An Introduction to Open-Source 3D Printing

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McGill SOCS Graduate Seminar

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What is 3D Printing?

- Additive layer manufacturing

(cybertron.cg.tu-berlin.de)

(Thingiverse: 32706)

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Overview of Presentation

- 3D printing workflow
- Fundamentals of 3D printing & printers
- Tools & resources for 3D printing

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3D Printing Workflow

1. Object Modeling

1.5 Model Repair

2. Model Slicing

2.5 G-code Verification

...and iterate!

3. Print!

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Workflow Demonstration

- **Object modeling & repair**
  - OpenSCAD
  - TinkerCAD
  - Netfabb

- **Model slicing & verification**
  - Slic3r
  - Gcode.ws

- **Printing**
  - Printrun
  - Makerware

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OpenSCAD
The Programmers Solid 3D CAD Modeler

Loxodrome
(Thingiverse: 46965)

“Empty” battery tray
(Thingiverse: 65356)

Arduino mounting library
(Thingiverse: 64008)

(Random) maze-lid box
(Thingiverse: 247199)

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# OpenSCAD Cheat Sheet

## Syntax
- `var = value;`
- `module name(...) {... name();`  
- `function name(...) = ... name();`  
- `include <...scad>`  
- `use <...scad>`

## Transformations
- `translate([x,y,z])`  
- `rotate([x,y,z])`  
- `scale([x,y,z])`  
- `resize([x,y,z],auto)`  
- `mirror([x,y,z])`  
- `multimatrix(m)`  
- `color("colorname")`  
- `color([r, g, b, a])`  
- `hull()`  
- `minkowski()`

## Mathematical
- `abs`  
- `sign`  
- `acos`  
- `asin`  
- `atan`  
- `atan2`  
- `cos`  
- `sin`  
- `floor`  
- `round`  
- `cell`  
- `ln`  
- `len`  
- `log`  
- `lookup`  
- `max`  
- `min`  
- `pow`  
- `sqrt`  
- `exp`  
- `rands`

## Boolean operations
- `union()`  
- `difference()`  
- `intersection()`

## Modifier Characters
- `* disable`  
- `! show only`  
- `# highlight`  
- `% transparent`

## Other
- `echo(...)`  
- `str(...)`  
- `for (i = [start: end]) {... i ...}`  
- `if (...) {... i ...}`  
- `assign (...) {... i ...}`  
- `search(...)`  
- `import("...stl")`  
- `linear_extrude(height,center,convexity, twist, slices)`  
- `rotate_extrude(convexity)`  
- `surface(file = "...dat",center,convexity)`  
- `projection(cut)`  
- `render(convexity)`  
- `children([idx])`  
- `parent_module([idx])`

## Special variables
- `$fa minimum angle`  
- `$fs minimum size`  
- `$fnn number of fragments`  
- `$st animation step`

[www.openscad.org/cheatsheet/index.htm](http://www.openscad.org/cheatsheet/index.htm)
Demo: Robot Arm Gripper

(derived from Thingiverse: 65081)
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1.5 Model Repair

2. Model Slicing

2.5 G-code Verification

3. Print!

...and iterate!

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What can you 3D-print?

Replacement Parts
(Rucksack Buckle,
Thingiverse: 68488)

Mounts & Cases
(Handheld Kinect Grip,
Thingiverse: 18125)

Instruments
(Banjo Ukelele,
Thingiverse: 113908)

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What else can you 3D-print?

- Robots & Prosthetics
  (Talon Hand 2.0, Thingiverse: 229620)

- Clothing
  (Nylon Fibonacci Gown, Shapeways)

- ... and Weapons 😎
  (Liberator Handgun, Wikipedia)

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3D Printer Fundamentals

- Printing technologies
- Print materials
- Mechanical components
- Electronics

(Rostock Max Delta Printer)

(MBE Extruder v9 Dual)

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(Rostock Max Delta Printer)

(MBE Extruder v9 Dual)

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Fundamentals: Printing Technologies

- **Fused deposition modeling (FDM™) / Fused Filament Fabrication (FFF)**
  - Material extrusion (plastic, clay, chocolate, cake batter, ...)

- **Stereolithography (SLA)**
  - Light polymerization

- **Selective laser sintering (SLS)**
  - Sintering/melting/caramelization

Prusa i3 (RepRap Project)

Choc Creator

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Fundamentals: Print Materials

- The most popular 2 thermoplastics

<table>
<thead>
<tr>
<th></th>
<th>Polyactic Acid (PLA)</th>
<th>Acrylonitrile Butadiene Styrene (ABS)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sample Items</strong></td>
<td>One-time-use cups, plastic food containers</td>
<td>LEGO bricks, (naturally) white pipes</td>
</tr>
<tr>
<td><strong>Benefits</strong></td>
<td>Biodegradable</td>
<td>Strong(er)</td>
</tr>
<tr>
<td><strong>Extrusion Temperature</strong></td>
<td>180°-230°</td>
<td>230°-280°</td>
</tr>
<tr>
<td><strong>Ideal Adhesion Surface</strong></td>
<td>Painter’s tape @ 70°</td>
<td>Kapton @ 120°</td>
</tr>
</tbody>
</table>

  - My takeaways: PLA emit *some* nanoparticles (1-2x vs. background) but are *biodegradable*; ABS emit *a lot* more nanoparticles (2-10x vs. background)

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Fundamentals: More Materials

- Glow-in-the-dark PLA & ABS
- Nylon (Taulman 618/645, etc.)
- Wood (WoodFill, Laywoo-D3, etc.)
- PET (Taulman T-GLASE, etc.)
- Flexible (FlexPLA, FilaFlex, BendLay, etc.)
- Dissolvable Support (PVA, etc.)

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Fundamentals: Mech. Components

- Actuation structure
  - Cartesian gantry (XY/Z, XZ/Y, ...)
  - Polar gantry
  - Delta gantry
  - Robot arm (SCARA, ...)

- Print platform
  - Heated bed
  - Glass surface

- Hot-End nozzle

Prusa i2 (RepRap Project)
Fundamentals: Electric/-tronics

- Control unit
  - Arduino Mega + RAMPS shield
  - Custom ATmega boards

- Temperature sensors
  - For hot-end (end heated bed)

- DC stepper motors

- End-stops
3D Printing Problems & Limitations

- Contaminated plastic / jammed nozzle
- Corner warp / lift (due to low-temp bed adhesion)
- Hot-end breakdown (melting, jam, leak, ...)

- Limitations of FFF 3D prints
  - Difficult to polish
  - Minimal clearance from extrusion width
  - Support often required for bridges & suspensions

Success in (hobbyist) 3D printing requires a bit of persistence and a lot of experience!

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Free 3D Modeling/Design Tools

- OpenSCAD (openscad.org / openscad.net)
- TinkerCAD (tinkercad.com)
- Trimble SketchUp (sketchup.com)
- 123D Design, Catch, Meshmixer (www.123dapp.com)
- Blender (blender.org)
3D Model Databases

- Thingiverse (www.thingiverse.com)
- The Free 3D Models (tf3dm.com)
- Archive 3D (archive3d.net)
- GrabCAD (grabcad.com/library)
- Shapeways 3D Parts Database (www.shapeways.com/themes/3dparts)
- Trimble 3D Warehouse (sketchup.google.com/3dwarehouse)

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3D Printing Tools

- Slicing & Visualization
  - Slic3r (slic3r.org)
  - Tatlin (github.com/dkobozev/tatlin)
  - Gcode.ws

- Unified printer interfaces
  - Printrun (github.com/kliment/Printrun)
  - Repetier (repetier.com)
  - OctoPrint (octoprint.org)
  - ReplicatorG (replicat.org)

- Controller firmwares
  - Marlin (github.com/ErikZalm/Marlin)
  - Repetier-Firmware (repetier.com)

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3D Printing Resources

- IEEE McGill McNaughton center

- Professional 3D Printing Service
  - Shapeways.com

- Building your own FFF 3D printer
  - Voxel Factory: Montreal 3D Printer Build Workshop (~$1100 CAD)
  - dx.com/p/238922: Economical Prusa i2 kit (~$600 CAD)

- Buying an assembled FFF 3D printer
  - Ultimaker 2 (~$3000 CAD)
  - MakerBot Replicator 2 (~$2300 CAD)

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3D Printing Communities

- RepRap Forums (forums.reprap.org)
- RepRap Montreal Builders Mailing List (reprap@kohd.ca)
- 3D printer and 3D printing news site (3ders.org)
- Maker Faire (www.makerfaire.com)
- International Conference on Additive Manufacturing and 3D printing (www.am-conference.com)

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