Additive Manufacturing Technology and Trends

MCA Session Topic: CAD to CAM

6/20/25

Instructors:

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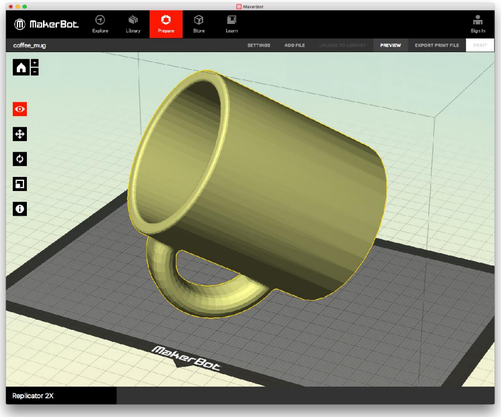
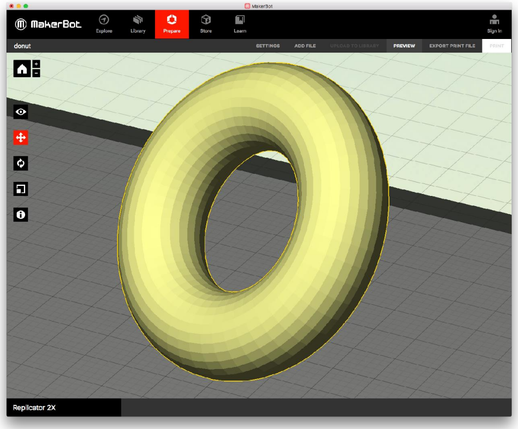
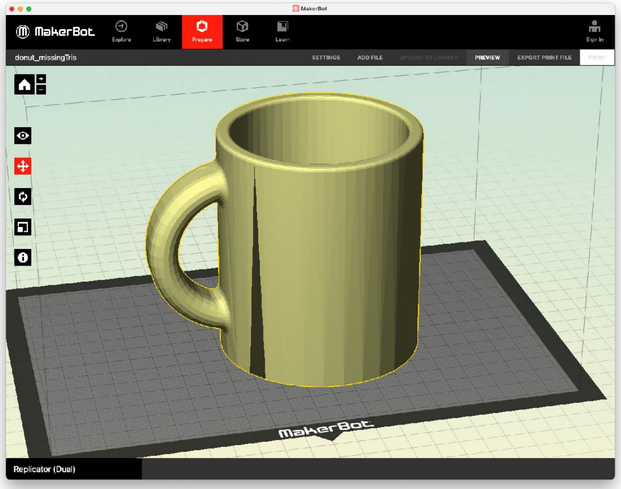
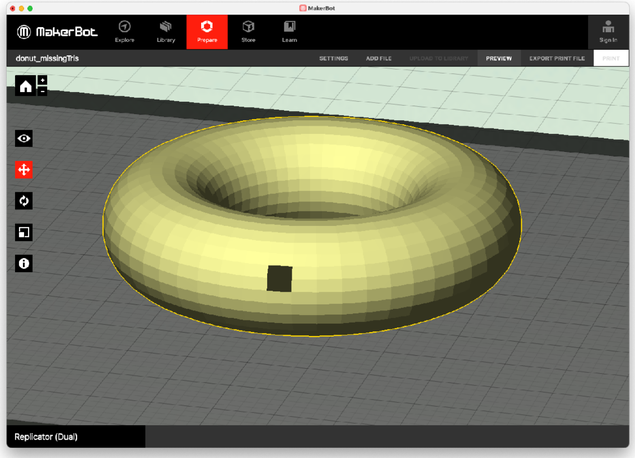
Activity #1

- 3D printer training with Alex (30 minutes)
- 3D printing software training with Spencer and Chloe
  - 30 minutes Cura
  - 30 minutes Prusaslicer)
  - Good mug and donut then bad mug and donut 3D models









Eight Steps[1] in Additive Manufacturing

1. Conceptualization and CAD
2. Conversion to STL/AMF
3. Transfer to AM Machine and STL File Manipulation
4. Machine Setup
5. Build
6. Removal and Cleanup
7. Post-Processing
8. Application

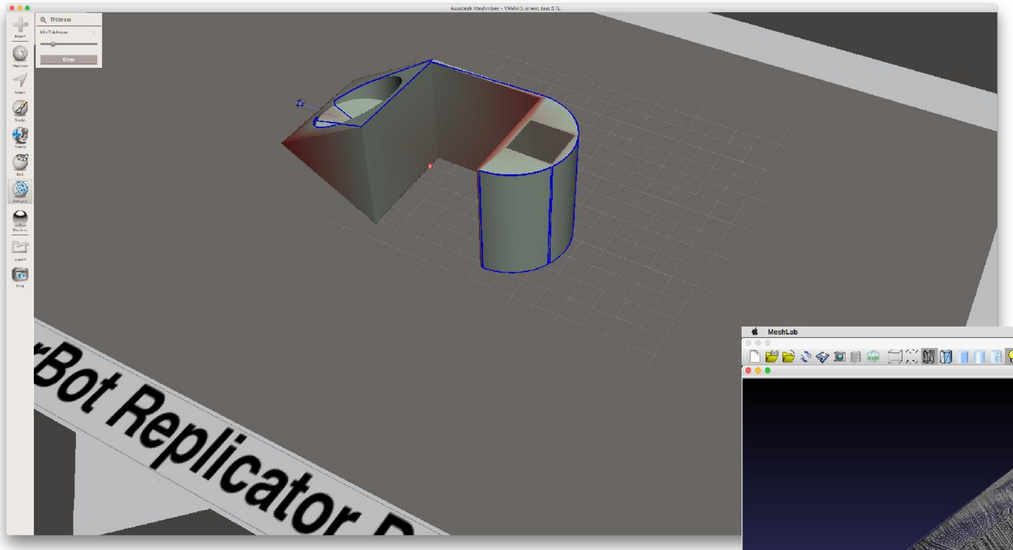
Legend:		
CAD	Machine	Post Process(es)

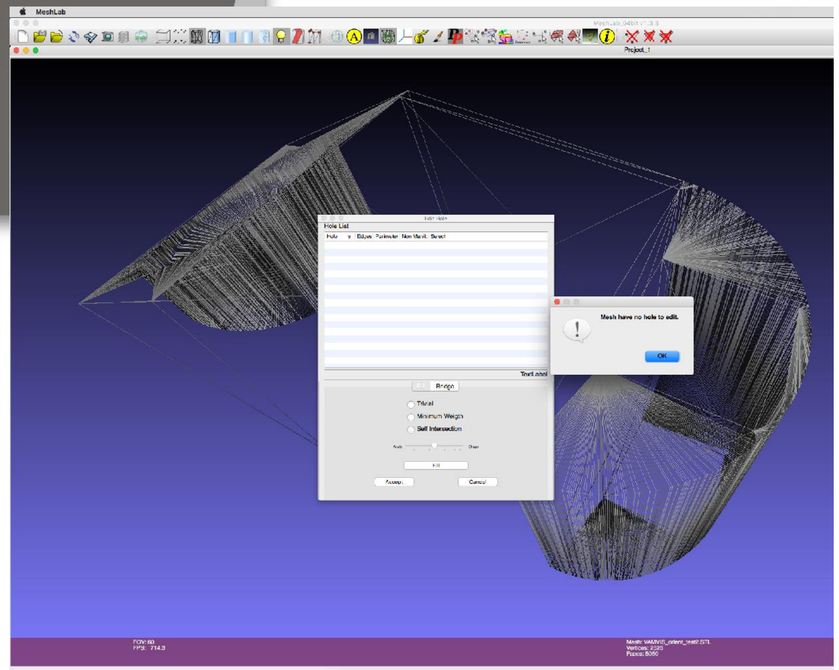
- The **rapid** part of the process
- Users **assume** Additive Manufacturing is the **best** solution.
- Expenses and potential cost savings are **high**.

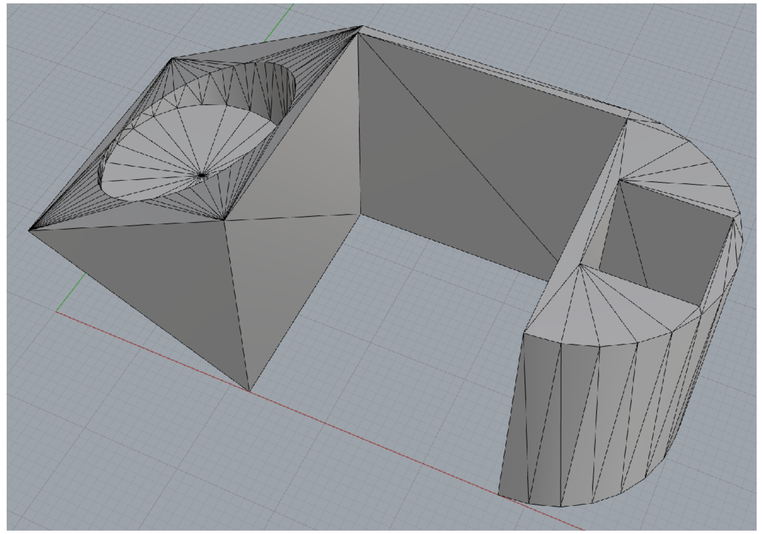
1) Gibson, Ian, David W. Rosen, and Brent Stucker. *Additive manufacturing technologies*. Vol. 238. New York: Springer, 2010.

Near-CAD Model Analyses

- Does not open in 3D printer software?
- Does open but does not print “well”?
- Is there an intermediate step?
- If so: what else can you do as the designer…?



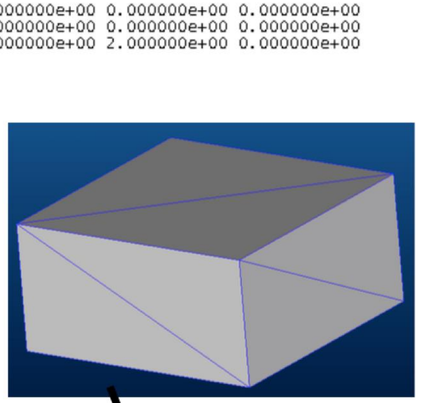


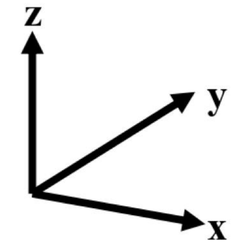


Rules Make STL Files Good

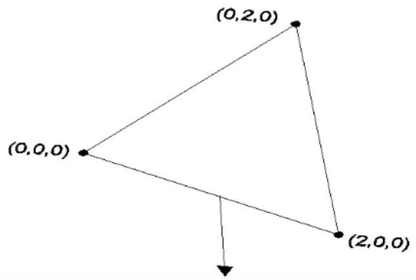
- Calculated Normals
  - Normals calculated with cross-product
  - Normals generated during export and stored with each facet's vertex information
- Vertex to Vertex Rule
  - Every triangle must share exactly two vertices with each adjacent triangle.
  - Every segment must be shared by two and only two triangles

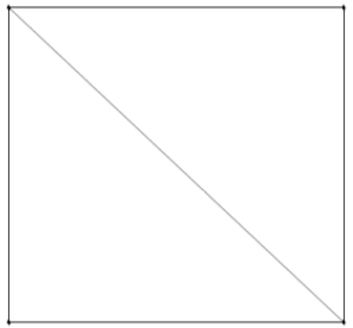
```
solid BOX3
  facet normal 0.000000e+00 0.000000e+00 -1.000000e+00
    outer loop
      vertex 2.000000e+00 0.000000e+00 0.000000e+00
      vertex 0.000000e+00 0.000000e+00 0.000000e+00
      vertex 0.000000e+00 2.000000e+00 0.000000e+00
    endloop
  endfacet
```



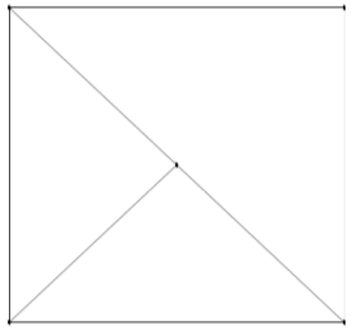


*The facet normal always points to the "outside"





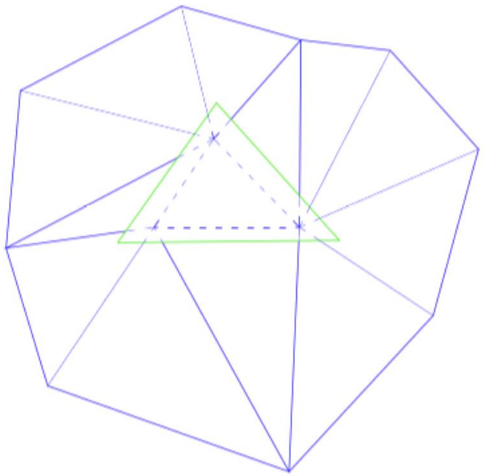
VALID



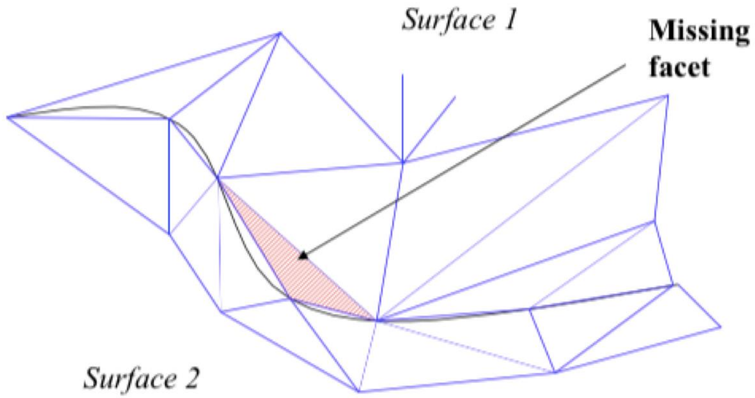
INVALID

STL Tessellation Errors

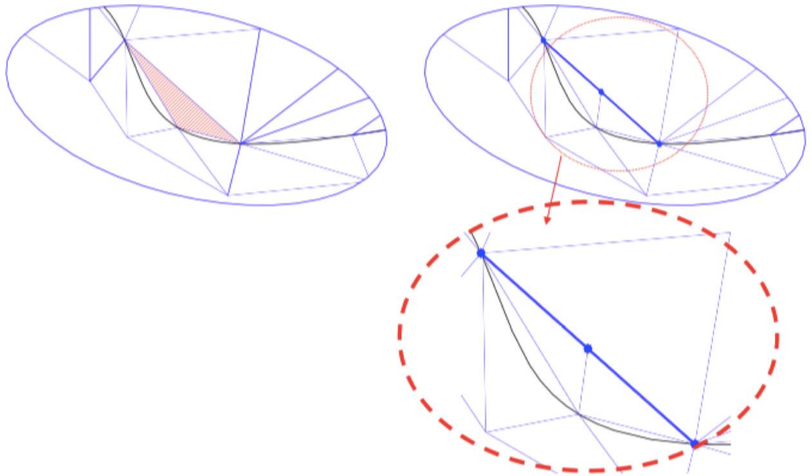
Overlapping Facets



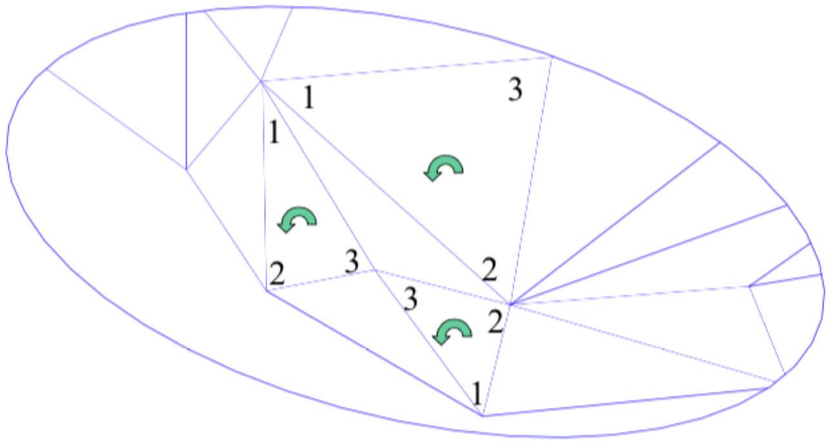
Missing Facets

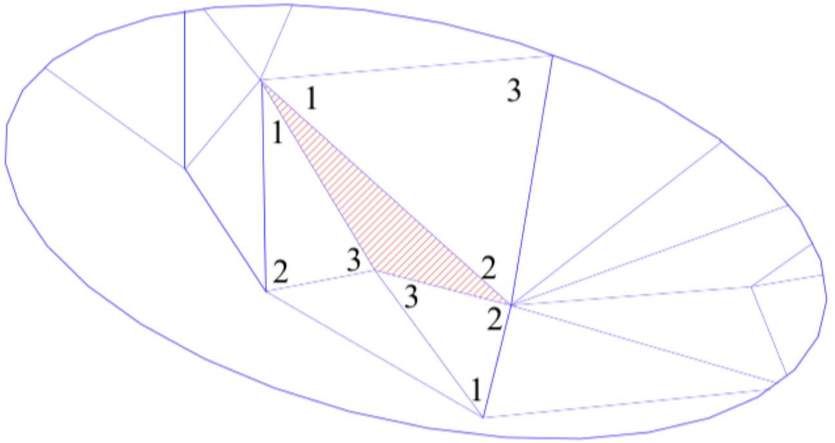


Degenerate Facets



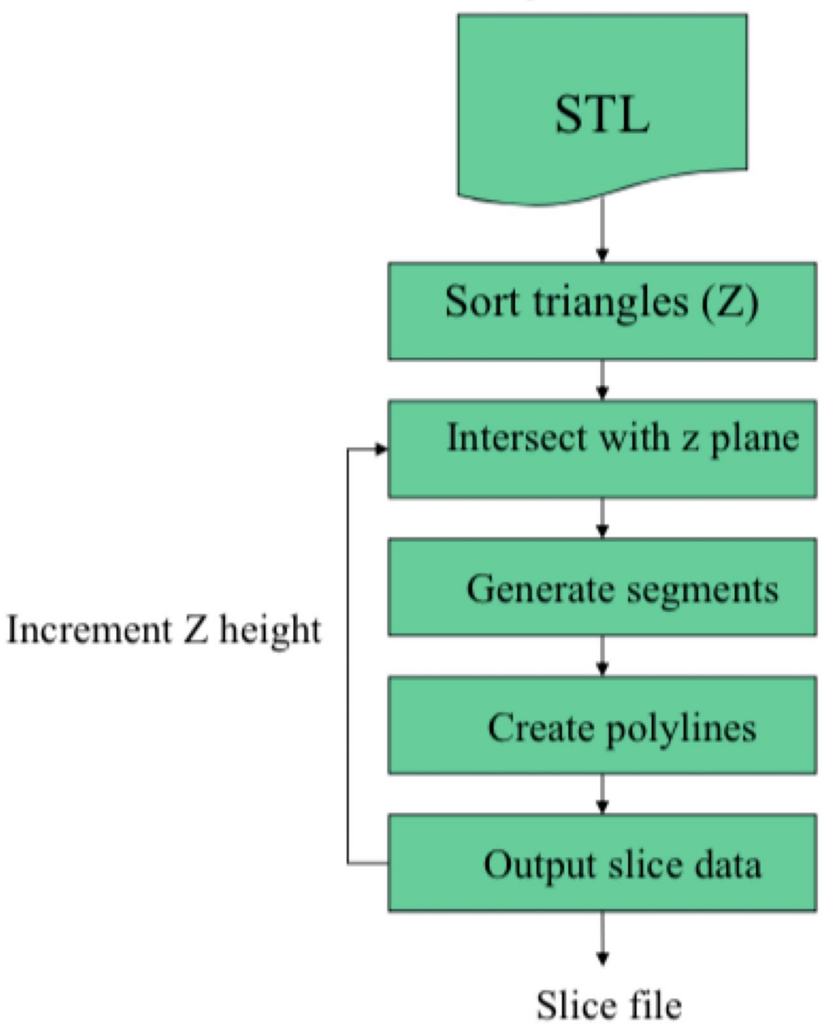
Cannot Slice if not Watertight



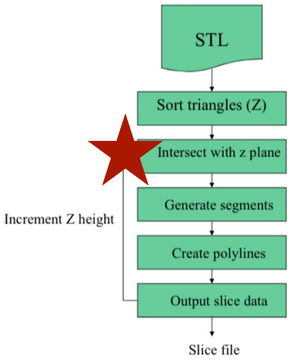


10 Minute Break

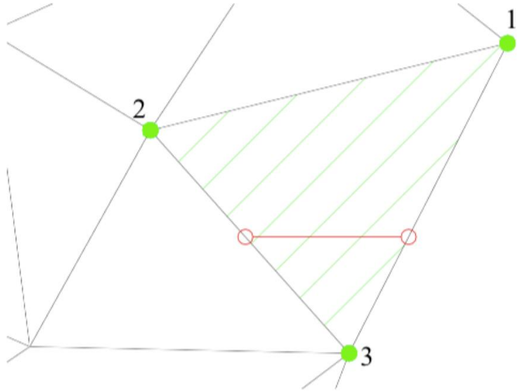
Slicing an STL File



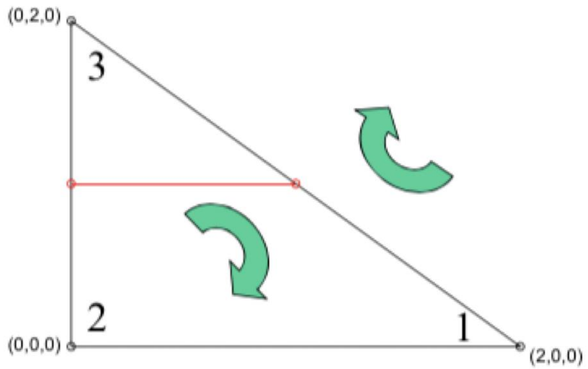
Intersect With Z-Plane



- Every segment belongs to exactly two triangles (vertex to vertex rule)
- Right hand rule…
- STL facet normals always point to the “outside” of the 3D model
- Now we can find the adjacent facet…
- If segment 3-1 exists, then segment 1-3 must exist, otherwise?

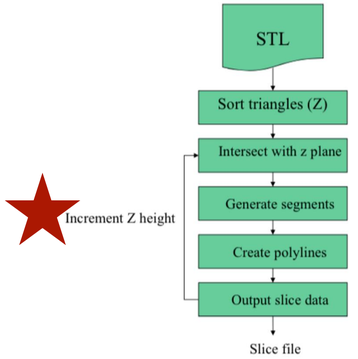



```
solid BOX3
  facet normal 0.000000e+00 0.000000e+00 -1.000000e+00
    outer loop
      vertex 2.000000e+00 0.000000e+00 0.000000e+00
      vertex 0.000000e+00 0.000000e+00 0.000000e+00
      vertex 0.000000e+00 2.000000e+00 0.000000e+00
    endloop
  endfacet
  facet normal -1.000000e+00 0.000000e+00 0.000000e+00
    outer loop
      vertex 0.000000e+00 2.000000e+00 1.000000e+00
      vertex 0.000000e+00 2.000000e+00 0.000000e+00
      vertex 0.000000e+00 0.000000e+00 0.000000e+00
    endloop
  endfacet
  facet normal 0.000000e+00 0.000000e+00 -1.000000e+00
    outer loop
      vertex 2.000000e+00 2.000000e+00 0.000000e+00
      vertex 2.000000e+00 0.000000e+00 0.000000e+00
      vertex 0.000000e+00 2.000000e+00 0.000000e+00
    endloop
  endfacet
  ...
...
...
endsolid BOX3
```

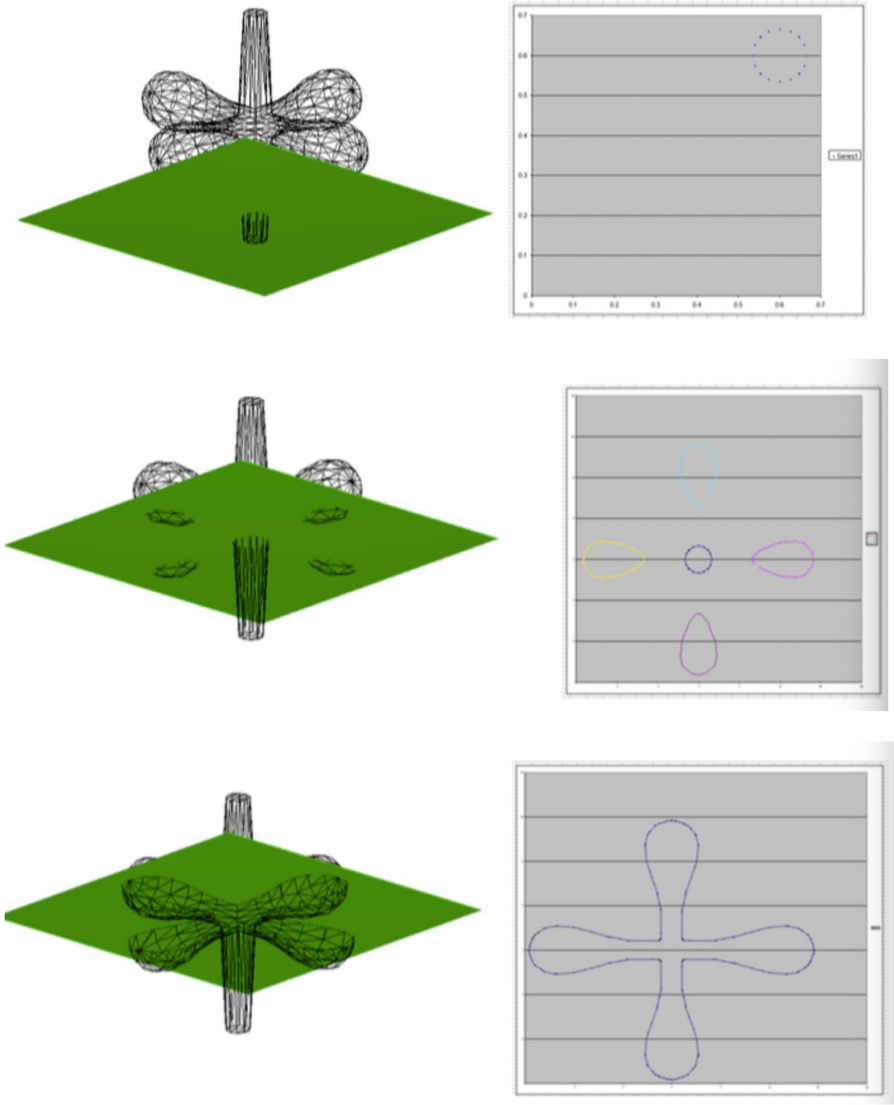


If Segment 3-1 exists, then segment 1-3 must also exist…else?

Increment Z height

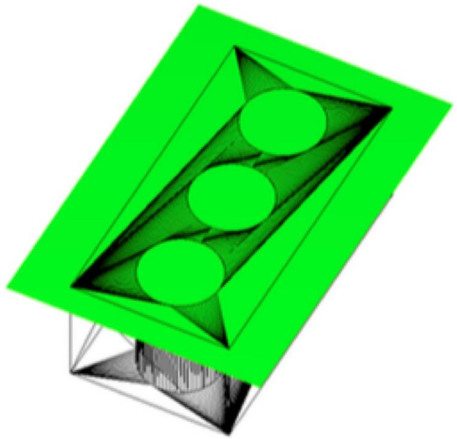


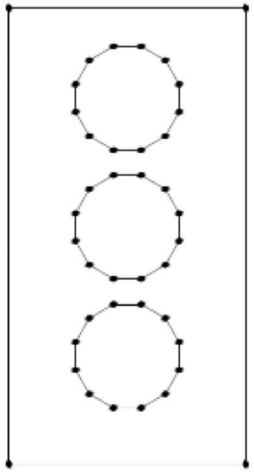
1. Green plane slices through STL
2. Resulting 2D contour Plotted
3. Change Z position
4. Repeat

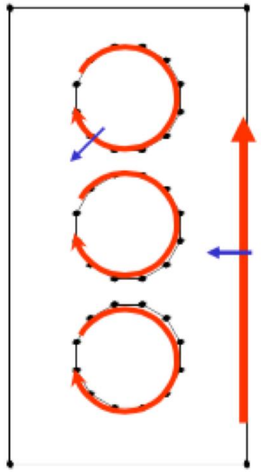


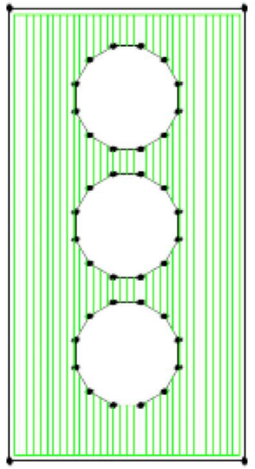
Color In-Between The Slice File Lines

- CCW polygonal chains are exterior chains
- CW polygonal chains are interior chains
- Machine fills in using slice file polygon chain
- Fill based on polygon chain CW or CCW calculation
- “Raster” is the term for how filling occurs





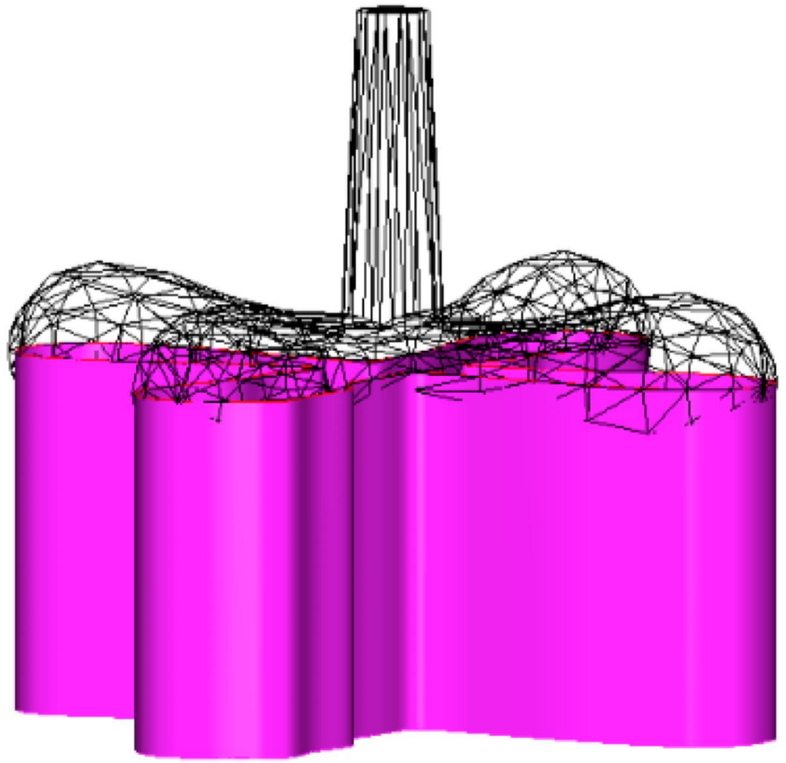




What's Up?

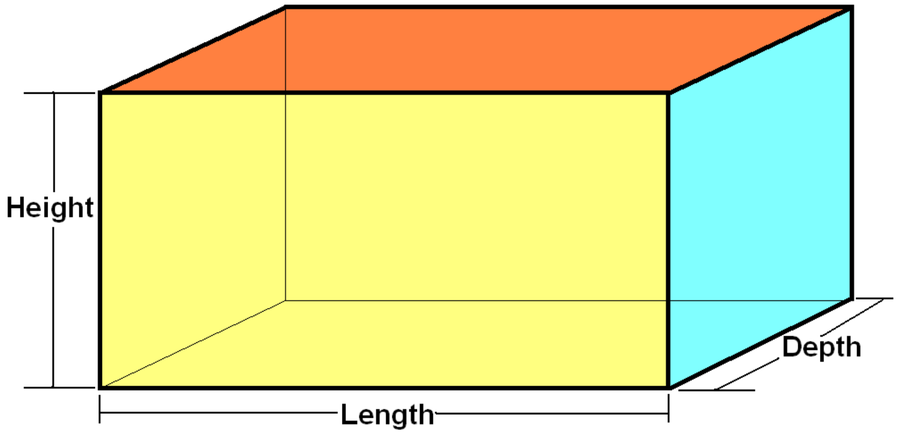
- Once you slice, you defined what's up*
  - Must re-slice the 3D model for any and every orientation change
  - Beneficial if you know how orientation changes
- 3D Models can be sliced from any orientation
  - AM user's "Best" orientation depends on slices and layers
  - Designer's "Best" orientation depends on features/aspects of the design

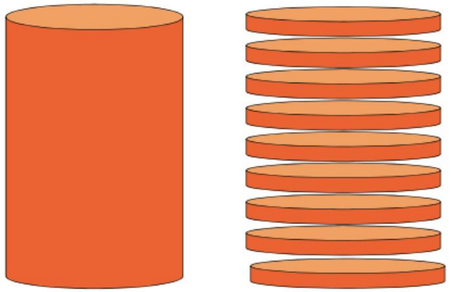
```
solid Box3
 facet normal 0.000000e+00 0.000000e+00 -1.000000e+00
   outer loop
     vertex 2.000000e+00 0.000000e+00 0.000000e+00
     vertex 0.000000e+00 0.000000e+00 0.000000e+00
     vertex 0.000000e+00 2.000000e+00 0.000000e+00
   endloop
 endfacet
 facet normal -1.000000e+00 0.000000e+00 0.000000e+00
   outer loop
     vertex 0.000000e+00 2.000000e+00 1.000000e+00
     vertex 0.000000e+00 2.000000e+00 0.000000e+00
     vertex 0.000000e+00 0.000000e+00 0.000000e+00
   endloop
 endfacet
 facet normal 0.000000e+00 0.000000e+00 -1.000000e+00
   outer loop
     vertex 2.000000e+00 2.000000e+00 0.000000e+00
     vertex 2.000000e+00 0.000000e+00 0.000000e+00
     vertex 0.000000e+00 2.000000e+00 0.000000e+00
   endloop
 endfacet
 ...
```

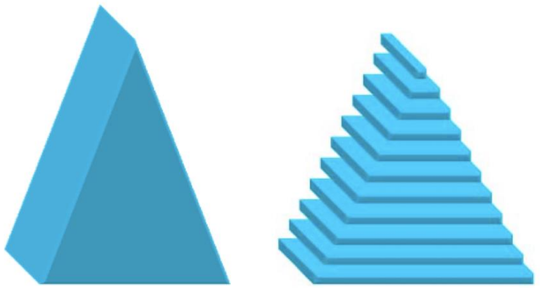


Activity #2

- Sketch the cylinder and triangular extruder shape
- Sketch hyperrectangle shapes inside the cylinder and extruded triangle shapes

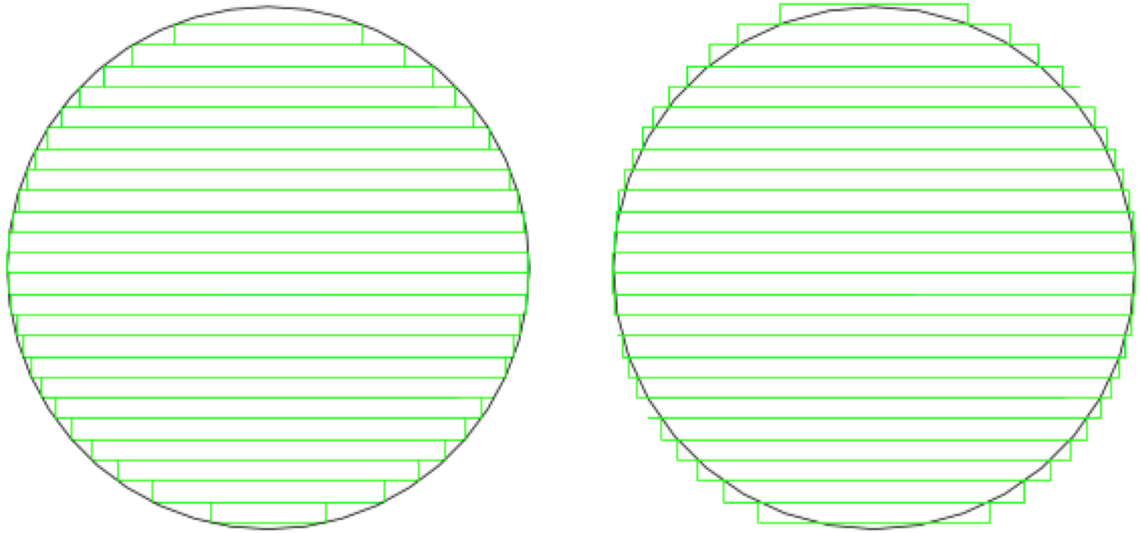




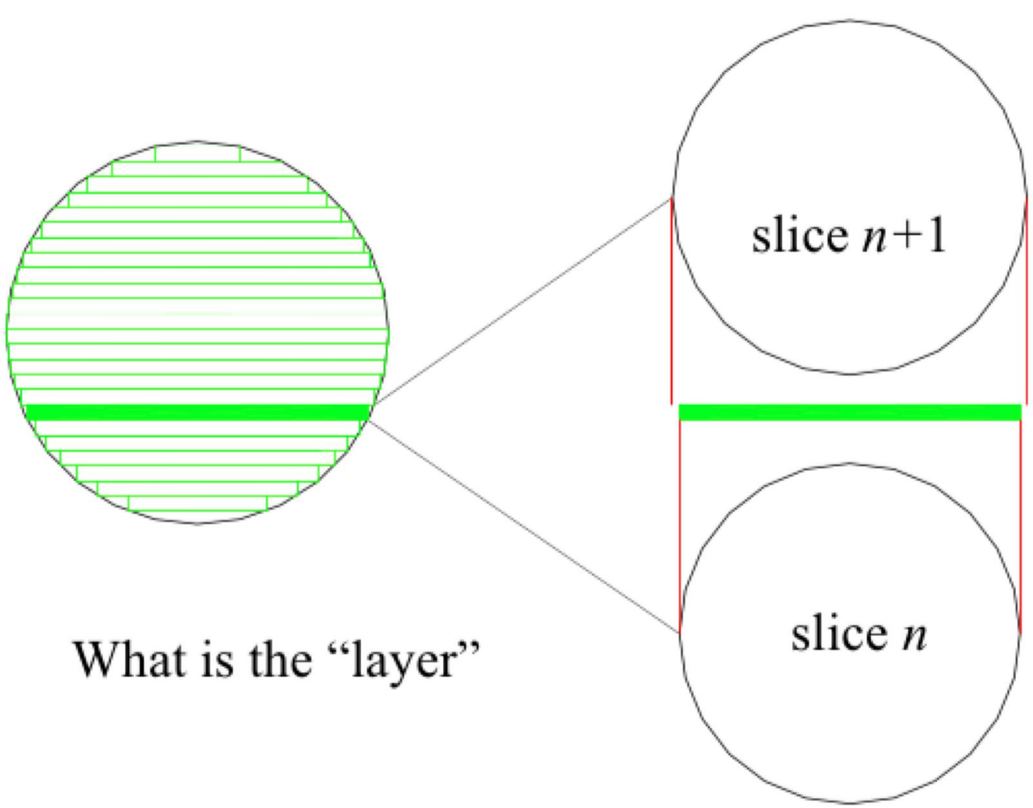


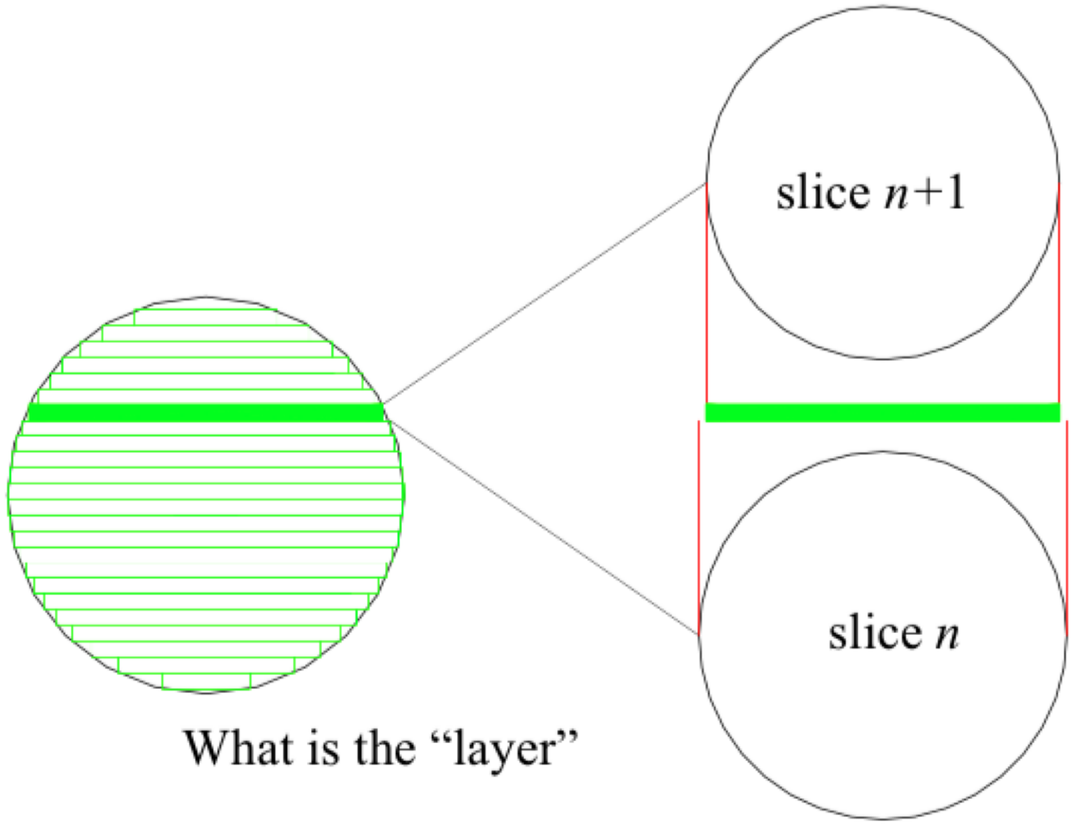
From Slices to Layers

- Slices and layers are not the same thing
- Slice is a 2D cross-section of the CAD (STL) model
- Layer is a 2.5D thin slab of material between two slices
- Slice exists at the top and bottom of a layer…
- Important question then becomes: which slice corresponding to a layer (top or bottom)
- The same slices can create different layers

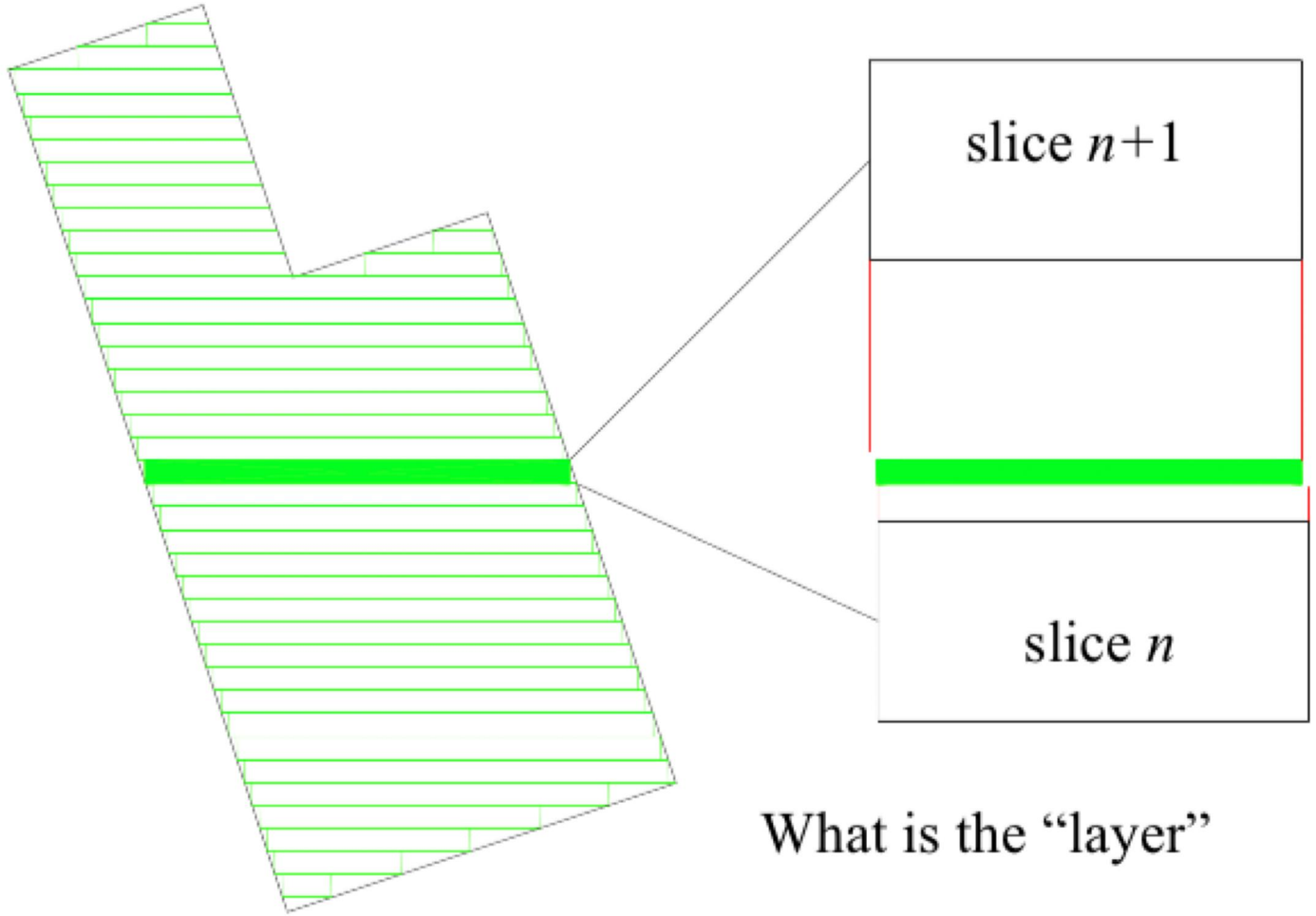


Over and Under Approximation Error





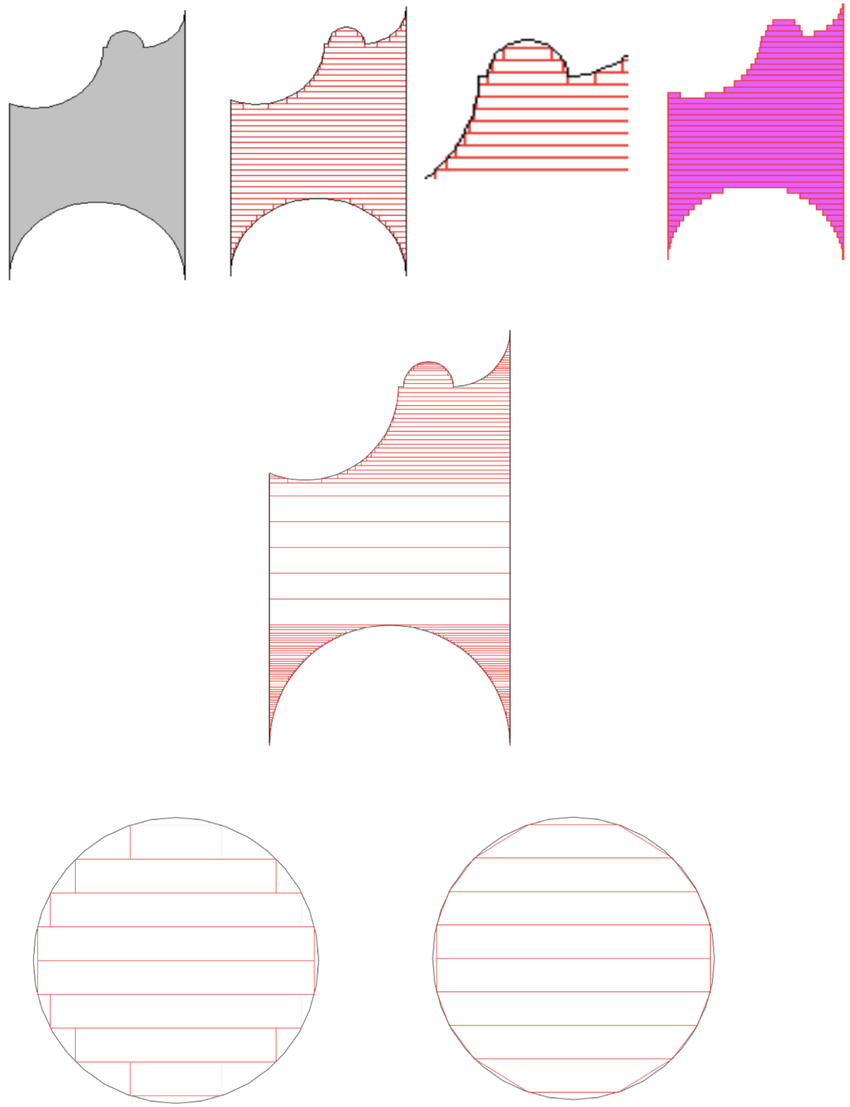
Different Geometry, Similar Slice/Layer Problems



What is the “layer”

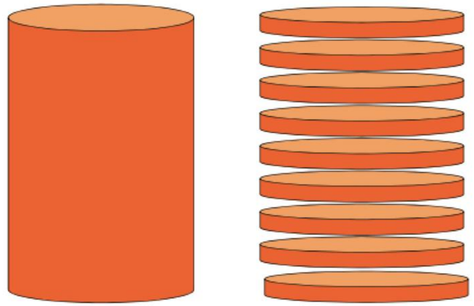
Layer Generation Techniques

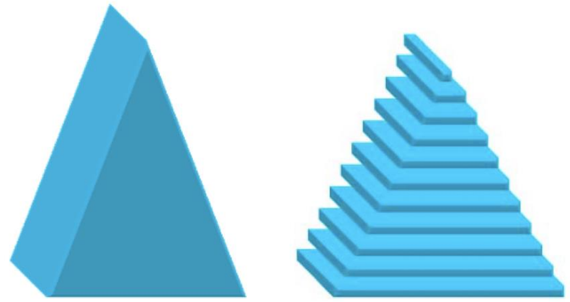
- Most layers are 2.5 D objects (x-y contour and some constant depth)
- Creating each layer is significantly easier than creating 3D freeform shape
- Some systems can perform “Adaptive Slicing” to change the thickness of a layer
- Layers are zeroth order approximations of 3D models
- Some of the best systems can perform First-order ruled approximations of the shape



Layers vs. 3D Shapes

- Isometric views of the two shapes on the right highlight the importance of orienting a part for 3D printing
- Which part will be “near net shape”?
- (Hint: layer thickness is almost always larger than X-Y positional tolerance)





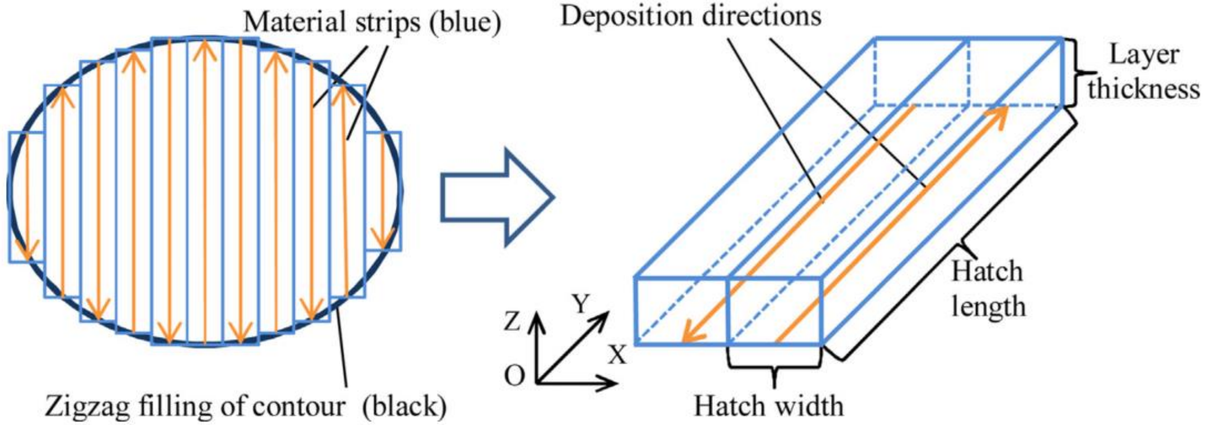


Fig. 10. Cuboid dexel-based simulation for vector-based MMLM process.

Homework

- Read a journal paper and be reading to discuss on Monday
- 1-s2.0-S0965997822001466-main copy.pdf
- Be ready to discuss what VAMVIS is and what does it do