A Roadmap Towards Parallel Printing for Desktop 3D Printers

SFF 2021

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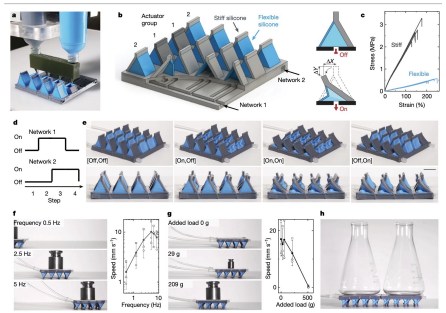
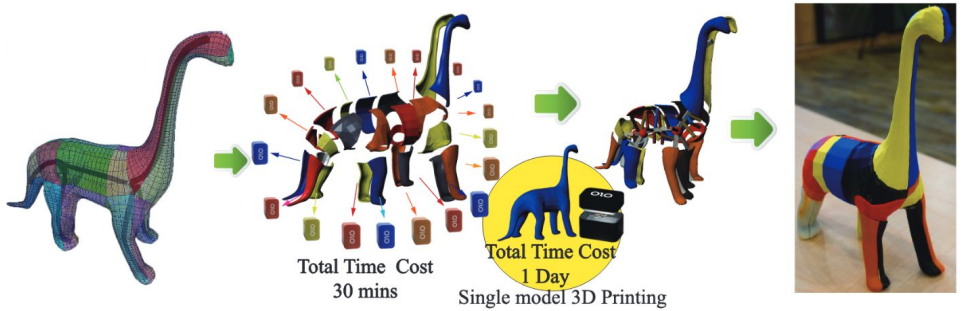
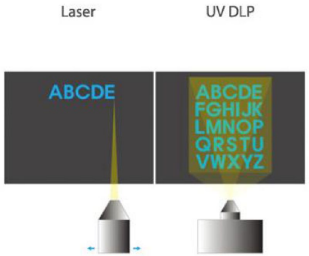
Existing Parallel 3D Printing



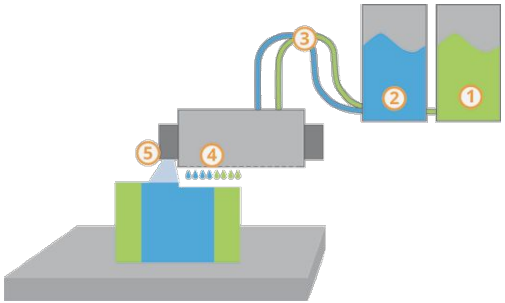
Lewis et al.



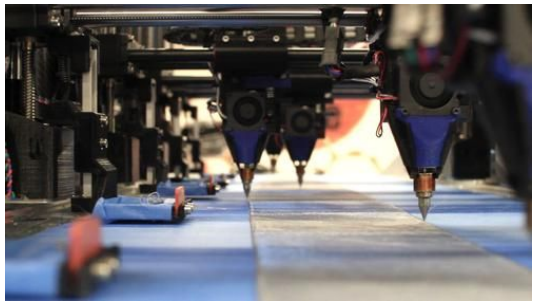
Chen et al.



DLP



Polyjet



Escher

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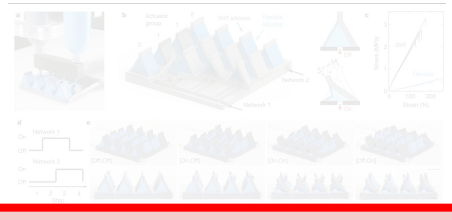


What about FDM Printers?

DLP

Polyjet

Escher

Parallel 3D Printing for FDM Printers

Parallel programming: multiple processes speed up compute times

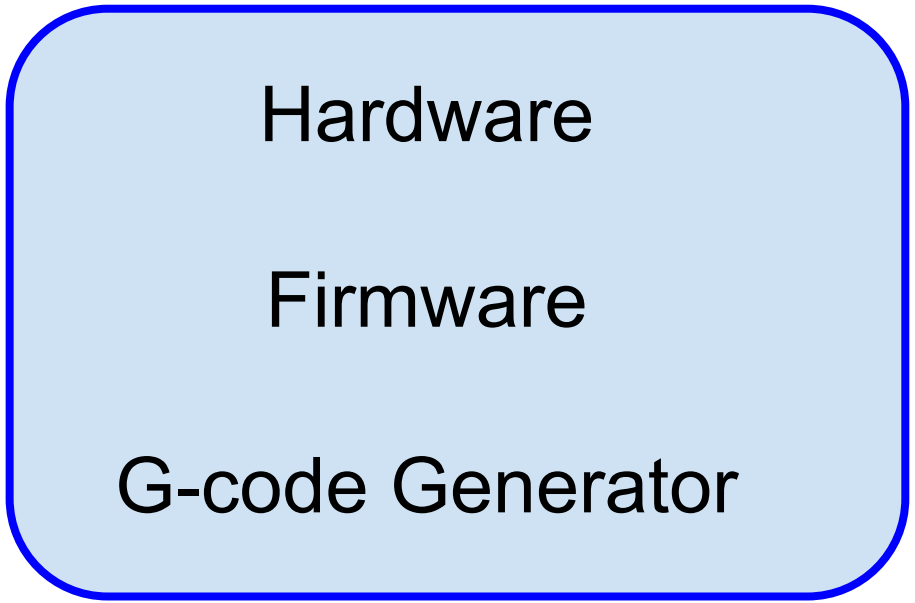
Can we use the extruders simultaneously to print faster by generating parallel toolpaths?

DLP

Polyjet

Escher

How to Repurpose Existing Tools for Parallel Printing



How to Repurpose Existing Tools for Parallel Printing

Each component affects the others

Hardware

Firmware

G-code Generator

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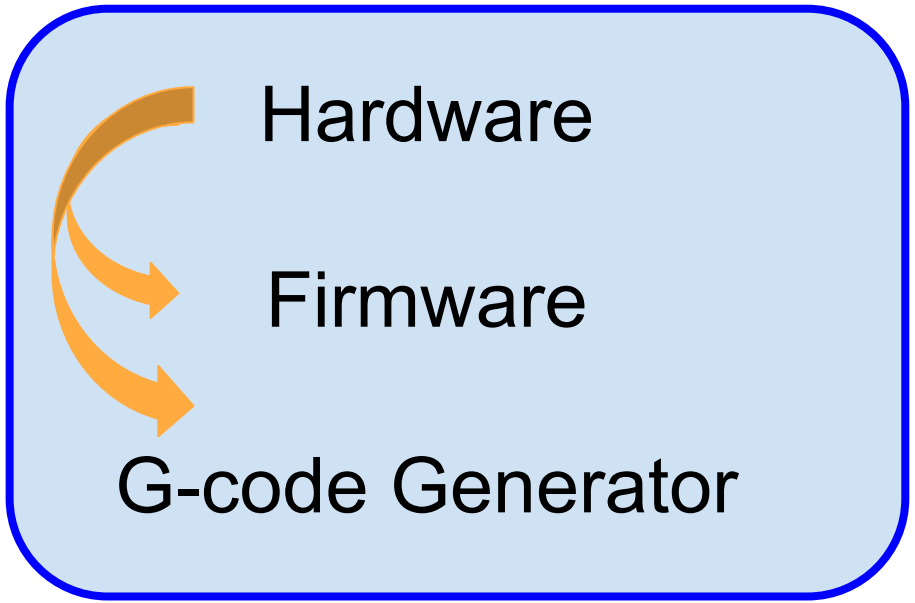
DOFs



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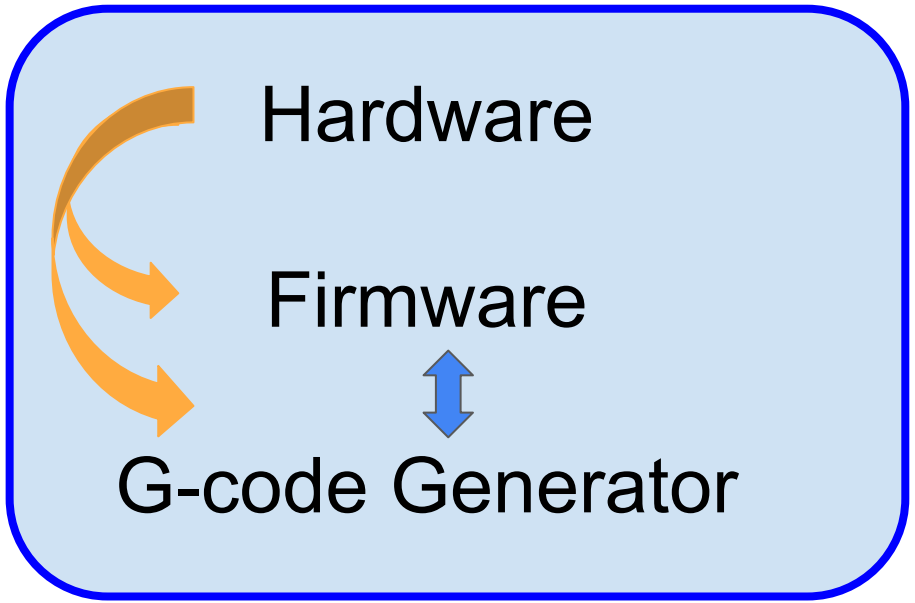
Instruction set and semantics



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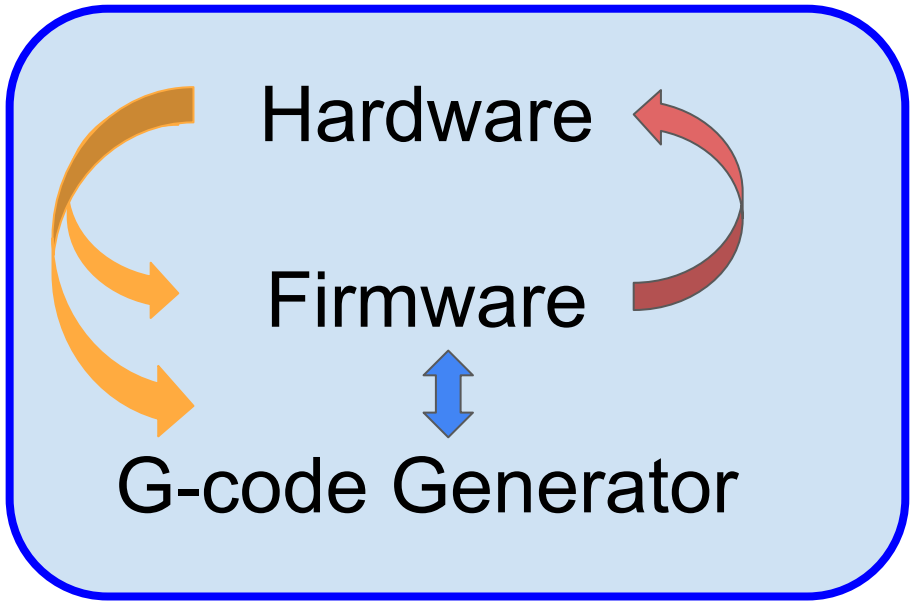

DOFs

Instruction set and semantics

Motor Controls

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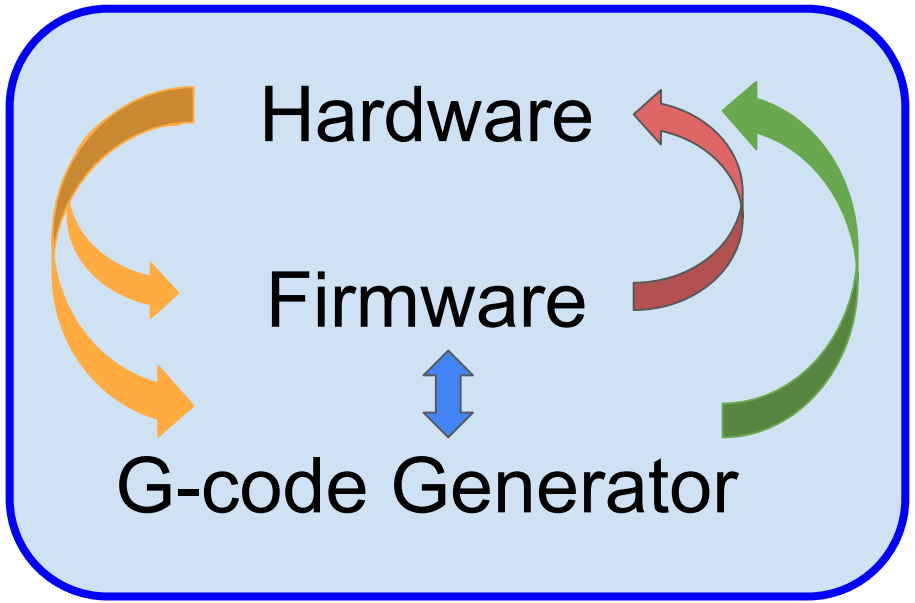

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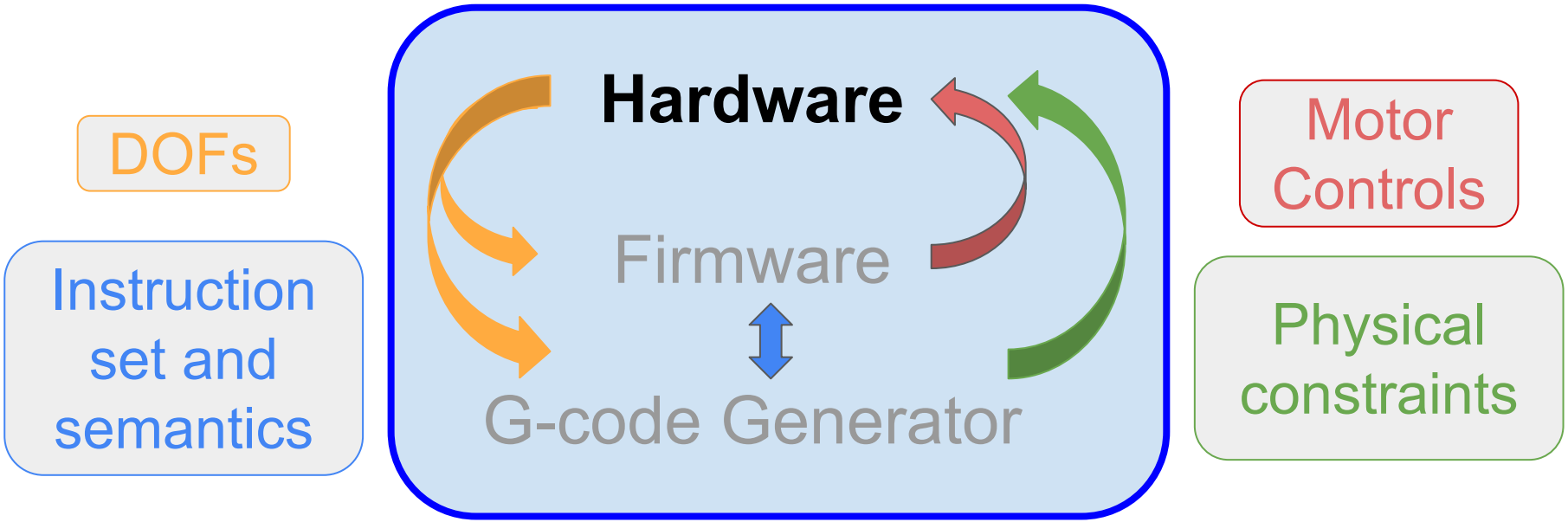
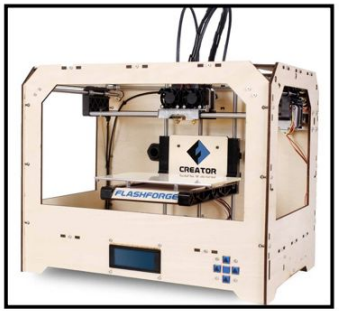
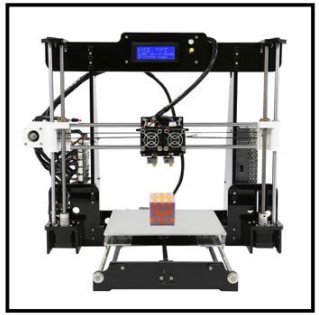
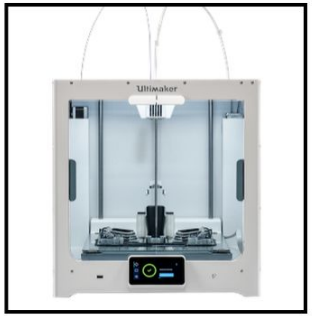


FDM 3D Printer Models



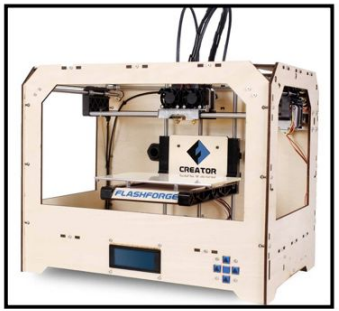



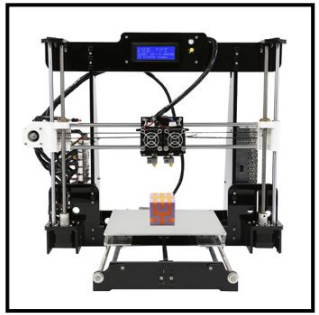
Many FDM 3D printers have multiple extruders!

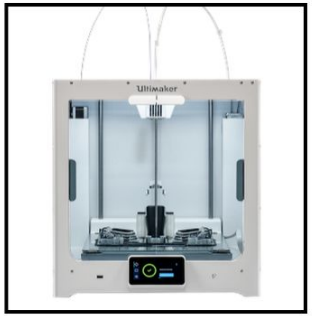
None use them simultaneously to print the same object

Main uses: ditto printing, multi-color printing, multi-material printing

FDM 3D Printer Models

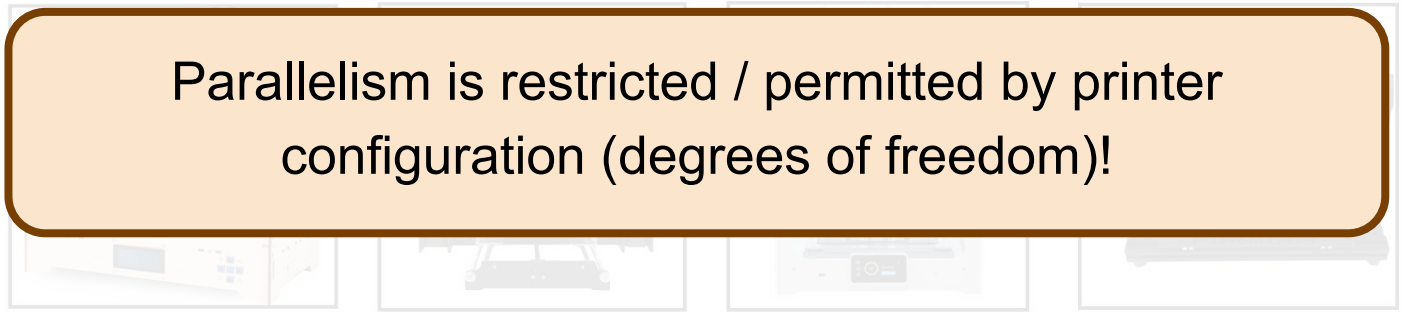






- N extruders moving in lockstep
- N extruders with a single independent axis
- N extruders with two independent axes
- N extruders with three independent axes

FDM 3D Printer Models



Parallelism is restricted / permitted by printer configuration (degrees of freedom)!

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FDM 3D Printer Models

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Fixed-width dual extrusion printers are the most common

Hardware Support for Parallel Printing

Affordable

Open-source

Ease of experimentation

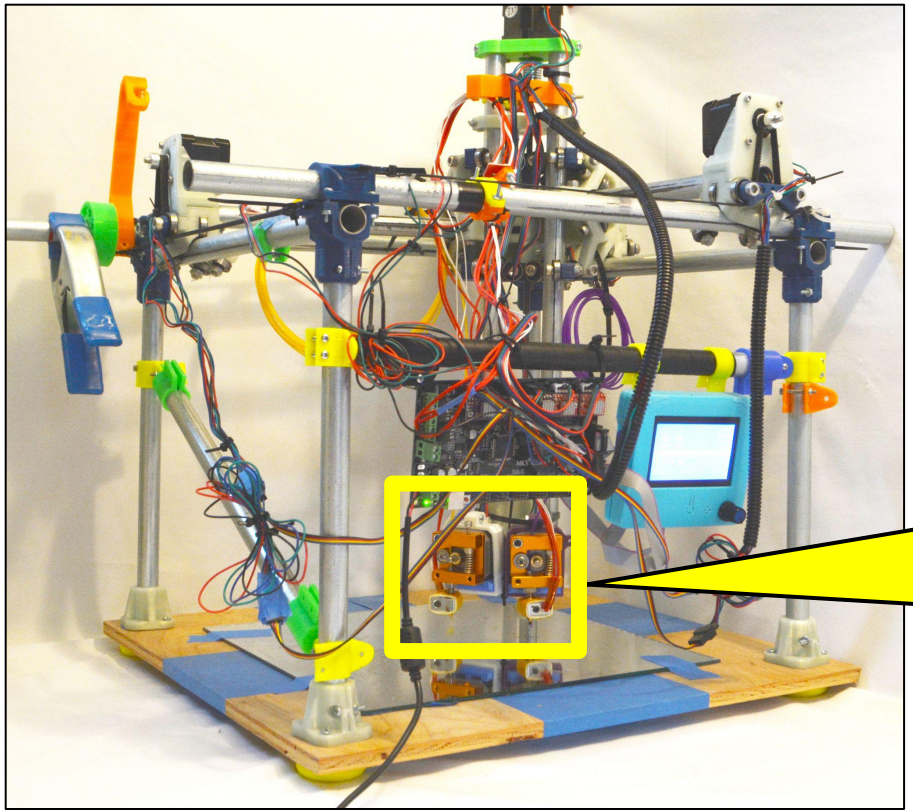
MPCNC 3D Printer

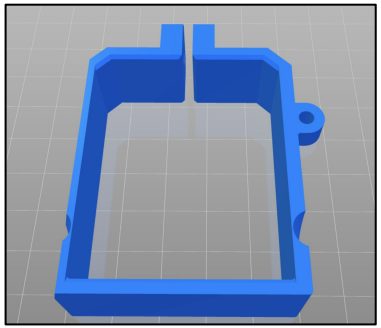
Cheap

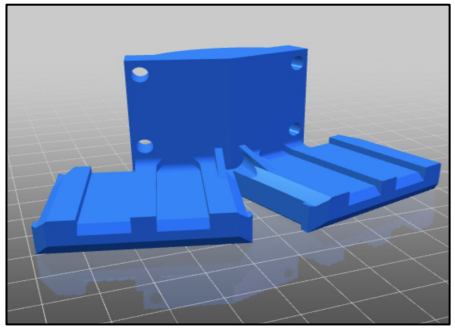
Online community

Reconfigurable

Experimental Hardware: Customized MPCNC 3D Printer







https://www.thingiverse.com/thing:4883743

70%, large print area frame

Fixed-width dual extrusion model

Custom dual extruder mount

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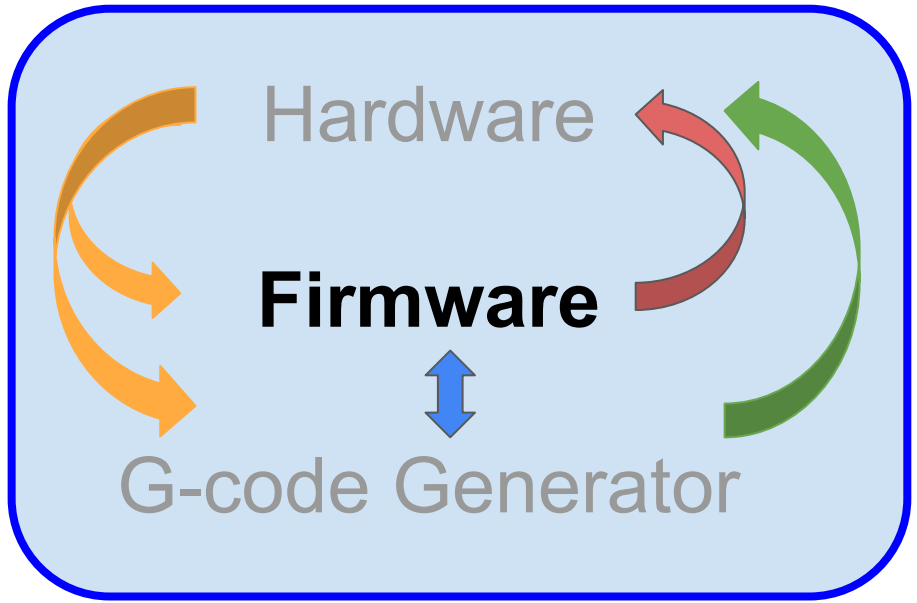

DOFs

Instruction set and semantics

Motor Controls

Physical constraints

Firmware: Interprets G-code

```
G1 X80.000 Y0.80 Z0.00 E2.40
```

Move motor to specified **`X, Y, Z`** coordinates while extruding the length of filament provided in the argument to **`E`**

Typically straight line code interpreted and executed sequentially

How to allow firmware packages to interpret parallel G-code?

Firmware Support for Parallel Printing

Language support

Extend interpreter

Ease of editability

Marlin firmware

- Use the M605 command
- Modify the interpreter
- Open-source codebase

Firmware Support for Simultaneous Extrusion

`M605 S2: Dual Nozzle Duplication Mode`

Enable both extruders even when inactive

`M605 S2` toggles extruder duplication

< 20 LOC

Firmware Support for Simultaneous Extrusion

```
; Part 1
T1 ; switch to extruder T1
G1 X40.00 Y0.80 Z0.00 E2.40 ; extrude with T1 up to (40.00, 0.80, 0.00)
; Part 2
M605 S2 ; turn on dual extrusion mode
G1 X80.000 Y0.80 Z0.00 E2.40 ; extrude with both up to (80.00, 0.80, 0.00)
M605 S2 ; turn off dual extrusion mode
; Part 3
T0 ; switch to extruder T0
G1 X120.00 Y0.80 Z0.00 E2.40 ; extrude with T0 up to (120.00, 0.80, 0.00)
```

Firmware Support for Simultaneous Extrusion

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; Part 1
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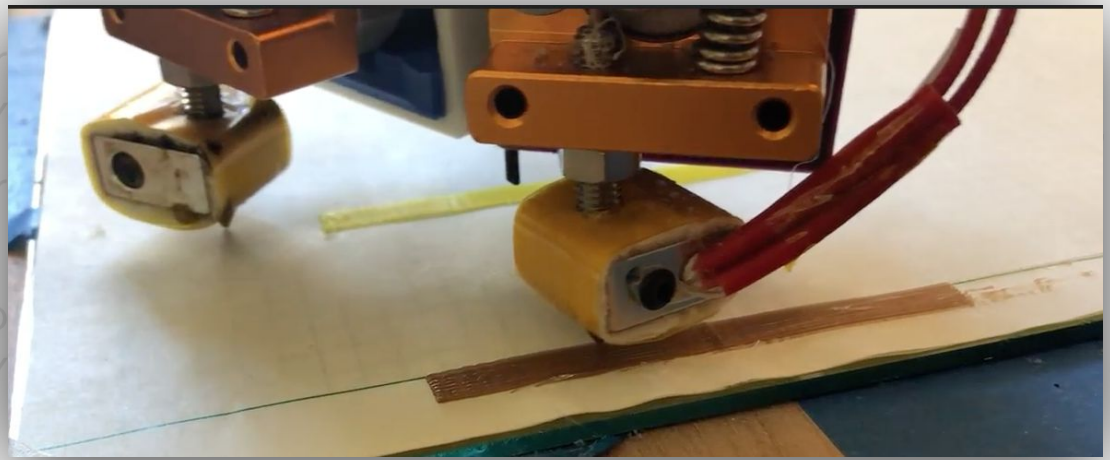

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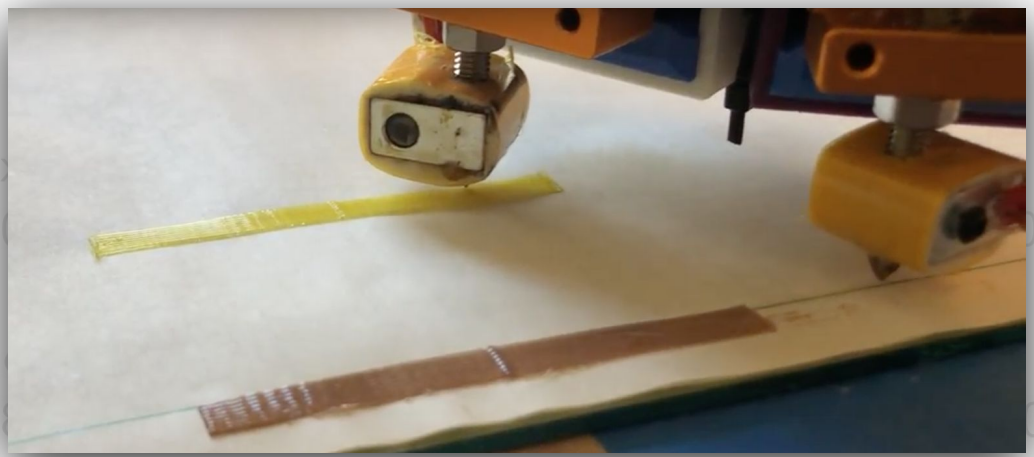

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; Part 3
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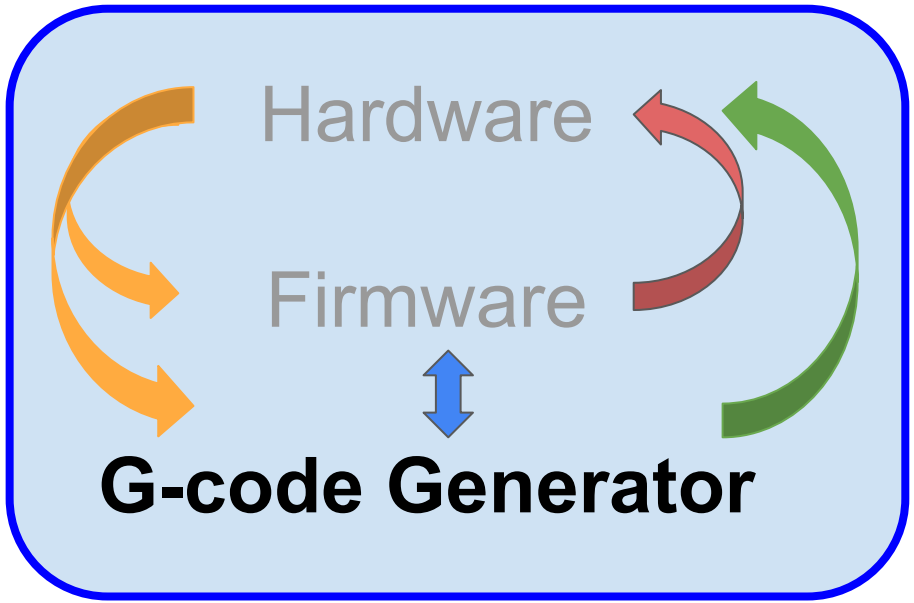

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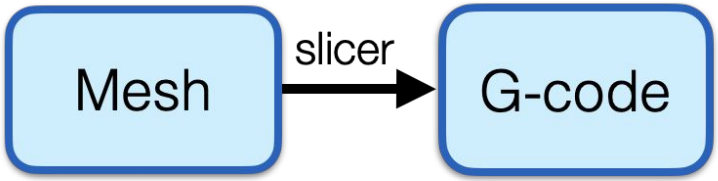

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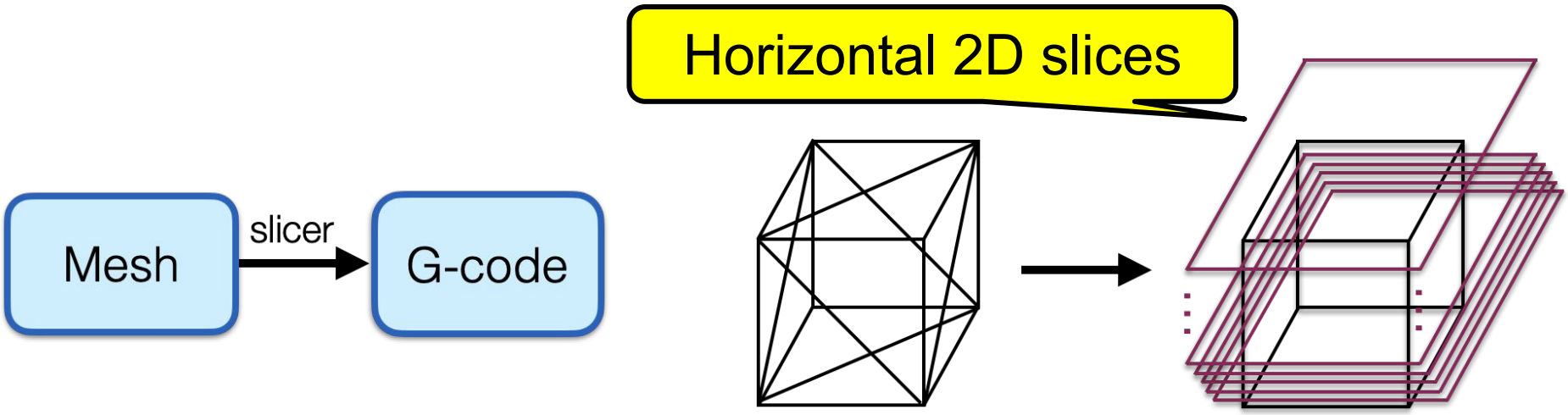

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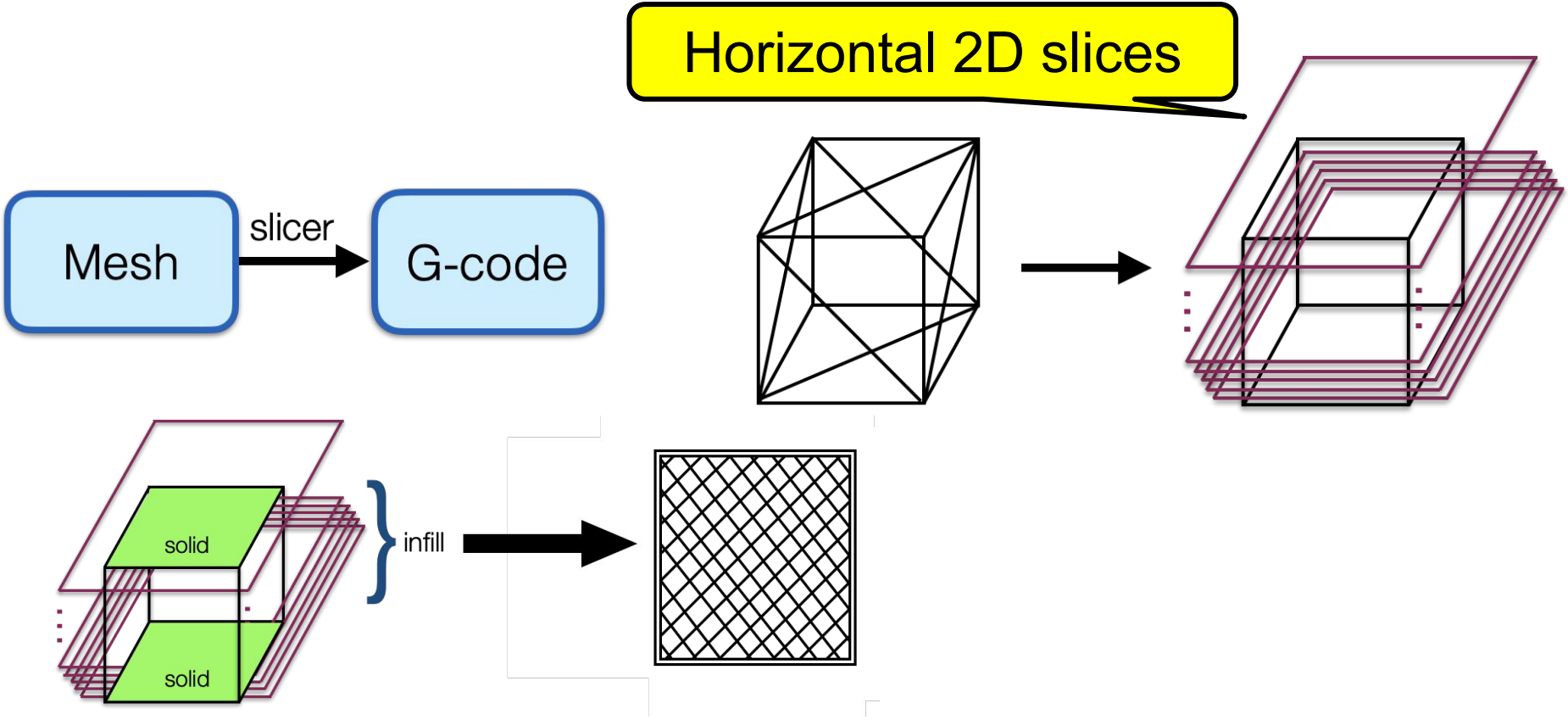

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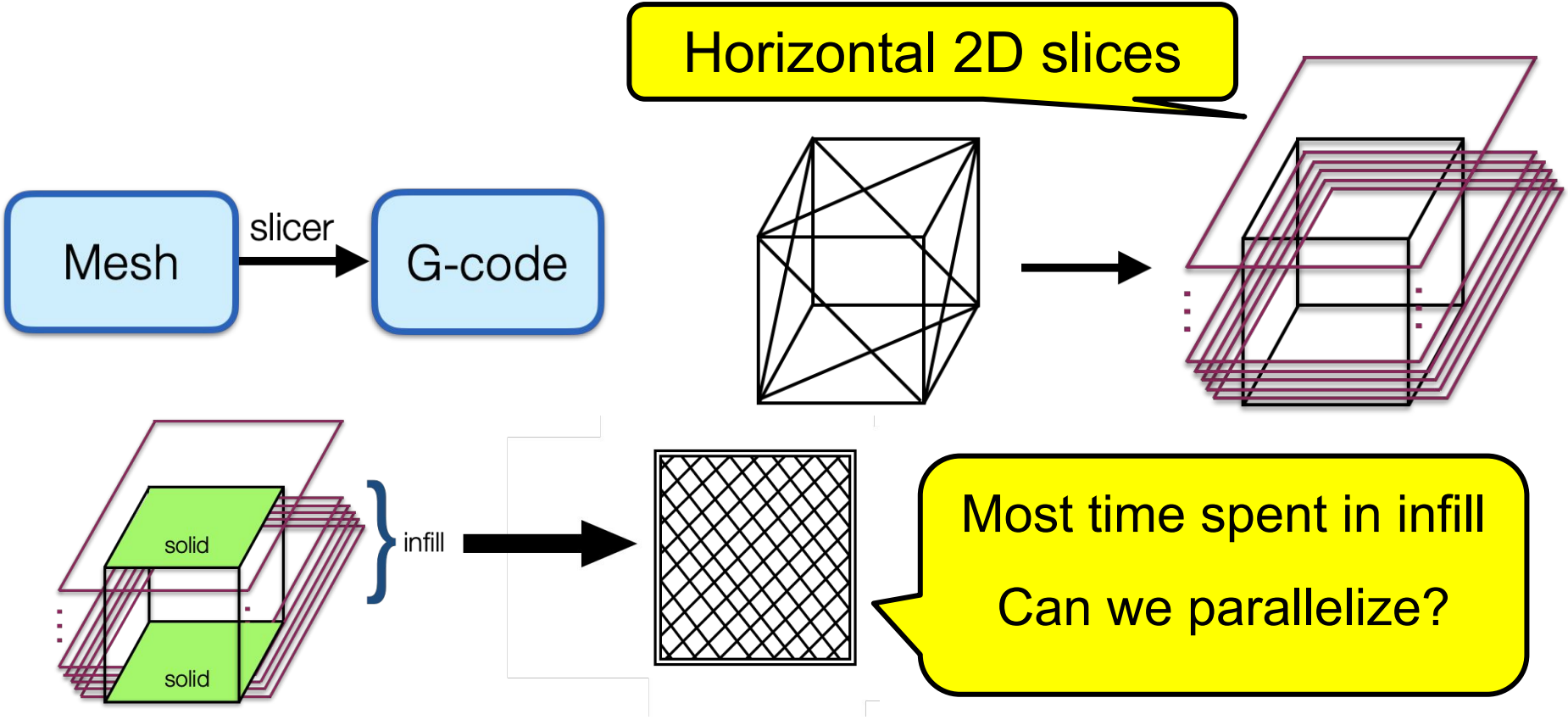


G-code Generation for Parallel Infill

Printer and design agnostic

Works on single model

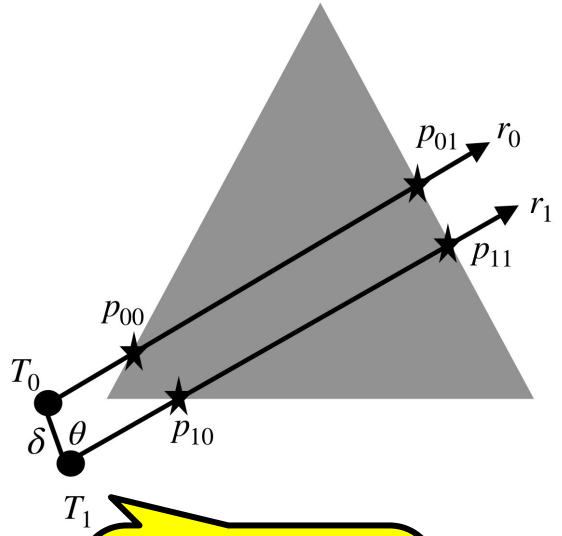
Simulate results

Early prototype parameterized by design

Parallelize infill on single model

Early simulator prototype

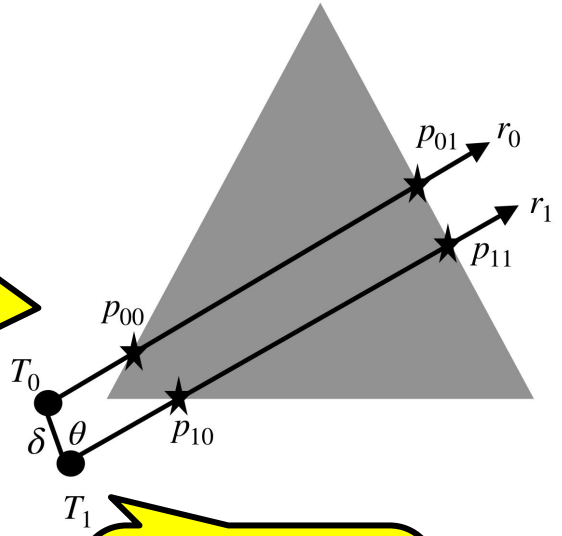
Early Ideas for G-code Generation for Parallel Infill



T0 and T1 are two extruders separated by δ

Early Ideas for G-code Generation for Parallel Infill

Compute start and stop points for both extruders based on ray intersections with the perimeter



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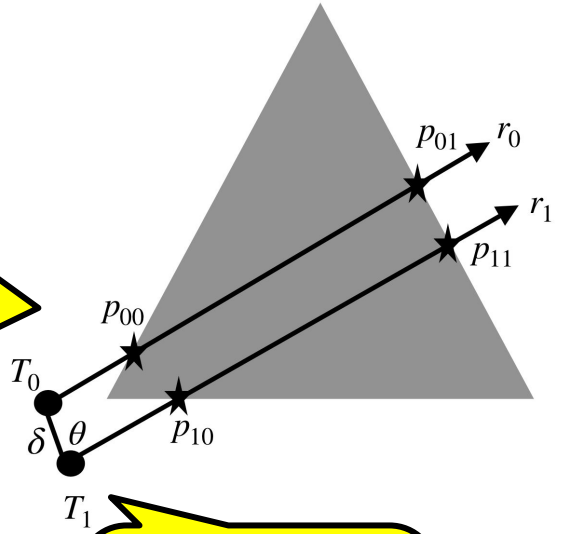
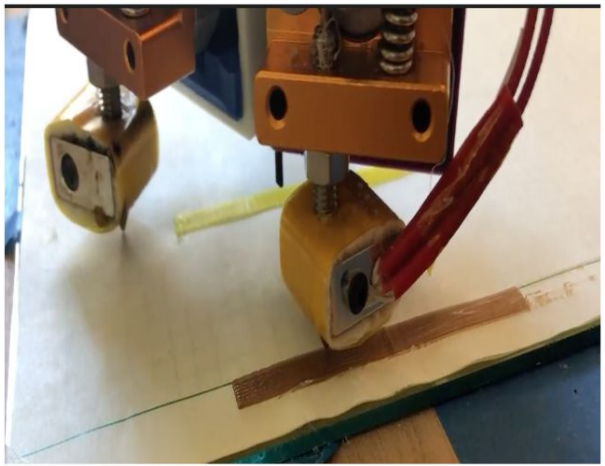
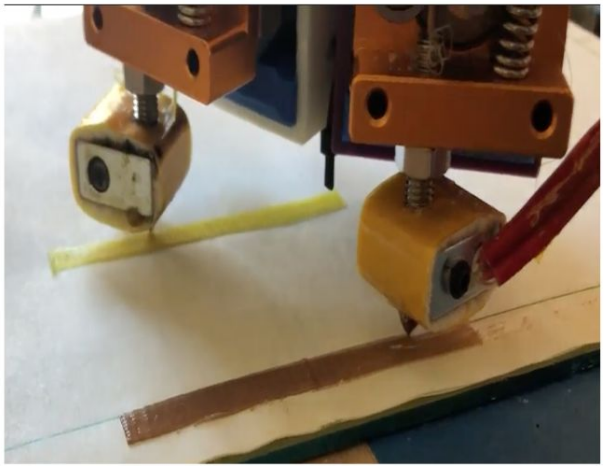
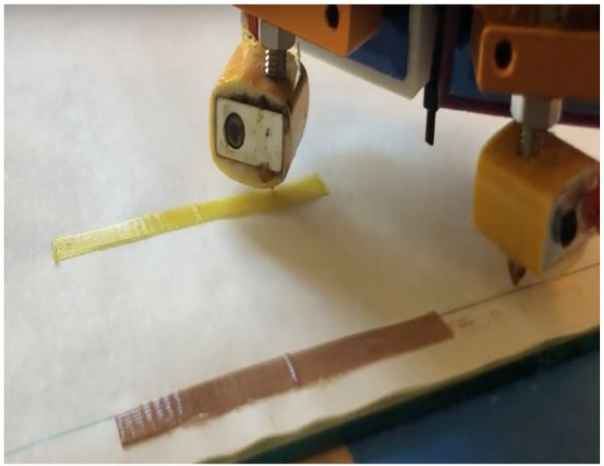


T0 and T1 are two extruders separated by δ

Generate G-code commands wrapped by `M605 S2` where both extruders should extrude

Early End-to-End Experiments

Simulated estimates indicate up to 2x speedups possible for basic models

Going Forward from Our Exploration

Support complex models with multiple islands

Extend to support parallel perimeter

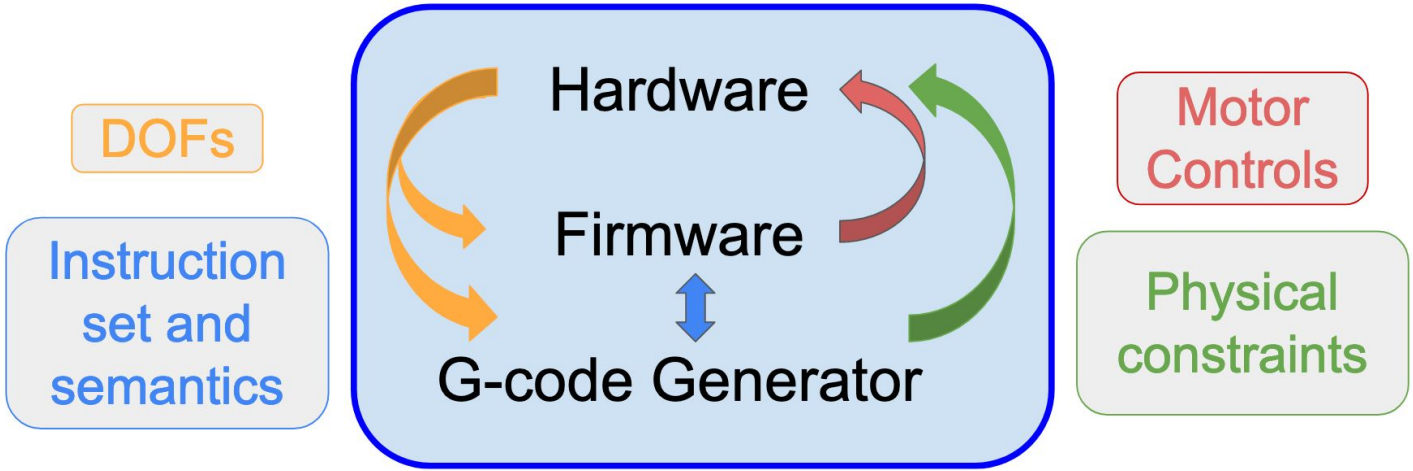
Support different printers

Analyze mesh to detect additional opportunities for parallelism

Analyze CAD to recommend more parallelizable designs

Better simulators for parallel G-code

A Roadmap Towards Parallel Printing for Desktop 3D Printers



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