

# Firmware

3D printing—building by learning

X. Chen

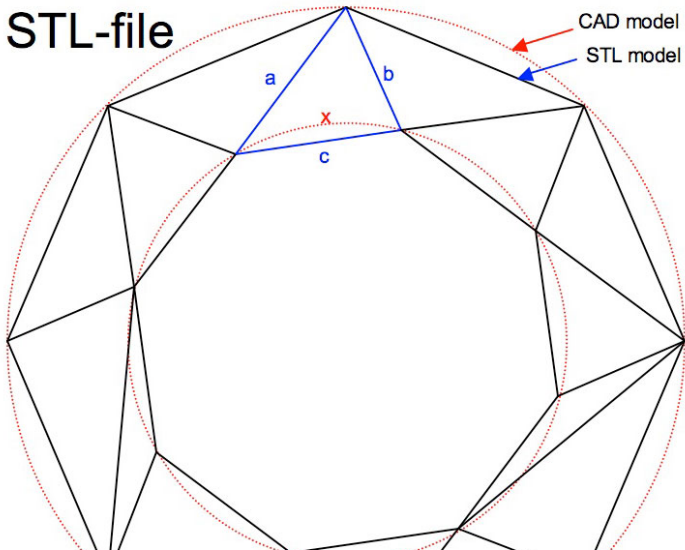
University of Washington

# 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

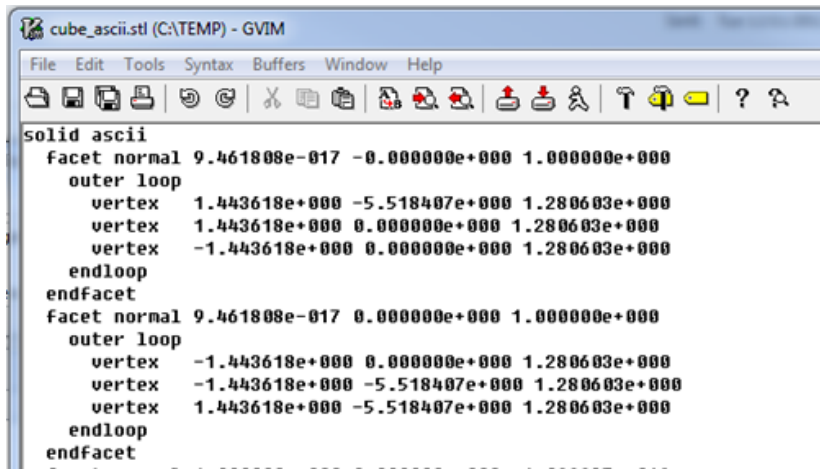
## .STL (Standard Tessellation Language) file

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



## .STL file

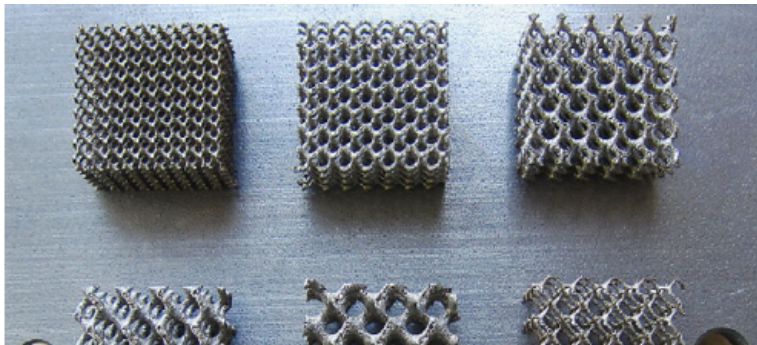
- ▶ each triangle facet is described by a perpendicular direction and three points which represent the corners of the triangle. An STL file provides a complete listing of the x, y and z coordinates of these corners and perpendiculars.

A screenshot of a text editor window titled "cube\_ascii.stl (C:\TEMP) - GVIM". The window has a menu bar with "File", "Edit", "Tools", "Syntax", "Buffers", "Window", and "Help". Below the menu bar is a toolbar with various icons for file operations and editing. The main text area contains the following STL file content:

```
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
```

## .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

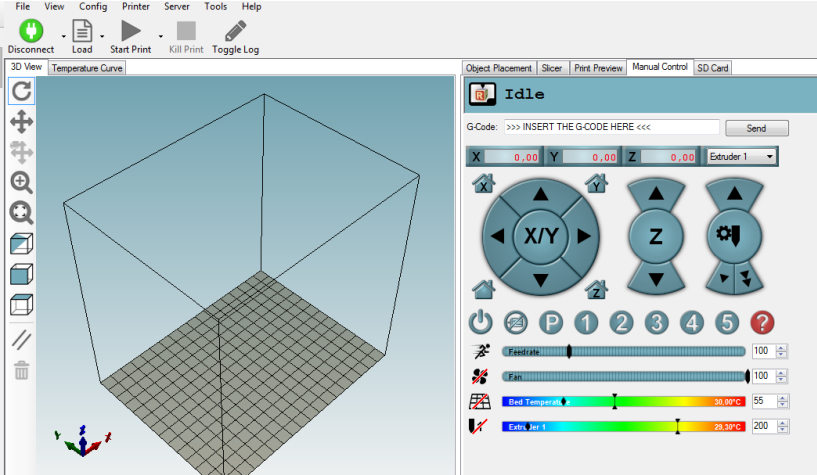


Figure 4: G-code manual control example: repetier host

# Common G-Codes

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Code	Function
G0, G1	linear move
G2, G3	controlled arc move
G4	dwll (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

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## RepRap GCode Cheat Sheet



### Comm. Parameters

G0	Axis [X/Y/Z] Position
G1	Axis [X/Y/Z/E] Position Feed [F]
G4	Time in ms [P]
G20	none
G21	none
G28	<Axis [X/Y/Z]>
G90	none
G91	none
G92	Axis [X/Y/Z/E] Value

### Description

Rapid Movement
Controlled Movement
Dwell / Wait
Set units to inch
Set units to mm
Home
Absolute Positioning
Relative Positioning
Set Position to value

### Example

G0 X50
G1 F150 X10
G4 P500
G20
G21
G28 X Y
G90
G91
G92 X5 Y10

### Comm. Parameters

M0	none
M17	none
M18	none

### Description

Stops everything after buffer is empty
Enable all stepper motors
Disable all stepper motors (move freely)

### Example

M0
M17
M18



## 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)]

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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

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## 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 & G3<sup>1</sup>

- 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)

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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

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<sup>1</sup>not available in all firmwares

## G2 & G3: Example

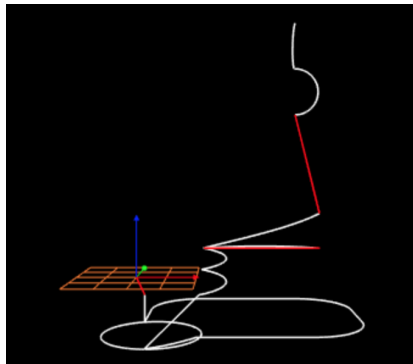
- G2 X90.6 Y13 I5 J10 E24 (Move in a Clockwise arc from the

In picture, this looks like:



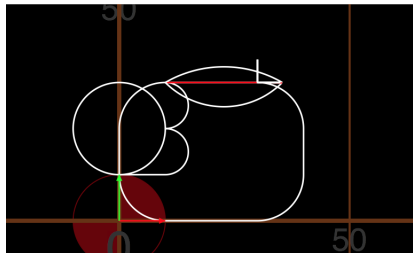
# Common G-Codes » A More Comprehensive Example

```
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
```



# 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>