Basics of FDM printing

Yuriy Sukhorukov @ysukhorukov,
BS17-RO “Adeptus Mechanicus”,
Innopolis Aerial Robotics lab engineer

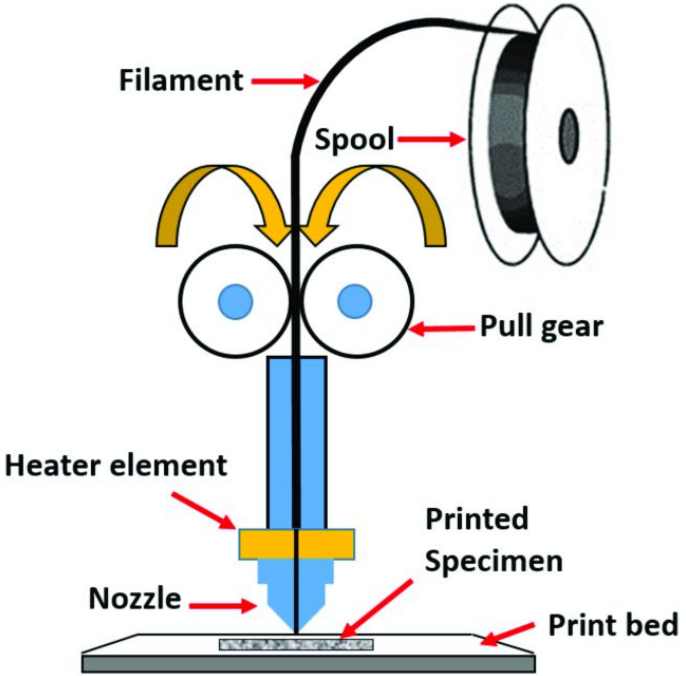
Lecture outline

- Printing process description
- Printer kinematics
  - X, Y, Z movement
  - Extruder
- Printer firmware
- Printer choice
- Fits & Tolerances
- Slicing process & software
- Post-processing

Printing process description

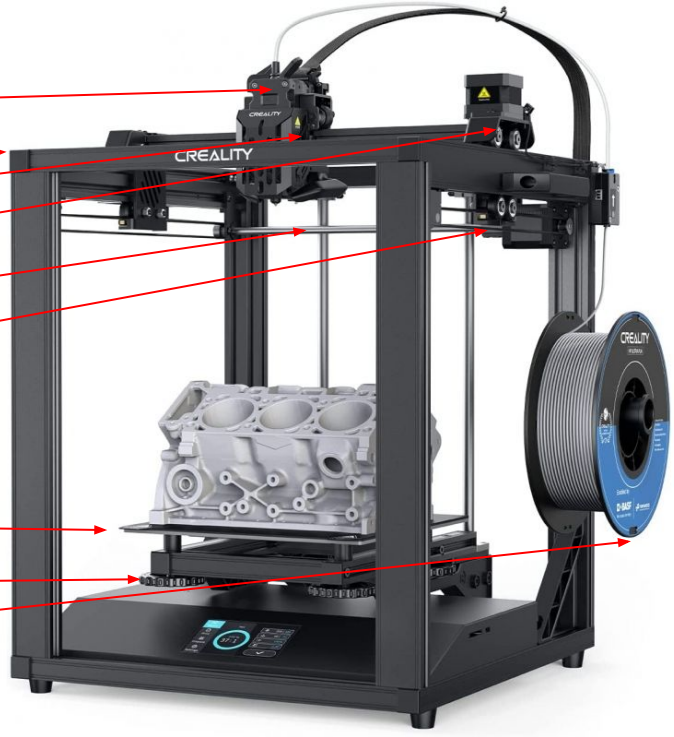
How does the printer print?

- FDM - fused deposition modeling
- Plastic is heated and pushed through a small orifice - nozzle
- Nozzle block (printhead) can move in X, Y, Z directions
- Molten plastic is deposited layer by layer to form a solid object



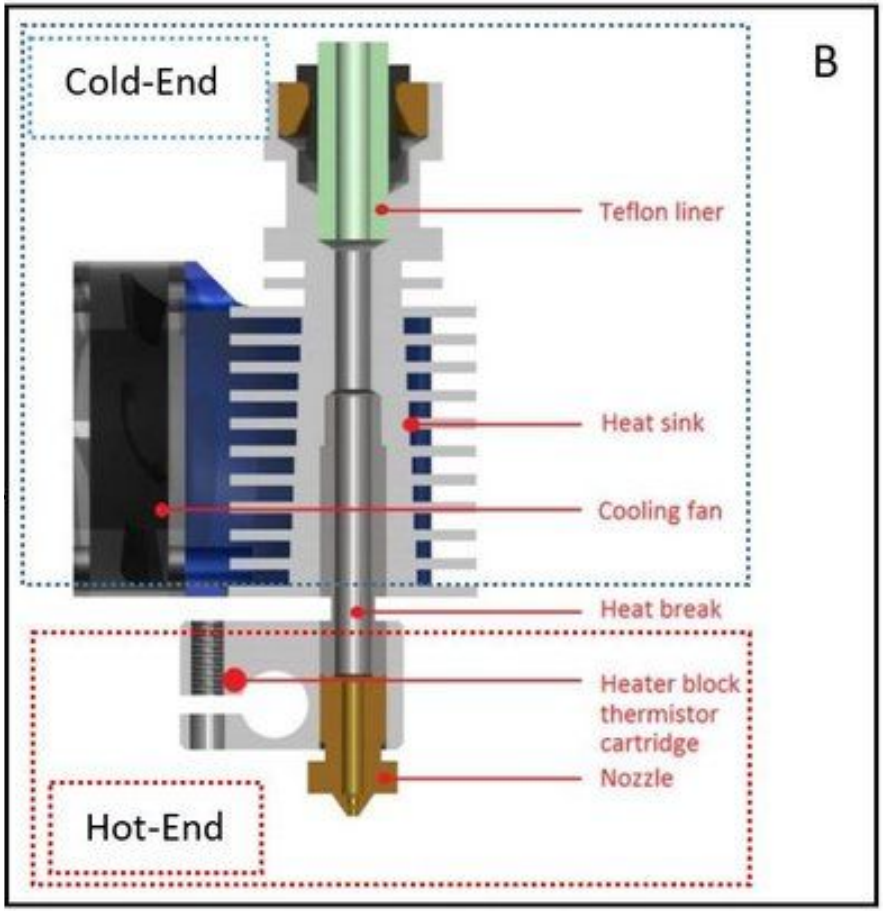
Printer parts

- Printhead
- Chassis
- Gantry
- Stepper
- Rails
- Belts
- Printbed / buildplate
- Printbed screws
- Filament spool/roll



Printer parts

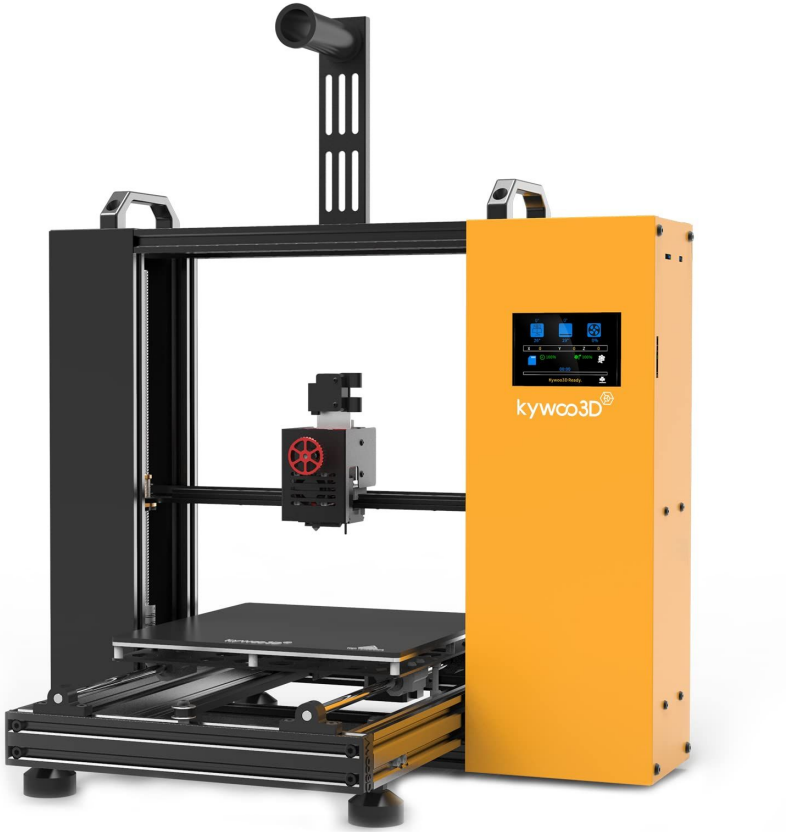
- The printhead consists of several parts which ensure that the printer works as intended
- Especially important
  - Heatbrake
  - Cooling



Printer kinematics (X,Y,Z)

Bed-slinger

- Printhead moves in X, Z axis
- Bed moves in Y axis



Bed-slinger

Pros

- Cheap
- Simple

Cons

- Y-axis is slower than X-axis
- Possible artefacts on high accelerations and/or tall parts

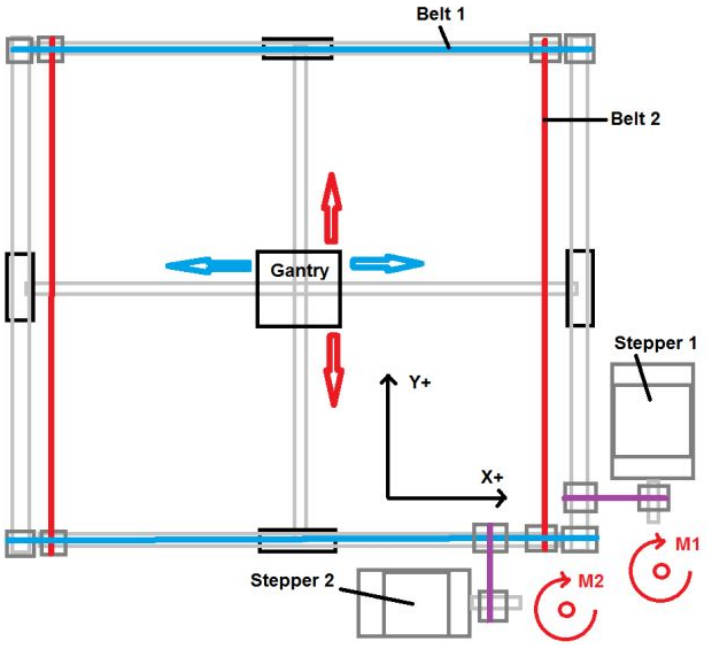
Bed-slinger, specimens

- Ender 3
- Anet A8
- Prusa i3
- Longer LK4
- **Bambulab A1 / mini**

Good for someone starting their maker’s career or for 3D printer farm

Box design

- Two gantries allow movement in X and Y directions
- Bed moves in Z direction



Box design

Pros

- No print quality degradation on tall models
- Still relatively cheap
- Can have huge print volume

Cons

- More expensive than the Bedslinger
- Not as fast as CoreXY/HBOT

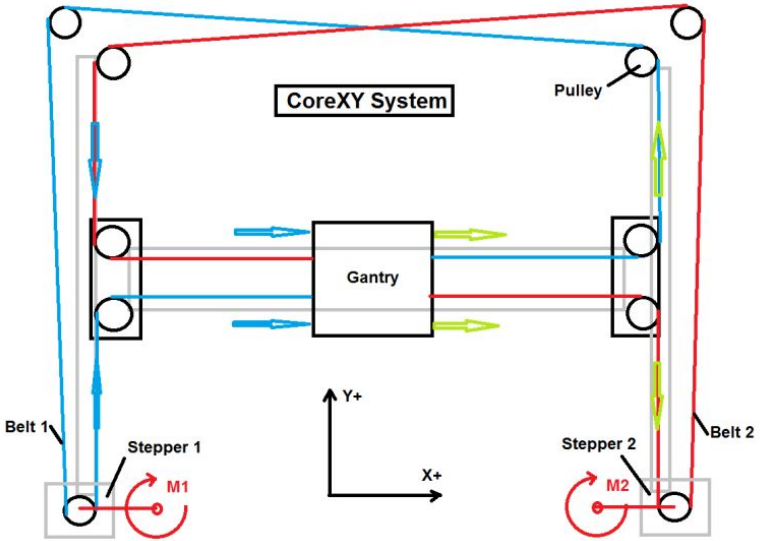
Box design: specimens

- **Ultimaker**
- **Raise 3D**
- Flying bear

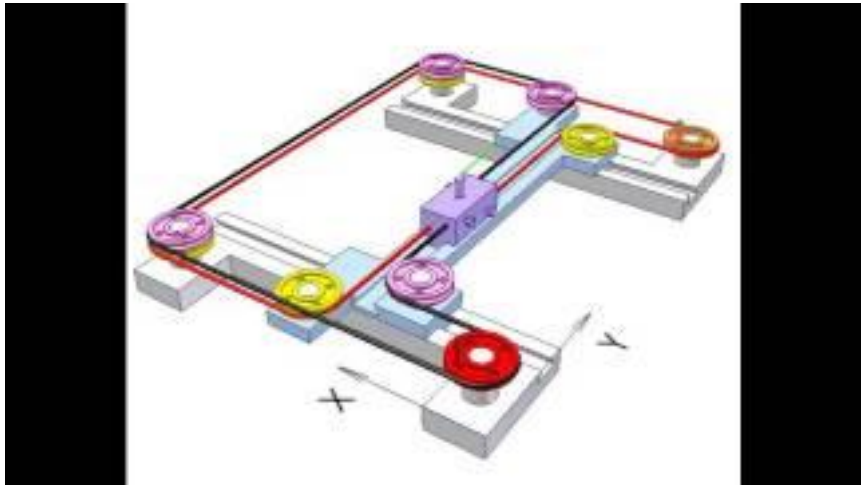
Higher-end printers tend to have really good out-of-the-box performance, and print quality in general. Good for those who want better print quality and ready to pay for it

CoreXY and HBot

- One gantry that is moved in X direction
- Printhead can slide along the gantry in Y direction
- Bed is moved in Z direction

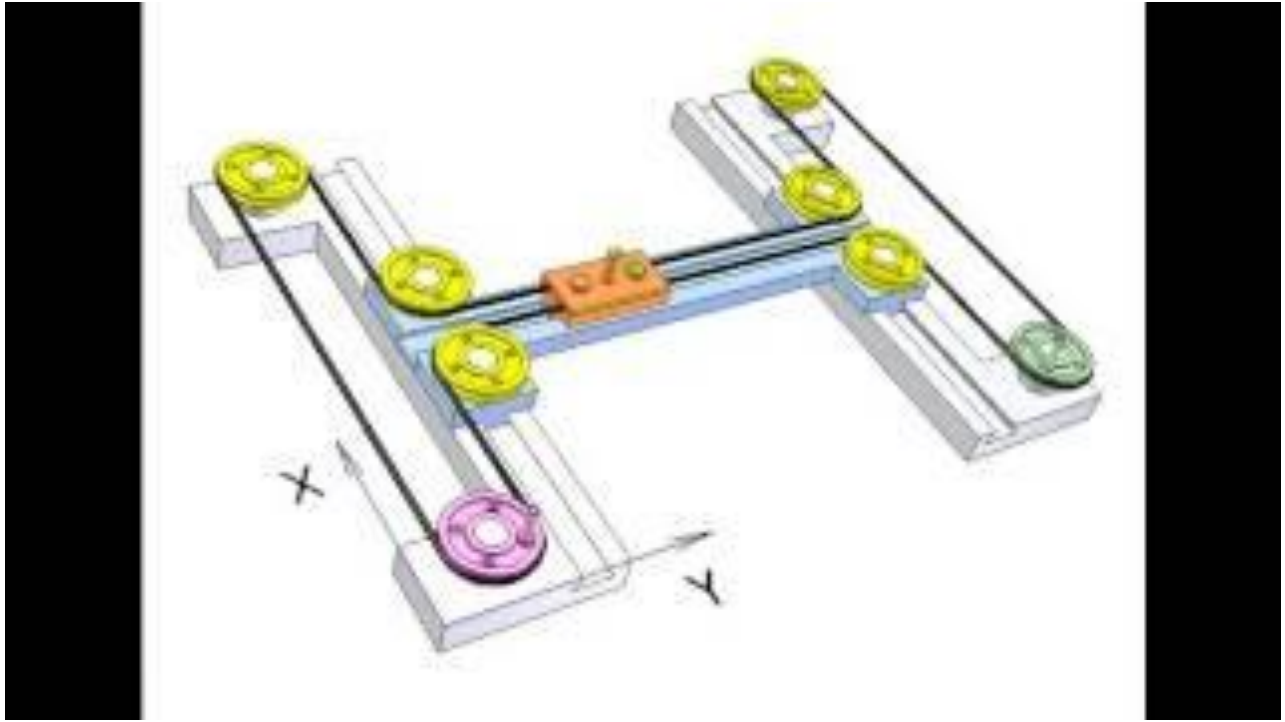


CoreXY video



Видео

Hbot video



Виде
о

CoreXY and HBot

Pros

- Faster than the Box-Style design

Cons

- More expensive than Box-Style
- Require especially tight tolerances when assembling

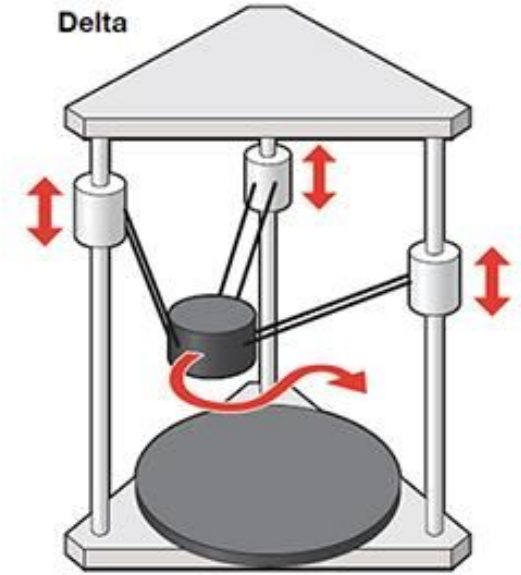
CoreXY and HBot: specimens

- Voron
- **Anisoprint A4**
- Ender 6
- **Bambulab X1C**

For “speed-junkie” type of makers, or for those willing to pay extra for print quality

The mighty Delta

- Instead of gantries, it uses 3 arms arranged in a triangular fashion
- Simultaneous motion of arms controls all 3 axis



Delta

Pros

- Fast
- Can print tall objects
- Compact

Cons

- Calibrating is a royal pain
- Sensitive to arm length irregularities

Delta

Видео

Delta: specimens

Pros

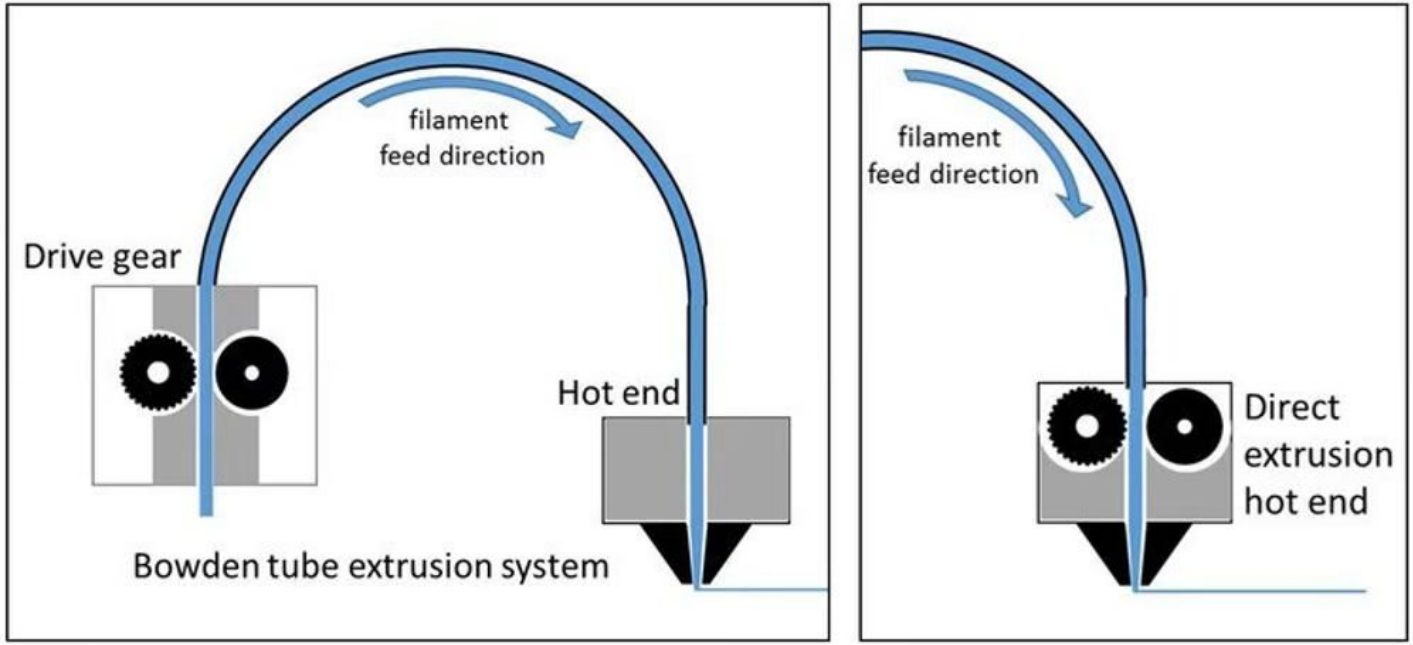
- **Anycubic Kossel**
- Flsun Q5
- Delta Go

For “speed-junkie” type of makers, who are well-versed in the subtle art of 3D printing or for those who want print tall parts.

Aircraft parts, anyone?

Extruder: Direct vs Bowden

Direct or Bowden?



Bowden pros & cons

Pros

- Lighter printhead
  - Higher speed
  - Flimsier chassis
- Cheaper

Cons

- Problems with retracts due to springiness of the material
- Hard to print with flexible plastics

Entry-level machines are usually bowdens

Direct pros & cons

Pros

- Less problems with the springy filaments
- Able to print even softest of TPU plastics

Cons

- Heavier printhead
- Usually found on higher-end machines

In general, there are less problems with direct extruder

Printer firmware

Printer firmware

- **Klipper**
- Marlin
- Repetier
- Prusa & other proprietary

Printer firmware: Main takeaways

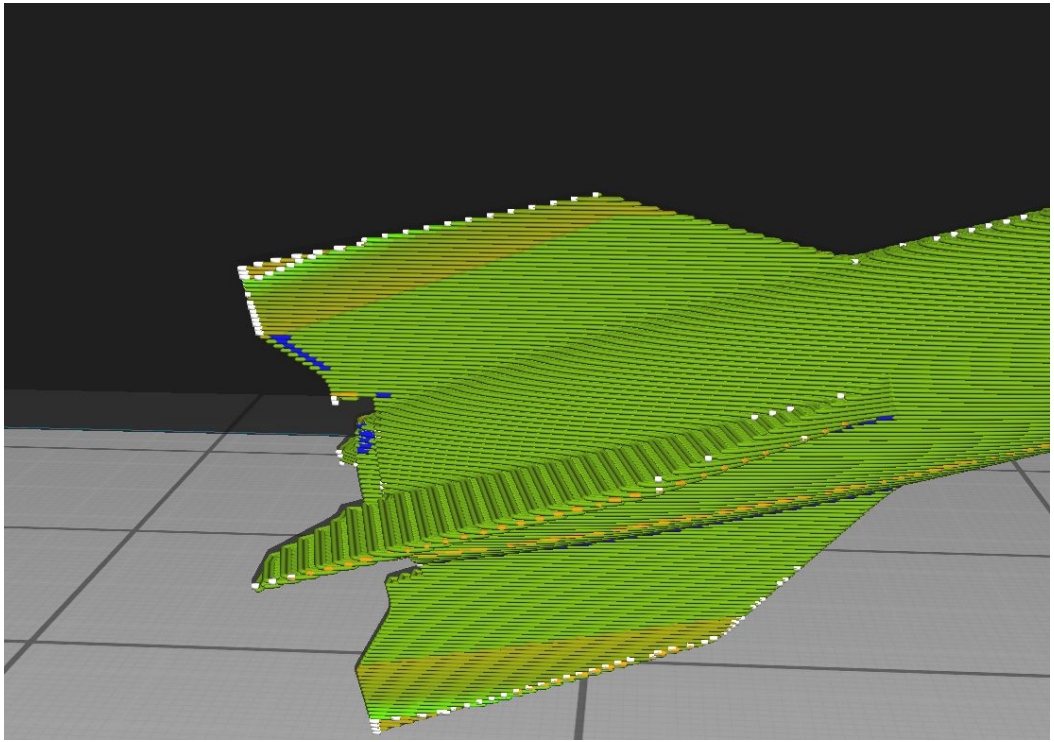
- If your stock firmware works good enough for you, and that is usually the case with higher end machines - just leave it be
- If you want to print faster and possess substantial skill in FDM technomagic, then you can try Klipper
    - Or maybe you want to print over internet if your printer does not support it

Printer choice

Hard choice

- If you are starting your career in FDM, or want to save money - Bed-slinger printer is a good choice
- From there you will figure out what you want next
  - Tall parts?
  - Fast prints?
  - Superb print quality?

Enough hardware!



Slicing process & Software

Slicing software choice

- Cura (free)
- Simplify 3D (paid)
- Slic3r (free)
- PrusaSlicer (free)
- Orca (free)
- Bambu Slicer (free)

Slicing software choice

- It is a matter of personal choice, previously I used Cura because it is
  - Feature-rich
  - Extendable via plugins
  - Actively maintained
  - Free
- I use Bambu Slicer now because that’s what you use with Bambulab printers

Filaments overview

PLA

+ Easy to print
+ Strong
+ Recyclable
- Not heat resistant
- Hard to machine

PETG

+ Should be flexible
+ More heat resistant than PLA
- Hard to print
- Prone to stringing
- Very brittle

ABS

+ Easy to machine
+ Easy to smooth with solvent
- Extremely poor layer adhesion
- Stinks
- Requires an enclosure

Filaments overview

TPU-95A

+ Printable on a bowden machine
+ Extremely tough
+ Semi-flexible
- Semi-flexible
- Harder to print than previous ones

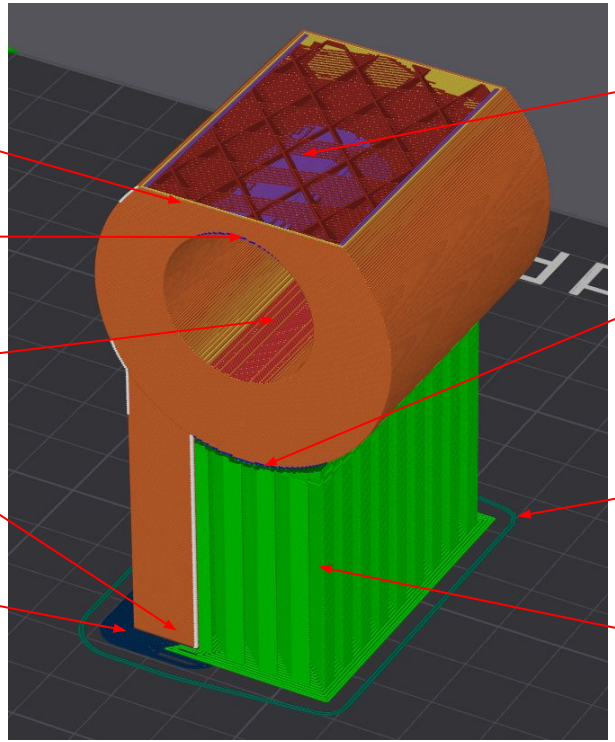
TPU-75A

+ Super soft, shock-absorbing
- Requires a direct machine
- Extremely hard to print, tends to clog

PA-CF

+ Heat resistant
+ Strong and tough
+ Solvent-resistant
- Abrasive
- High printing temp
- Requires an enclosure

Anatomy of a 3D printed part



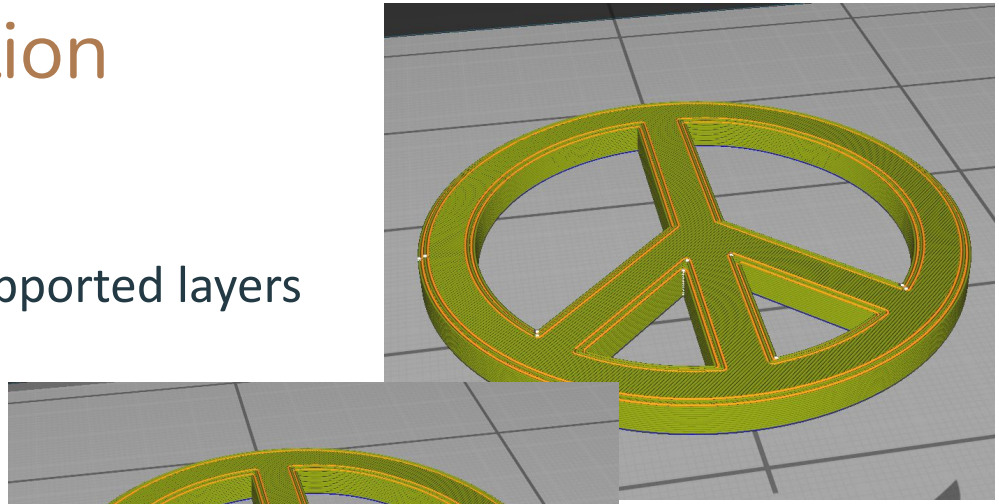
Print part orientation

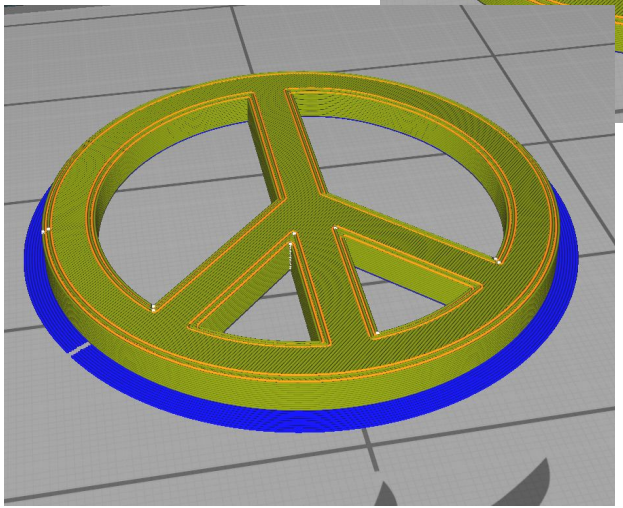
Good part has

- No layers that are either completely or partially not supported by the previous layer
- High print bed contact area
- Such an orientation that the main loading is parallel to the bed

Print part orientation

- Good
- No partially or fully unsupported layers
- Good bed contact area

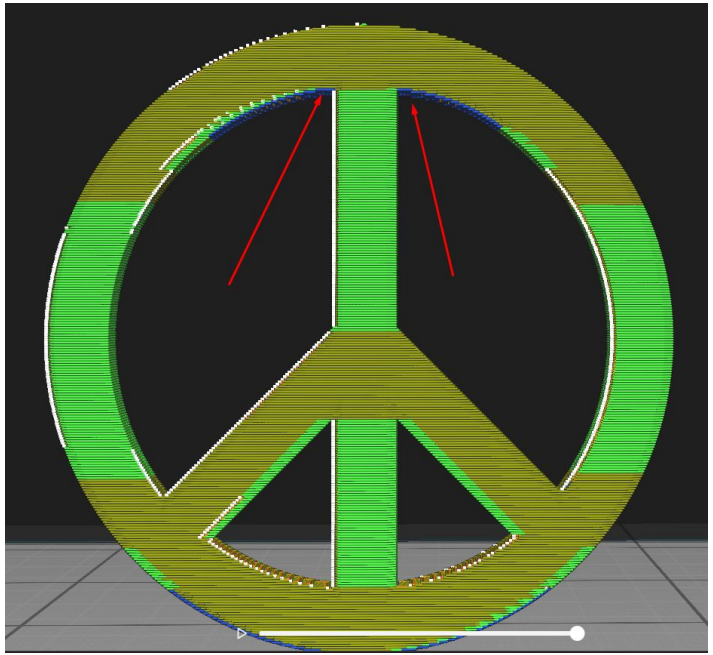




Print part orientation

- Poor
- Some layers are partially unsupported, like green sides
- Some are completely (marked with red arrows)
- Low bed contact area

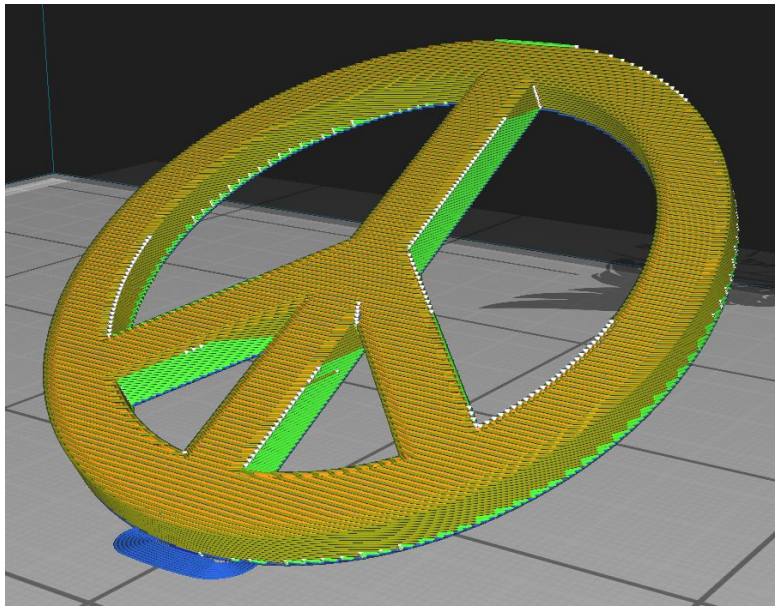
- Don’t do this unless you really know what you are doing



Print part orientation

- Extremely poor
- Many layers are completely unsupported
- Miniscule bed contact area

- Don’t do this. Just don’t.

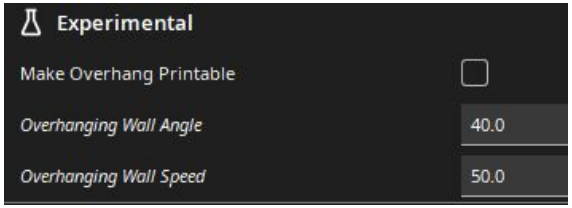


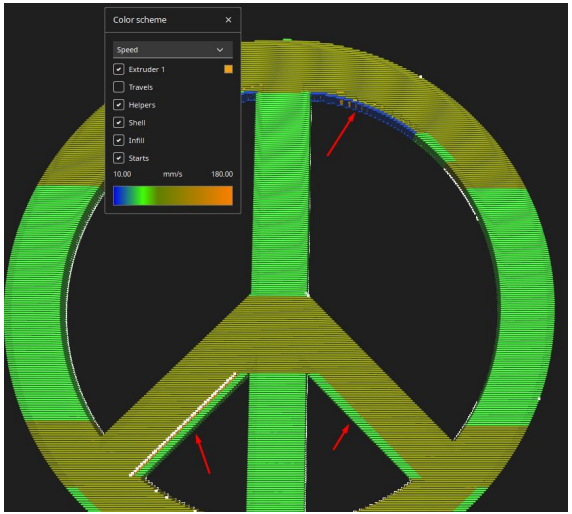
What if you design really needs “bad” parts

If you really want unsupported print lines

- Use overhangs. The main idea is to go slower on partially unsupported lines to prevent sagging
- You might want to boost cooling as well

- Here are fields that you can tune in Cura (experimental)

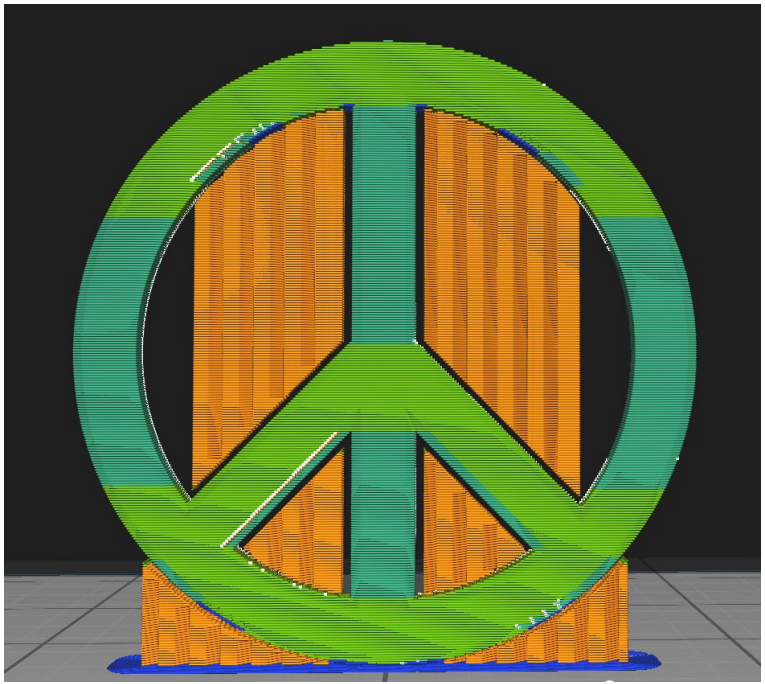




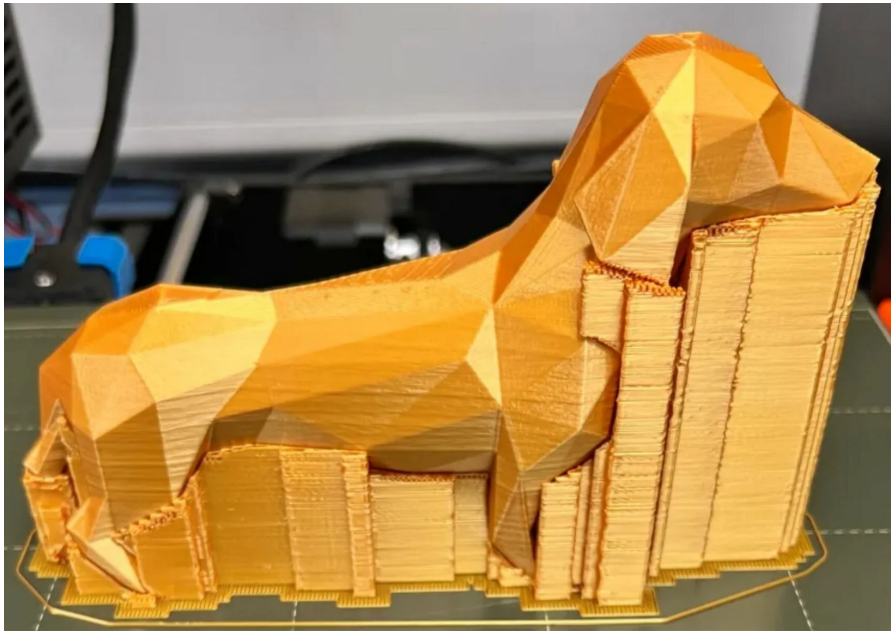
Bad sagging

If you really want unsupported print lines

- Use a support. Support is a sacrificial structure that allows you to print “in the air” and is placed by your slicer for you
- Supports have a plethora of parameters, but you should look out for your
  - Support cooling settings
  - Top and bottom clearance
  - Support pattern



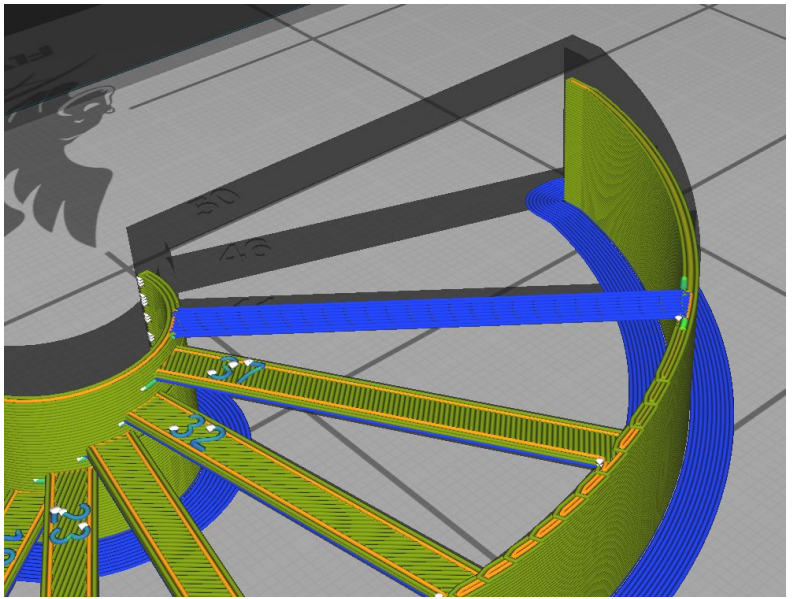
Supports ain’t that bad



If you really want unsupported print lines

- Use bridges. Bridge is printed hanging in the air and is quickly solidified with a part cooling fan

- Default parameters from Cura usually work for short bridges (up to 2 cm) and machines with an adequate cooling



On strong parts and layer adhesion

If you want to make your parts stronger and print faster you might

- Ramp up the temperature (don’t go crazy for PETG tho)
- Increase the line width, i.e. 0.6 for 0.4 nozzle
- Decrease cooling, but beware of supports and overhangs!
- A little bit of over-extrusion also helps (1-2%)

- Some plastics respond better to this technique than others.

  More here: https://www.youtube.com/watch?v=9YaJ0wSKKHA&t=736s

On strong parts

- If your part is subjected to a bending load, it is better to increase the number of polygons, because the outer shell is what bears the load in this scenario
- If your part is subjected to a stretching or shearing load, increasing the infill to the gills is more beneficial

Under/over-extrusion

Gaps between the lines

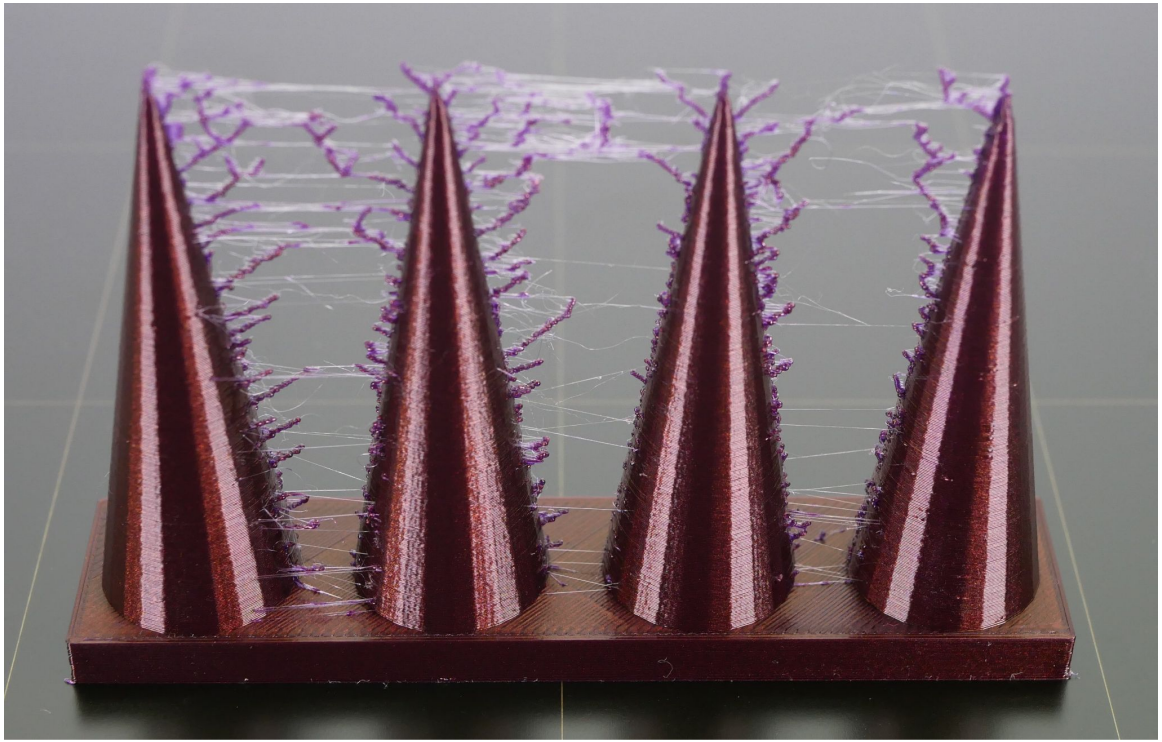
Underextrusion

OK

Too much material in the corner and more visible layers

Overextrusion

Stringing



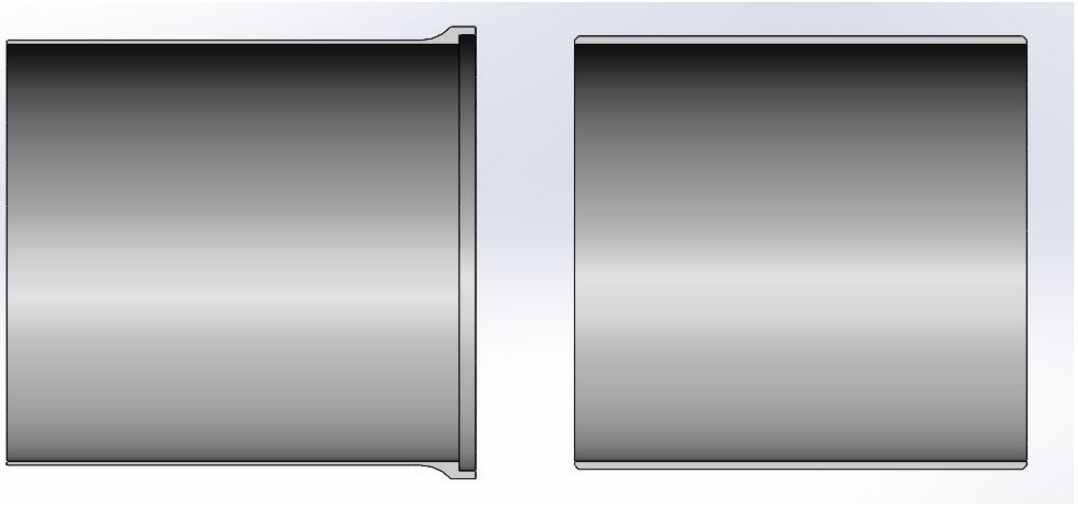
Post-processing: Gluing

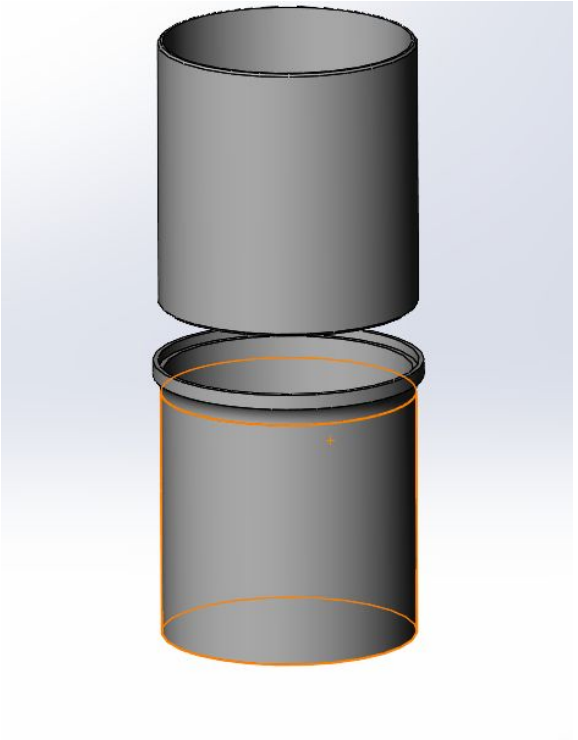
Gluing

- Dry-fit first
- Maintain high contact surface
- Glues suitable for 3D printed parts
  - CA (possibly with a catalyst)
  - Epoxy
  - Hot glue
  - PUR
- Glues not suitable for 3D printed parts
  - UHU Por
  - PVA glue
  - Dissolving glues (Dichloromethane / Dichloroethane)

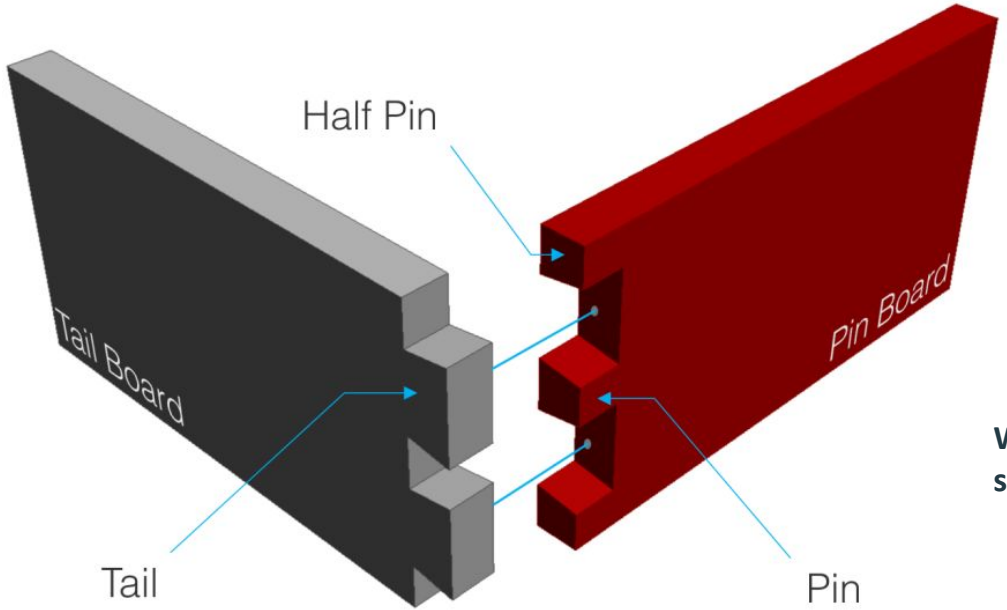
Gluing: Flanges & Dovetail joint

What clearance
should I use?



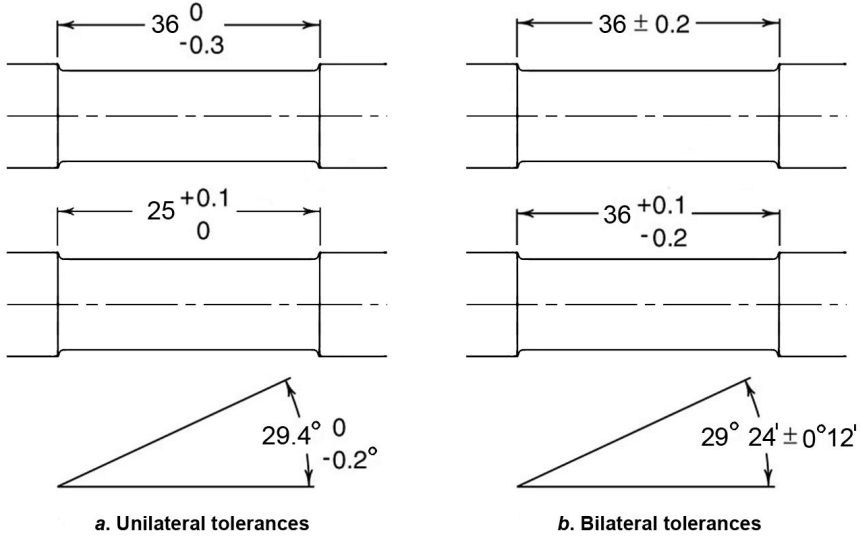


Gluing: Flanges & Dovetail joint



What clearance should I use?

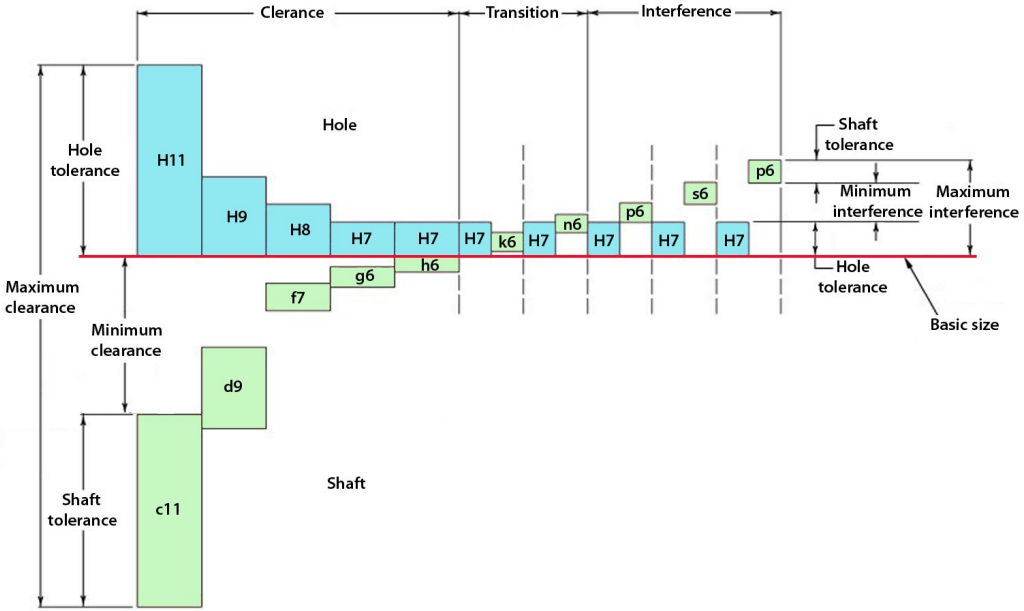
Fits and tolerances



a. **Unilateral tolerances** *b.* **Bilateral tolerances**

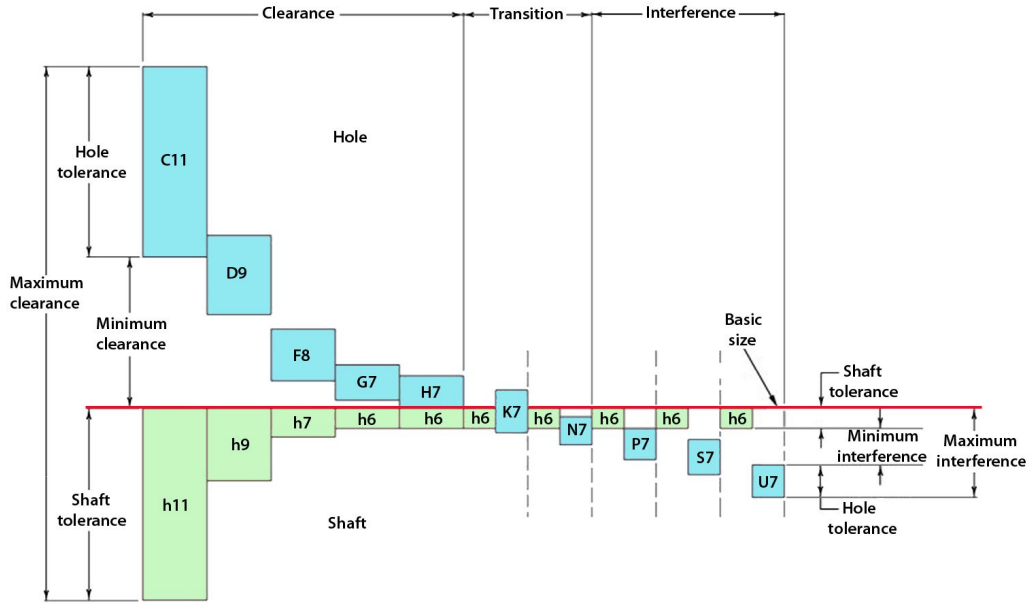
Taken from: https://www.mcgill.ca/engineeringdesign/step-step-design-process/basics-graphics-communication/principles-tolerancing

Fits and tolerances, Hole-basis



Taken from: https://www.mcgill.ca/engineeringdesign/step-step-design-process/basics-graphics-communication/principles-tolerancing

Fits and tolerances, Shaft-basis



Taken from: https://www.mcgill.ca/engineeringdesign/step-step-design-process/basics-graphics-communication/principles-tolerancing

Some commonly used fits, clearance

Hole basis	Shaft basis	Uses	
H11/c11	C11/h11	Loose Running Fit	Pivots, parts with corrosion and dust, parts exposed to thermal changes
H8/f7	F8/h7	Close Running Fit	Machine tool spindles, shaft bearings, sliding joints
H7/h6	H7/h6	Locational Clearance Fit	Machine tool guides, roller guide rails

Some commonly used fits, transitional

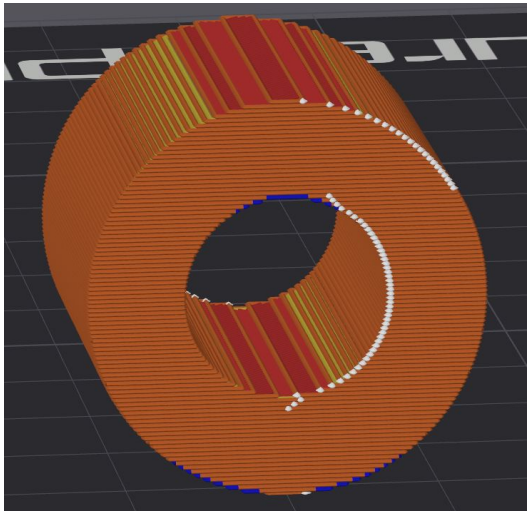
Hole basis	Shaft basis	Uses	
H7/k6	K7/h6	Locational Transition Fit	Wheels, brake disks, gears/pulleys on shafts
H7/n6	N7/h6	Locational Transition Fit	Motor armature windings, gears

Some commonly used fits, interference

Hole basis	Shaft basis	Uses	
H7/p6	P7/h6	Locational Interference Fit	Hubs, clutches, bushings for bearings
H7/s6	S7/h6	Medium Drive Fit	Permanent gear/pulley assemblies, bearing mounting
H7/u6	U7/h6	Force Fit	Flange mounting, gears, shafts

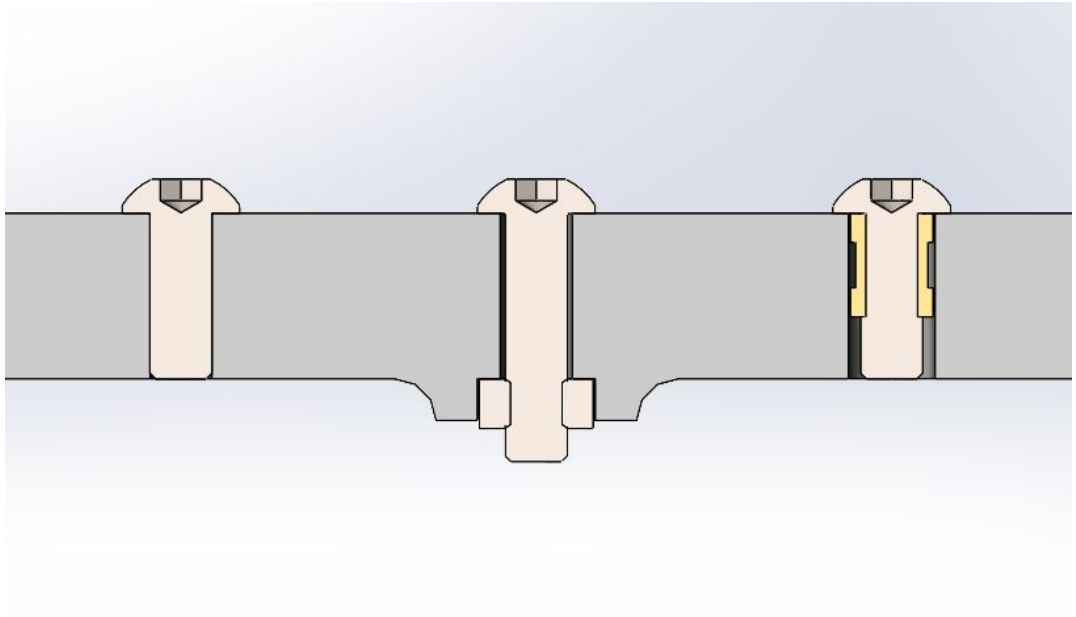
Tolerances for 3D printing

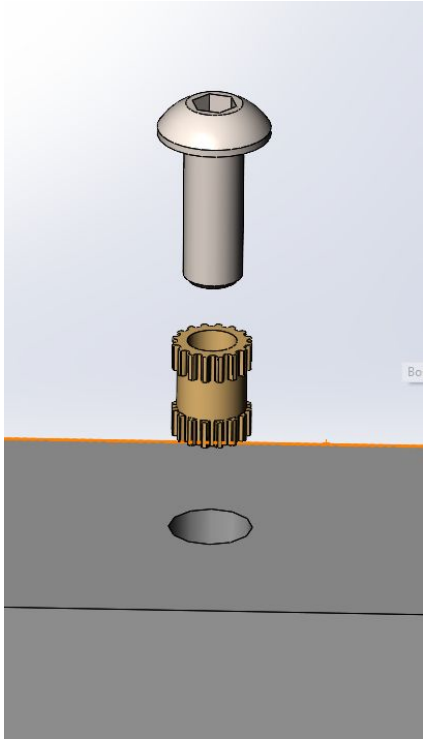
Type	Vertical holes	Horizontal holes
Clearance	+0.40	+0.3
Transitional	+0.3	+0.24
Interference	+0.24	+0.2
Interference (TPU & Co)	+0.0	+0.0

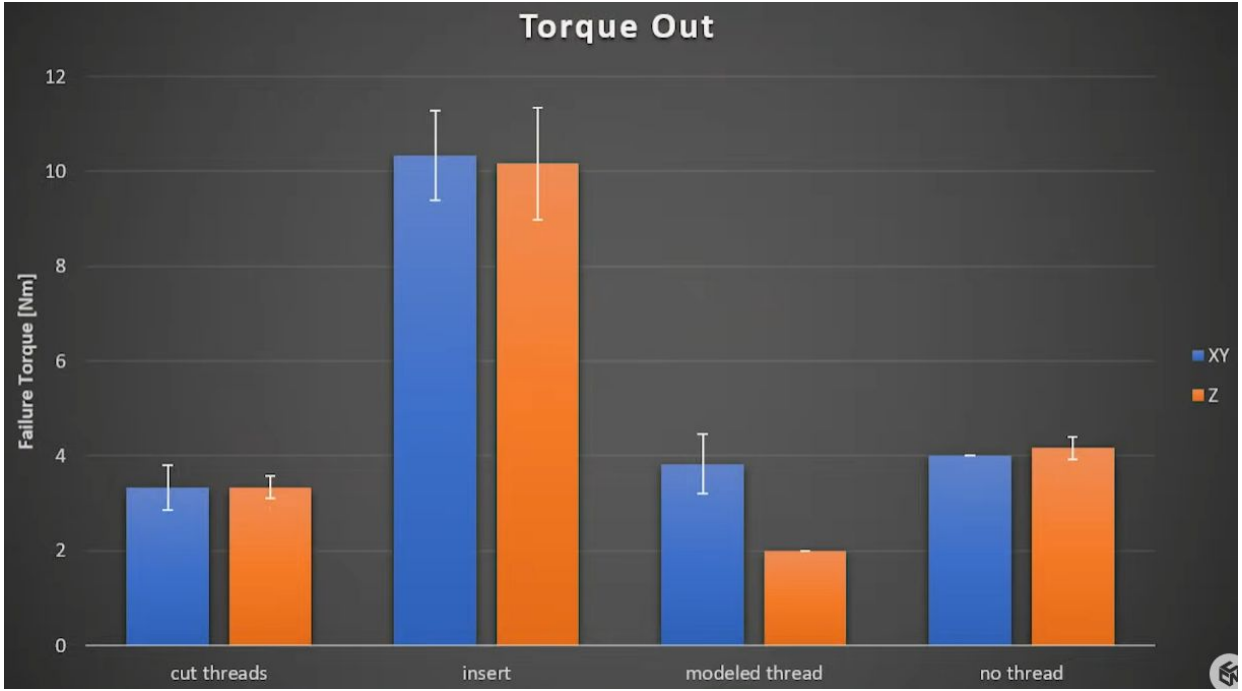


Post-processing: Screwing

Direct screwing, hex nuts, hot-set nuts







Taken from: https://www.youtube.com/watch?v=iR6OBlSzp7I&t=19s

Visit for more information and scientific tests

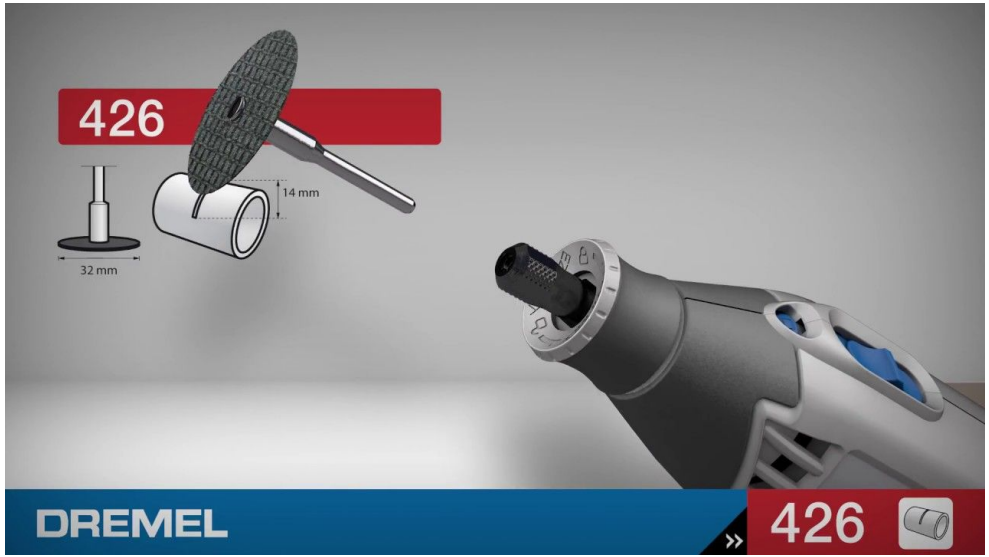
Post-processing:
Cutting Drilling Sanding Bathing

Abrasive machining

- Sanding should be avoided if possible for plastics like PLA and PETG
- If you really want to sand some part- avoid overheating

- Cutting with cutaway discs for a rotary tool is easier, even if the plastic melts. You are just throwing more power at the problem and it apparently works
- Beware! A disc can shatter if subjected to a bending load
- Hand tools like hacksaw will also work

Abrasive machining



Drilling

It is easy to drill 3D printed parts, but there are few caveats

- Watch out for the wall thickness (polygon count)
- Use a good, sharp drill bit, avoid overheating
- Safety first

Bathing

Parts are exposed to vapour of a solvent that partially dissolves outer surface

Different plastics require different solvents

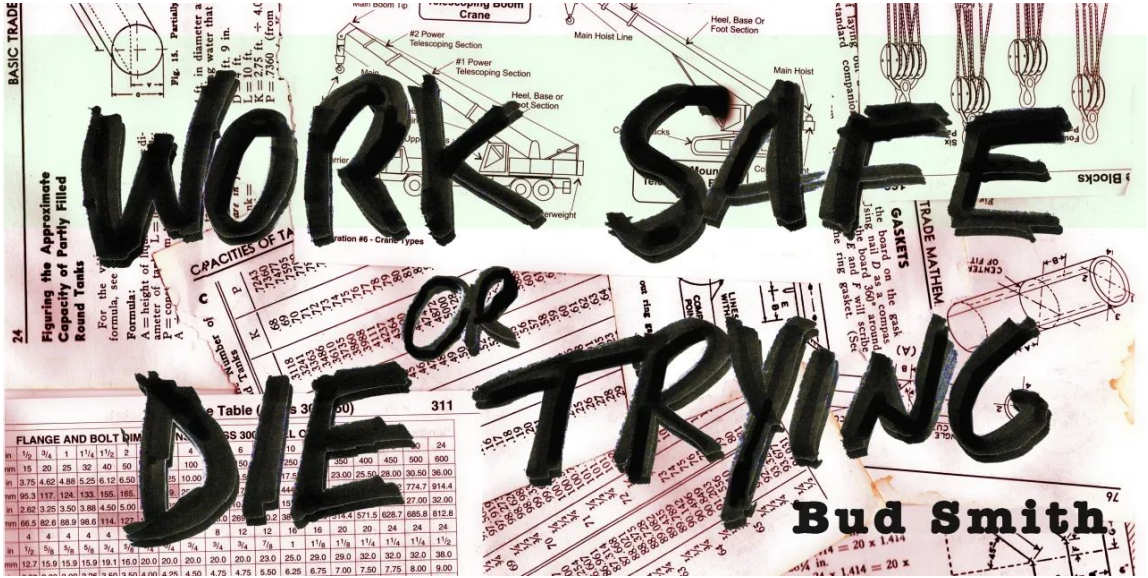
- ABS: acetone, dichloromethane
- PETG: dichloromethane
- PLA: limonel, dichloromethane

Bathing

- Mainly good for decorative parts
- Works best with ABS + acetone

Bathing

- Most solvents used for bathing are toxic and highly flammable



That’s it for today!
The Emperor protects!

Tasks: 3D printed joint

Let the 3D modeling commence!

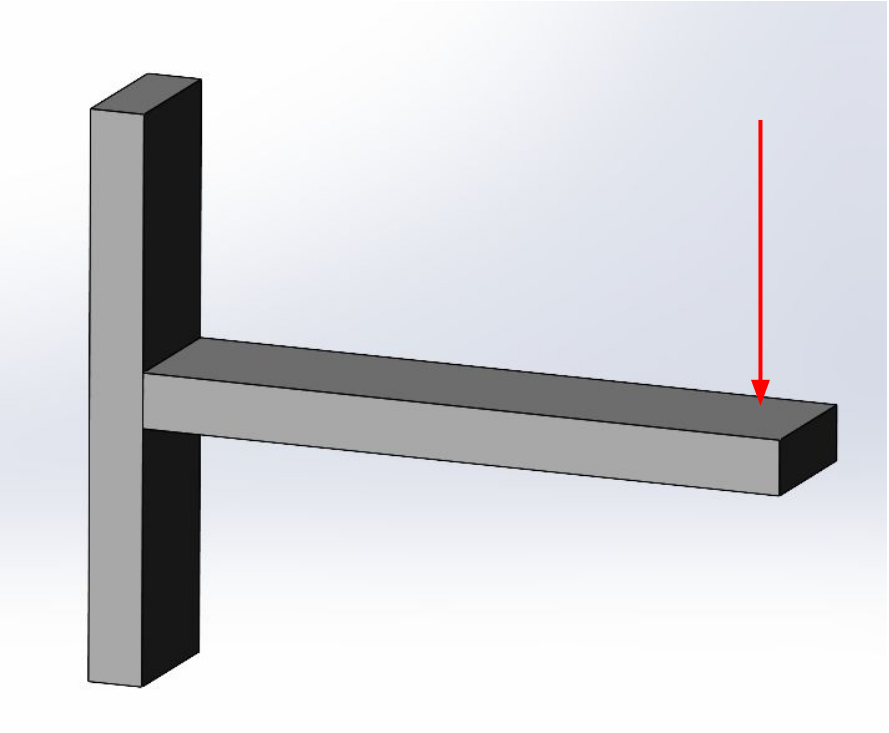
Please scan this QR code and download part for your next tasks

Tasks: 3D printed joint

Your task is to join two parts so that they can be printed and assembled. Please use

- Two types of screw joints
- Two types of screwless joints

* Take the load applied along the red line into account



Tasks: 3D printed joint

What should you tweak if you want to load your part like this?