

Algorithms for 3D Printing and Other Manufacturing Methodologies

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Gcode

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Outline

1 Gcode

- Introduction
- Specification



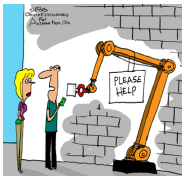
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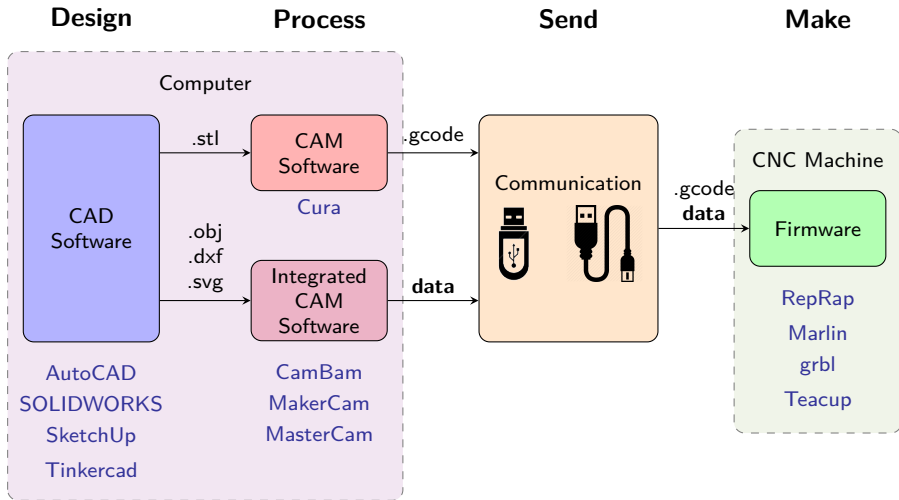
Introduction

- 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.



"Yesterday there was a homeless person here. I told you automation can replace anybody."

CNC Tool Chain



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., EIA¹ RS-274-D, ISO² 6983, and DIN³ 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.

¹EIA stands for “Electronic Industries Alliance”.

²ISO stands for “International Organization for Standardization”.

³DIN 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](#).



The Marlin Firmware

- Marlin is firmware for RepRap⁴ 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.

⁴RepRap 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.

Ultimaker	Original(+)	2(Go/Extended)	2+(Extended)
Gcodeflavor	Marlin	UltiGCode	UltiGCode
Start/End-Gcode	Yes	No	No
Nozzle Temperature	Cura: start-GCODE	Machine	Machine
Heated Bed Temperature	Cura: start-GCODE	Machine	Machine
Diameter	Cura: start-GCODE	Machine	Machine
Fan	GCODE	GCODE, Machine ⁵	GCODE ⁵
Flow	GCODE, Machine ⁶	Machine	Machine
Retraction	GCODE	Machine	Machine

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

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 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.

Letter	Description	Info
A	Absolute or incremental position of A-axis ⁷	
E	Precision feedrate for threading on lathes	
G	Address for preparatory commands	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.
N	Line (block) number in program	Optional; often omitted; Necessary for certain tasks, such as 'goto' statements (if the control supports those).
M	Miscellaneous function	Action code, auxiliary command; descriptions vary. Many M-codes call for machine functions, which is why people often say that the "M" stands for "machine", although it was not intended to.
X	Absolute or incremental position of X axis.	
Y	Absolute or incremental position of Y axis.	
Z	Absolute or incremental position of Z axis.	
:		
:		

⁷The 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

```
G0 Xnnn Ynnn Znnn Ennn Fnnn Snnn  
G1 Xnnn Ynnn Znnn Ennn Fnnn Snnn
```

- 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)



Miscellaneous

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
```

