DIY 3D Printing and the Makerbot Thing-O-Matic

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softsolder.com

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MHV Linux Users Group
September 2011

Upcoming Events

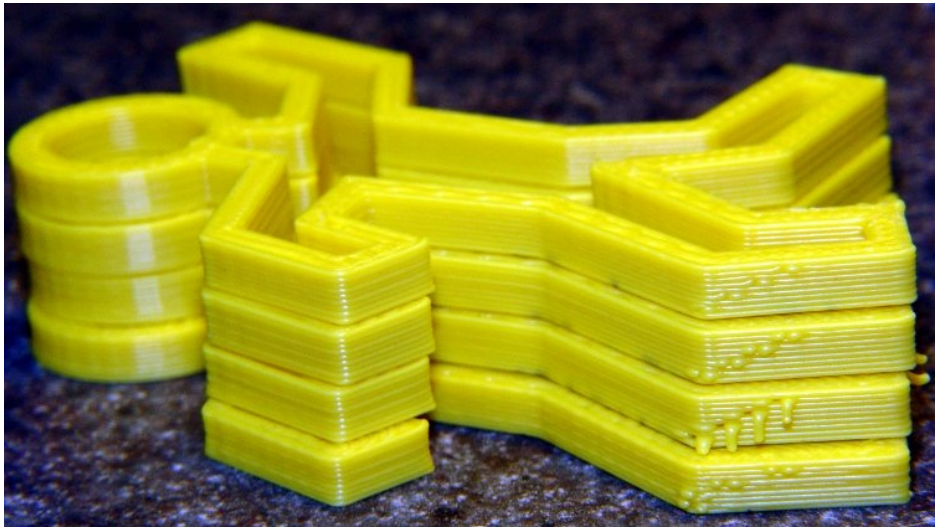
- *Tchotchkes*!
- 3D Printing Mechanics
- Tux Cookie Cutter Movie
- 3D Printer Genealogy
- Printing Your Stuff
  - CAD: Idea → Model
  - CAM: Model → Plastic
- Door Prize!
- Q&A + Touchy-Feely

Tchotchkes!

- Chalk people
  - Boys & Girls, too
- Octopi (Octopodes?)
- Stanford Bunnies
- Dodecahedra
  - With a rattle!
- Tiny Storage Cubes

Tchotchkes

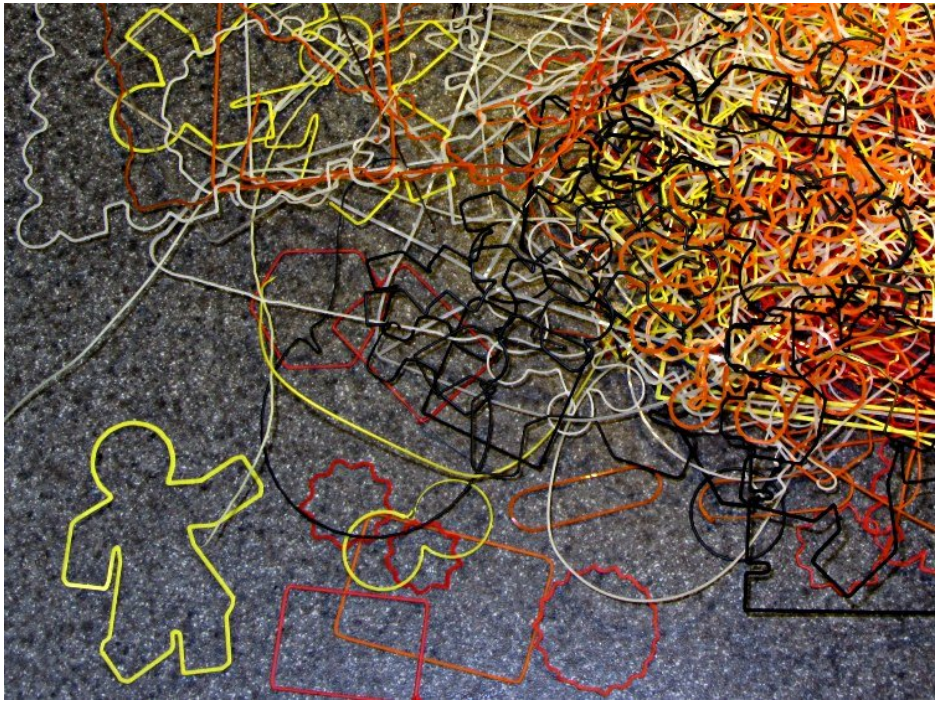
- Simple examples
  - Quick printing
  - Not so much plastic
- These are test pieces
  - Some have defects
  - Understand the limits
- Share nicely...



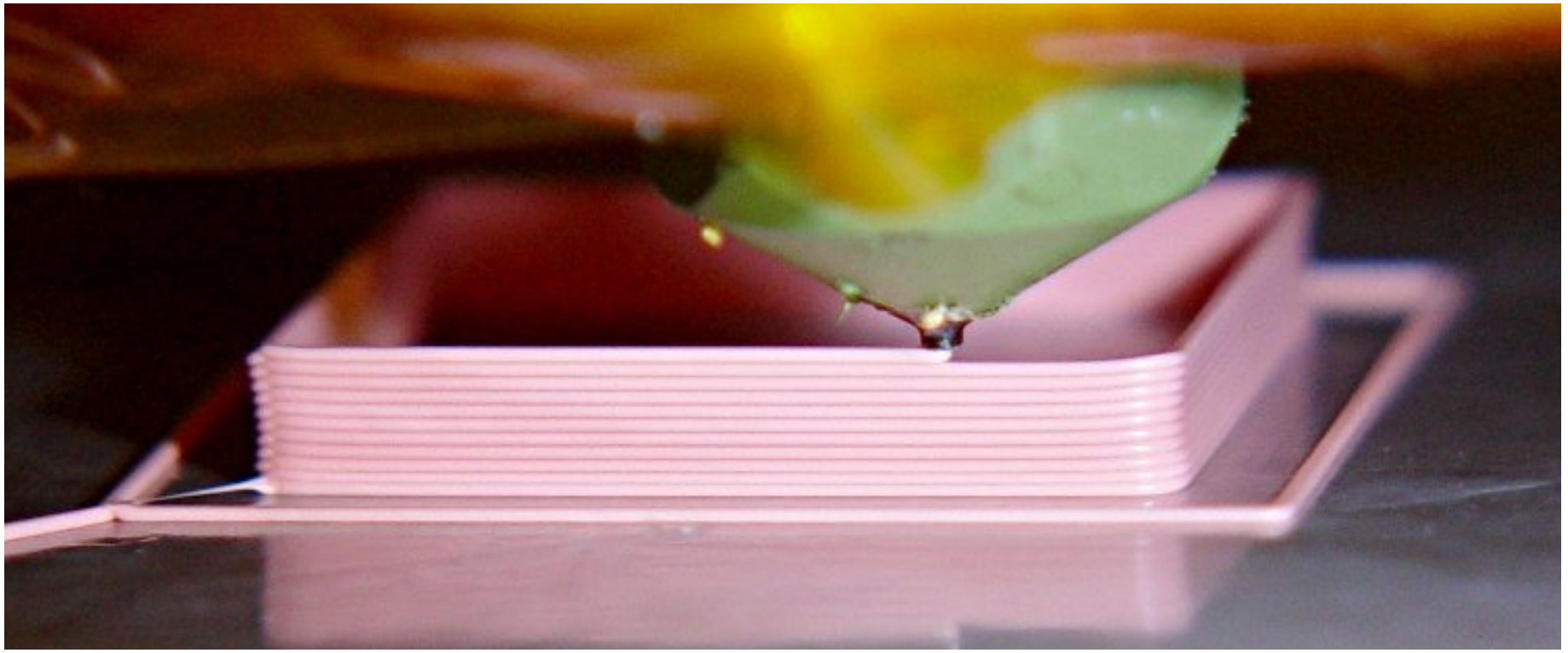
http://www.thingiverse.com/thing:8692

Threads

- Object “Skirt”
- Test/verify extrusion
  - 0.33±0.1 mm thick
  - 0.66 mm wide, mostly
- All layers like this!
  - For my printer
- Data!



DIY 3D Printing Mechanics

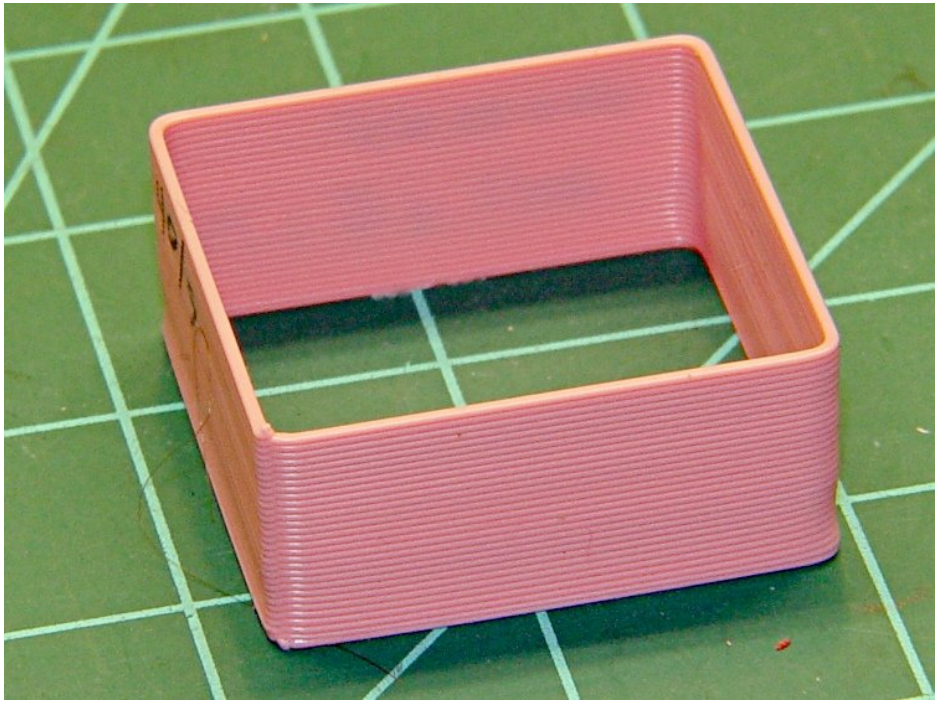


- Building things with a hot-melt glue gun
  - A very small glue gun: nozzle 0.2 to 0.6 mm dia
  - A very hot glue gun: 190 to 230 °C = 350 to 450 °F

http://www.thingiverse.com/thing:2064

Cartesian Coordinates

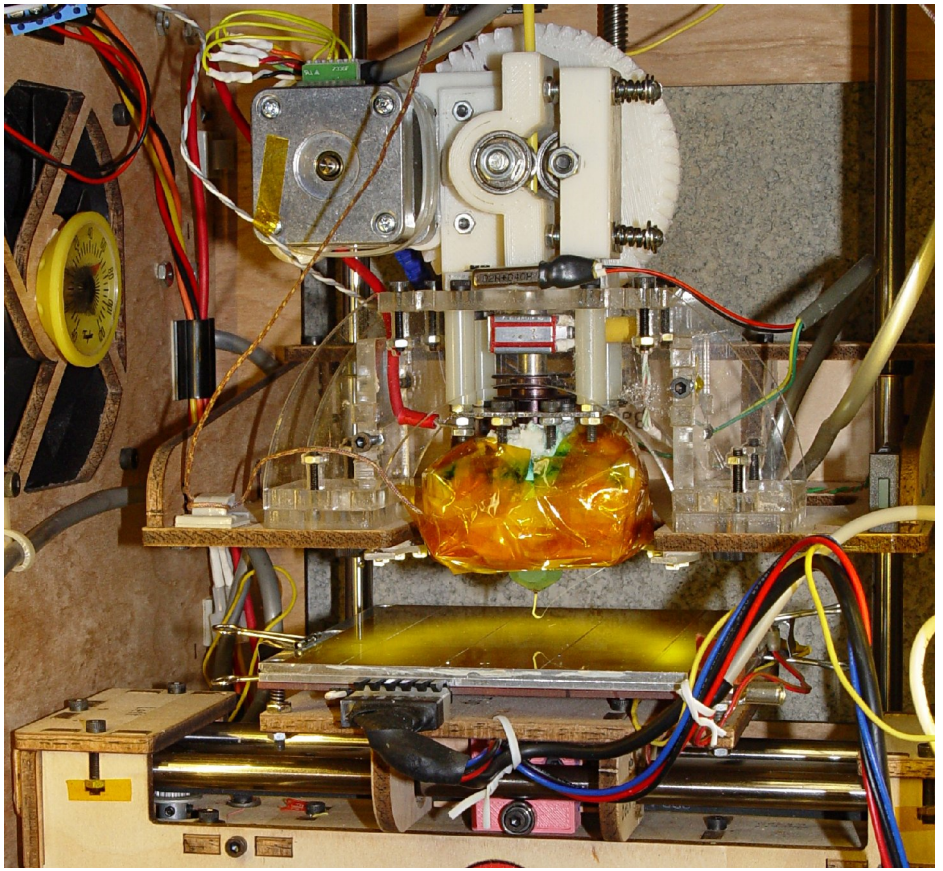
- Z Axis
  - +Up -Down
- X Axis
  - +Right -Left
- Y Axis
  - +Back -Front
- A Axis
  - Filament drive!



http://www.thingiverse.com/thing:2064

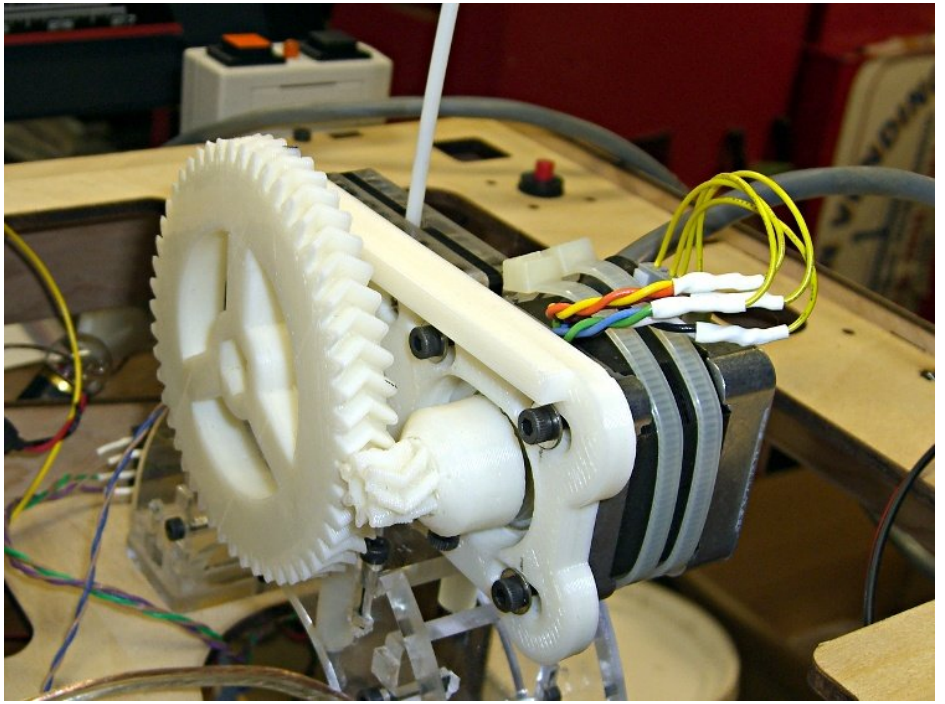
3D Printing Mechanics

- Z Axis stage
  - Filament drive = A Axis
  - Extruder “Hot End”
  - Nozzle
- X and Y Axis Stages
  - Heated build plate(s)
  - Automated belt (?)
- Build Chamber
  - LED strip lighting!



Filament Drive

- 3 mm or 1.75 mm
- MBI Geared DC motor
  - #include long story
- Printed upgrade
  - NEMA 17 stepper
    - eBay FTW!
  - Herringbone gears
  - 7:51 reduction

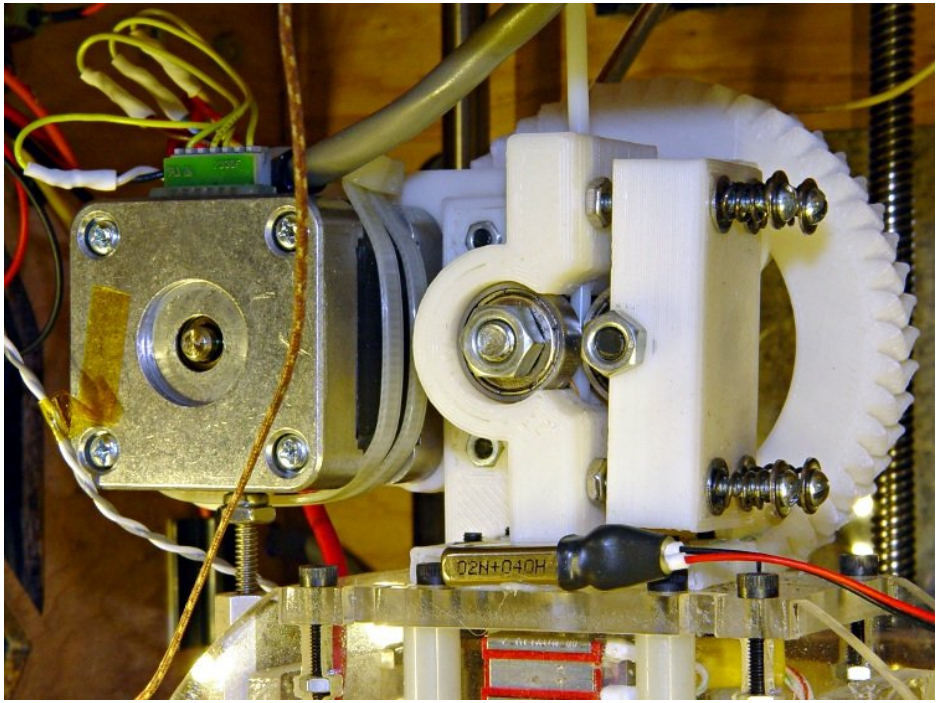


http://www.thingiverse.com/thing:5795

http://softsolder.com/2011/03/21/thing-o-matic-stepper-extruder-first-steps/

Filament Tensioner

- Hard plastic filament
- TOM = Delrin + screw
- Printed upgrade
  - Ball bearings!
  - Spring loaded idler
  - MBI OEM drive gear
- Recent improvements
  - This works OK



http://www.thingiverse.com/thing:6402

http://softsolder.com/2011/03/28/thing-o-matic-wade-scribblej-filament-tensioner/

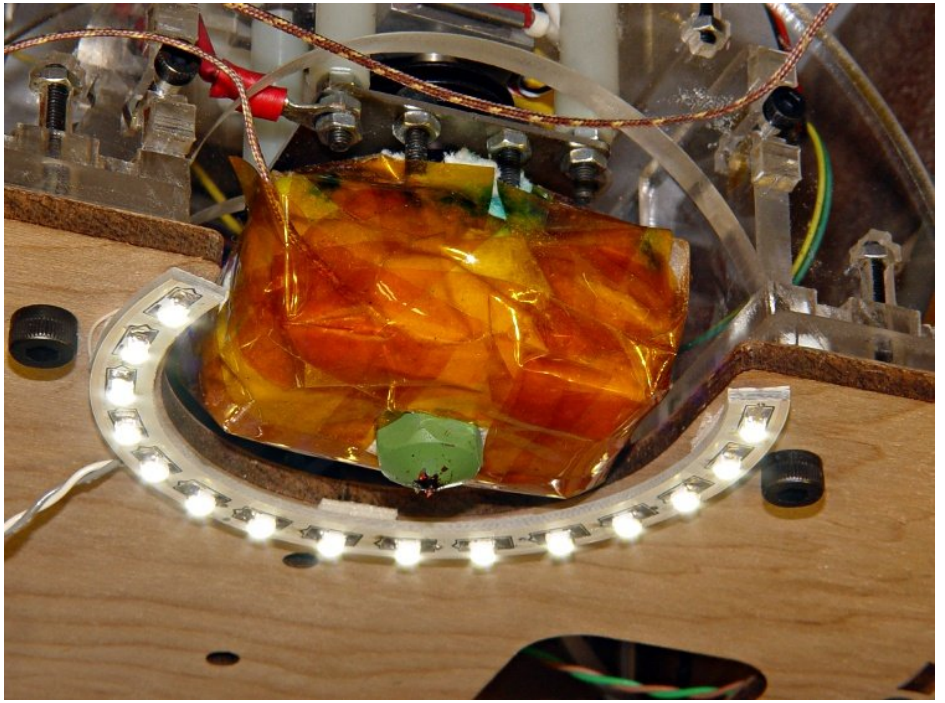
Filament Drive Gear

- MBI OEM part
- Can homebrew
  - Don’t bother
- Need both bearings
  - Springs → 25+ lbf

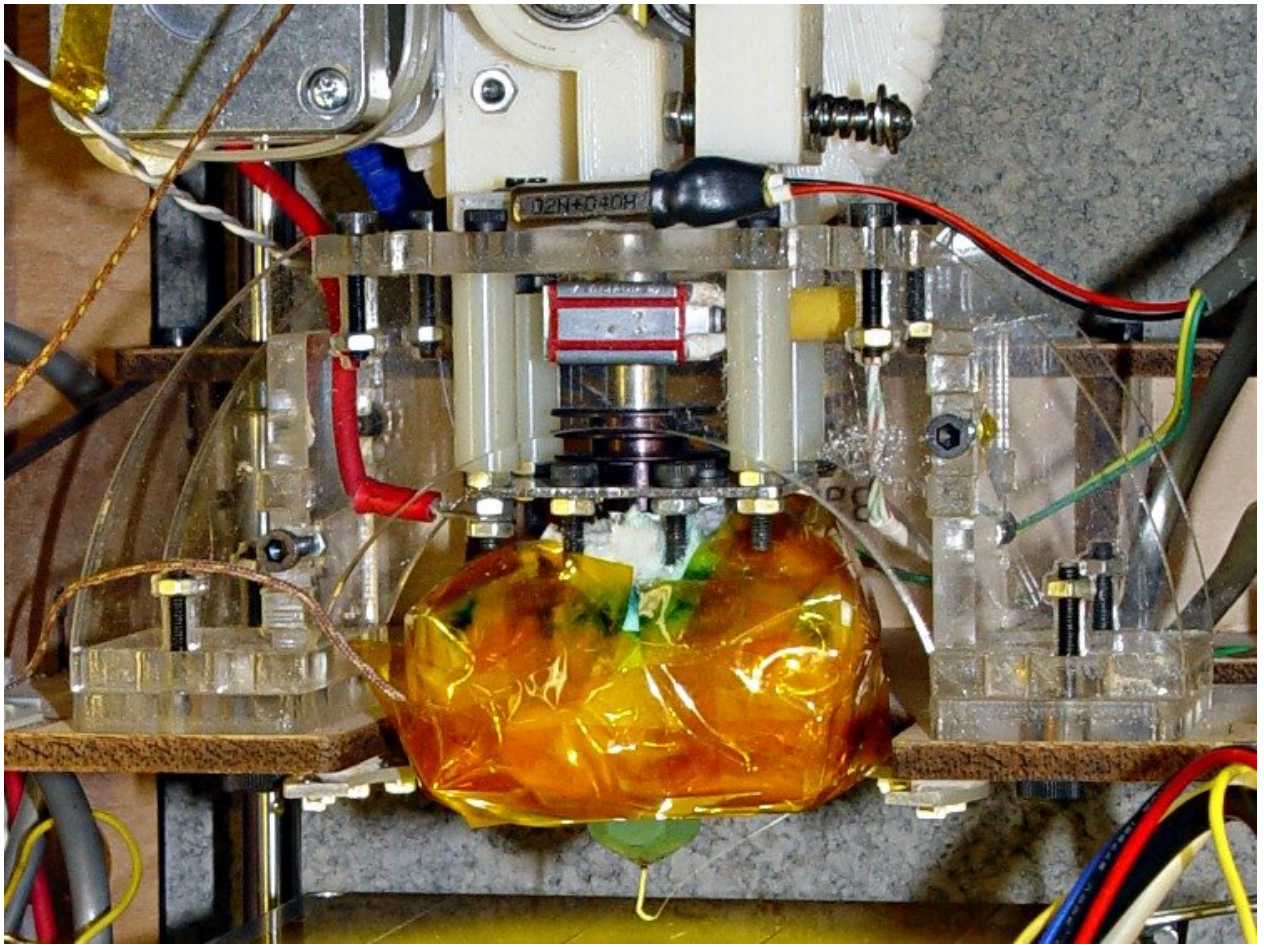
http://store.makerbot.com/mk5-drive-gear.html

Hot End

- Melts plastic filament
  - 200 °C = 400-ish °F
- MBI power resistors
  - Premature failures
    - #include long story
  - Cartridge heaters
    - #include long story
- Nozzle
  - 0.2 to 1.0 mm diameter

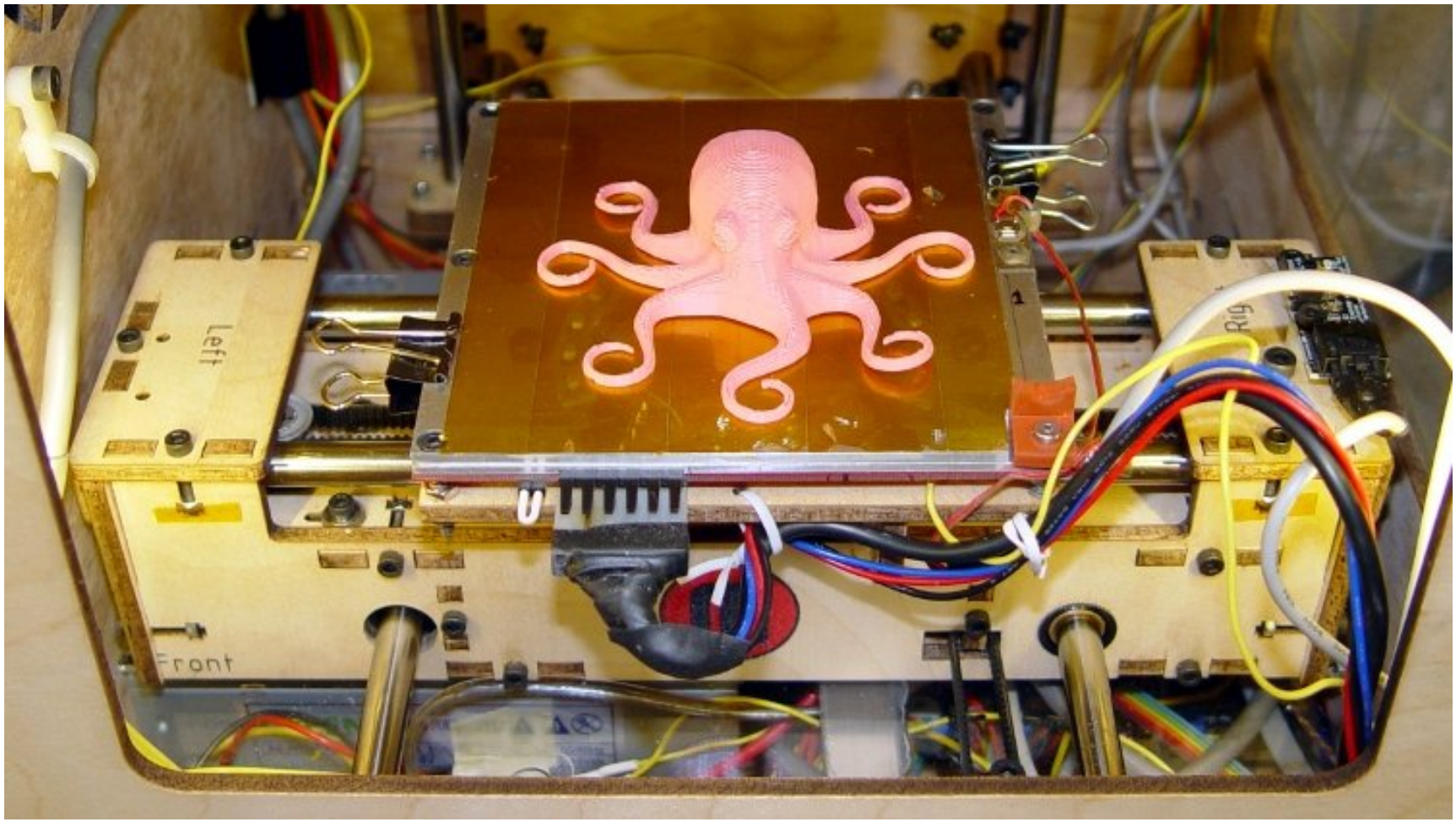


Thermal Isolation



Molten plastic vs. plastic structure...

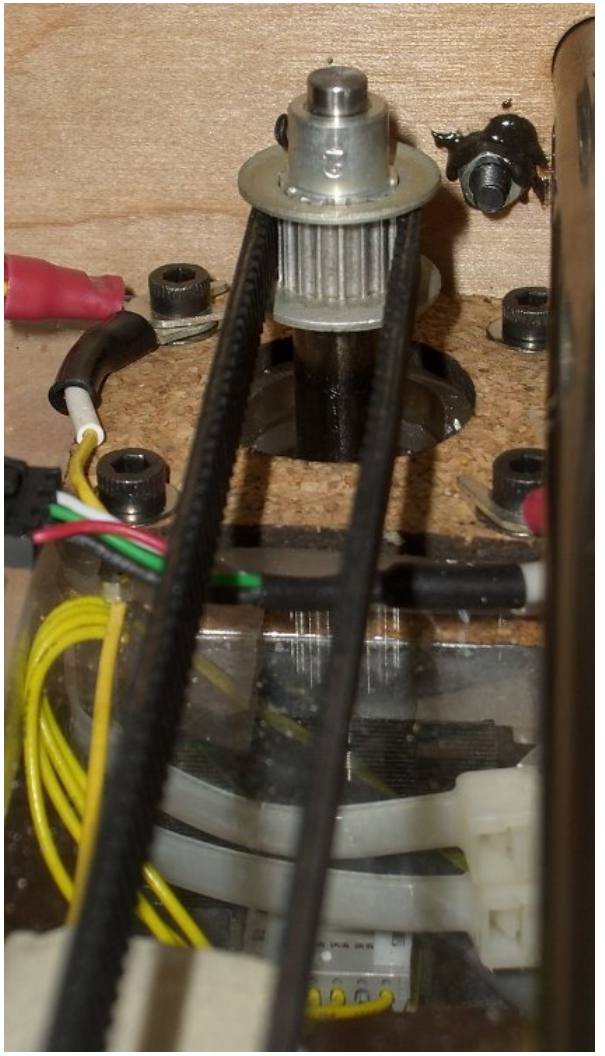
X- and Y-Axes



Small stepper motors moving large masses

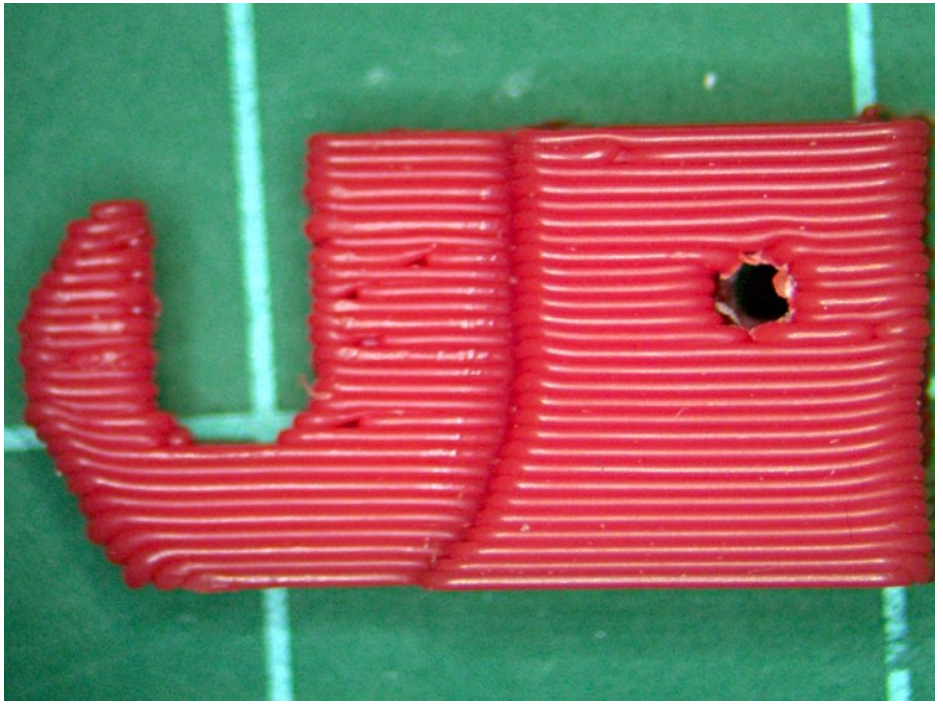
Stepper Motors

- Toothed drive belt
  - Not stretchy at all
  - Low speed / low torque
    - By industrial standards
    - About 1 to 2 rev/s
- Original MBI stepper motors
  - For L/R drive, not microstep
  - #include long story



Resolution – Z Axis

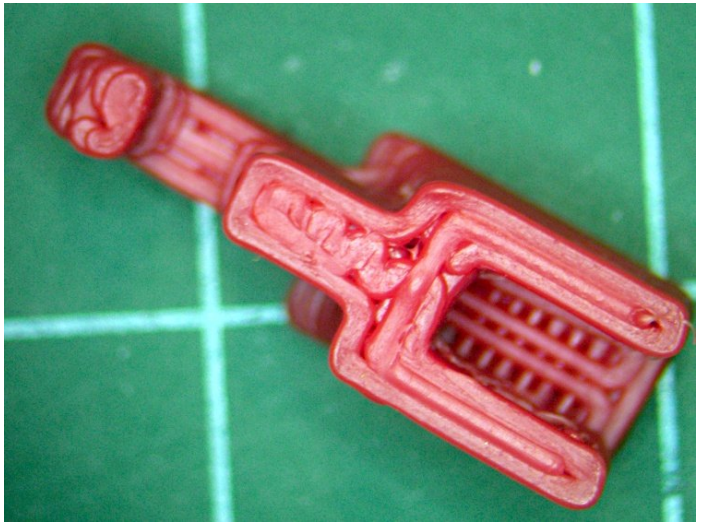
- Layer Thickness
  - a.k.a. Layer Height
  - 0.2 to 1.0 mm
  - For every layer!
  - 0.33 mm for my stuff
- Print time ≈ # layers
  - ≈ 1 / thickness



http://softsolder.com/2011/05/27/thing-o-matic-caliper-repair-perfection/

Resolution – X&Y Axes

- Thread Width
  - Generally ≥ nozzle ID ≤ OD
  - 0.25 to 1.0 mm
  - 0.66 mm for my stuff
- Min feature size ≥ width
  - Holes can be smaller, maybe
  - Closed loop wall = 1 x width
  - Peninsula ≥ 2 x width
  - Fill ≥ 3 x width

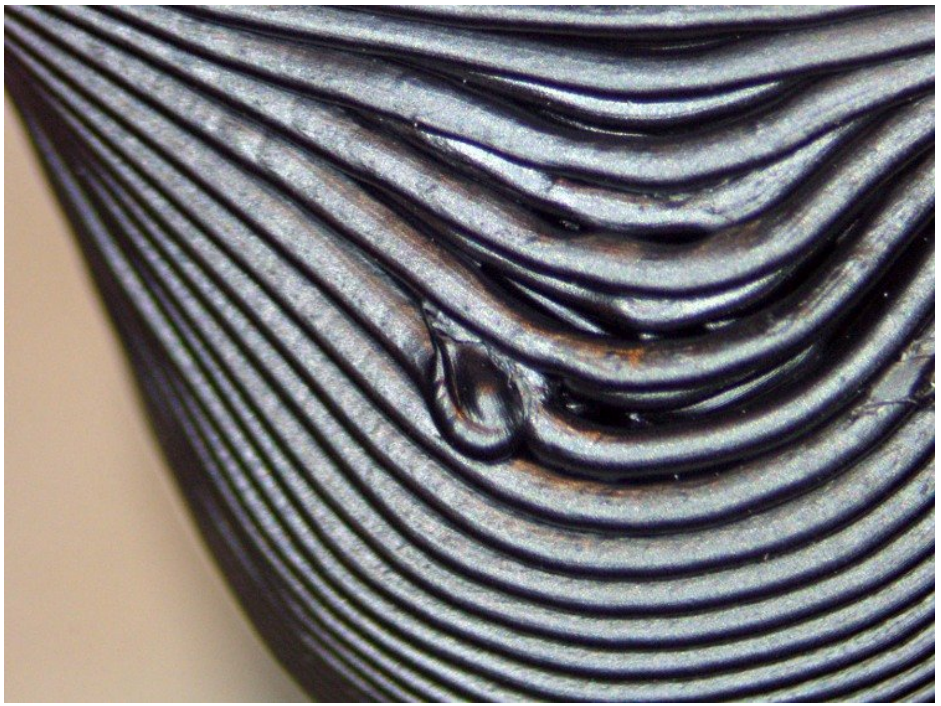


Resolution – X&Y Axes

- Physical Constraints
  - 100 mm build platform
  - 0.66 mm thread width
    - It takes two!
- Object:feature = 75:1
  - Call it 1%
  - *Of largest object!*
- Think Pong / Pacman
  - “8-bit resolution”

Resolution – X&Y Axes

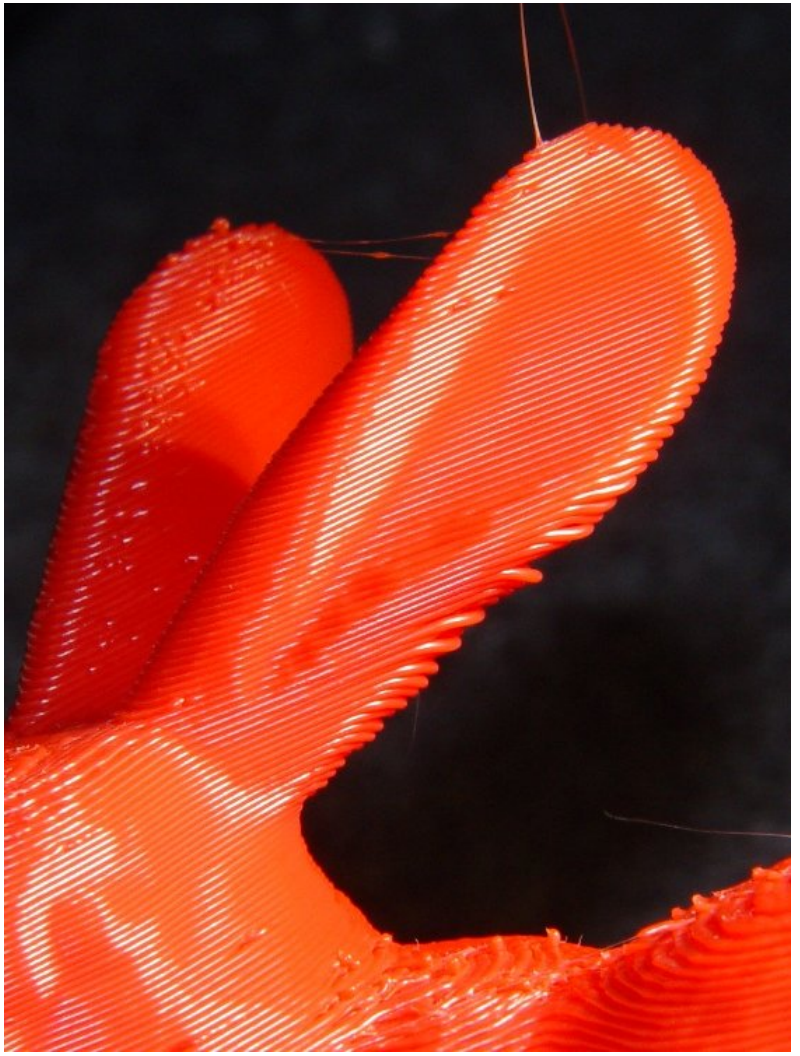
- Size ≥ n x Width
  - n x 0.66 mm for mine
  - Blocky Features
- Position ≈ 0.01 mm
  - Smooth curves!
  - Vector, not bitmap
- Model resolution?
- Mind the zits ...



http://www.thingiverse.com/thing:1216

Overhang

- No shelves!
  - Cliffhanging OK
- Overhang < 40° or so
- Support material
  - DIY = same plastic
  - $$$ = water soluble
  - Maybe next year?
- Pick build orientation!

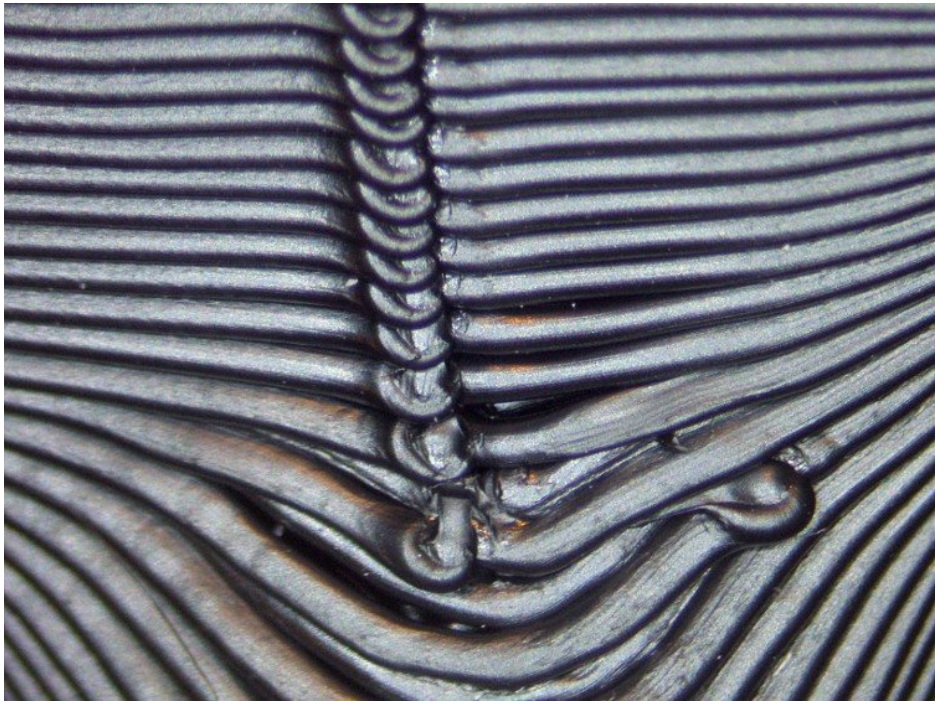


Infill

- What's not inside ...
  - Conserve plastic
  - Reduce print time
    - Varies as cube of length!
- Automatic generation
  - Typical density ≈ 0.15 to 0.3
  - 1.0 for small or rigid objects
- Various patterns
  - Usually hexagonal

Limitations

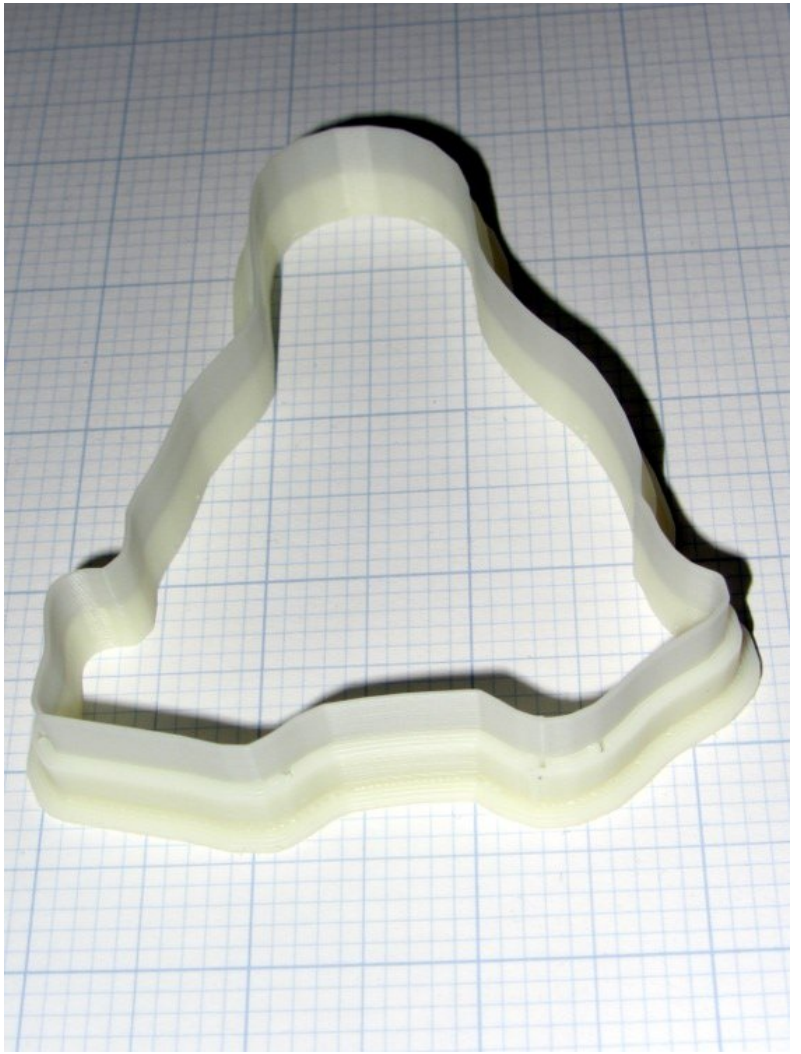
- Free vs. $$$ Software
- *Affordable* hardware
  - Good CNC = $$$
- Frenetic improvement
  - You will be left behind
- Perfect is not possible
  - Reality is pretty good
  - Art vs. engineering
  - Hobby vs. lifestyle



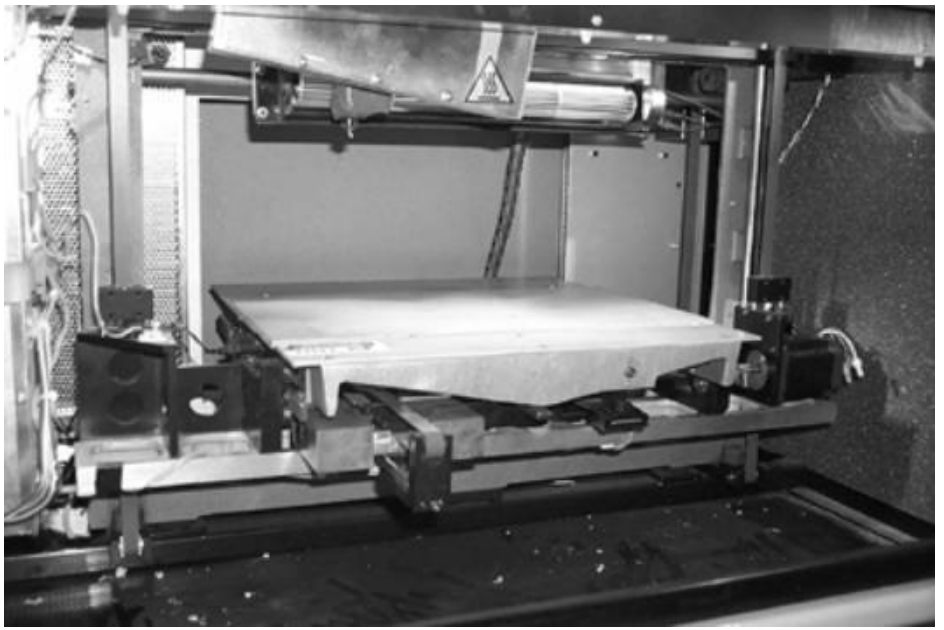
http://www.thingiverse.com/thing:1216

Tux Cookie Cutter

The Movie!



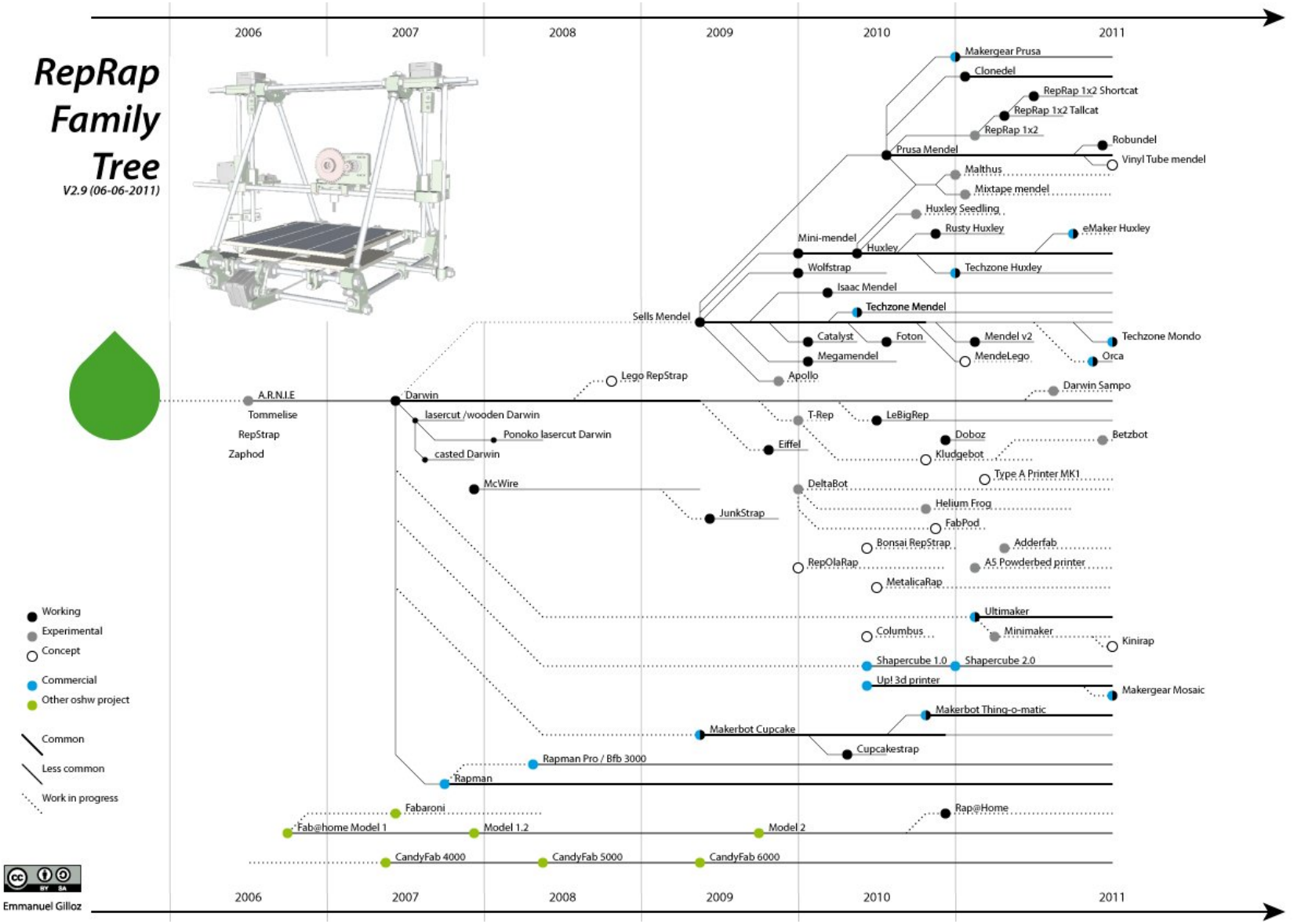
$$$ 3D Printer Genealogy



- 3D Systems – 1986
  - SLA – UV Laser Curing
  - SLS – Laser Sintering
- Stratasys – 1989
  - Hot melt glue gun!
  - FDM™ - Fused Deposition Modeling
  - Dimension uPrint Personal Printer - $15k+
- Objet – 1998
  - PolyJet – UV Cured Inkjet

http://www.cs.cmu.edu/~unsal/research/ices/cubes/pics2/genisys.jpg

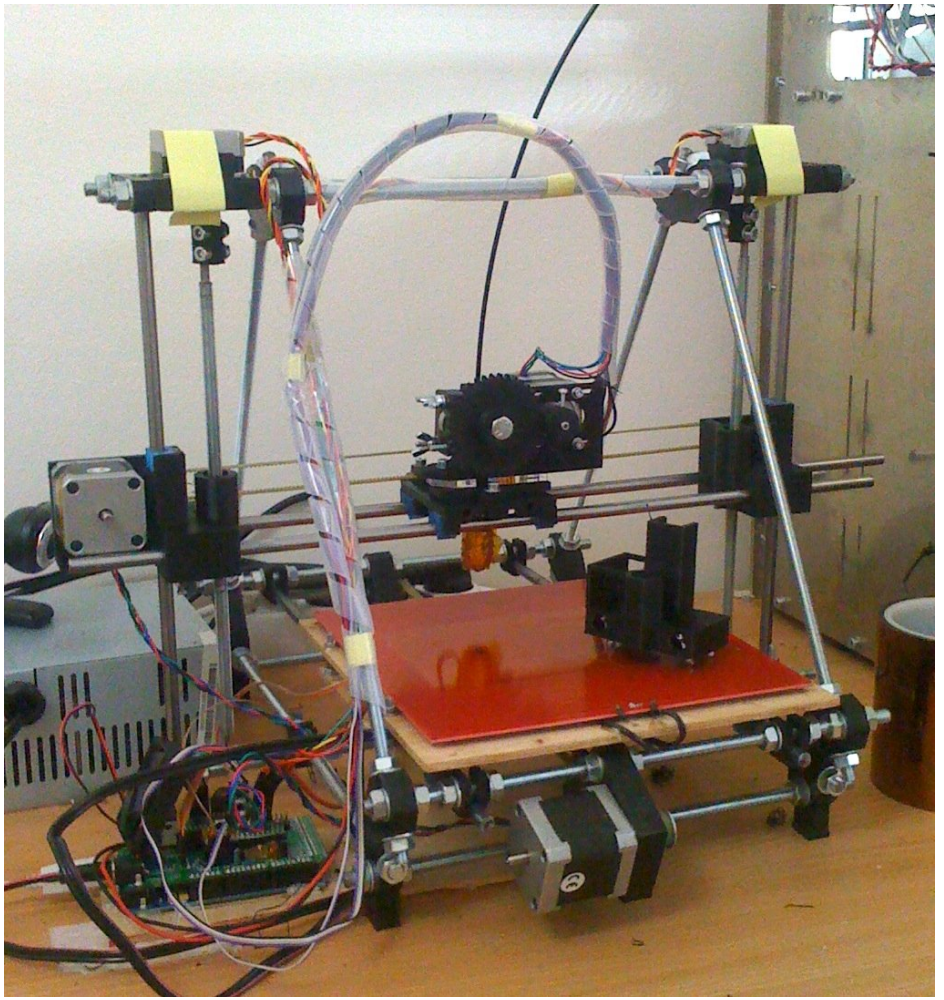
DIY 3D Printer Genealogy



http://www.thingiverse.com/thing:9088

DIY 3D Printer Genealogy

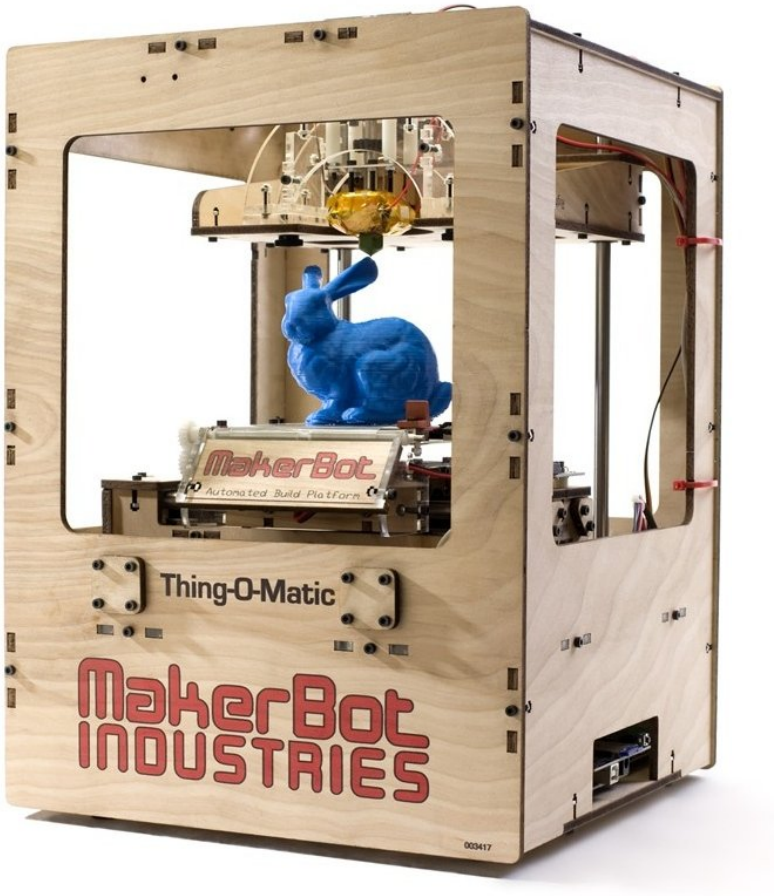
- Reprap.org project
  - Darwin - 2007
  - Mendel - 2009
    - Prusa Mendel - 2010
  - Huxley - 2010
- Goal: self-replication
  - Just add *vitamins*
  - Truly Do-It-Yourself
  - Full Prusa kit ≈ $900



http://reprap.org/wiki/Prusa

DIY 3D Printer Genealogy

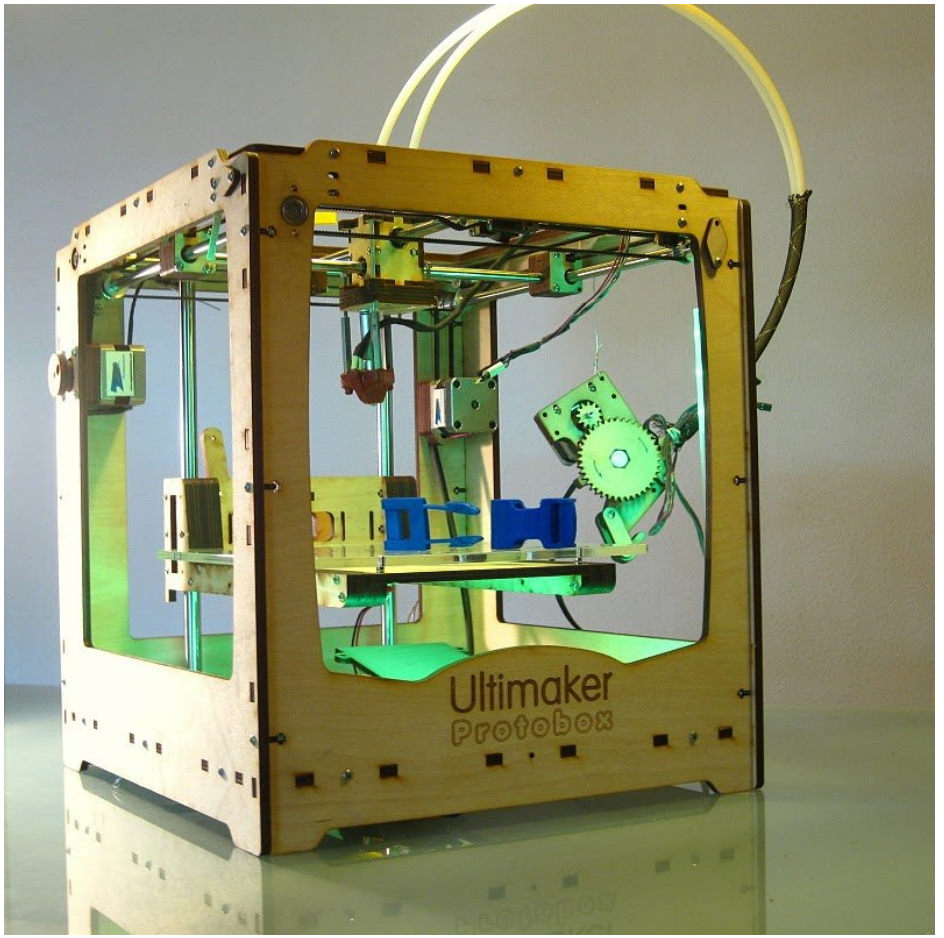
- Makerbot Inc
  - Cupcake - 2009
  - Thing-O-Matic - 2010+
- Goal: Practicality
  - Also - make money
  - Full Kit ≈ $1300
    - Plus mods & fixes &c ...
  - Assembled ≈ $2500
    - Includes *some* mods & fixes



http://store.makerbot.com/makerbot-thing-o-matic.html

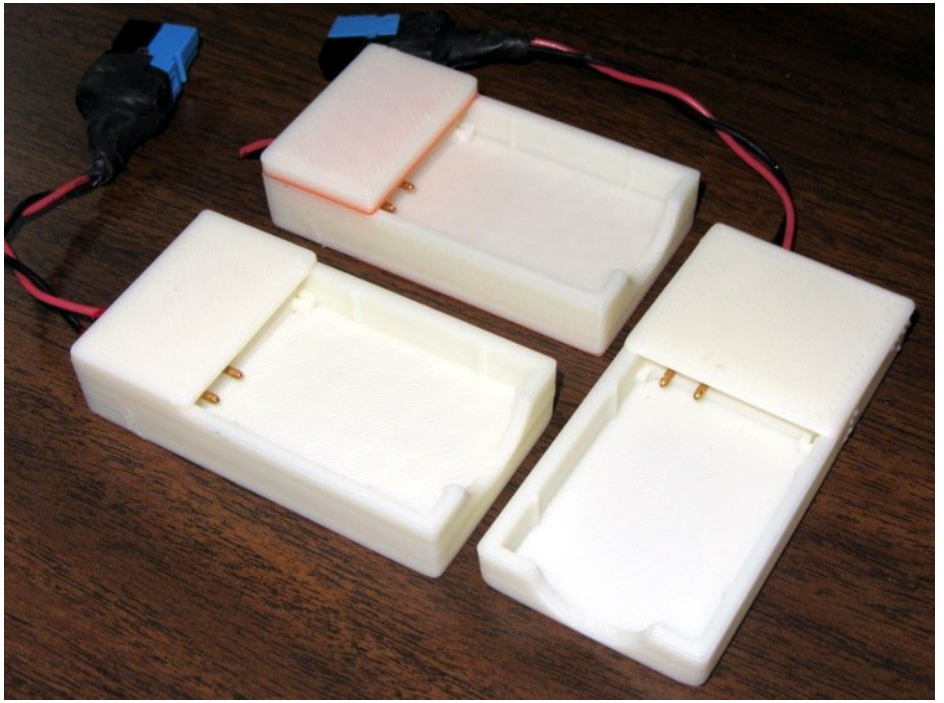
Other 3D Printers

- Ultimaker - NL
  - DIY Kit
- PP3DP - CN?
  - UP!
- Makergear - US
  - Mosaic
- Bits From Bytes - UK
  - BFB-3000 - US
- Etc, etc, etc ...



Outsourcing

- Let *them* print it
  - Shapeways
  - Pokono
  - eBay vendors
  - etc
- Cost per iteration
  - Money
  - Time!
  - Attention span ...



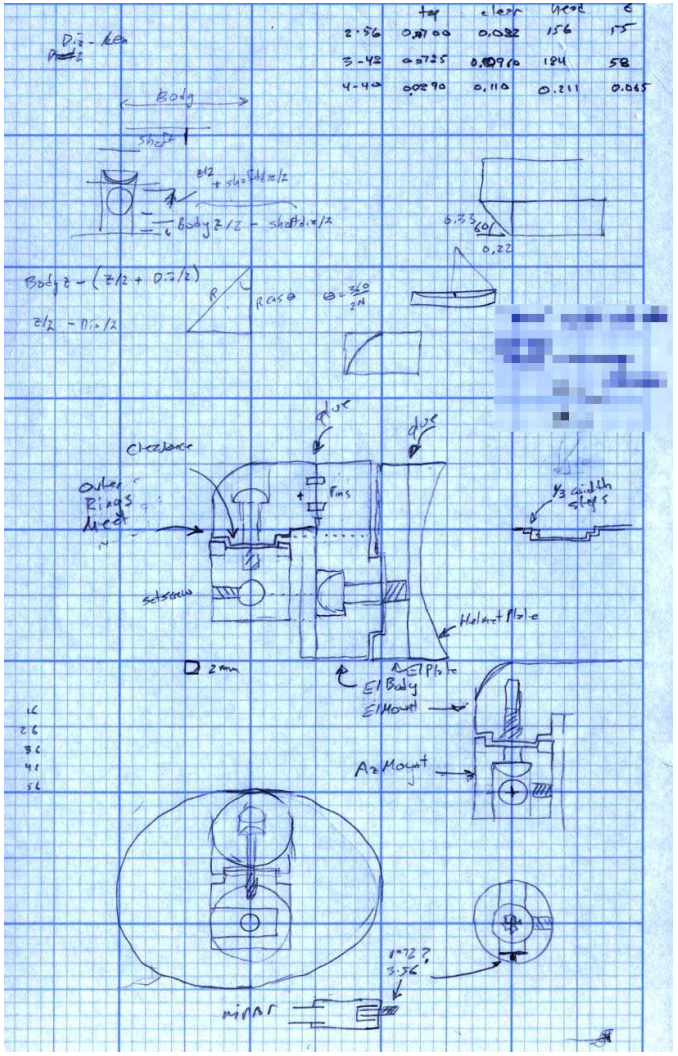
Printing Your Stuff

- “If you can dream it...”
  - *Maybe* you can print it
- One piece or many?
  - Some assembly ...
- Dimensions!
  - Metric FTW!
- Printability
  - How much overhang?
  - Surface finish

http://softsolder.com/2011/07/01/helmet-mirror-mount-first-light/

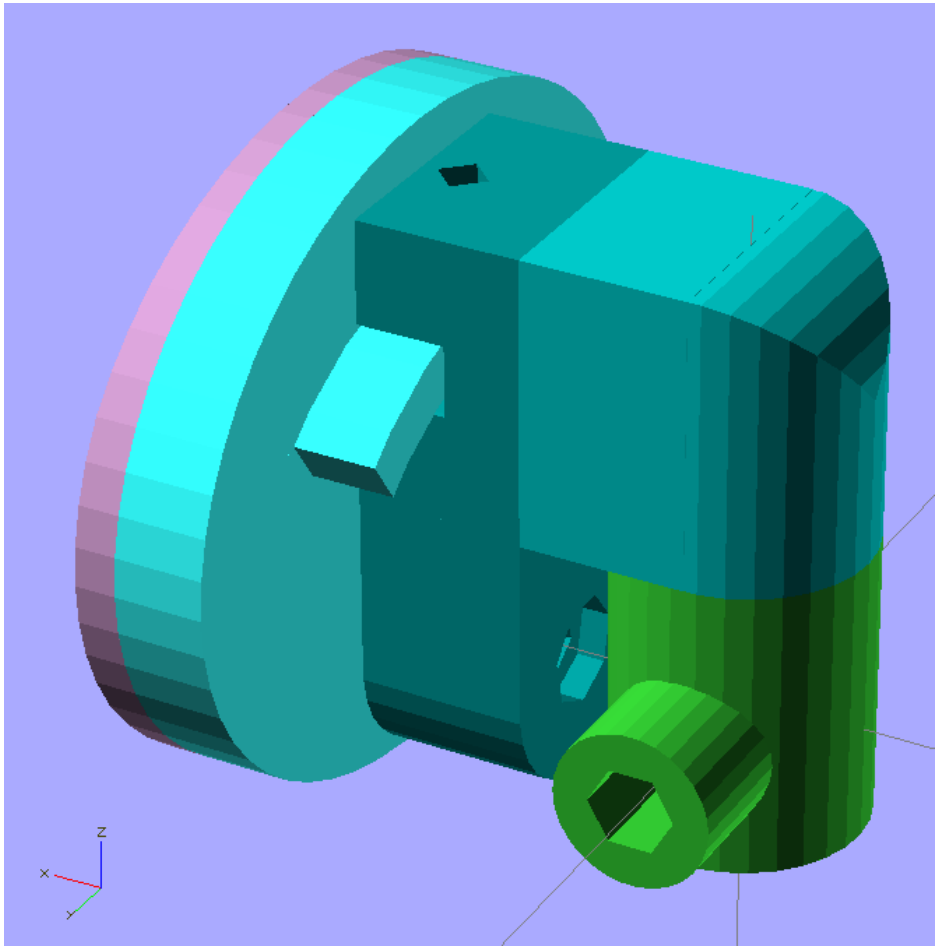
Start With an Idea

- Doodling helps
  - Before using CAD program
- Dimensions!
  - XYZ resolution limits
- Assembly?
  - Printable snaps
  - Screws & nuts
  - Adhesives FTW!



Solid Modeling = CAD

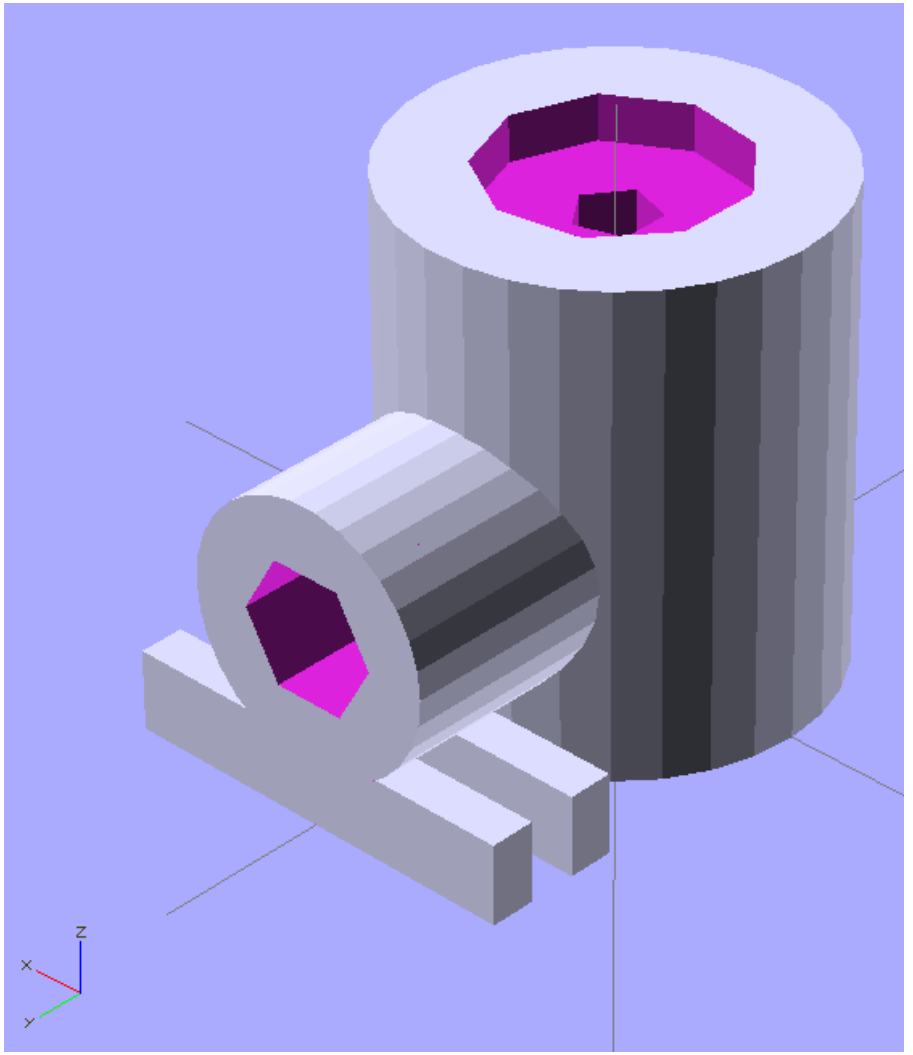
- 3D CAD
  - Mesh vs CSG
- OpenSCAD
  - CAD for programmers
  - Love it or hate it
- Dimensions!!!!
  - Parametric relations
  - They will change
  - Redrawing is tedious



http://softsolder.com/2011/06/29/helmet-mirror-mount-solid-model/

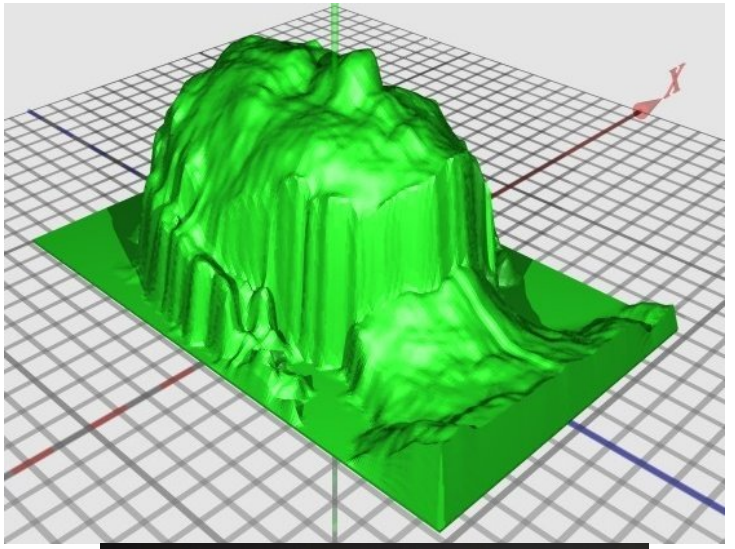
Solid Modeling

- *Exactly* what you want
  - Dimensions!
  - Angles, etc
- DIY Overhang Support
  - Better than auto support
- Improve with practice



3D Scanning

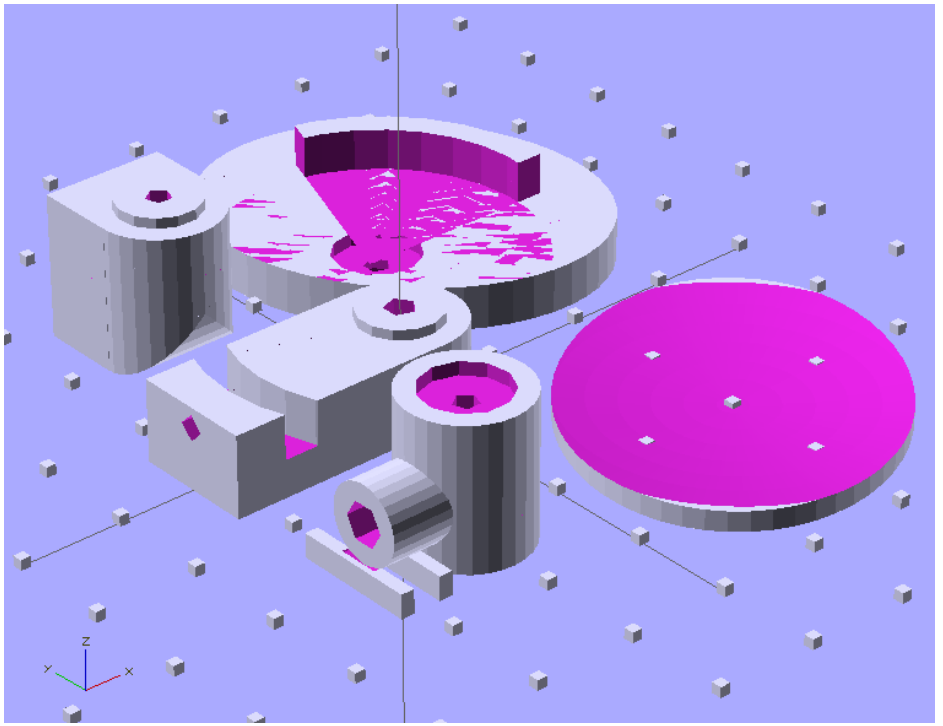
- DIY Kinect scanner
  - Usable low res
- DIY laser scanners
  - Serious DIY hardware
  - Software
- Polhemus scanners
  - If you can afford them, you aren't doing DIY



http://www.thingiverse.com/download:26630
http://www.thingiverse.com/thing:9275

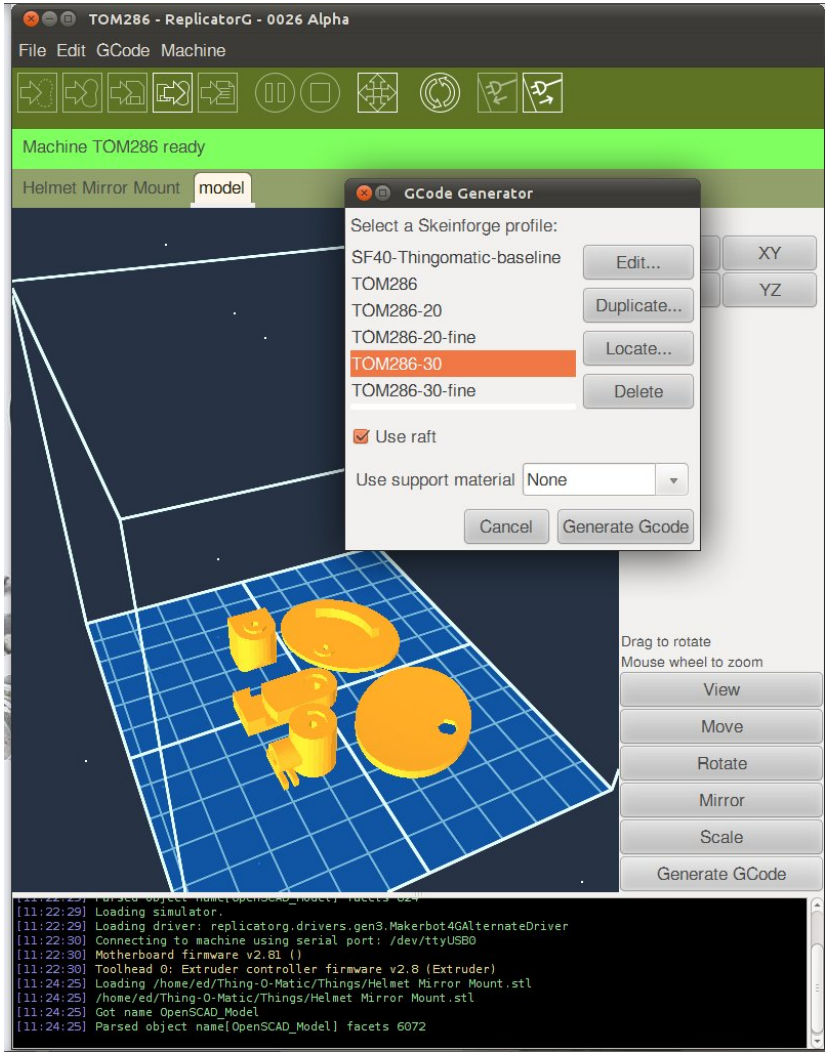
Printing Layout

- OpenSCAD FTW!
  - Layout parameters
- Orientation
  - Fill vs. orientation
- Export as STL file
  - “STereo Lithography”
  - Triangles everywhere
  - Other formats?



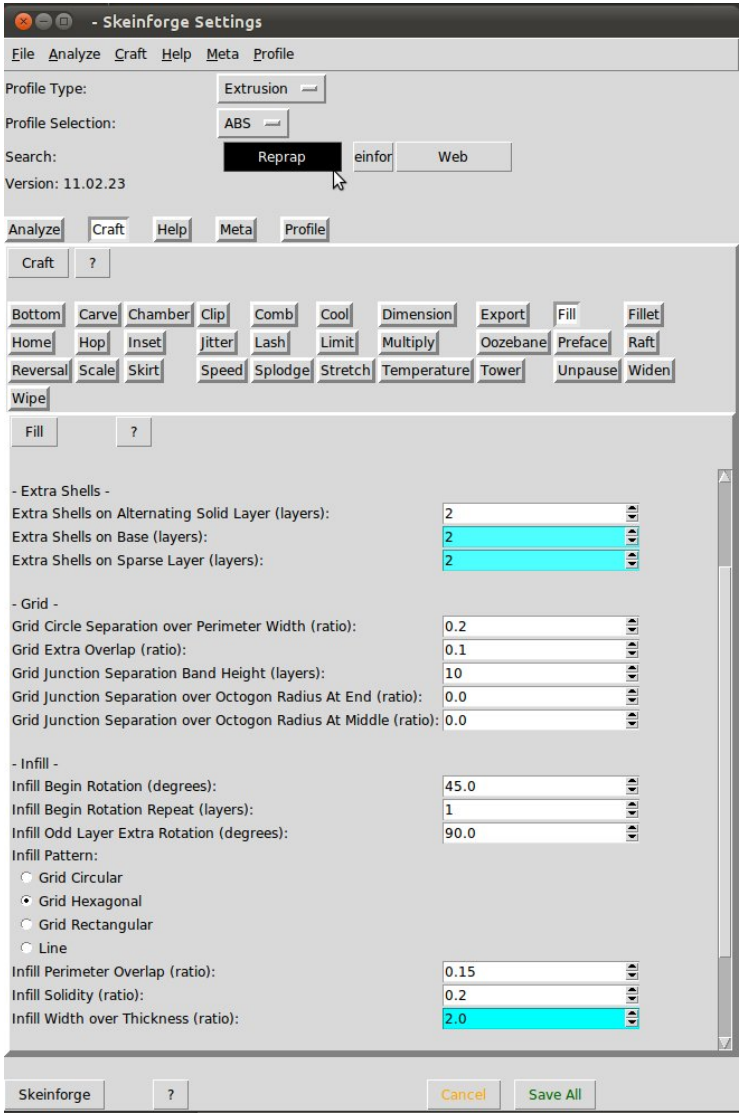
STL To G-Code = CAM

- Makerbot ReplicatorG
  - Printer control
  - STL manipulation
  - Skeinforge wrapper
  - Java!
- Skeinforge
  - “Slice” STL triangles
  - G-Code per layer
  - Python!



Skeinforge Parameters

- Myriad plug-in modules
- Myriad parameters
  - Defaults mostly OK
  - Vital ones scattered all over
  - Print-O-Matic helps
    - For SF 35, not 40 or 41 or ...
- *All* advice is misleading
  - For your printer, anyway
  - Tune for best printing

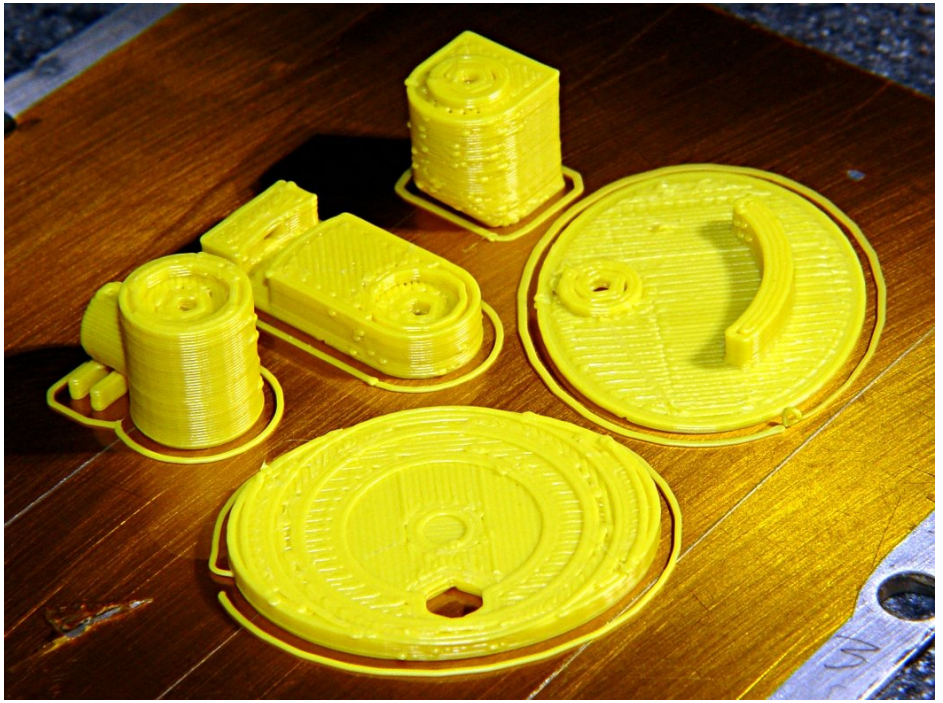


Printing!

- No user intervention
  - An occasional cancel
- Very, very tedious
  - Unless it's your part
  - Watching Channel 0
  - 10 min to 5+ hours
- Time ≈ model volume
  - 6.5 mm^3/s for my config

Remove Parts

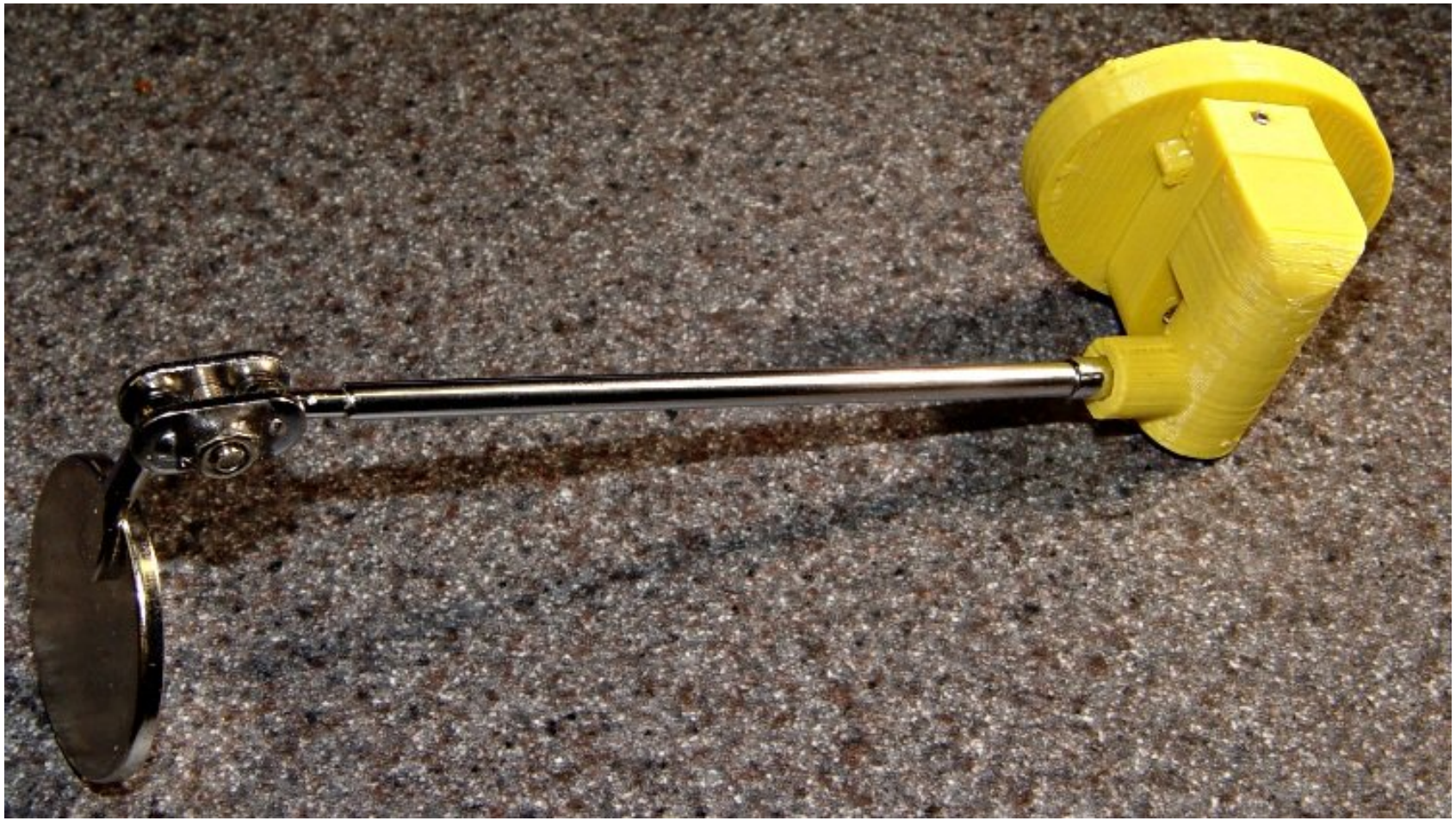
- *Excellent* adhesion
  - After many attempts
  - Much folklore
    - Most inapplicable
  - Wood chisel ...
- Kapton tape
- “Skirt” thread



Assemble

- Follow your directions
  - Adhesives
  - Screws
  - Snaps
- This is the easy part!
  - Patience ...

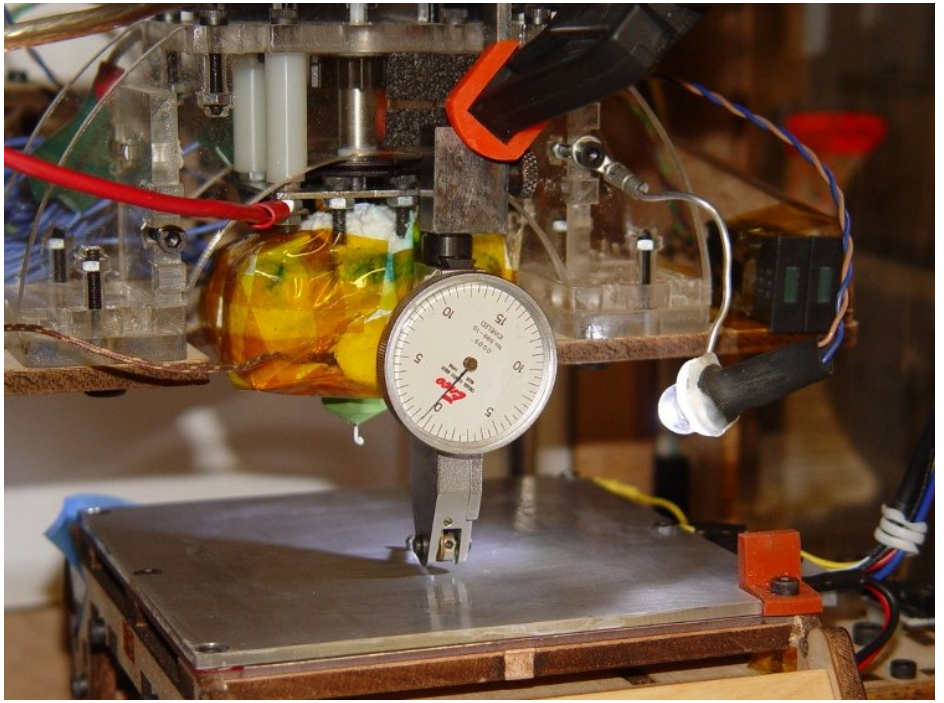
Use It!



That’s all there is to it!

Should I Get A DIY 3D Printer?

- Are you an engineer?
  - Do you know one?
- Willing to DIY?
  - Have parts / tools?
  - Have time?
  - Willing to learn?
- Imperfections OK?
  - Even ugly ones?
- Go for it!

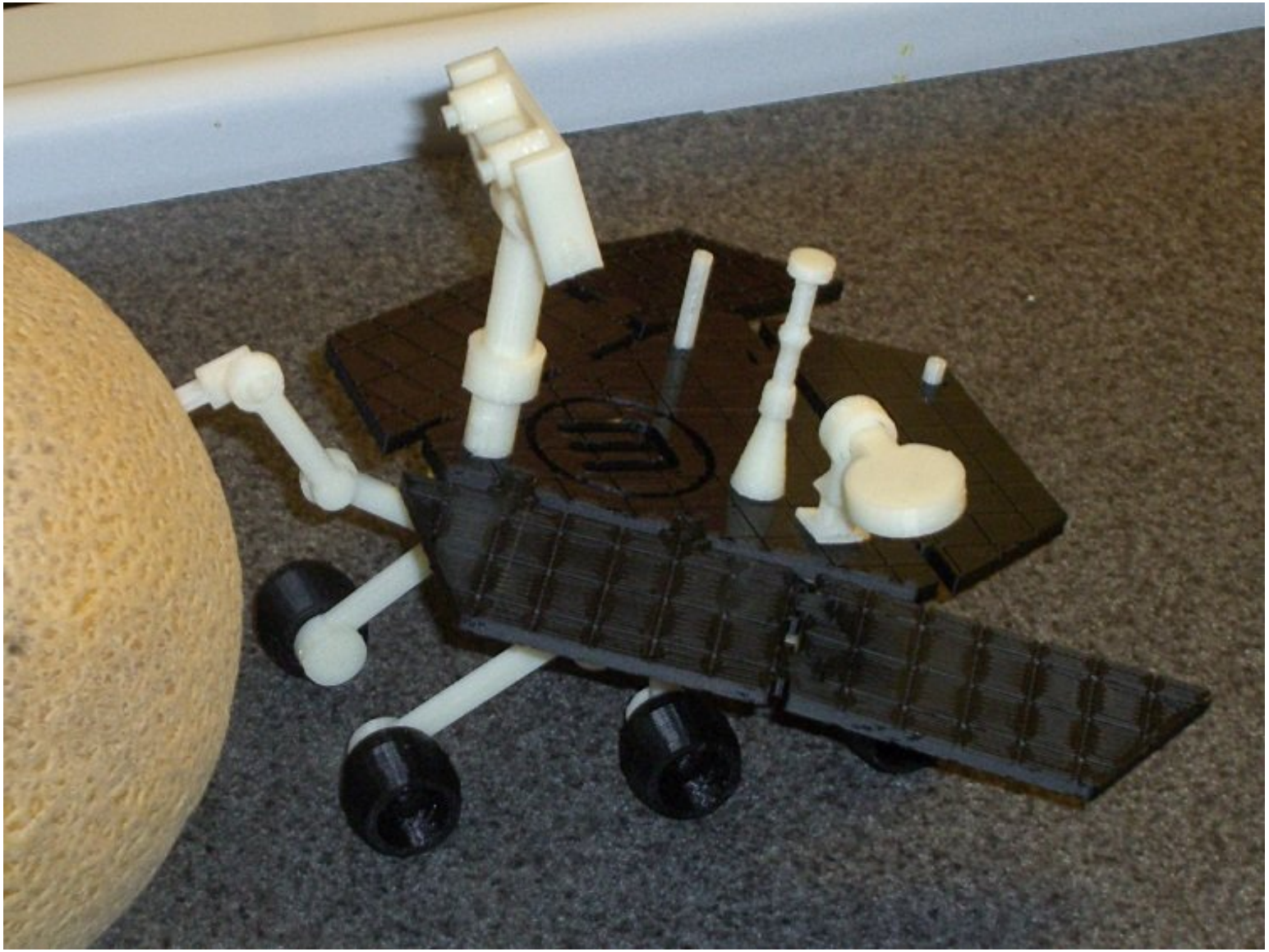


http://softsolder.com/2011/03/05/thing-o-matic-measuring-build-plate-alignment/

Which One?

That’s a *very* good question ...

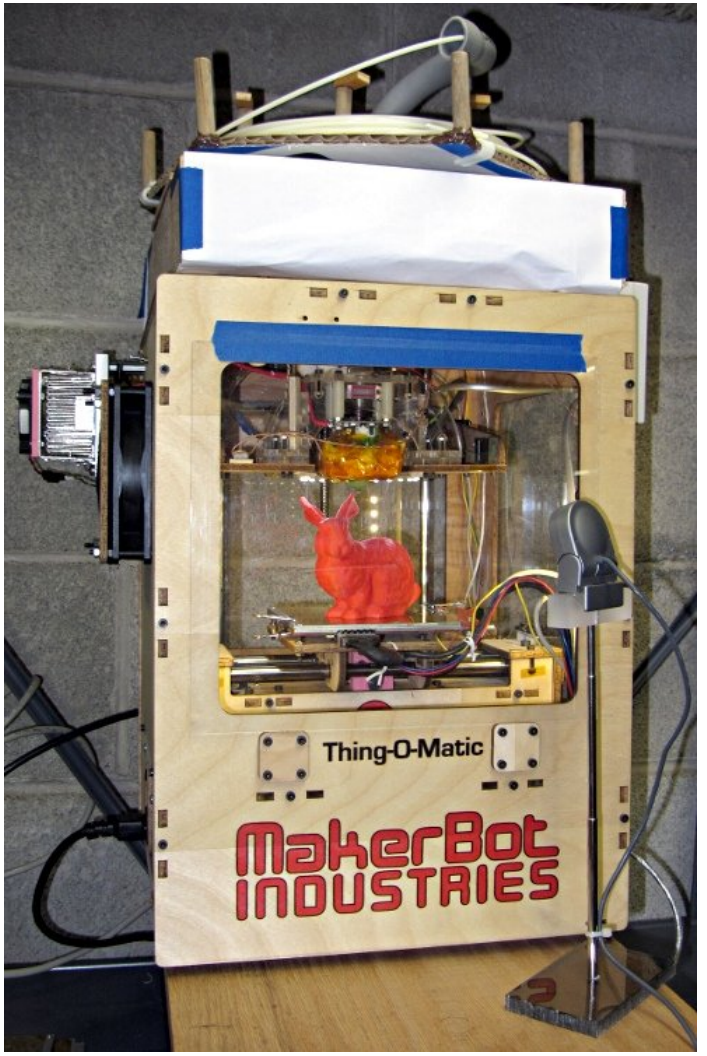
Door Prize



http://www.thingiverse.com/thing:10057

Q&A + Touchy-Feely

- Ask questions
- Mill around
- Examine stuff
- Watch printer!
- *Ask questions*
- Iterate ...



Other Places To Go

en.wikipedia.org/wiki/Additive_manufacturing

en.wikipedia.org/wiki/3D_printing

hydraraptor.blogspot.com

makerbot.com

www.makergear.com

www.openscad.org

replicat.org

reprap.org

www.thingiverse.com

www.ultimachine.com

Or just search for the obvious terms

Copyright-ish Stuff

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[whatever that is]

The rest is my own work

•

Ed Nisley

Say “NISS-lee”, although we're the half-essed branch of the tree

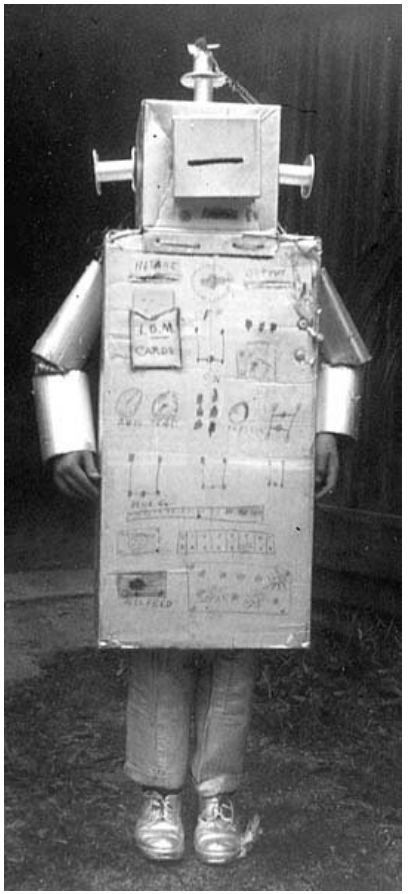
Engineer (ex PE), Hardware Hacker, Programmer, Author

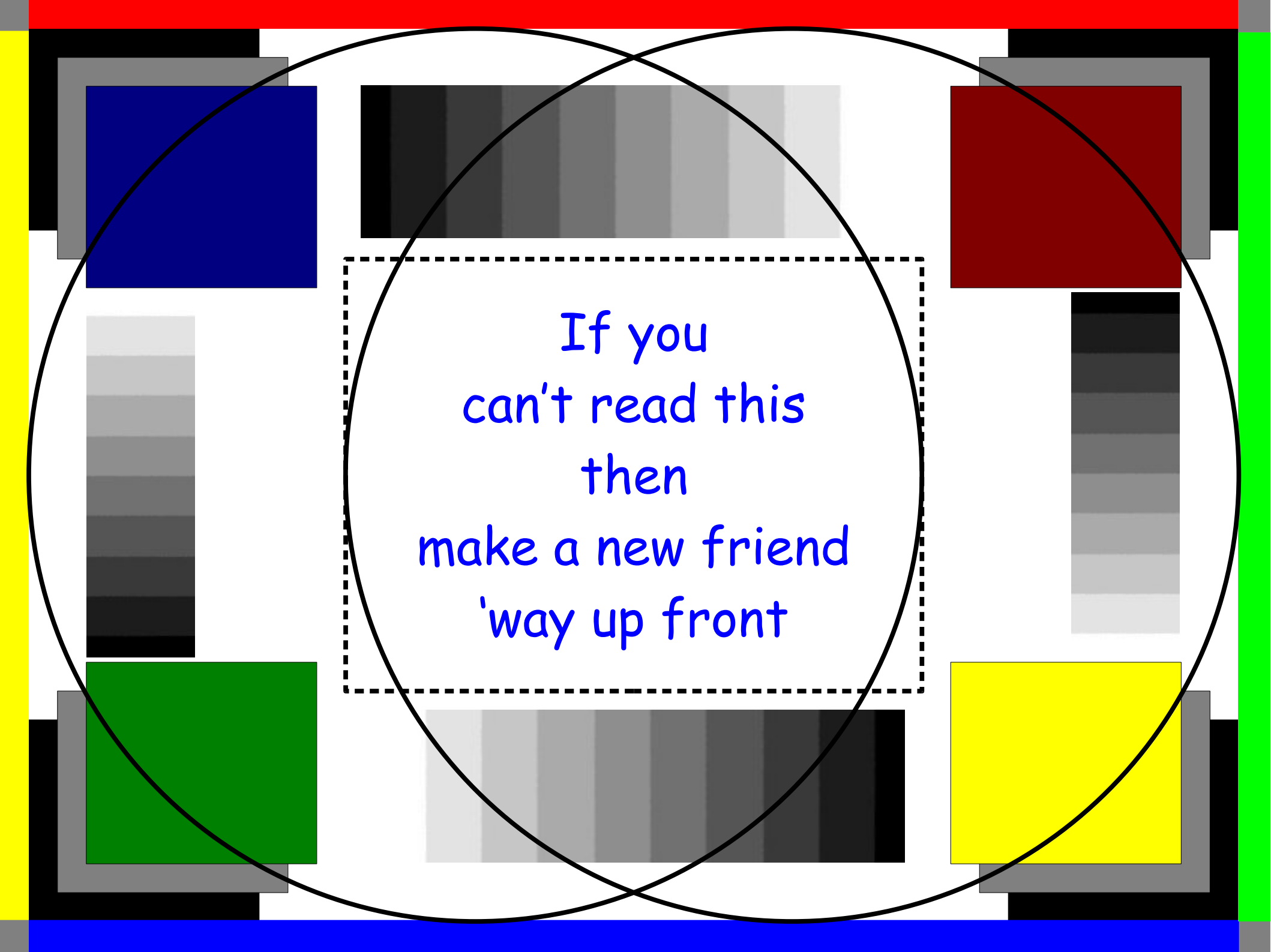
The Embedded PC's ISA Bus: Firmware, Gadgets, Practical Tricks

Circuit Cellar www.circuitcellar.com
- Firmware Furnace (1988-1996) - Nasty, grubby hardware bashing
- Above the Ground Plane (2001 ...) - Analog and RF stuff

Dr. Dobb’s Journal www.ddj.com
- Embedded Space (2001-2006) - All things embedded
- Nisley’s Notebook (2006-2007) - Hardware & software collisions

Digital Machinist www.homeshopmachinist.net
- Along the G-Code Way (2008 ...) - G-Code, math, 3D printing

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