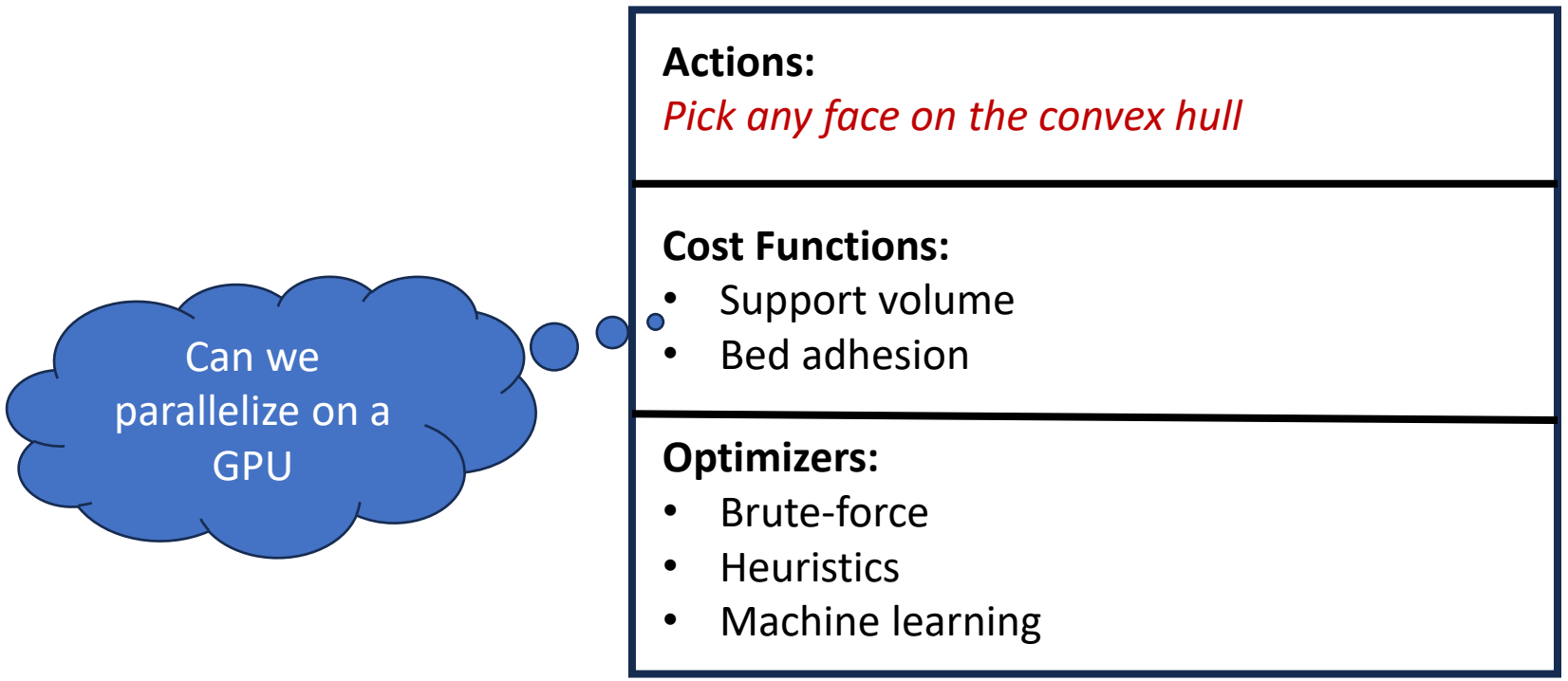
# Progress

**Actions:**
Rotate a part in **X** and **Y** at small increments

**Cost Functions:**
- Support volume
- Bed adhesion

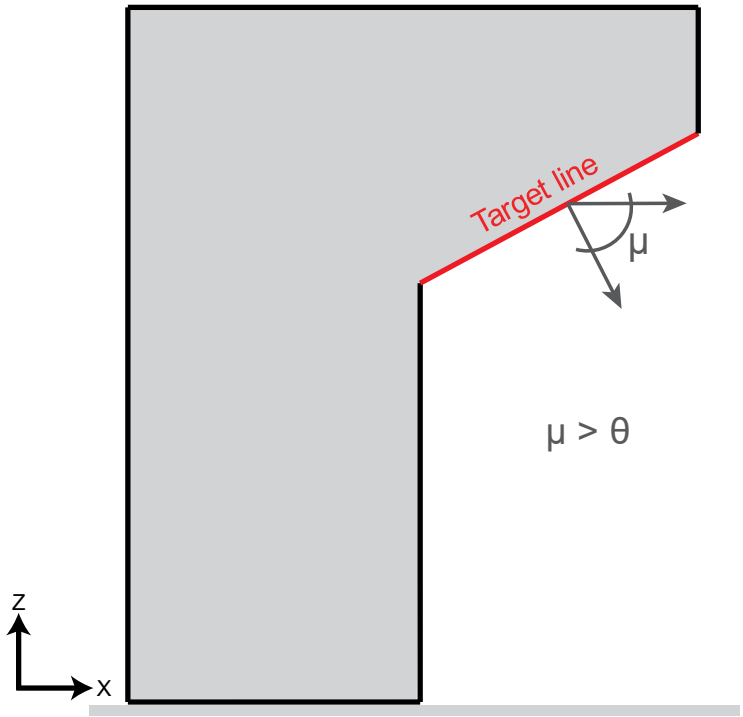
**Optimizers:**
- Brute-force
- Heuristics
- Machine learning

# Progress

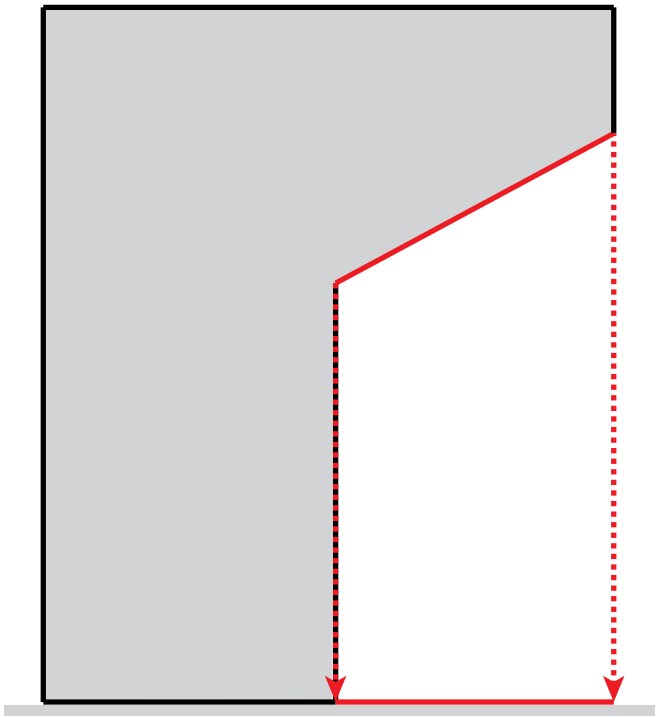

Can we parallelize on a GPU
Actions:
Pick any face on the convex hull
Cost Functions:
• Support volume
• Bed adhesion
Optimizers:
• Brute-force
• Heuristics
• Machine learning

# Computing Support Volume

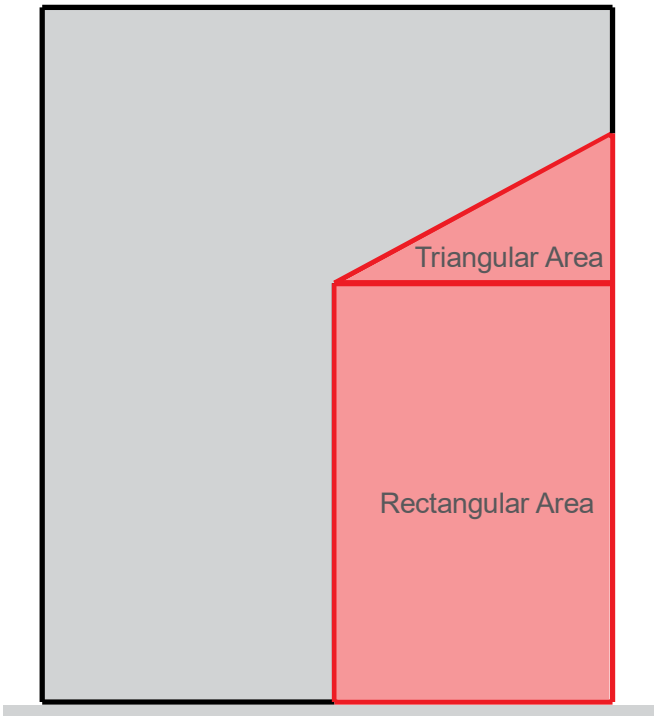
**For every line/ triangle:**




1. Determine if support is required for line



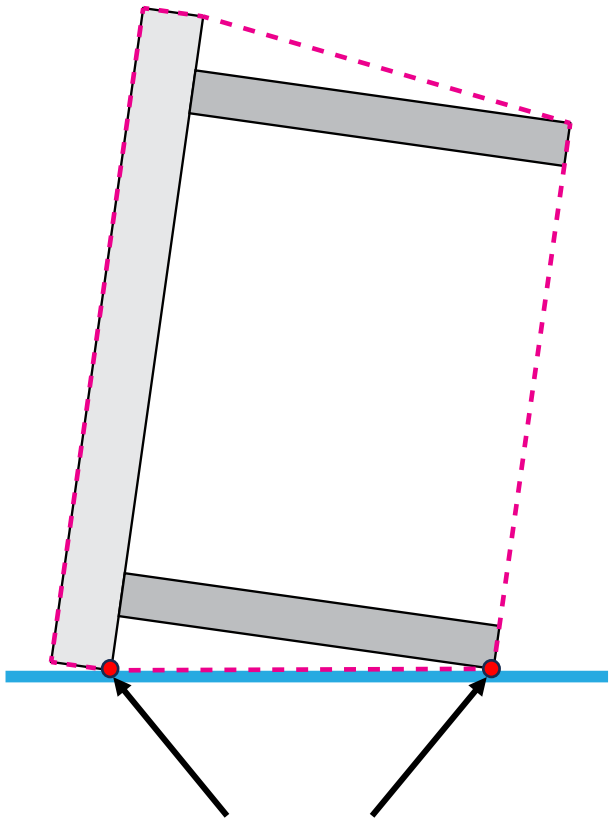
2. Project line down to build surface



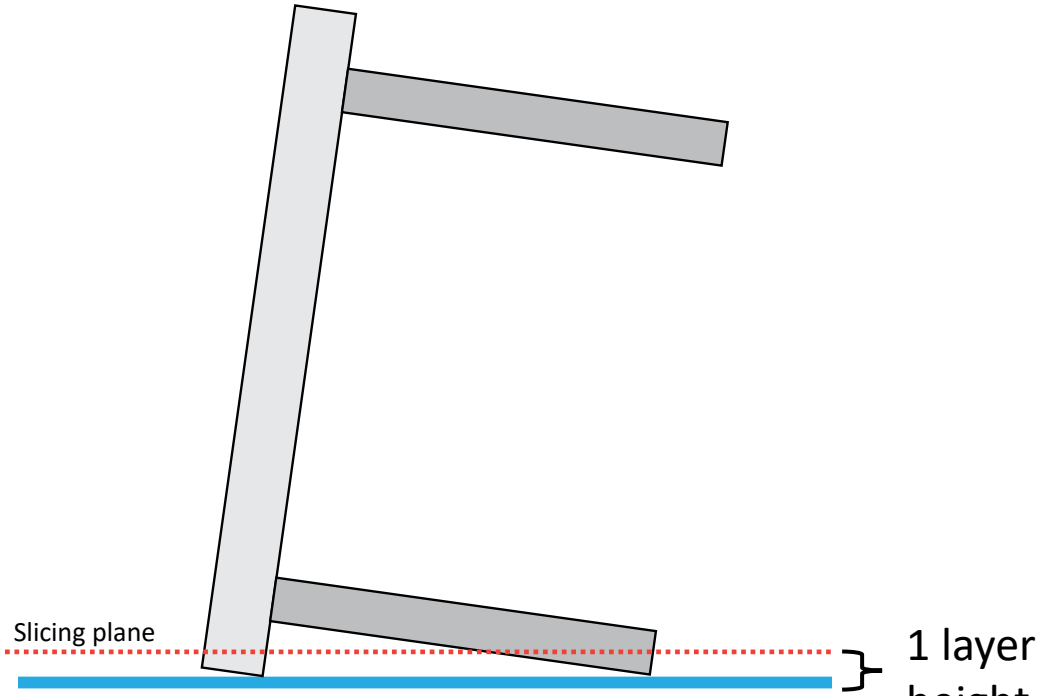

3. Sum rectangular and triangular areas

**Repeat for all triangles in mesh to get total supports volume**

# Computing Surface Area on Build Plate

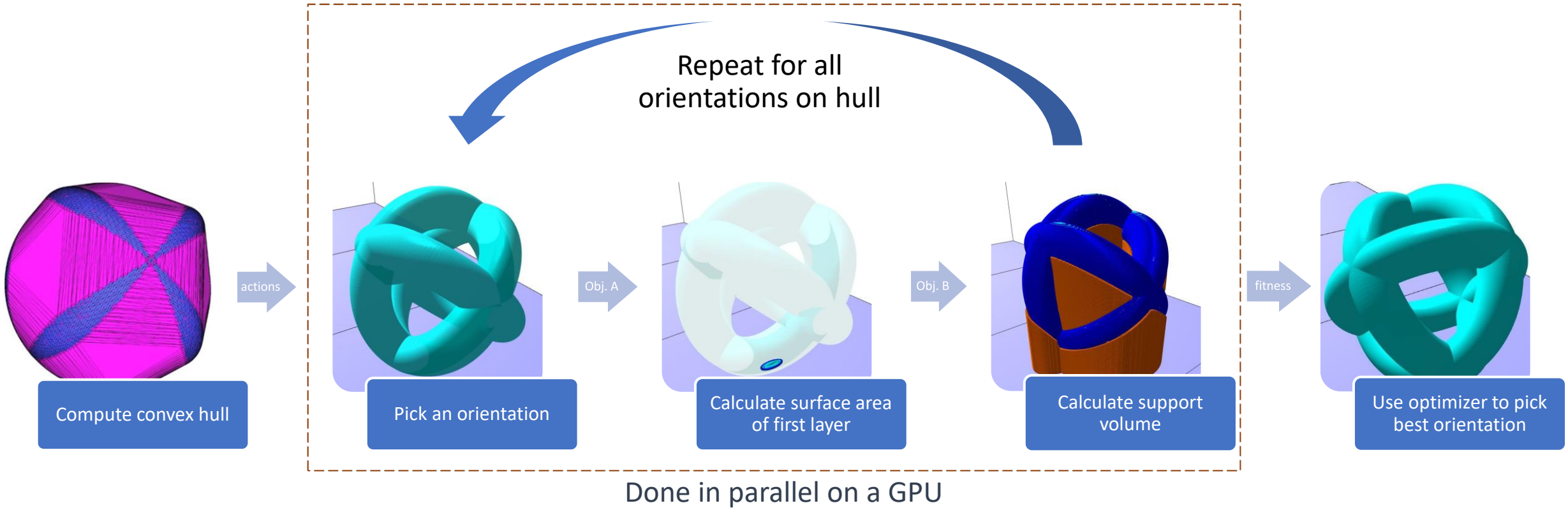


Contact at single points
**Yields no area**




Slicing at 1 layer height
**Yields real area**

# Putting this together




Done in parallel on a GPU

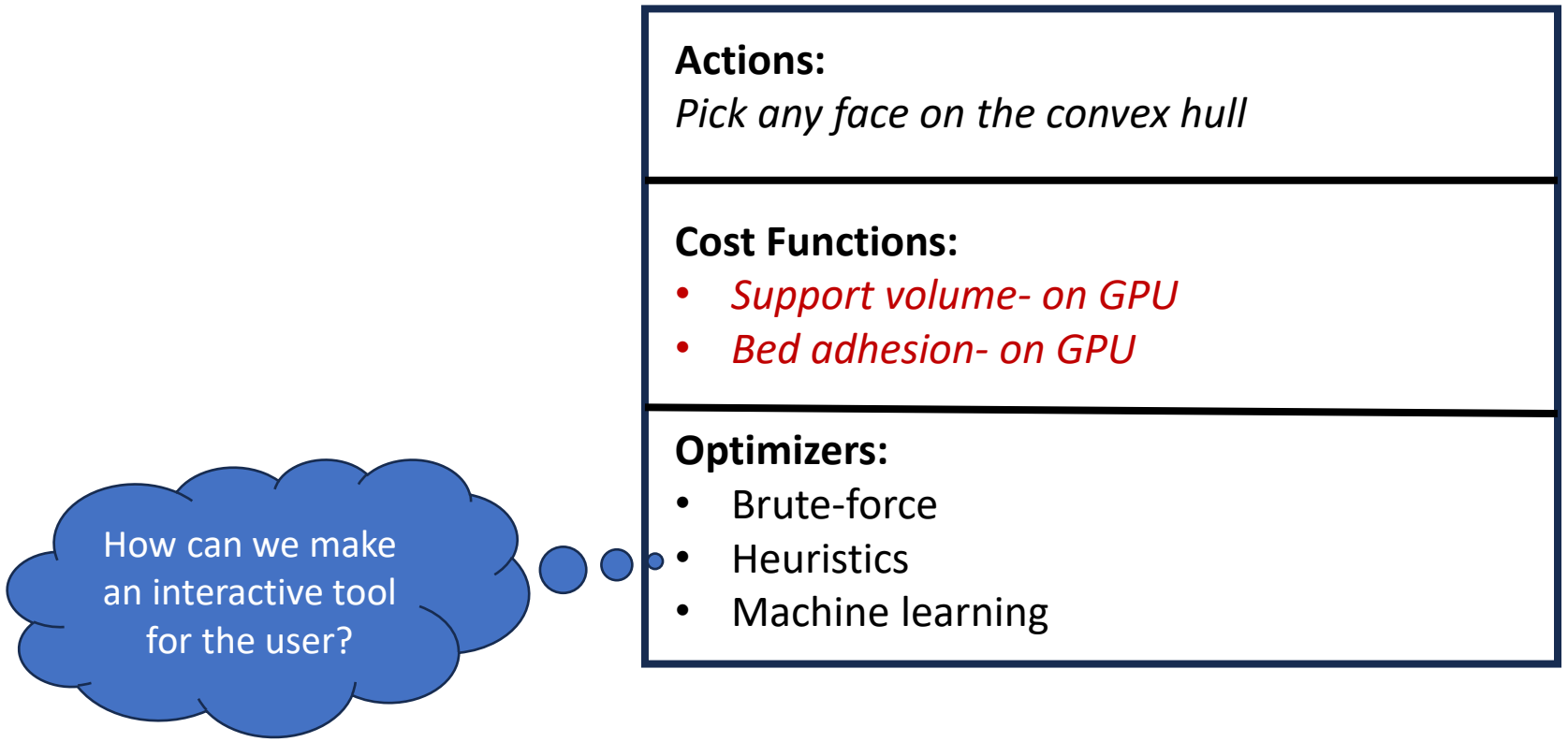
# Progress

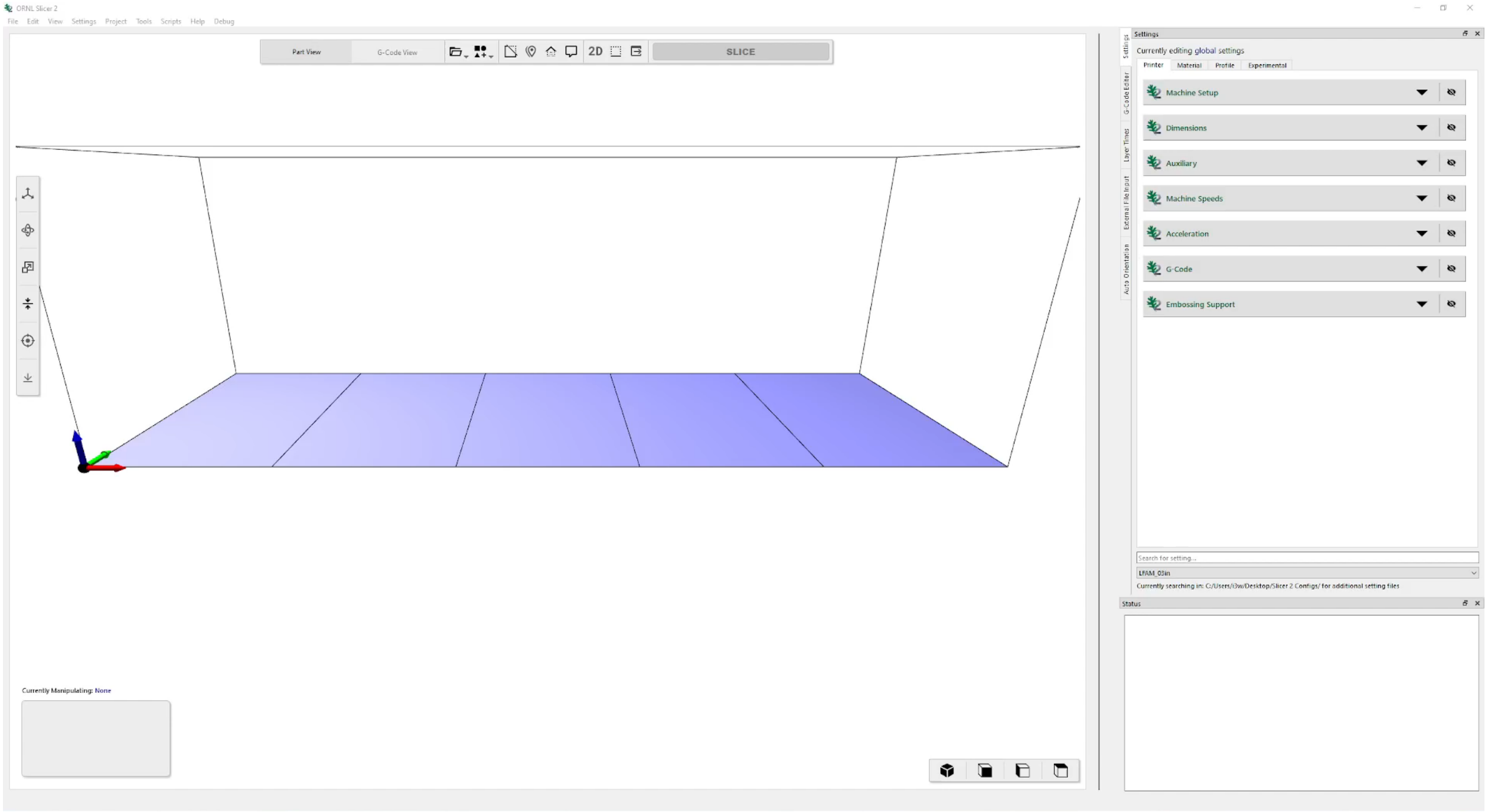
**Actions:**
*Pick any face on the convex hull*

**Cost Functions:**
- Support volume
- Bed adhesion

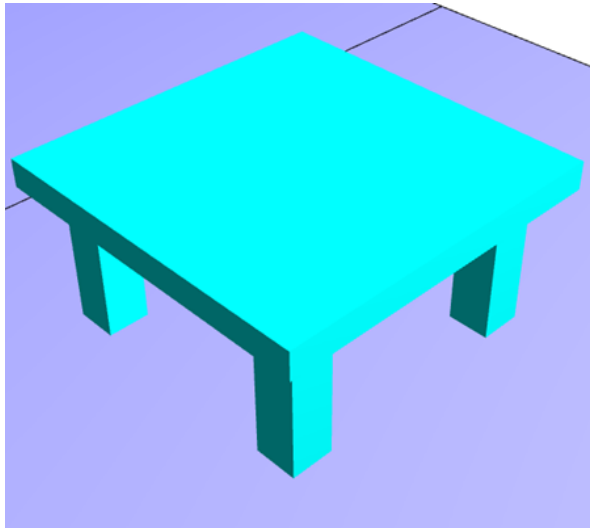
**Optimizers:**
- Brute-force
- Heuristics
- Machine learning

# Progress

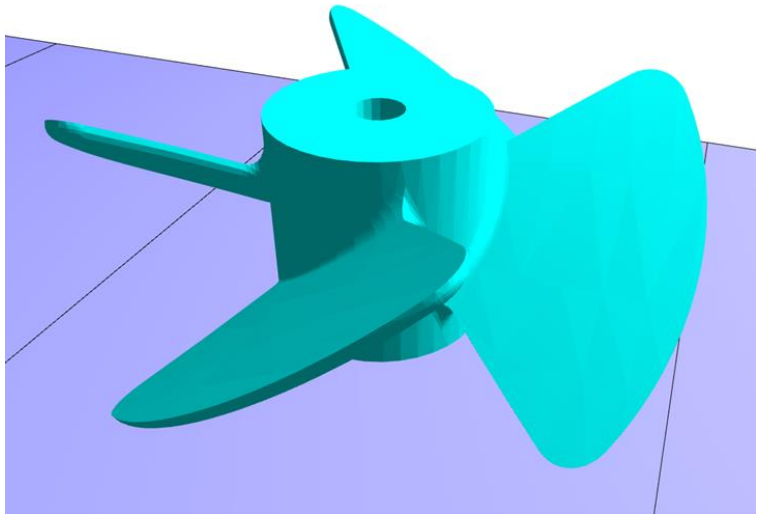

How can we make an interactive tool for the user?
Actions:
Pick any face on the convex hull
Cost Functions:
Support volume- on GPU
Bed adhesion- on GPU
Optimizers:
Brute-force
Heuristics
Machine learning


ORNL Slicer 2
File
Edit
View
Settings
Project
Tools
Scripts
Help
Debug
Part View
G-Code View
2D
SLICE
Settings
Currently editing global settings
Printer
Material
Profile
Experimental
Machine Setup
Dimensions
Auxiliary
Machine Speeds
Acceleration
G-Code
Embossing Support
Settings
G-Code Editor
Layer Times
External File Input
Auto Orientation
Search for setting...
LFAM_03in
Currently searching in: C:/Users/i3w/Desktop/Slicer 2 Configs/ for additional setting files
Status
Currently Manipulating: None

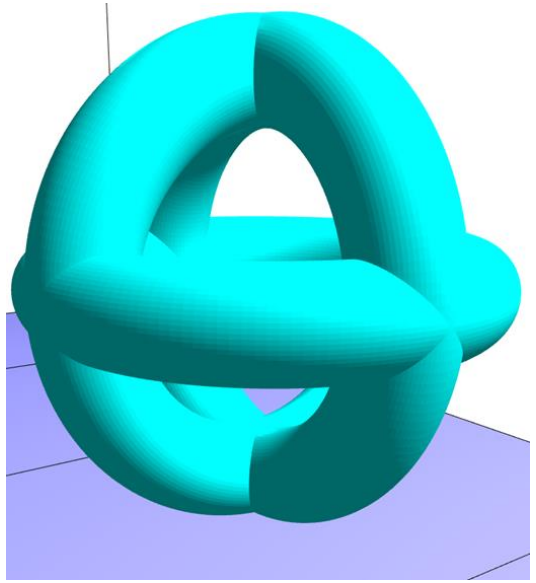
# Case Studies:



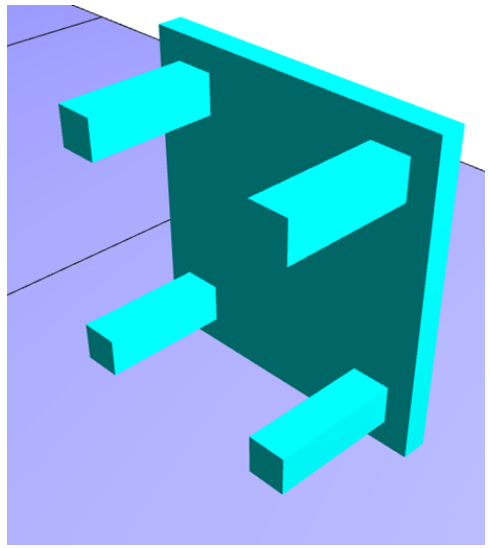
Simple 4-legged table



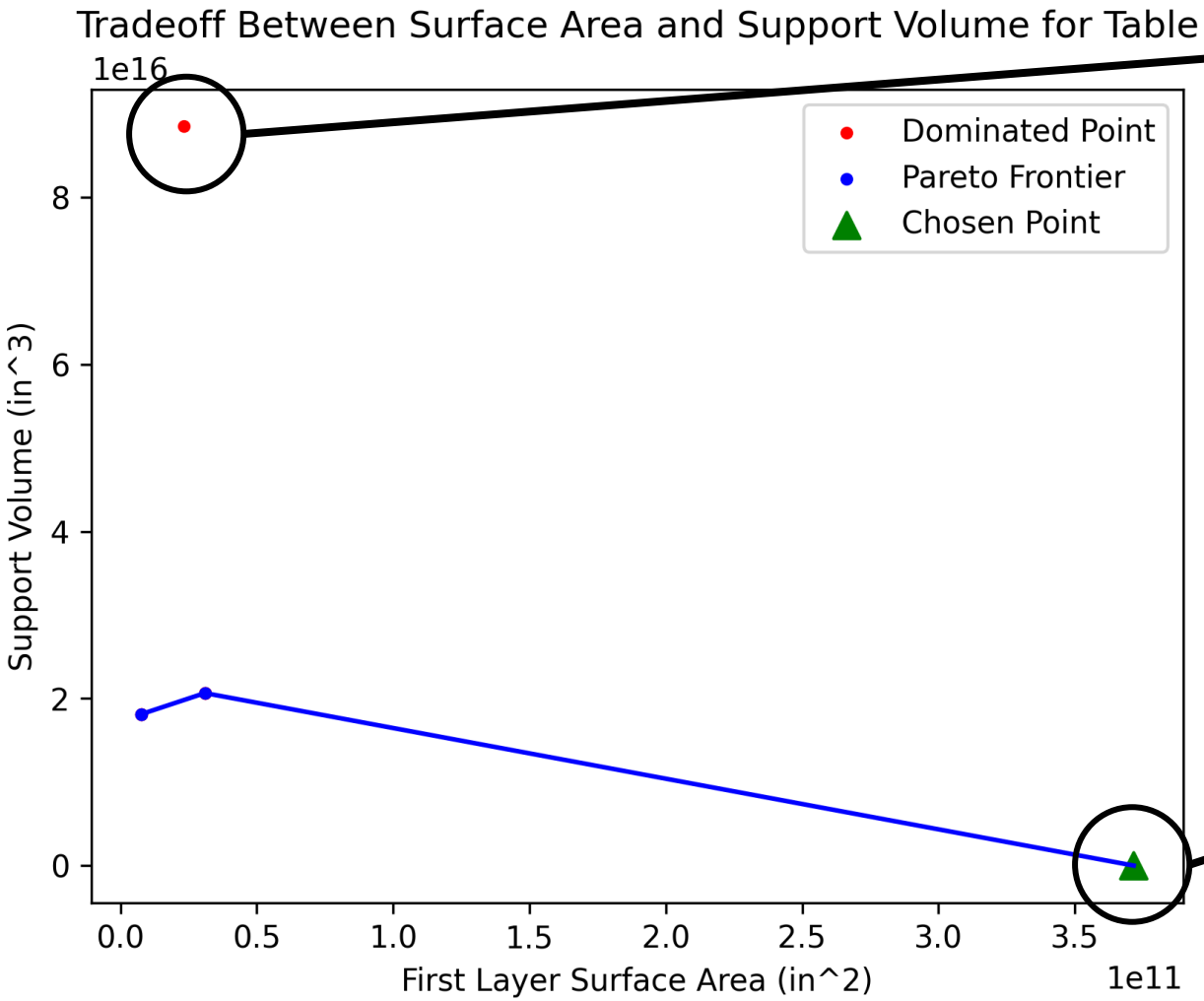
Propeller

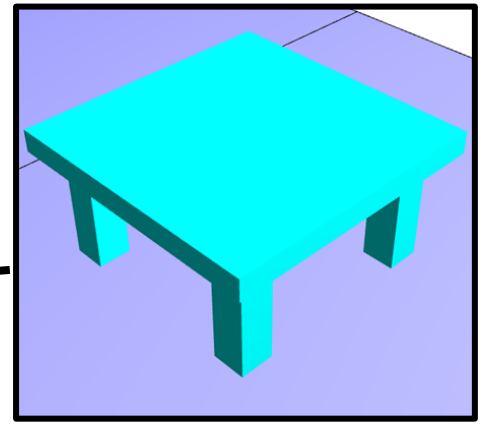


Rings

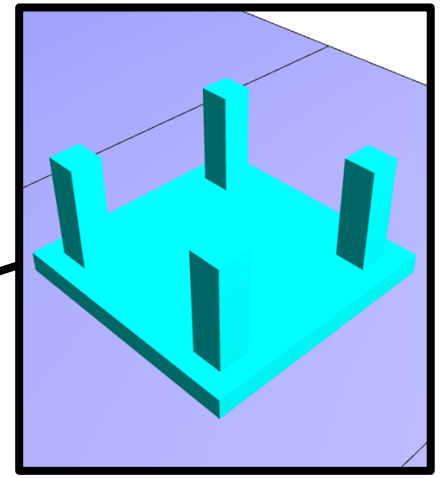


Initial random orientation

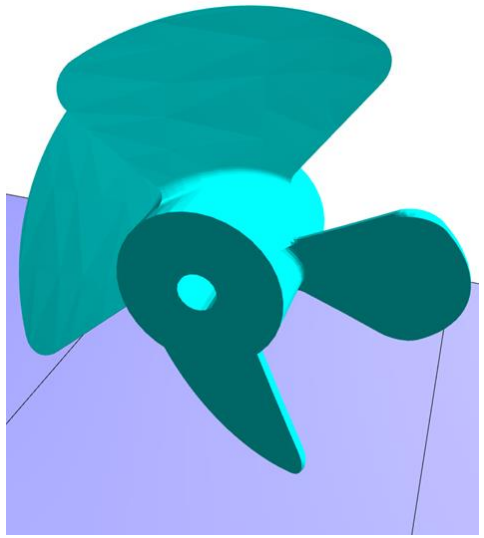


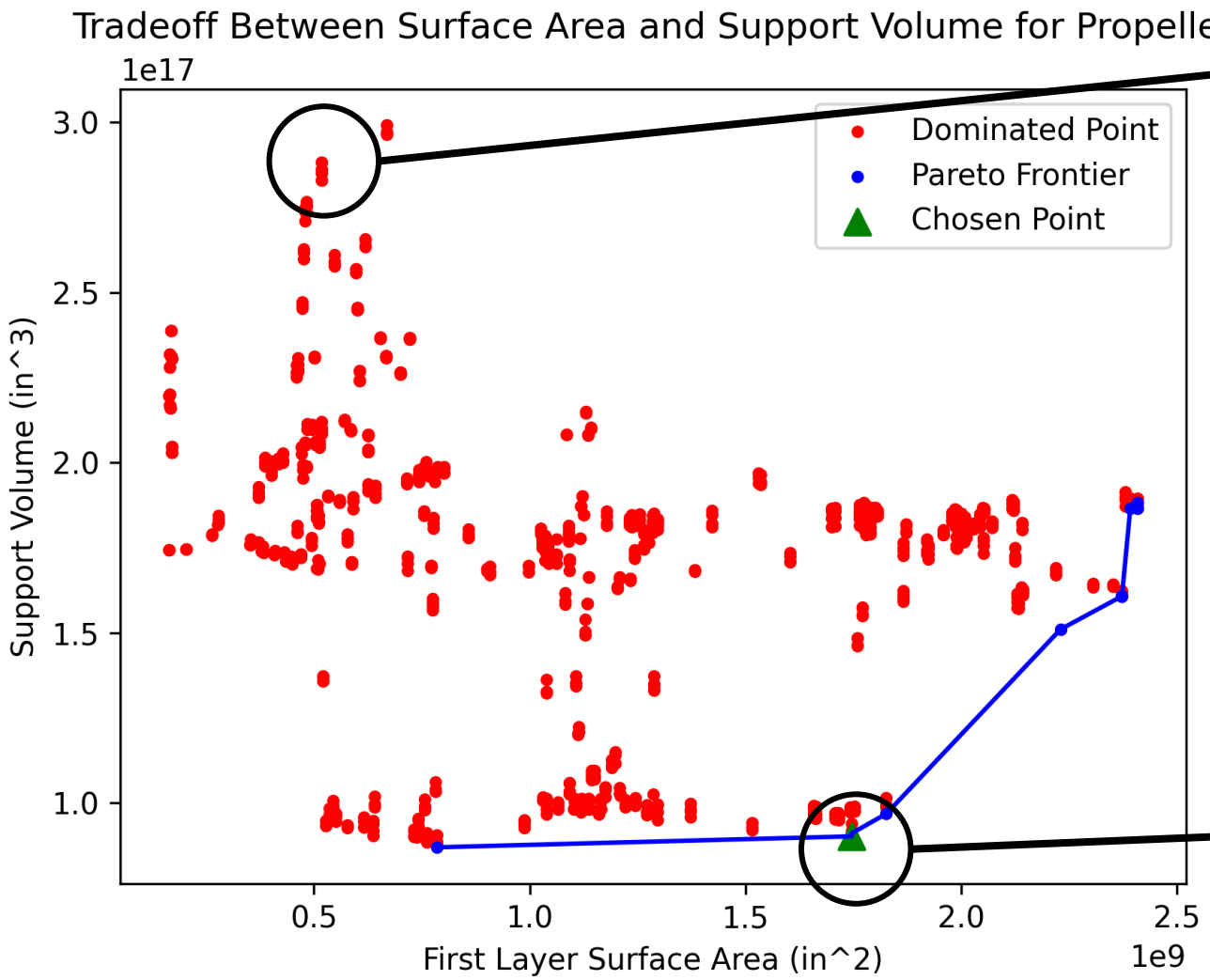
Worst orientation

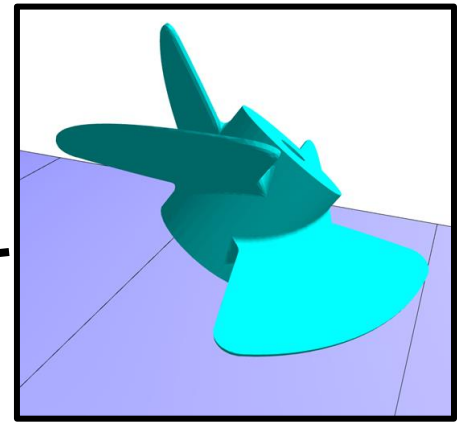


Best orientation

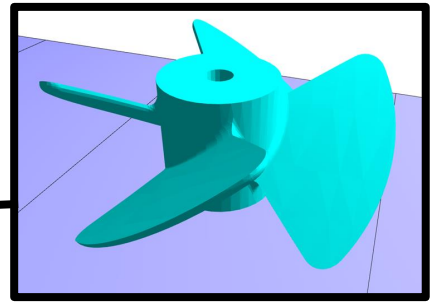


Initial random orientation

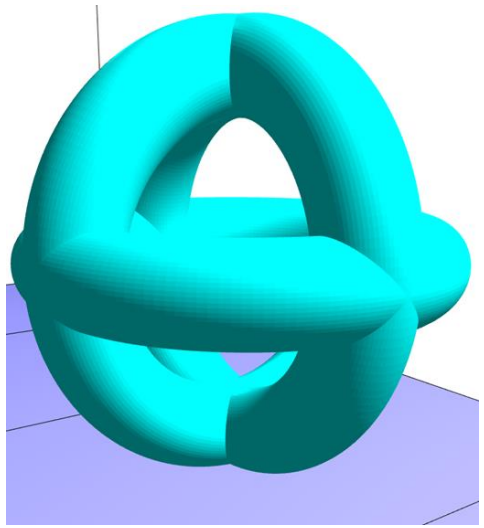


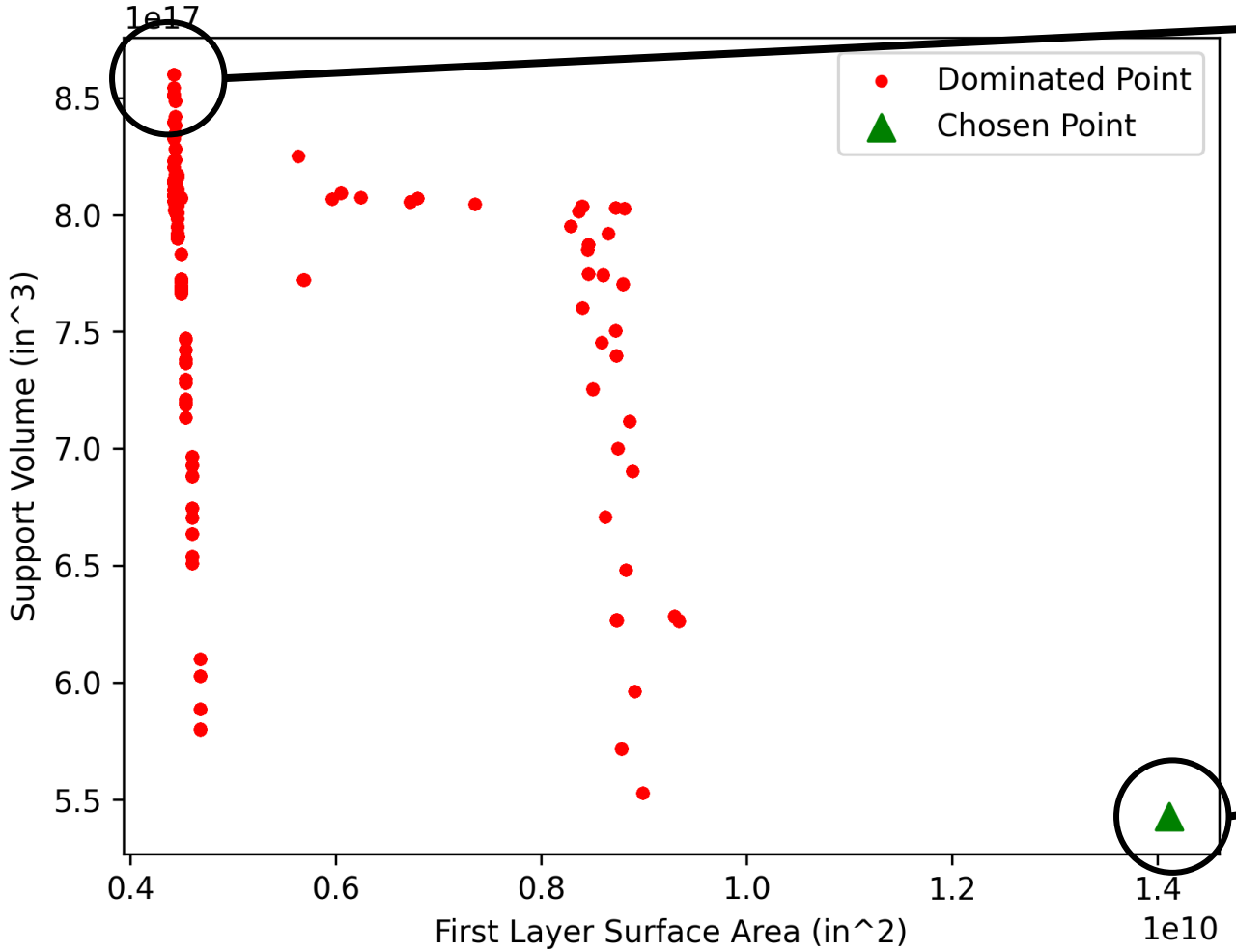
Worst orientation

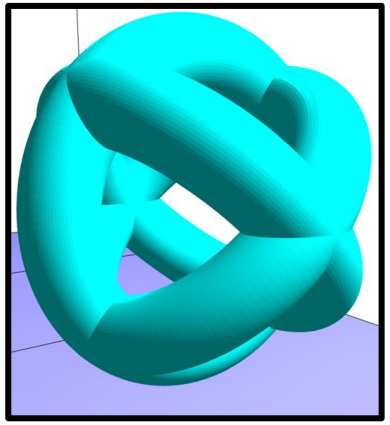


Best orientation

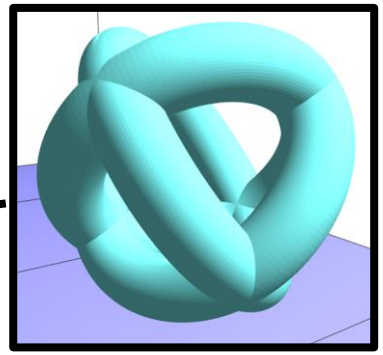


Initial random orientation



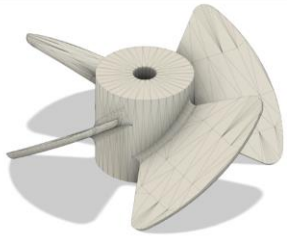
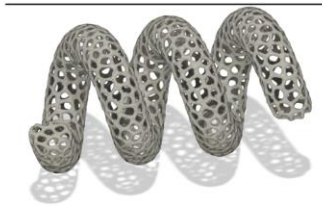



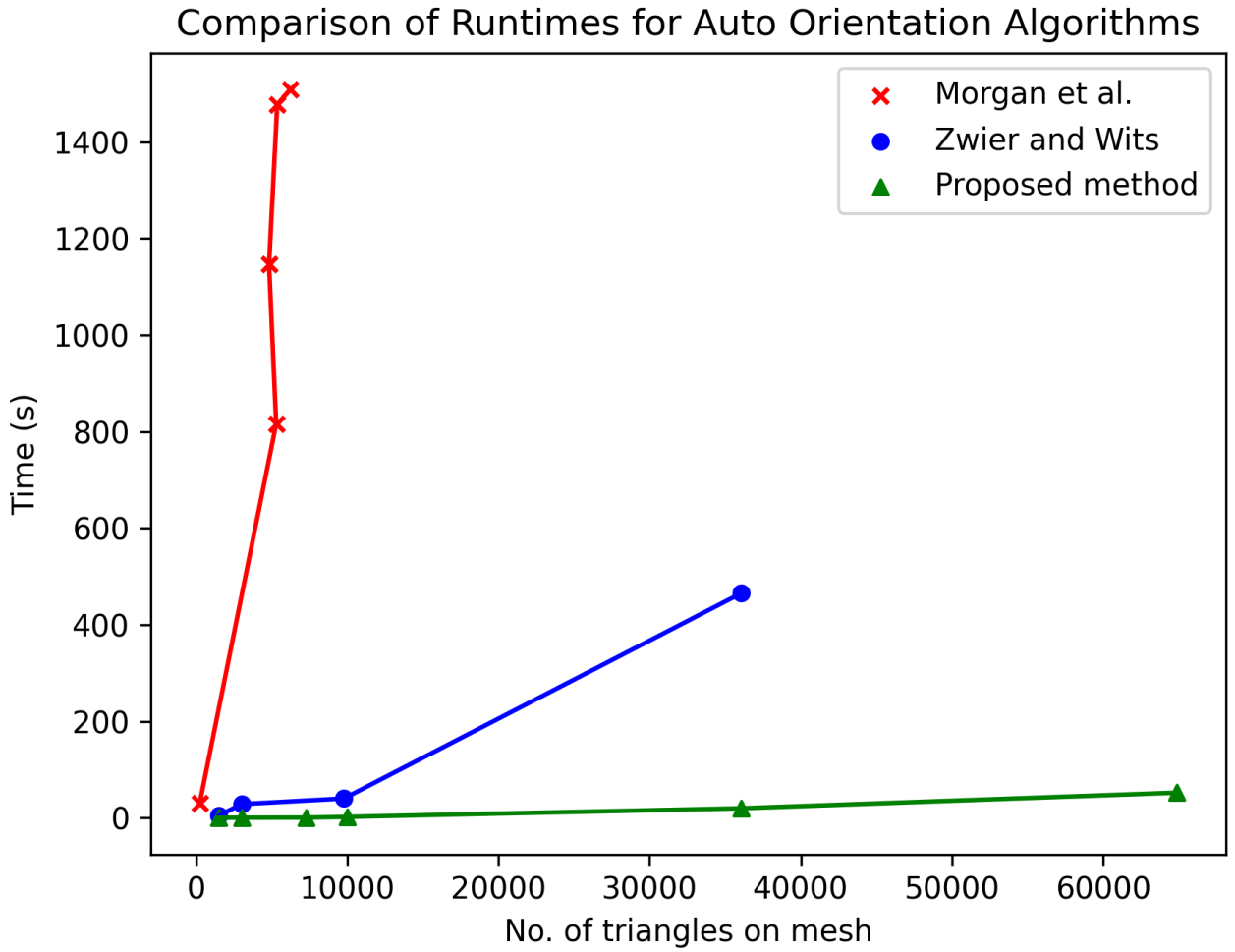
Worst orientation



Best orientation

# Runtime Results

| Design | Triangular Faces | Computation Time (s) |
|---|---|---|
|  | 7,286 | 0.75 |
|  | 64,896 | 11.9 |
|  | 299,256 | 22.6 |
|  | 675,528 | 66.7 |



# Want to try it yourself?

Integrated into **ORNL Slicer 2** as an interactive tool.