15-294 Rapid Prototyping Technologies:
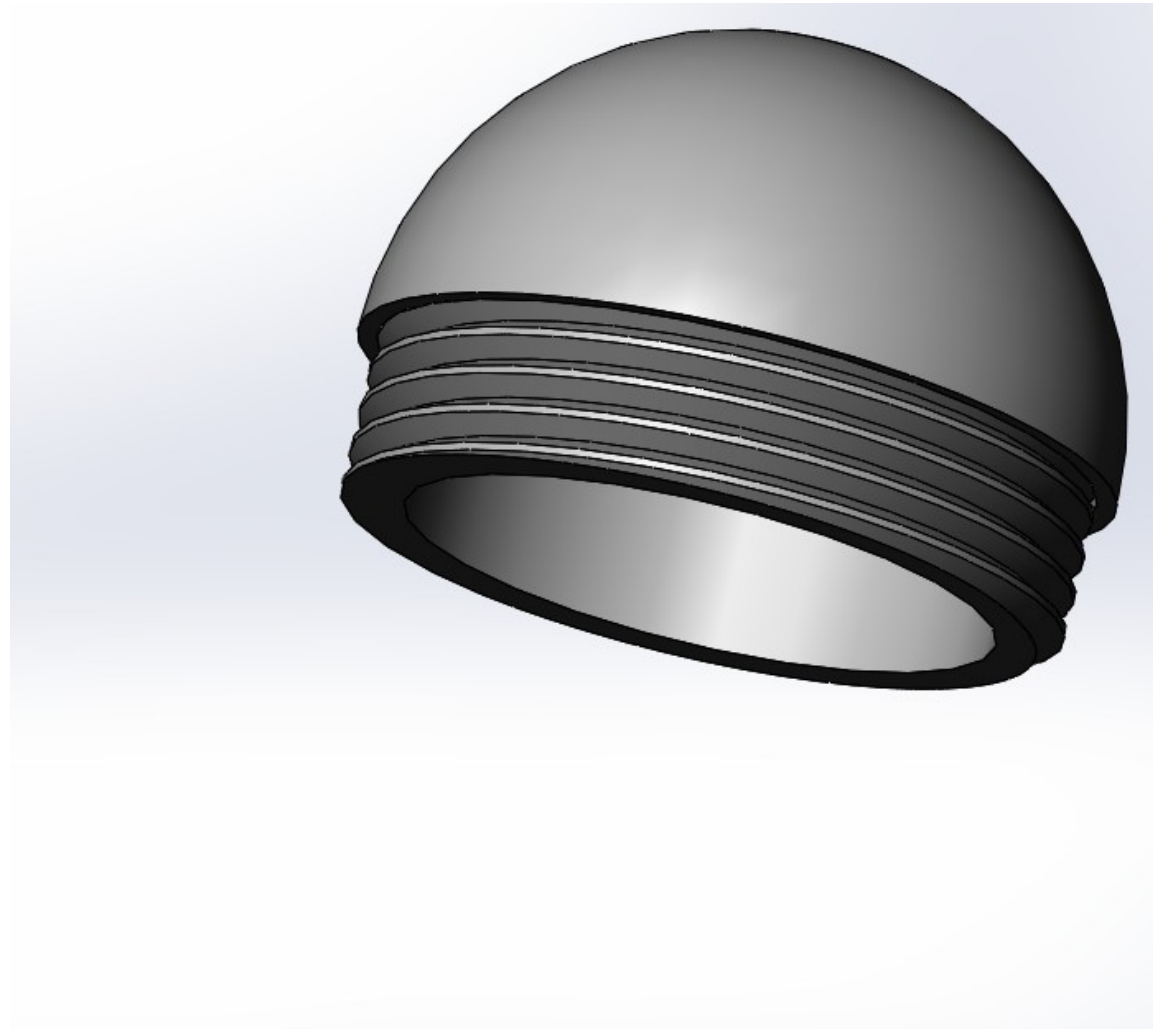
STL Files and Slicing Software

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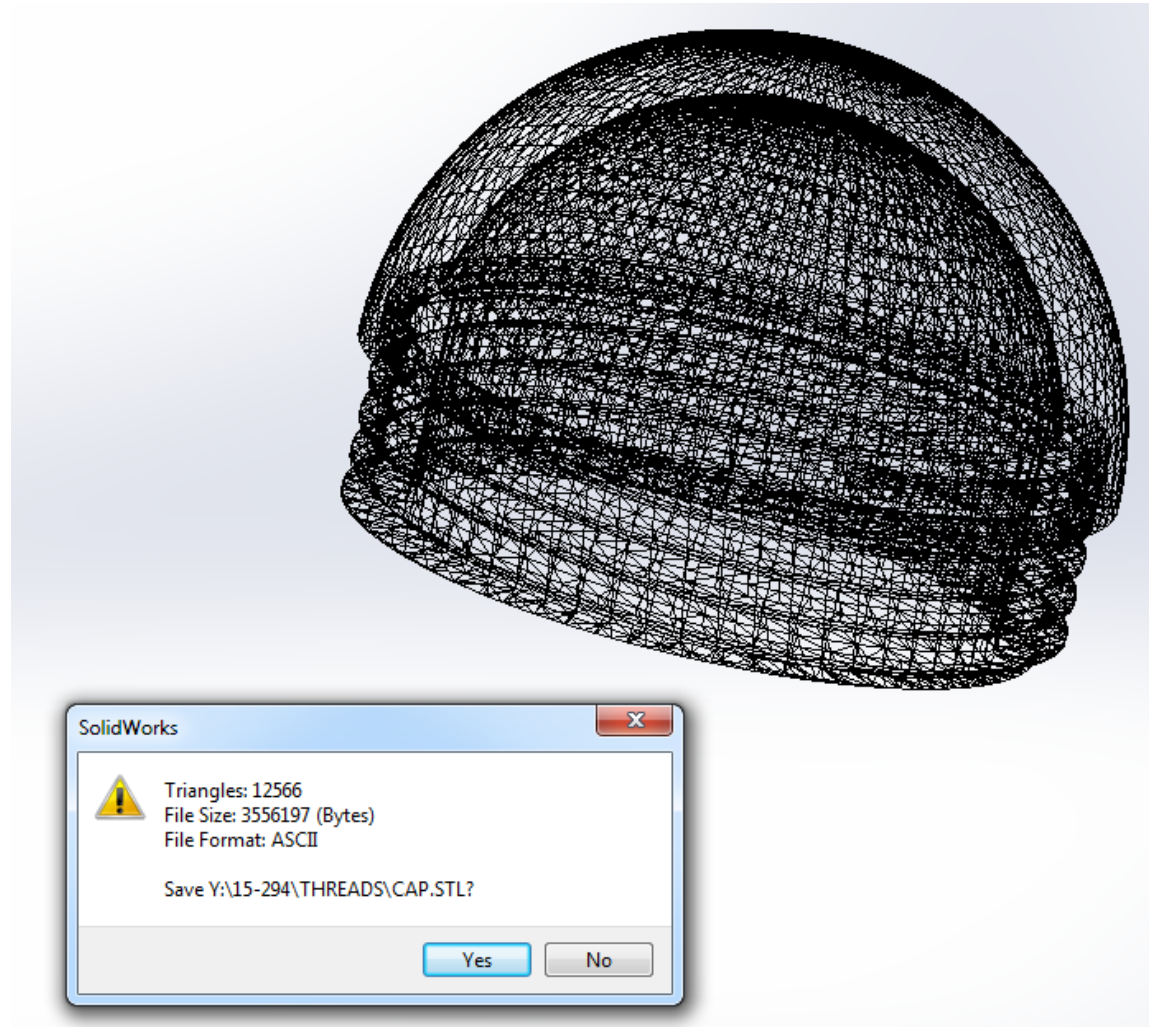Computer Science
Carnegie Mellon University

The STL File Format

- StereoLithography file
    – *or* –
  Standard Tesselation Language

- Originally developed by 3D Systems.

- Now widely used for describing 3D surfaces for CAD or printing.

- Two flavors: ASCII or Binary.

Object With Complex Surfaces

Triangular Tesselation from SolidWorks "Save As STL" Dialog

ASCII STL File

solid *<name>*
facet normal n_i n_j n_k
  outer loop
    vertex $v1_x$ $v1_y$ $v1_z$
    vertex $v2_x$ $v2_y$ $v2_z$
    vertex $v3_x$ $v3_y$ $v3_z$
  endloop
endfacet
…
endsolid *<name>*

Binary STL File

UINT8[80] – Header (must not begin with "solid")

UINT32 – Number of triangles

for each triangle:

    REAL32[3] – Normal vector

    REAL32[3] – Vertex 1 x,y,z

    REAL32[3] – Vertex 2 x,y,z

    REAL32[3] – Vertex 3 x,y,z

UINT16 – Attribute byte count (typically zero)

Some variants of STL store color information in the attribute byte count.

Python Code to Write STL Files

- See demo files in class STL directory.

- Rules for STL creation:
  - Triangles are flat (planar). To make a curved surface, use more triangles.
  - Every vertex belongs to at least two triangles.
  - No vertex can touch an edge of another triangle.
  - Vertices should be in counter-clockwise order when viewed from the exterior of the object.

Example: Making a Cube

s = 3.0   # length of a side

Eight corner points of a cube

p1 = (0, 0, 0)
p2 = (0, 0, s)
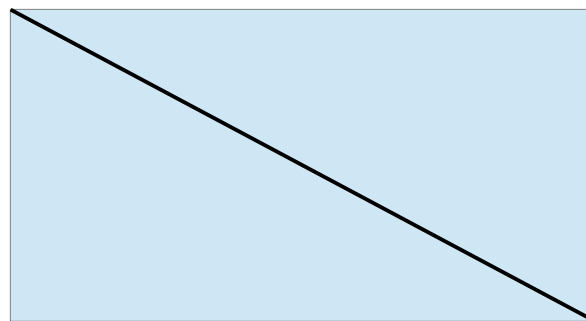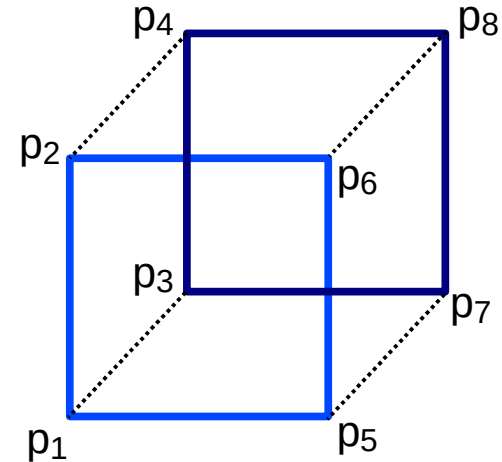p3 = (0, s, 0)
p4 = (0, s, s)
p5 = (s, 0, 0)
p6 = (s, 0, s)
p7 = (s, s, 0)
p8 = (s, s, s)

Cube Faces

Six faces of a cube; each face yields two triangles.
Vertices must be in counter-clockwise order.

```
[
    [p1, p3, p7, p5],
    [p1, p5, p6, p2],
    [p5, p7, p8, p6],
    [p7, p3, p4, p8],
    [p1, p2, p4, p3],
    [p2, p6, p8, p4],
]
```
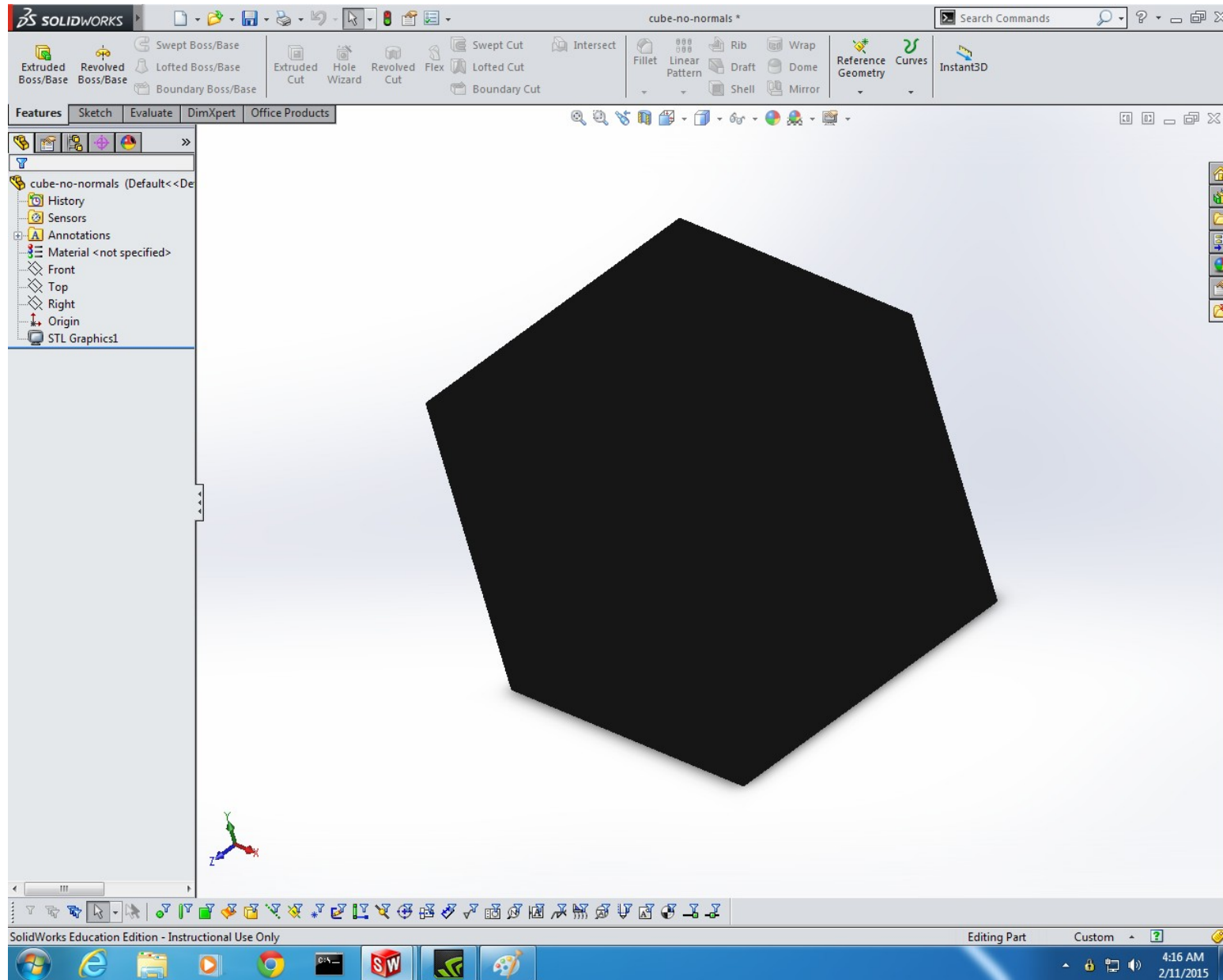

Dividing a rectangle into two triangles.
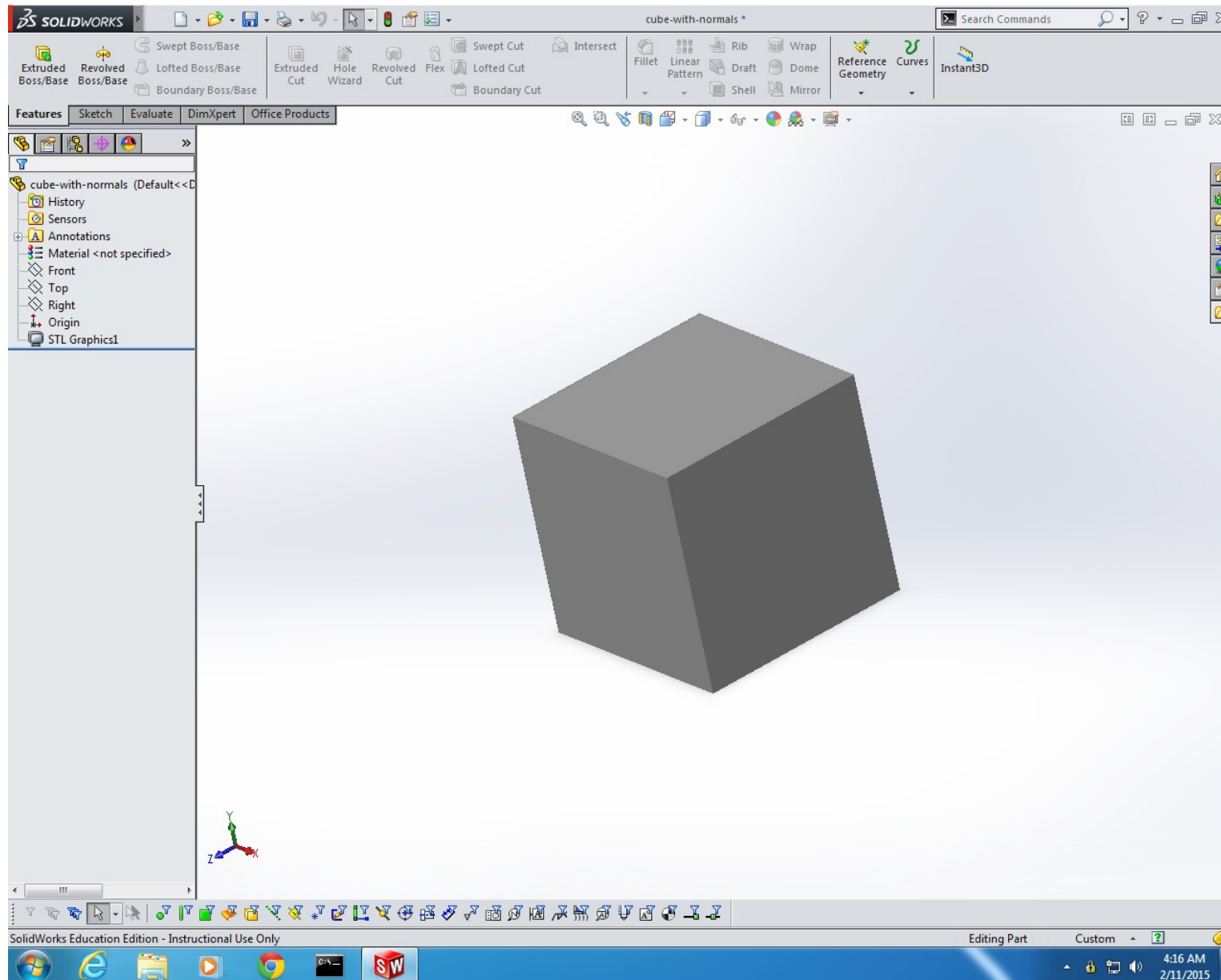
Writing the STL File: cube_demo.py

```
with open('cube.stl', 'wb') as fp:
    writer = ASCII_STL_Writer(fp)
    writer.add_faces(get_cube())
    writer.close()
```
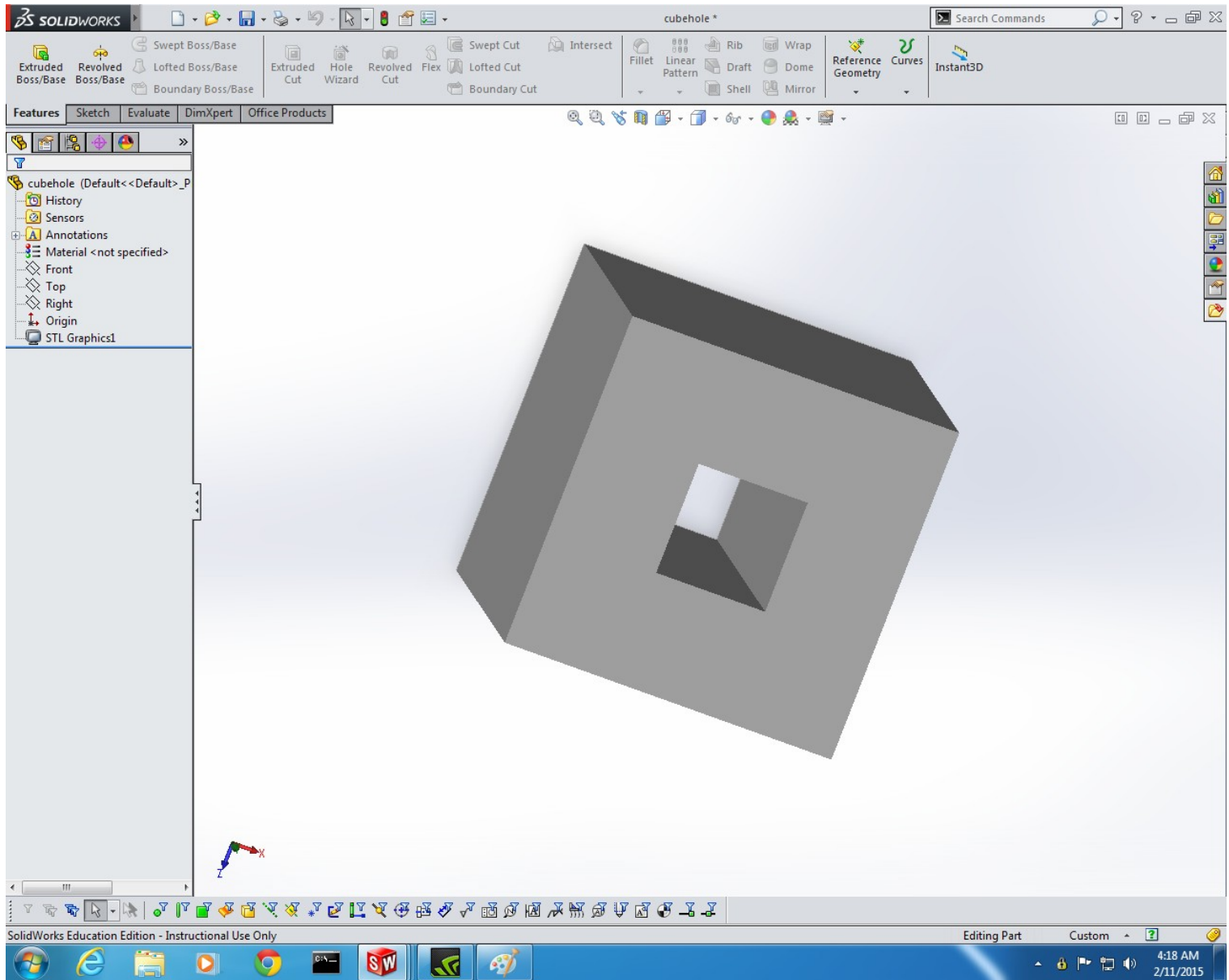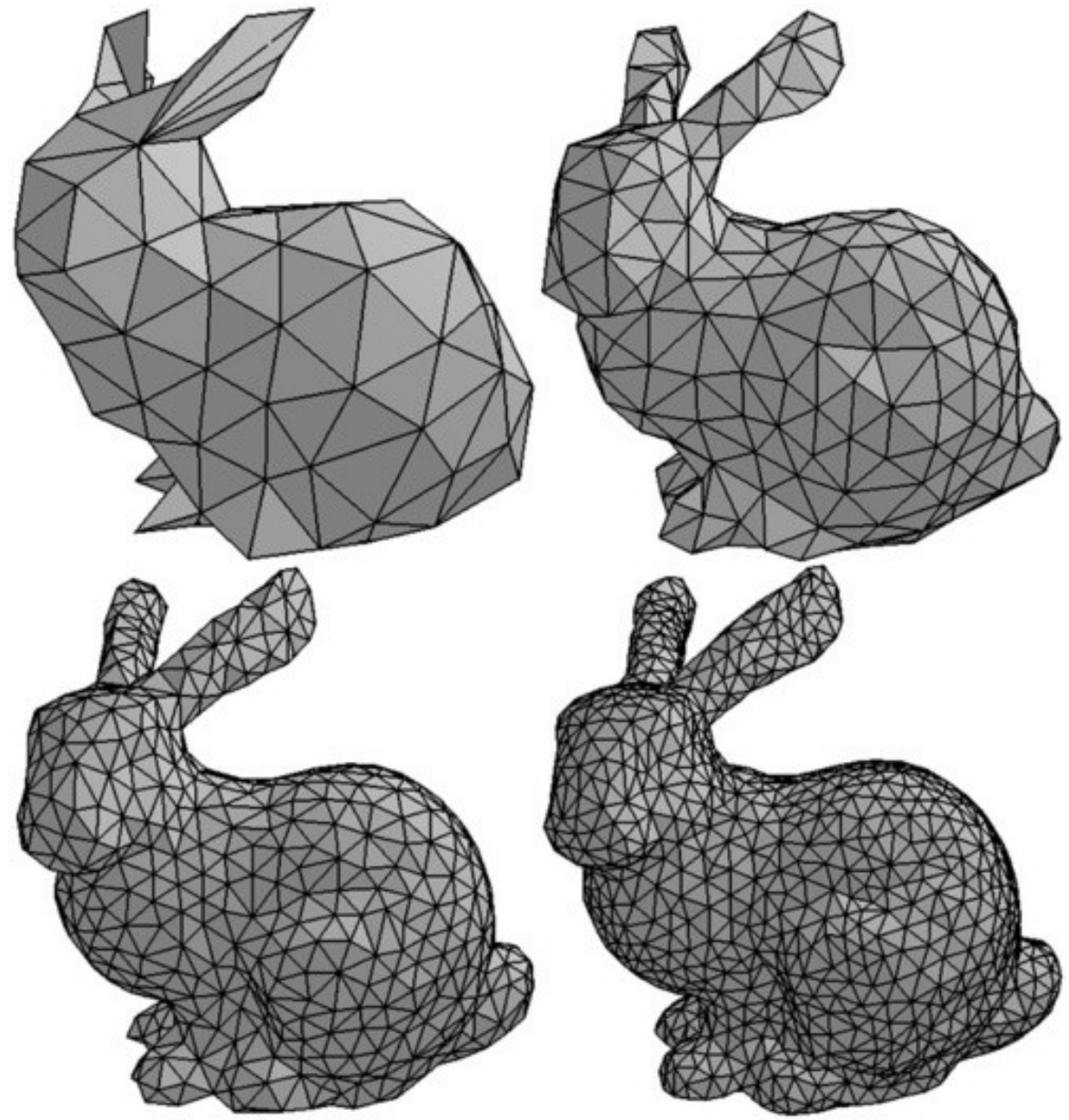
With Zero Surface Normals
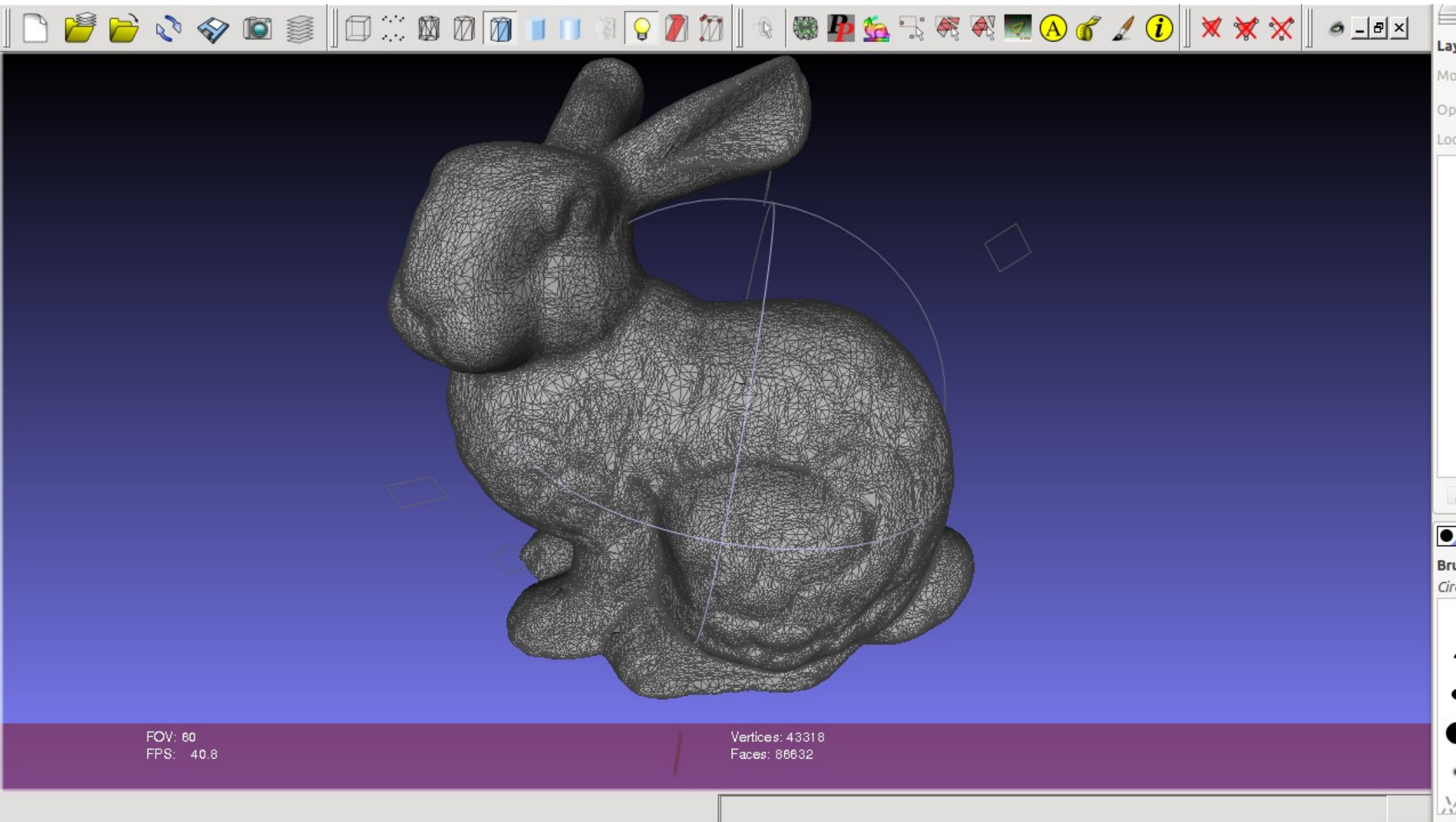
With Proper Surface Normals

Cube With a Hole In It

The Stanford Bunny: Low Res

MeshLab: Hi-Res Bunny

FOV: 60
FPS: 40.8

Vertices: 43318
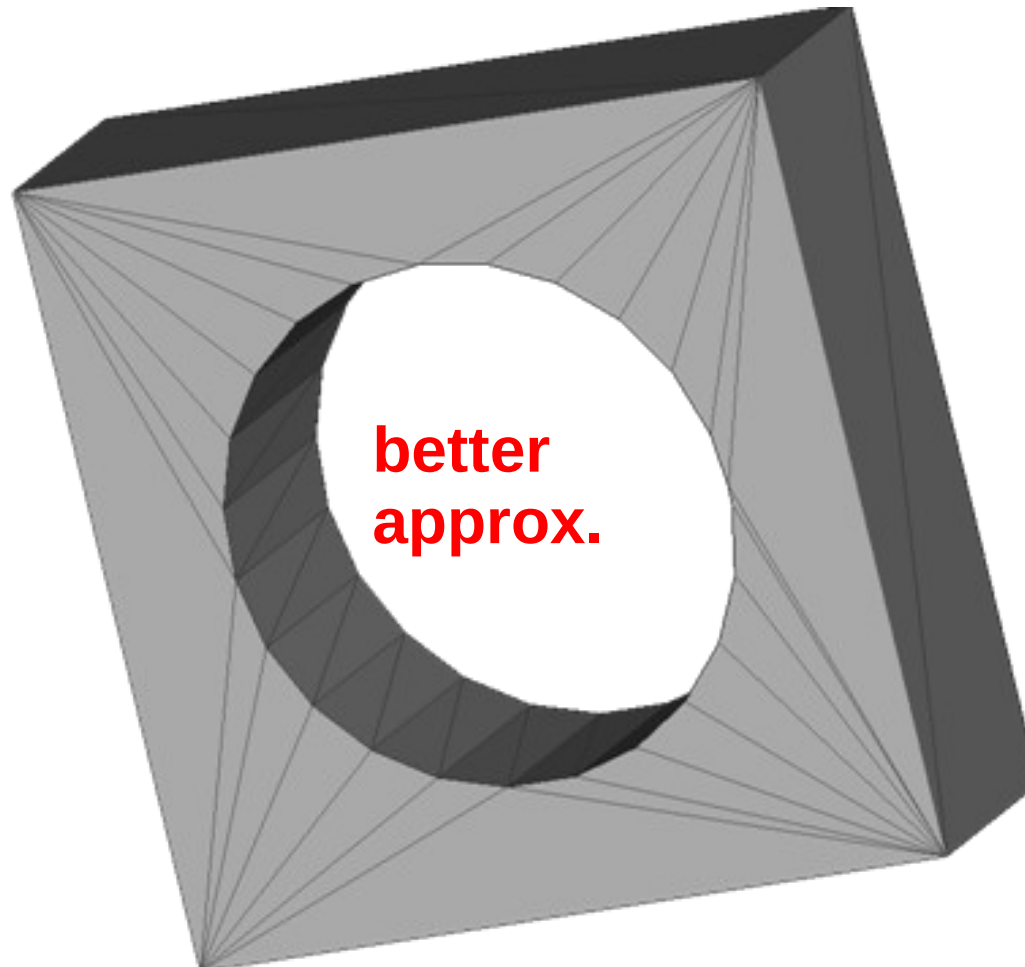Faces: 86632

Zooming In with MeshLab
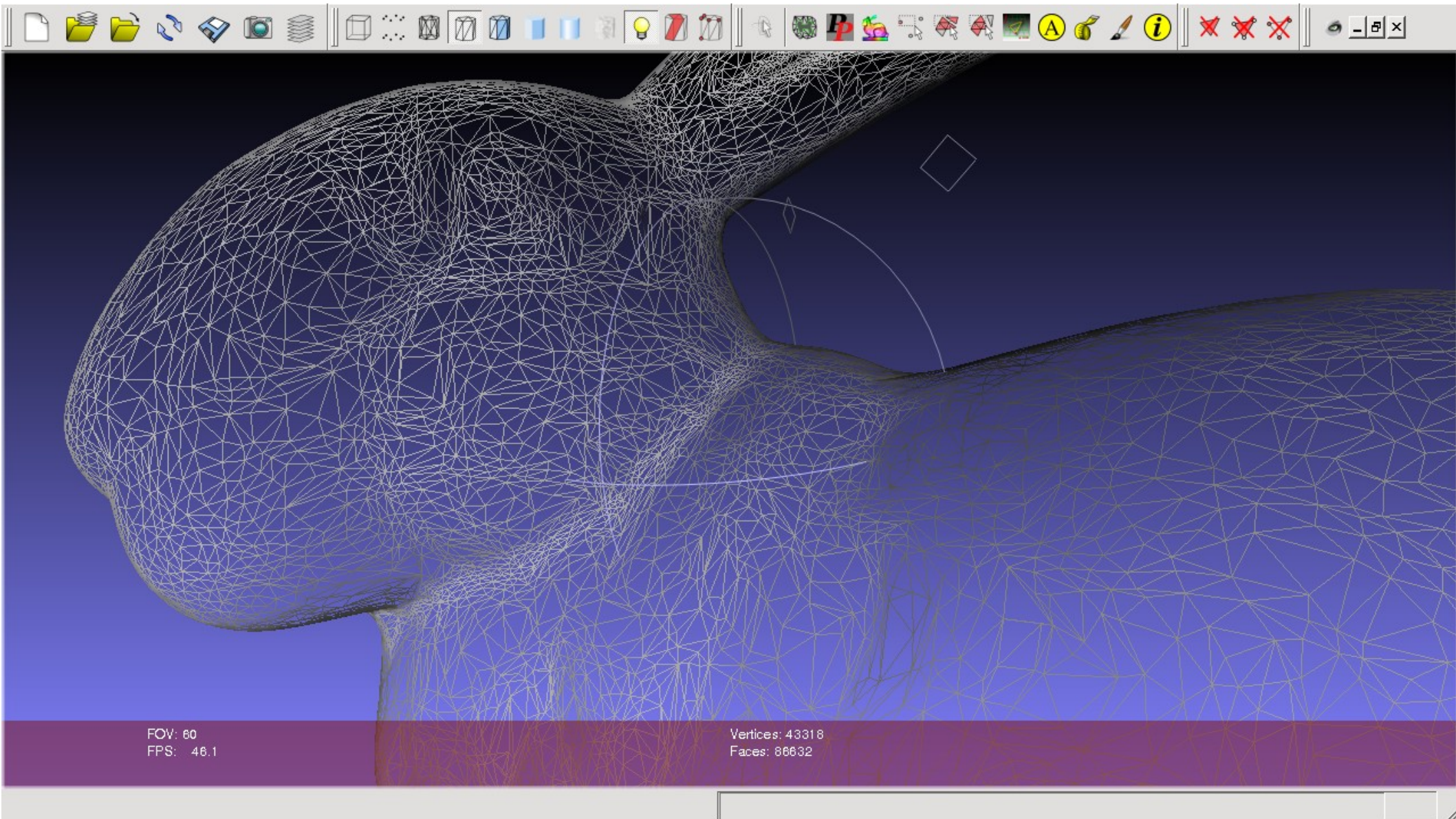
Triangulation: Resolution 0.1 Inches

2 inch round hole

coarse approx.

Resolution 0.01 Inches

better approx.

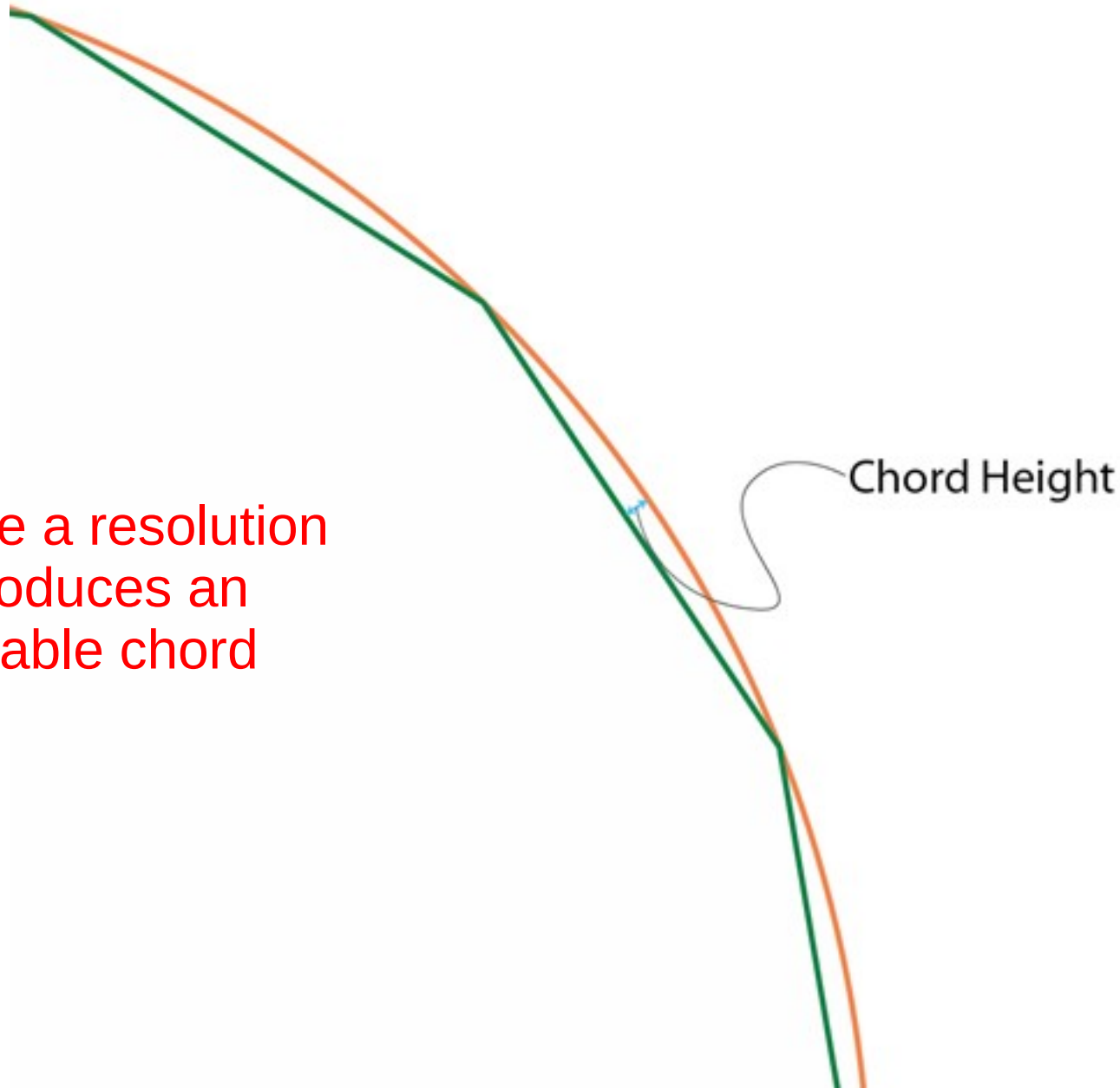# Resolution 0.001 Inches

smooth approx.
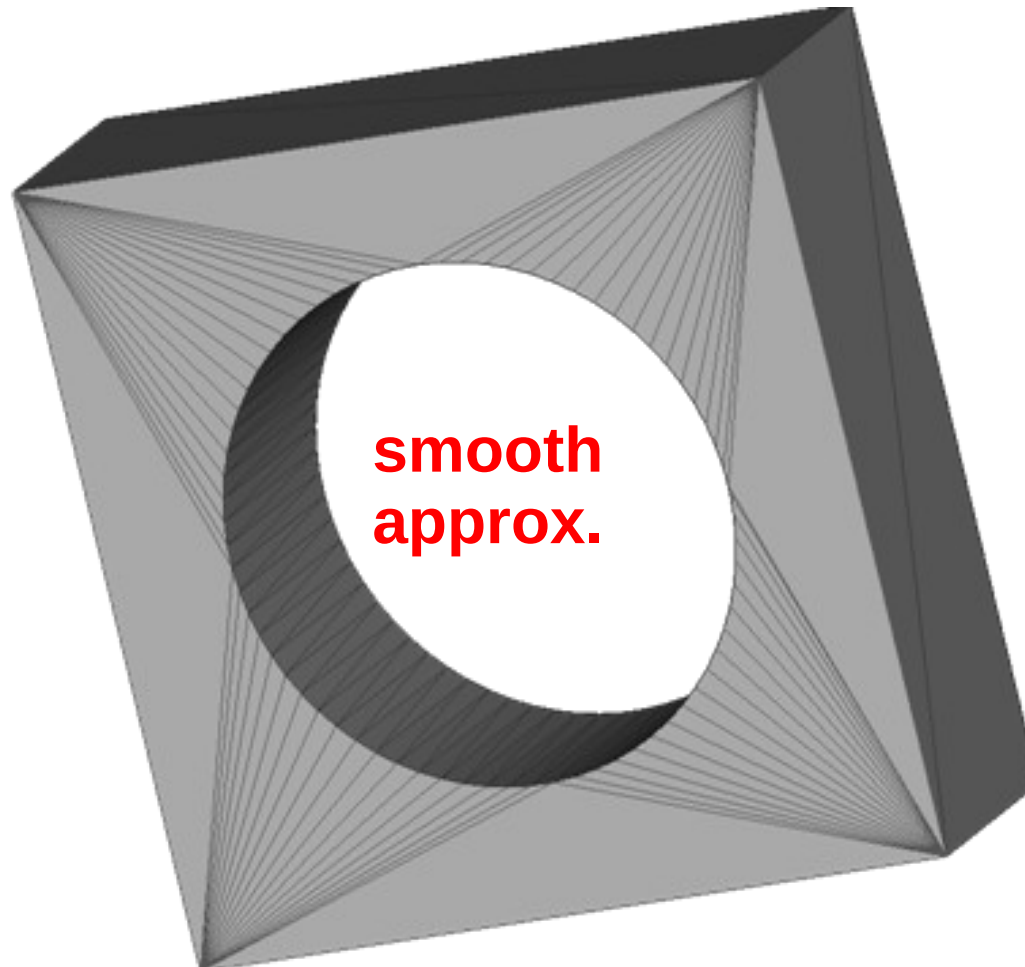
Resolution 0.0001 Inches

too
much
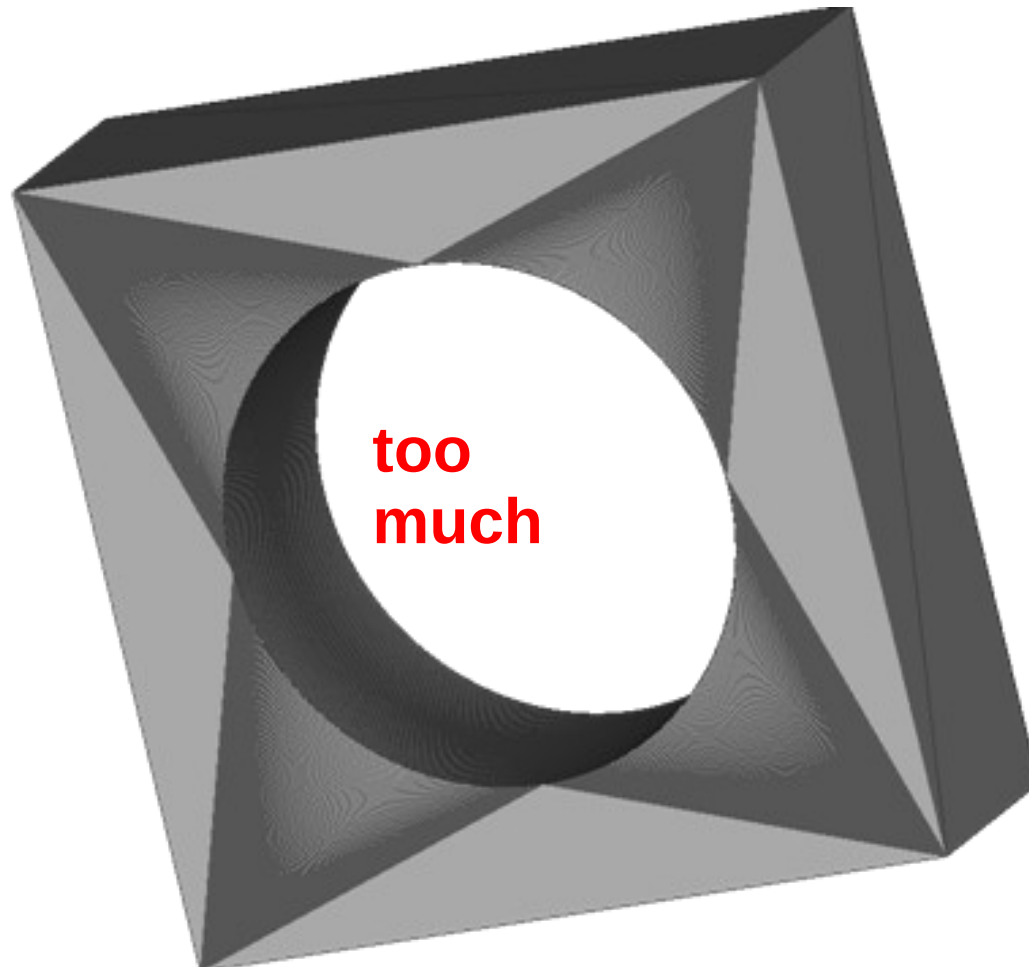
# Chord Height = Max Distance from Actual Surface to the Facet

Choose a resolution that produces an acceptable chord height.
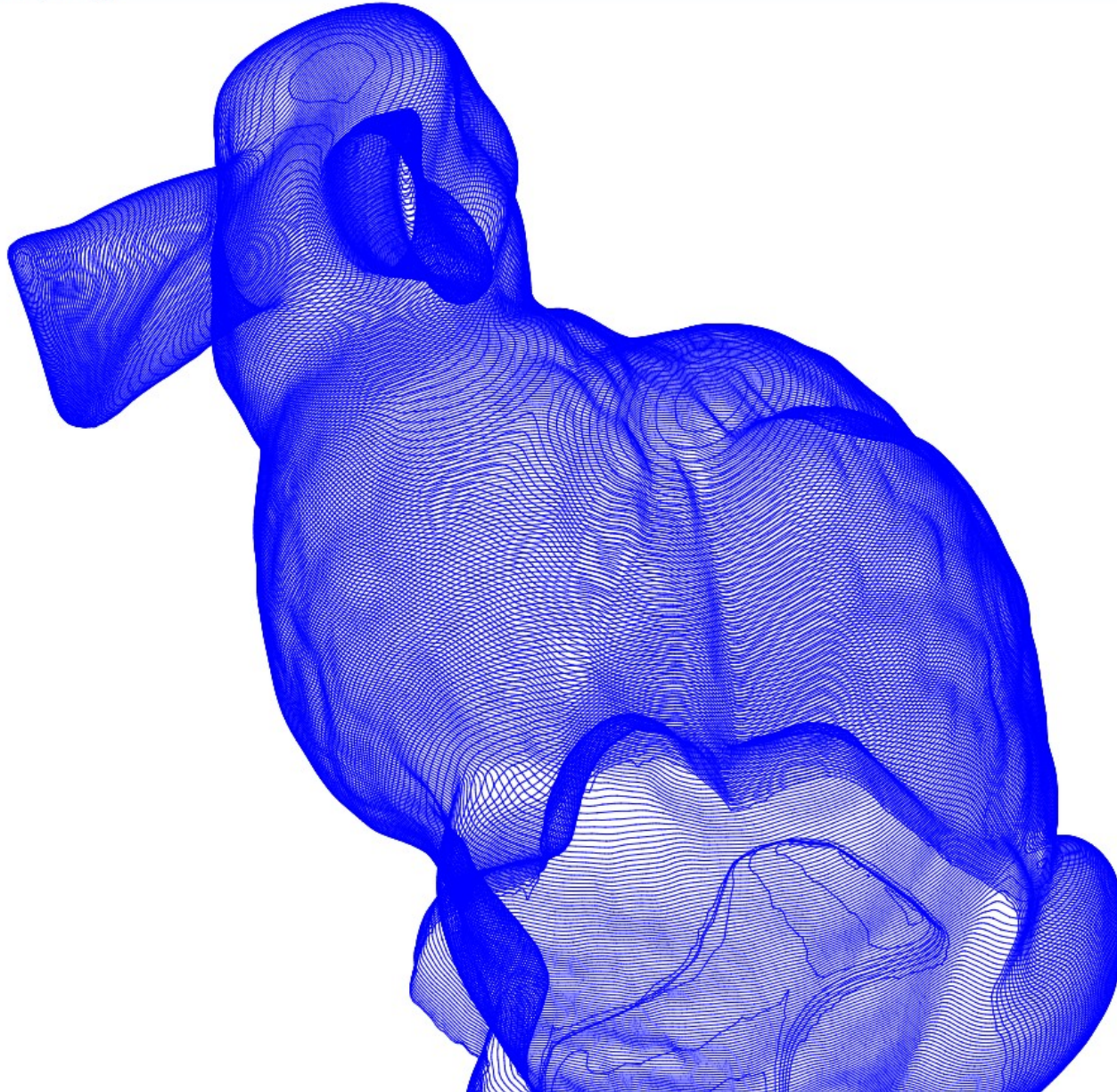
Chord Height

3D Printing Tool Chain (Simplified)

- Shell the object.

- Add infill (internal lattice) for strength.

- Add supports and raft if requested.

- Slice the object into layers.

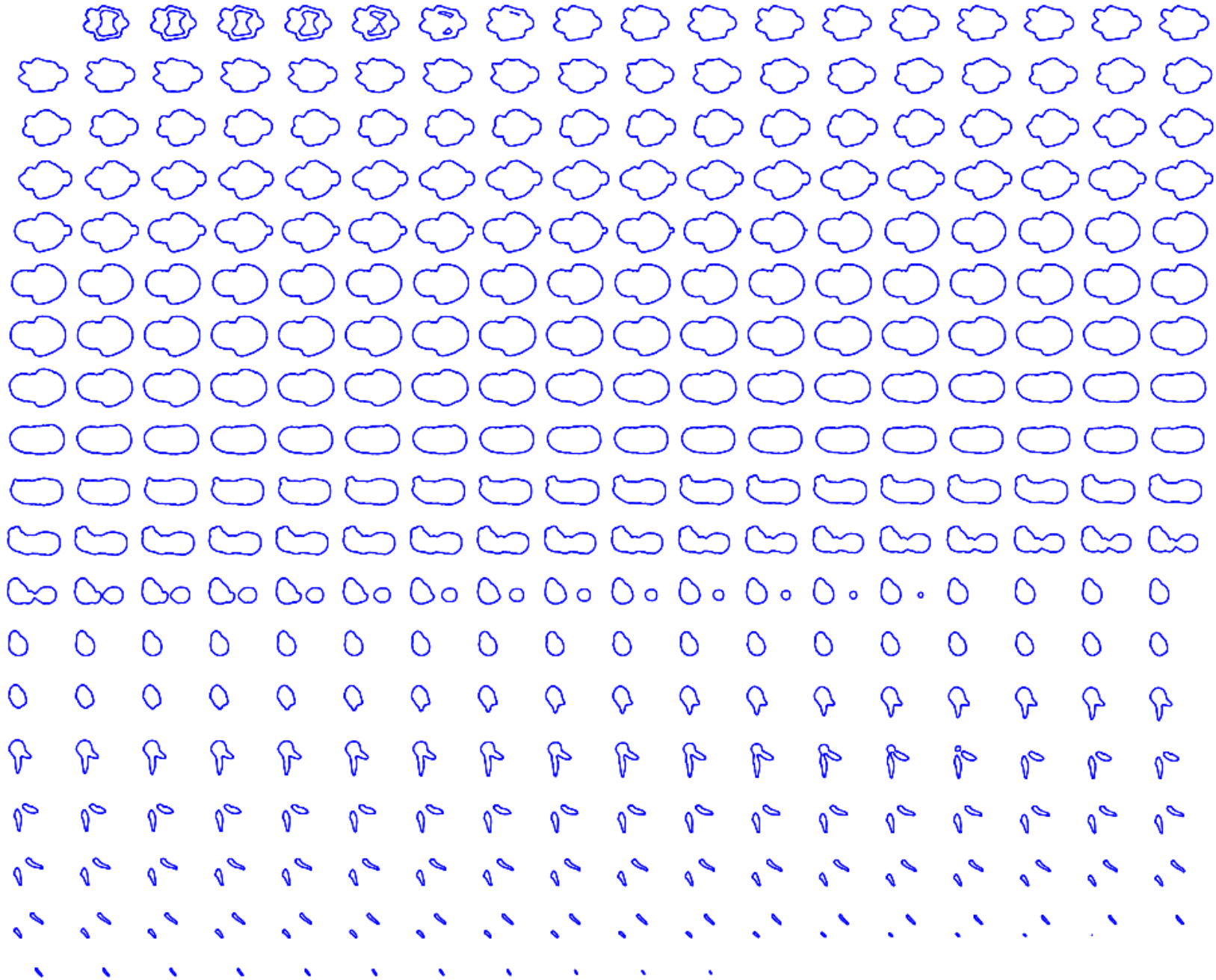- For each layer, compute a "tool path" for the extruder to follow.

Slicing the Bunny
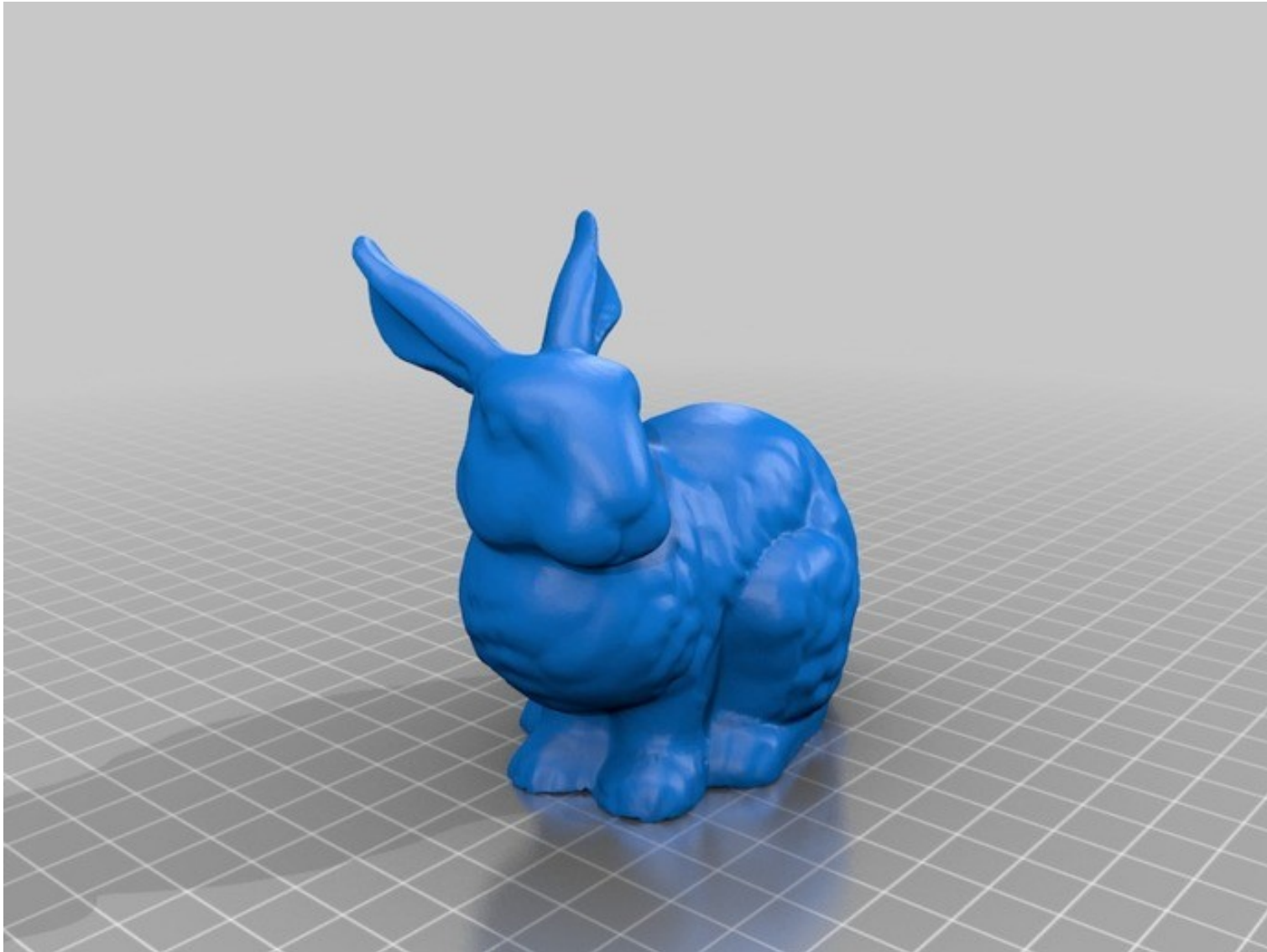
Sliced Bunny

Bunny Slice Outlines

Ears →

25

Slicing Algorithm

- Given the cutting plane orientation and the bounding box of the object, determine the number of slices (cutting planes).

- For each triangle in the mesh:

  - For each cutting plane:

    - Compute the intersection of the cutting plane and the triangle.
    - If the intersection contains exactly 2 points, add that line to the list of line segments for that cutting plane.

- For each cutting plane:

  - Assemble the list of line segments to form a set of continuous lines. These will be converted to tool paths.

Does the Triangle Intersect the Cutting Plane?
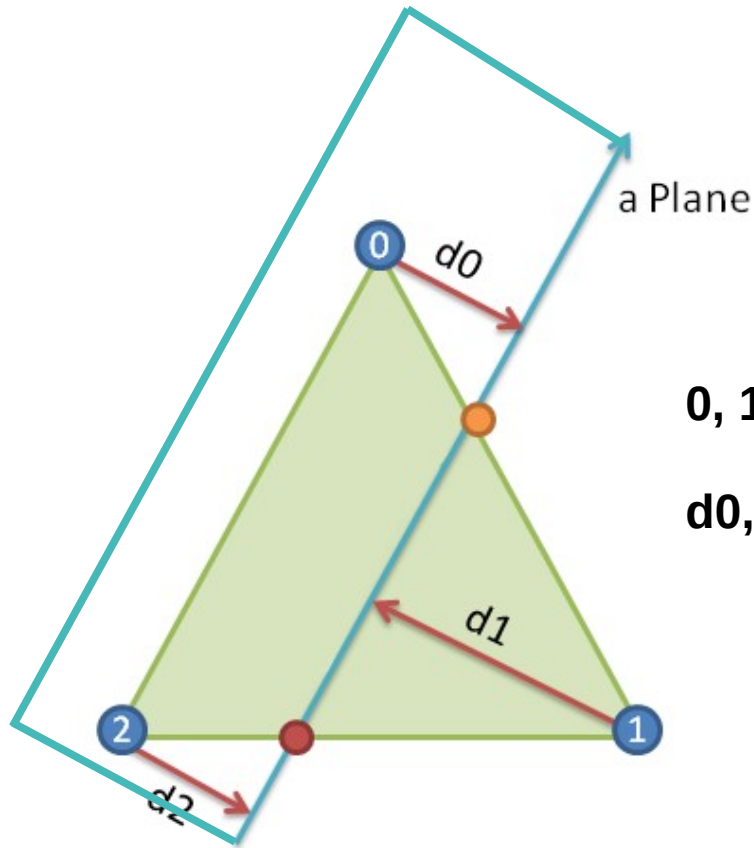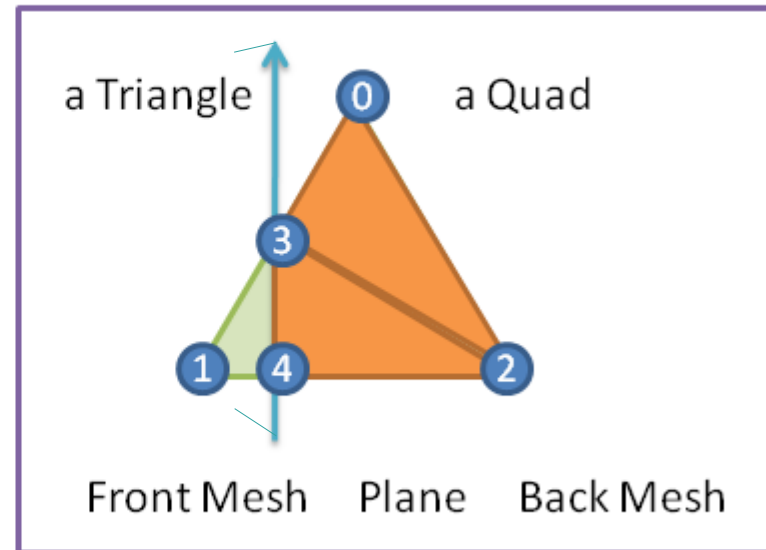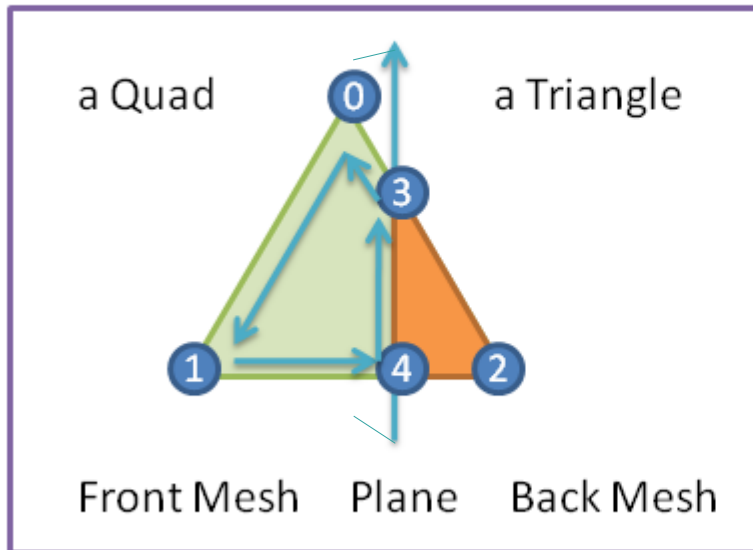

a Plane

0, 1, 2 – triangle vertices

d0, d1, d2 – distance of vertex from cutting plane

A **Plane** has {v3 normal, float distance}
Distance from vertex to plane: vertex.dotproduct(plane.normal) – plane.distance

Figure from ravehgonen.wordpress.com.

Triangle Slicing – 4 Cases

Front Mesh   Plane   Back Mesh

Front Mesh   Plane   Back Mesh

a Quad   a Triangle

Front Mesh   Plane   Back Mesh

a Triangle   a Quad

Front Mesh   Plane   Back Mesh
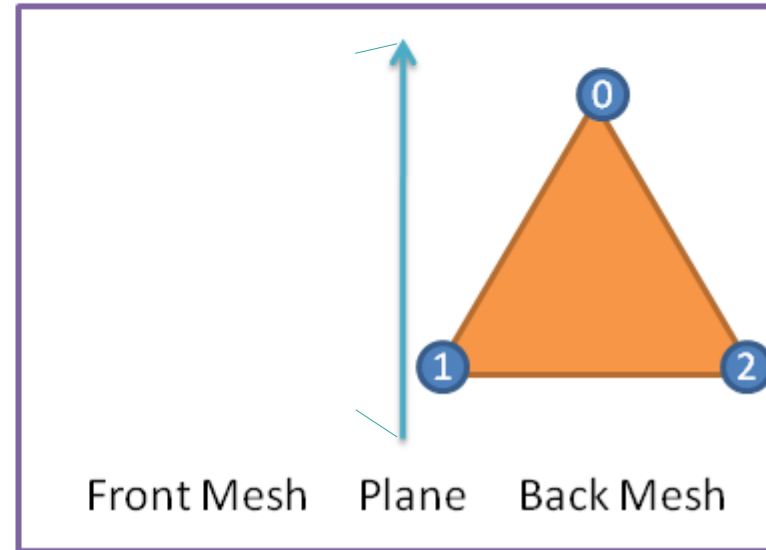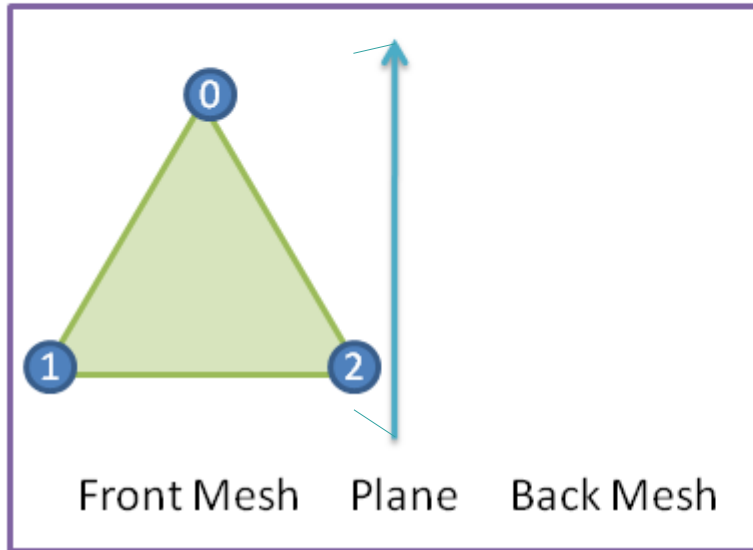
* There are more degenerate cases (The plane "falls" on one of the original vertices –>no quad generated)

Figure from ravehgonen.wordpress.com.

Algorithm Outline

for_each △ 'T' in Triangle Mesh △ 'TM' **do**

    for_each ☐ Plane 'P' in Planes (model.z0..model.z1) **do**

        If (all distances from T vertices to P <0) -> T is on **back Plane**

        If (all distances from T vertices to P >0) -> T is on **front Plane**

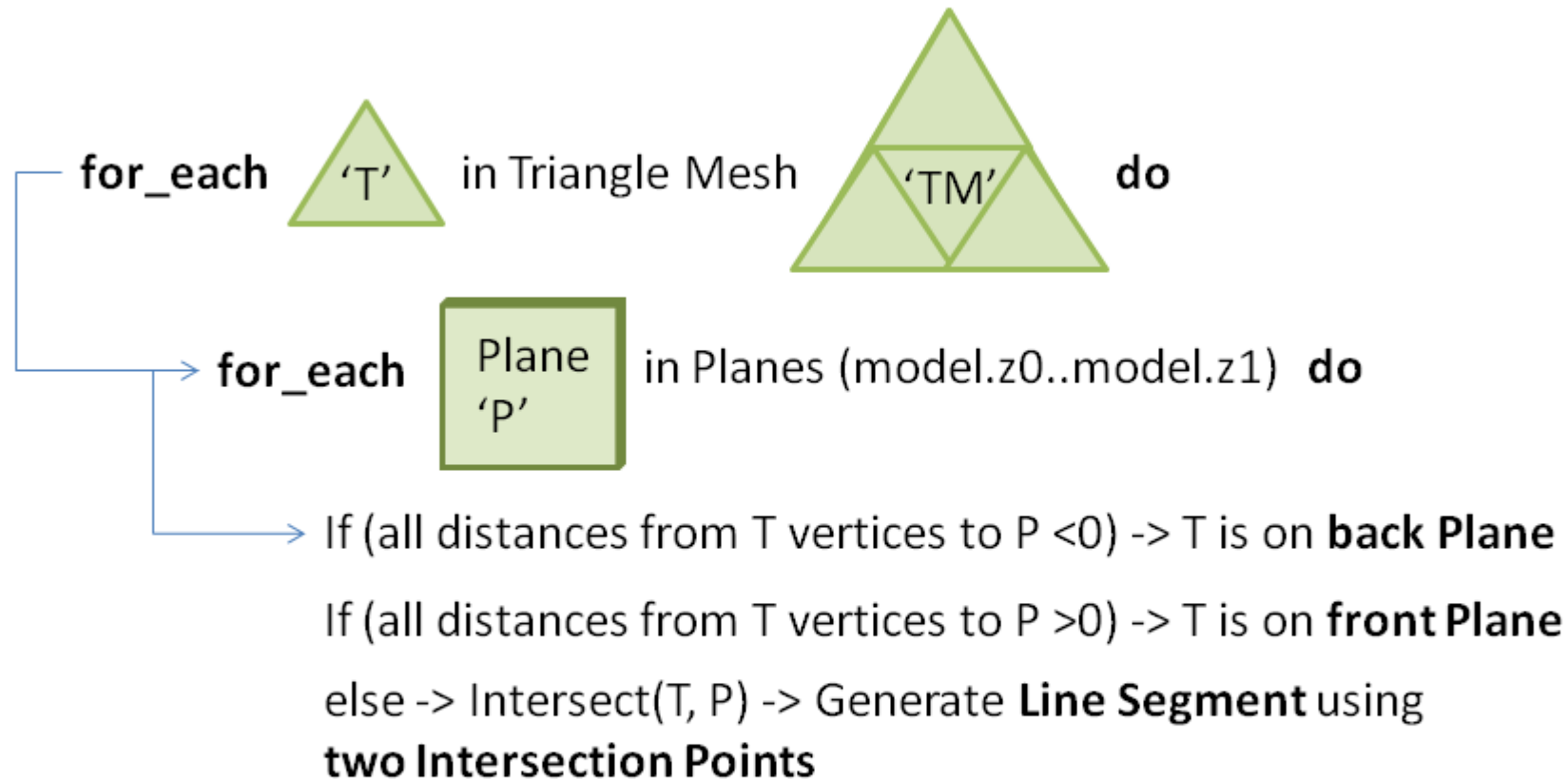   else -> Intersect(T, P) -> Generate **Line Segment** using **two Intersection Points**
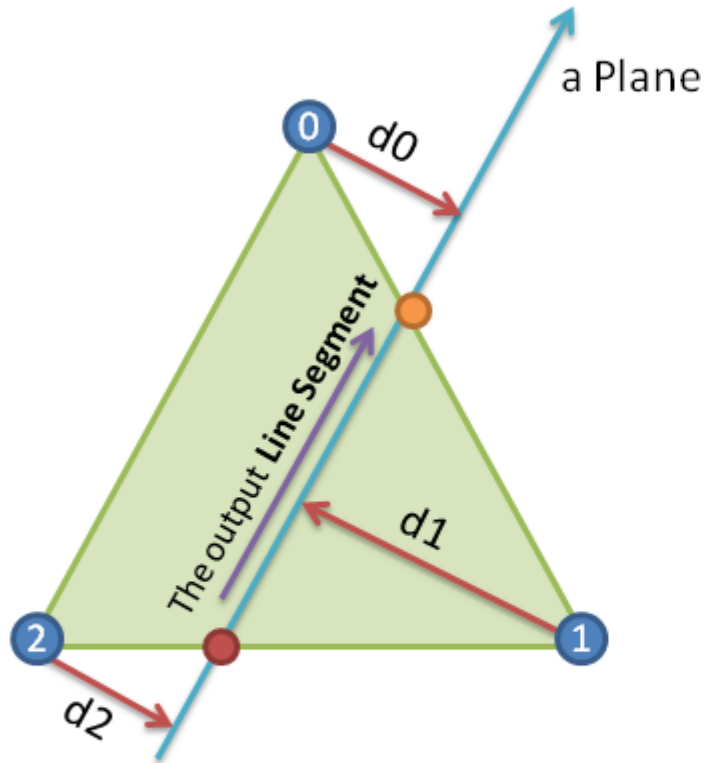
Figure from ravehgonen.wordpress.com.

A **Plane** has {v3 normal, float distance}
Distance from vertex to plane: vertex.dotproduct(plane.normal) − plane.distance

Finding Triangle Plane Intersection

a Plane

If (d0*d1<0)

s10 = d1/(d1-d0)   s21 = d2/(d2-d1)

🟠 Intersection points = LinearInterp(1, 0, s10)

🔴 Intersection points = LinearInterp(2, 1, s21)

——— Output line segment

Figure from ravehgonen.wordpress.com.

A **Plane** has {v3 normal, float distance}
Distance from vertex to plane: vertex.dotproduct(plane.normal) − plane.distance

GCcode

- The output of the slicer program is typically a GCode file.

- GCode is used in many types of CNC machines. (CNC = Computerized Numerical Control)

- Includes commands to move the extruder to specified (x,y,z) coordinates, feed (or stop feeding) plastic, etc.

Popular Slicing Programs

- Slic3r
- Cura
- KISSlicer
- Skeinforge