Building a 3D Printer the Hard Way

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Outline

Witty Quip About Location

What?

"RepRap is humanity's first general-purpose self-replicating manufacturing machine."

- 3D printers, laser cutters, and CNC mills
- Mostly 3D Printers
- Goal is to be able to replicate at least 50% of a machine's parts on the machine itself
- Openly licensed hardware designs (CC BY/SA, GPL)
- Free Software firwmare and host software

Most libre hardware designs are not repraps any more, but that's ok.

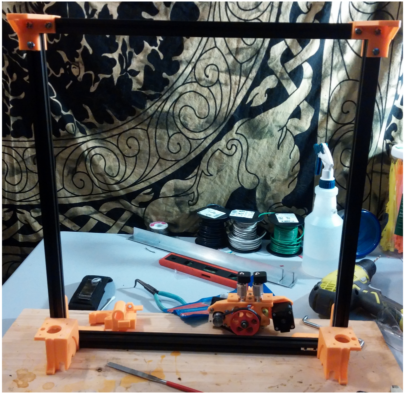
But Really, Why?

- Cheaper Than Buying
- The Experience
- Experimentation
- Fame and Fortune

Witty Quip About Location

Parts ("Vitamins")

- Frame (sheet metal, extrusion, wood)
- Fasteners, springs, hobbed bolt
- Motion components: linear rods, lead screw, stepper motors, bearings, belts, pulleys
- Control Board and stepper drivers
- Heat bed / print surface
- Power Supply (12V or 24V)
- DC Fans
- Wires and pins (12/14 + 20/22 awg)
- Printed Parts (not vitamins)



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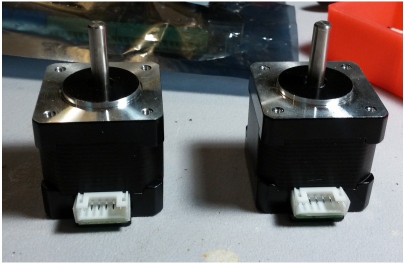

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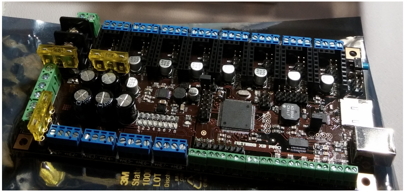

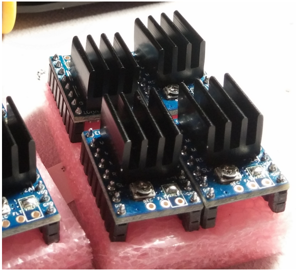

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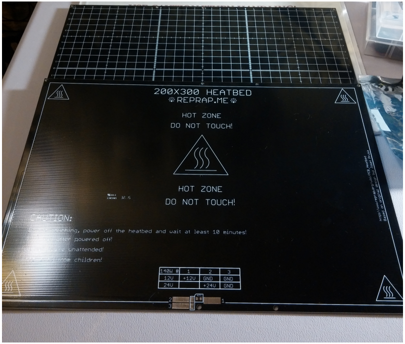

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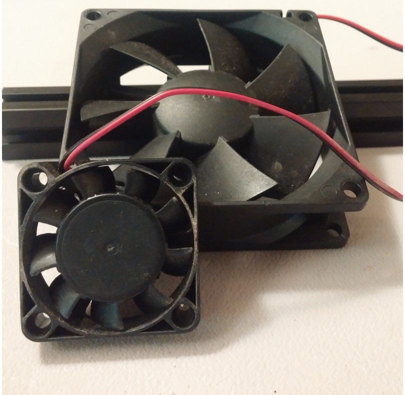

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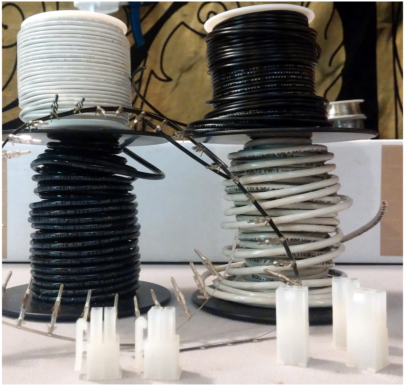

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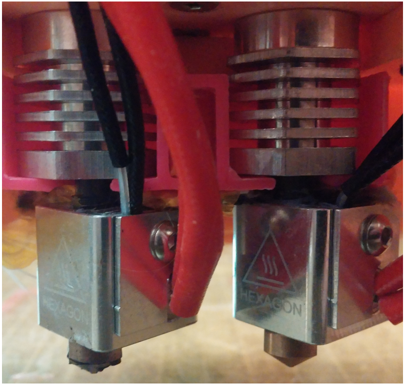

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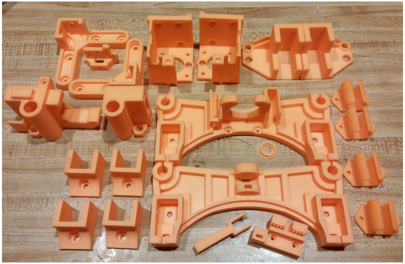

Tools

- Screwdrivers / allen keys
- Needle nose pliers
- Wire strippers / cutters
- Crimping pliers
  - Engineer PA-21 for common pins on 18-26 awg wire
- Hand saw and drill for MDF y-axis
- Diamond files or Sandpaper
- Calipers (or an engineering ruler)
- For wood/2020 frames: Square (speed or framing)
- Optional(ish): Soldering iron
- Optional: Multimeter (highly recommended)

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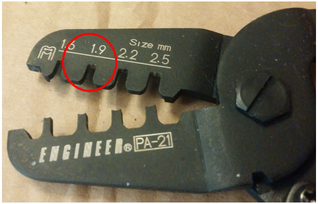
Skills

- Basic mechanical aptitude (or: using a screwdriver)
- Soldering (but you can work around this)
- Wire pin crimping (will make you a better person)
- Patience (squaring is tedius)

Which Pins Can I Use?



Witty Quip About Location

Cartesian vs Delta vs CoreXY

- Cartesian is the most common and best supported by firmware and the RepRap community
  - Separate x/y/z, simple math and construction
  - Mass on axes limited by smooth rods, frame rigidity
- Delta printers look really cool but are trickier to calibrate
  - Three arms with an effector, circular build platform
  - Faster than Cartesian – but extruder must be light (bowden only)
- CoreXY has theoretically superior positioning accuracy over others, but there are few working designs available and limited firmware support
  - X and Y motion are combined into A/B axes

Common Designs

http://reprap.org/wiki/RepRap_Machines

- Prusa i3 and derivatives
  - Wilson TS/Wilson II are popular now (I built a Wilson TS)
- MendelMax
- Delta
  - Kossel (original and mini)
  - Rostock Max

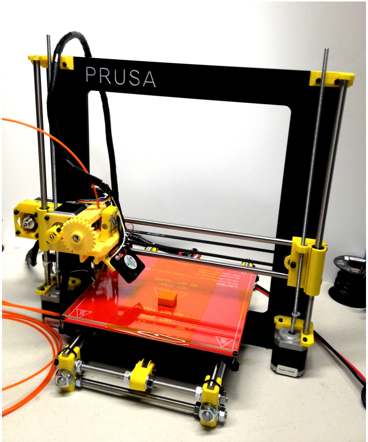


Figure: (c) 2013 John Abella CC BY 2.0 https://flic.kr/p/eEebd7

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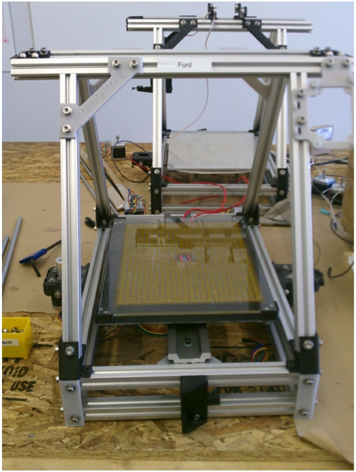

Figure: (c) 2012 Chris Cecil https://flic.kr/p/cPmbb7

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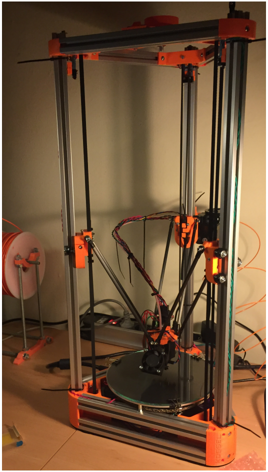

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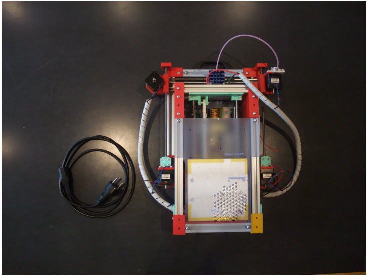

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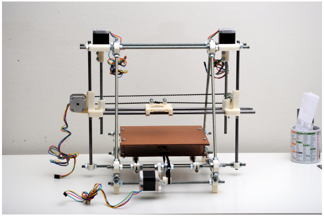
The Prusa i3 Family

Evolution: Mendel -> Prusa (easier to build Mendel) -> Prusa i2 (improved) -> Prusa i3 (introduces the single frame)
Proliferation thanks to easily modified OpenSCAD source code.

- Extremely popular
- Easy to build (4-6 hours)
- Dozens of variants
- Hundreds of alternative parts



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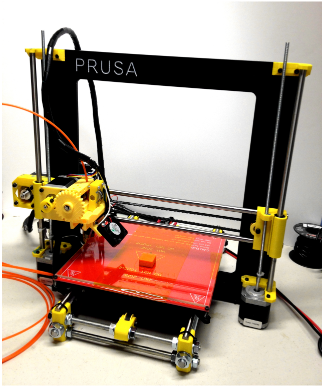

Figure: (c) 2013 John Abella CC BY 2.0
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Witty Quip About Location

The Easy Way: Kits

- Almost everything you need in one box
- Fewer choices, some compromises
- bq Hephestos, Prusa Research i3, Martin Rice's Wilson II, SeeMeCNC Rostock max, Openbeam Kossel, ...
- Beware cheap Prusa i3 clones from Aliexpress
  - All of them suck and you will regret it

Resources page has links to specific kits.

The Really Really Hard Way

- Print your own plastic components
  - Find a friend
  - Print-It-Forward
  - Makergeeks, kit makers
  - 3D Hubs
  - The Colonel O'Neil method: build a Repstrap
- Mcmaster-Carr (fasteners), Misumi (linear motion), Digikey/Mouser (pins, power supply, fans), Amazon/eBay/various 3D printer companies (everything else: controller, motors, hotend)
- Reduce bolt count by cutting your own
- Beware cheap components!
- Good BOM is essential to retaining sanity

Witty Quip About Location

Y-axis Bed

MDF or Aluminum/Steel

- MDF
  - Easy to manufacture (saw, drill)
  - Tricky bearing alignment, heavy, can warp from heat bed
- Aluminum/Steel
  - Must be plasma / laser / water-jet cut
  - Bearings self-align, lightweight, no warping from heat bed

Prusa i3 Frame

- Wooden box frame
  - Easy to make (plywood + hand saw and drill), hard to align
  - Not very rigid
- Sheet metal frame
  - Will come with matching y-axis bed
  - Alignment of y- and z- is trivial
  - Aluminum: slight flex, light
  - Steel: heavier, more rigid
- 2020 extrusion frame
  - Inexpensive (even precut), easy to assemble
  - Potentially less rigid than sheet metal frame
  - Flexible accessory attachment (t-slot nuts)

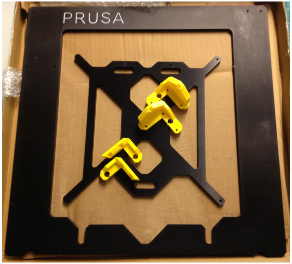

Figure: Prusa single plate frame (c) 2013 John Abella CC BY 2.0 https://flic.kr/p/eE83ur

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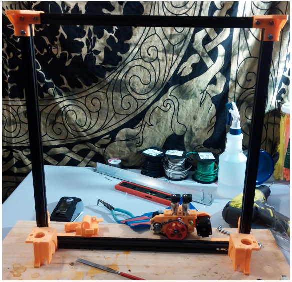

Figure: 2020 extrusion frame

Linear Motion

- Linear rods
  - M8 is OK under 200mm
  - M10 is much more rigid, required for 200mm+
- V-Slot: frame becomes linear motion system
- Bearings or Bushings?
  - Igus bushings allow use of cheaper rods
- Lead screw or threaded construction rod for z-axis?
  - M5 rod: inexpensive, wears quickly, limited speed, subtle layer wobble
  - Lead screw: expensive, designed for motion, moderate speed, precise layering, can bind from z-axis misalignment
- Lead screw starts: single, double, quadruple
  - More starts = faster motion, lower resolution
  - Double is best for z-axis

Extruder

- Most extruders are based on the Wade Extruder
- Dual or Single?
  - Dual materials: ninjaflex and abs, abs and hips, pla and pva
  - Mediocore slicer support for dual extrusion
- Bowden, Direct Drive, or Geared?
  - Bowden: motor mounted on frame, lightweight x-axis, poor retraction
  - Direct/Geared: motor mounted on x-axis, heavier x-axis, good retraction

Recommended: Greg's Wade Reloaded or the Itty Bitty Double Flex Extruder.

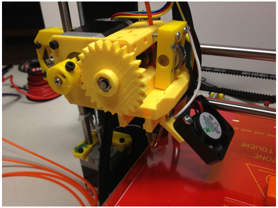

Figure: Prusa Extruder (c) 2013 John Abella
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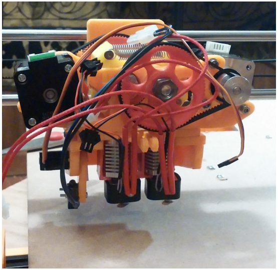
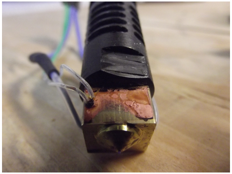


Figure: Itty Bitty Double Flex

Hotend

- All Metal or PTFE/PEEK?
  - PEEK is easier to use, can't print some materials
- Nozzle diameter: 0.4mm or 0.5mm typical, 0.35 detail
- Filament diameter: 3mm or 1.75mm?
- Popular Hotends
  - AO Hexagon (CC BY-SA 4.0)
  - JHead (GPL)
  - non-free: E3Dv6
- Experimental stuff
  - Diamond Hotend (triple color), CC BY-SA-NC
  - E3D Cyclops, Kraken (non-free)
  - Paste extrusion (icing, ceramic, . . .)



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Control Board: Firmware

- Marlin (GPLv3+, C++)
  - AVR only (experimental ARM support)
    - Supports dozens of different boards
  - Limited to ~40k steps per second
  - Well supported, actively developed by community
  - Code is a bit hairy, requires Arduino libraries
  - Initial configuration is complicated
- Smoothieware (GPLv3+, C++)
  - ARM (Cortex-M3+) only, few available boards
  - Extremely high stepping rates possible
  - Moderately well supported
  - Clean, modular code
  - Configuration is easy (plaintext, loaded onto sd)
  - Built-in networked printing support

Control Board: Hardware

- Smoothieware / Cortex M3
  - Smoothieboard (CERN OHL v.1.2+) $100-150
    - v2 should be out "soon"
  - Azteeg x5 mini (license unclear) $110: 1/128th microstepping
- Marlin / ATMega2560
  - RAMPS (GPLv3+) $40-80: Add-on board for Arduino MEGA
    - Requires an Arduino MEGA, 12V only
  - RAMBo (CC BY-SA) $110: Integrated stepper drivers
  - Azteeg X3 Pro (CC BY-SA) $135: five extruders, dual heatbeds
  - RUMBA (GPLv3+) $100: three extruders
- Stepper drivers $10-15 (3 + extruders)
  - Standard form factor (pololu breakout)
  - DRV8825, Allegro A4988, Trinamic TMC2100

Recommendation: RAMBo or RUMBA, Smoothieboard

Heat Bed / Print Surface

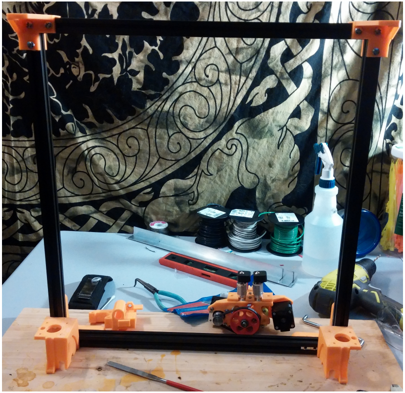
- MK2a/b/... PCB heatbed (GPLv2+)
  - Can be etched at home, easily scaled
  - Slow to heat (insulation helps)
  - Inexpensive (under $30)
  - Usually supports 12V or 24V operation
  - Make sure board is etched and not plated
- Silicone heater: fast, expensive, permanently attached
- Common form factors (mm): 200x200, 200x300, 300x300
- Glass or 3-5mm aluminum sheet print surface
  - Window glass from hardware store is OK, borosilicate is better
- PEI sheet attached with 486MP adhesive = Magic
  - Seriously, just do it.

Recommendation: any MK* or silicon heat mat

Witty Quip About Location

Building It Is Fun

- Total time: ~6-15 hours, a bit more for Delta
- Sub-assemblies: Z-frame, Y-Axis, X-axis, Extruder
- Final assembly
    - Check alignment now or pay later



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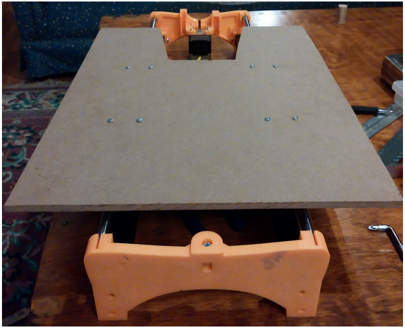

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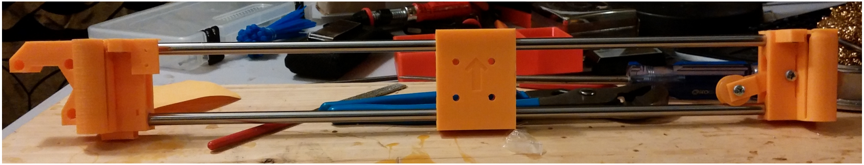

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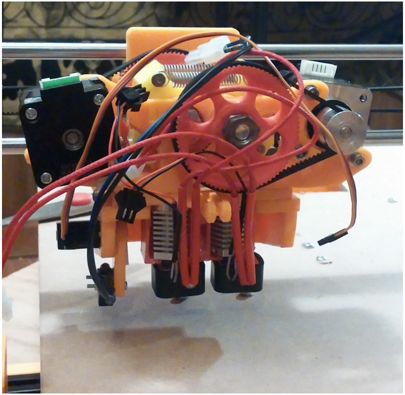

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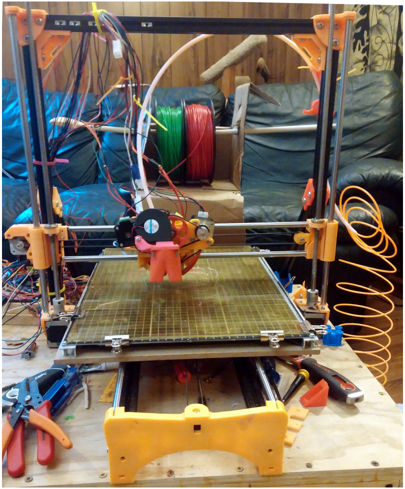
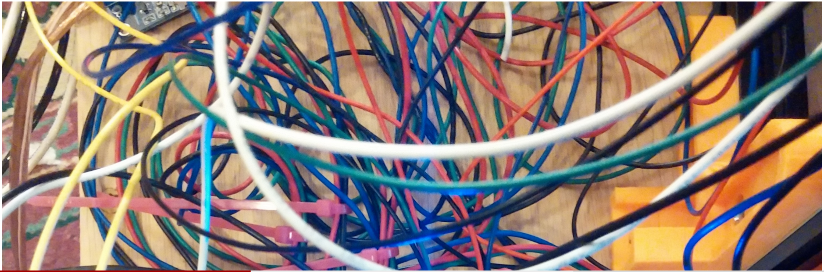


Wiring Is Even More Fun

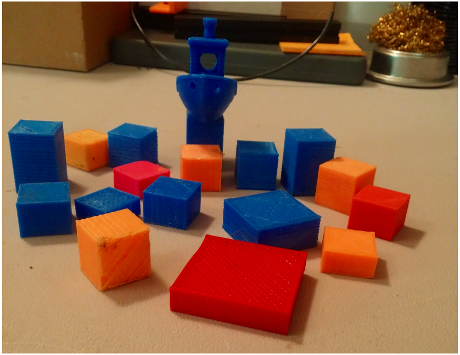
You'll be great at crimping if you're not already.
20/22 awg, 12 awg for input power and heat bed; ?? meters (?? ft) total
Lots of wires (x2 for harnesses):

- Stepper motors (5x4)
- Hotend heater/thermister (2 + 2)
- Extruder cooling fan (2)
- Heat bed (2 12 awg)
- Power supply (5-. . .)



Calibration Bites

- Configure firmware
  - Some kits have a Marlin configuration
  - Edit Configuration.h with steps/mm, dimensions, etc.
- X/Y Movement should Just Work™
- Z Axis may need minor realignment
- Level the bed
- Extruder will need tuning
  - steps/mm
  - calibration models



Upgrading It Is Actually Fun

Armed with a printer, you can print things for the printer. And you will. Of course you need rgb leds that change color in time with the stepper frequency and maybe a laser cannon.

- Filament guide
- Spool holder
- Improved parts

Witty Quip About Location

Materials

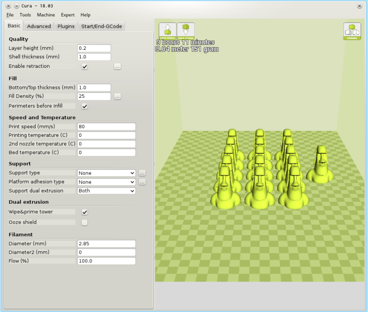
- PLA: low fumes, no warping, *biodegradable*, brittle, translucent
- ABS: emits styrenes, tendency to warp/split, bad for the planet, stronger than PLA, opaque
- Ninjaflex: prints slowly, but objects are flexible.
- Nylon and PETG: print slowly, extremely strong parts
- Funky PLA/$thing blends
    - Wood fiber
    - Metal (brass, copper, bronze, stainless steel)
    - Coffee

Host Software

- Printer host software to control the printer
- Slicer for converting 3D models into GCode
- CAD and modeling software for creating things to print

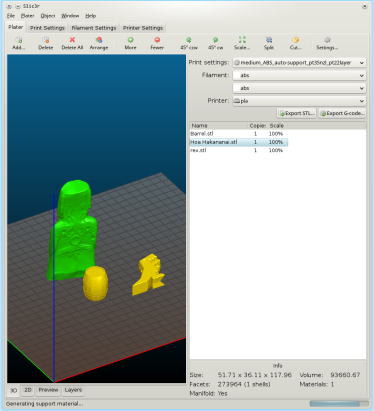
Slicer: Cura

- Python, AGPLv3+
- Pros: easy to use, fast slicing engine, good dual extrusion support, integrated print host, easy plugin protocol
- Cons: not very configurable, poor bridging, no support for overlays, not very many plugins available



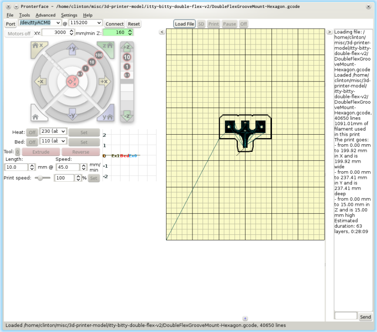
Slicer: slic3r

- Perl, AGPLv3+
- Pros: extremely configurable, high quality output, overlays for tuning parts of models
- Cons: poor defaults, interface only a hacker could love, difficult to configure correctly, slow slicing engine



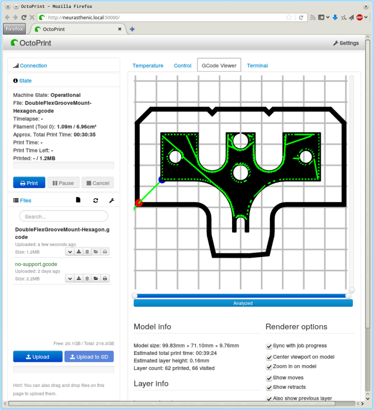
Printer Control: Pronterface

- Python, GPLv3+. Desktop and console application.
- Pros: Mature, easy to install
- Cons: A bit clunky, not very actively maintained, no remote control



Printer Control: Octoprint

- Python, AGPLv3+. Web server application.
- Pros
  - viewable from anywhere
  - webcam support
  - runs on Raspberry Pi 2 or later
  - adequate touch interface
- Cons
  - gcode visualizer hogs cpu
  - no 3d gcode preview
  - moderately annoying to install



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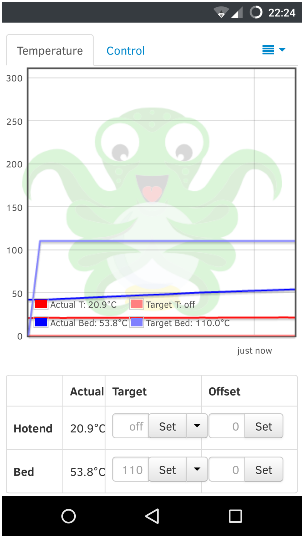

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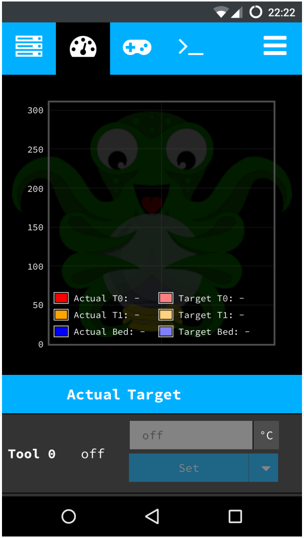
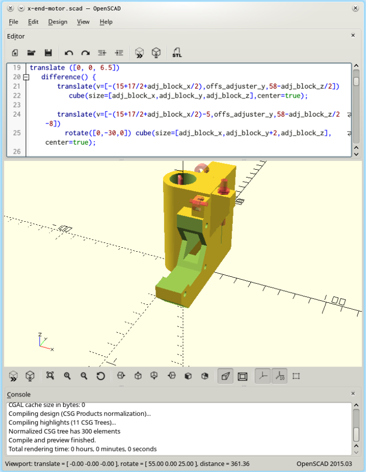


Designing Models

- Meshlab for repairing and tweaking models
- Blender for anything artistic
- OpenSCAD, FreeCAD for designing functional parts
- Anything that can export a mesh that Meshlab can import/convert to STL will work
- Finding/Sharing Models: Youmagine, Thinigverse, Reprabables, Yeggi

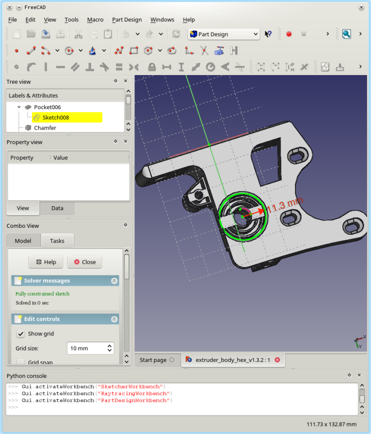
Designing Models: OpenSCAD

- Constructive Solid Geometry programming language
- Extremely easy to pick up if you know any C-like language
- 3D Modeling with Emacs and Git
- Modules and variables make it somewhat easy to compose objects
- The Bad: rendering is slow, weak support for large programs, no automatic constraint solver, fundamental limitations of CSG



Designing Models: FreeCAD

- GUI oriented (smells like Windows)
- Boundary Representation is very powerful
- Everything is scriptable in Python
- Powerful constrained sketch support
- Variables simulated using named spreadsheet cells



Witty Quip About Location

Finding the Community

- Reprap forums (http://forums.reprap.org)
- Reprap wiki (http://reprap.org)
- reddit r/3dprinting, r/reprap
- #reprap on freenode
- Planet reprap (http://planet.arcol.hu/)

Some Problems in the Community

- Modifying 3D meshes instead of CAD sources
- Ignoring GPL, CC licensing on derivatives
- Heavy use of non-free programs (Solidworks, Sketchup)
- Move toward non-free CC -NC variants for parts and printers

More Info

Additional material and presentation source at
http://triprint.unknownlamer.org/
Questions? Comments?