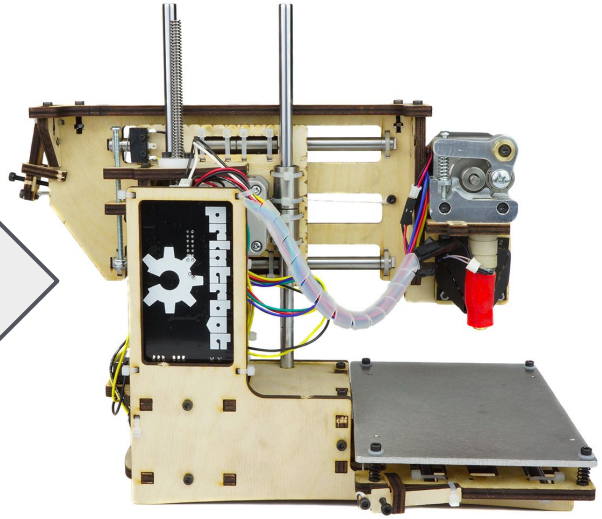
PiBakers

"Fast, Cheap 3D Printing ...from anywhere"

Ray Cload, Max Miller, William Corlett

The Endgame

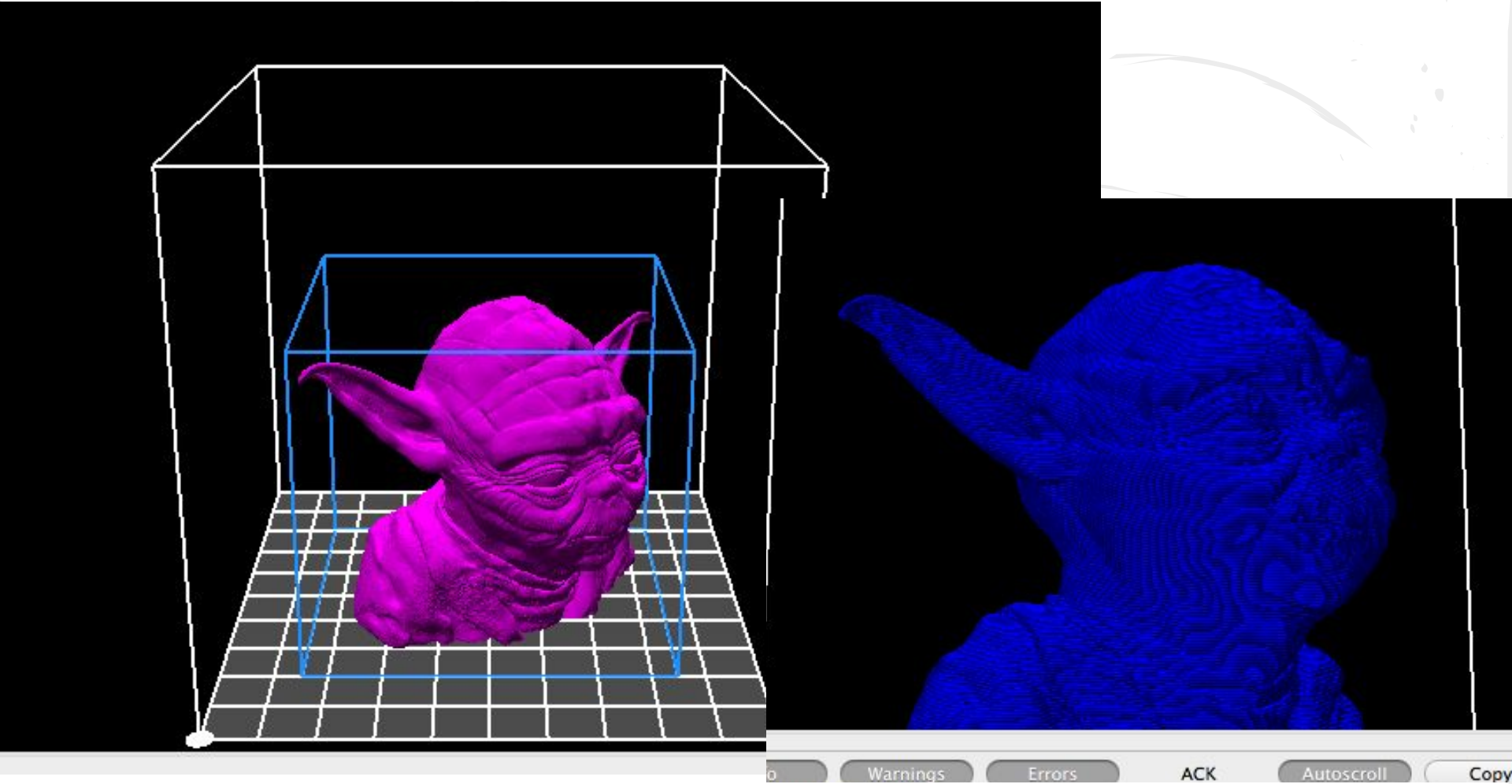


…And there’s more

Open source ‘hub’ solution for a printing lab

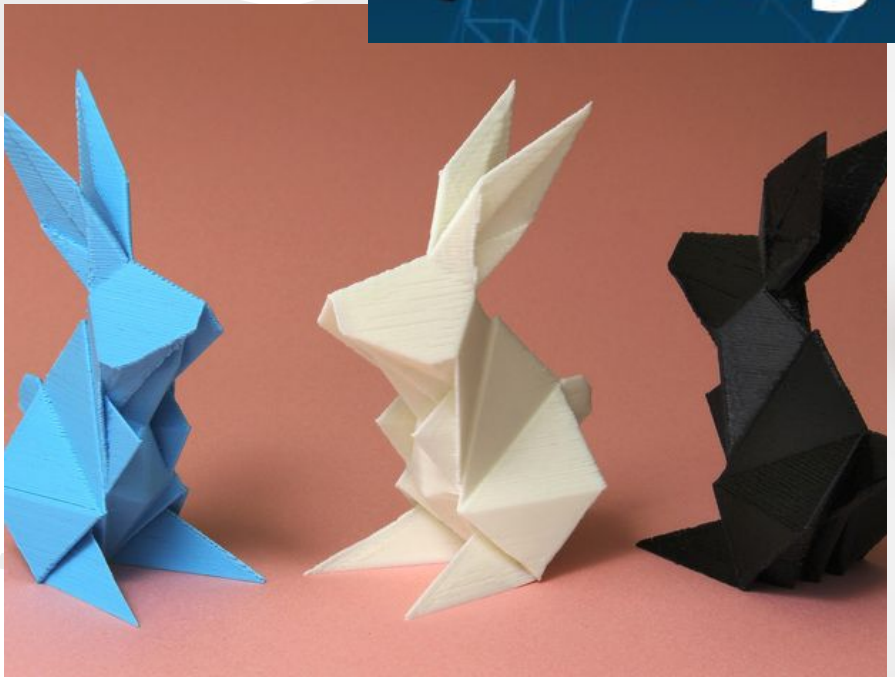
3D Printing Basics

- “Fused Deposition Modeling” or *additive manufacturing*
- Extrude hot plastic through a nozzle and “trace” out the desired object layer by layer


Warnings
Errors
ACK
Autoscroll
Copy

3D Printing Basics

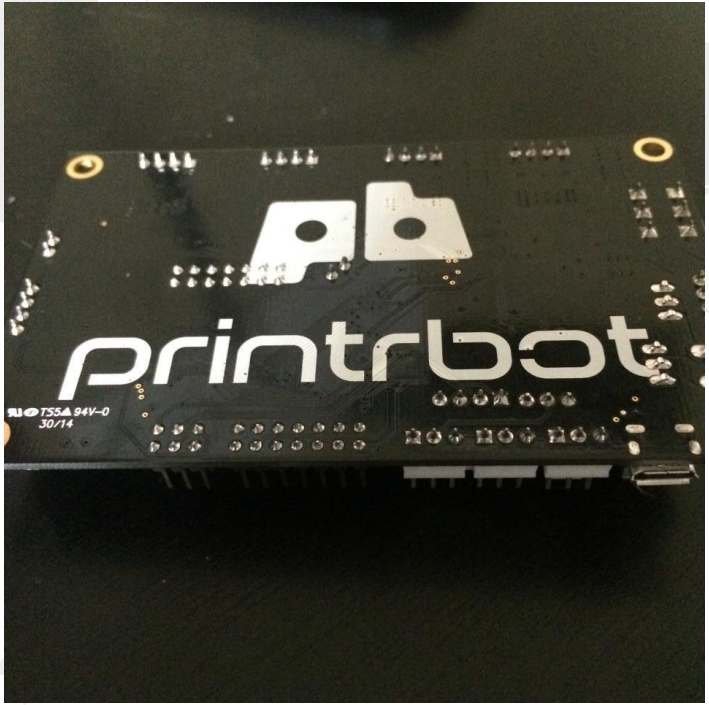
Thingiverse

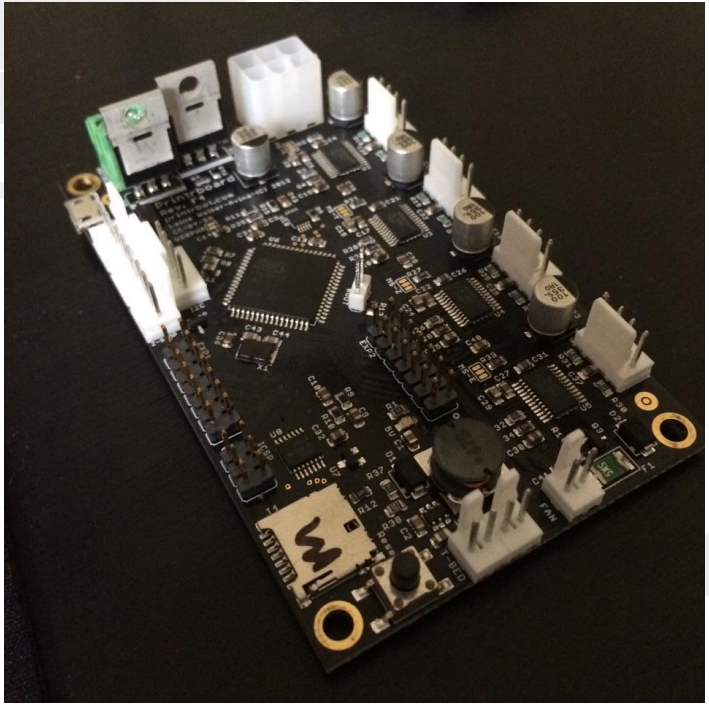


3D Printing Basics

- **G-Code**: A language which tells a computerized machine tool how to make something
- Defined by instructions on:
  - Where to move
  - How fast
  - Via what path?

3D Printing Basics

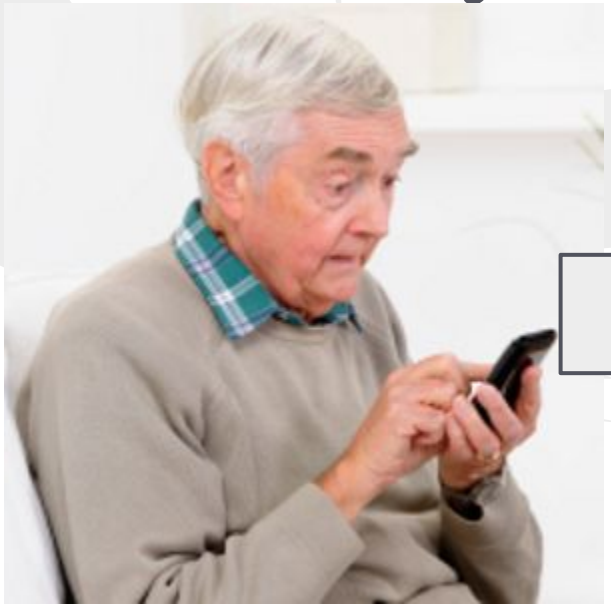


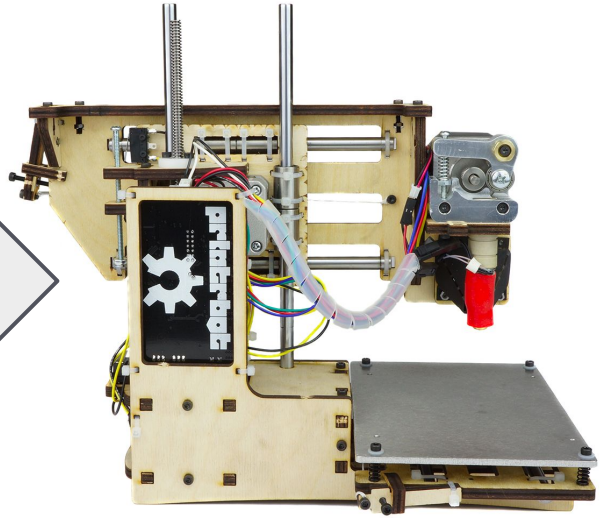


The Old Way

Thingiverse

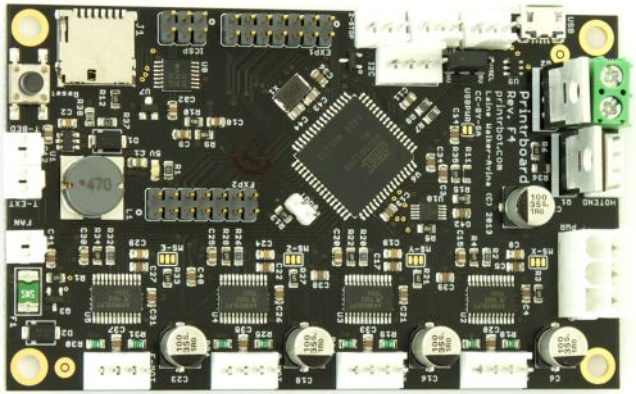
Our Way





Goals and Objectives

- Open source Raspberry Pi based solution to replace expensive proprietary controllers
- $99 vs $35



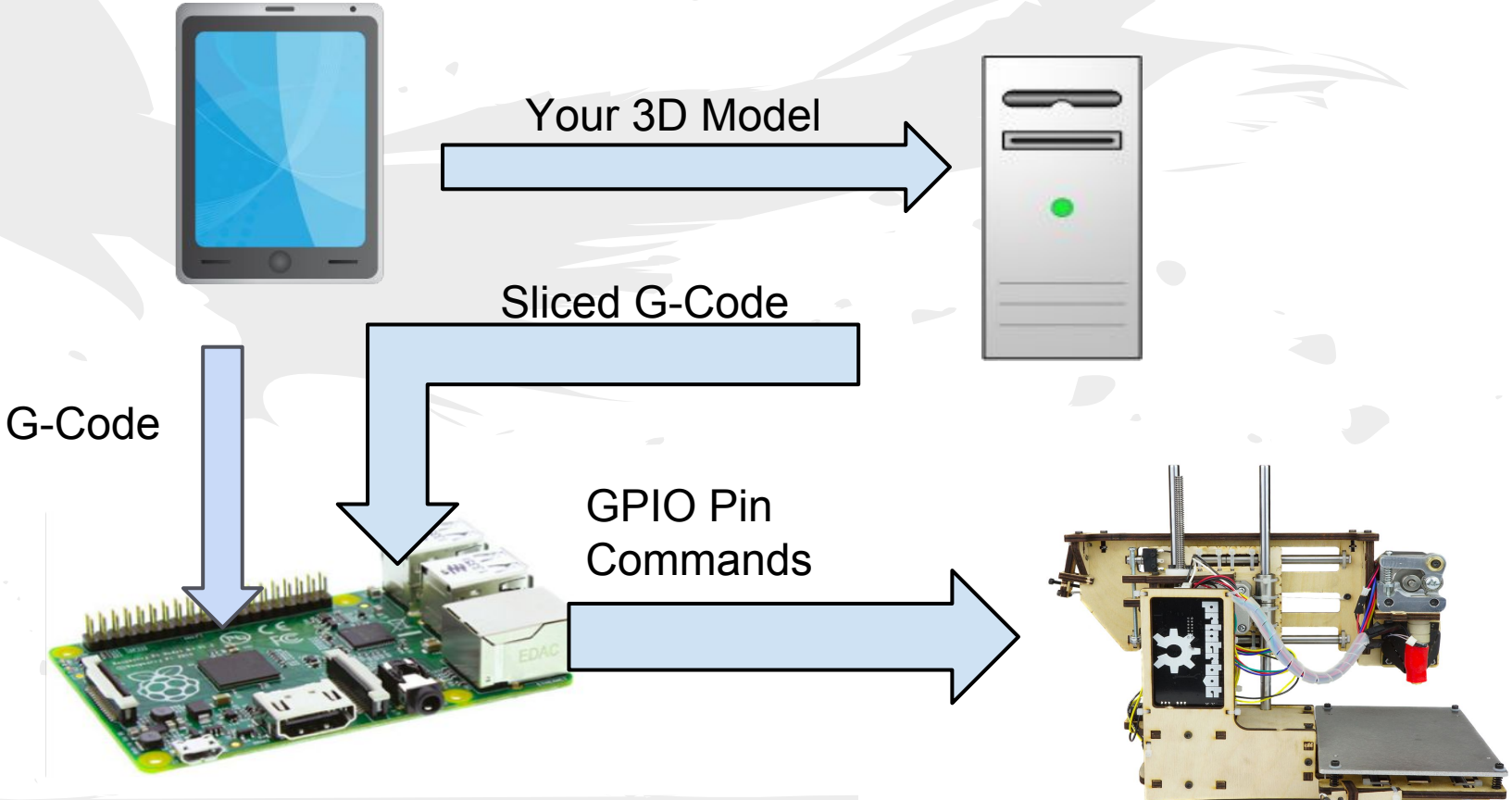
Goals and Objectives

- Design hardware interface between Raspberry Pi and standard 3D printer components
- Implement an interpreter to run G-code on the Raspberry Pi
- Create an interface which allows the user to initiate a print job, and manages the process

Requirements

- "***Fast***" - computationally heavy slicing done in the cloud
- "***Cheap***" - replace pricey controllers with RPi
- "**3D Printing**" - successfully print
- "...***from anywhere***" - using your PC, phone or tablet to start your prints without plugging into your printer

System Design Diagram



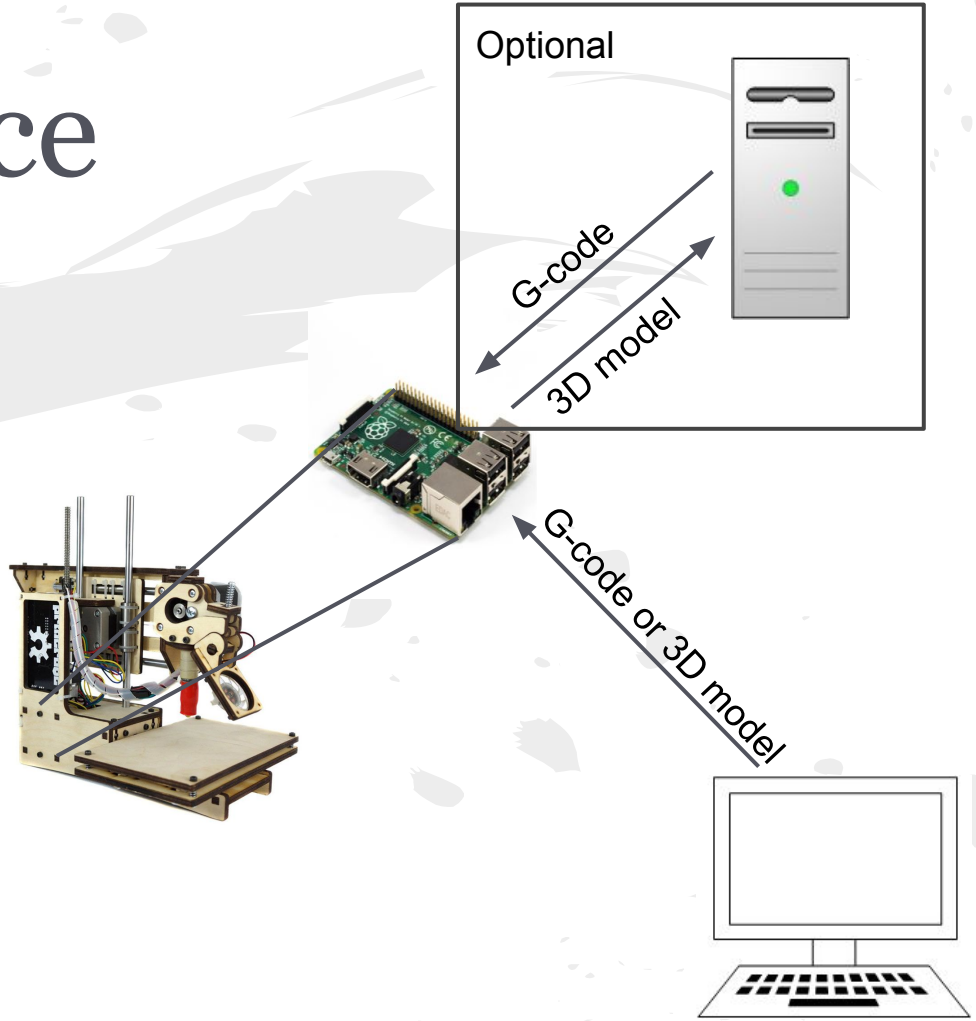
Printing

Two ways to start a print job

- Interfacing with the printer directly
- Interfacing with the management hub (running on a separate server)

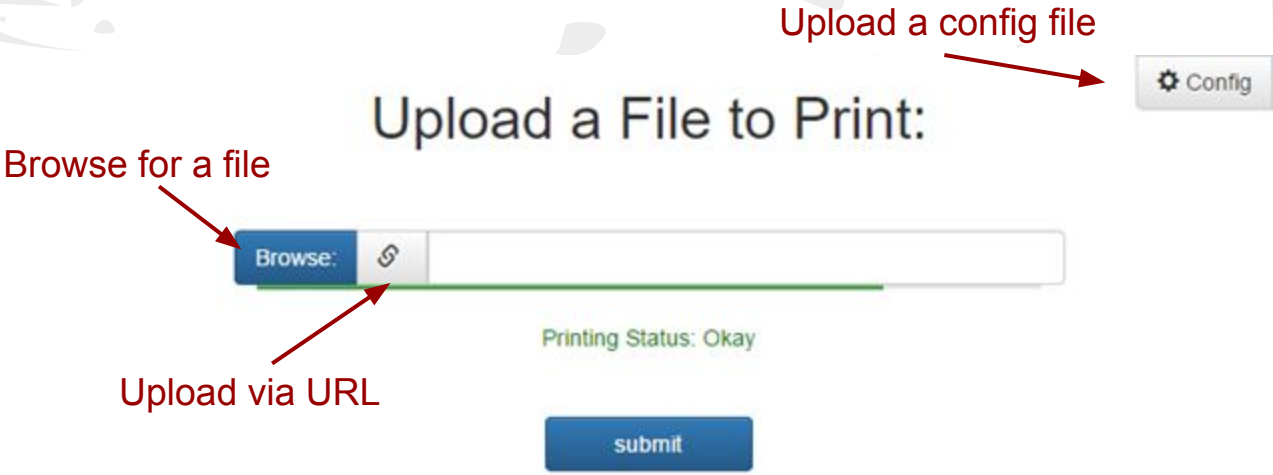
Local Interface

- No configuration needed
- Access over the local network
- Can only print G-code files by default



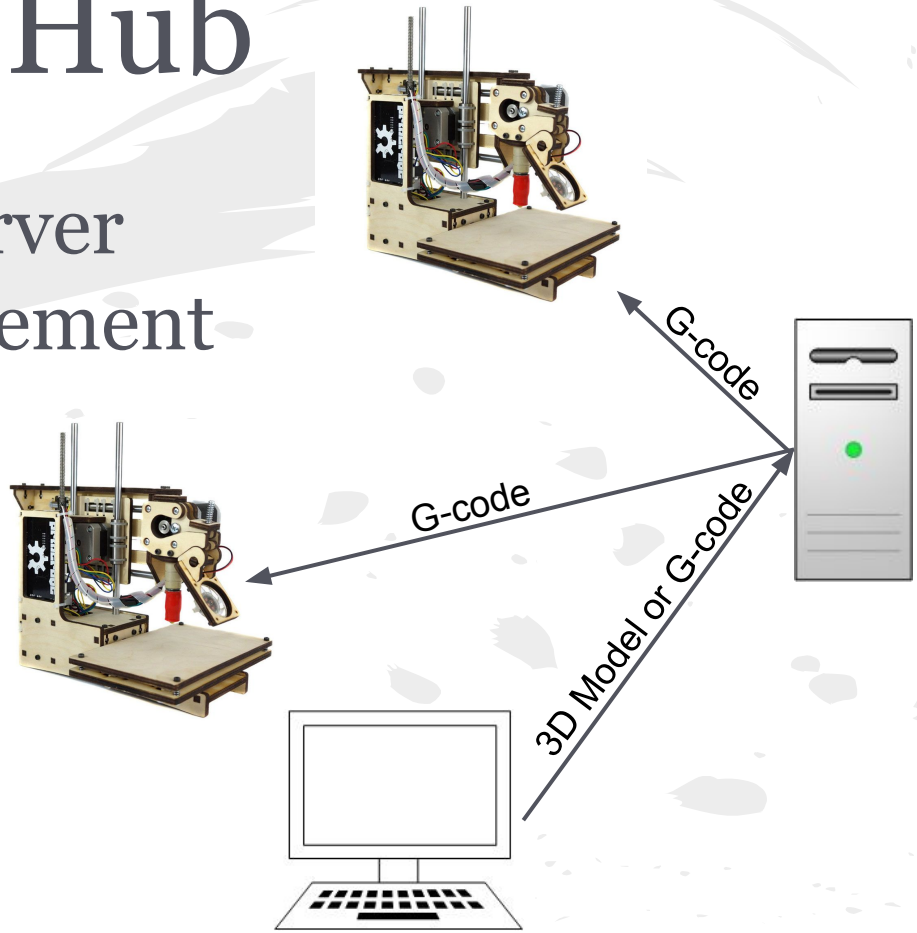
Using the Local Interface

- Web interface runs on the printer
- 3D models and G-code can be uploaded
  - A management hub must be registered to slice models



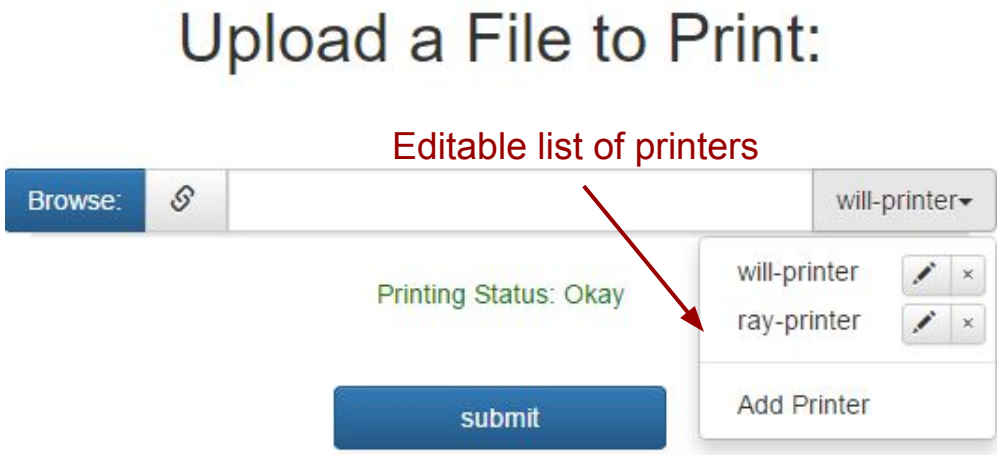
Management Hub

- Need a separate server
- Allows easy management of multiple printers
- Allows for slicing of 3D models



Using the Management Hub

- Printers are registered with the server
- Users can upload a model and choose which printer to send it to
- The list of servers can be locked by an administrator

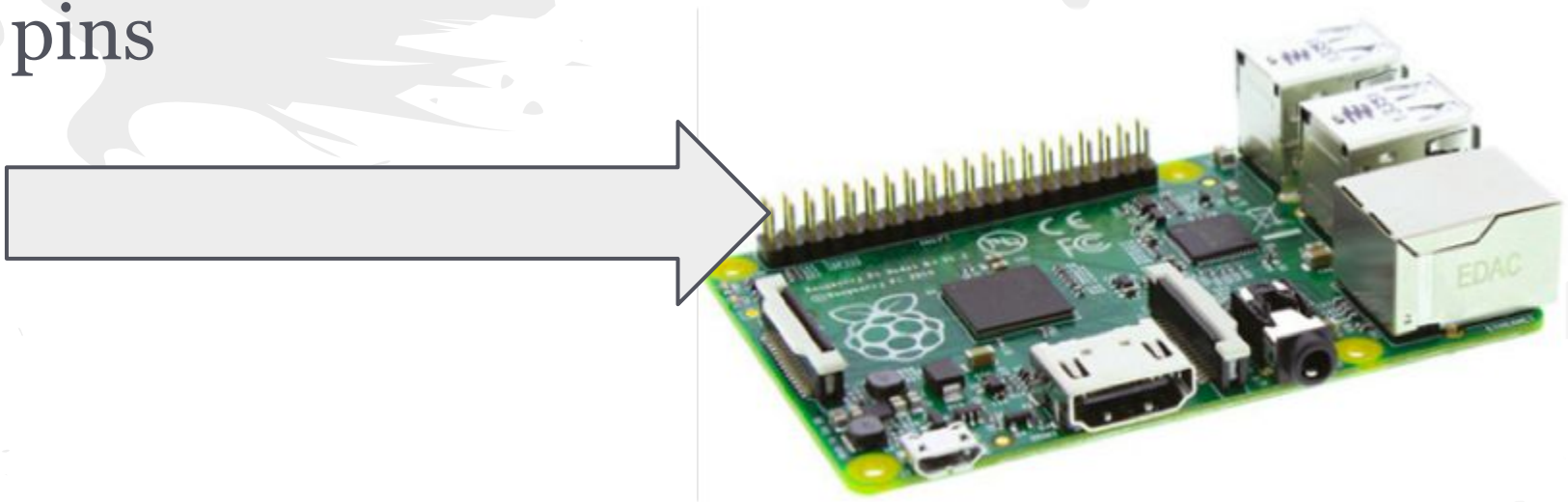


Technologies

- Node.js
  - Used for the web-interface back-end
  - Extensible
  - Lightweight
- Bootstrap & jQuery
  - Creating a consistent cross-browser interface
- Slic3r
  - Creates G-code from 3D models

The Interpreter & the Pi

- Interpreting in python allows for immediate action upon parameter capture via the GPIO pins



```
; generated by Slic3r 1.1.0 on 2014-04-08 at 16:31:08

; perimeters extrusion width = 0.40mm
; infill extrusion width = 0.65mm
; solid infill extrusion width = 0.65mm
; top infill extrusion width = 0.65mm

G21 ; set units to millimeters
M104 S208 ; set temperature
G28 X0.0 Y0.0 ; home XY axis
G1 Y10.0 F8000.00
G29
M109 S208 ; wait for temperature to be reached
G90 ; use absolute coordinates
G92 E0
M82 ; use absolute distances for extrusion
G1 F1800.000 E-1.00000
G1 Z1.361 F6000.000
G92 E0
G1 X50.949 Y51.120 F6000.000
G1 Z0.361 F6000.000
G1 E1.00000 F1800.000
G1 X51.702 Y50.433 E1.06739 F1500
G1 X52.532 Y49.842 E1.13478
G1 X53.427 Y49.356 E1.20218
```

G-Code’s Complexities

```
G1 X51.7 Y50.4 E1.0 F1500
```

G-Code's Complexities

```
G1 X51.7
G1 Y65.3
G1 Z1.65
G1 Y51.7 Z65.3
G1 X51.7 Y65.3 Z1.65 E1.34 F1200
```

Parsing the G-Code

- Python Module PLY (Python Lex Yacc)
  - open source implementation of lex and yacc
  - Developed in 2001 at University of Chicago for an Intro to Compilers course
  - www.dabeaz.com/ply/ply.html
  - Extremely picky due to origin as an educational tool

Using PLY.lex

- Lex allows us to define tokens through regular expressions

```
def t_NUMBER(t):
    r'[-|.|0-9*]+'
    t.value = float(t.value)
    return t

def t_LETTER(t):
    r'\w'
    return t
```

Using PLY.yacc

Yacc goes through our stream of tokens from lex and imposes our set of grammar rules

```
207  def p_gCommand_gWord(p):
208      '''gCommand : gWord
209                  | gWord LETTER NUMBER
210                  | gWord LETTER NUMBER LETTER NUMBER
211                  | gWord LETTER NUMBER LETTER NUMBER LETTER NUMBER
212                  | gWord LETTER NUMBER LETTER NUMBER LETTER NUMBER LETTER NUMBER
213                  | gWord LETTER NUMBER LETTER NUMBER LETTER NUMBER LETTER NUMBER
214                  | gWord LETTER NUMBER LETTER NUMBER LETTER NUMBER LETTER NUMBER
215                  | gWord COMMENT
216                  | COMMENT'''
217
```

PLY.yacc parser.out

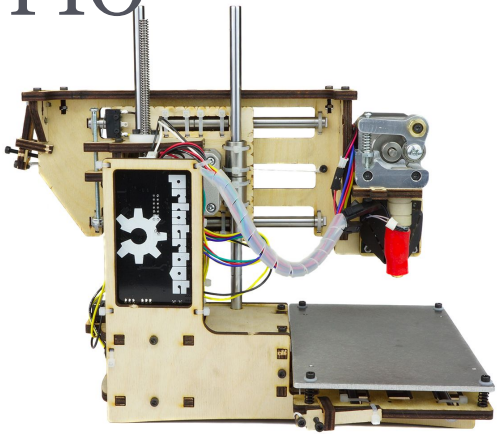
Yacc generates a document with the current Backus-Naur Form (BNF) of your grammar rules

```
Grammar

Rule 0     S' -> gLine
Rule 1     gLine -> gCommand
Rule 2     gLine -> gCommand gCommand
Rule 3     gLine -> <empty>
Rule 4     gCommand -> gWord
Rule 5     gCommand -> gWord LETTER NUMBER
Rule 6     gCommand -> gWord LETTER NUMBER LETTER NUMBER
Rule 7     gCommand -> gWord LETTER NUMBER LETTER NUMBER LETTER NU
Rule 8     gCommand -> gWord LETTER NUMBER LETTER NUMBER LETTER NU
Rule 9     gCommand -> gWord LETTER NUMBER LETTER NUMBER LETTER NU
Rule 10    gCommand -> gWord LETTER NUMBER LETTER NUMBER LETTER NU
Rule 11    gCommand -> gWord COMMENT
Rule 12    gCommand -> COMMENT
Rule 13    gWord -> MOVE
Rule 14    gWord -> DWELL
Rule 15    gWord -> MOVE_TO_ORIGIN
Rule 16    gWord -> SET_POSITION
Rule 17    gWord -> SET_INACTIVITY_SHUTDOWN
Rule 18    gWord -> SET_AXIS_STEPS
Rule 19    gWord -> SET_TEMP
Rule 20    gWord -> FAN_ON
```

Moving the Motors

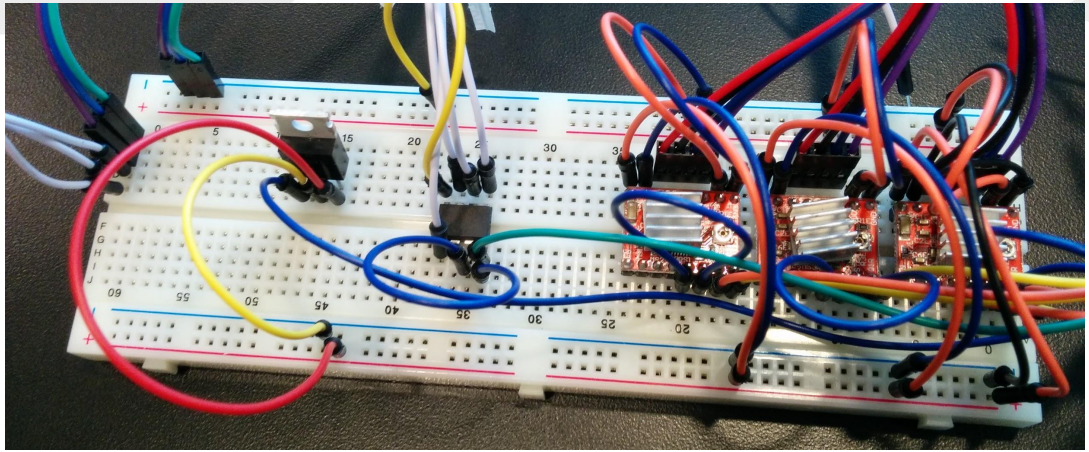
- “One-pass compilation”
- Once the current G-Code command has been tokenized and captured the GPIO commands can be fired



Hardware

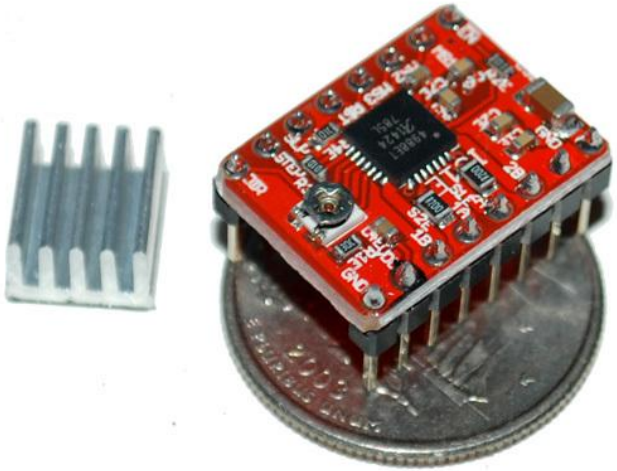
The goal was to create a hardware interface to allow the Pi to control:

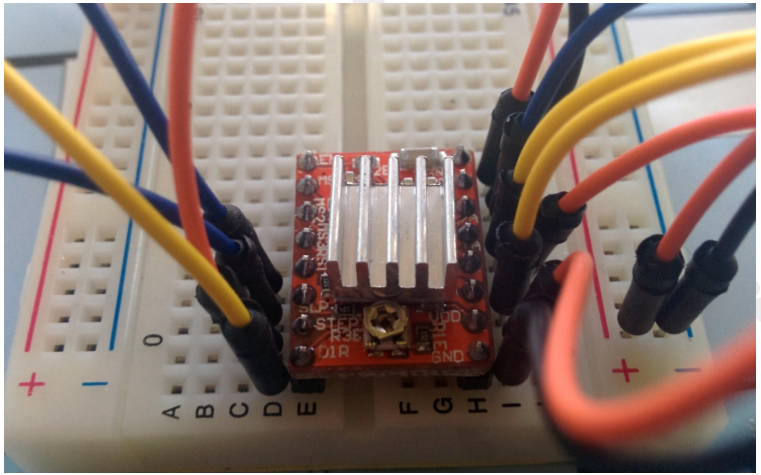
- 4 stepper motors (XYZ axis' and extruder)
- Control and read the temperature of the hot end
- Read endstop status



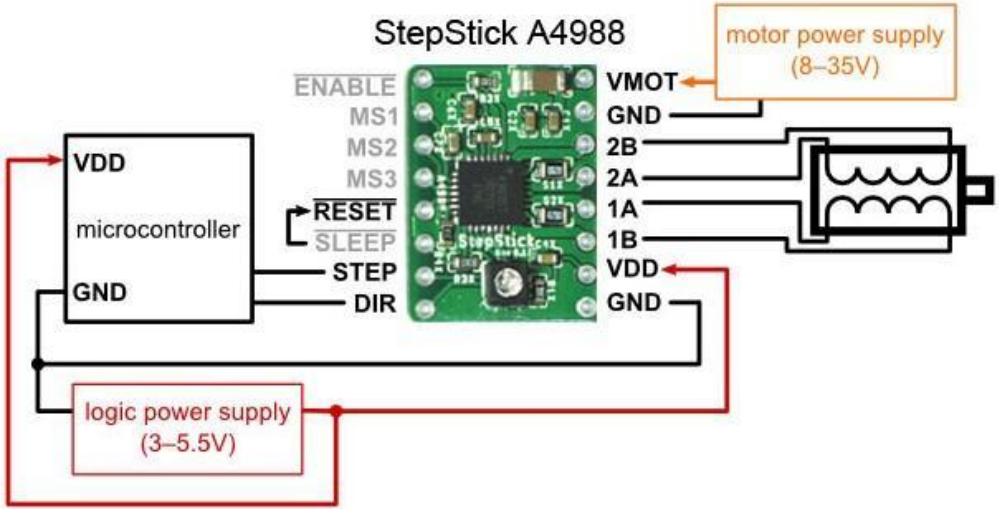
Stepper Drivers

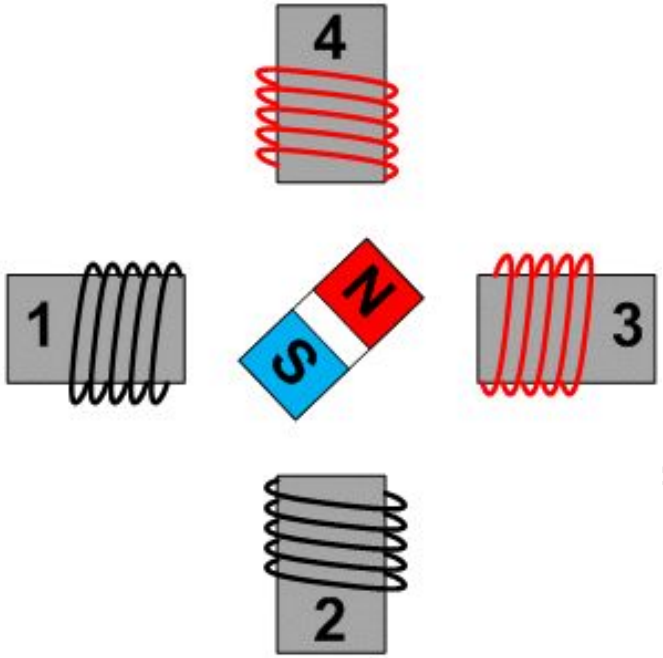
We used the standard A4988 stepper drivers used in most 3D printers, which are capable of driving bipolar and unipolar stepper motors.





Advantage to Using a Stepper Driver

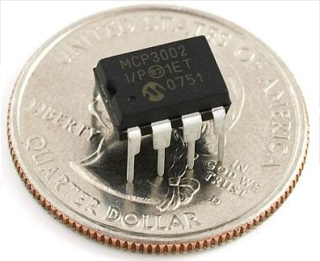




Hot End Temperature Control

One small problem: No analog input on the Pi

Solution: Use a converter



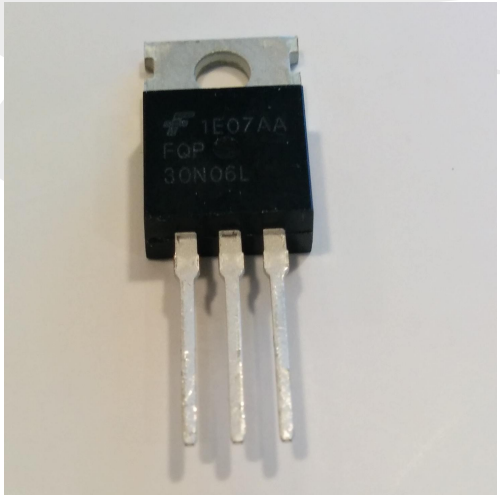
Hot End Temperature Control

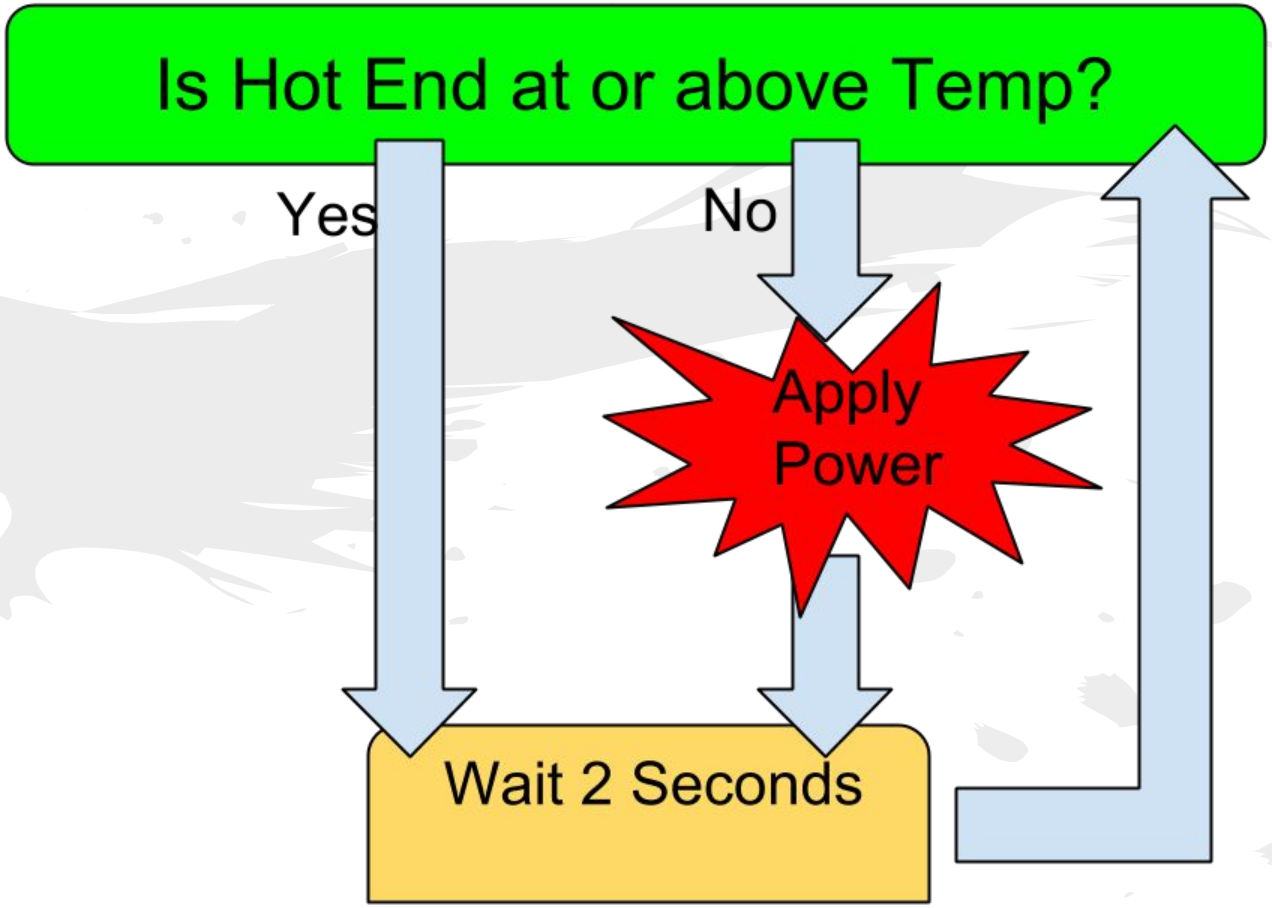
Temperature lookup table

[[23, 300.0],[25, 295.0],[27, 290.0],[28, 285.0],[31, 280.0],[33, 275.0],[35, 270.0],
[38, 265.0],[41, 260.0],[44, 255.0],[48, 250.0],[52, 245.0],[56, 240.0],[61, 235.0],
[66, 230.0],[71, 225.0],[78, 220.0],[84, 215.0],[92, 210.0],[100, 205.0],[109, 200.0],
[120, 195.0],[131, 190.0],[143, 185.0],[156, 180.0],[171, 175.0],[187, 170.0],[205, 165.0],
[224, 160.0],[245, 155.0],[268, 150.0],[293, 145.0],[320, 140.0],[348, 135.0],[379, 130.0],
[411, 125.0],[445, 120.0],[480, 115.0],[516, 110.0],[553, 105.0],[591, 100.0],[628, 95.0],
[665, 90.0],[702, 85.0],[737, 80.0],[770, 75.0],[801, 70.0],[830, 65.0],[857, 60.0],[881, 55.0],
[903, 50.0],[922, 45.0],[939, 40.0],[954, 35.0],[966, 30.0],[977, 25.0],[985, 20.0],[993, 15.0],
[999, 10.0],[1004,5.0],[1008,0.0]]

N-channel Mosfet

A mosfet is a voltage toggled switch that allows us to use the Raspberry Pi's 3.3 volt GPIO to toggle the 12 volt power to the heating cartridge in the hot end.




Is Hot End at or above Temp?
Yes
No
Apply Power
Wait 2 Seconds

Endstops

- The easiest part to implement, 3 momentary switches wired to their own GPIO pin to allow us to tell if the individual axes are at their respective 0 coordinates.

Our Budget

- Unsponsored, student-imagined and student funded senior design project
- All necessary equipment/services purchases were incurred at personal expense

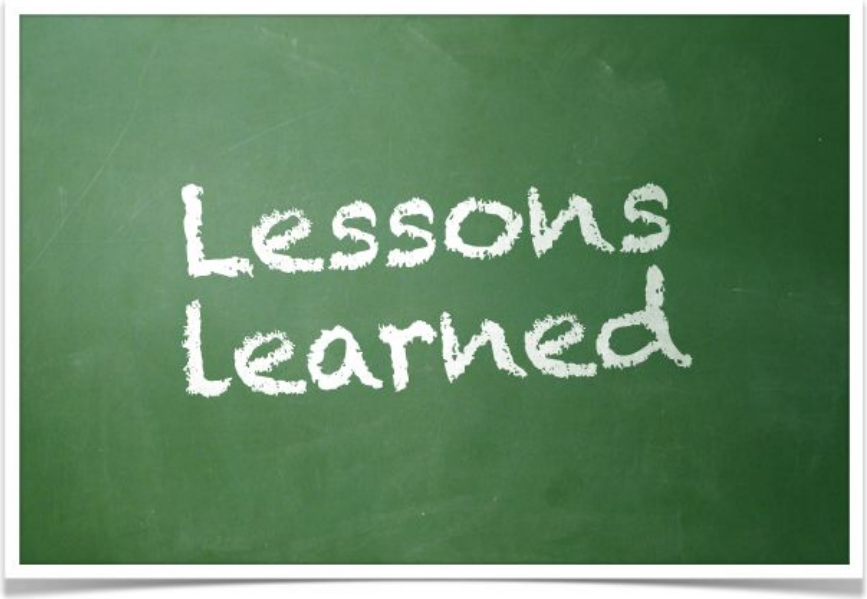
Fast, Cheap, 3D Printing...*Anywhere*			
Item	**Price**	**Num. Purchased**	**Cost**
Raspberry Pi B+	$35	3	$105
Sunfounder Dev Kit	$33	3	$99
Pack of 5x A4988 Stepper Drivers	$13	2	$26
Printrbot Simple	$350	2	$700
Azure Virtual Machine	$55	Monthly*	$55
Misc. digital switches, headers, ribbons, cables	*	*	$74.65
		Total	**$1059.65**

‘Customer’ Budget

Item	Price	Num Req.	Cost
A4988 Stepper Driver	$2.60	4	$10.40
MCP3002 Analog to Digital Converter	$2.30	1	$2.30
GPIO Ribbon Cable	$9.95	1	$9.95
N-Channel MOSET	$0.95	1	$0.95
AdaFruit Perma-Proto Full Sized Breadboard	$6.65	2	$13.30
3-Pin Terminal Block	$0.79	1	$0.79
Breakaway Headers	$0.50	4	$2.00
Total			**$39.69**

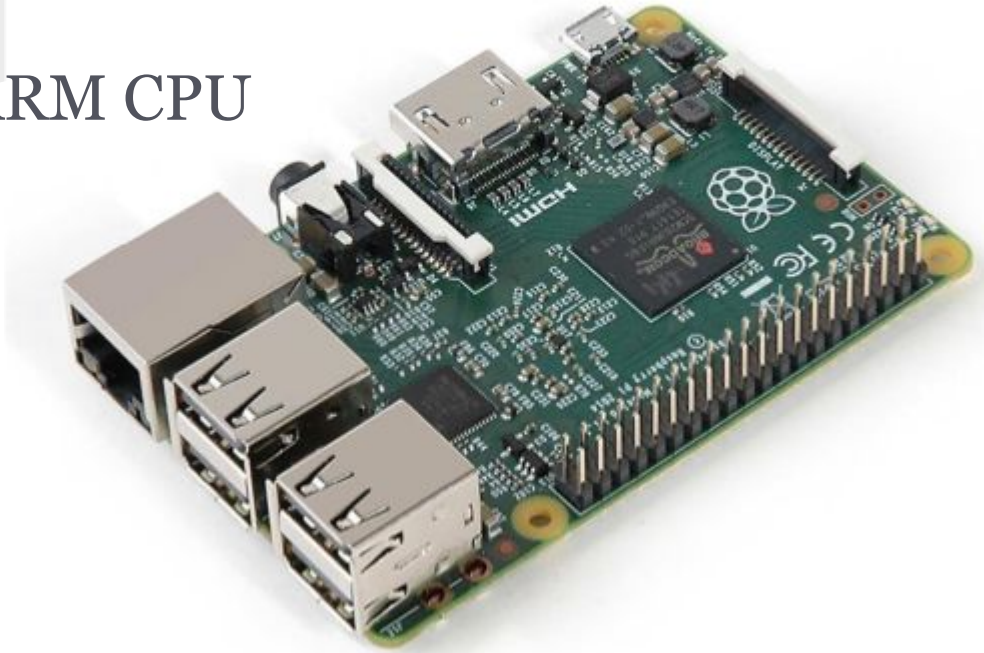
Retrospective

- Management Hub
- Interpreter
- Hardware



Where to go from here

- The Raspberry Pi 2
  - 900 MHz Quad Core ARM CPU
  - 1 GB Mem.

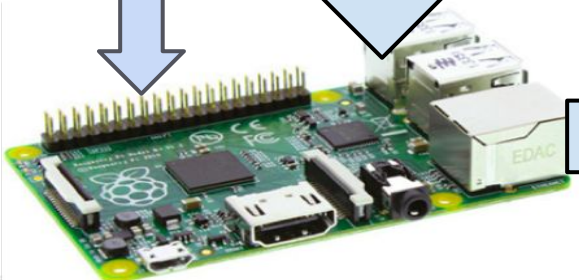
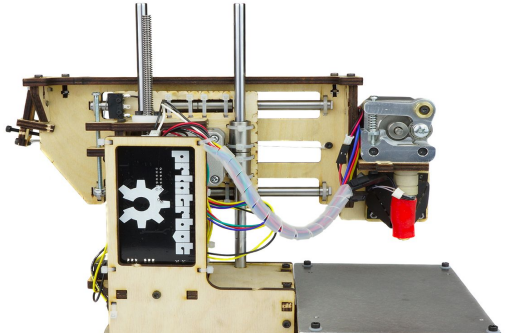


“Fast, Cheap 3D Printing ...Anywhere”

Your 3D Model

Sliced G-Code

G-Code



GPIO Pin
Commands