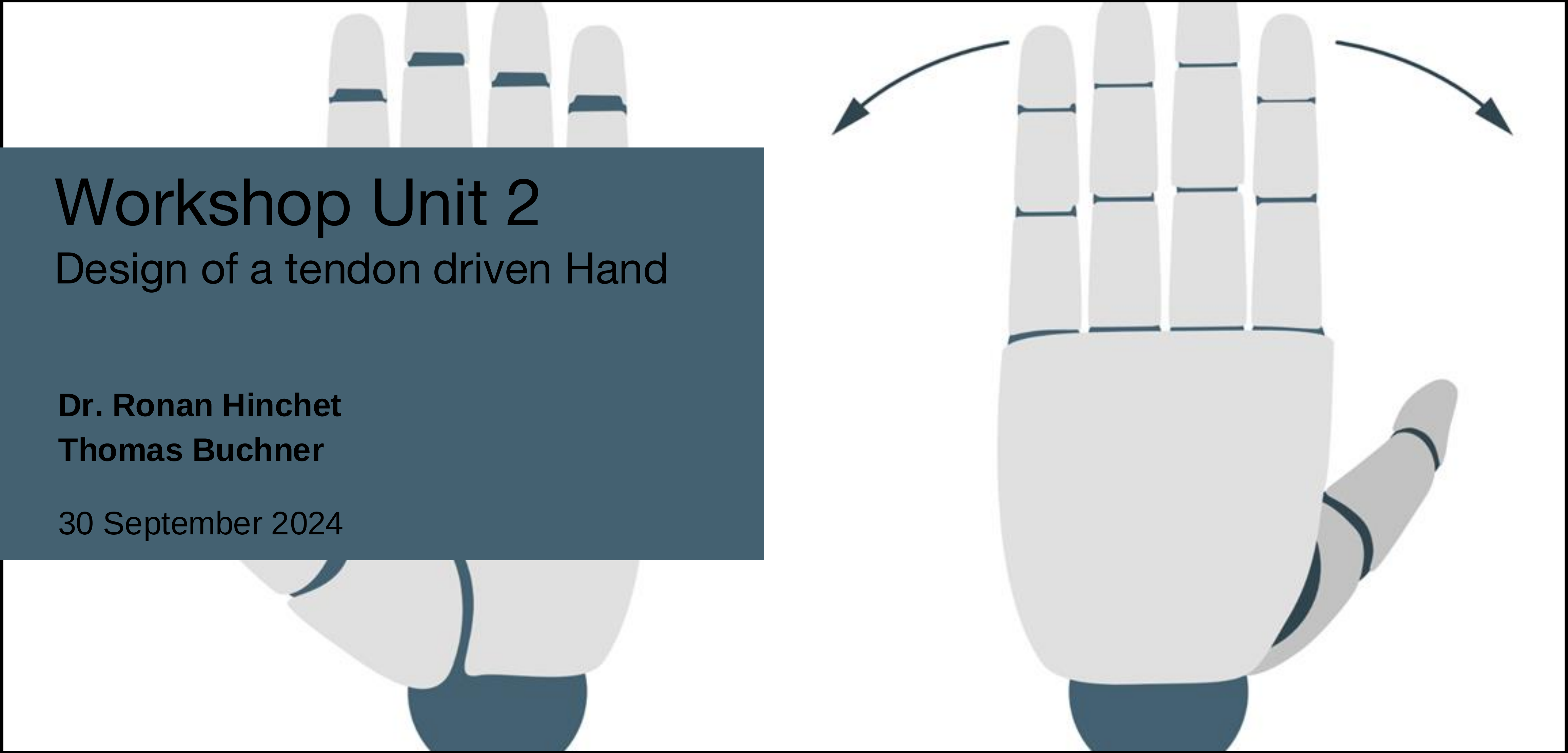


Workshop Unit 2

Design of a tendon driven Hand

Dr. Ronan Hinchet
Thomas Buchner

30 September 2024

SoftRobotics Laboratory

Overview

1. Joints
    a. Joint types
    b. Material choices
2. Tendons
    a. Tendon routing
    b. Antagonistic tendons
    c. Important aspects of tendon routing
3. Spools
    a. Tendon kinematics
    b. Effect of spool radius
    c. Antagonistic spools
4. DOFs
    a. Choice of DOFs
    b. Under & Overactuation

Joints

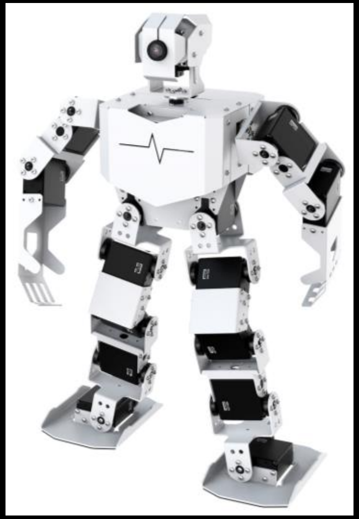
- **Multiple types: Robot joints enable movement in robots by connecting two rigid links**
  linear-rotary-spherical joints, rolling contact joint, flexure joint … any combination (*treadmill*)

- **What are the advantages and disadvantages of your joint type?**
  Design, manufacturing, dexterity, compliance, modelling & control, etc.
  Resistance/Friction, slack/backlash, precision

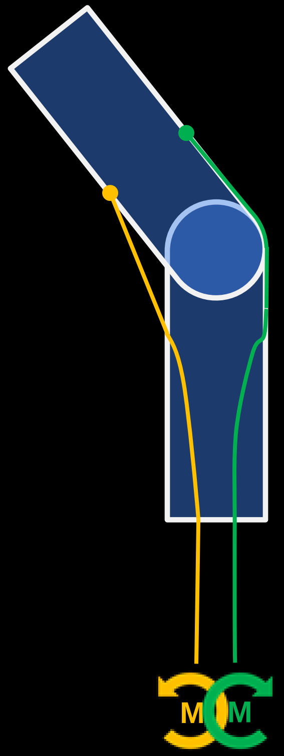
- **Which materials can or should be used for your joint type?**
  Different materials for each part of the joint?

Tendons

Direct joint actuation



Actuation “away from joint”

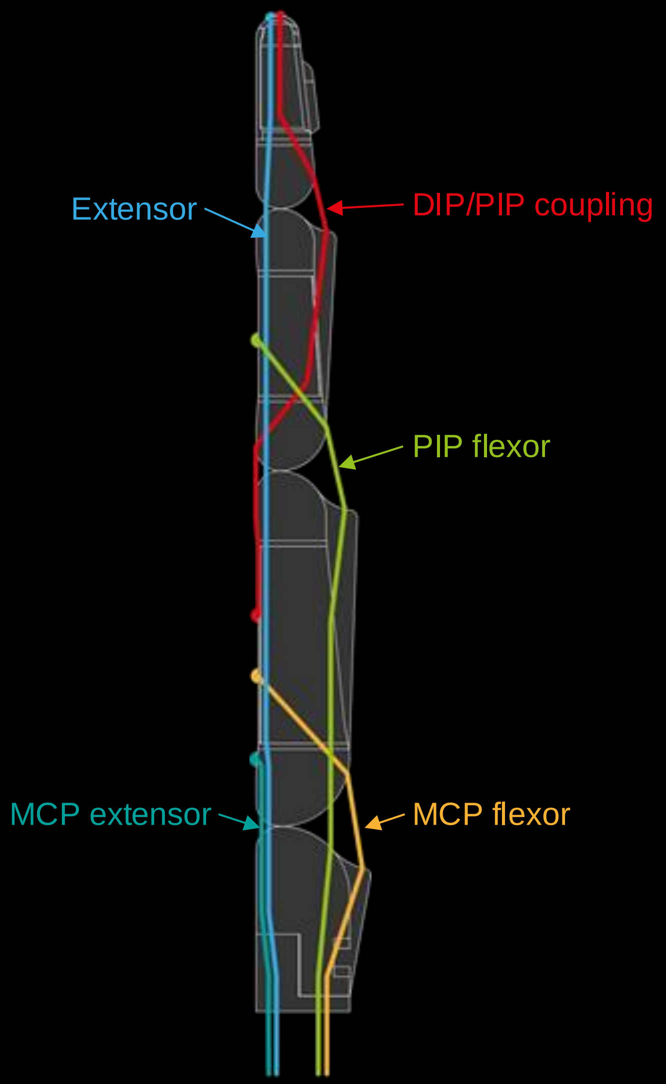


Tendons

Tendon Routing
- At least one individual tendon per active DOF
- Tendons can actuate multiple joints
- Tendons can couple multiple joints

How to reduce friction:
- No sharp edges / direction changes
- smooth guiding holes
- smooth tendon material

Influence of entry & exit points:
- Influence joint force (lever arm)
- Influence joint speed



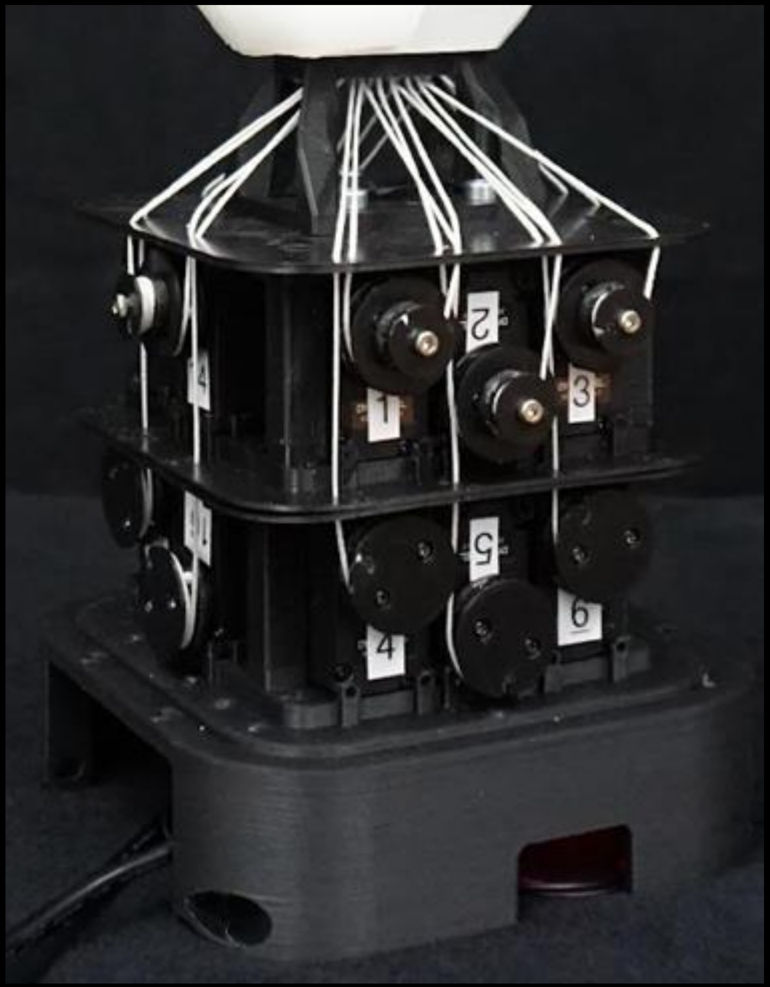
Spools

Spools convert a rotary motion to a linear motion!

Finding tendon kinematics
Joint angle → free tendon length → motor position

Effect of the spool radius
- Balances tendon (joint) force and speed

Antagonistic Spools
Connect two antagonistic tendons to the same motor
+ reduce required motors
- Tendons can become slack, due to different kinematics for each tendon



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Degrees of Freedom

How many motors can we use per joint?

1 Motor (+2 spool):
+ Reduces weight & controlling effort,
+ increased dexterity with constant number of motors
- Can lead to tendon slack & inaccuracies

1 Motor +1 spring:
+ no tendon slack
- Limited force in one direction

2 Motors:
+ Reduce tendon slack & increase accuracy
+ more flexible to adjust joint speeds & torques
- double the size & weight

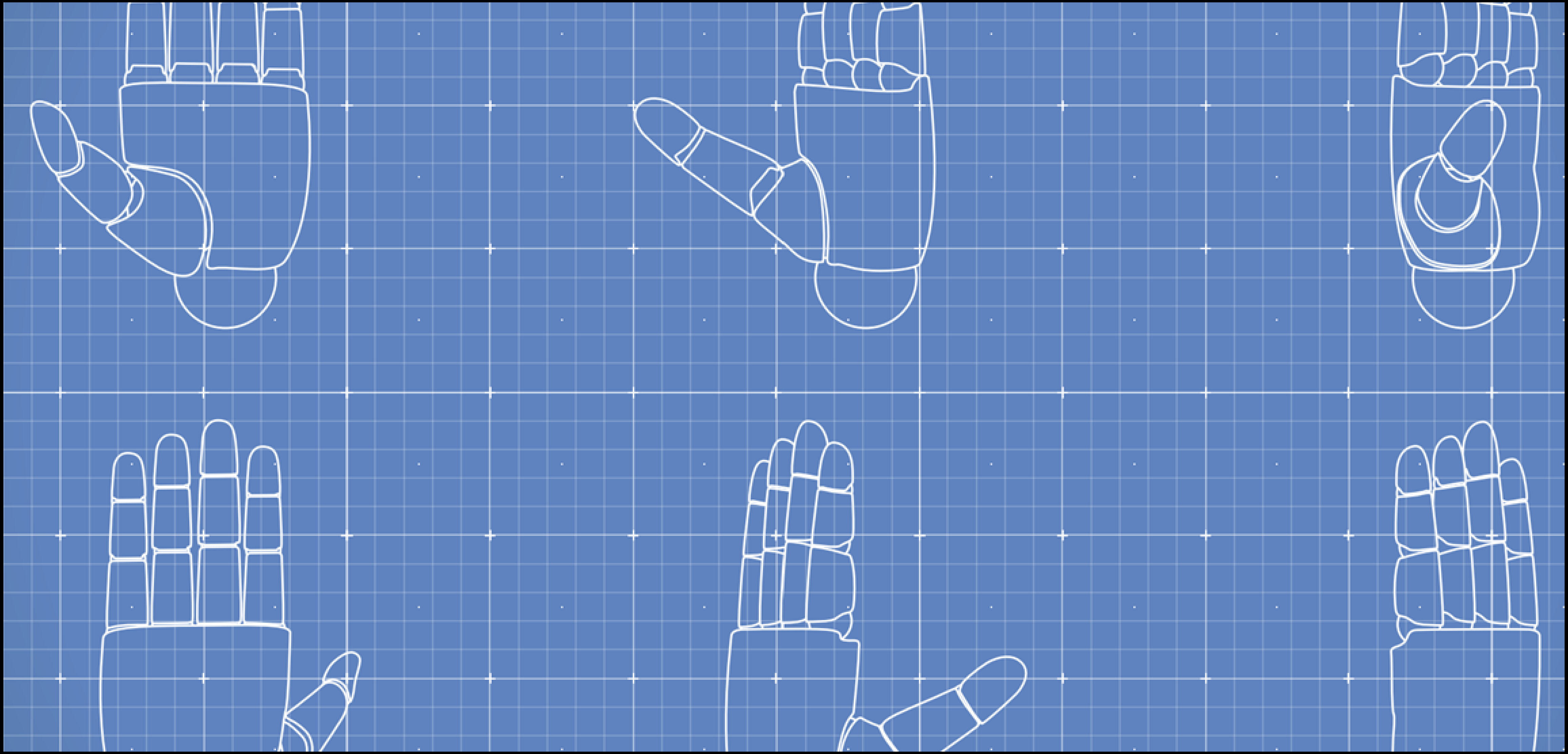
> 2 Motors:
+ Can increase forces of certain joints
- increased size & weight
- system is overactuated

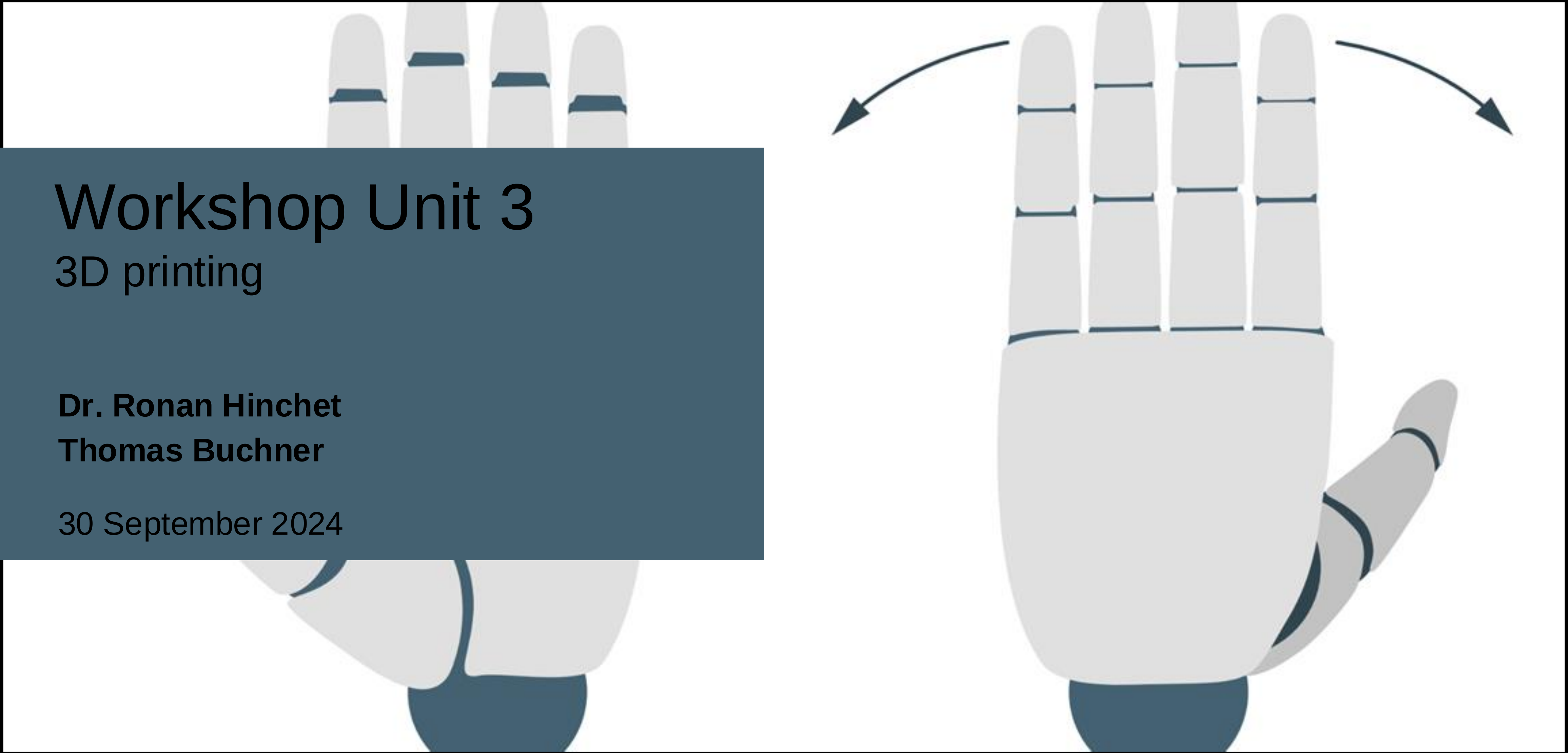
Under- and Overactuation

Underactuation:
Less motors than joints
+ increased DOF without increase in motors (passive DOF)
- joint coupling can reduce the accuracy and controllability

Overactuation:
More motors than joints
+ selectively increase forces
- increase in weight and size of actuation

For under- and overactuated systems, the Inverse Kinematics and Dynamics can become complex!





Workshop Unit 3

3D printing

Dr. Ronan Hinchet
Thomas Buchner

30 September 2024

Why 3D printing?

Alternative to machining and injection molding techniques

Cost Effective

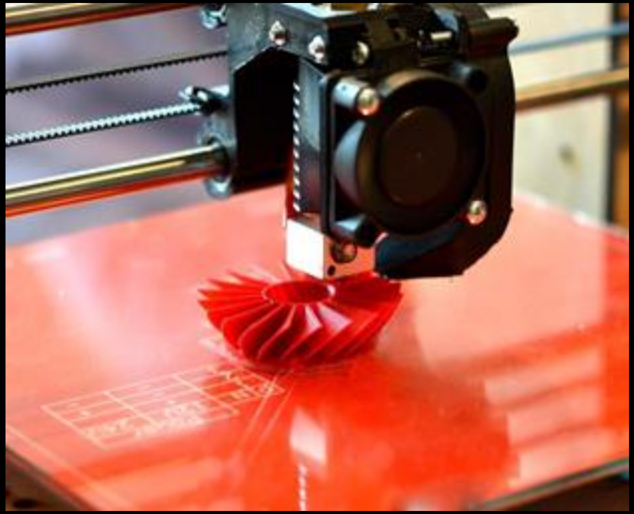
Rapid Prototyping

- Fast Design to Production

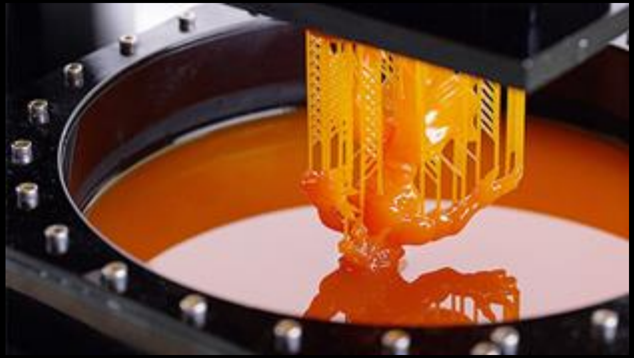
- Proximity Designer and Manufacturing

Common types of 3D printing

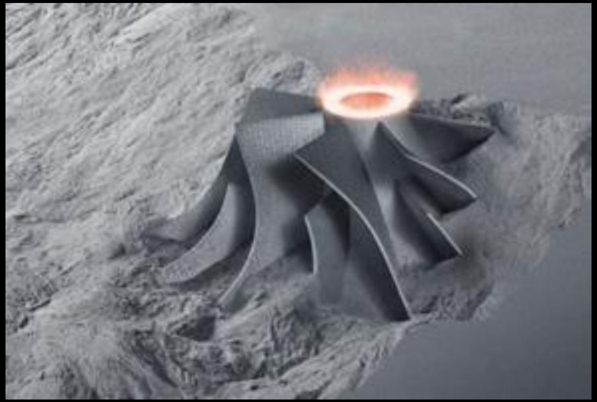
Fused Deposition Modeling
(FDM)



Stereolithography Apparatus
(SLA, DLP, LCD)



Selective laser sintering
(SLS, DMLS, EBM)



Remarks: Multi Jet Fusion (MJF), PolyJet
FDM pellet extrusion (05A) ≈ Paste extrusion. For food, gel, EAP, ceramic, clay, metal

Fused deposition modeling (FDM)

Additive manufacturing process where material is selectively deposited layer by layer.

Materials:

Thermoplastics (PLA, PET, TPU), composites (CF, GF, BP), and specialized filaments (PVA, PVB, Wax)

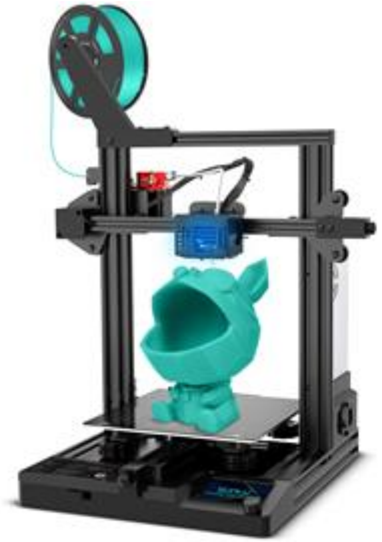
Technique compatible with pellet and paste extrusion

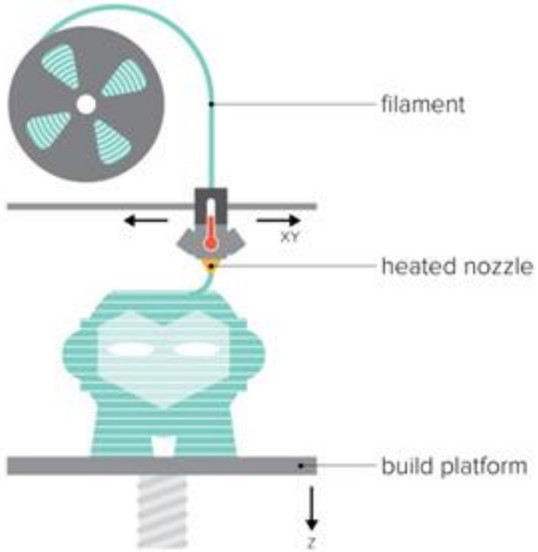
Advantages:

- Easy to use
- Wide range of materials
- Cost-effective for prototyping
- Suitable for functional parts

Limitations:

- Layer lines visible on finished product
- Support structures often required (improved a lot: organic/tree)
- Slower than some other 3D printing methods



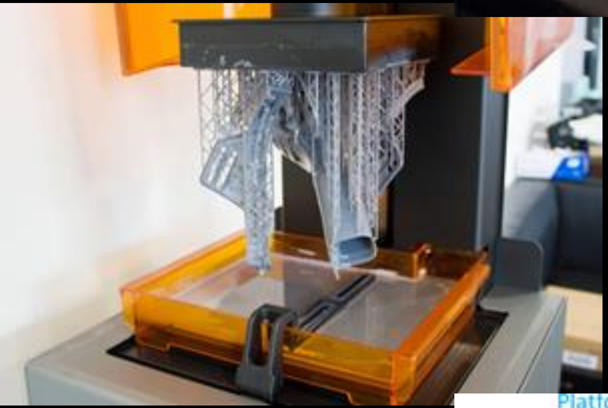


Stereolithography (SLA)

Additive manufacturing process that uses UV light to cure and solidify layers of liquid resin.

Materials:

Photopolymer resins, varying from rigid to flexible, clear to opaque

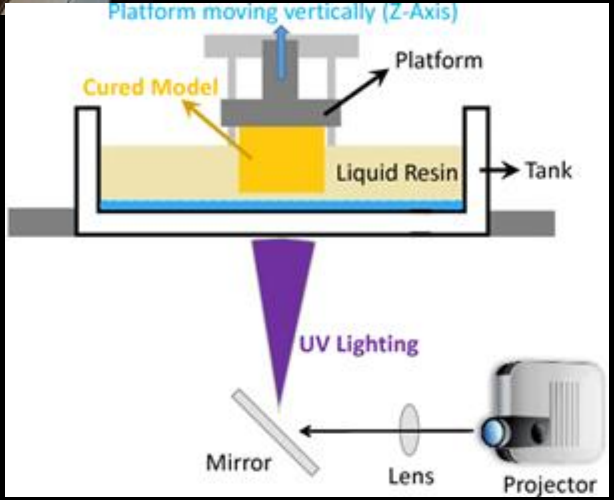


Advantages:

- High precision and detail.
- Smooth surface finish.
- Suitable for intricate designs and molds.

Limitations:

- Expensive
- Slow for single parts
- Hard to remove remaining liquids from cavities
- Has to add drain holes
- Single material
- Post processing: Chemical washing and UV curring



Selective laser sintering (SLS)

Additive manufacturing process where a laser selectively sinters powder material layer by layer.

Materials:

Nylon (Polyamide), glass-filled nylon, TPE (thermoplastic elastomer), **Metals, and ceramics.**

Advantages:

- No support structures needed; overhanging parts are supported by unsintered powder
- Good mechanical properties
- Ability to produce complex geometries and internal structures
- Thermally resilient

Limitations:

- Rougher surface finish compared to SLA
- Limited material color choices
- Limited cavities (drain powder?)
- Single material !

Print speeds

		FDM	SLA	SLS
 Split Duct	**Small Part**	FAST 150 - 340 minutes	FAST 75 - 350 minutes	120-200 minutes
 Pump Housing	**Medium Part**	SLOW 420 - 1275 minutes	FAST 150 - 660 minutes	660 minutes
 Razor Heads	**Multiple Parts**	SLOW 21 parts 690 - 1710 minutes 33 - 81 minutes per part	12 parts 90-420 minutes 7,5-35 minute per part	FAST 300 parts 2400 minutes (40 hours) 8 minutes per part

Still improving (Bambu)

Printing technique selection

In most cases
- composite part
- flexible part
- tough part (HT materials PEEK & Continuous CF Markforge)

→ **FDM**

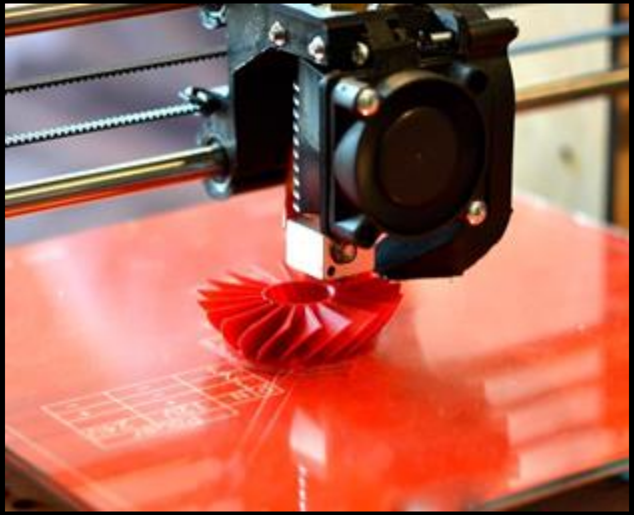
Part with high resolution
- very fine structures
- flexible part

→ **SLA**

Strong parts
- especially tough part
- conductive part

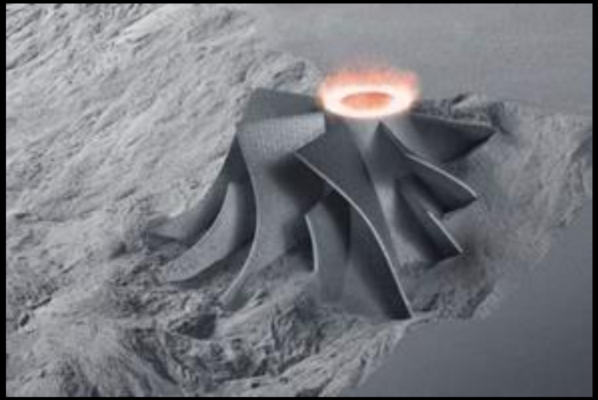
→ **SLS**

Fused deposition modeling (FDM)

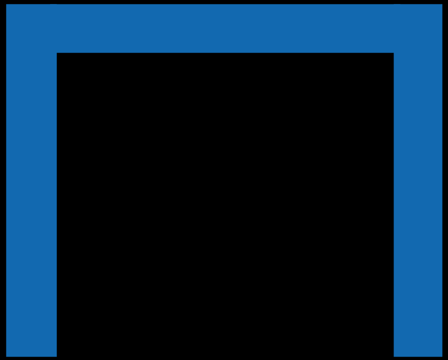


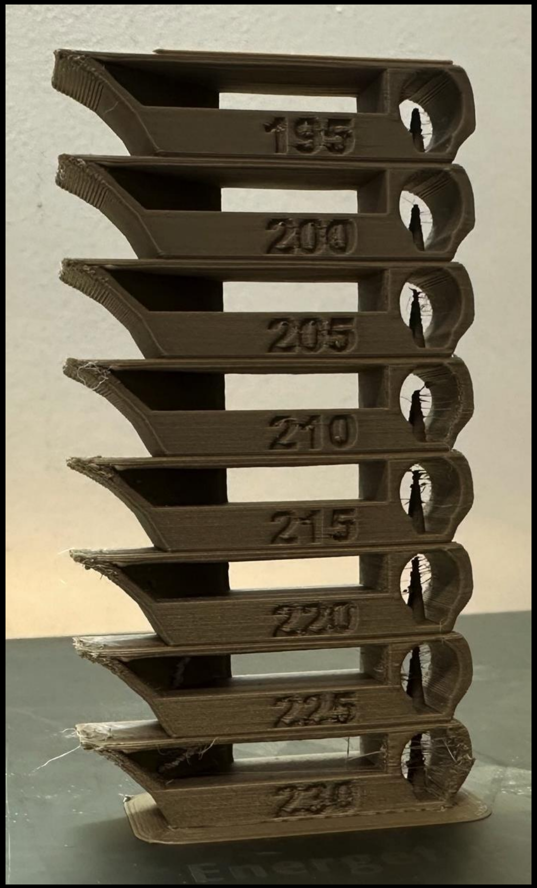
Stereolithography (SLA)

Selective laser sintering (SLS)

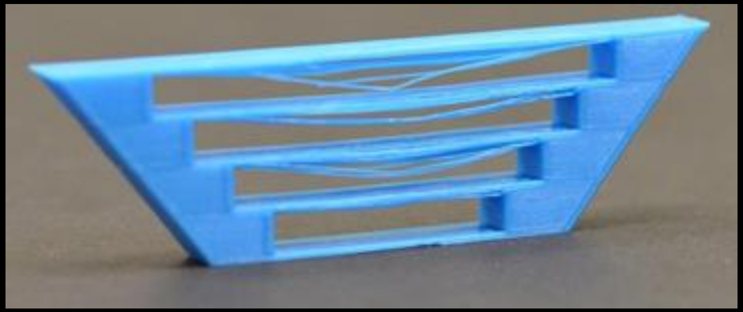


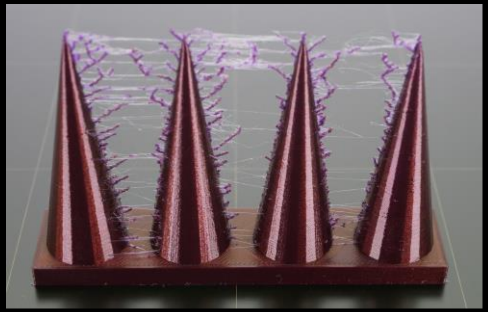
FDM: Bridges and overhangs





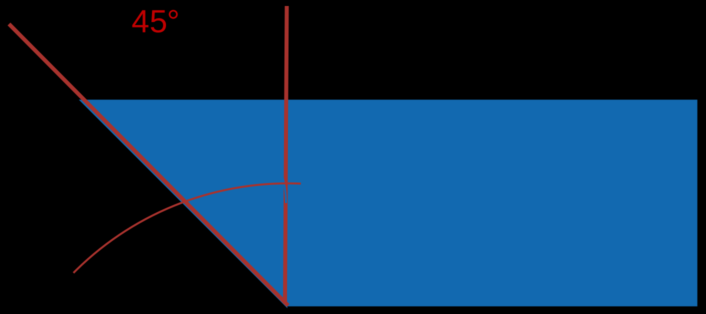
Any doubt?
Use test structures
- stringing
- oozing
- temp
- overhang

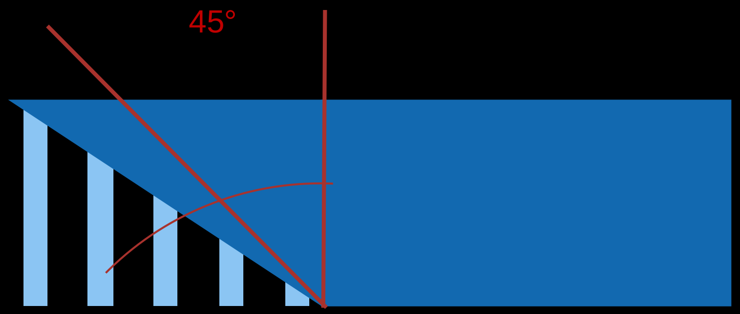




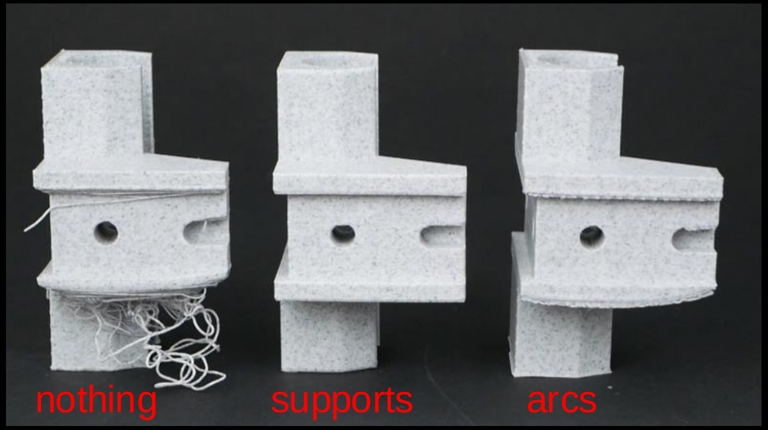
FDM: Overhang limitations

Generally supports are created, when an overhang steeper than 45° exists. At angles smaller than this the printer can simply print the overhang on the existing layer.





But technique is still improving



FDM: Strength of printed parts

Material choice
Stiff/hard/strong/tough
Check the technical datasheet values (cf)

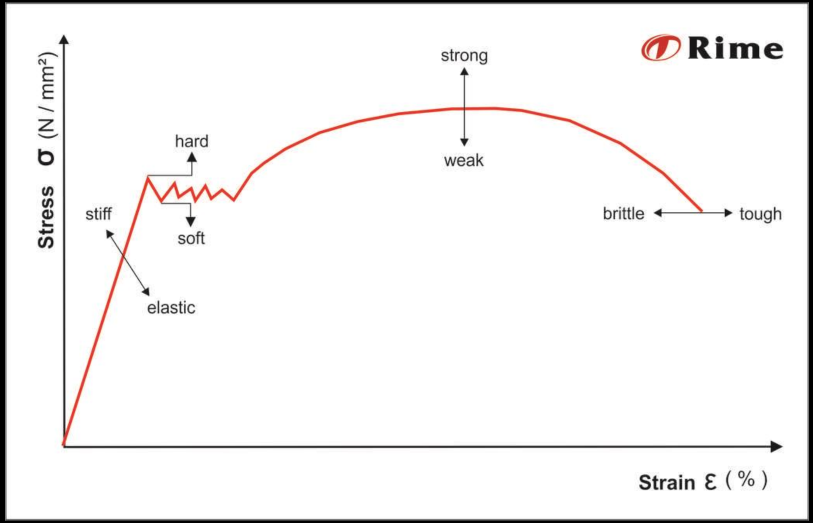
Orientation
Parts are a lot weaker in the z-direction, perpendicular to the layers
Mind the print orientation of your part (Bambu auto orient)
You can split your model into several parts (Prusaslicer cut)

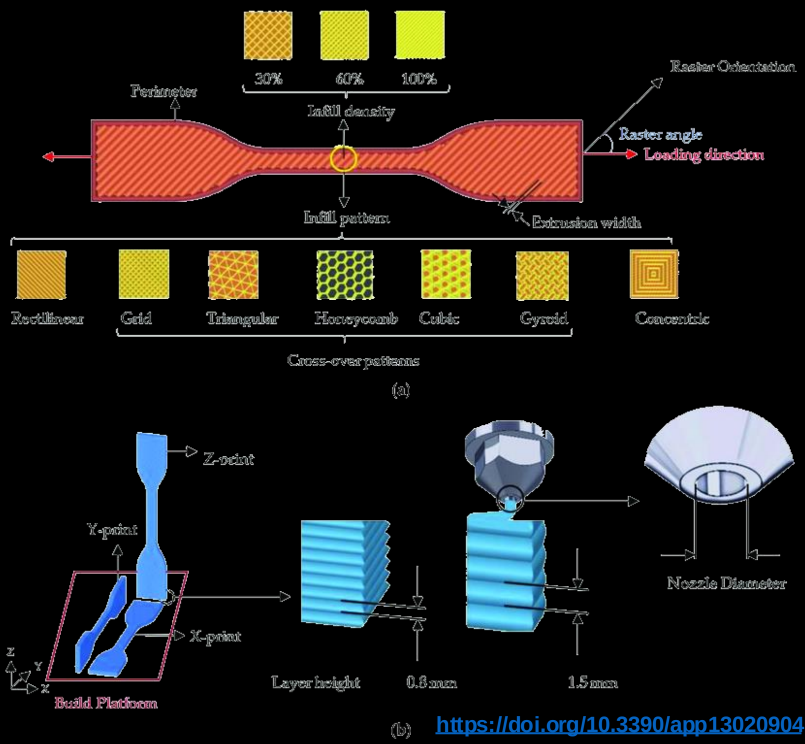
Infill
Isotropic (gyroid), not isotropic (honeycomb)
Layer height (0.15 is good)

Wall thickness
3 is the optimal strength/weight

Ext. width, Temp, color …

https://rime.de/en/wiki/stress-strain-curve/





https://doi.org/10.3390/app13020904

In practice for this class

What printer?
What you really need - what you can get (cost) → FDM

Prusa MK3S+ is ok
0.4mm nozzle is ok
single material

What materials?
PLA is among stiffest, easy and cheap, PLA+ is tougher.
PETG is flexible, easy and cheap too
TPU 98A-85A is soft and remain accessible (medium cost and difficulty)
No ABS (TOXIC)

no need enclosure
no harden steel nozzle
dry box is a plus

What Slicer?
The official slicer of the printer (bundle)
or any another one IF possible.

Prusaslicer
Bambu, Orca …

Supports?
Don’t be afraid, organic supports do a good job

Design Tips for FDM 3D Printing

Bridging:
Recommended Value: <10 mm

Feature Size:
Recommended Value: 4-3 times extrusion line width (Prusa MK3S+ 0.4mm nozzle Ø, 1.6mm feature size)

Wall Thickness
Recommended Value: > 0.9 mm (2-3 times extrusion line width)

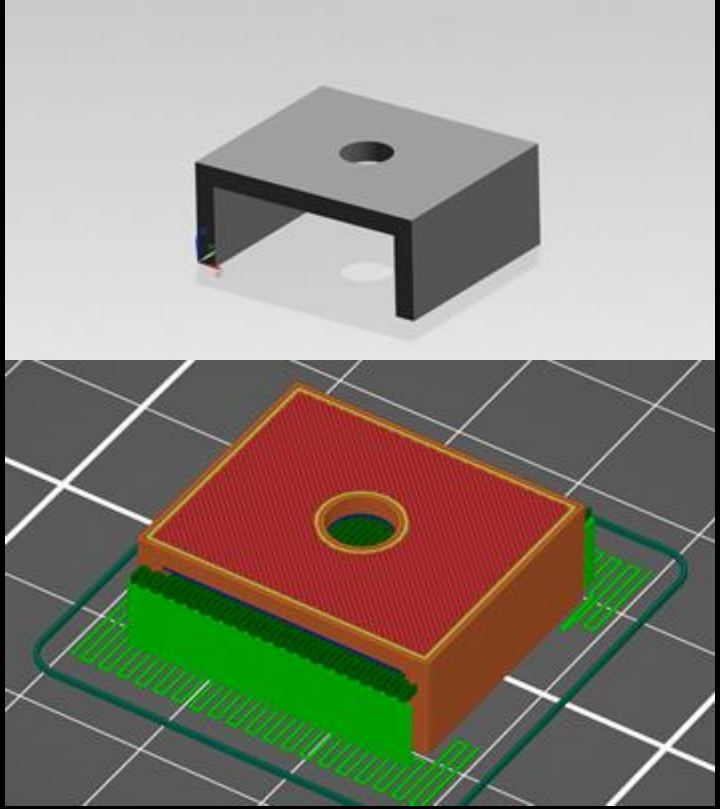
Speed
Not too fast but not too slow. Depends on the printer (nozzle, heat block, input shaping) and material (High speed, flexible). Start conservative **using presets** and then increase

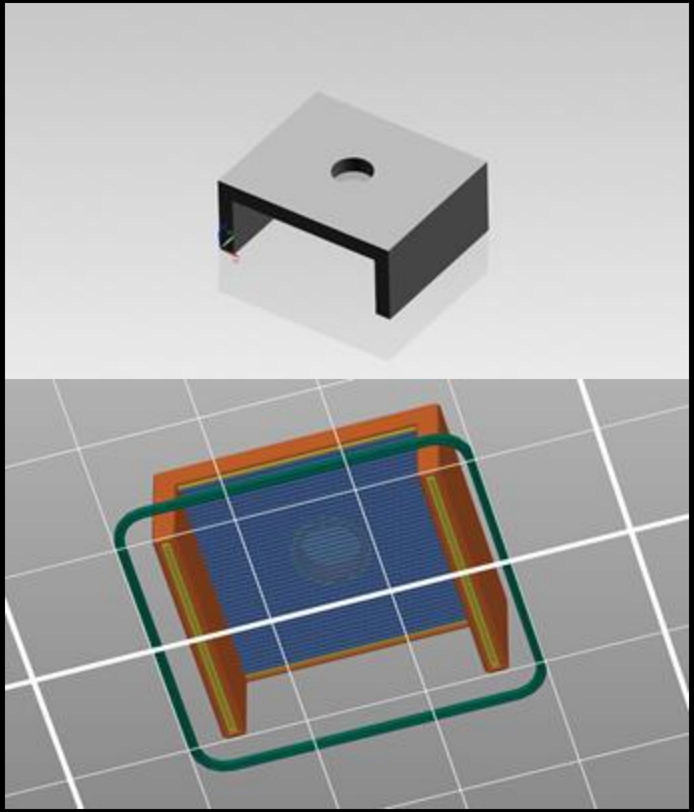
*For soft TPU you must print it very slowly. Release the tension on the gear at maximum and remove as much resistance upstream (friction) and down stream (higher temp, not too close from the bed) as possible. Little to no retraction. Use glue stick on the bed before because TPU stick a lot and might not come off.

https://www.youtube.com/watch?v=iWZw7RO2Sks
https://www.youtube.com/watch?v=4InFd5DoZa4

Design Tipps: Holes (For screws, Tubes, etc)

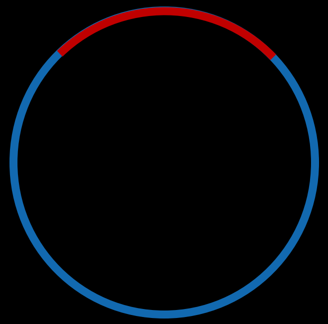
When modelling vertical holes for screws, tubes etc, it might make sense to add a single solid layer, so bridging is possible and supports can be avoided.



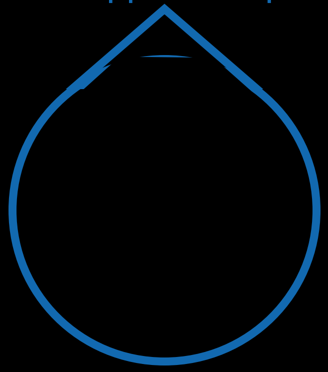


When modelling horizontal, supports could be generated, because the top side of the hole has an overhang greater than 45°. To avoid this, hole can be modeled in a teardrop shape.

Supports required

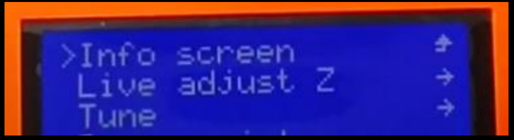


No supports required



Design Tipps: First layer and Elephant foot print

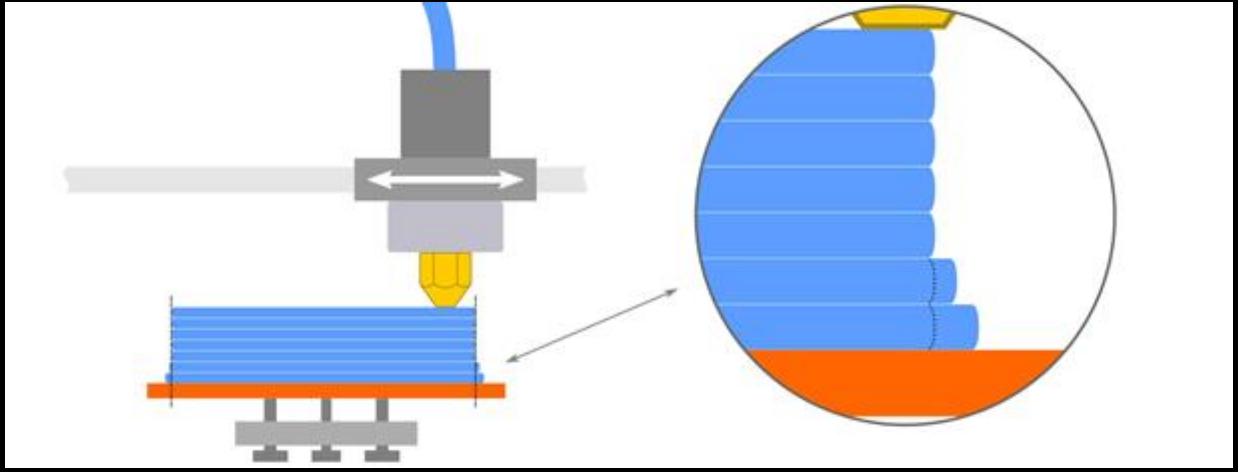
Your first layer is the most important. Use a one loop skirt and stay to watch it at the beginning of your print. If the plastic line is too flat or fine, it means you are too close to the print bed. If the line is circular or move, it means you are too far from the print bed. → clic the printer and select «Live adjust Z» and move up (decrease) or down (increas) to get a the perfect first layer



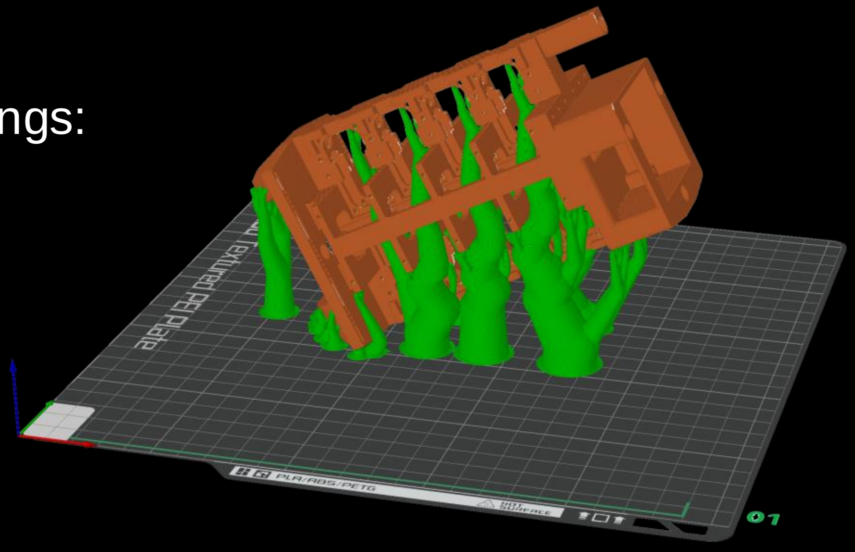
If the first layer does not stick (finger grease), clean the bed with isopropanol

Filets are round and might cause an overhang that is greater than 45°. You can use chamfers instead

The bottom of the print might be wider than expected due to elephant foot effect (which is good).
You can compensate for it adding 0.2mm to the «elephant foot compensation» parameter in prusa



Slicing Parameters: Model orientation



When orienting your model on the print plate consider the following things:

- Will there be support-material generated in the current orientation?
- Round shapes parallel to the print bed for better resolution
- enough surface area for sticking?
- Will there be support material in unreachable areas?
- Can I split the model to make it easier to print?
- Printing in z-direction generally takes longer than printing in x/y-direction. Orient your model accordingly.

Useful tutorial links

https://www.youtube.com/watch?v=GE-lrRbU124

https://www.youtube.com/watch?v=_klqMPNQNSw

Silicon casting