

Firmware

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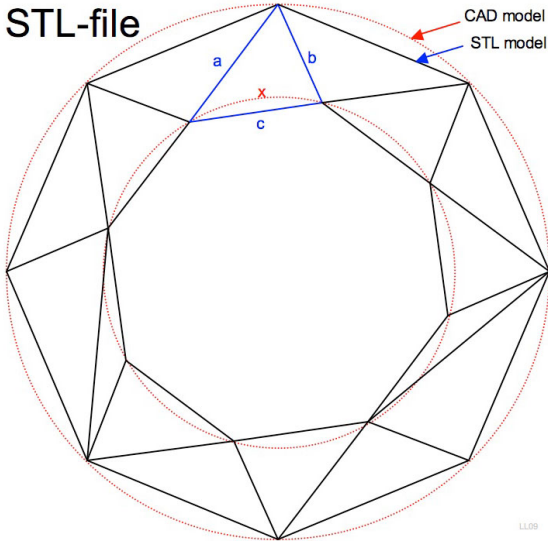
UConn 3D printing—building by learning, 2016 fall

Review of the FDM 3D Printing Process

- ▶ Modeling
 - ▶ input: 3D concept of an object
 - ▶ output: .STL file
- ▶ Slicing
 - ▶ input: 3D model as a .STL file
 - ▶ output: G-Code
- ▶ Printing

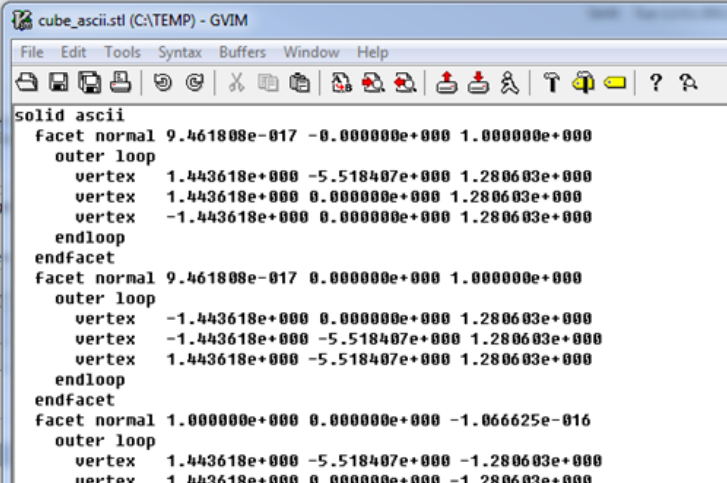
.STL (Standard Tessellation Language) file

- ▶ the STL file format uses a series of linked triangles to recreate the surface geometry of a solid model.



.STL file

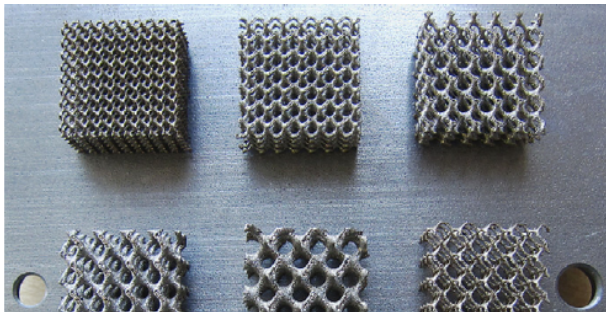
- ▶ each triangle facet is described by a perpendicular direction and three points which represent the corners of the triangle. An STL file provides a complete listing of the x, y and z coordinates of these corners and perpendiculars.



```
cube_ascii.stl (C:\TEMP) - GVIM
File Edit Tools Syntax Buffers Window Help
[Toolbar icons]
solid ascii
  facet normal 9.461808e-017 -0.000000e+000 1.000000e+000
    outer loop
      vertex 1.443618e+000 -5.518407e+000 1.280603e+000
      vertex 1.443618e+000 0.000000e+000 1.280603e+000
      vertex -1.443618e+000 0.000000e+000 1.280603e+000
    endloop
  endfacet
  facet normal 9.461808e-017 0.000000e+000 1.000000e+000
    outer loop
      vertex -1.443618e+000 0.000000e+000 1.280603e+000
      vertex -1.443618e+000 -5.518407e+000 1.280603e+000
      vertex 1.443618e+000 -5.518407e+000 1.280603e+000
    endloop
  endfacet
  facet normal 1.000000e+000 0.000000e+000 -1.066625e-016
    outer loop
      vertex 1.443618e+000 -5.518407e+000 -1.280603e+000
      vertex 1.443618e+000 0.000000e+000 -1.280603e+000
```

.STL file

- ▶ STL is an old standard (3 decades old)
- ▶ not keeping up with the improving 3D printers and design software
- ▶ new standard AMF (Additive Manufacturing Format)
- ▶ maintains the surface mesh structure
- ▶ added capabilities to reflect advances in design software and printers
- ▶ can handle e.g. different colors, different materials, lattice internal structures



G-Code

- ▶ the most widely used numerical control (NC) programming language.
- ▶ used mainly in computer-aided manufacturing to control automated machine tools (like CNC's and 3D printers).
- ▶ a.k.a RS-274, G programming language, etc.

G-Code

3D printers can be manually controlled with G-codes

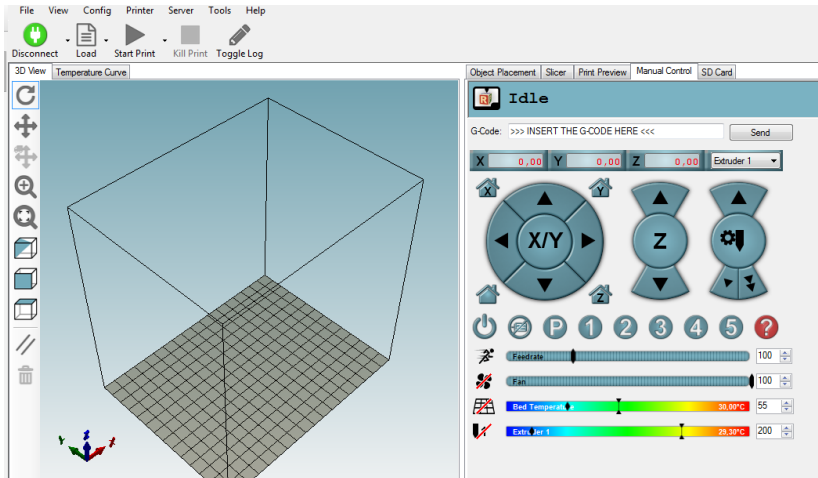


Figure 4: G-code manual control example: repetier host

Common G-Codes

Code	Function
G0, G1	linear move
G2, G3	controlled arc move
G4	dwel (delay or pause)
G10 & G11	retract and unretract (the filament)
G28	move to home position
M104	set extruder temperature
M140	set bed temperature
M116	wait for temperature to stabilize
M112	emergency stop

RepRap GCode Cheat Sheet



Comm. Parameters	Description	Example	
G0	Axis [XYZ] Position	Rapid Movement	G0 X50
G1	Axis [XYZ/E] Position Feed [F]	Controlled Movement	G1 F150 X10
G4	Time in ms [P]	Dwell / Wait	G4 P500
G20	none	Set units to inch	G20
G21	none	Set units to mm	G21
G28	<Axis [XYZ]>	Home	G28 X Y
G90	none	Absolute Positioning	G90
G91	none	Relative Positioning	G91
G92	Axis [XYZ/E] Value	Set Position to value	G92 X5 Y10

Comm. Parameters	Description	Example	
M0	none	Stops everything after buffer is empty	M0
M17	none	Enable all stepper motors	M17
M18	none	Disable all stepper motors (move freely)	M18
M30	none	List files at the root folder of the SD Card	M30
M21	none	Initialise (mount) SD Card	M21
M22	none	Release (unmount) SD Card	M22

Common G-Code: linear move

G0: rapid linear movement; | **G1**: rapid movement

usage: G0 [E(pos in mm)] [F(mm/min)] [X(pos in mm)] [Y(pos in mm)] [Z(pos in mm)]

All the specified axes will move simultaneously to arrive at the given coordinates at the same time using linear interpolation. The speed may change over time following an acceleration curve, according to the acceleration and jerk settings of the given axes.

Marlin treats G0 (rapid linear movement) as an alias to G1 (rapid movement). Some G-Code generators may have separate implementations.

G0 & G1: Parameters

G0 [E(pos in mm)] [F(mm/min)] [X(pos in mm)] [Y(pos in mm)]
[Z(pos in mm)]

Argument	Description
E(pos in mm)	The amount to extrude between the starting point and ending point
F(mm/min)	The maximum movement rate of the move between the starting and ending point
X(pos in mm)	A coordinate on the X axis
Y(pos in mm)	A coordinate on the Y axis
Z(pos in mm)	A coordinate on the Z axis

G0 & G1: Example 1:

- G0 X12 ; move to 12mm on the X axis
- G0 F1500 ; set the feedrate to 1500mm/minute
- G1 X90.6 Y13.8 ; move to location (X,Y)=(90.6mm, 13.8mm)

G0 & G1: Example 2:

- G1 F1500 ; set the feedrate to 1500mm/minute
- G1 X50 Y25.3 E22.4 ; move while extruding

Here, when moving the nozzle to the target position of 50mm on the X axis and 25.3mm on the Y axis, the machine extrudes 22.4mm of filament between the two points.

G0 & G1: Quiz

Explain each line of the following G-codes:

- G1 F1500
- G1 X50 Y25.3 E22.4 F3000

Common G-Code: Controlled Arc Move

G2 & G3¹

- G2 Xnnn Ynnn Innn Jnnn Ennn Fnnn (Clockwise Arc)
- G2 Xnnn Ynnn Rnnn Ennn Fnnn (Clockwise Arc)
- G3 Xnnn Ynnn Innn Jnnn Ennn Fnnn (Counter-Clockwise Arc)

Argument	Description
Xnnn	The position to move to on the X axis
Ynnn	The position to move to on the Y axis
Innn	The point in X space for the current position to maintain a constant distance from
Jnnn	The point in Y space for the current position to maintain a constant distance from
Rnnn	Radius of the arc

¹not available in all firmwares

G2 & G3: Example

- G2 X90.6 Y13 I5 J10 E24 (Move in a Clockwise arc from the

In picture, this looks like:

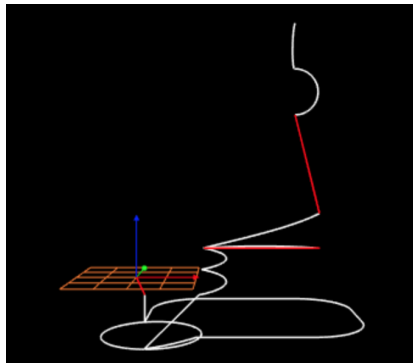
G2 & G3: Exercise

Suppose the current position of the nozzle is (80,0). Sketch the tool path of the following G-code

- G3 X90.6 Y13.8 I5 J10 E22.4

Common G-Codes >> A More Comprehensive Example

```
G0 Y10 Z-5  
G1 Z-10  
G1 Y20  
G2 X10 Y30 R10  
G1 X30  
G2 X40 Y20 R10  
G1 Y10  
G2 X30 Y0 R10  
G1 X10  
G2 X0 Y10 Z-15 R10  
G3 X-10 Y20 R-10  
G3 X0 Y10 I10 (center)  
G91 G1 X10 Z10  
G3 Y10 R5 Z3 (circle in incremental)  
Y10 R5 Z3  
G20 G0 X1  
G3 X-1 R1 (radius in inches)  
G3 X1 Z0.3 I0.5 J0.5 (I,J in inches)  
G21 (back to mm)  
G80 X10 (do nothing)  
G90  
G0 X30 Y30 Z30
```



M-Codes

- M0 - Unconditional stop
- M1 - Same as M0
- M17 - Enable/Power all stepper motors
- M18 - Disable all stepper motors; same as M84
- M20 - List SD card
- M21 - Init SD card
- M22 - Release SD card
- M23 - Select SD file (M23 filename.g)
- M24 - Start/resume SD print
- M25 - Pause SD print
- M26 - Set SD position in bytes (M26 S12345)
- M27 - Report SD print status
- M28 - Start SD write (M28 filename.g)
- M29 - Stop SD write
- M30 - Delete file from SD (M30 filename.g)

Reference

- ▶ Marlin: <http://www.marlinfw.org/docs/basics/introduction.html>
- ▶ Online Gcode Preview: <http://nraynaud.github.io/webgcode/>
- ▶ RepRap G-code page: <http://reprap.org/wiki/G-code>