Lecture 2 - The General AM Process

Dr Chris Steer

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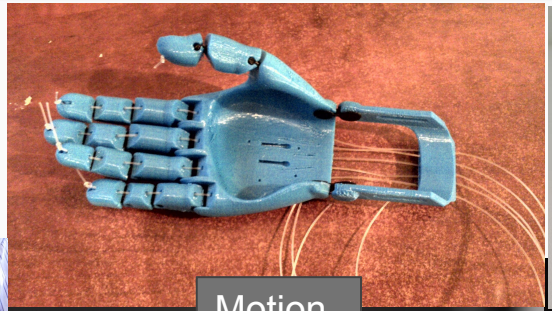
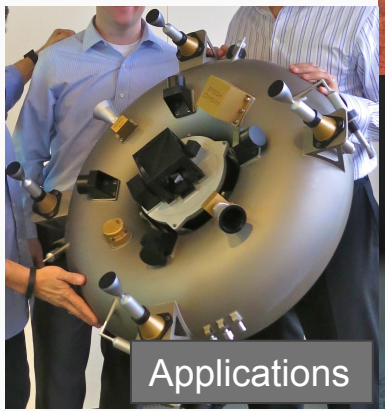
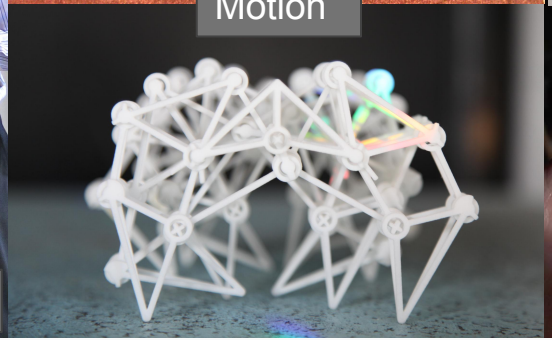


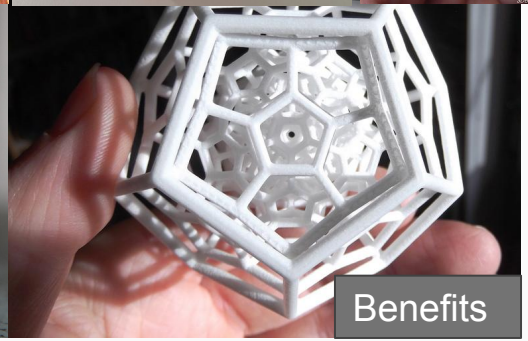
Motion

Limitations



Applications





Benefits

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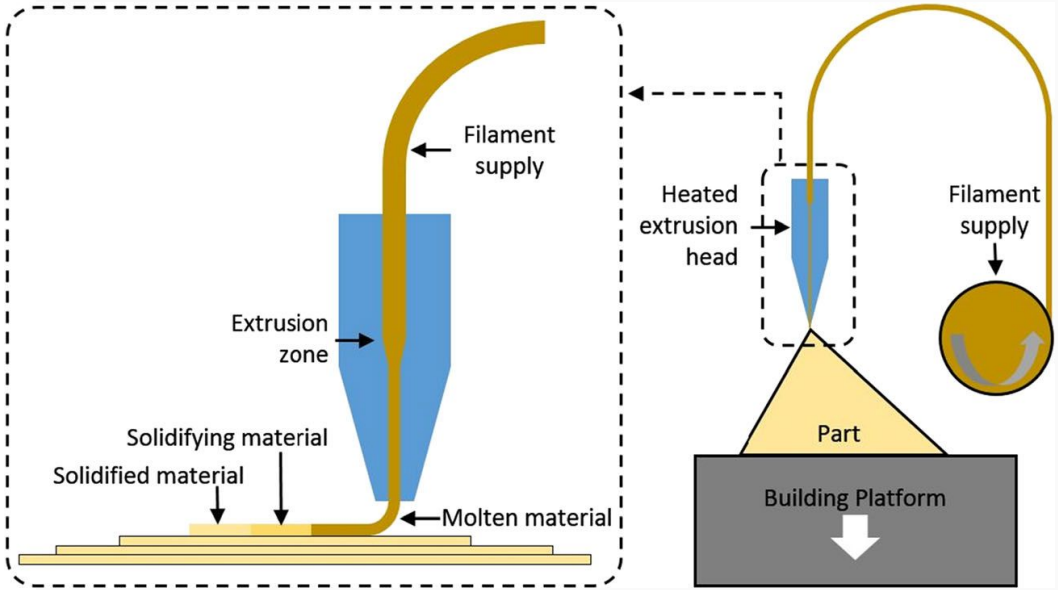
Example Printing System : Fused Filament Fabrication



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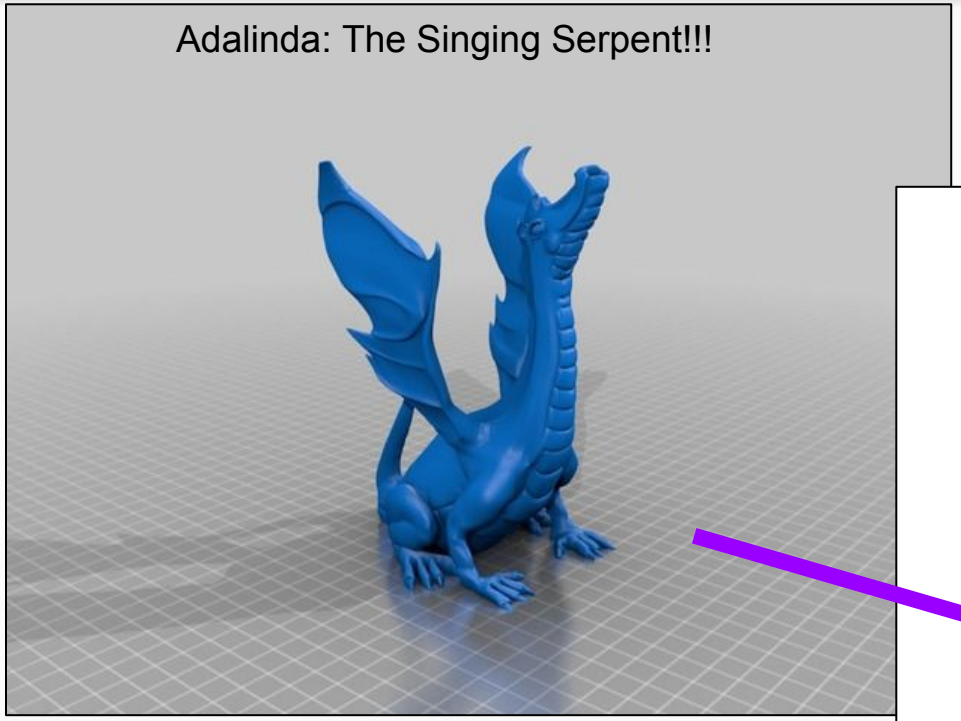
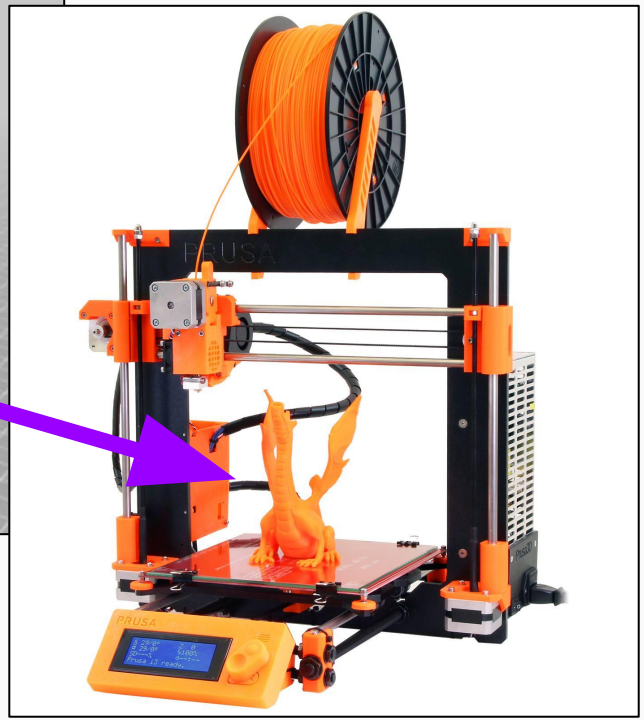
Example Printing System : Fused Filament Fabrication



Digital model (continuous surfaces)

Print parameters and settings



http://www.thingiverse.com/thing:246198

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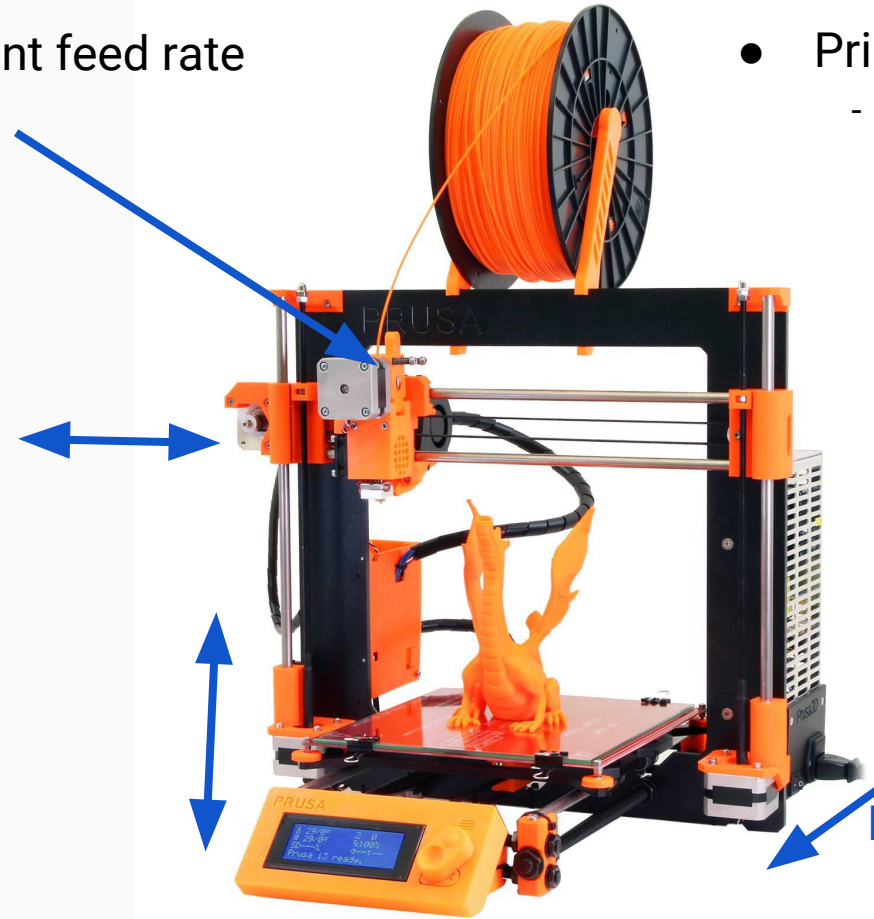
Example : Fused Filament Fabrication Main Print Parameters

- Filament feed rate



- Printhead movements
  - Three stepper motors to move printhead and bed in three directions

- Extruder and bed temperatures

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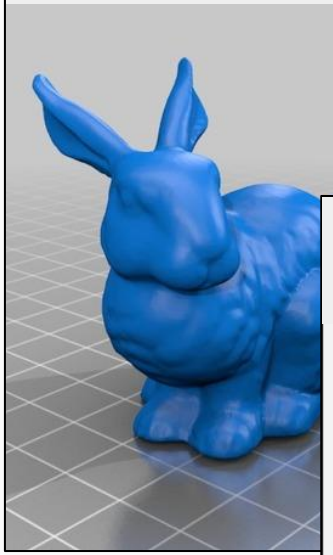
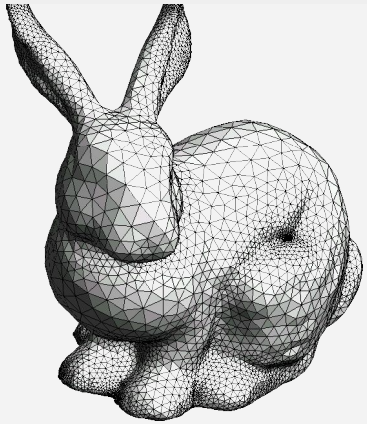
General 3D Printing Process

The Design to Print Process

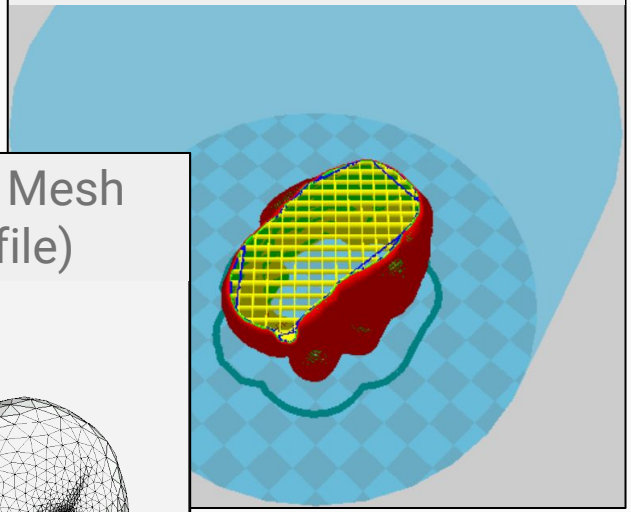
CAD Design



Surface Mesh
(STL file)



Slices and Settings
(G-Code file)



Printed Object

What are these?

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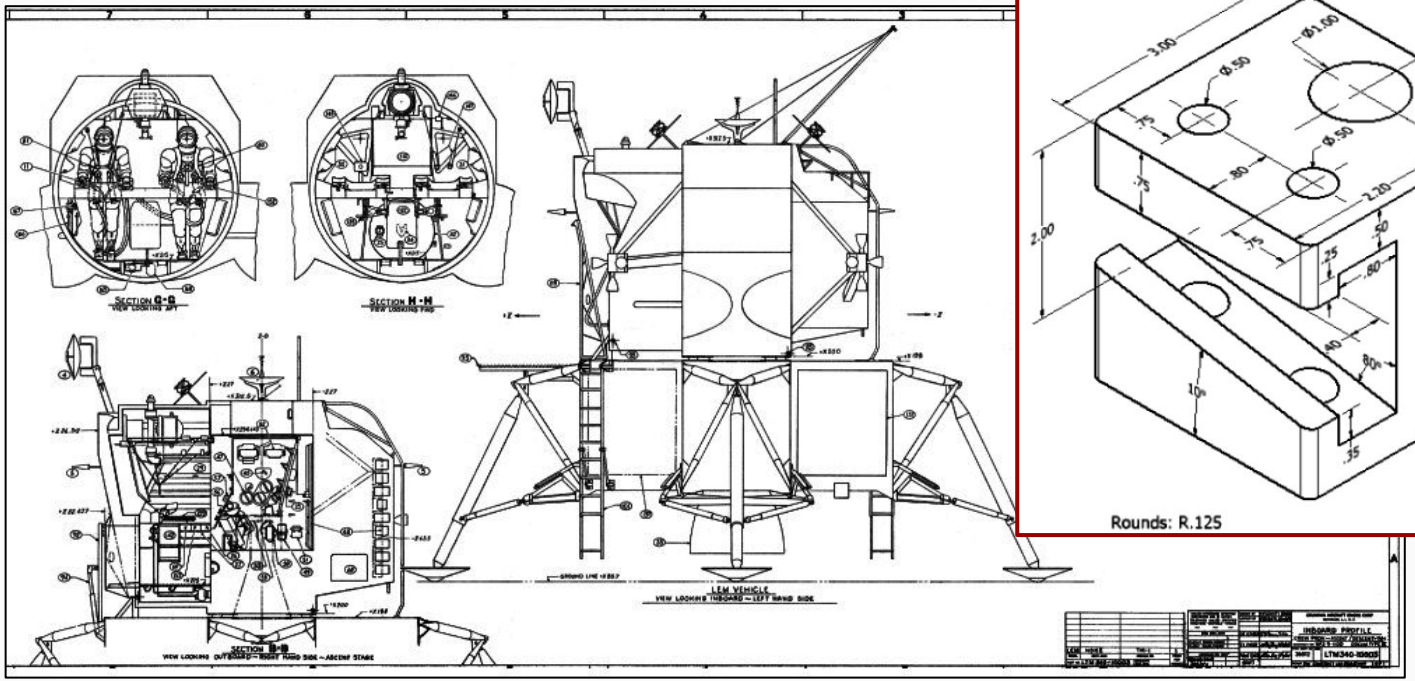
Computer-Aided Design / CAD

Computer-Aided Manufacture / CAM

Computer-Aided Design CAD

- CAD software allows 2D and 3D drafting of designs
- Essential if you would like to ask an **non-3D printing** engineering or prototyping firm to make something for you



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Computer-Aided Design CAD

- Design drawing information when communicating it
  - All relevant dimensions must be included
  - Drawing scale e.g. 5:1
  - Tolerances must be given e.g. upper and lower limits, *“All dimensions to +/- 5%”, or “ +/- 0.5mm”...*
  - State material if given
  - Relevant cross-sections
  - If it’s multiple parts, then drawings of both the individual parts *and the assembly*

- Note : Higher marks in the design part of the coursework will require good communication of the design

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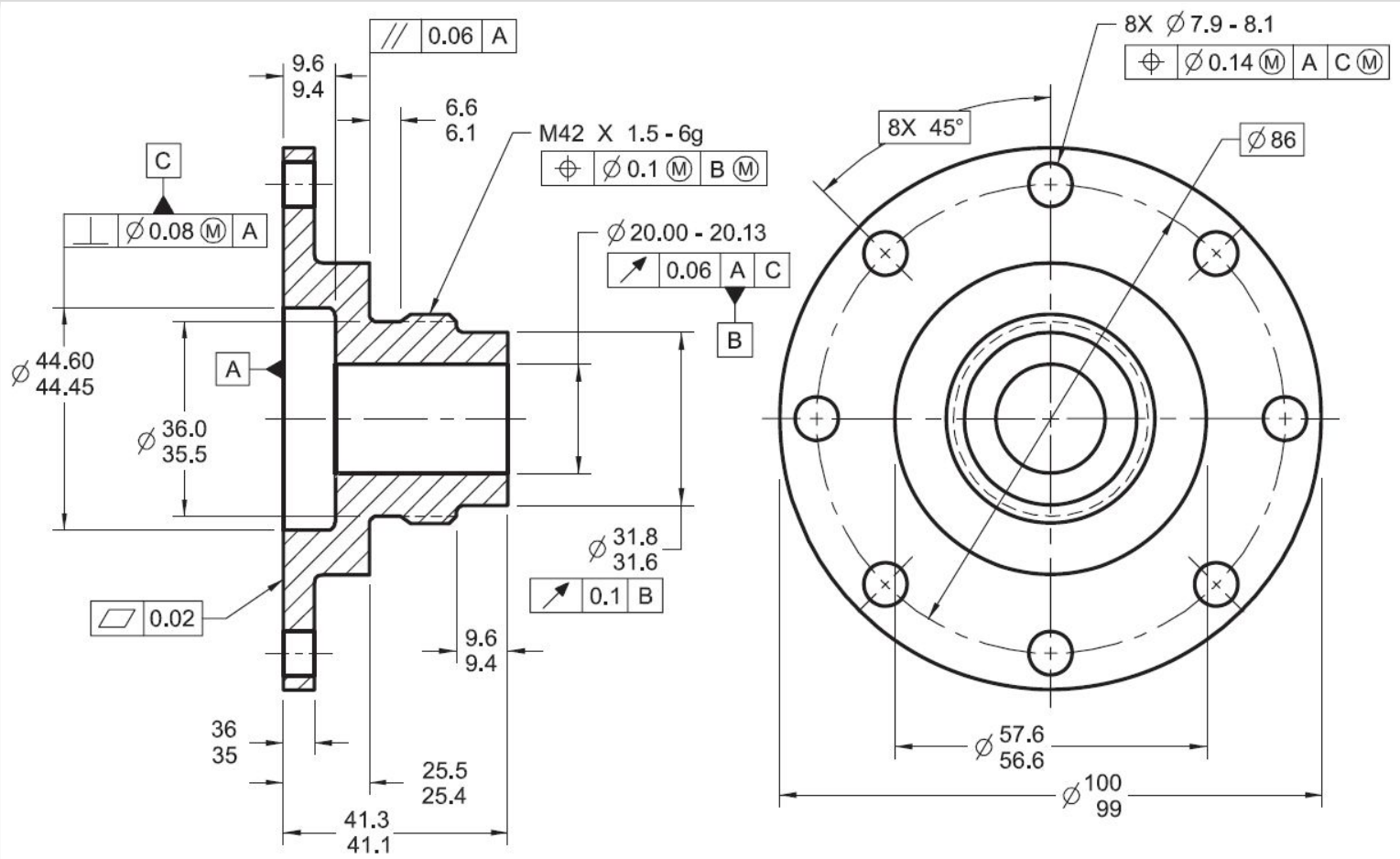
Computer-Aided Design CAD : Example with cross-section



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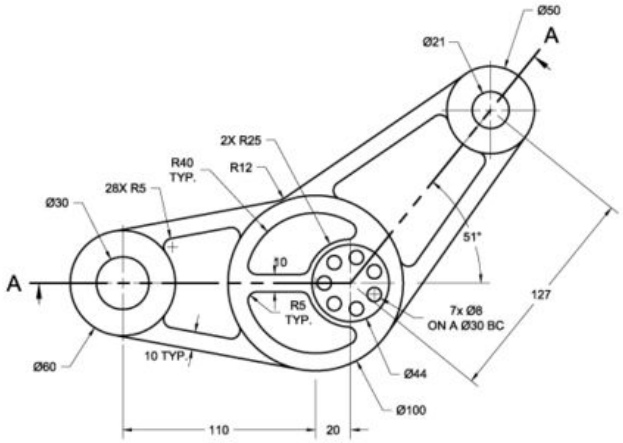
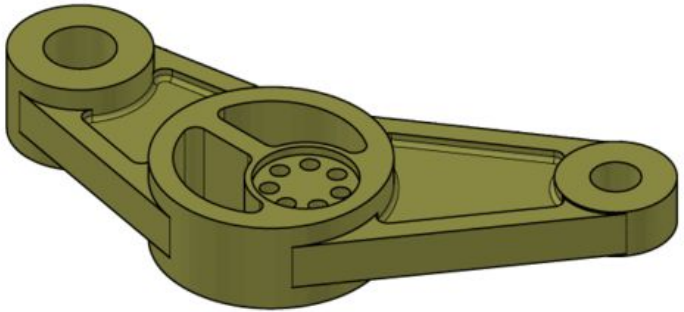
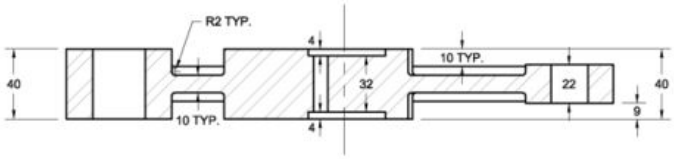
What's missing?



TOP VIEW (1:2)



3D VIEW #1



ALIGNED SECTION A-A (1:2)

3D VIEW #2

AutoCAD 3 3D Modeling	
PROJECT:	Lesson 14 Practice 14_2
DRAWING TITLE:	CONTROL ARM
DRAWN BY:	KB
DATE:	03/08/2013
SCALE:	1:2
CLASS:	CADD3
CHECKED BY:	KB
DRAWING NUMBER:	M-1

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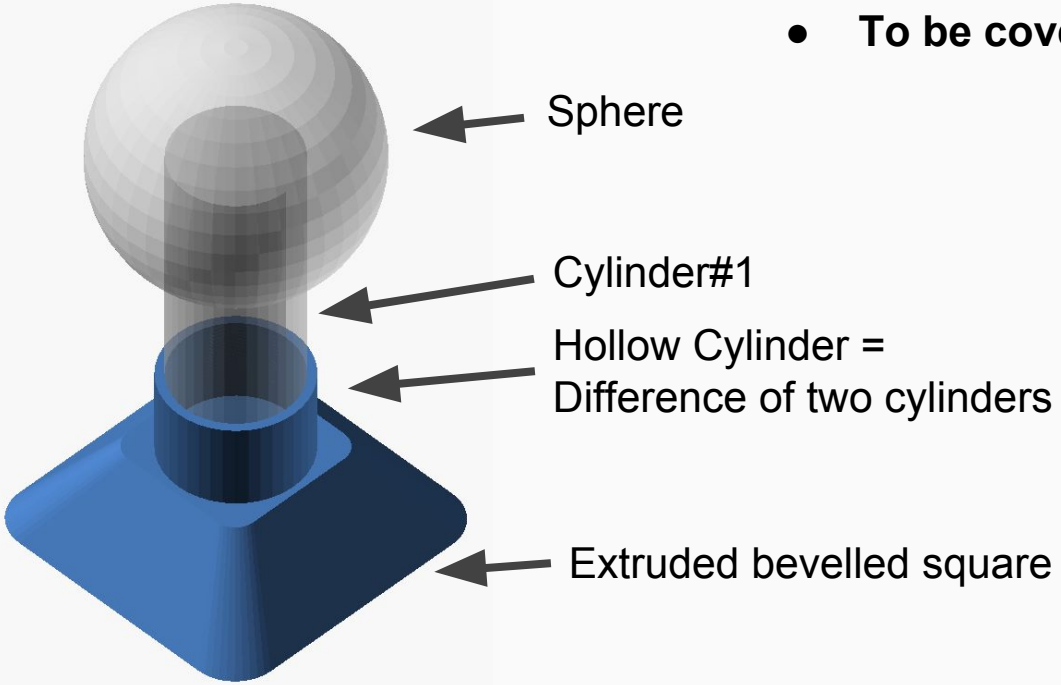
Parametric Design

- 3D CAD design starts with simple shapes
- Computational Solid Geometry (CSG) deals with how to make complicated objects from simpler ones



- **To be covered in more detail later in the course**

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CAD Software

- There are many CAD packages available - some examples :
    - OpenSCAD : Parametric modelling tool (developed by 3D printing community)
    - Solidworks : Used by design engineers, GUI-based
    - SketchUp : Also used within community, GUI-based
    - FreeCAD : Open sources GUI-based
    - Rhino : Design modelling tool
- Online browser based software : www.tinkercad.com, www.3dtin.com, www.onshape.com
- **OpenSCAD will be used later on in this course**
- Additional features to look out for:
    - Mating constraints and assemblies
    - Integration with simulation software

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Preliminary OpenSCAD Demonstration

- Open up example basics/CSG.scad

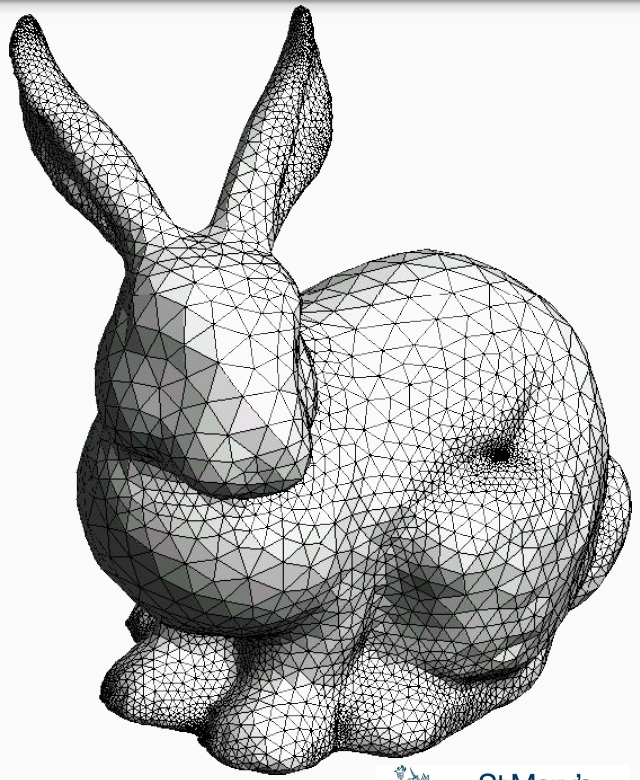
CAD Summary

- CAD software packages permit drafting of 2D and 3D objects
- CAD allows you to communicate your design effectively through drawings or file transfer
- Drawings must contain:
  - All necessary dimensions
  - Tolerances
  - Materials
  - Assembly information or another drawing
- Practical experience of OpenSCAD later
- Questions?

Surface Mesh

CAD Software Output

- CAD software must output a stereolithography (STL) file
- STL files contain the decomposition of the object's surface into triangular facets
- Surface must be watertight and fully separate an interior from exterior (no gaps!)
- Free MeshLab software exists to check the mesh watertightness and apply other modifiers…
- Check watertightness within MeshLab
  - Import STL model
  - Click Render/Show Non-Manif edges



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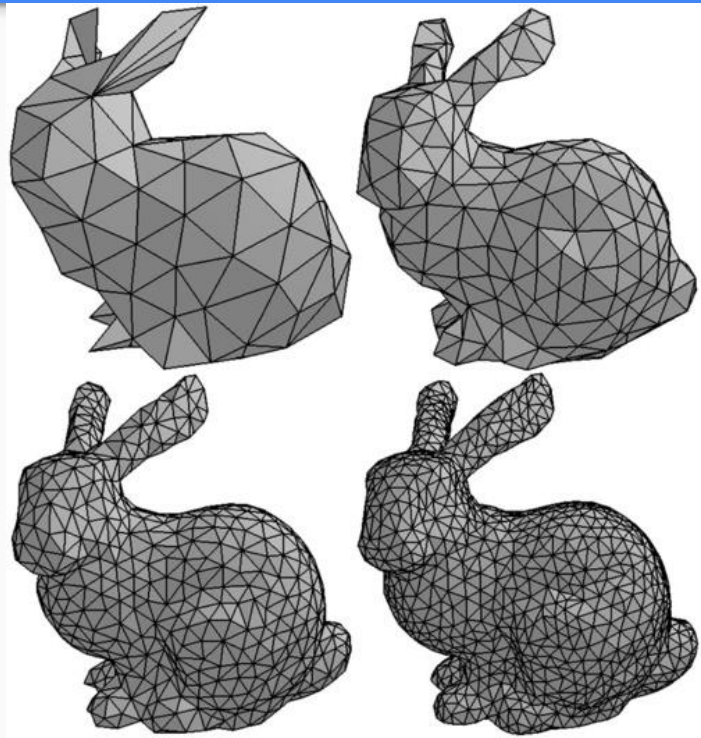
STL Mesh File Considerations

- Object's surface is approximated by triangles
- The surface appears smoother with more triangles
- But the file size increases with more triangles...
- Can show that each triangle is around 72 bytes per vertex

- **Stanford Bunny Low Res : 33426 vertices x72b = 2.3 MB**
- **Actual file size = 3.2MB**

- **Stanford Bunny High Res : 135624 vertices x72b = 9.3 MB**
- **Actual file size = 13.2MB**

- Issue with STL format is that no checks are performed on duplicated vertices - see Chapter 2, Polygon Mesh Processing, M. Botsch *et al*



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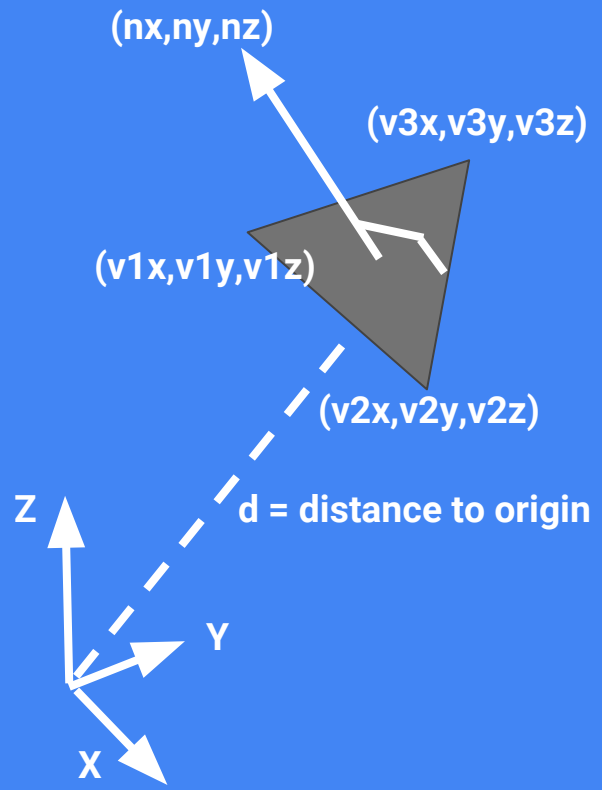
Meshlab Demonstration

- Example STL files available at : -
- https://en.wikipedia.org/wiki/List_of_common_3D_test_models
- http://www.thingiverse.com/
- … and others

- Demonstration
- Load in Bunny
- Show that it is watertight - /Render/Show Non-Manif edges
- Reduce the number of triangles - /Filters/Remeshing… /Quadric Edge Collapse Decimation

STL Mesh Files

- **Surface data only**

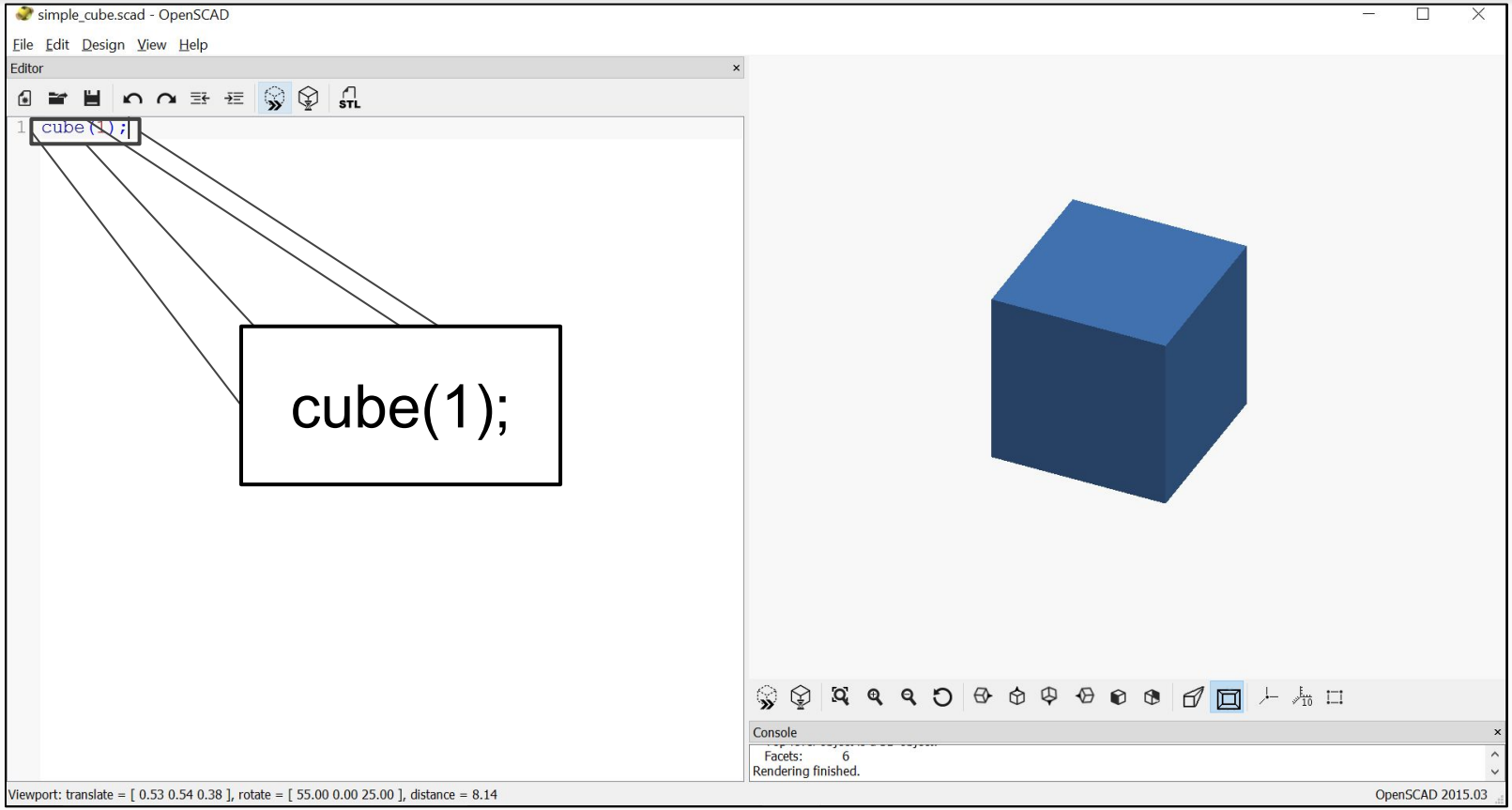


- STL file data are triangulated points on the object's surface
- Each triangle has the format :

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

- STL files are either ASCII (human-readable text) or binary

Simple STL Example



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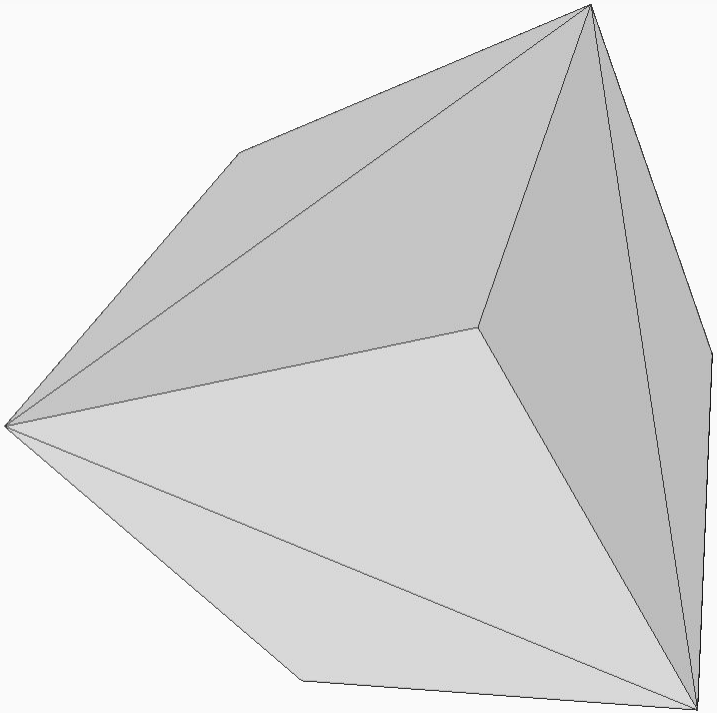
Simple STL Example

```
cube(1);
```



```
solid OpenSCAD_Model
  facet normal -0 0 1
    outer loop
      vertex 0 1 1
      vertex 1 0 1
      vertex 1 1 1
    endloop
  endfacet
  facet normal 0 0 1
    outer loop
      vertex 1 0 1
      vertex 0 1 1
      vertex 0 0 1
    endloop
  endfacet
  facet normal 0 0 -1
    outer loop
      vertex 0 0 0
      vertex 1 1 0
      vertex 1 0 0
    endloop
```

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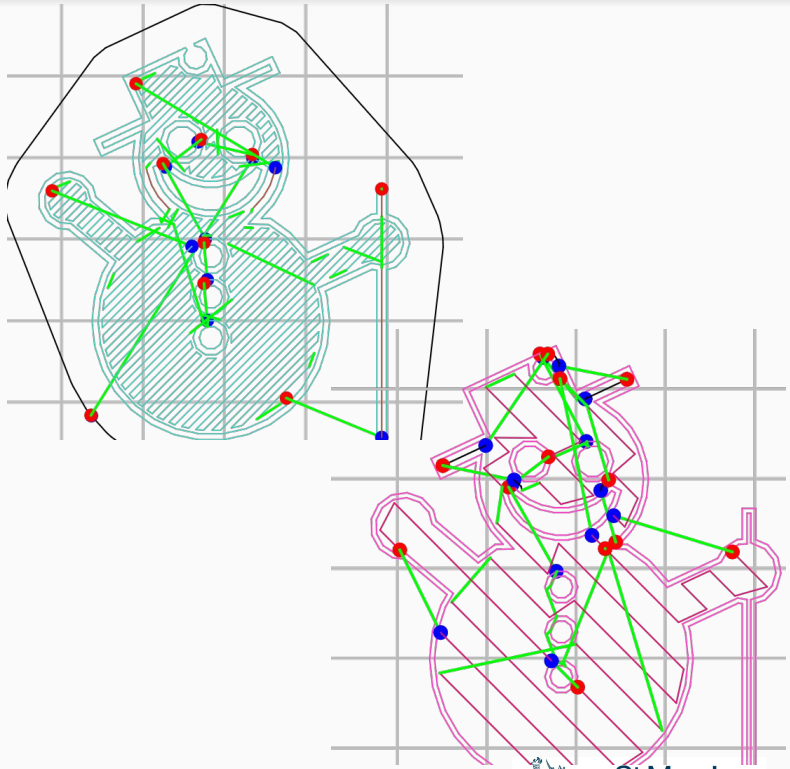
Mesh / STL Summary

- CAD exports the design to STL format
- The STL format contains a description of the surface of the CAD model
  - The surface data contains triangular facets and their normals
- For the next stages to work, the mesh must be watertight
- STL file is not efficient representation of the mesh - it is larger than necessary for human-readability
- Questions?

Slices and G-code

Slicing Software : G-code to 3D Object

- Slicer software uses the watertight STL mesh and calculates where the printhead moves for horizontal slices
- e.g. Snowman Christmas tree decoration
- **Skirt** (black outer line) : This is wasted material but useful to start the flow of material through the nozzle
- **Perimeters** : The lines around the slice of the object
- **Infill** : The diagonal lines which fill the object
- **Retraction** : Red/Blue points where the system retracts filament and moves quickly to the next point



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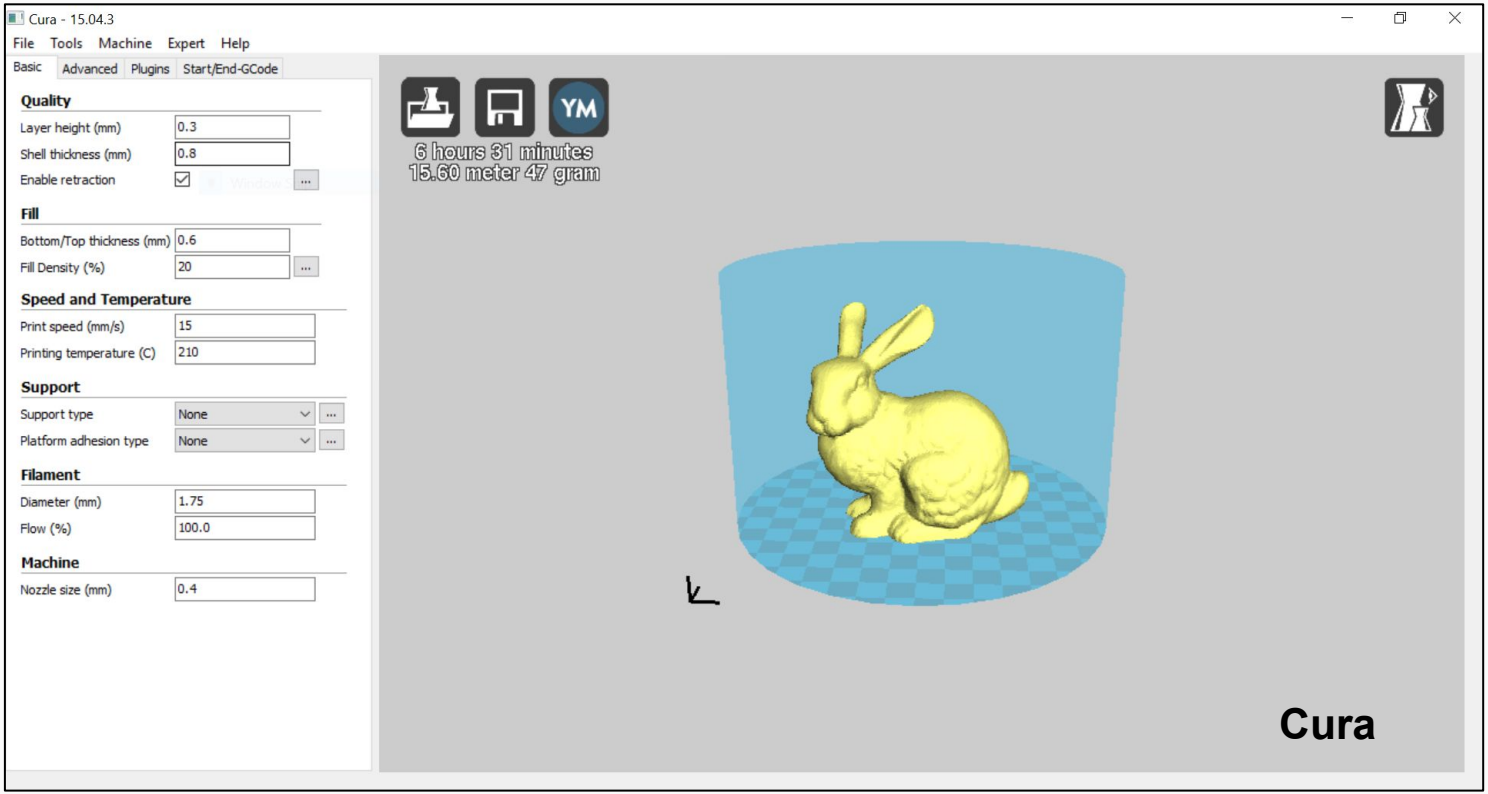
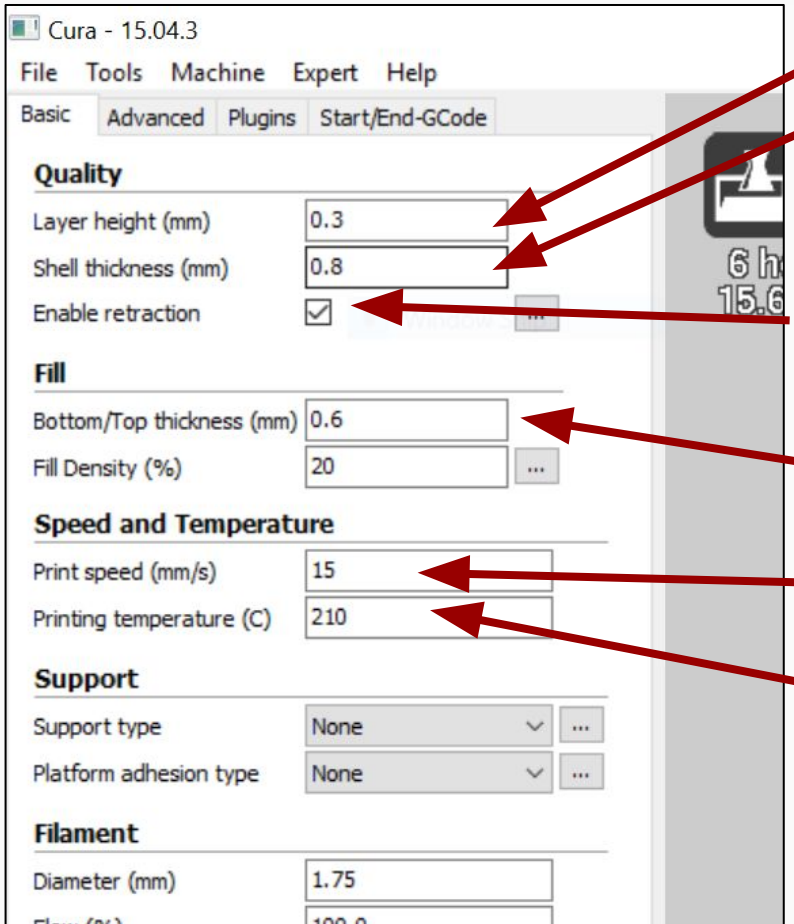
Free Slicing Software

- Slic3r and Cura are two popular slicer software packages



Parameters and Settings



- **Layer height :** slice layer height very important to get right
- **Shell Thickness :** The plastic lines on the outside of the model will be thicker to give it strength and a good appearance. This is thickness of this outer shell in a horizontal direction only.
- **Enable retraction :** When the printhead needs to move a long way it will pull the filament back so that the filament doesn't ooze out of the nozzle.
- **Bottom/Top thickness :** Same as shell thickness for the vertical faces too.
- **Print speed :** Controls the print time - too fast and mistakes are more likely, too slow and get blobs
- **Print temperature :** Nozzle temperature

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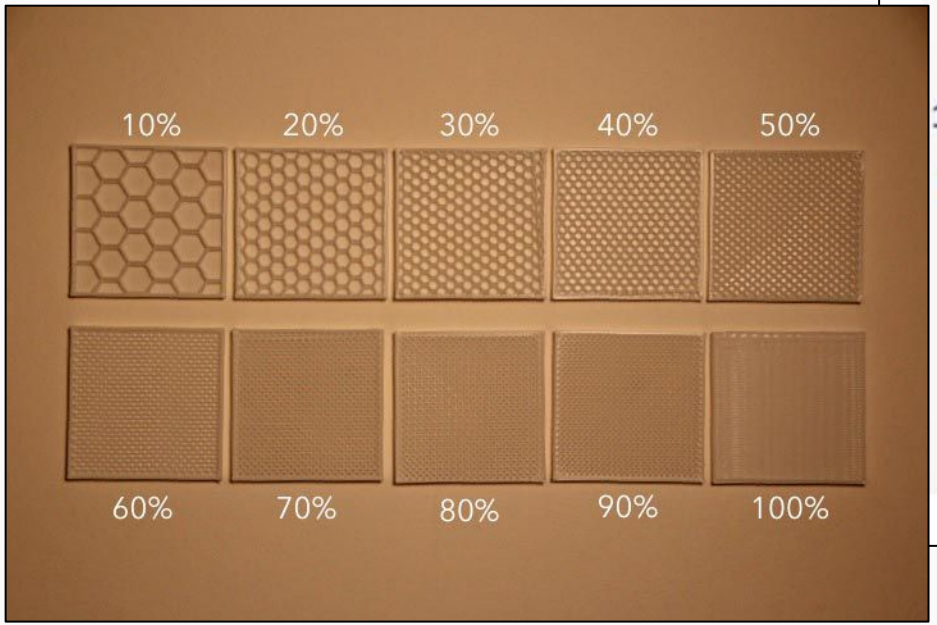
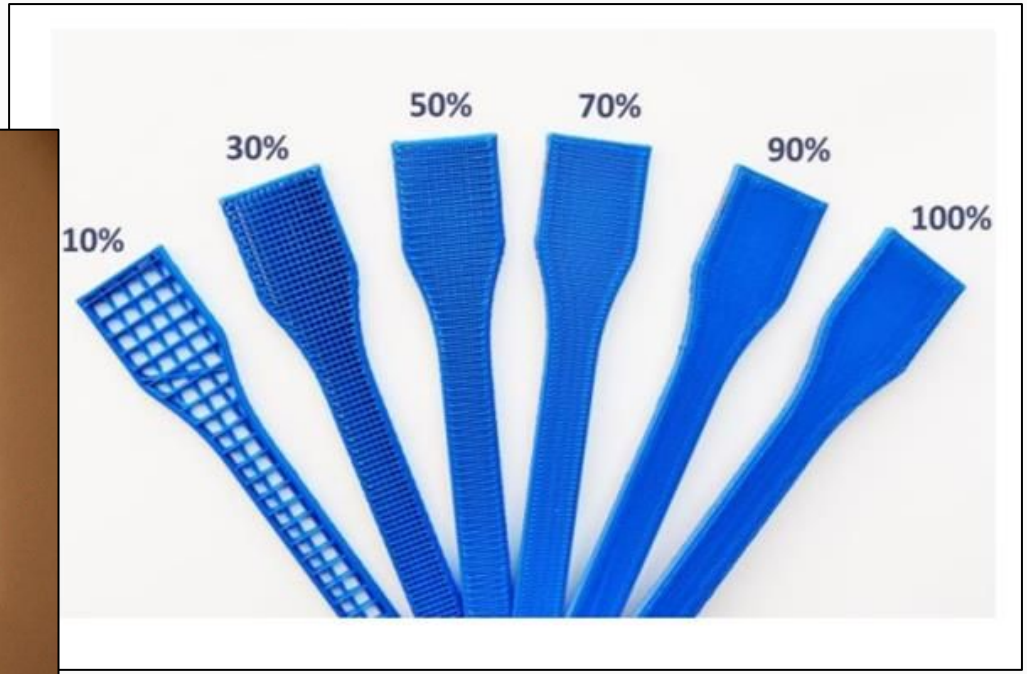
Infill and Patterns

- **Cura** provides only a simple line infill pattern at varying densities (in development)
- **Slic3r** is able to provide many more





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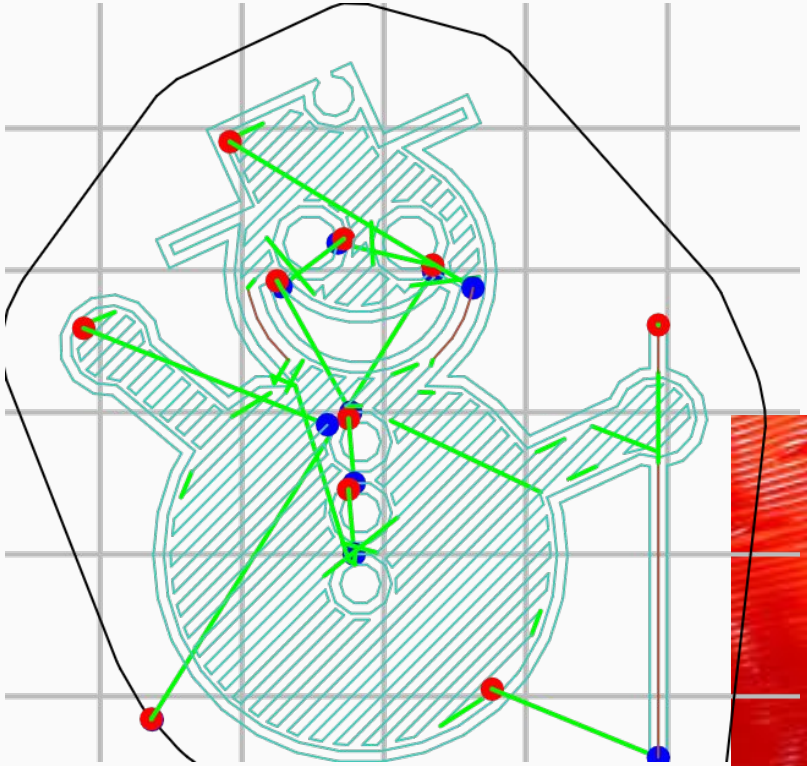
G-code to 3D Object



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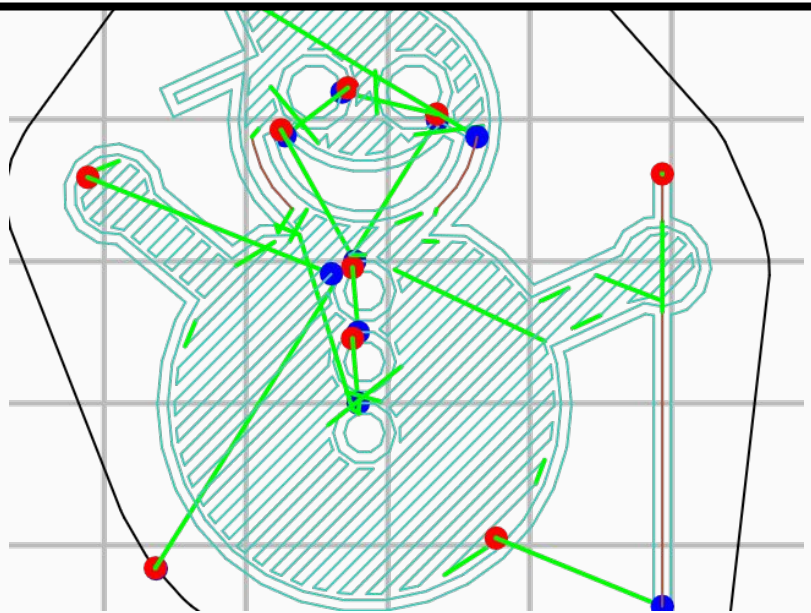
G-code File Header

- **G*** :** Commands which control the printing operations
- **M*** :** Commands which set parameters



```
; generated by Slic3r 1.2.6 on 2015-04-24 at 10:01:16
; external perimeters extrusion width = 0.50mm
; perimeters extrusion width = 0.72mm
; infill extrusion width = 0.72mm
; solid infill extrusion width = 0.72mm
; top infill extrusion width = 0.72mm

M107
M190 S57 ; set bed temperature
G28 ; home all axes
M83;
G10 P0 S195 R160
; Set tool 0 operating and standby temperatures
T0 ; set the extruder temperature to 0
```

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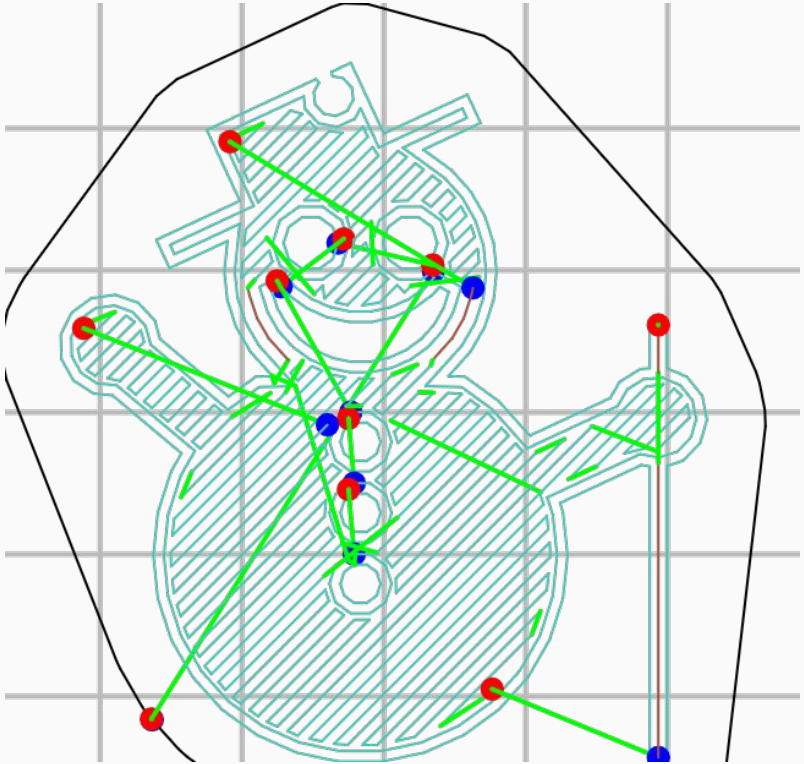
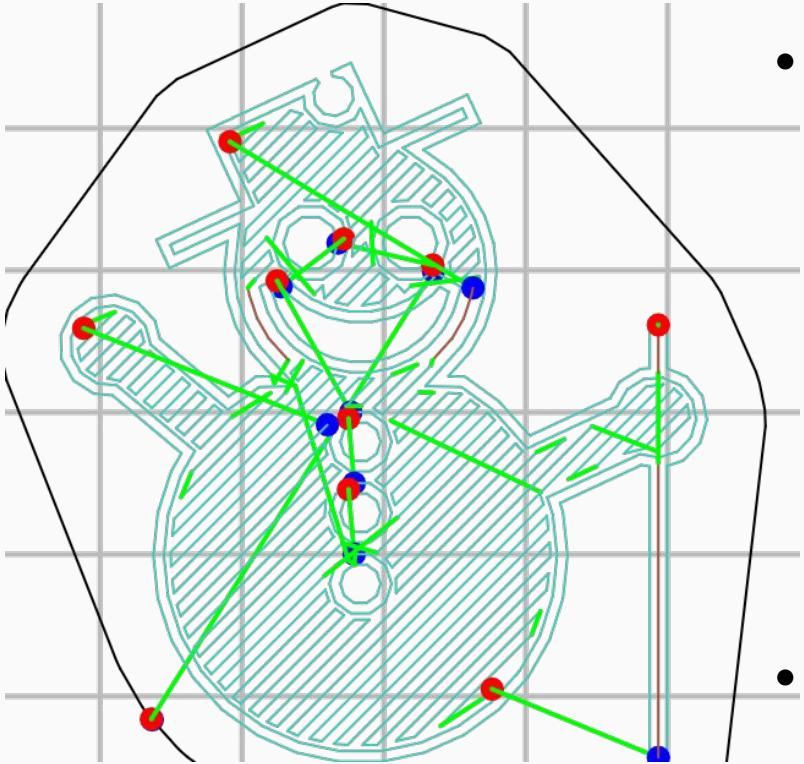
G-code File Header



...

G21 ; set units to millimeters
G90 ; use absolute coordinates
M83 ; use relative distances for extrusion
G1 E-3.50000 F2400.00000
G1 Z0.300 F12000.000
G1 X53.661 Y48.317 F12000.000
G1 E3.50000 F2400.00000
G1 X55.530 Y46.241 E0.25623 F1200.000
G1 X56.110 Y45.719 E0.07166
G1 X58.647 Y43.875 E0.28772
G1 X59.324 Y43.485 E0.07166
G1 X62.189 Y42.210 E0.28772
G1 X62.931 Y41.968 E0.07164
G1 X65.999 Y41.316 E0.28772
G1 X66.761 Y41.235 E0.07036
G1 X90.343 Y41.152 E2.16369
G1 X92.014 Y41.547 E0.15755
G1 X93.332 Y42.648 E0.15755 F1200.000

G-code Move Command



- **G0/G1 :** Move commands

G1 Xnnn Ynnn Znnn Eaaa Fbbb Sccc
Move to (X,Y,Z) in mm
Extrude [aaa] mm of filament
Sets filament feed rate of [bbb] mm/minute
Check if end stop was hit (default=ignore,ccc=0)

G1 F1500
Sets filament feed to 1500mm/minute
G1 X50 Y25.3 E22.4
Move to X=50mm, Y=25.3mm while extruding 22.4mm of filament

- **Refer to g-code cheatsheet!**

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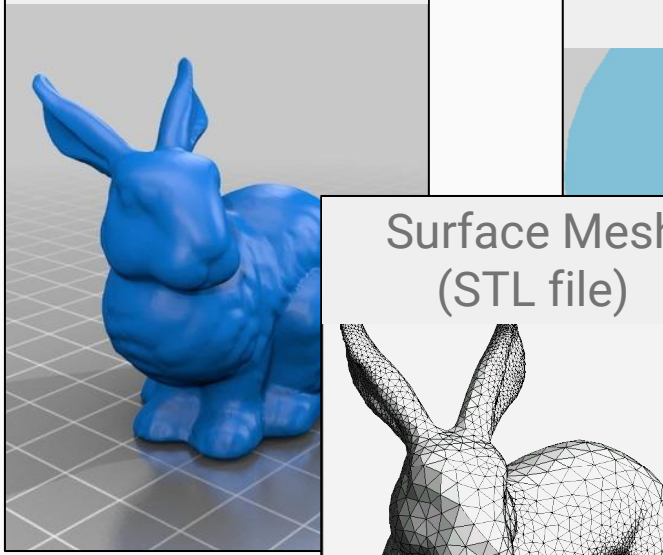
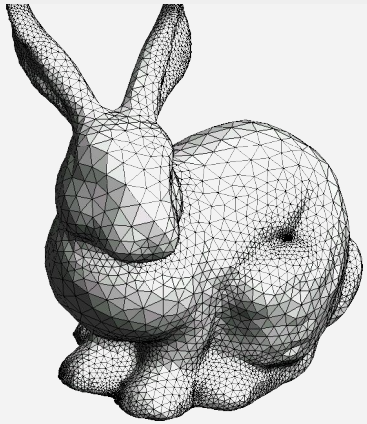
SUMMARY

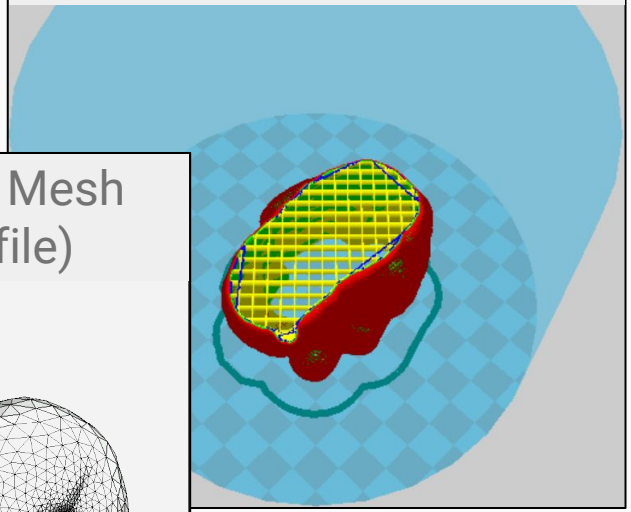
CAD Design

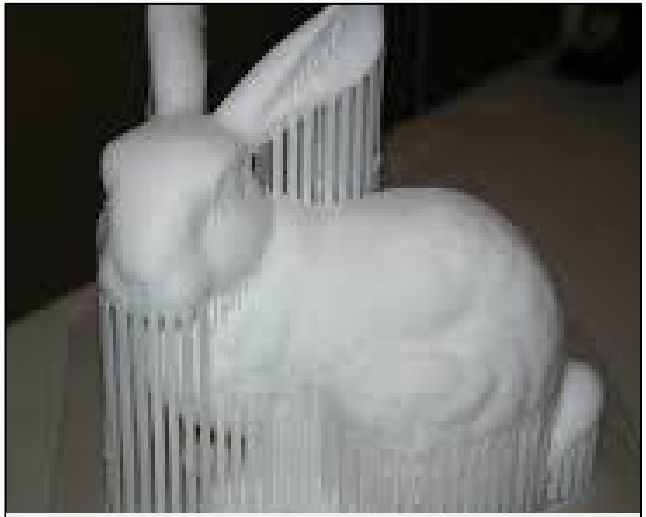


Surface Mesh
(STL file)



Slices and Settings
(G-Code file)





Printed Object

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Get excited and make things…

- Useful websites to help you…

- www.thingiverse.com 3D Printing Designs
- www.youimagine.com 3D Printing Designs
- http://www.3ders.org/ 3D Printing News
- https://www.3dhubs.com/ Local 3D Printing Services
- http://www.reprap.org/ RepRap are the ‘original’ 3D printer
- http://www.openscad.org/ Openscad software
- http://slic3r.org/ Slic3r software