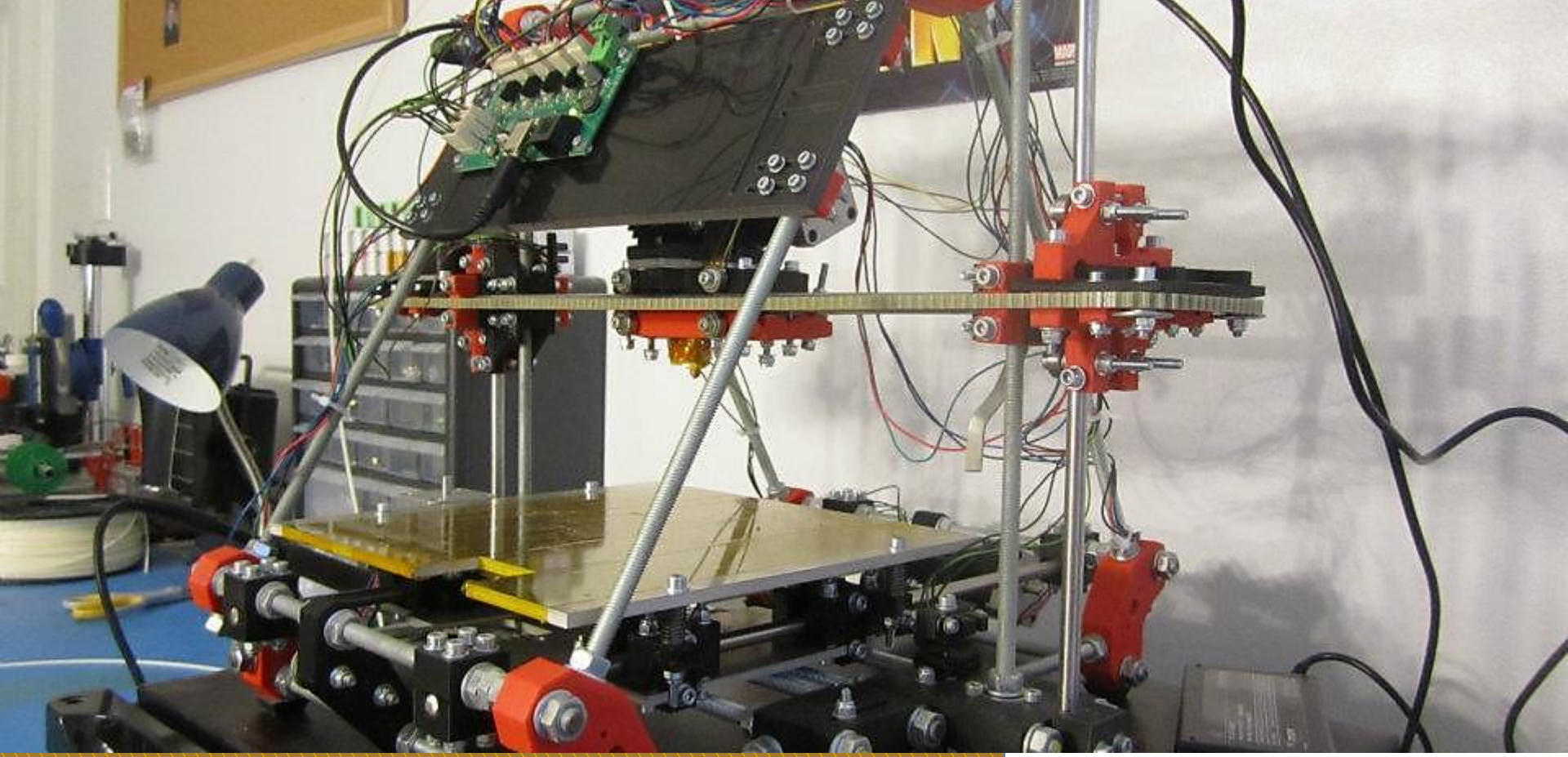

CASE STUDY: THE REPRAP PROJECT

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3D PRINTING

3D Printing Today

- 3D Printing in the news: 3D printed…
  - Organs, toys, cars, buildings, astronaut food
  - 3D printers (I'm so meta even this acronym…)
- 3D Printing Materials commercially available today
  - Plastics
  - Ceramics (including food grade)
  - Metal
- Rapid prototyping accessible for artists, engineers, etc.

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3D PRINTING

3D Printing Technology for RepRap

- Fused Deposition Modeling (FDM): Method of 3D printing in which thin filament of material is pushed through a heated nozzle and deposited layer-by-layer on a surface
  - Based on US Patent 5,121,329 (first full description of FDM technology; now expired)
- Objective of the RepRap project: create an open source 3D printer capable of printing all of the parts necessary to build a new RepRap (assisted self replication)

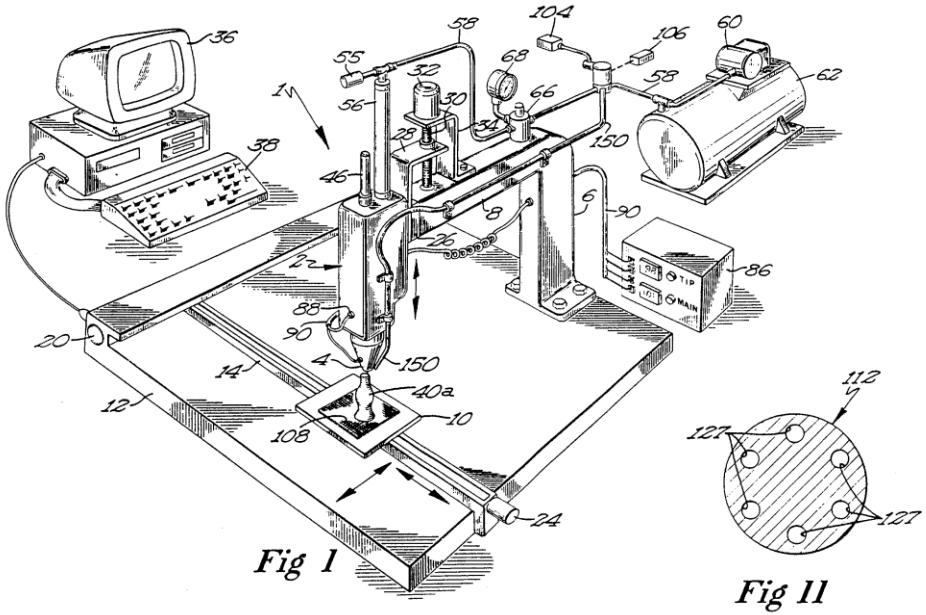

Fig 1

Fig 11

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3D PRINTING

Anatomy of an FDM 3D Printer

- 3 Axis CNC Platform: Provides motion for the tool head and print bed in the X, Y, and Z axes
- Extruder: Geared mechanism which accepts filament and feeds it into the hot end
- "Hot End": Heated nozzle which receives filament from the extruder and deposits it on the print surface
- Control Electronics: Used to control movement of tool head and print bed, heating controls for print bed and hot end, homing and other features
- Sensors: Provide feedback to control electronics about the position of tool head and print bed, as well as other features

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3D PRINTING

Anatomy of an FDM 3D Printer

- Filament: A “wire” of material on a reel which is used by the 3D printer to create the 3D shape
  - 3D printable materials exhibit phase changes making them easy to deposit and then resolidify on cooling
  - Many material options available:
    - Polycarbonate: Durable plastic; used in bulletproof glass
    - Vinyl: Flexible rubber/plastic
    - PLA: Plant-based plastic
    - ABS: Oil-based plastic
    - And many more

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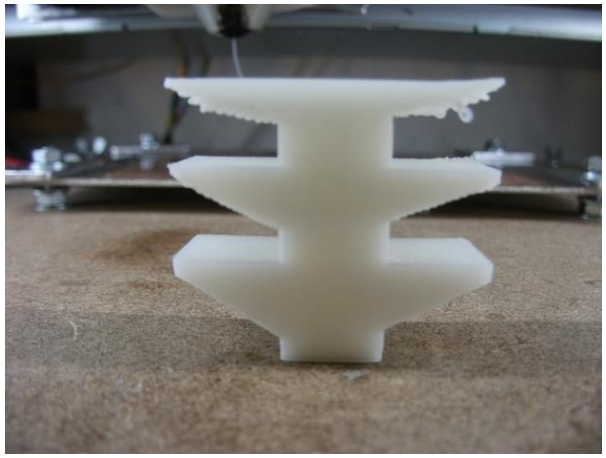
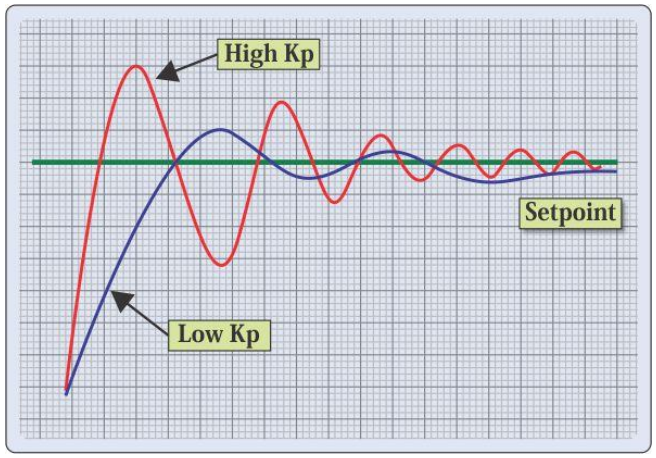
3D PRINTING

RepRap Development Technical Challenges

- High precision positioning of the print bed and tool head (the positioning problem)
- Preventing error accumulation in the position of the print bed and tool head (the drift problem)
- Precise control of the heating elements (the heating problem)
- Handling unsupported gaps in the 3D models (the overhang problem)





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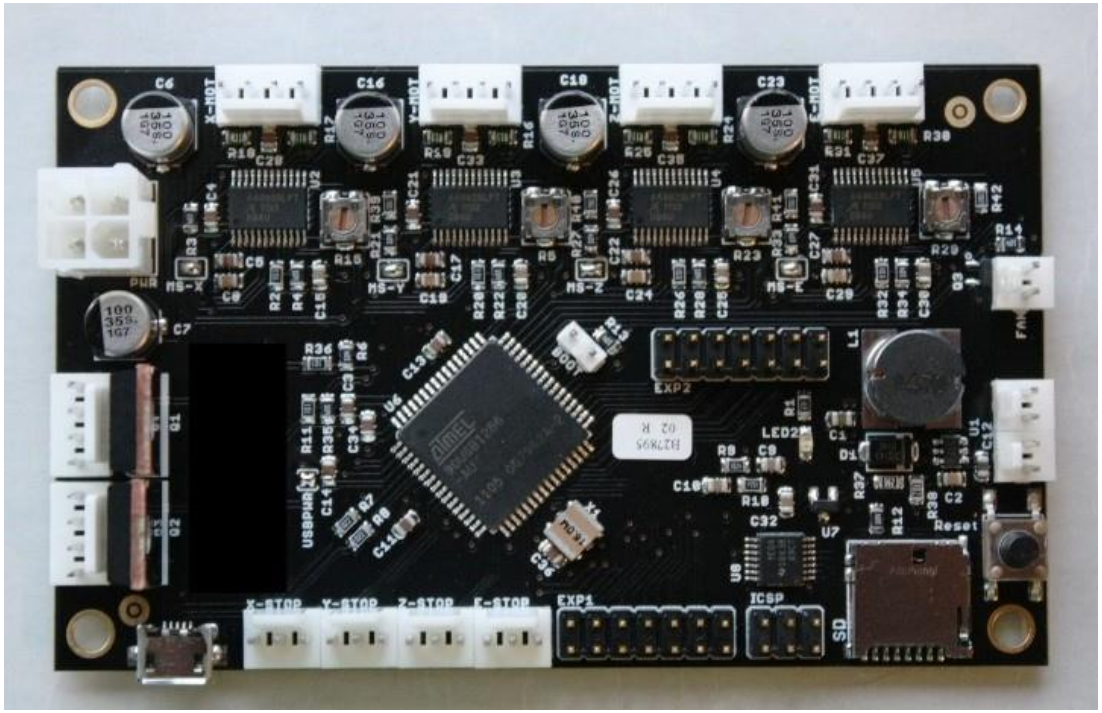
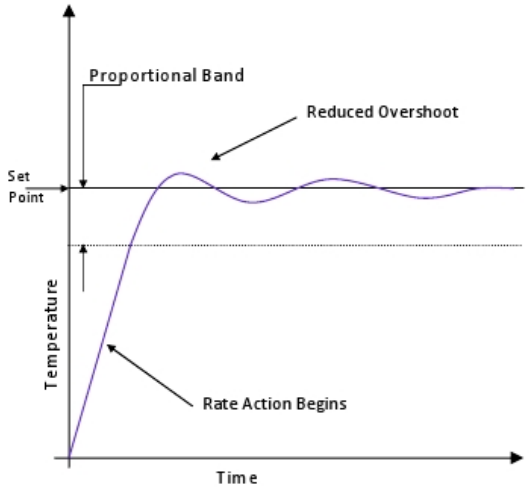
RepRap Solutions – Previously Solved Problems

- Positioning problem: Stepper motor control, partial stepping
- Heating problem: Tuned PID controller – minimizes overshoot without substantially increasing settling time





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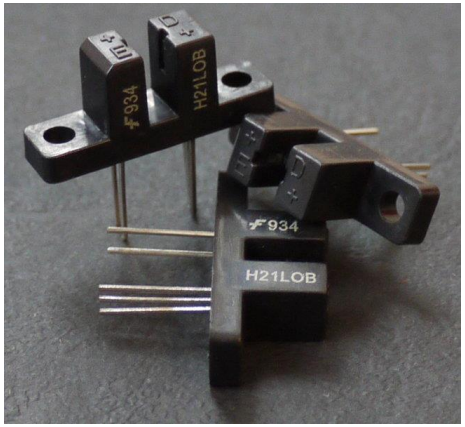
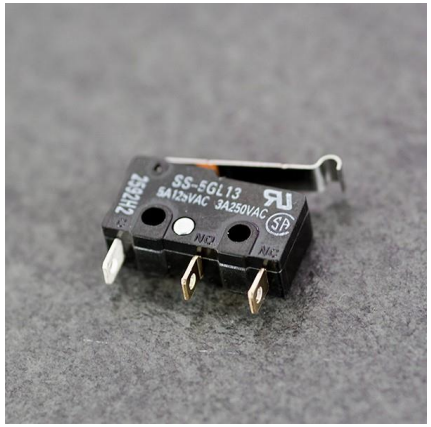
3D PRINTING

RepRap Solutions – The Drift Problem

- If allowed to run freely, errors could accumulate and throw the printer out of calibration over time
- At some point during a print, the position of the tool head w.r.t the print bed needs to be known
- Solution: provide limit switches which identify the edges of allowed movement for the RepRap, and use these switches to “home” the tool head and print bed





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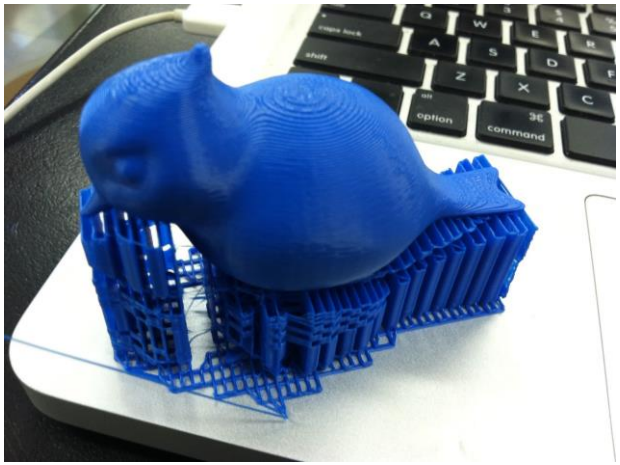
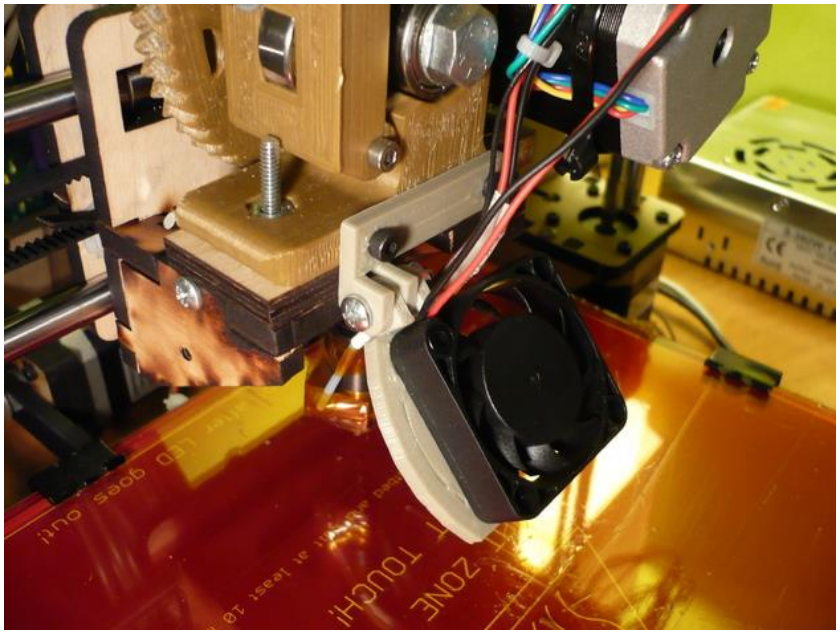
RepRap Solutions – The Overhang Problem

- Many 3D printable models contain gaps or unsupported spaces; if not handled properly, gravity could drag the cooling filament in these gaps down, ruining the print
- Solution 1: Add in scaffolding to support the gaps (can be removed post-print)
- Solution 2: Over a gap, rapidly extrude filament, cool it (to harden), and move quickly





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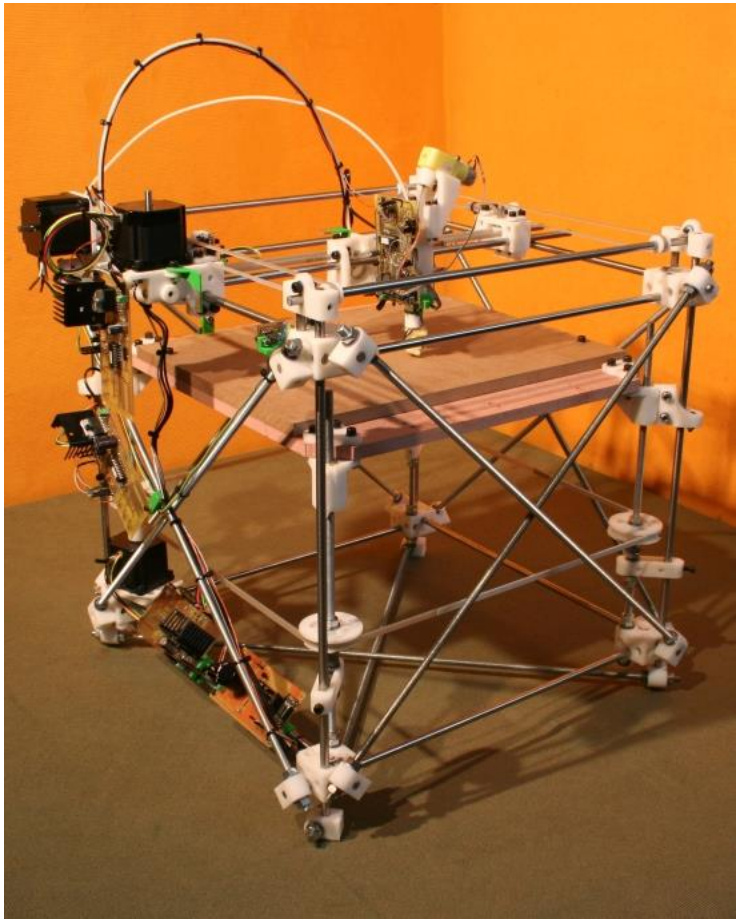
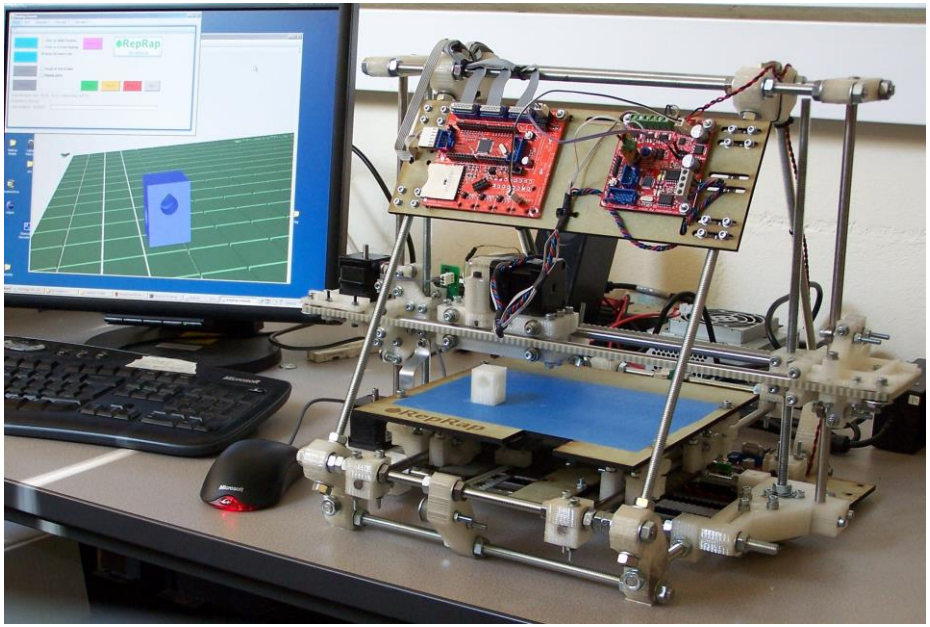
Evolution of the RepRap

Generation 1: RepRap Darwin





Generation 2: RepRap Mendel

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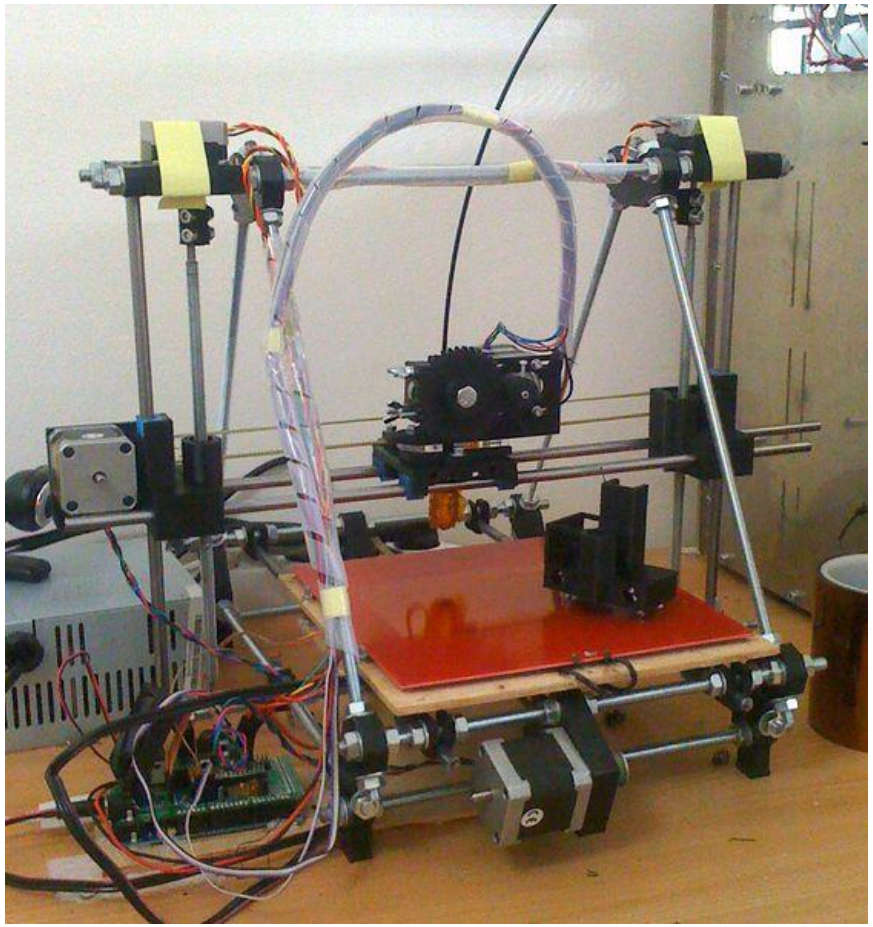
Evolution of the RepRap

Generation 3: “Prusa” Mendel



Generation 4: Prusa Mendel i3

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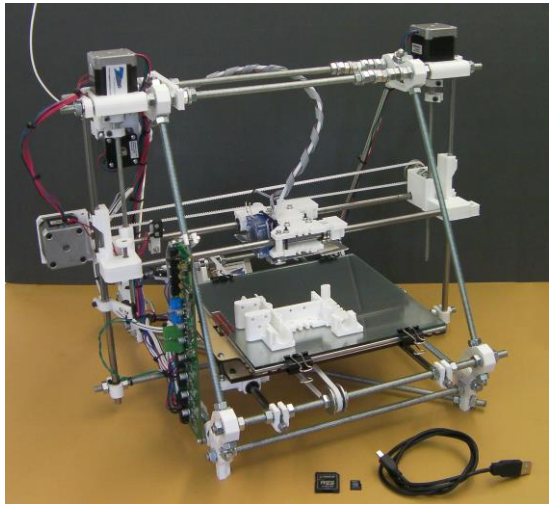
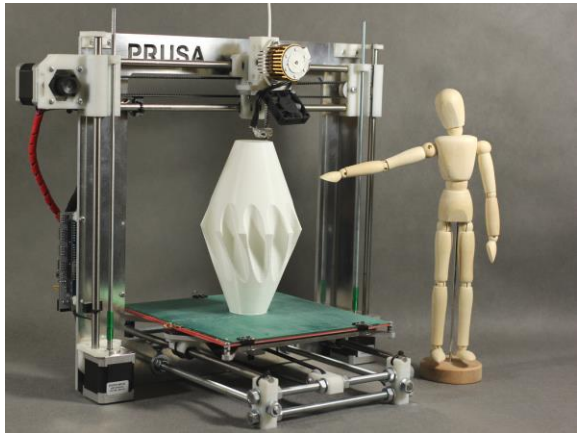
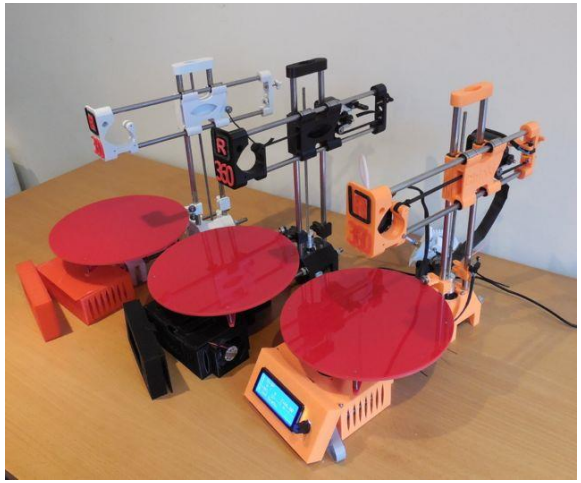
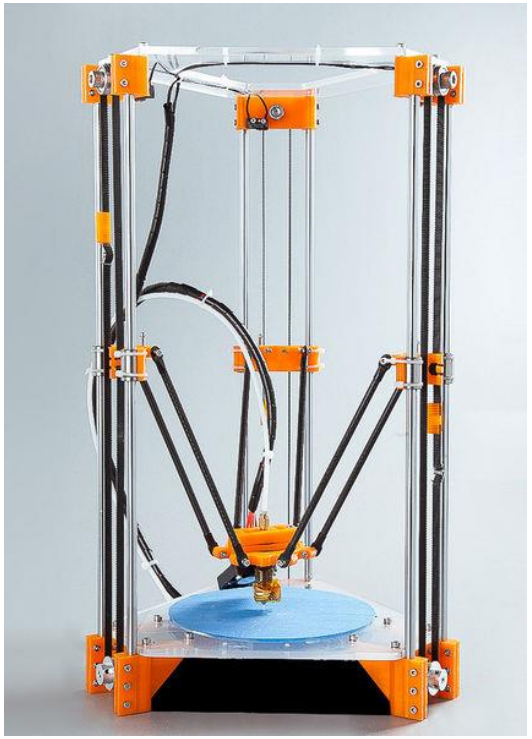
RepRap Options – A Flurry of Open Source

- RepRap open source licenses encourage sharing, distribution, and numerous options - http://reprap.org/wiki/RepRap_Options









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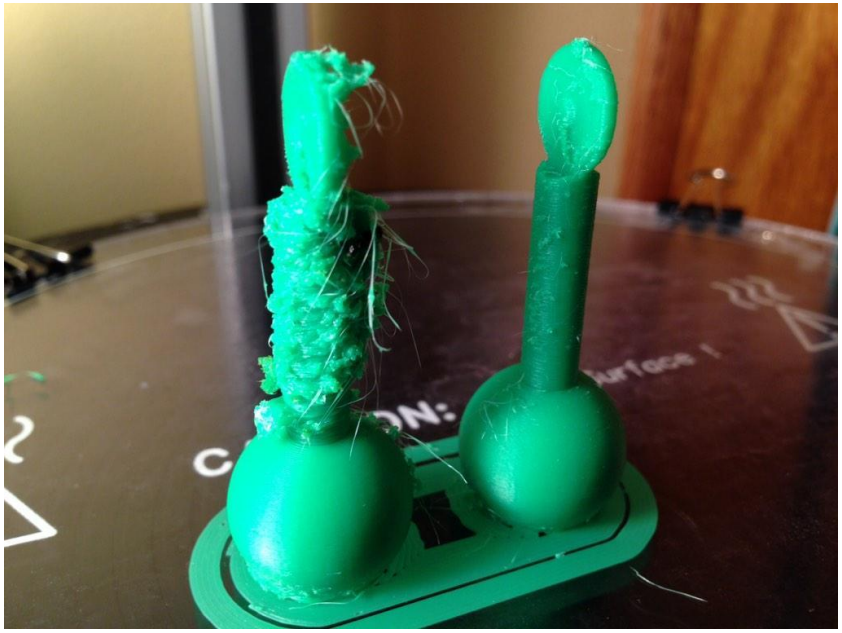
3D PRINTING

Current Challenges in Consumer 3D Printing

- Current hobbyist 3D printers require A LOT of tuning and calibration on the part of the user (ideal: automatic calibration and test procedures)
- Most available printers require an attached computer to handle model processing and sending commands to the control electronics (ideal: networked, standalone solutions)
- Improved repeatability and reliability
- Improved printing speed



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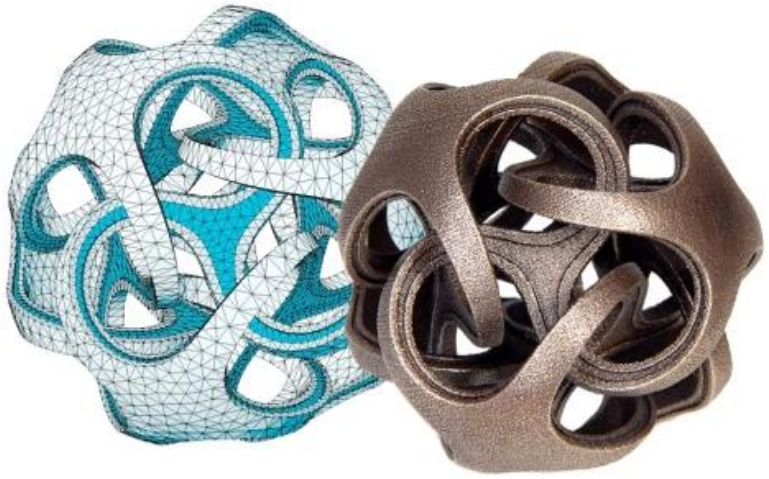
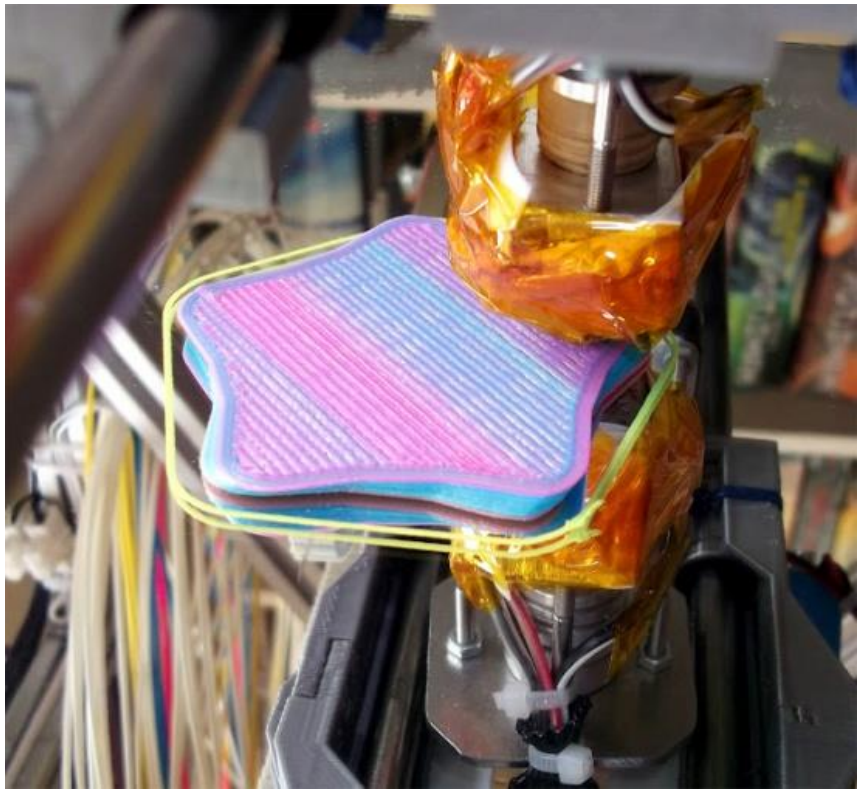
3D PRINTING

Future Frontiers in Consumer 3D Printing

- Expanded range of useable printing materials (metal, glass, ceramics, etc.)
- Multi-material printing (2+ different materials in a single print)
- Full color 3D printing





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Future Frontiers in Consumer 3D Printing

- Making use of different 3D printing technologies (thanks to patent expirations):
  - Stereolithography
  - Laser Sintering
  - Powder Printing

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