Algorithms for 3D Printing and Other Manufacturing Methodologies

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Ultimaker 3 & Cura
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Outline

1. Cura
   - Additive Manufacturing
   - Ultimaker 3
   - Cura
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   - Ultimaker 3
   - Cura
Additive Manufacturing

- *Additive Manufacturing* (AM) is the official term for 3D-printing.
- *3D printing* is the fabrication of objects through the deposition of some material under computer control. The deposition forms successive layers using one of several technologies.

- A large number of different AM processes exist.
  - The deposition technique differentiates between the different types.
- 1,000 different 3D printer models are available on the market today.
Additive Manufacturing Main Types

- Material Deposition Processes
  - Cold Spray
  - Blown Powder
  - Exrusion
  - Laser Melting
  - Laser Sinter
  - Binder Jet
  - Other Materials that melt and harden
- Powder Bed Processes
  - Metal spray
  - Other Materials that are in powder form
- Liquid Bed Processes
  - Electron Beam Melting
  - Stereolithography
  - Non-Ferrous Alloys
  - Thermosetting Resin

- Additive Manufacturing
  - Metals
  - Thermoplastic
  - Elastomers
  - Graphite
  - Ceramics
  - Other
Additive Manufacturing Main Types

**Additive Manufacturing**

- **Material Deposition Processes**
  - Cold Spray
  - Blown Powder
  - Extrusion
    - Thermoplastic
      - Elastomers
      - Graphite
      - Metals
      - Other
    - Materials that melt and harden
  - Laser Melting
    - Metals
  - Laser Sinter
  - Binder Jet
    - Non-Ferrous Alloys
  - Electron Beam Melting
  - Stereolithography
    - Thermo-setting Resin

- **Powder Bed Processes**
  - Laser Sinter
  - Binder Jet
  - Electron Beam Melting
  - Stereolithography

- **Liquid Bed Processes**
  - Electron Beam Melting
  - Stereolithography

**Materials**
- Metals
- Thermoplastics
- Elastomers
- Graphite
- Ceramics
- Other
- Materials that are in powder form
Fused Filament Fabrication (Fused Deposition Modeling)

- Fused Filament Fabrication (FFF) is the most popular additive manufacturing (AM) process by number of machines.
- The term Fused Deposition Modeling™ and its abbreviation FDM™ are trademarks of Stratasys Ltd.
- FFF is equivalent to FDM and is used by the rest of the world.
- The machine may dispense multiple materials, either
  - multiple colored thermoplastic materials to build the object, or
  - one thermoplastic material and another soluble support material.

- The object is produced by extruding small flattened strings of molten material to form layers.
- The material hardens immediately after it is extruded from the nozzle.
# Fused Filament Fabrication Types

<table>
<thead>
<tr>
<th>Type</th>
<th>Machine</th>
<th>Head Type</th>
<th>Additional Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>BigRep, Large</td>
<td>BigRep</td>
<td>Cartesian XZ-head</td>
<td></td>
</tr>
<tr>
<td>Baam, Huge</td>
<td>Baam</td>
<td>Cartesian Z-head</td>
<td></td>
</tr>
<tr>
<td>Prusa, Felix</td>
<td>Prusa</td>
<td>Cartesian X-head</td>
<td></td>
</tr>
<tr>
<td>Ultimaker, 3D Printers</td>
<td>Ultimaker</td>
<td>Cartesian XY-head, XYZ-head, mobile</td>
<td>Bowden extruder</td>
</tr>
<tr>
<td>Go</td>
<td>Go</td>
<td>Cartesian XYZ-head, mobile</td>
<td></td>
</tr>
<tr>
<td>Kossel, Polar 3D</td>
<td>Kossel</td>
<td>Delta technique</td>
<td></td>
</tr>
<tr>
<td>Morgan</td>
<td>Morgan</td>
<td>Scara</td>
<td>1</td>
</tr>
</tbody>
</table>

1. Selective Compliance Assembly Robotic Arm
### Fused Filament Fabrication Types, more

<table>
<thead>
<tr>
<th>Controlling all 6 degrees of freedom of the nozzle, Sextuperon</th>
<th>A curved house by Contour Crafting, a computerized construction company</th>
<th>Lunar settlement of space colonies, simulation by NASA</th>
<th>Printing 3-dimensional curves instead of layers by Mataerial.</th>
</tr>
</thead>
</table>

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*Algorithms for 3D Printing and Other Manufacturing Methodologies*
Bioprinting

- Artificially construct living tissue, printing layers of living cells.

Bioprinters print replacements of human organs
Outline

1 Cura
   ● Additive Manufacturing
   ● Ultimaker 3
   ● Cura
Ultimaker 3 printers are designed and built for FFF.
# Ultimaker 3 Specification

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dimensions</strong></td>
<td></td>
</tr>
<tr>
<td>Net</td>
<td>342 x 380 x 389</td>
</tr>
<tr>
<td>Gross</td>
<td>342 x 505 x 588</td>
</tr>
<tr>
<td><strong>Build Volume</strong></td>
<td></td>
</tr>
<tr>
<td>Single extrusion</td>
<td>215 x 215 x 200</td>
</tr>
<tr>
<td>Dual extrusion</td>
<td>197 x 215 x 200</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>10.6 kg</td>
</tr>
</tbody>
</table>
### Ultimaker 3 Specification, cont.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Layer resolution</strong></td>
<td>20–200 µm</td>
<td>The thickness of a 3D printed layer. Thin layers are used for high detailed prints, thick layers are used to high speed printing.</td>
</tr>
<tr>
<td><strong>Build plate temperature</strong></td>
<td>20°–100°</td>
<td>Affects the selection of printing materials.</td>
</tr>
<tr>
<td><strong>Build speed</strong></td>
<td>≤ 16 mm³/secs</td>
<td>The filament extrusion speed, which affects the printing speed. ²</td>
</tr>
<tr>
<td><strong>Print head travel speed</strong></td>
<td>30–300 mm/secs</td>
<td>The speed of the printer head. ²</td>
</tr>
<tr>
<td><strong>XYZ accuracy</strong></td>
<td>12.5, 12.5, 2.5 µm</td>
<td>The accuracy of the stepper motors, which determines the accuracy of the print.</td>
</tr>
<tr>
<td><strong>Nozzle diameter</strong></td>
<td>0.4 mm</td>
<td>Affects the printing speed,² accuracy, grabbing to the print bed, and sticking to the layer underneath, which affects the support requirements.</td>
</tr>
<tr>
<td><strong>Nozzle temperature</strong></td>
<td>180°–280°</td>
<td>Affects the selection of printing materials.</td>
</tr>
<tr>
<td><strong>Nozzle heat up time</strong></td>
<td>&lt; 2 min</td>
<td>Affects the overhead time it takes to start printing and melting the material.</td>
</tr>
<tr>
<td><strong>Build plate heat up time</strong></td>
<td>&lt; 4 min</td>
<td>Affects the time it takes to start printing.</td>
</tr>
<tr>
<td><strong>Operating sound</strong></td>
<td>50 dBA</td>
<td>Suitable for use in quite environments.</td>
</tr>
</tbody>
</table>

² High printing speed decreases the risk that the process will fail at a late stage, wasting material and time.
Ultimaker 3 Head

Dual extrusion: Enables the combination of (i) build and support materials, or (ii) two build materials of different colors.

Swappable print cores: Enables easy and quick replacement of print cores.

The Ultimaker 3 comes with two print cores, namely, AA and BB, with different inner nozzle geometries customized for build material and water-soluble support material, respectively.
Ultimaker 3 Build Plate

Refined design: The Ultimaker 3 features a light & stiff build plate, which reduces vibrations, and a removable glass plate, which allows easy cleaning.

Heated glass build plate: Increases the range of usable printing material.

Active leveling: Build-plate calibration is done automatically.
  - The capacitive sensor in the print head measures distances between the print bed and the nozzles.
  - The tilt angle is compensated by adjusting the z-height in the first layers.
Ultimaker 3 Materials

Various Materials can be used by the Ultimaker 2 printer.

- **Nylon** (polyamide) has high strength-to-weight ratio, low-friction and is flexible.
- **PLA** (polylactic acid) is reliable, offers good surface quality, and is made from organic, renewable sources.
- **ABS** (acrylonitrile butadiene styrene) has good mechanical properties, e.g., it can withstand temperatures of up to 85°.
- **CPE** (co-polyester) is chemical and temperature resistant, with dimensional stability.
- **PVA** is a water soluble support material.

**Material recognition with NFC scanner:** Detects and identifies the material on the spool holder and checks the correspondence of a filament and print core type being used.
Ultimaker 3 Additional Features

**Optimized Cooling:** Ultimaker 3 has a low-noise fan system featuring two radial fans and fan shrouds; it builds up pressure for an improved airflow. This ensures better cooling, high quality bridging, faster print runs and smooth print surfaces.

**LED status indicators:** Alerts when a user interaction is needed.

**EEPROM print core chip:** The chip memorizes the size and type of the nozzle, notifies the user in case of misuse.

- USB port
- Wi-Fi, LAN
- Live camera
Ultimaker 3 Software

**Ultimaker 3 application:** The user of the application can start and monitor the printing process. Together with the integrated camera the user can check the progress and inspect the intermediate print.

**Cura** Prepares your model for 3D printing.
Outline

1 Cura
   - Additive Manufacturing
   - Ultimaker 3
   - Cura
Cura

- **Cura** is slicing software for 3D printers.
  - It accepts a digital 3D model, typically in the STL format, as input.
  - It computes the toolpath that the printhead(s) need to take to print the model.
  - It emits the instructions to the printer, in the **Gcode** format, to a file.

```
G0 F7200 X19.698 Y28.262 Z.36
G1 F1500 E0
G1 F1350 X22.467 Y26.175 E0.15654
G1 X23.338 Y25.568 E0.20447
G1 X24.246 Y25.027 E0.25218
```

- **Cura** is maintained by **Ultimaker Ltd.**
- **Cura** is well suited for Bowden-extruder machines,
  - e.g., RepRap, Ultimaker and most Delta-bots.
Where Do Models Come From?

- The Internet
  - A matrix of sources of printable models can be found here.
  - Thingiverse
  - Youmagine
  - GrabCAD

- The product of a modeler running 3D-modeling software
  - A list of 3D modeling software can be found here
  - A collection of useful software can be found here.
  - Tinkercad—freeware, cloud
  - Sketchup—freemium

- The output of a 3D-reconstruction process
Cura Software

- **Cura** is Open Source software released under the AGPLv3 license.
- **Cura** is made of two parts:
  - The GUI, written in Python, is based on the Uranium framework.
    - A Python framework for building 3D printing related applications.
  - The slicing engine, namely **CuraEngine**, is written in C++.
- There are additional optional parts and plugins,
  - e.g., **OrientationPlugin**—a wrapper around **Tweaker**, a Python module that finds the optimal printing orientation of a 3D model.
- **Cura** is a multiplatform app. for **Linux**, **Mac**, and **Windows**.
- **Cura 2.3.1** is now available.
Cura Features (Version 2.3)

- There are two operational modes:
  - basic offers few settings, good for novice users.
  - advanced offers all settings, good for experienced users.
- Handles various profiles
  - Maintains a set of predefined profiles
  - Automatically adjusts the settings for each material and print core
- Accepts files in the STL, 3MF, and OBJ file formats
- Supports dual extrusion printing
- Supports various infill types

- Provides time and weight estimation
- Supports wireless printing
- Enables live monitoring
Cura Simple Mode

1. Profile selection
2. Simple mode settings
Cura Interface

1. Open file
2. Toolbar: move, scale, rotate, mirror & per-object settings
3. View modes: solid, X-ray & layers
4. Brim/skirt margin
5. 3D model
6. Profile settings
7. Printer selection
8. Print core & material selection
9. Simple/advanced mode
10. Save GCODE
11. Progress bar
12. Estimated print time & cost
13. 3D-model dimensions
14. Print-job name
Cura Model Viewing

1. X-ray view mode
2. View mode
3. 3D viewer
4. Error in model

1. Layers view mode
2. View mode
3. Model preview
4. Layer slider
5. Layer number
Cura Custom Mode

**Machine**  Machine related settings.

**Quality**  Settings that define the (visual) quality of the print.

  - **Shell**  Settings related to the outside of the print.
  - **Infill**  All settings that have to do with the inside of the print.

**Material**  Material related settings.

  - **Speed**  Speeds at which the print head moves while printing.
  - **Travel**  How the print head behaves during travel moves.
  - **Cooling**  Settings that define how the plastic is cooled.
  - **Support**  Options for printing with support structures.

**Platform adhesion**  Defines the adhesion of your model to the build plate.

  - **Mesh fixes**  Options for fixing faults in models.

**Special modes**  Features that influence the way of printing.

**Experimental**  Experimental new features.
Cura Quality

- **Layer height**
  - The thickness of one printed layer.
  - Acceptable values must be in [0.06–0.20mm].
  - Thinner layer height increases the quality.
  - Thicker layer height decreases printing time.
  - Options:
    - ★ First layer height.
    - ★ All other layers.

- **Line width**
  - The width of a single printed line.
  - Affects the extrusion rate.
  - Options:
    - ★ Wall line width
    - ★ Top/bottom line width
    - ★ Infill line width
    - ★ Skirt line width
    - ★ Support line width
    - ★ Support interface line width
    - ★ Prime tower line width
Cura Support

Enable Support

Placement options:
- Touching build plate
- Everywhere

Overhang angle the maximum angle of overhangs for which support material is added.

Support pattern

- Concentric
- Grid
- Lines
- Triangle
- Zig Zag

Connect zig zags

Support density
Cura Platform Adhesion

**Skirt** A line printed around the object on the first layer.
- It is not connected to the model.
- It helps priming the extrusion.

**Brim** A flat area around the base of the model on the first layer.
- It is connected to the model.
- It prevents warping.
- It may enlarge the bounding box.

**Raft** Several sparse layers between the model and the build plate.
- Useful when the bottom surface of a model is not flat, or
- the contact area with the build plate is small.

Visualization of the raft settings

The printed raft