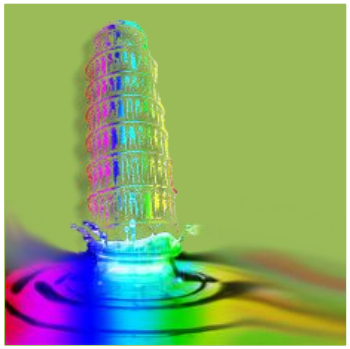
CENTRO E. PIAGGIO
Bioengineering and Robotics Research Center

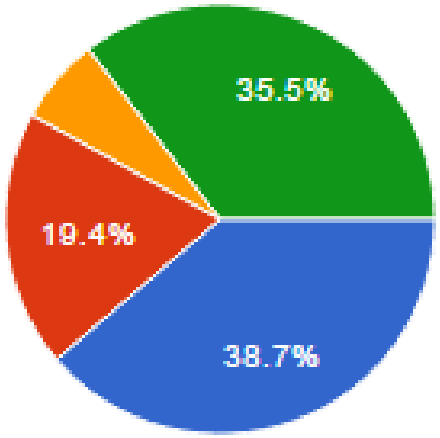


Software for Additive manufacturing

carmelo.demaria@centropiaggio.unipi.it

Question #1 08/10/2015

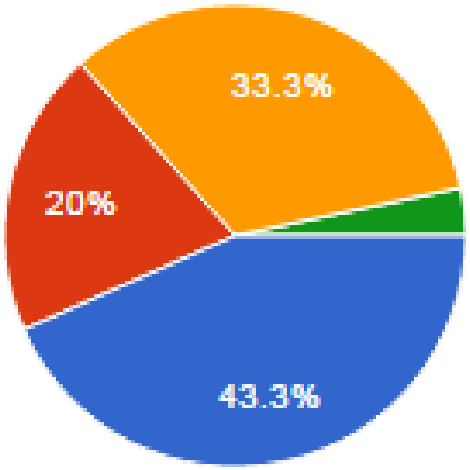
An STL file describes



a surface	**12**	38.7%
a volume	**6**	19.4%
a machine toolpath	**2**	6.5%
a wireframe CAD model	**11**	35.5%
Other	**0**	0%

Question #2 08/10/2015

The G-code is



is sequentially processed	13	43.3%
is processed in parallel	6	20%
represents the 3D model	10	33.3%
Other	1	3.3%

Additive manufacturing Process Flow

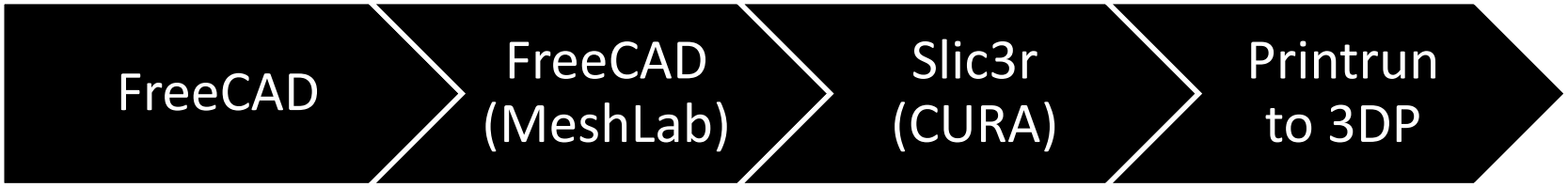
- Solid Modelling
- Tesselation/Generation of STL file
- Support Generation
- “Slicing” of the Model
- Model Physical Buildup
- Cleanup and Post Curing
- Surface Finishing

Additive manufacturing Process Flow

File

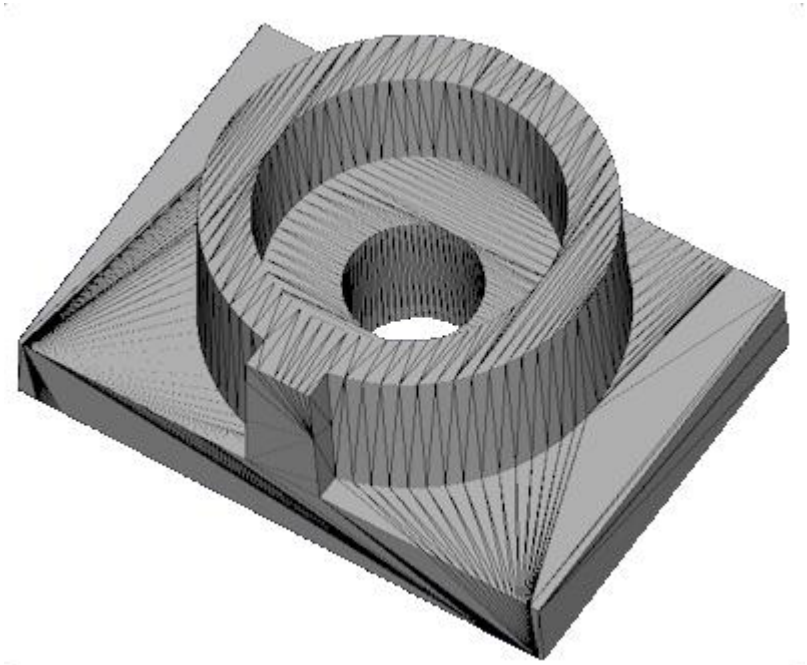
Description

Software

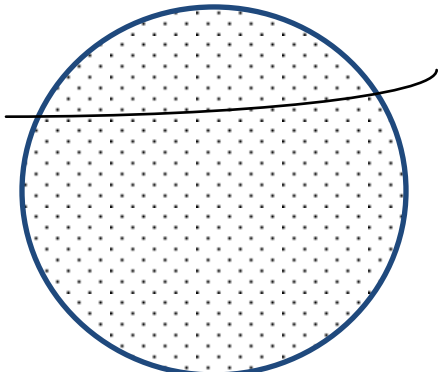


EXCHANGE FORMATS

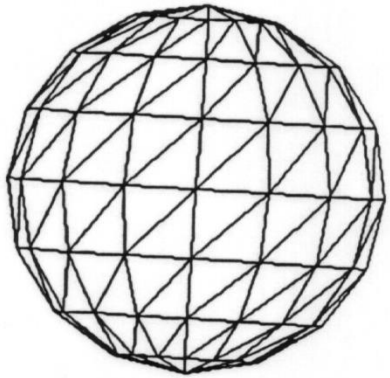
Example of *.stl Representation

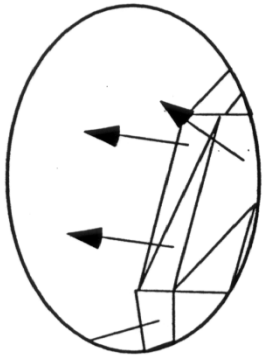


Example of *.stl Representation



Representing
a sphere





```
solid obj1
 facet normal 1.457591e-01 -9.885599e-01 -3.877669e-02
   outer loop
     vertex 9.614203e+00 4.757629e+00 0.000000e+00
     vertex 7.875000e+00 4.501190e+00 0.000000e+00
     vertex 9.483117e+00 4.764183e+00 -6.598330e-01
   endloop
 endfacet
 facet normal 1.161178e-01 -9.870778e-01 -1.104267e-01
   outer loop
     vertex 9.483117e+00 4.764183e+00 -6.598330e-01
     vertex 7.875000e+00 4.501190e+00 0.000000e+00
     vertex 9.109818e+00 4.782848e+00 -1.219212e+00
   endloop
 endfacet
 facet normal 6.134766e-02 -9.843393e-01 -1.652652e-01
```

Additive manufacturing file format

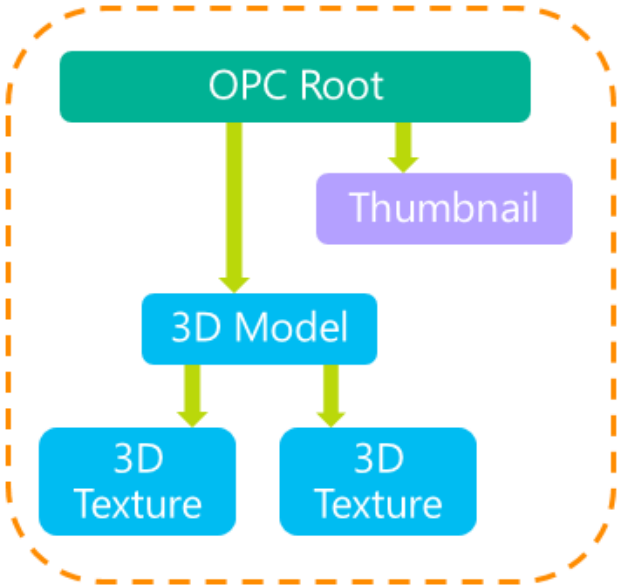
```
<?xml version="1.0"?>
<AMF>
  <Object PrintID = "0" units = "mm">
    <Mesh>
      <Vertices>
        <Vertex VertexID="0">
          <VertexLocation x="0" y="1.332" z="3.715"/>
        </Vertex>
        <Vertex VertexID="1">
          <VertexLocation x="0" y="1.269" z="3.715"/>
        </Vertex>
        ...
      </Vertices>

      <Region FillMaterialID = "0">
        <Triangle V1 = "0" V2 = "1" V3 = "3"/>
        <Triangle V1 = "0" V2 = "1" V3 = "4"/>
        ...
      </Region>
    </Mesh>
  </Object>
</AMF>
```

3MF format

http://3mf.io/

3MF design considerations



Complete

- Open Packaging Conventions (OPC)

Compact

- ZIP package
- References avoid duplication

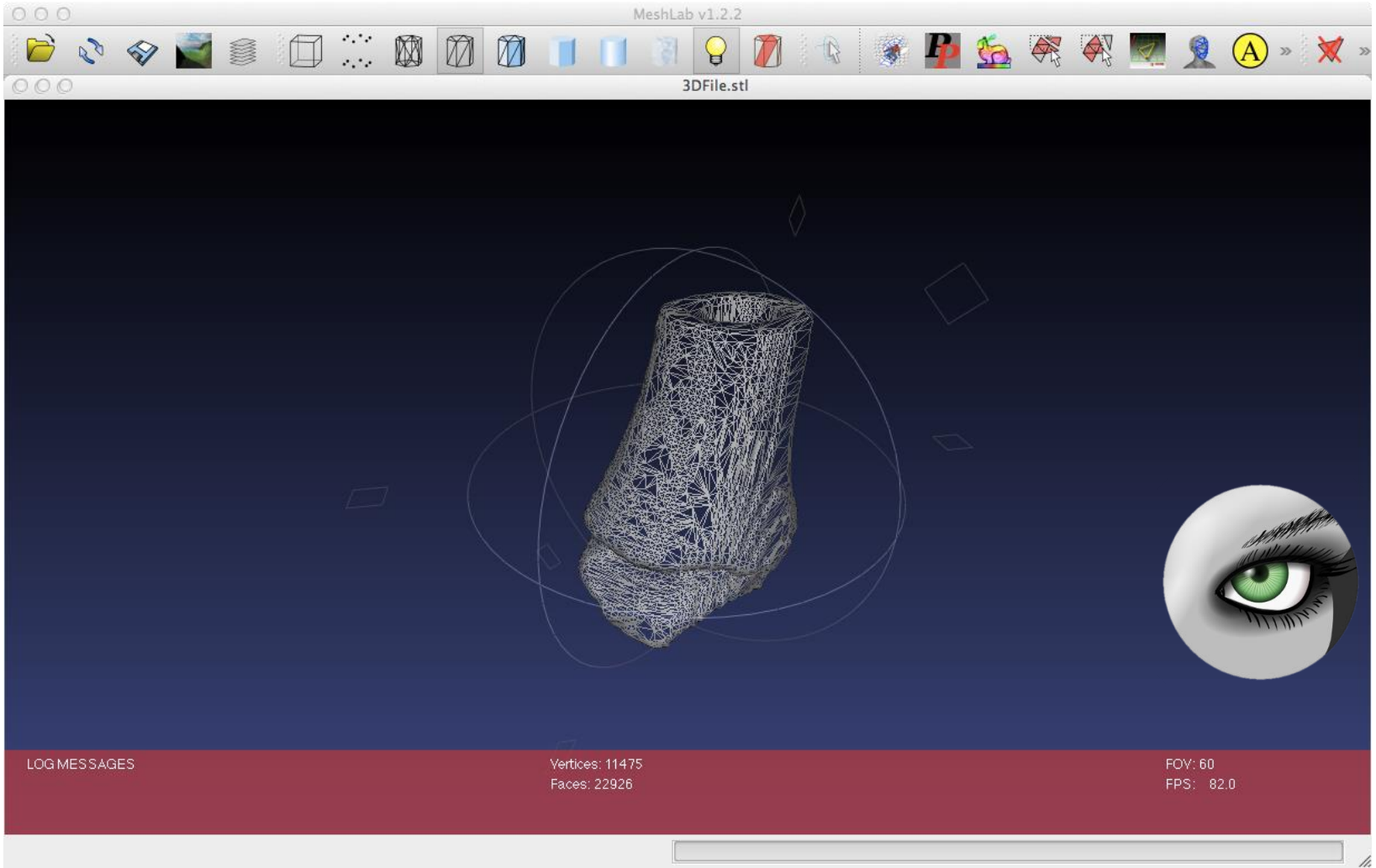
Human-readable

- XML
- Well-known binary formats (e.g. PNG, JPEG)

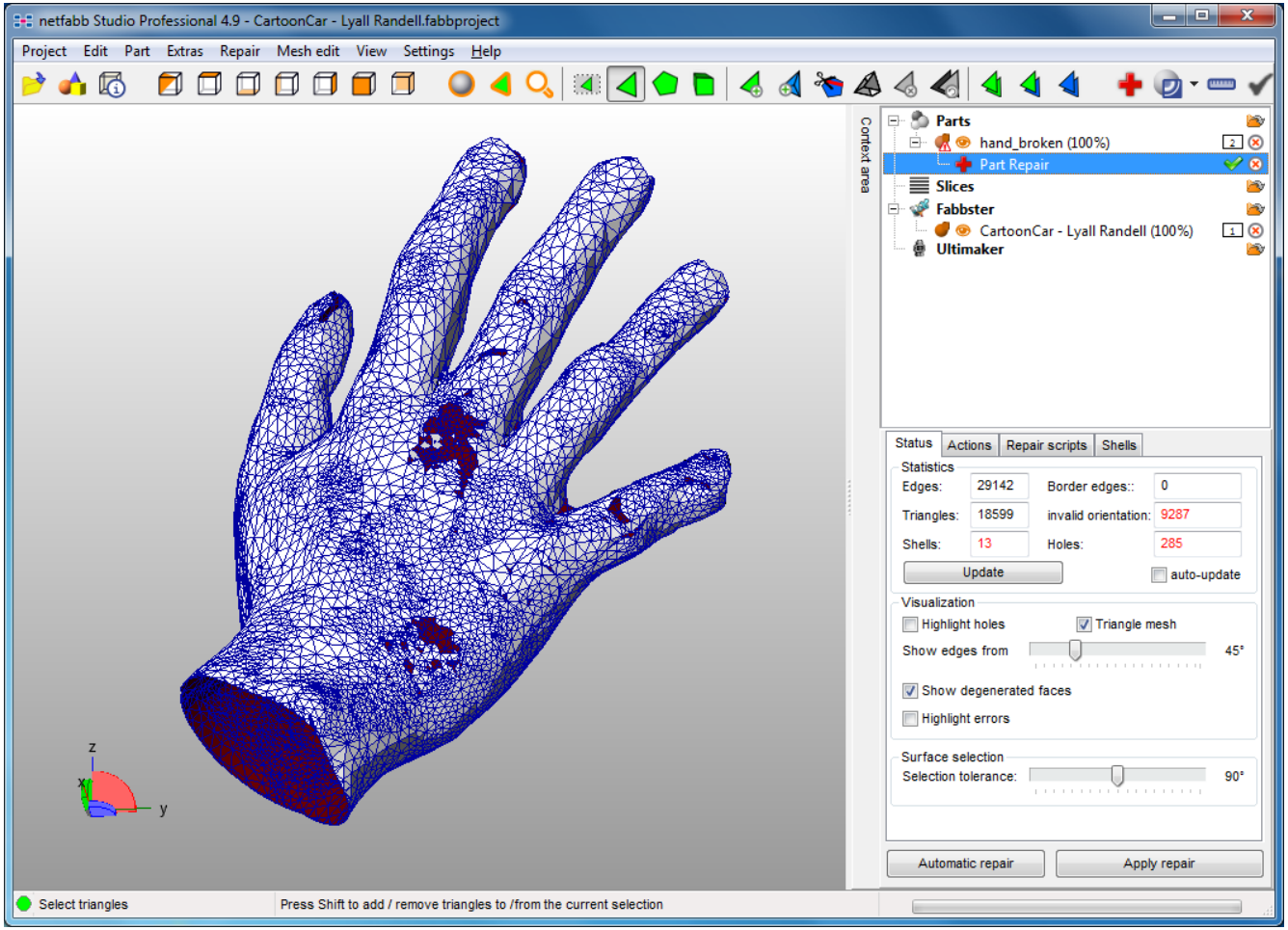
3MF CONSORTIUM

MeshLab

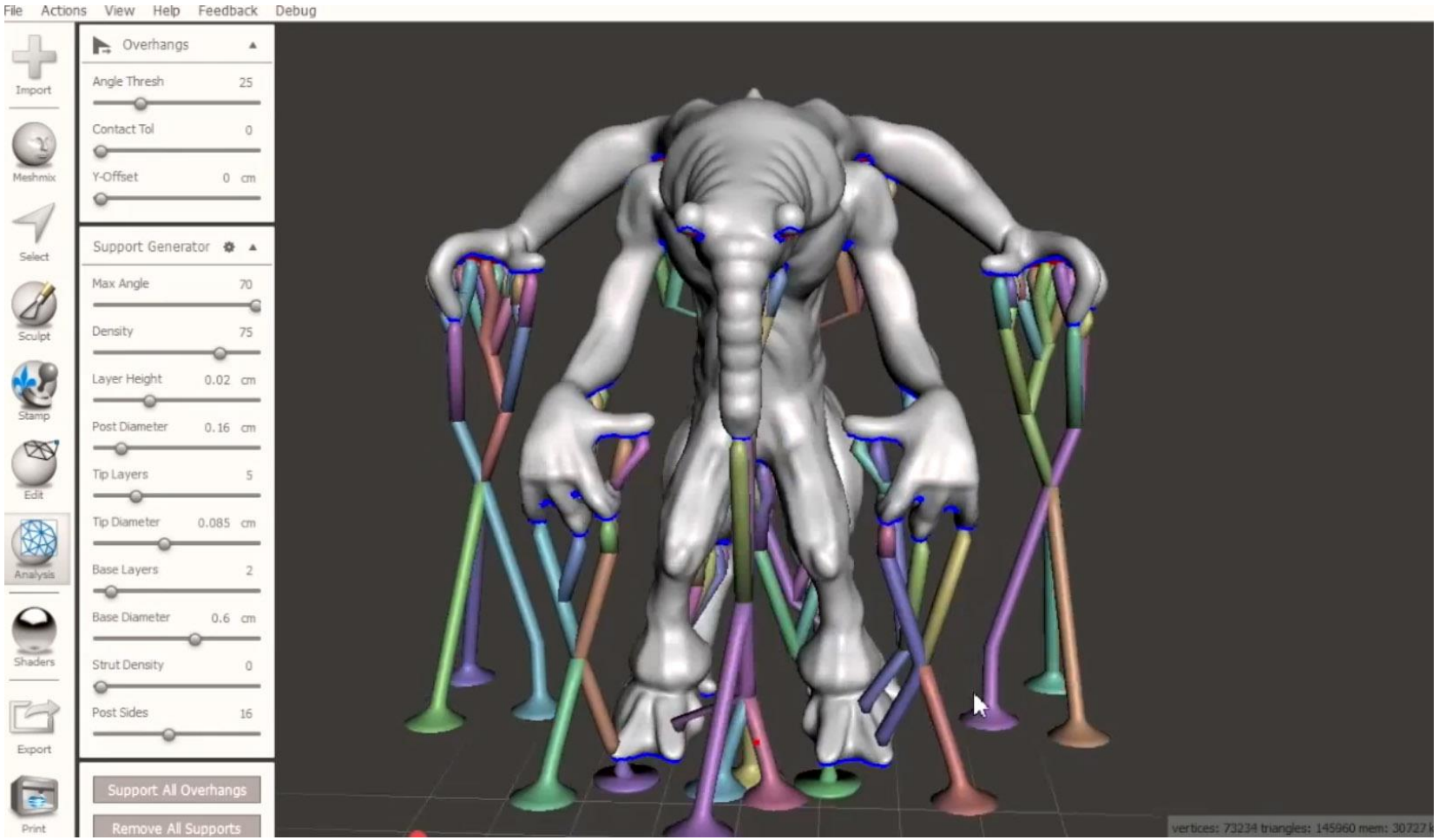
http://meshlab.sourceforge.net



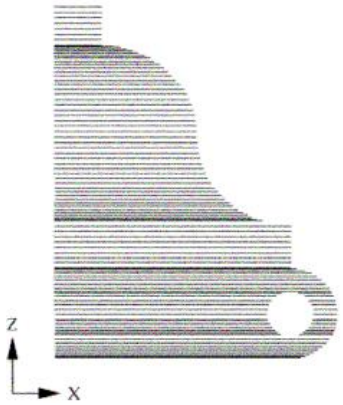
Netfabb

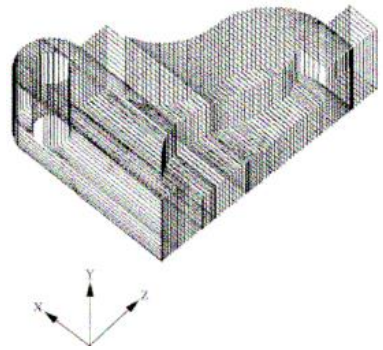

netfabb Studio Professional 4.9 - CartoonCar - Lyall Randell.fabbproject
Project Edit Part Extras Repair Mesh edit View Settings Help
Context area
Parts
hand_broken (100%)
Part Repair
Slices
Fabbster
CartoonCar - Lyall Randell (100%)
Ultimaker
Status Actions Repair scripts Shells
Statistics
Edges: 29142
Border edges:: 0
Triangles: 18599
invalid orientation: 9287
Shells: 13
Holes: 285
Update
auto-update
Visualization
Highlight holes
Triangle mesh
Show edges from
45°
Show degenerated faces
Highlight errors
Surface selection
Selection tolerance:
90°
Automatic repair
Apply repair
Select triangles
Press Shift to add / remove triangles to /from the current selection

Meshmixer


File
Actions
View
Help
Feedback
Debug
Import
Meshmix
Select
Sculpt
Stamp
Edit
Analysis
Shaders
Export
Print
Overhangs
Angle Thresh 25
Contact Tol 0
Y-Offset 0 cm
Support Generator
Max Angle 70
Density 75
Layer Height 0.02 cm
Post Diameter 0.16 cm
Tip Layers 5
Tip Diameter 0.085 cm
Base Layers 2
Base Diameter 0.6 cm
Strut Density 0
Post Sides 16
Support All Overhangs
Remove All Supports
vertices: 73234 triangles: 145960 mem: 30727

FROM CAD TO CAM





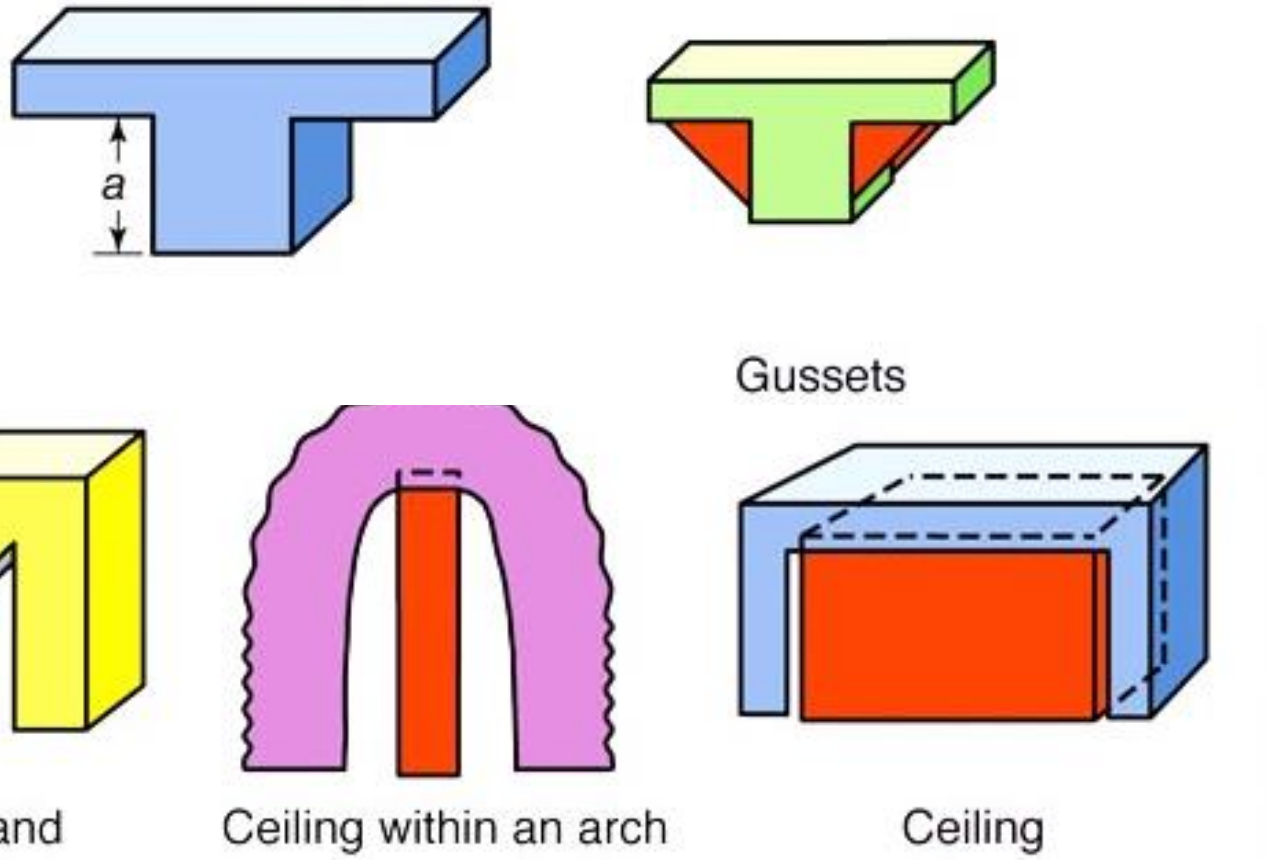
Processing of *.stl Files

- After the CAD system has generated *.stl file, it can be passed to the SFM machine
- Machine then processes the *.stl file, slicing it into many thin layers stacked on one another. The resulting files are called slice files.
- The shapes of the slices represent cross sections
- In SFM processes thick solid sections of material are often removed and replaced with cross hatching
- Thus SFM parts are usually hollow, with cross hatching on the inside to add strength/stability

Support material

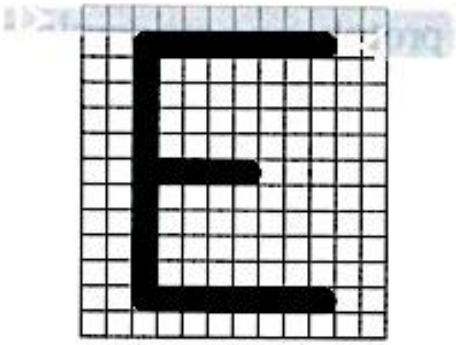
- Some solid freeform fabrication techniques use two materials in the course of constructing parts.
- The first material is the part material and the second is the support material (to support overhanging features during construction).
- The support material is later removed by heat or dissolved away with a solvent or water.

Support material

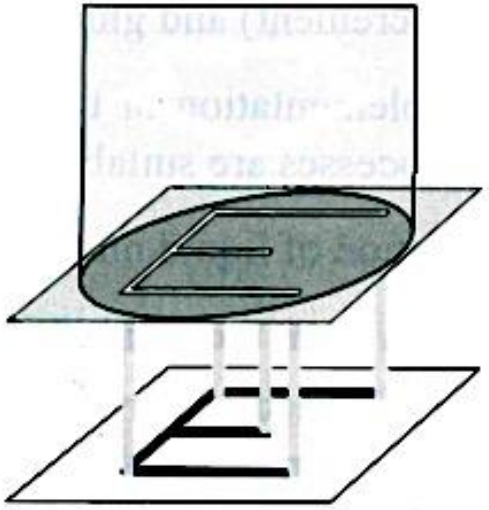


Patterning

Vector



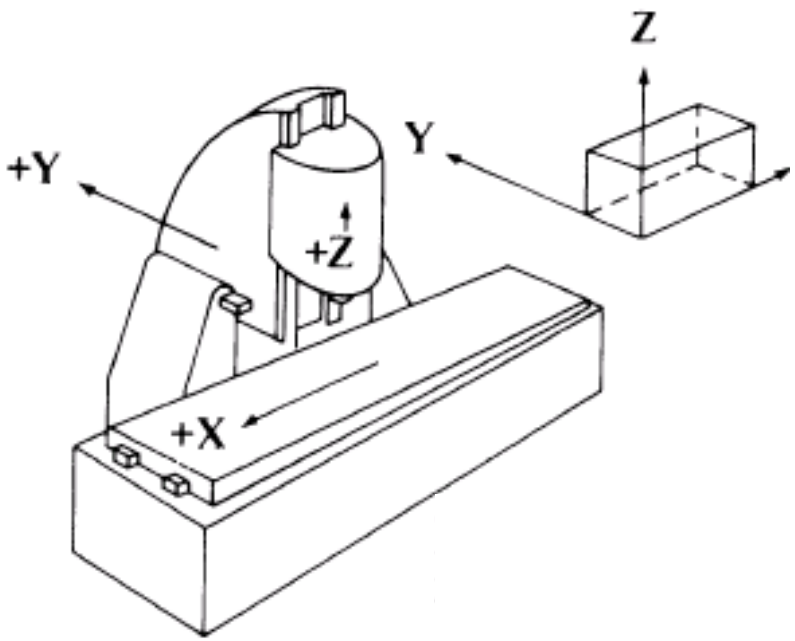
Raster



Projection

Basic Machine Axes: 3 axis

- Cartesian Robot: 3 axis
  - X – axis (table left and right)
  - Y – axis (table in and out)
  - Z – axis (usually the extruder



G-CODE

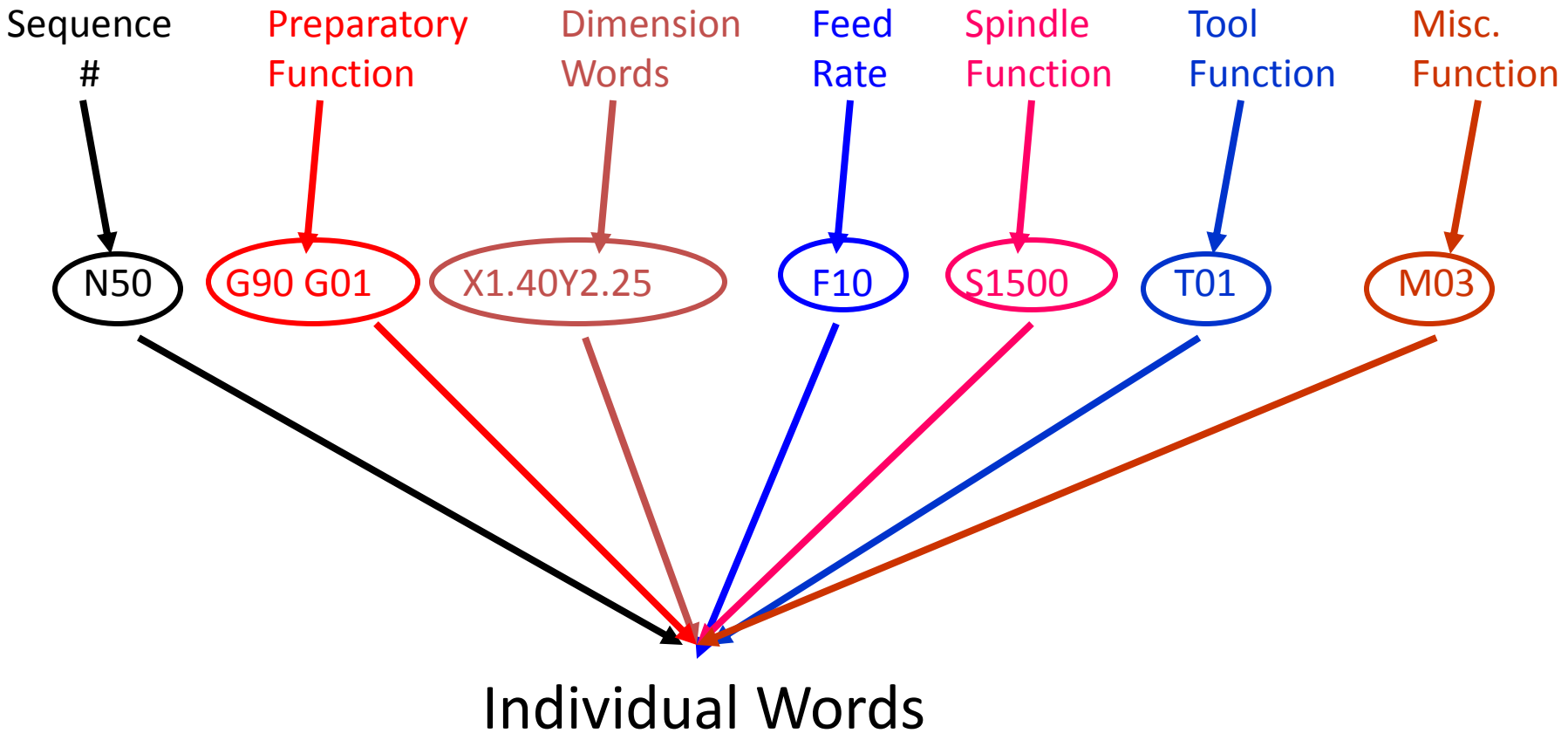
- G – Code Programming
- Originally called the “Word Address” programming format.
- Processed one line at a time sequentially.

Word address format

- Word address was developed as a tape programming format.
  - Another name for “word address” is “variable block” format, so named because the program lines (blocks) may vary in length according to the information contained in them.
  - Earlier tape formats required an entry for all possible machine registers. In these earlier formats, a zero was programmed as a null input if the register values were to be unaffected, but in work address, the blocks need only contain necessary information. Although developed as a tape format, word address is used as the format for manual data input on many CNC machines.

- <u>Addresses</u>
  - The block format for word address is as follows:
  - N … G … X … Y … Z … I … J … K … F … H … H … S … T … M …
  - Only the information needed on a line need be given. Each of the letters is called an address (or word)

Common Format of a Block



Word address

- Reserved Code Words Worksheet
  - N – Sequence or line number
  - G – Preparatory function
  - …
- Dimension Words:
  - X
  - Y
  - Z

Word Address 1/3

- N – Sequence or line number
  - A tag that identifies the beginning of a block of code. N numbers are ignored by the controller during the program execution. It is used by operators to locate specific lines of a program when entering data or verifying the program operation.

- G – Preparatory function
  - G words specify the mode in which the milling machine is to move along its programmed axes. Preparatory functions are called prep functions or, more commonly **G codes**

Word Address 2/3

- Dimension Words
  - X – Distance or position in X direction
  - Y – Distance or position in Y direction
  - Z – Distance or position in Z direction

- M – Miscellaneous functions
  - M words specify CNC machine functions not related to dimensions or axial movements.

Word Address 3/3

- F – Feed rate (inches per minute or millimeters per minute)
  - Rate at which cutting tool moves along an axis.
- S – Spindle speed (rpm – revolutions per minute)
  - Controls spindle rotation speed.
- T – Tool number
  - Specifies tool to be selected.

G Word

- G words or codes tell the machine to perform certain functions. Most G words are modal which means they remain in effect until replaced by another modal G code.

Common G Codes

- G00 – Rapid positioning mode
  - Tool is moved along the shortest route to programmed X,Y,Z position. Usually NOT used for cutting.
- G01 – Linear Interpolation mode
  - Tool is moved along a straight-line path at programmed rate of speed.

- G02 – Circular motion clockwise (cw)
- G03 – Circular motion counter clockwise (ccw)

M Word

- M words tell the machine to perform certain machine related functions, such as: turn spindle on/off, coolant on/off, or stop/end program.

Esempio G-Code

```
;Generated with Cura_SteamEngine 13.11.2
M109 T0 S227.000000
T0
;Sliced ?filename? at: Tue 26-11-2013 17:33:05
;Basic settings: Layer height: 0.2 Walls: 0.8 Fill: 20
;Print time: #P_TIME#
;Filament used: #F_AMNT#m #F_WGHT#g
;Filament cost: #F_COST#
G21       ;metric values
G90       ;absolute positioning
M107      ;start with the fan off
G28 X0 Y0  ;move X/Y to min endstops
G28 Z0     ;move Z to min endstops
G1 Z15.0 F?max_z_speed? ;move the platform down 15mm
G92 E0                  ;zero the extruded length
G1 F200 E3              ;extrude 3mm of feed stock
G92 E0                  ;zero the extruded length again
G1 F9000
M117 Printing...

;Layer count: 179
;LAYER:0
M107
G0 F3600 X87.90 Y78.23 Z0.30
;TYPE:SKIRT
G1 F2400 E0.00000
G1 F1200 X88.75 Y77.39 E0.02183
G1 X89.28 Y77.04 E0.03342
G1 X90.12 Y76.69 E0.05004
G1 X90.43 Y76.63 E0.05591
G1 X91.06 Y76.37 E0.06834
```

Question time!

http://goo.gl/forms/Jjm4uLd53j