Algorithms for 3D Printing and Other Manufacturing Methodologies

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Gcode
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Outline

1. Gcode
   - Introduction
   - Specification
Outline

1 Gcode
   • Introduction
   • Specification
Introduction

- **Gcode** is common for *numerical control programming language*.
- **Gcode** is mainly used to control automated machine-tools.
- Computerized machine-tools are instructed how to make something using **Gcode**.
- The "how" is defined by instructions on
  - where to move,
  - how fast to move,
  - and what path to follow.
- A cutting tool is moved according to **Gcode** instructions through a toolpath and cuts away material to leave only the finished workpiece.
- The same concept extends to non-cutting tools such as
  - forming or burnishing tools,
  - photoplotting,
  - additive methods such as 3D printing, and
  - measuring instruments.
CNC Tool Chain

**Design**
- CAD Software
  - AutoCAD
  - SOLIDWORKS
  - SketchUp
  - Tinkercad

**Process**
- CAM Software
  - Cura
  - Integrated CAM Software
  - CamBam
  - MakerCam
  - MasterCam

**Send**
- Communication
  - gcode data

**Make**
- CNC Machine
  - Firmware
    - RepRap
    - Marlin
    - grbl
    - Teacup

**Files**
- .stl
- .obj
- .dxf
- .svg
- .gcode data

**Computer**
- .gcode
Implementations

- Automatically Programmed Tool (APT) was the 1st numerical control programming language; it appeared at MIT in 1950.
- Many variants exist nowadays.
- Several standards are used by different CNC machine manufactures,
  - e.g., EIA\(^1\) RS-274-D, ISO\(^2\) 6983, and DIN\(^3\) 66025.
- Nowadays GCODE supports variables and constructs,
  - e.g., conditional operators and loops
- Some CAM applications nowadays either hide or bypass GCODE.
- A GCODE program is written for a specific machine.
  - It has a certain layout, and
  - it uses a specific instruction set.

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\(^1\) EIA stands for “Electronic Industries Alliance”.
\(^2\) ISO stands for “International Organization for Standardization”.
\(^3\) DIN stands for text that translates to “German institute for standardization”. 
Firmware

- Firmware is a type of software held in non-volatile memory of devices, e.g., embedded systems, computers, computer peripherals, mobile phones, digital cameras, and CNC machines.
- IBM prefers the term microcode.
- It provides low-level control; it monitors and manipulate data.
- Most firmware can be updated.
- Typically, firmware that resides on a CNC machine interprets GCODE, e.g., RepRap, Marlin, grbl, Teacup, MakerBot, and MK4duo.
Marlin is firmware for RepRap\textsuperscript{4} single-processor electronics. Marlin supports Arduino-based 3D printers, e.g., RAMPS, RAMBo, Ultimaker, and BQ. Marlin is licensed under the GNU GPL v3 or later. The Marlin Project is hosted on GitHub, current version is 1.0.2. Marlin, for example, can print arcs, which results in a nice finish. The firmware can choose the resolution. The firmware can perform the arc with nearly constant velocity. Less serial communication is needed.

\textsuperscript{4}RepRap is a free desktop 3D printer prototype capable of printing plastic objects.
The UltiGCode Firmware

- The Ultimaker printers use the UltiGCode Firmware.
- The original Ultimaker used the Marlin firmware.

<table>
<thead>
<tr>
<th>Ultimaker</th>
<th>Original(+)</th>
<th>2(Go/Extended)</th>
<th>2+(Extended)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gcodeflavor</td>
<td>Marlin</td>
<td>UltiGCode</td>
<td>UltiGCode</td>
</tr>
<tr>
<td>Start/End-Gcode</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Nozzle Temperature</td>
<td>Cura: start-GCODE</td>
<td>Machine</td>
<td>Machine</td>
</tr>
<tr>
<td>Heated Bed Temperature</td>
<td>Cura: start-GCODE</td>
<td>Machine</td>
<td>Machine</td>
</tr>
<tr>
<td>Diameter</td>
<td>Cura: start-GCODE</td>
<td>Machine</td>
<td>Machine</td>
</tr>
<tr>
<td>Fan</td>
<td>GCODE</td>
<td>GCODE, Machine</td>
<td>GCODE⁵</td>
</tr>
<tr>
<td>Flow</td>
<td>GCODE, Machine⁶</td>
<td>Machine</td>
<td>Machine</td>
</tr>
<tr>
<td>Retraction</td>
<td>GCODE</td>
<td>Machine</td>
<td>Machine</td>
</tr>
</tbody>
</table>

- A single GCODE program can be applied with different materials.

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⁵The fan speed has always been set from GCODE. However, Ultimaker 2 can modify this speed by a percentage. With Ultimaker 2+ this percentage is set to 100% for every material. The fan speed from GCODE is no longer affected by the machine setting.

⁶The flow is set in GCODE, but can be adjusted through the “tune” machine menu.
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Specifications

- The term **Gcode** comes from the literal sense of codes formed using the single letter 'G', e.g., G00.
- However, every letter of the English alphabet is used in the language.
- **Gcode** is established as the common name of the language.

<table>
<thead>
<tr>
<th>Letter</th>
<th>Description</th>
<th>Info</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Absolute or incremental position of A-axis(^7)</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Precision feedrate for threading on lathes</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Address for preparatory commands</td>
<td>Tells the control what kind of motion is wanted (e.g., rapid positioning, linear feed, circular feed, fixed cycle) or what offset value to use.</td>
</tr>
<tr>
<td>N</td>
<td>Line (block) number in program</td>
<td>Optional; often omitted; Necessary for certain tasks, such as 'goto' statements (if the control supports those).</td>
</tr>
<tr>
<td>M</td>
<td>Miscellaneous function</td>
<td>Action code, auxiliary command; descriptions vary. Many M-codes call for machine functions, which is why people often say that the &quot;M&quot; stands for &quot;machine&quot;, although it was not intended to.</td>
</tr>
<tr>
<td>X</td>
<td>Absolute or incremental position of X axis</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>Absolute or incremental position of Y axis</td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td>Absolute or incremental position of Z axis</td>
<td></td>
</tr>
</tbody>
</table>

\(^7\)The *A*-axis is the rotational axis around *X*-axis.
Format

- A program consists of blocks placed in separate lines.
- A block consists of one or more words.
- A word consists of
  - a letter that specifies the function to be performed followed by
  - a number that assigns value to the function.
- A comment begins at a semicolon, and ends at the end of the line.
- Special commands:
  1. **N**: line number
     Example: N123
     If present, the line number should be the first field in a line.
  2. *****: Checksum
     Example: *71
     If present, the checksum should be the last field in a line.

Either both or neither is allowed.

N3 T0*57 ; This is a comment
Preparatory

G0 Rapid linear Move
G1 Linear Move

- **Usage**

<table>
<thead>
<tr>
<th>Command</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>G0</td>
<td>Xnnn Ynnn Znnn Ennn Fnnn Snnn</td>
</tr>
<tr>
<td>G1</td>
<td>Xnnn Ynnn Znnn Ennn Fnnn Snnn</td>
</tr>
</tbody>
</table>

- **Parameters** Not all parameters need to be used, but at least one has to be used
  - Xnnn The position to move to on the X axis
  - Ynnn The position to move to on the Y axis
  - Znnn The position to move to on the Z axis
  - Ennn The amount to extrude between the starting and ending points
  - Fnnn The feedrate per minute of the move between the starting point and ending point (if supplied)
  - Snnn Flag to check if an endstop was hit (S1 to check, S0 to ignore, S2 see note, default is S0)
M107 turn fan off

M204 Set default acceleration: S normal moves, T filament only moves (M204 S3000 T7000) in mm/sec^2, also sets minimum segment time in ms (B20000) to prevent buffer underruns and M20 minimum feedrate

M205 Advanced settings: minimum travel speed S=while printing, T=travel only, B=minimum segment time X= maximum xy jerk, Z=maximum Z jerk, E=maximum E jerk
Example

T0
G92 E0
M109 S200
G0 F15000 X181 Y2.1 Z2
G280
G1 F1500 E−6.5
;LAYER_COUNT:168
;LAYER:0
M107
M204 S625
M205 X6
G1 Z4
G0 F4285.7 X84.728 Y98.161 Z2.27
M204 S500
M205 X5
;TYPE:SKIRT
G1 Z.27
G1 F1500 E0
G1 F1200 X89.56 Y94.831 E0.08693
G1 X93.876 Y91.478 E0.16789
G1 X98.009 Y87.873 E0.24913
G1 X101.924 Y84.049 E0.3302