

Print-and-Play Fabrication

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Acknowledgements





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Jess McIntosh



Osamu Fujimoto



Raf Ramakers



Sebastian Boring



Zhiyuan Li



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Hyunyoung Kim



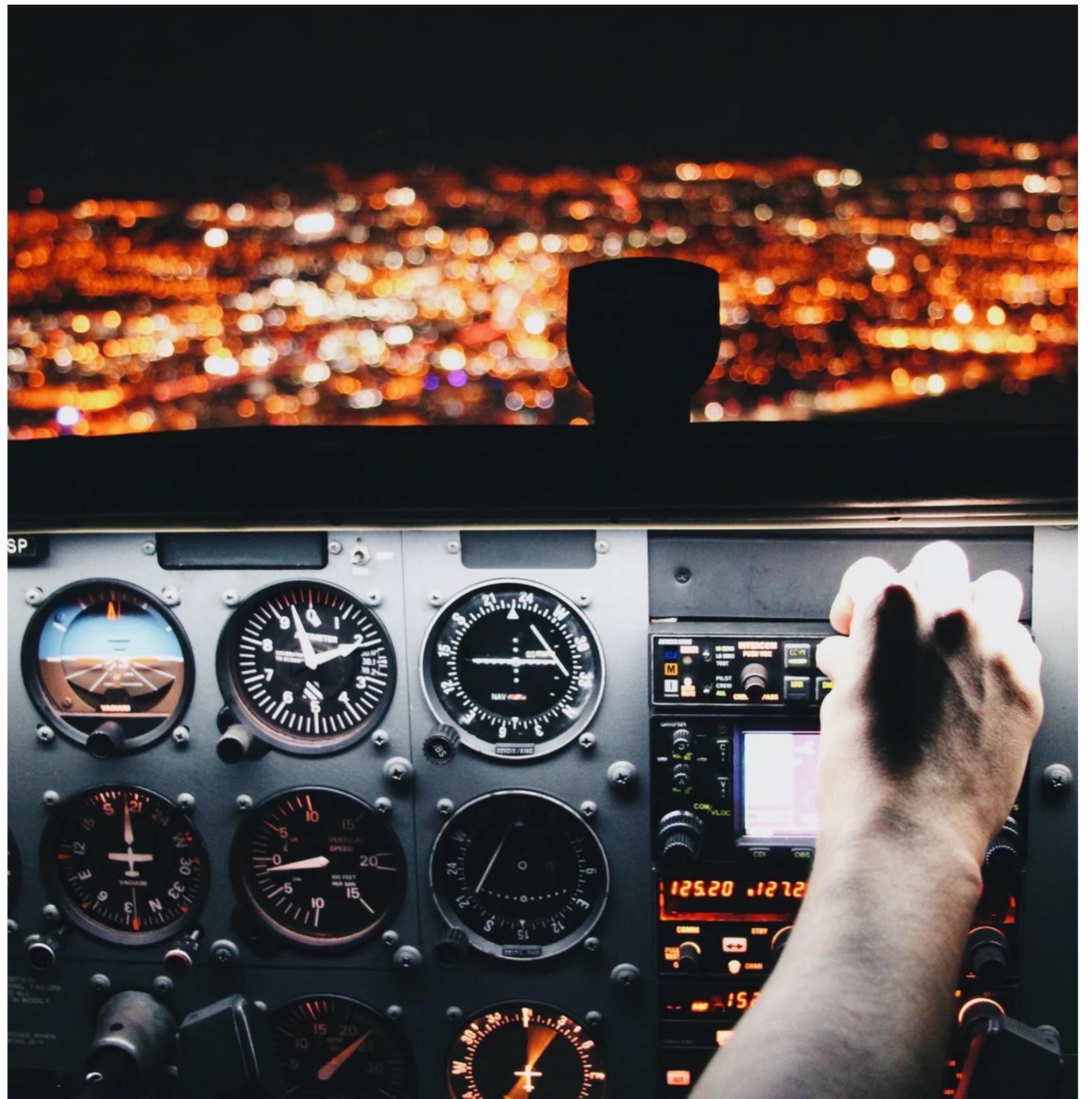
Aluna Everitt



Asier Marzo

Background

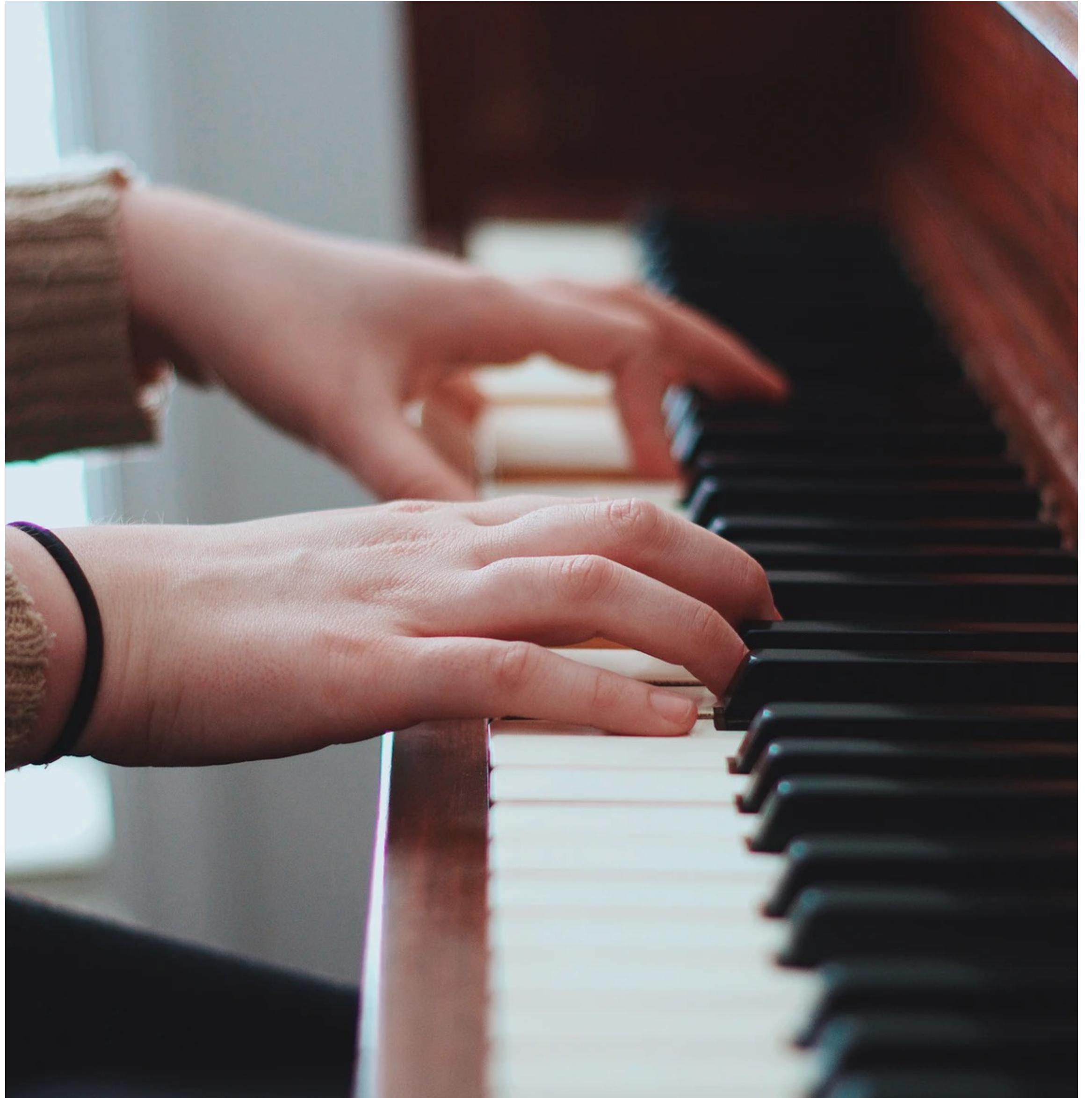
Importance of Physicality



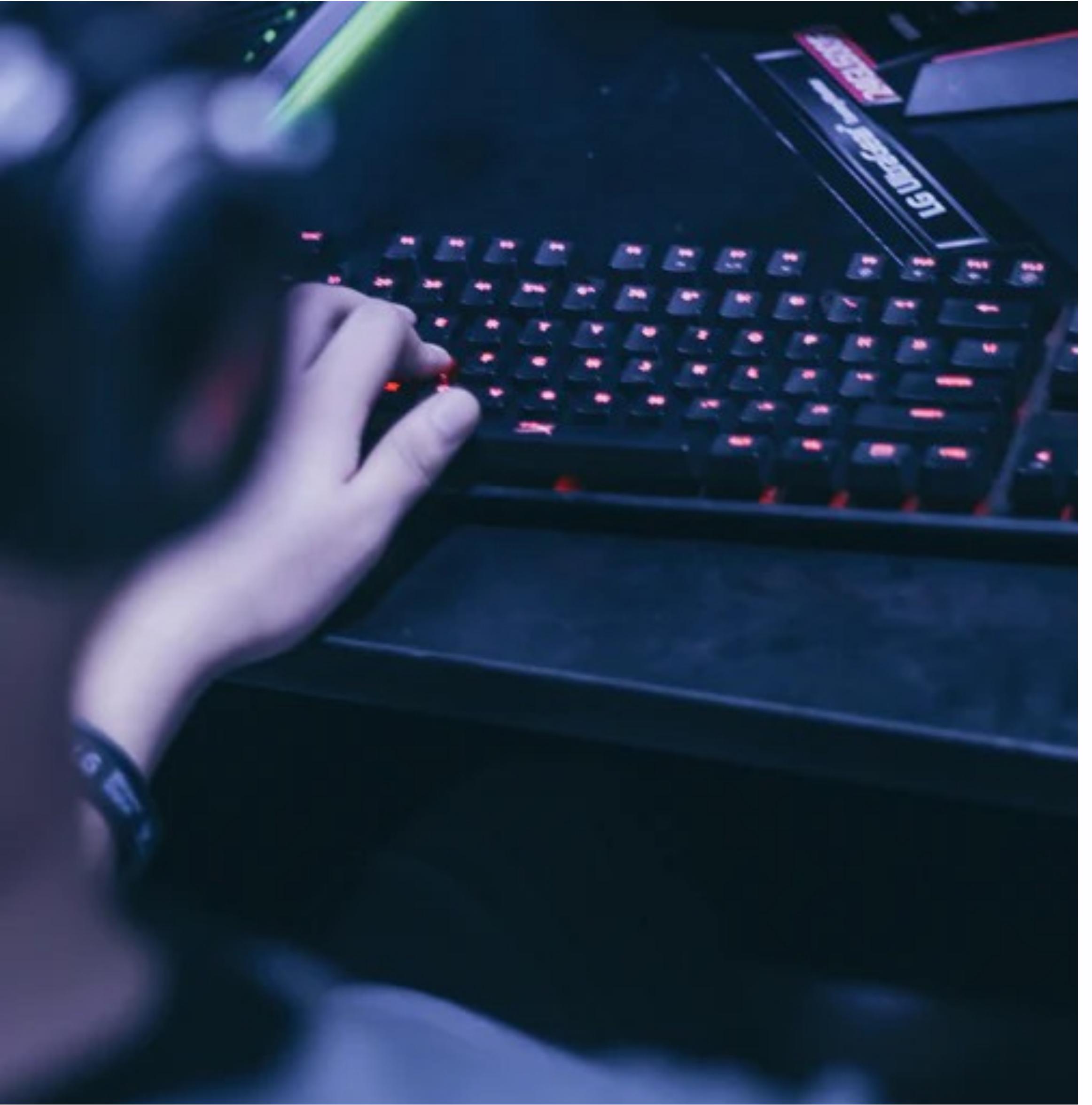
Importance of Physicality



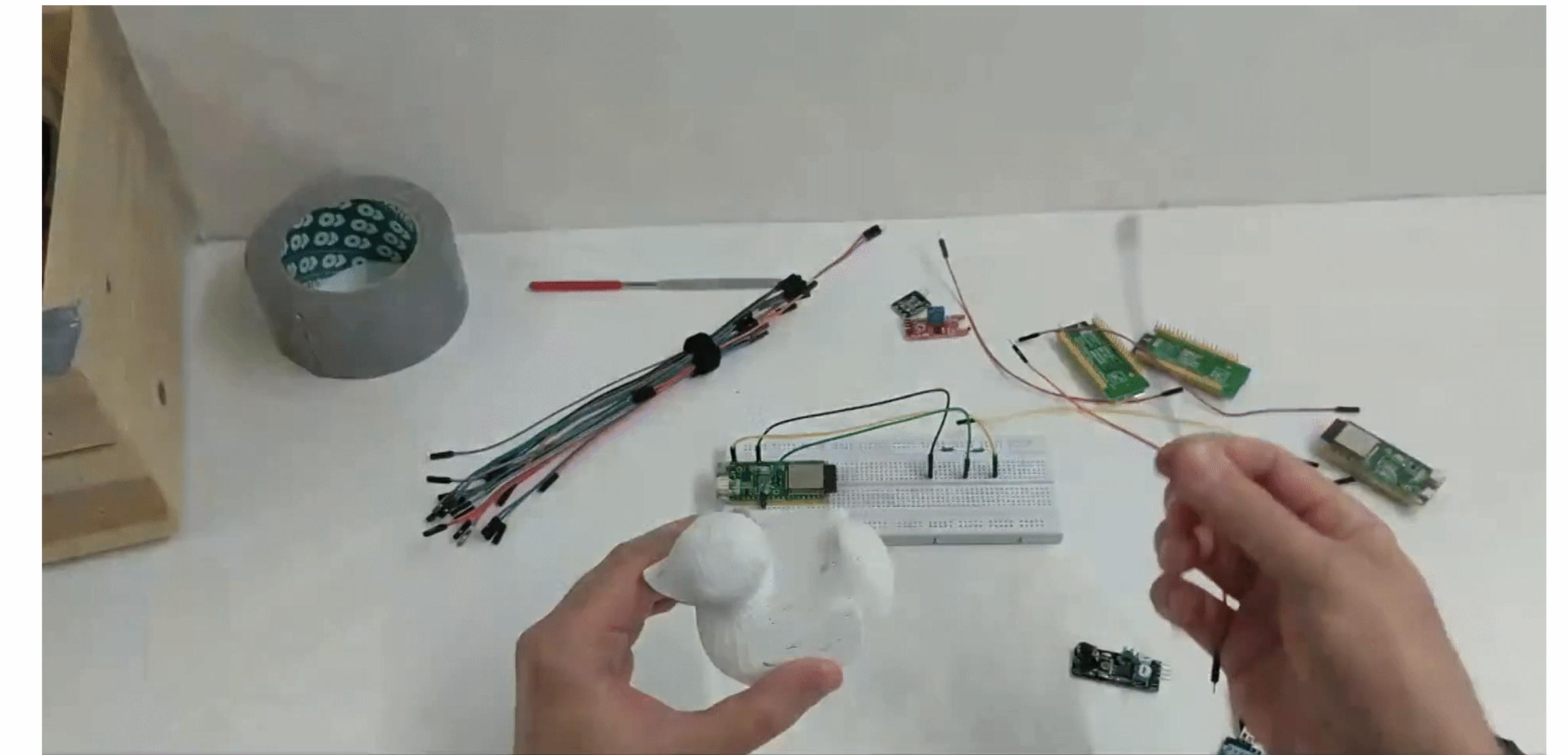
Importance of Physicality

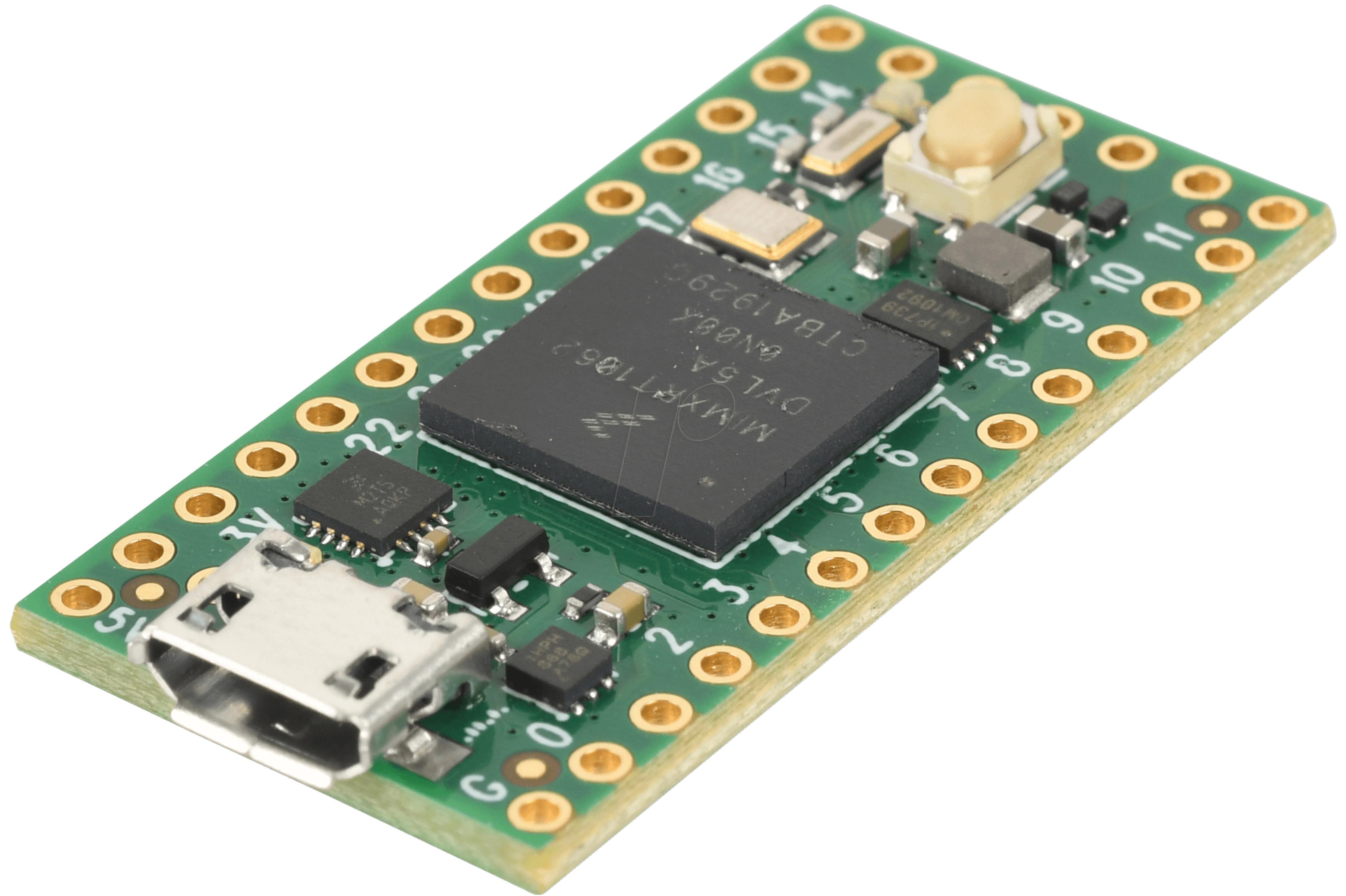


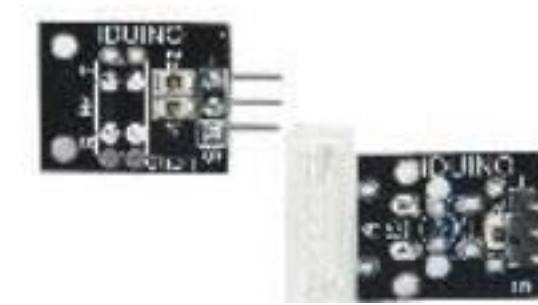
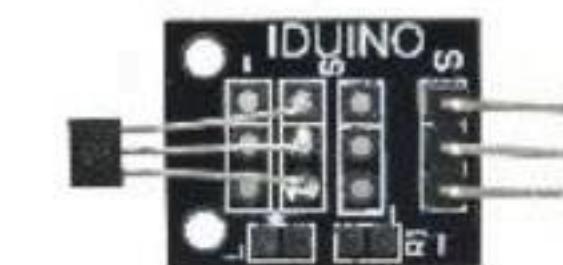
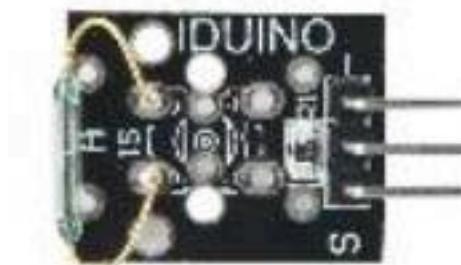
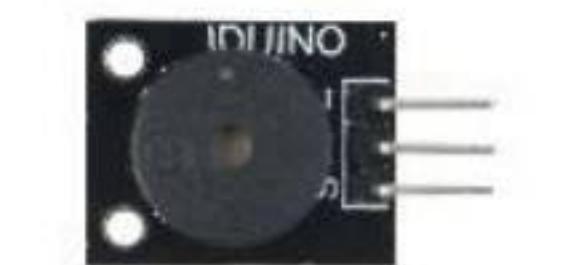
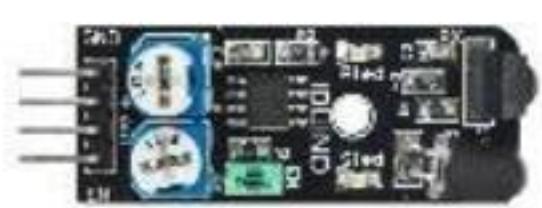
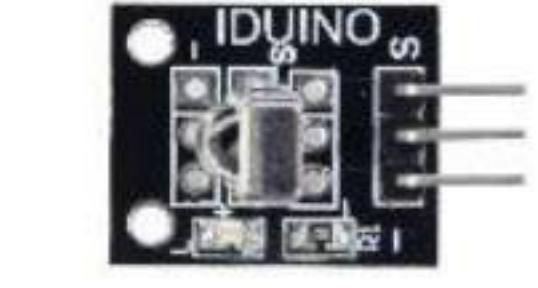
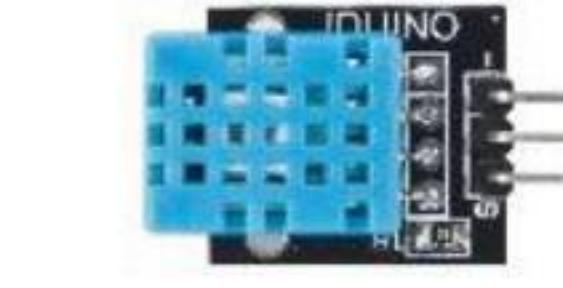
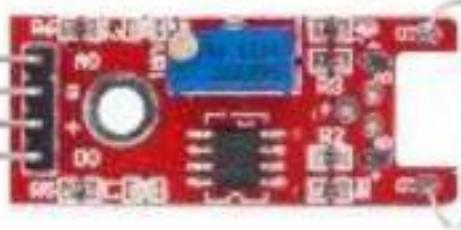
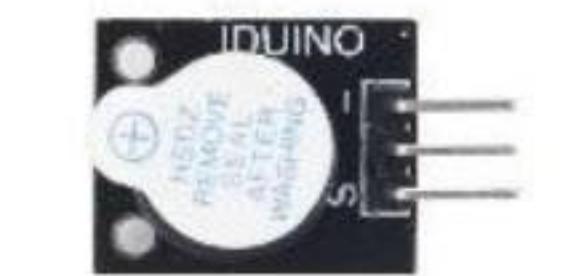
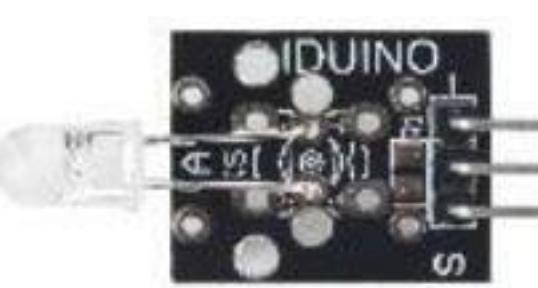
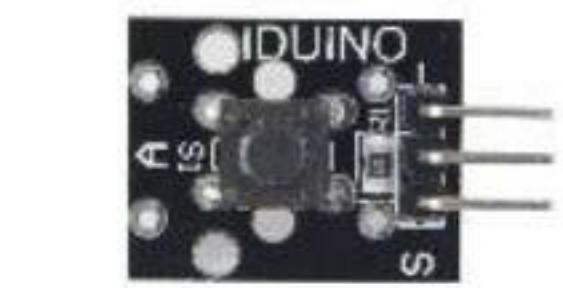
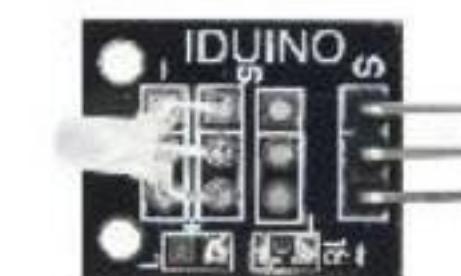
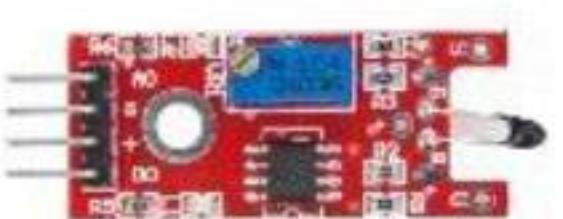
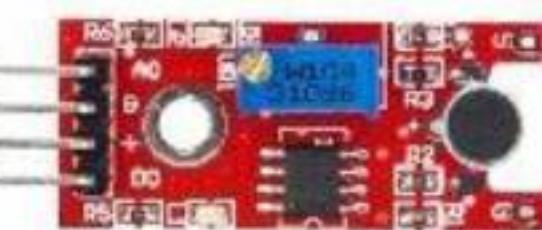
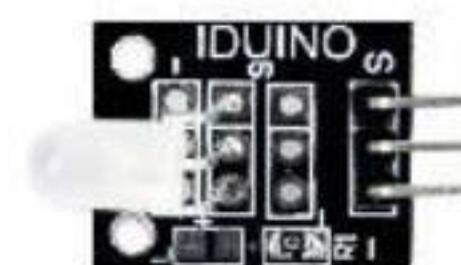
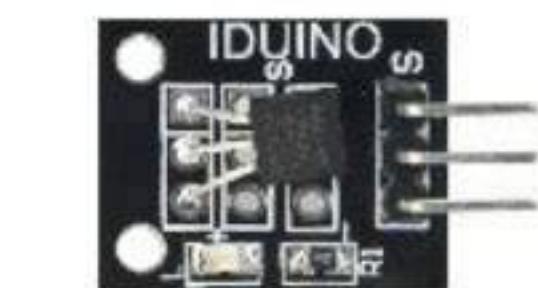
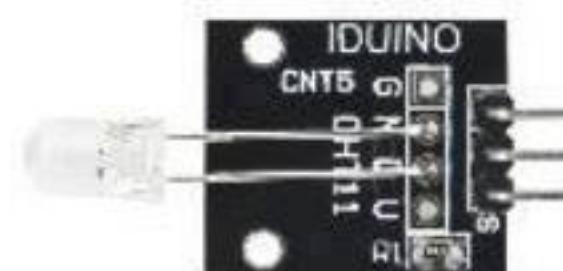
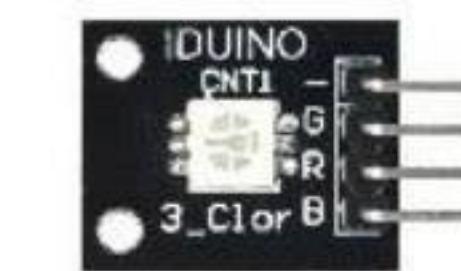
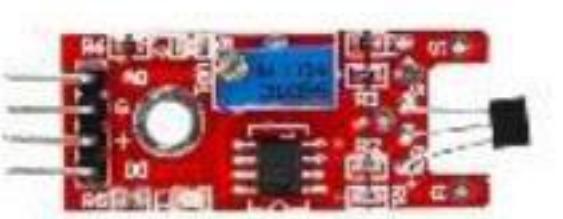
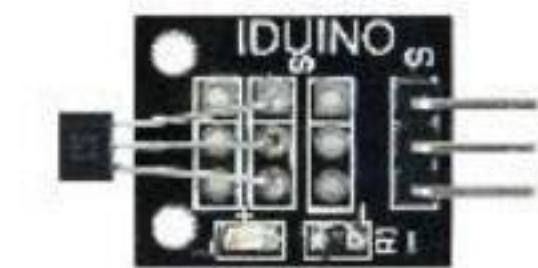
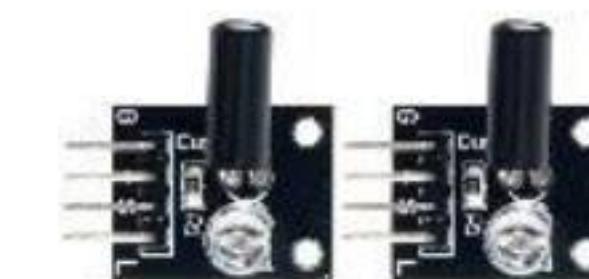
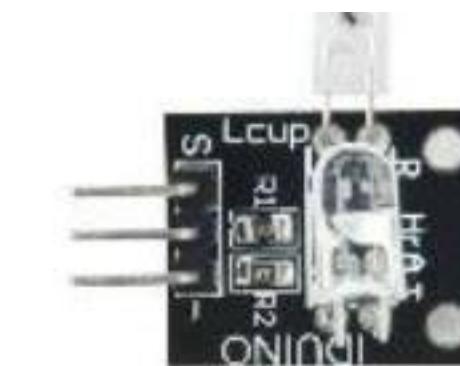
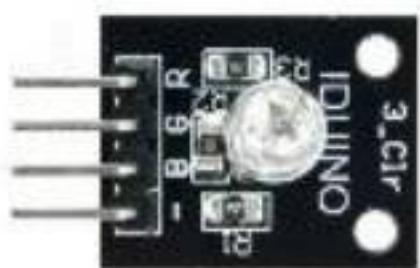
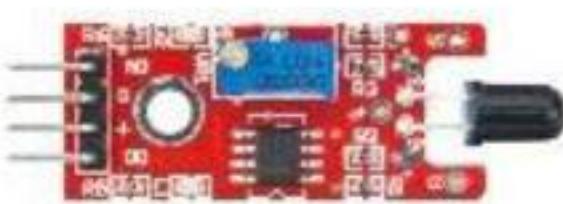
Importance of Physicality



Constructing
interactive physical
devices is hard

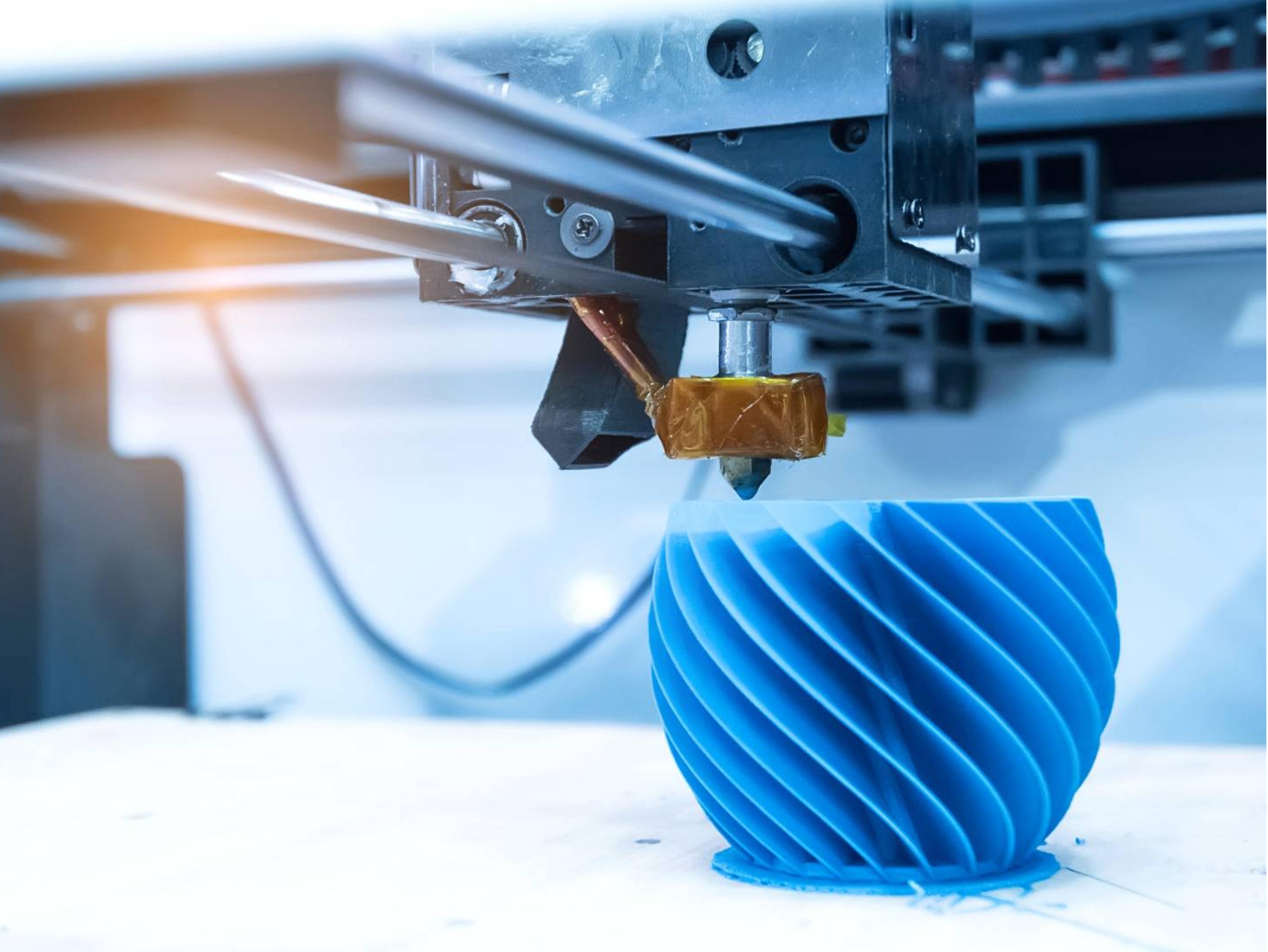


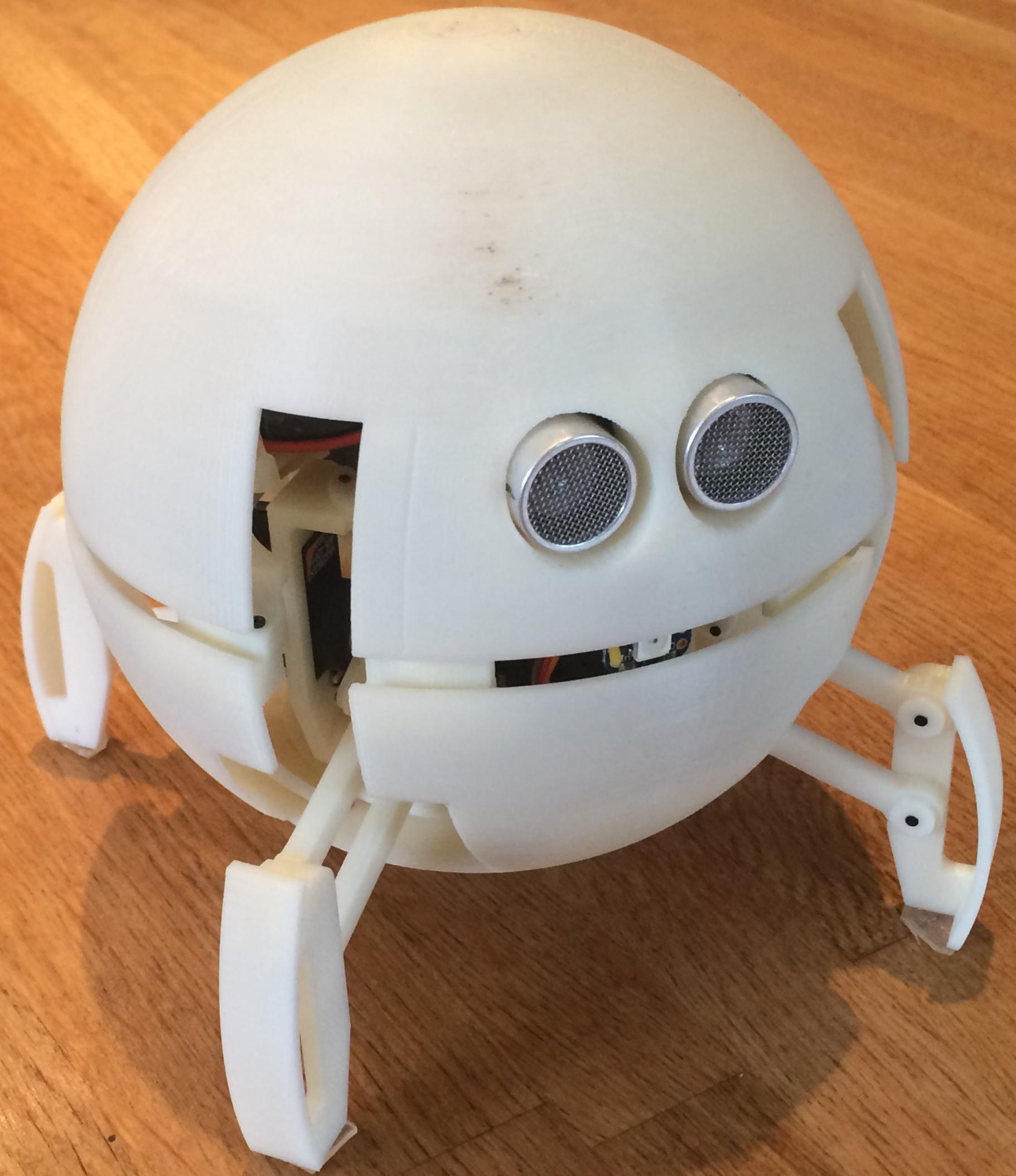






```
31     def __init__(self, path=None):
32         self.file = None
33         self.fingerprints = set()
34         self.logduplicates = True
35         self.debug = debug
36         self.logger = logging.getLogger(__name__)
37         if path:
38             self.file = open(os.path.join(settings['LOG_DIR'],
39                                         'fingerprint.log'), 'a')
40             self.file.seek(0)
41             self.fingerprints.update(fp.read())
42
43     @classmethod
44     def from_settings(cls, settings):
45         debug = settings.getbool('FINGERPRINT_DEBUG')
46         return cls(job_dir(settings), debug)
47
48     def request_seen(self, request):
49         fp = self.request_fingerprint(request)
50         if fp in self.fingerprints:
51             return True
52         self.fingerprints.add(fp)
53         if self.file:
54             self.file.write(fp + os.linesep)
55
56     def request_fingerprint(self, request):
57         return request_fingerprint(request)
```



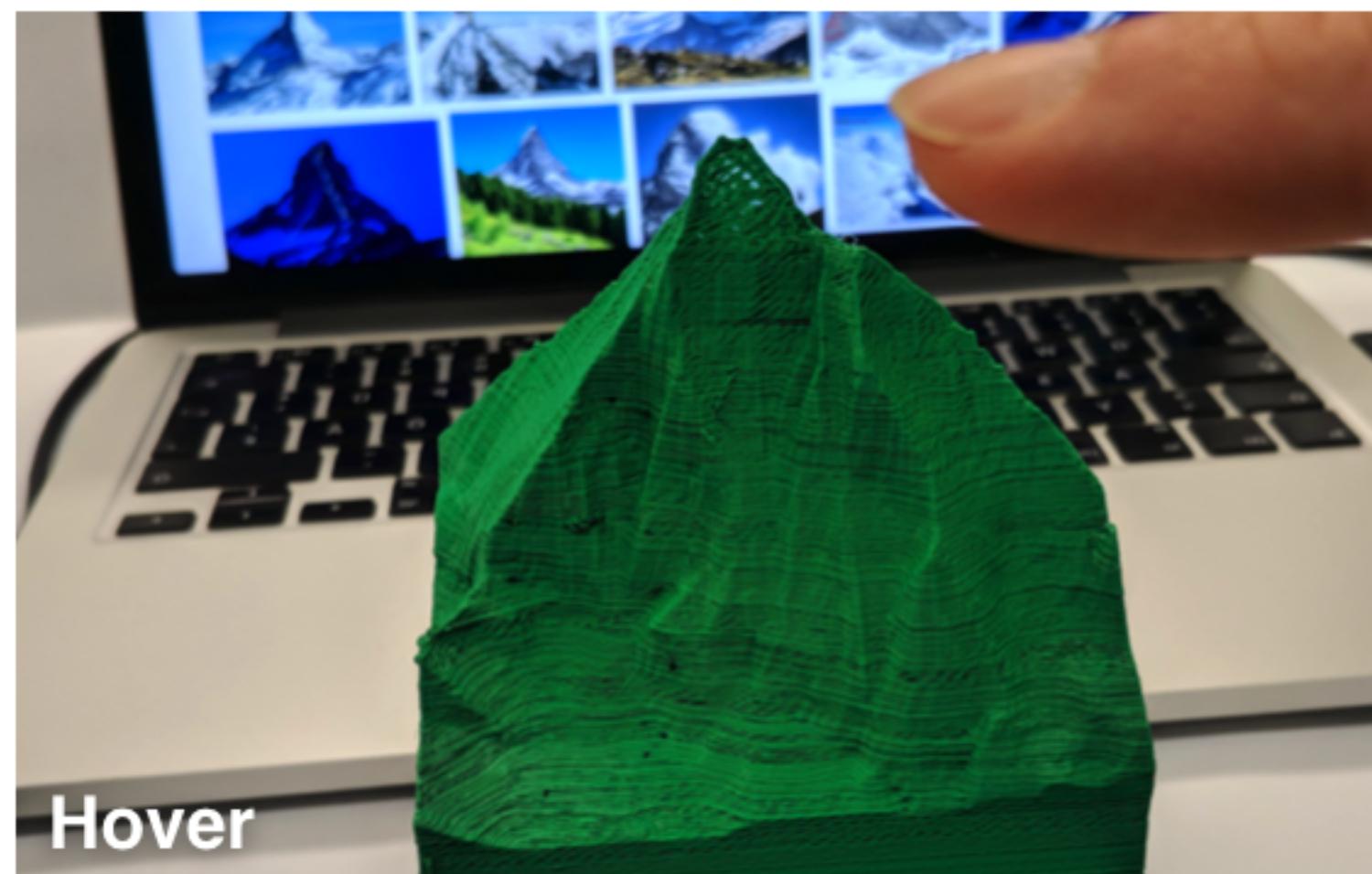


Not trivial

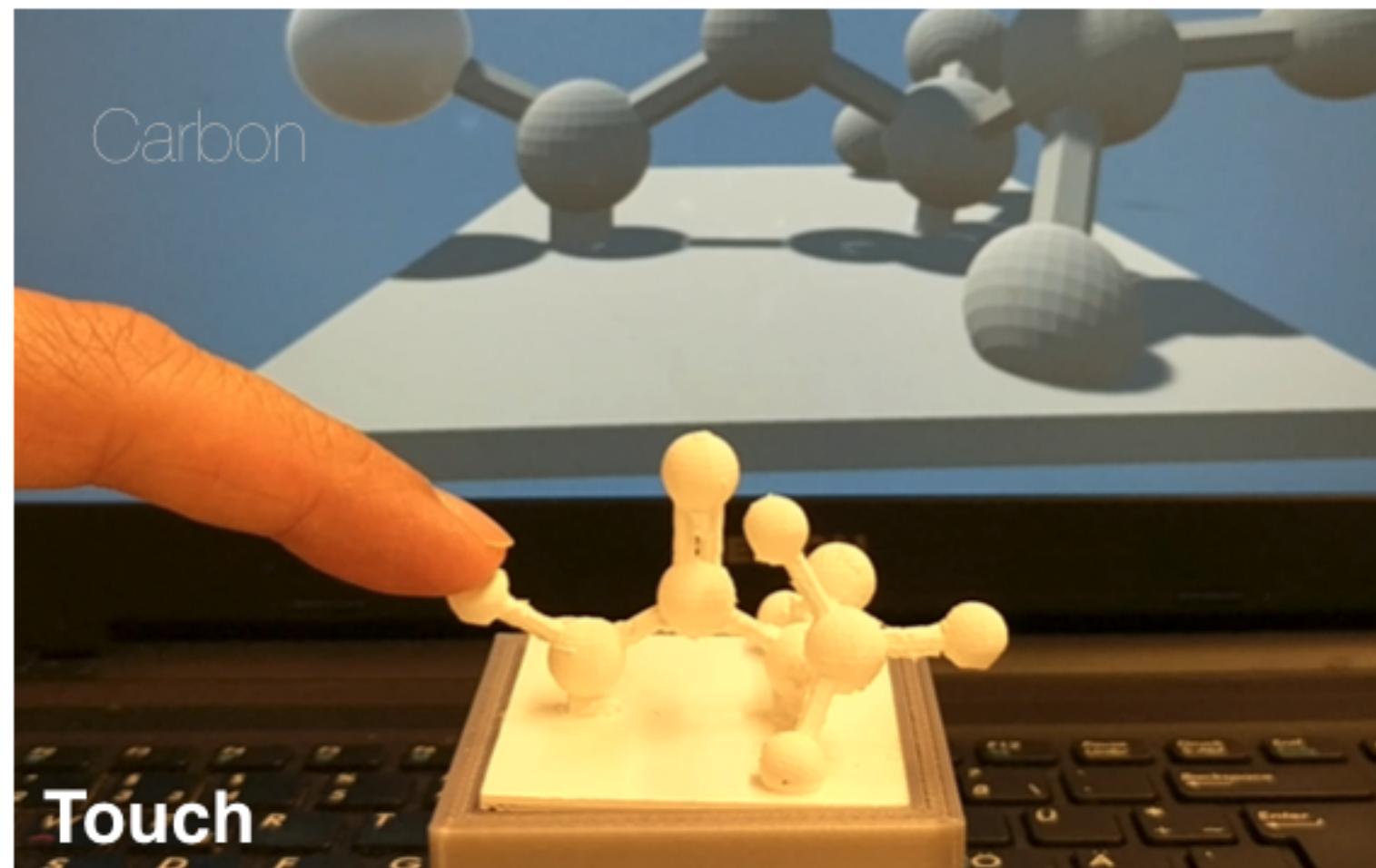
Not trivial

- Users need to have:
 - Electrical engineering expertise.
 - Programming knowledge.
 - Time to test and debug.
 - 3D Modeling expertise.

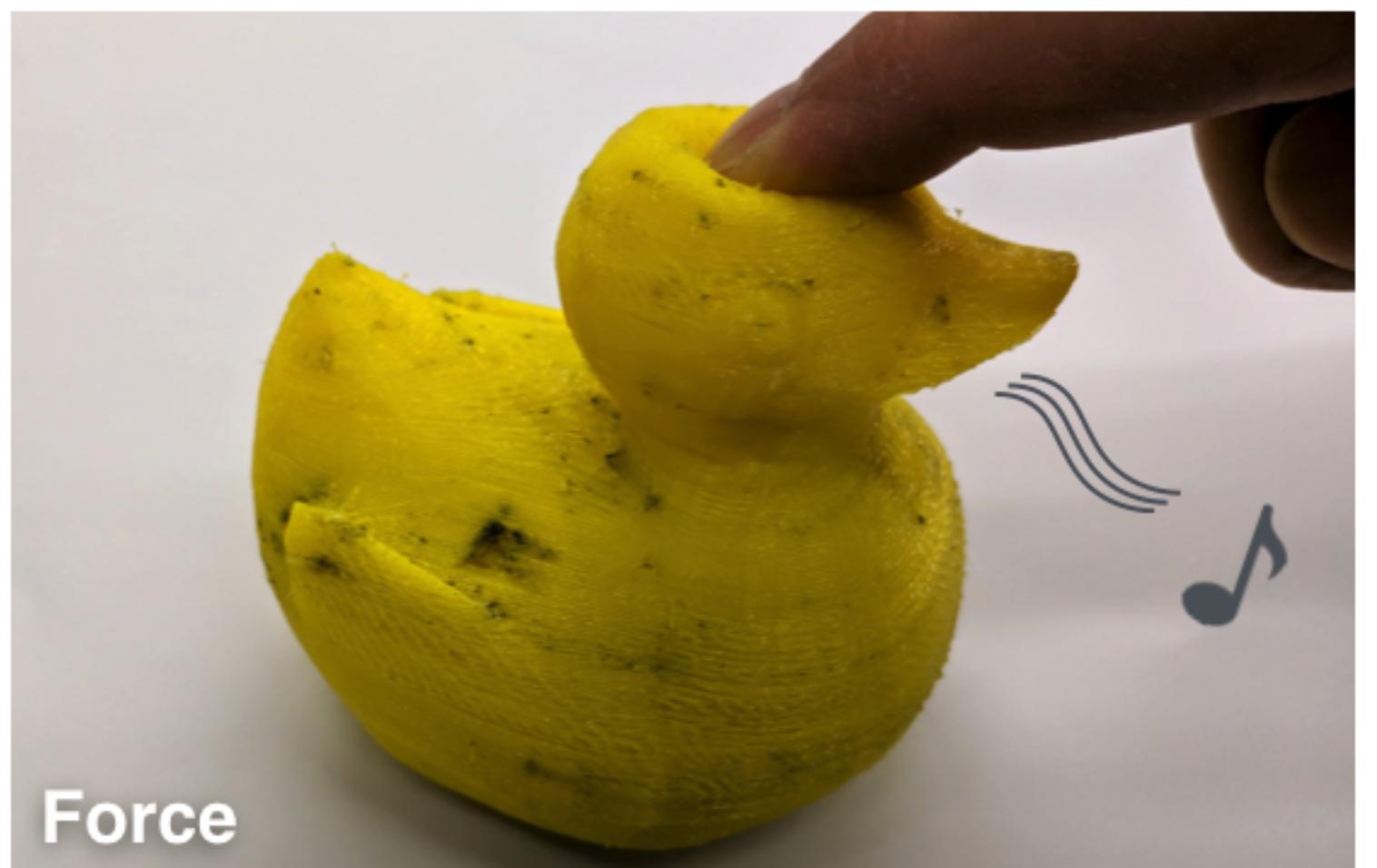
Research



Hover



Touch

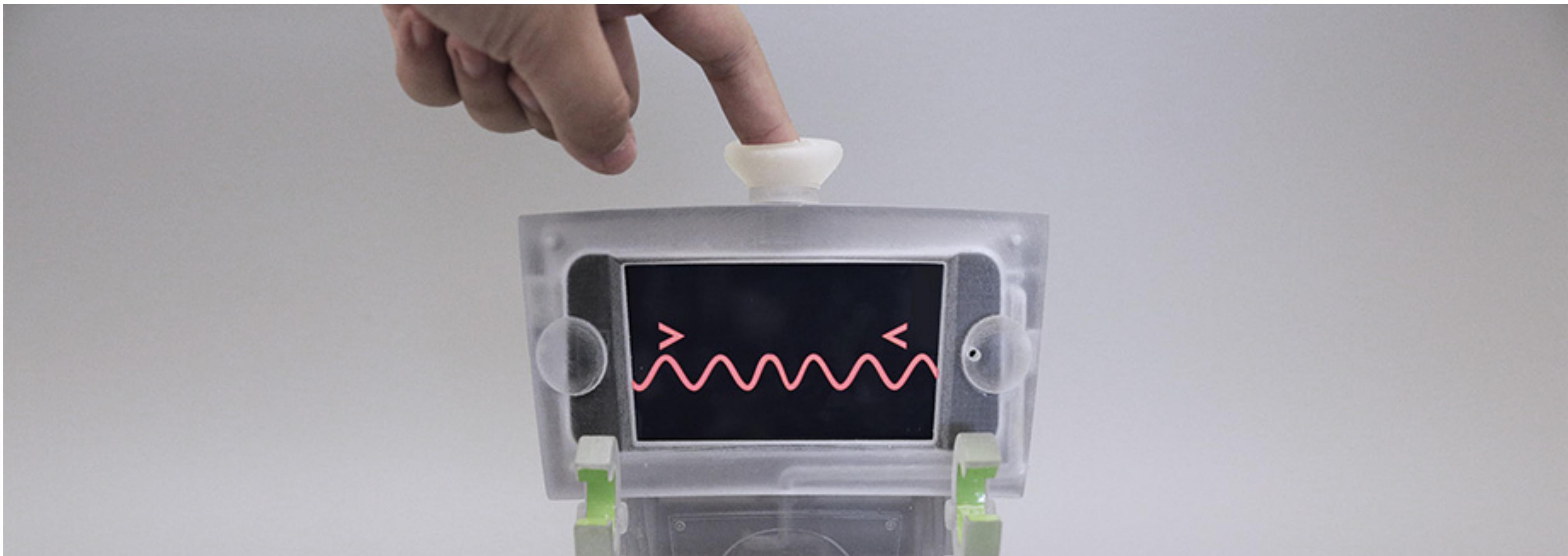


Force

./trilaterate: Schmitz et al.
CHI '19



Touch & Activate: Ono et al.
UIST '13



Acoustruments: Laput et al.
CHI '15



Tickers and Talkers: Shi et al.
CHI '16

Limitations

Limitations

- Become data scientists:
 - Get clean data.
 - Label it.
 - Train a machine learning model.
 - Evaluate its performance

Not trivial



Print-and-Play Fabrication

Print-and-Play Fabrication

Contributions

- Construction of tangible devices without requiring post-fabrication activities.
 - Devices that can sense, process, and provide output to user's interactions
 - Custom interior geometries that leverage well-studied physical phenomena.

Print-and-Play Fabrication

Contributions

- Air-powered techniques.
 - Pressurised sources or from the user's lungs.
 - Why air?
 - Fluid behaviour is widely understood.
 - Can use pre-trained machine learning techniques to identify interaction.

Print-and-Play Fabrication

Contributions

- Off-the-shelf 3D-printers.
- No electronics required.
- No per-object, or per-user training of machine learning models.

Print-and-Play Fabrication

CHI '20

AirTouch

3D-printed Touch-Sensitive Objects Using Pneumatic Sensing

Carlos Tejada

University of Copenhagen



Raf Ramakers

Hasselt University



Sebastian Boring

Aalborg University



Daniel Ashbrook

University of Copenhagen



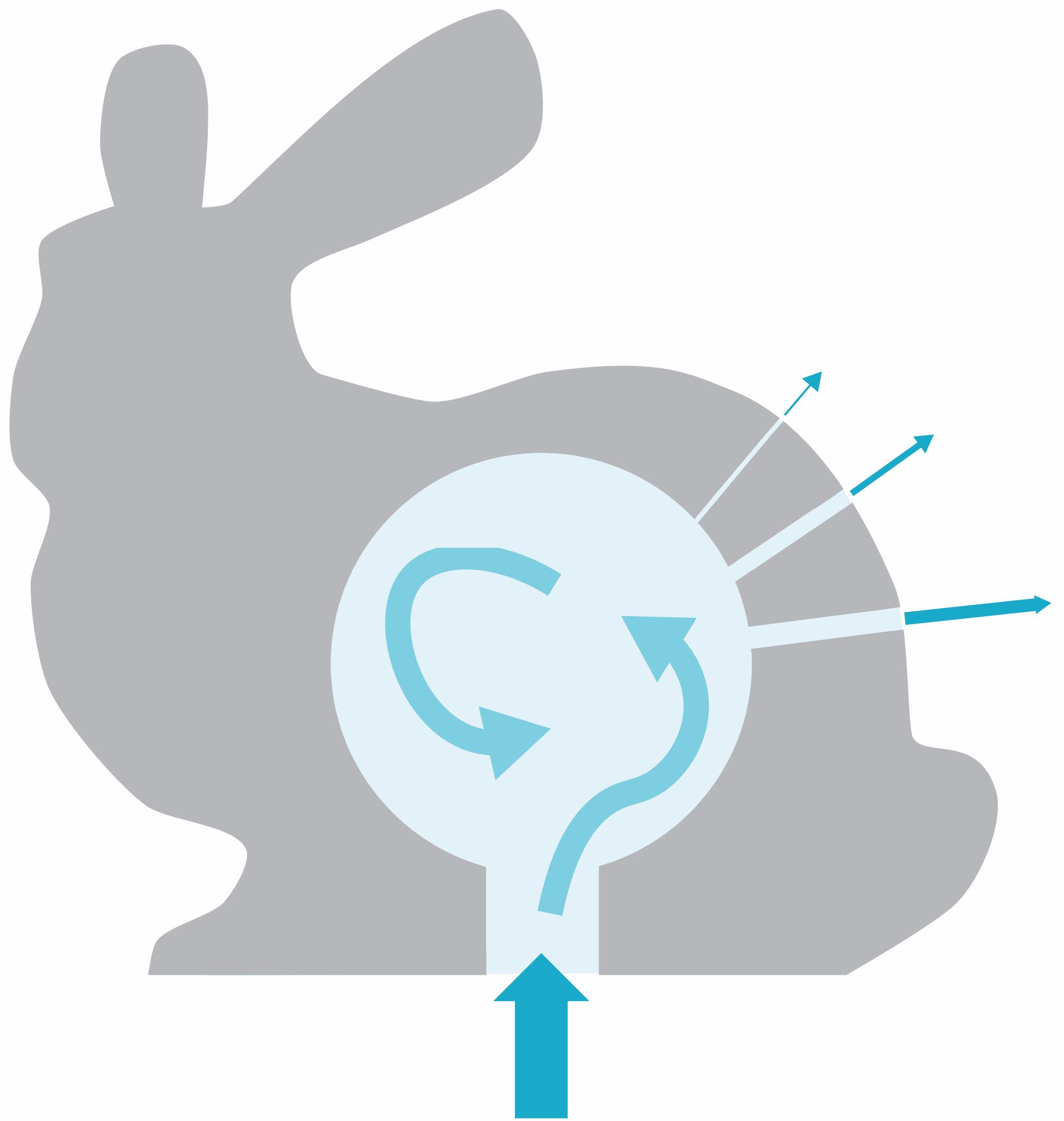
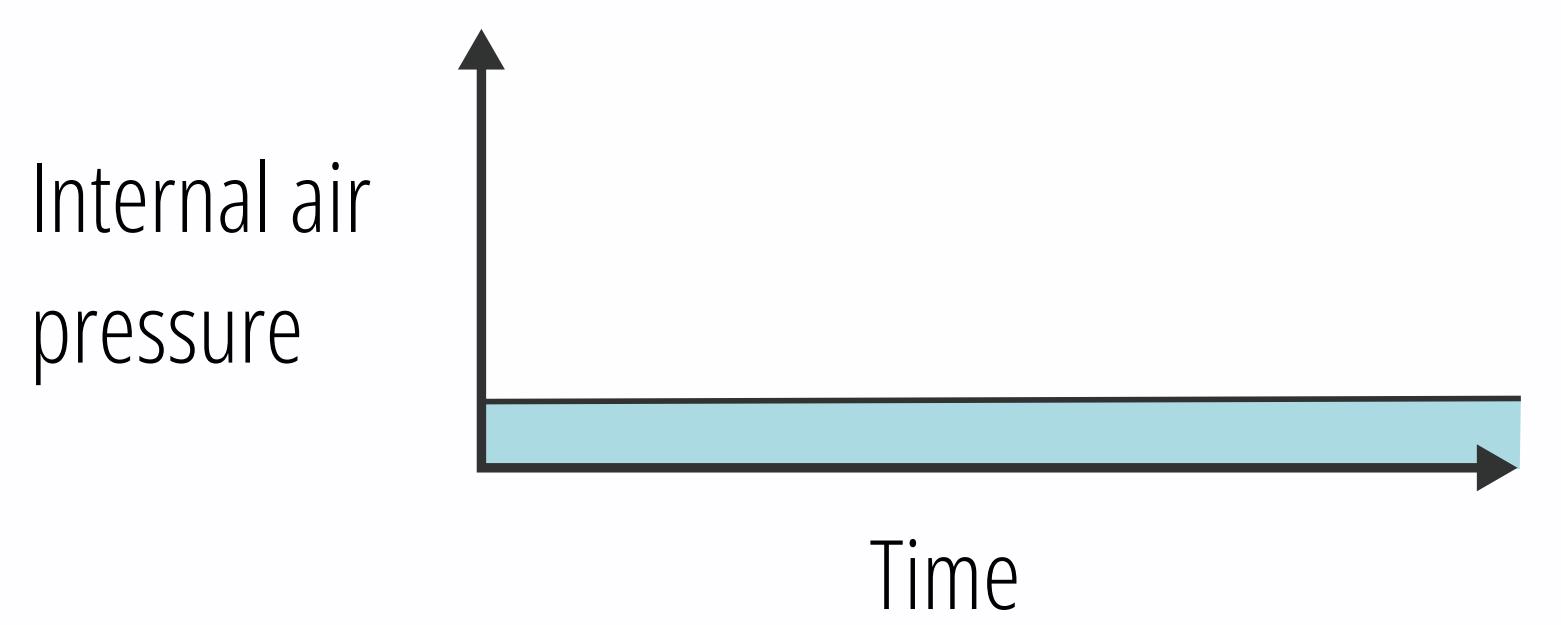
AirTouch

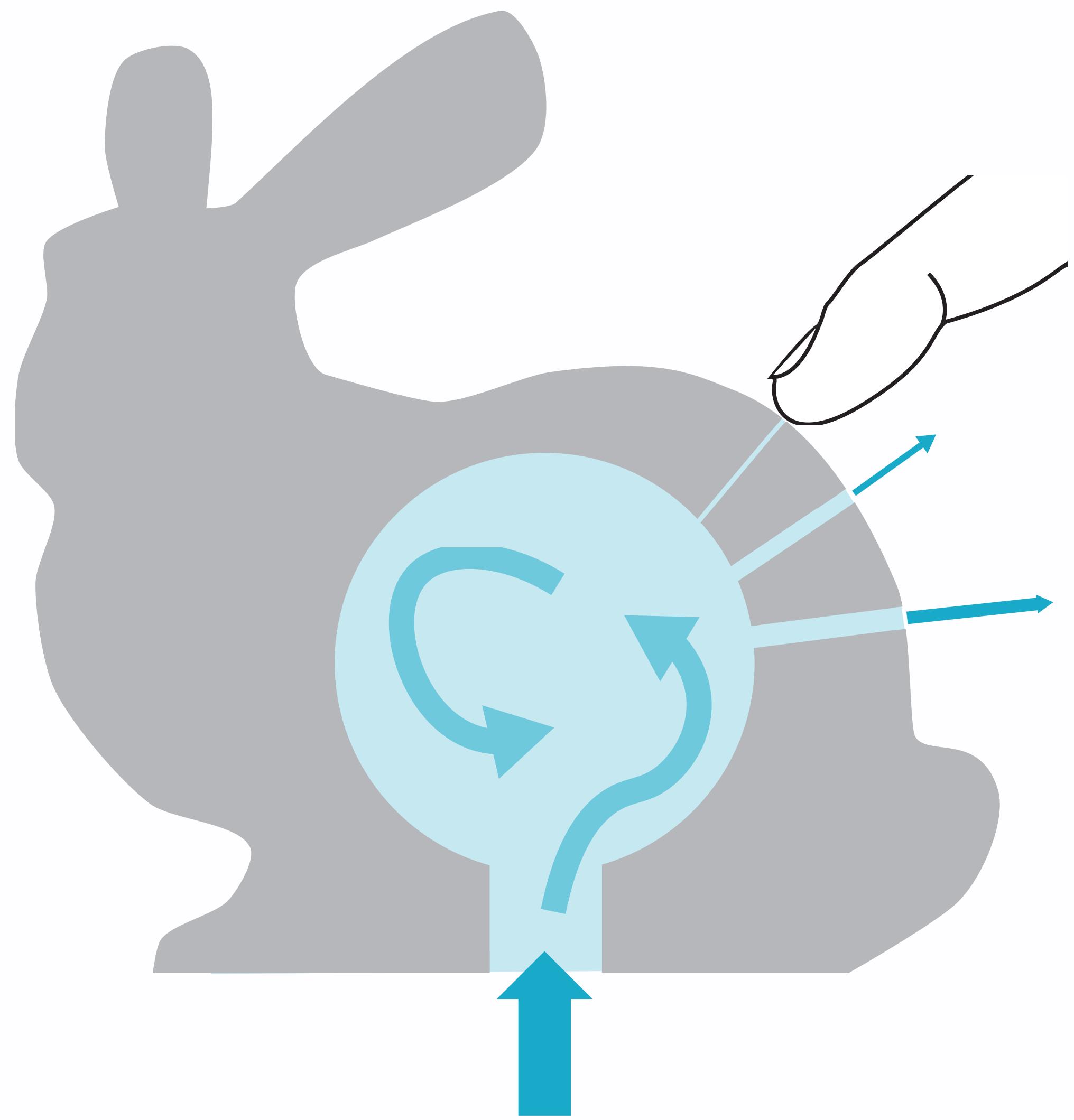
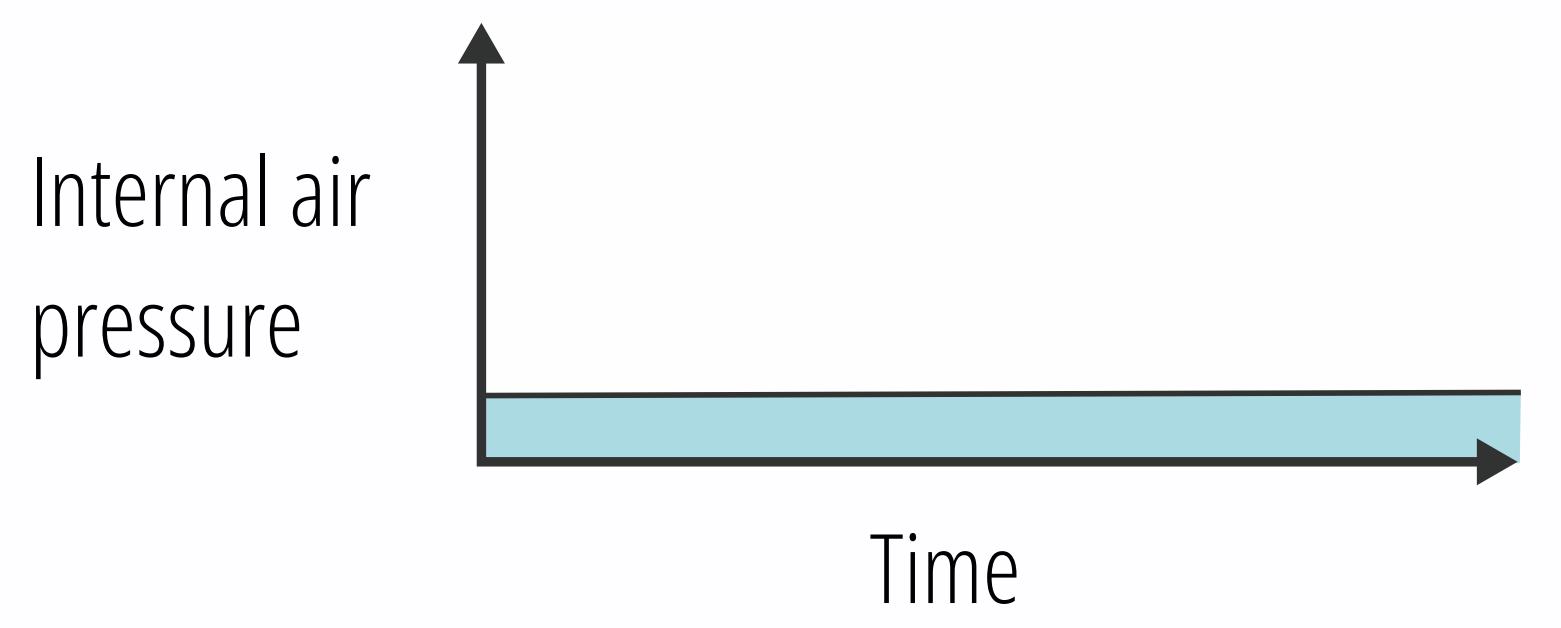
- No assembly of parts or circuits.
- No calibration.
- Single material, consumer-level 3D-printers.
- Minimal disruption of original geometry.

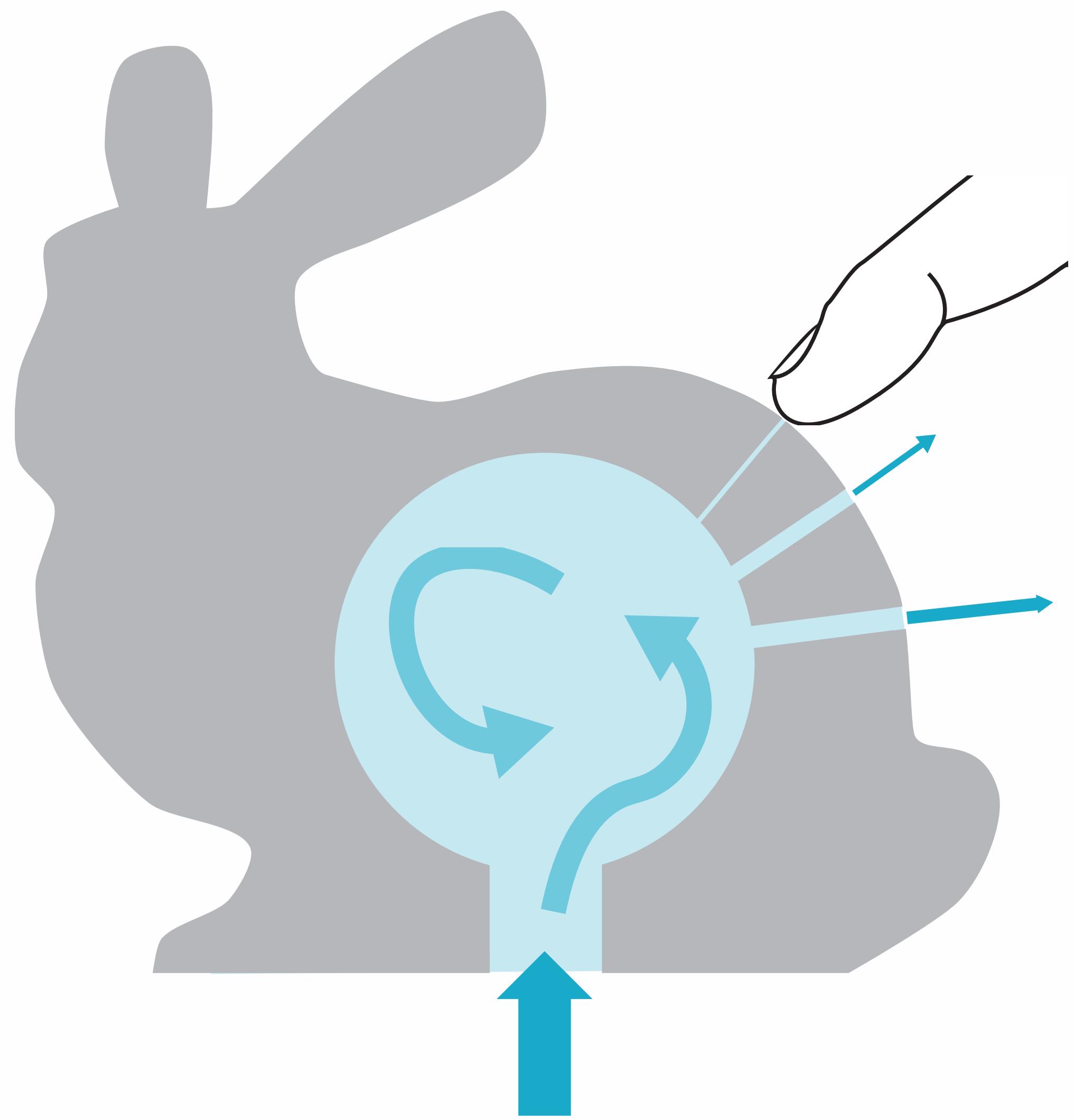
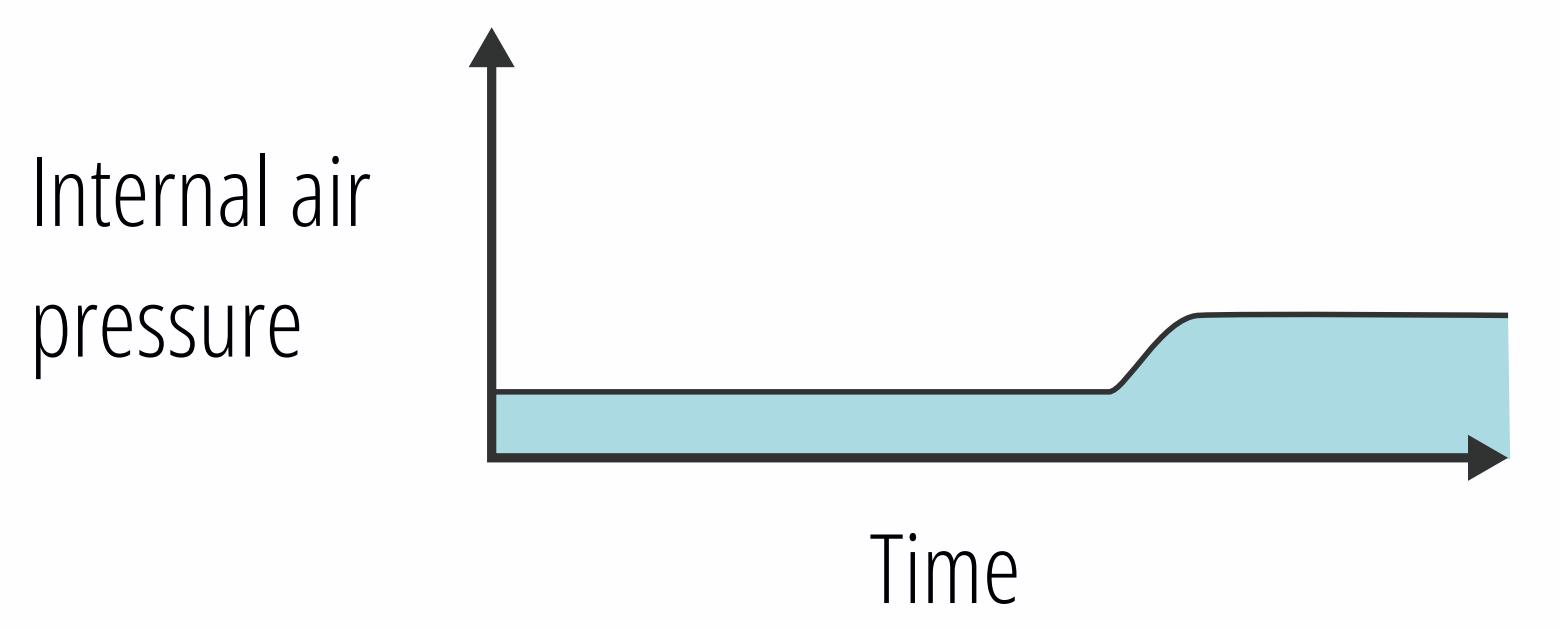


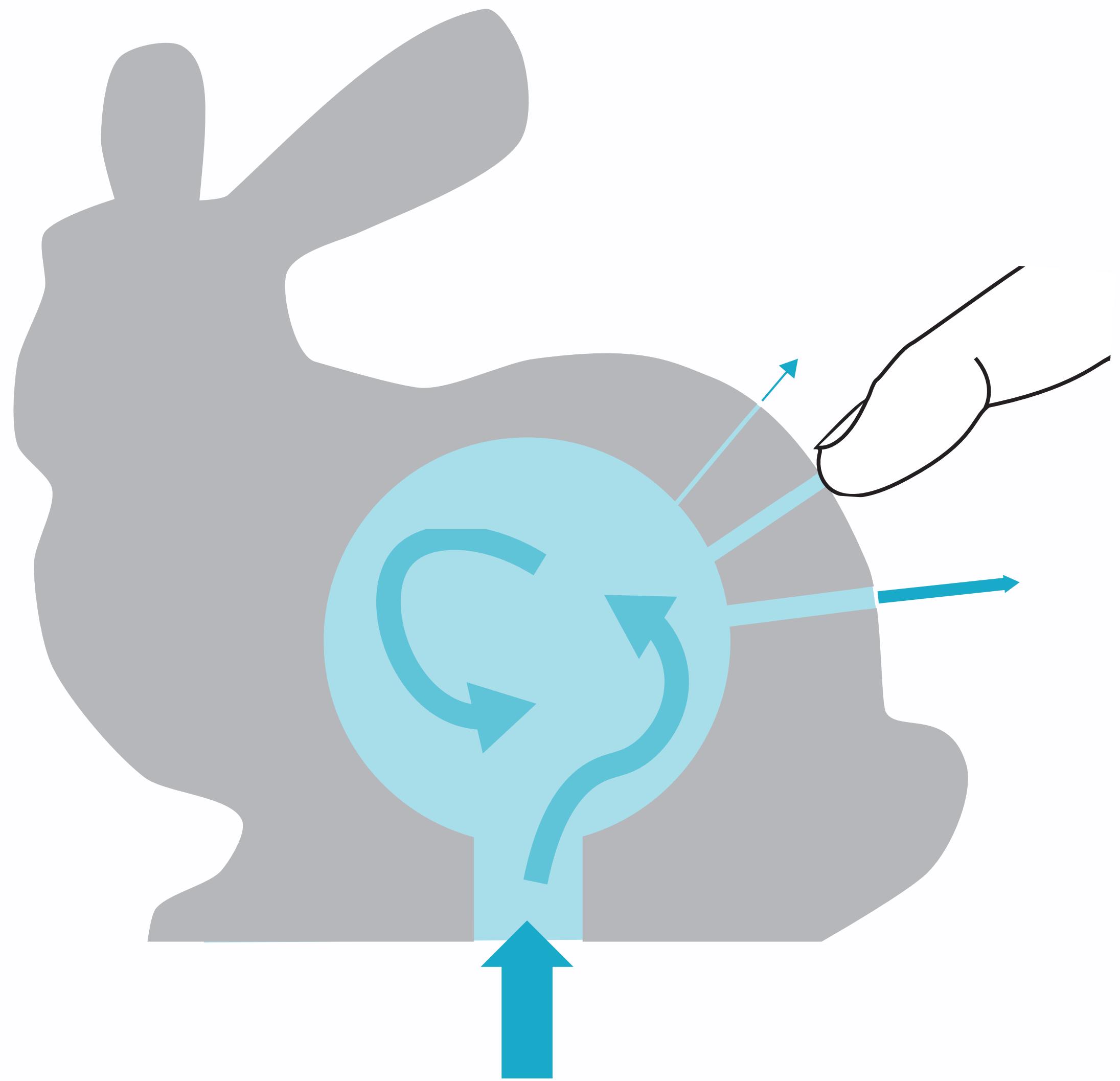
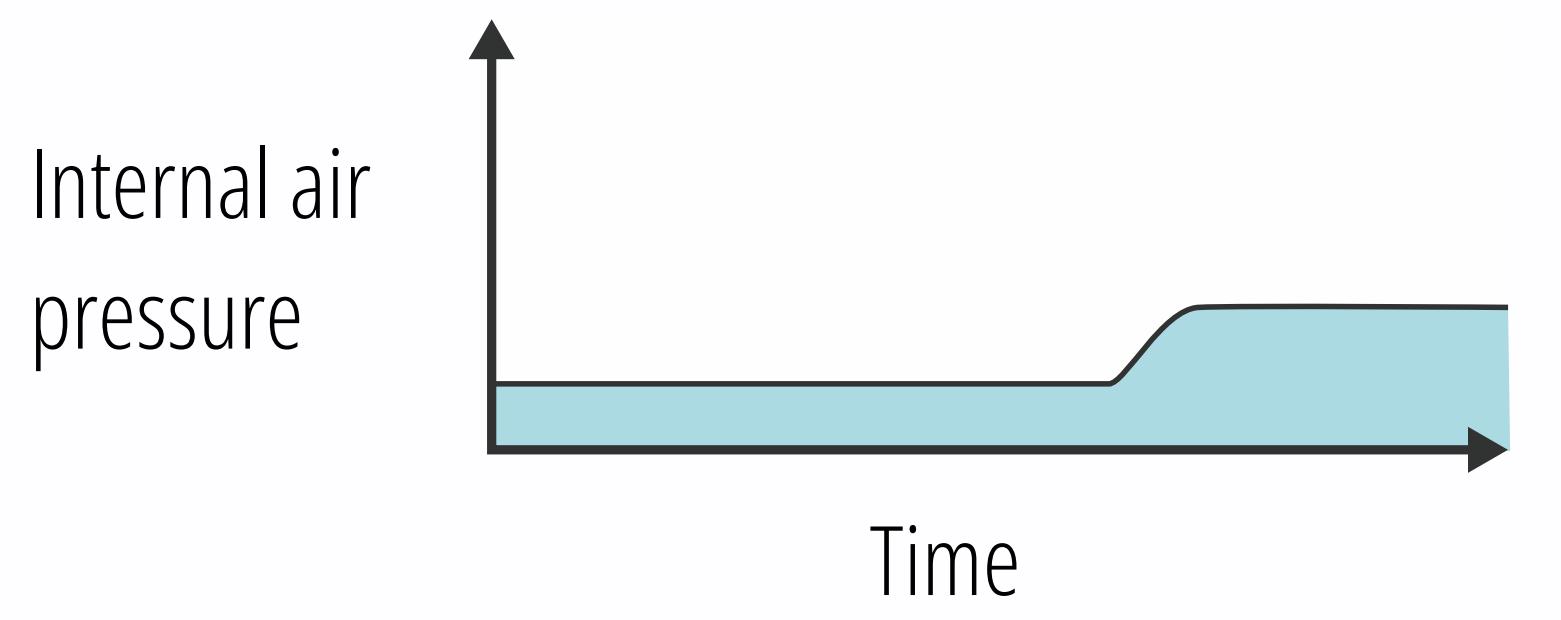
How does it work?

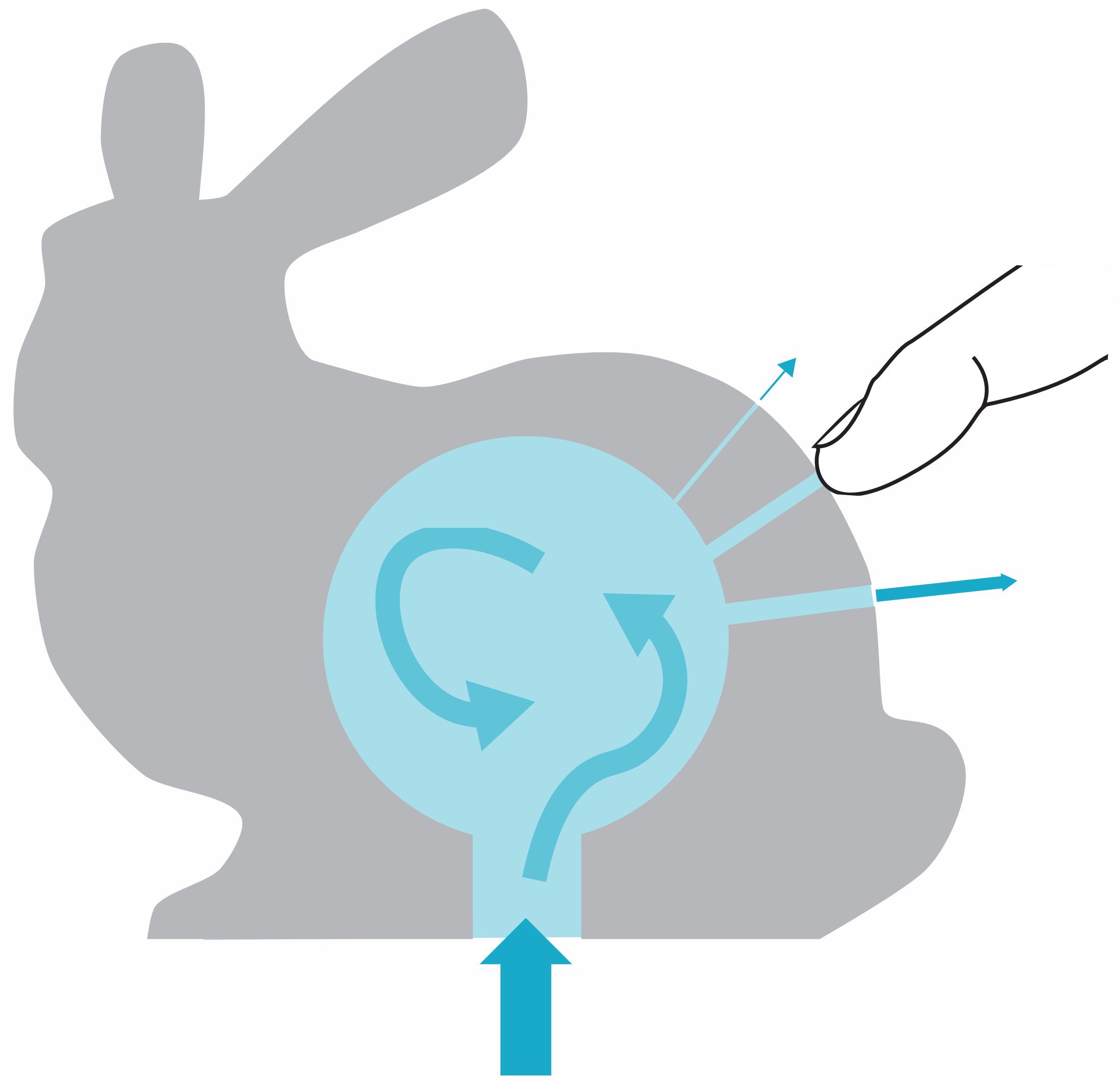
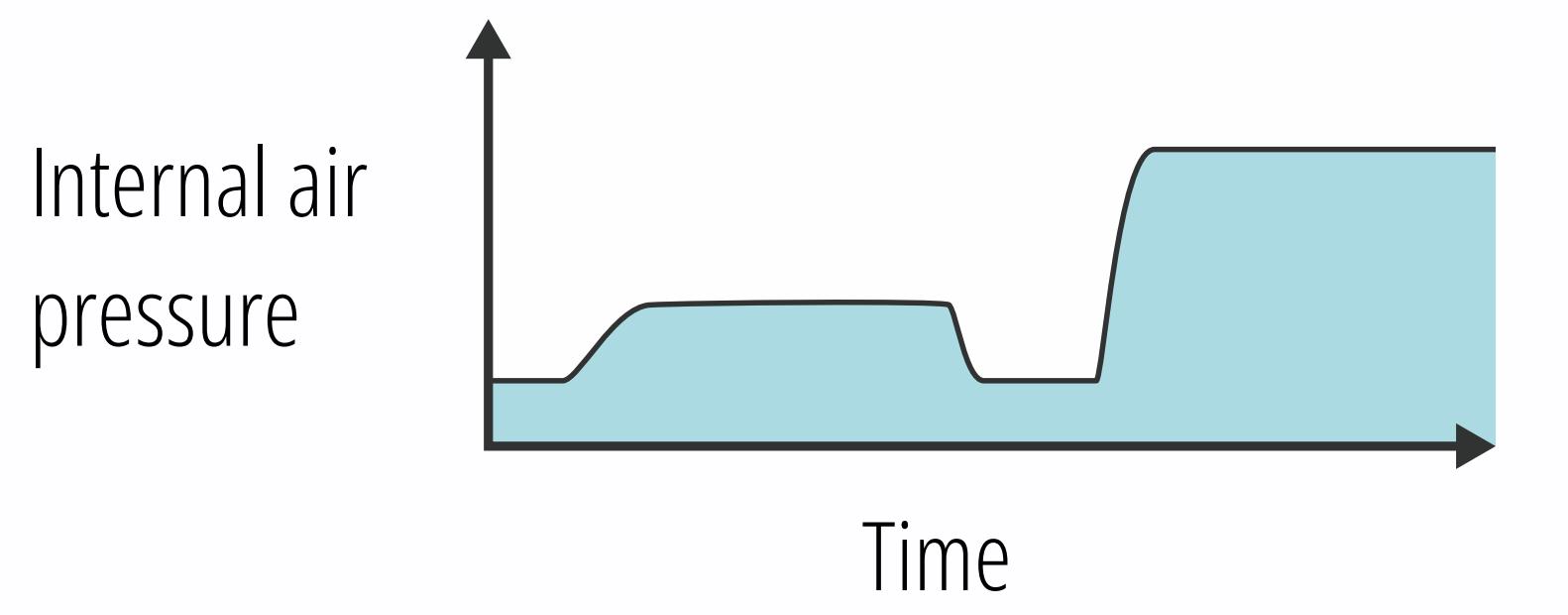












How does it work?

- Principle of fluid continuity.
- Bernoulli's principle.

$$\Delta P_x = \frac{(\sum A_i)^2 \Delta P}{(\sum A_i - A_x)^2}$$

- Change in size of openings → Change in pressure.

How does it work?

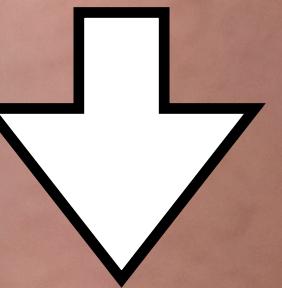
- Assumptions:
 - Incompressible fluids.
 - Perfectly shaped outlets and structures.
- Reality:
 - Air is compressible.
 - 3D-printed objects are not perfect.
 - Complex internal geometries.

Setup

Back

Back

Air
Compressor



Back

Pressure
Sensor

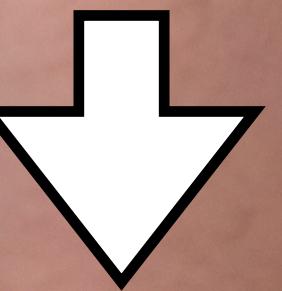
Air
Compressor

Computer

Back

Pressure
Sensor

Air
Compressor







AirTouch



AirTouch

- Cavity
- Tubes
- Outlets



Cavity

- Spherical cavities.
- 30 mm in diameter.
- Shared cavity size between all objects.
 - Shared machine learning model.



Tubes

- Cylindrical tubes.
- 5mm in diameter.
- Compromise between printability and size.

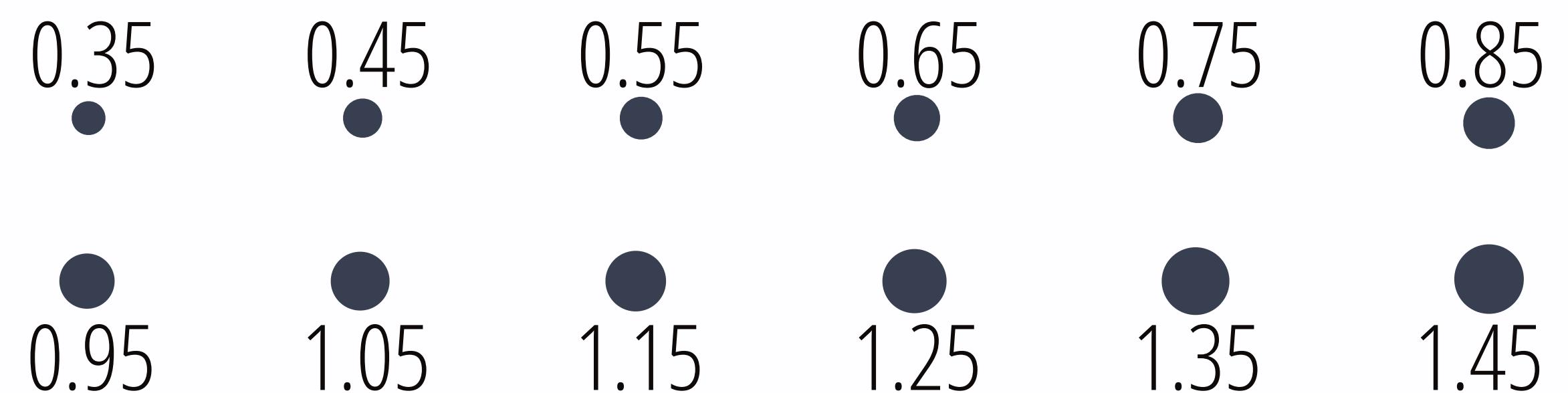


Outlets

- Outlets are placed on touch locations.
- Very small.
- Pressure increase depends on the area of outlet.

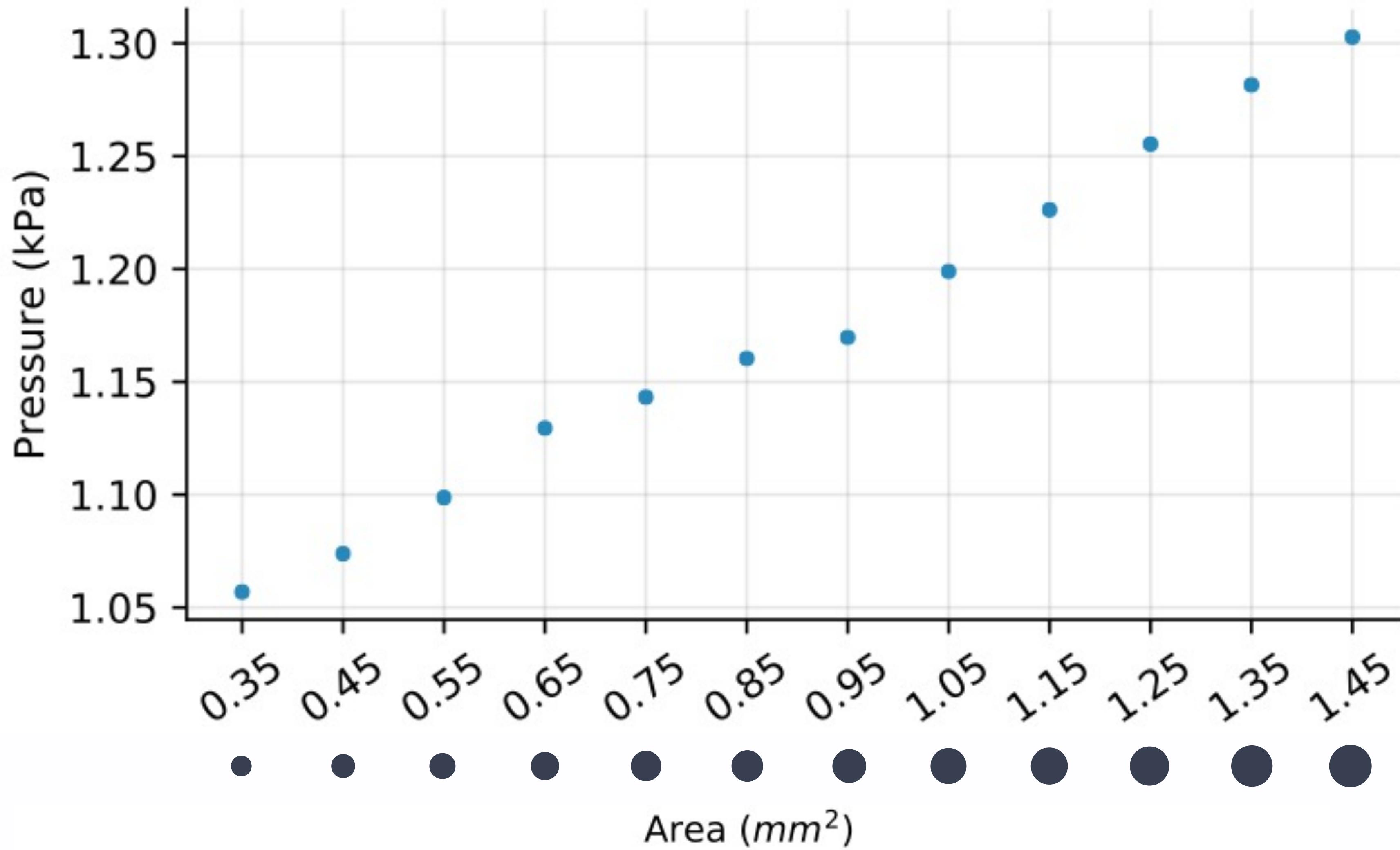


Final outlet dimensions



Outlet area, in mm²

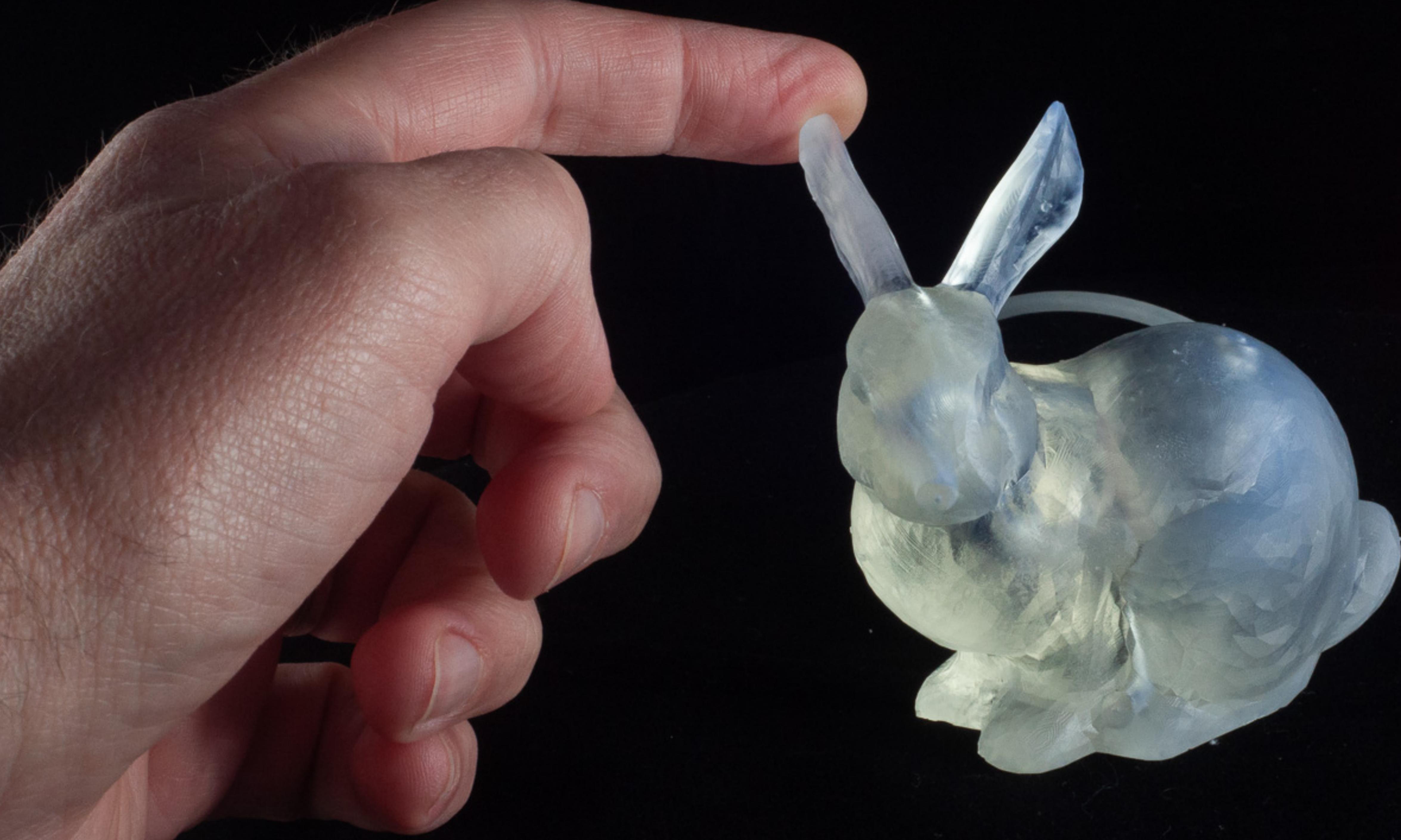


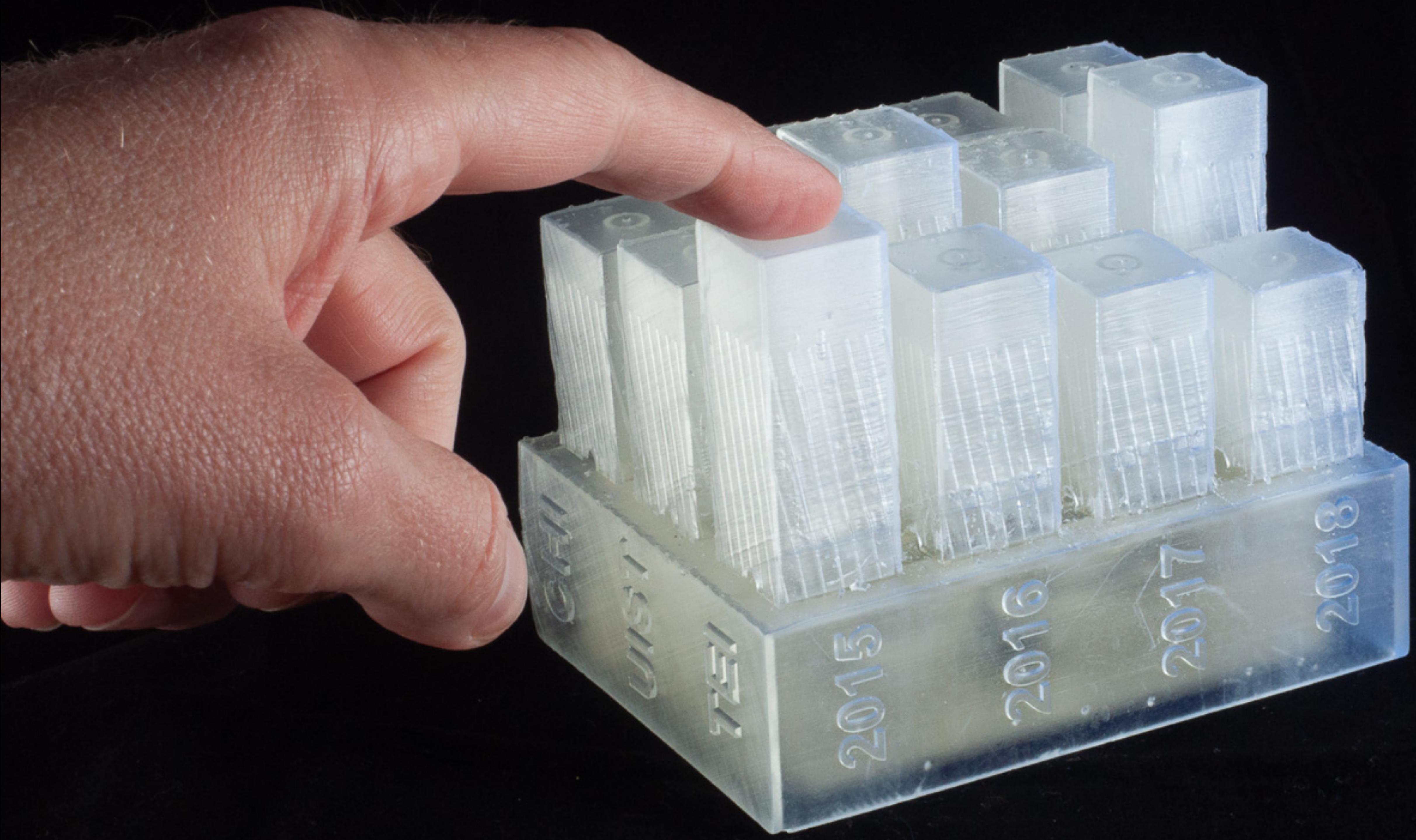


Performance Testing

Performance Testing

- Printed four objects.
- Pre-trained a machine learning model.
 - One instance per touch.
- Cycled through all touch locations.
- Repeated four times per object.

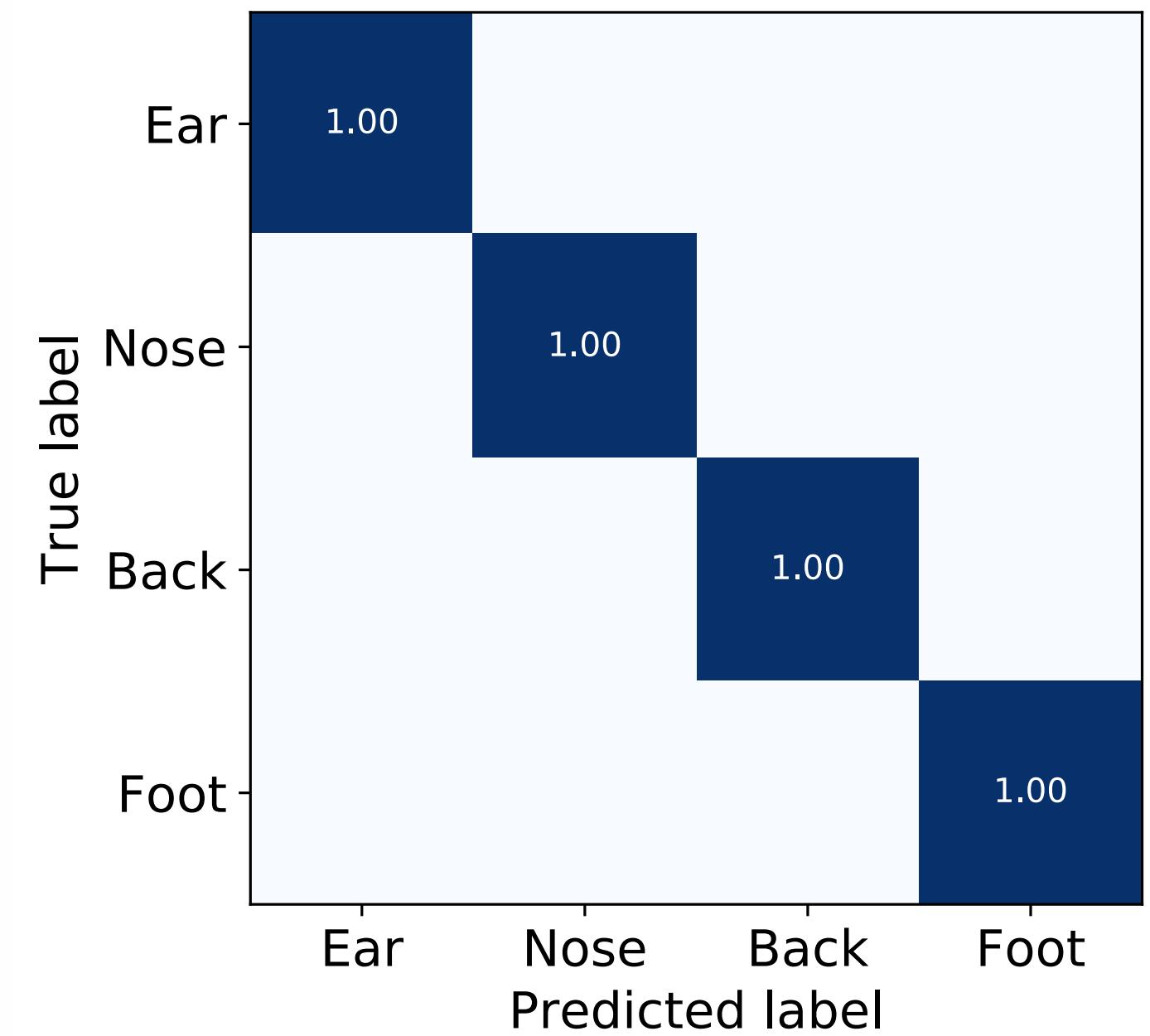






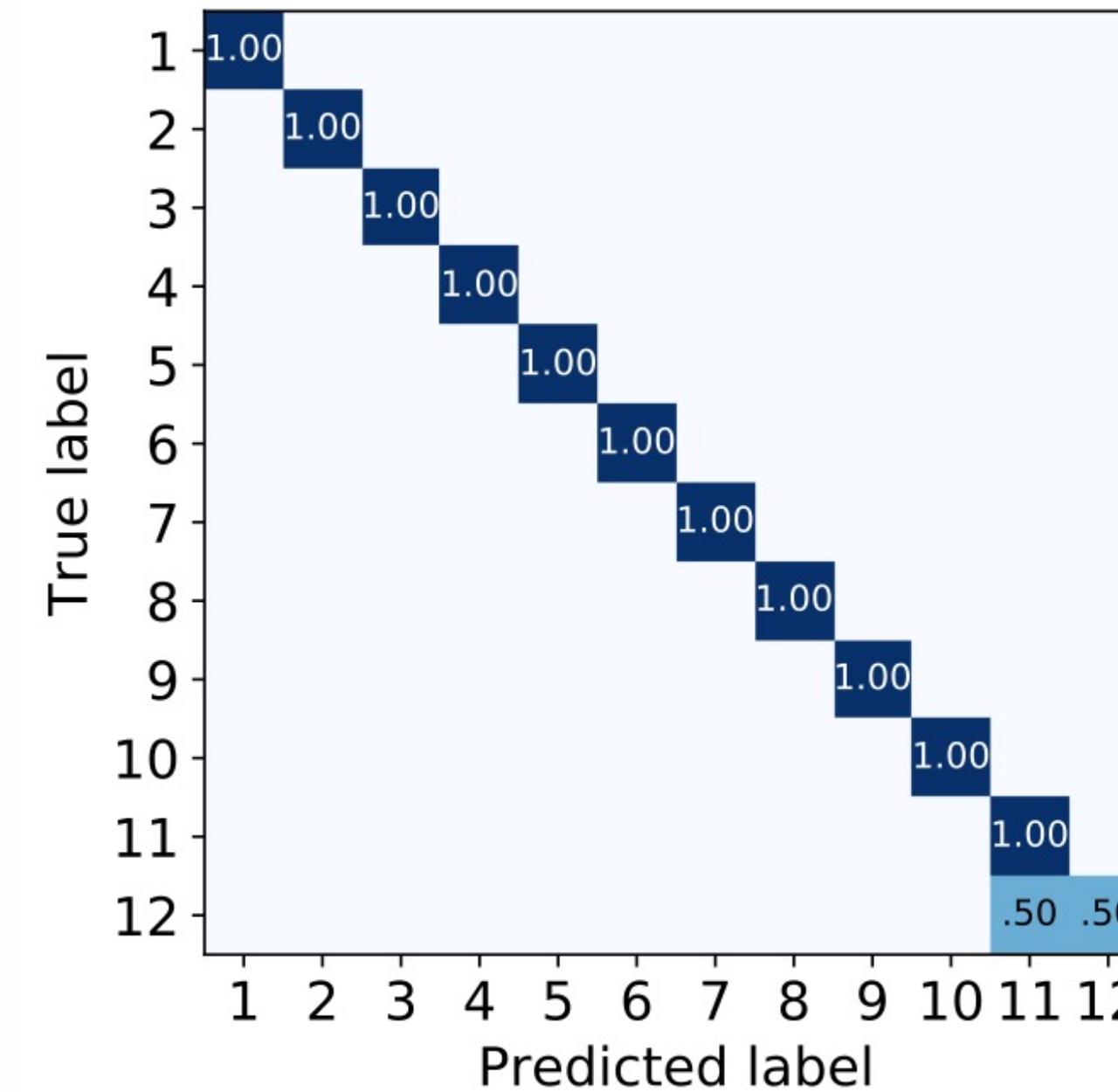


Stanford Bunny



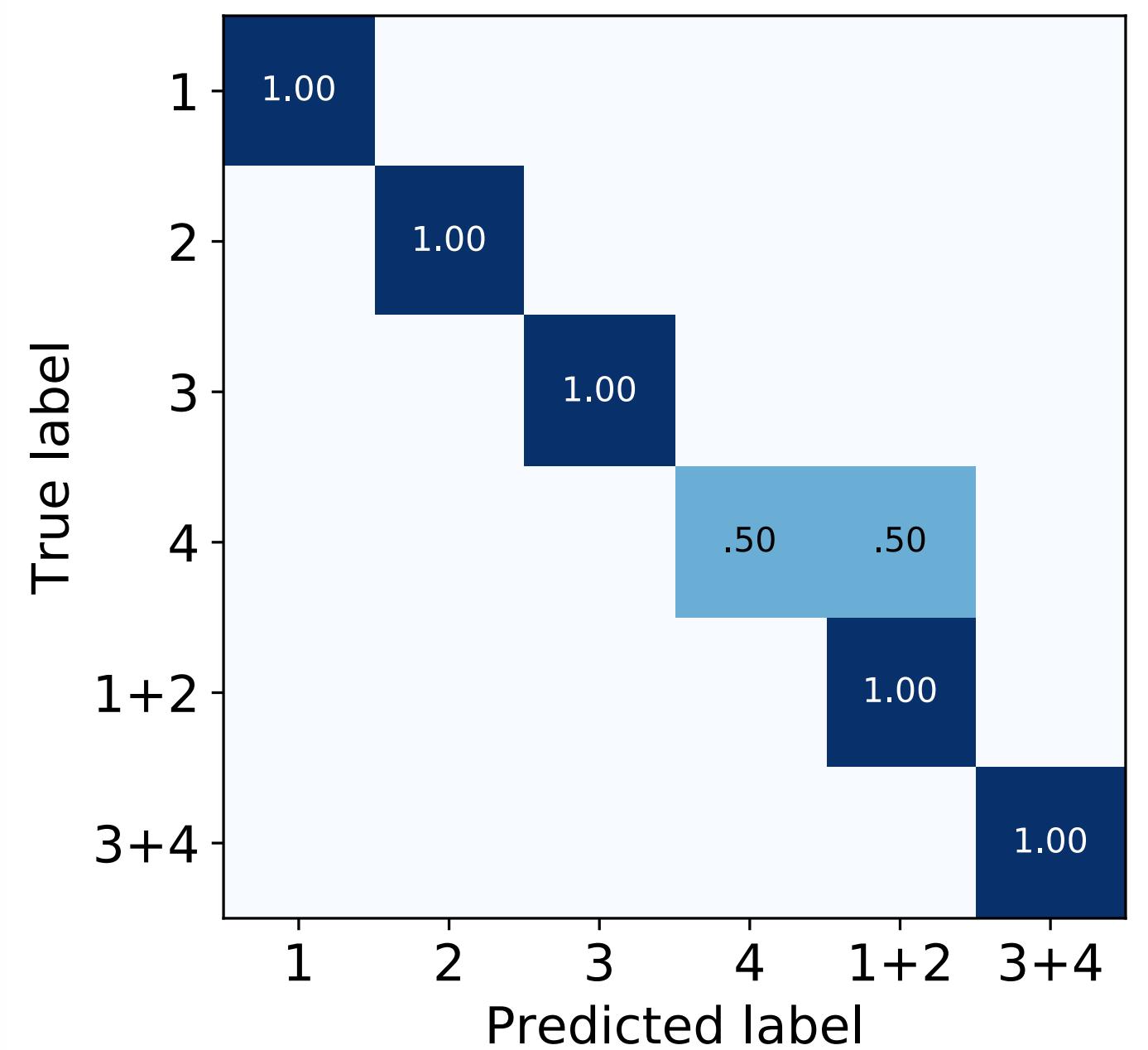
100%

Interactive Bar Chart



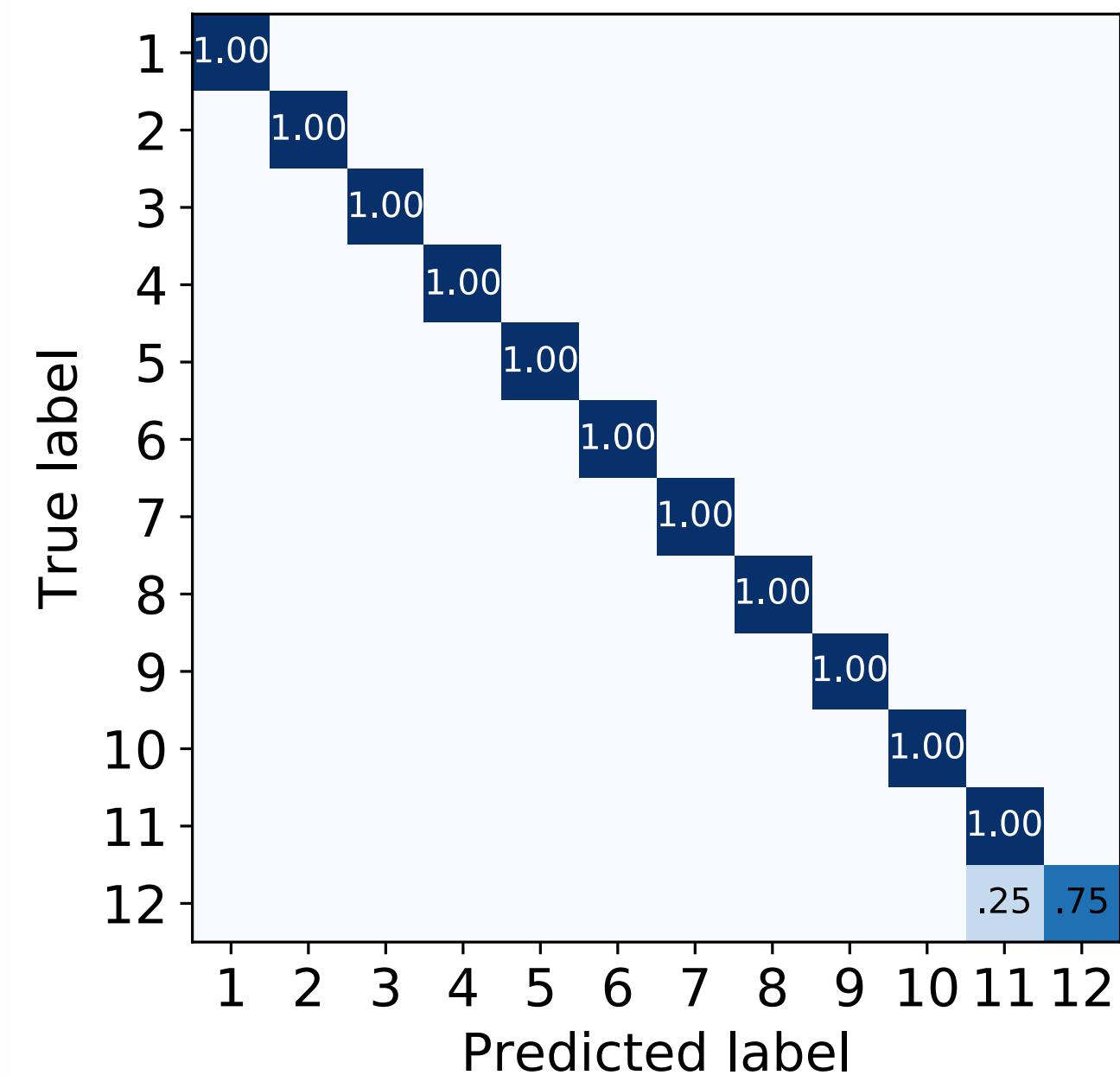
95.50%

Grasping Sphere



91.60%

Color Hue Selector



97.75%

Example Applications

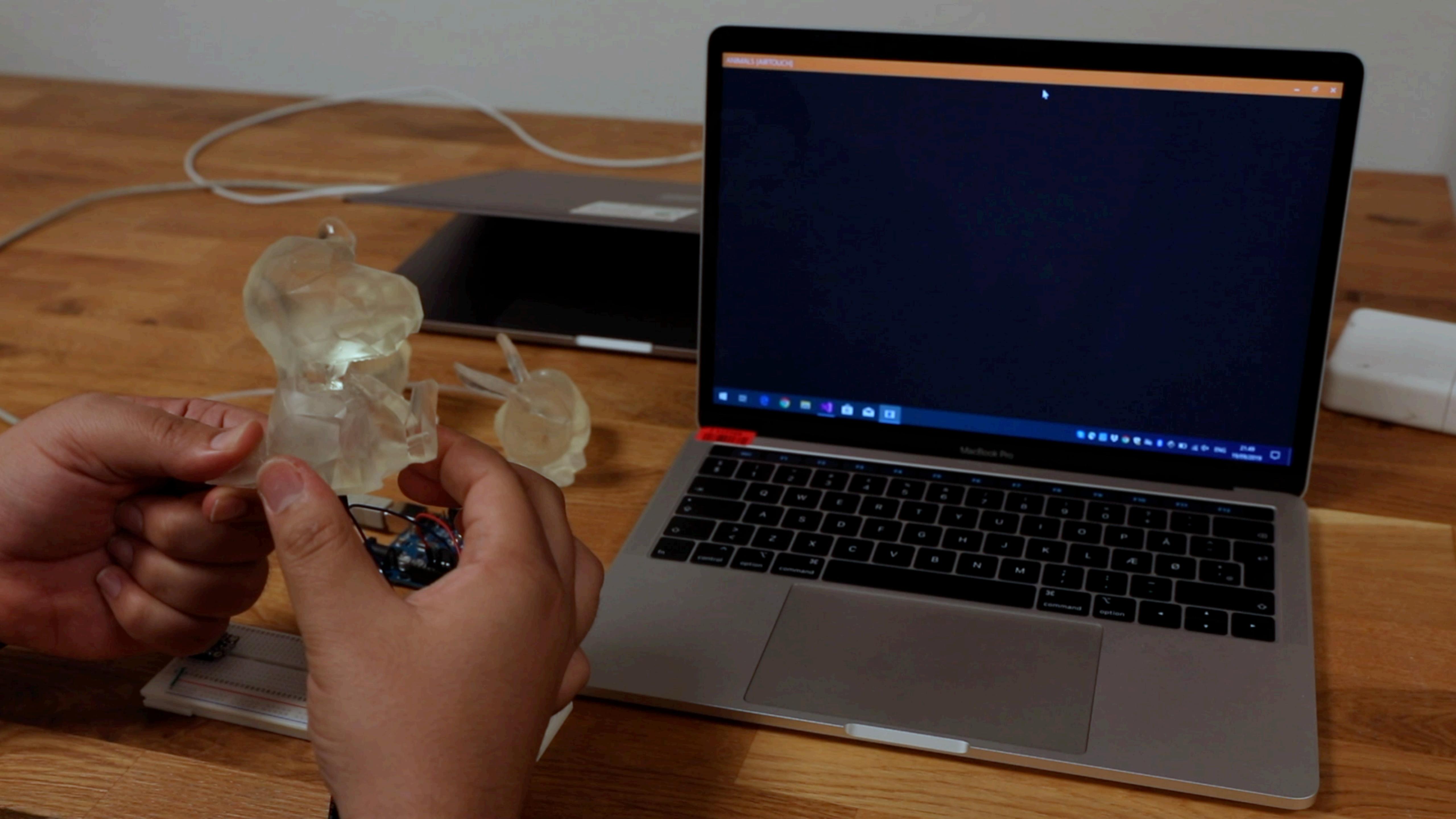


Accepted

Rejected







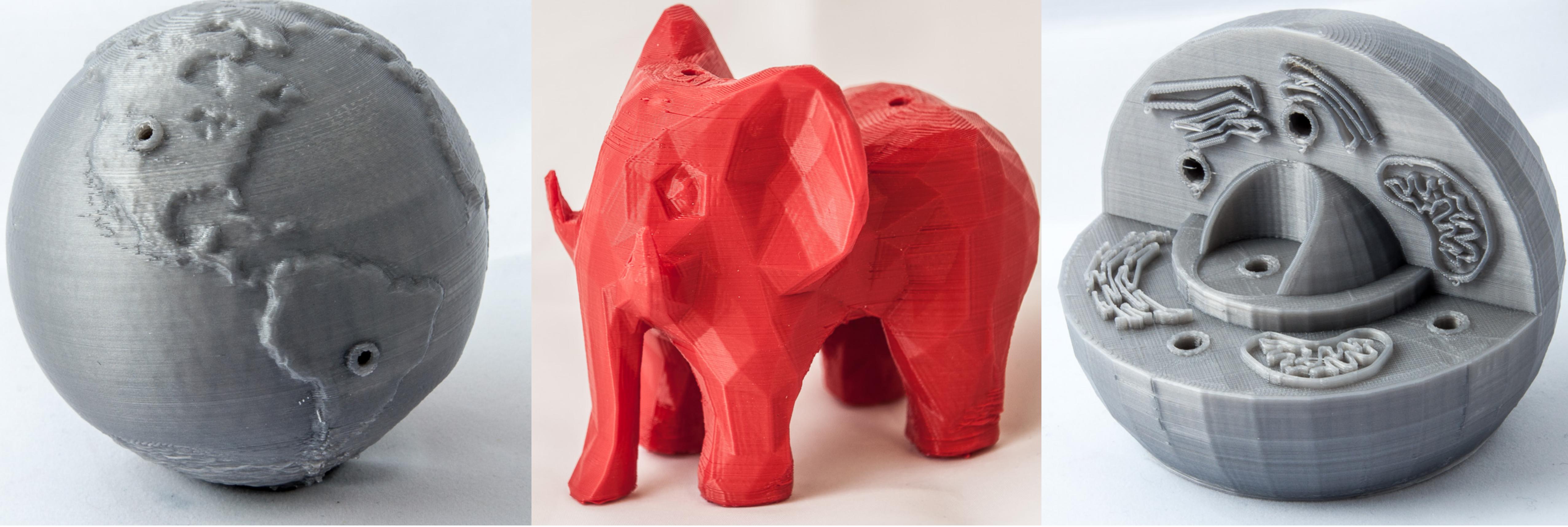
Takeaways

Takeaways

- No assembly of parts or circuits
- No calibration
- Single material, consumer-level 3D-Printers
- Minimal disruption of original geometry

Back





Blowhole

Blowing-Activated Tags for Interactive 3D-Printed Models

Carlos Tejada

Osamu Fujimoto

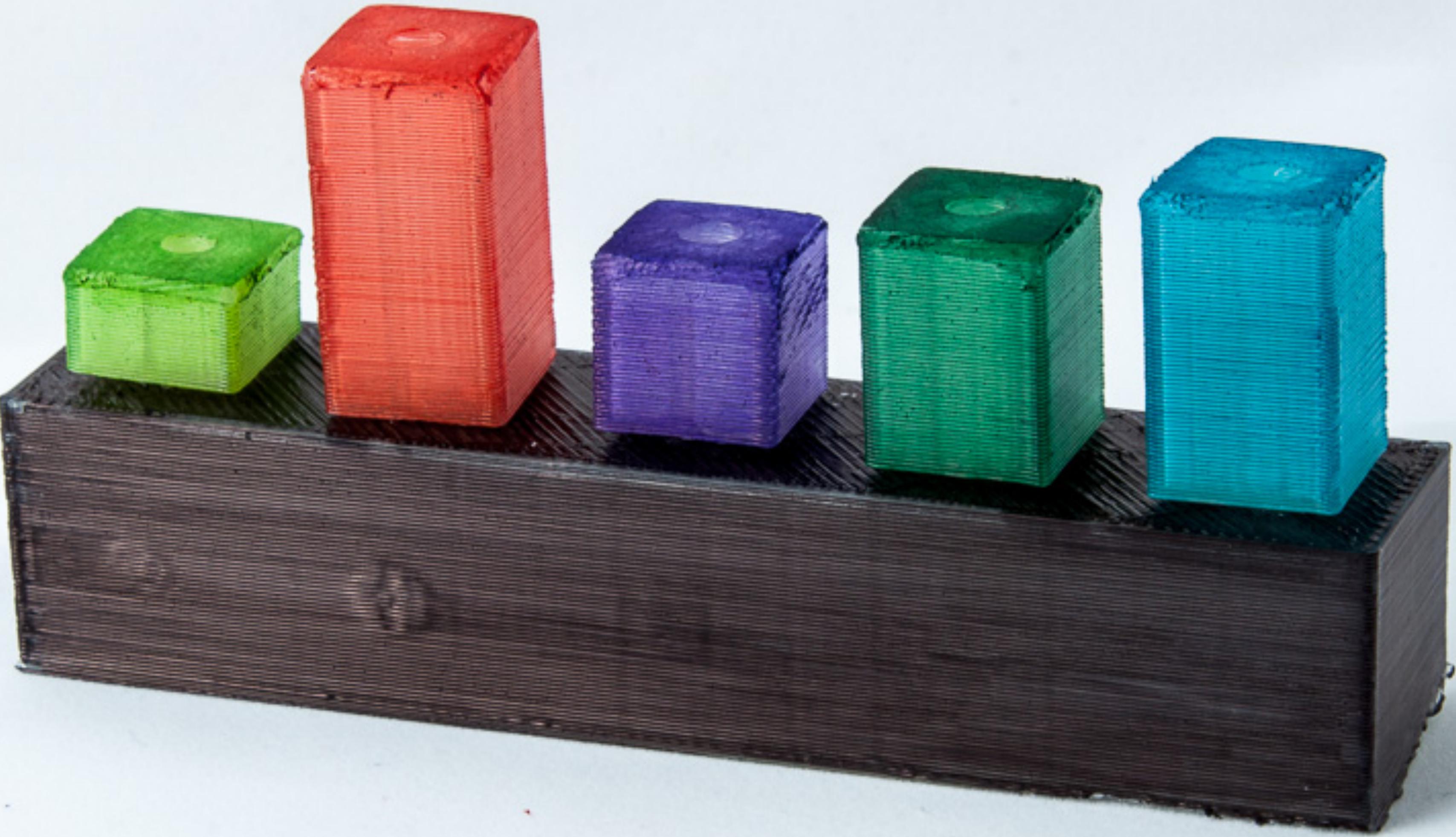
Zhiyuan Li

Daniel Ashbrook



GI '18





Introduction

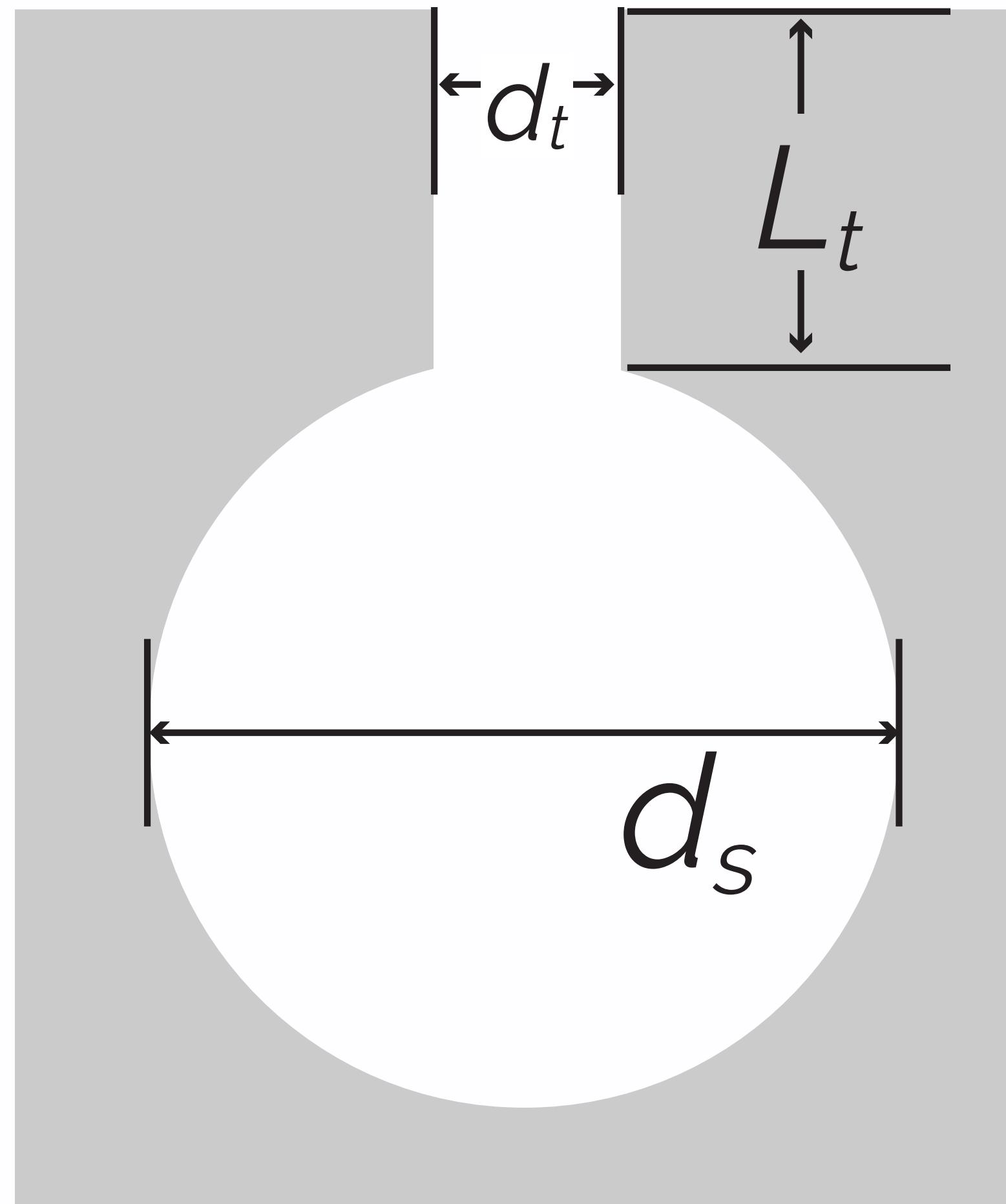
Blowhole



Blowhole Characterization

- Acoustic resonance.
- Modifying d_t , L_t and d_s varies the frequency emitted from the cavity.
- Modeled by Helmholtz's resonance equation.

$$f = \frac{cd_t}{\pi} \sqrt{\frac{3}{8(L_t + .75d_t)d_s^3}}$$

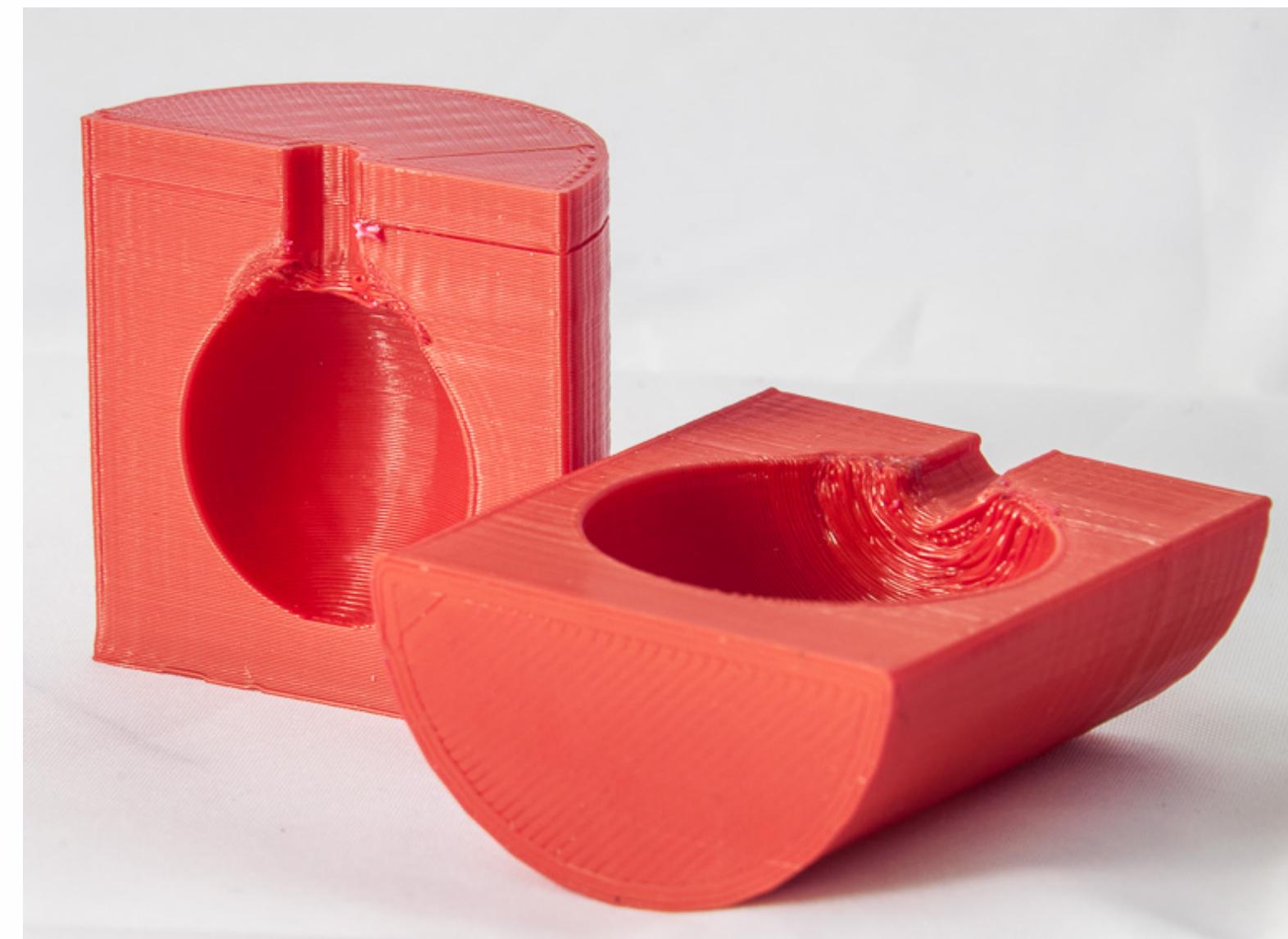


Blowhole Characterization

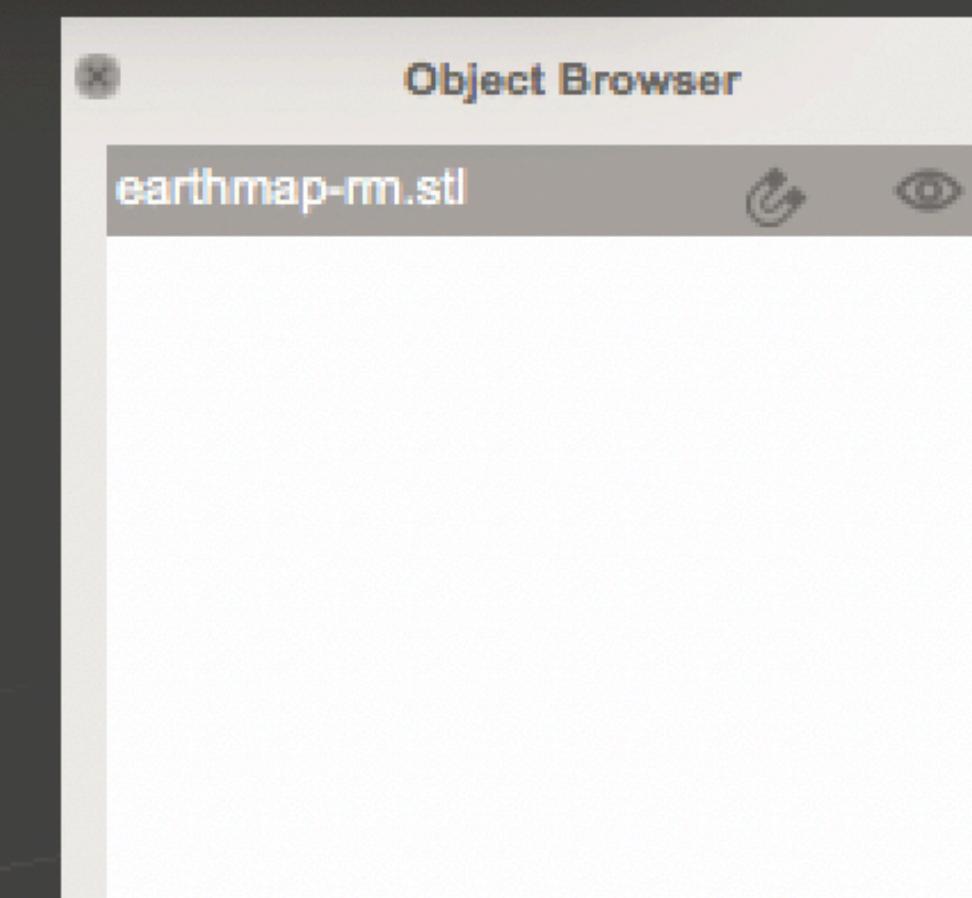
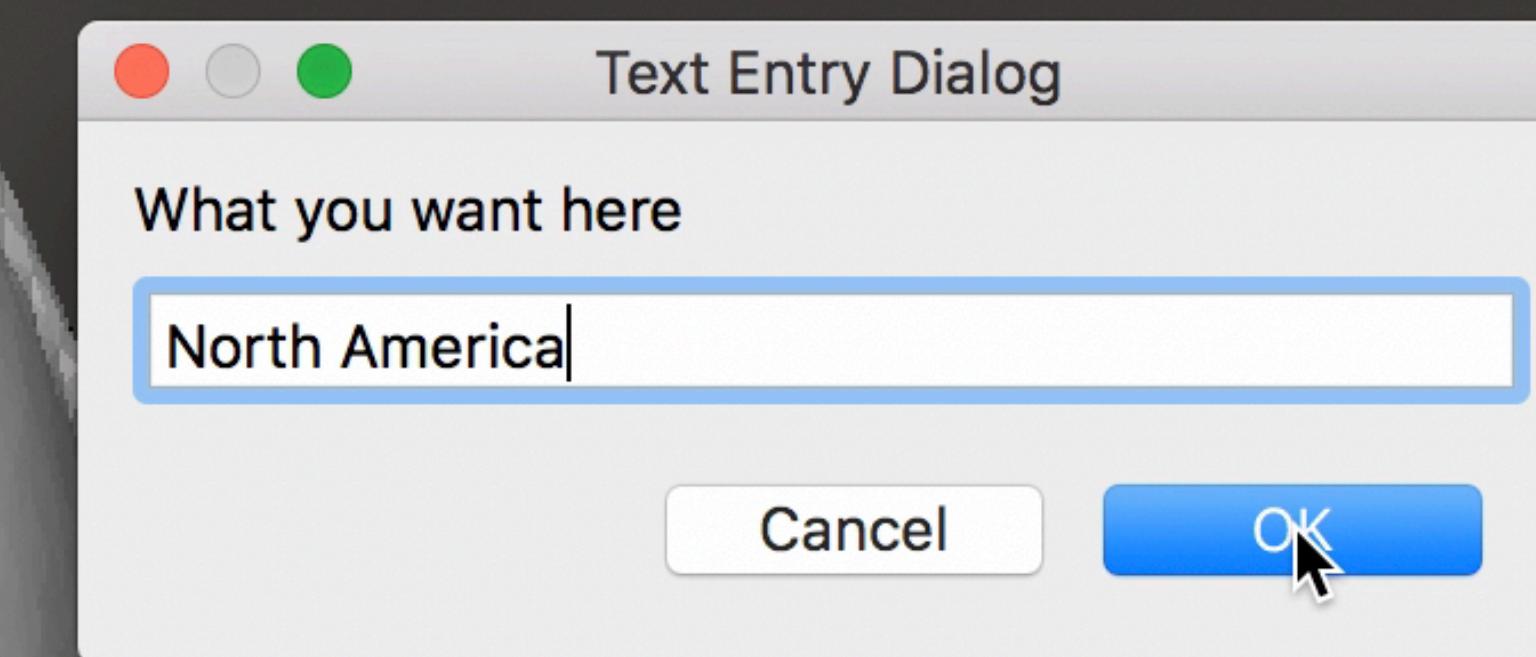
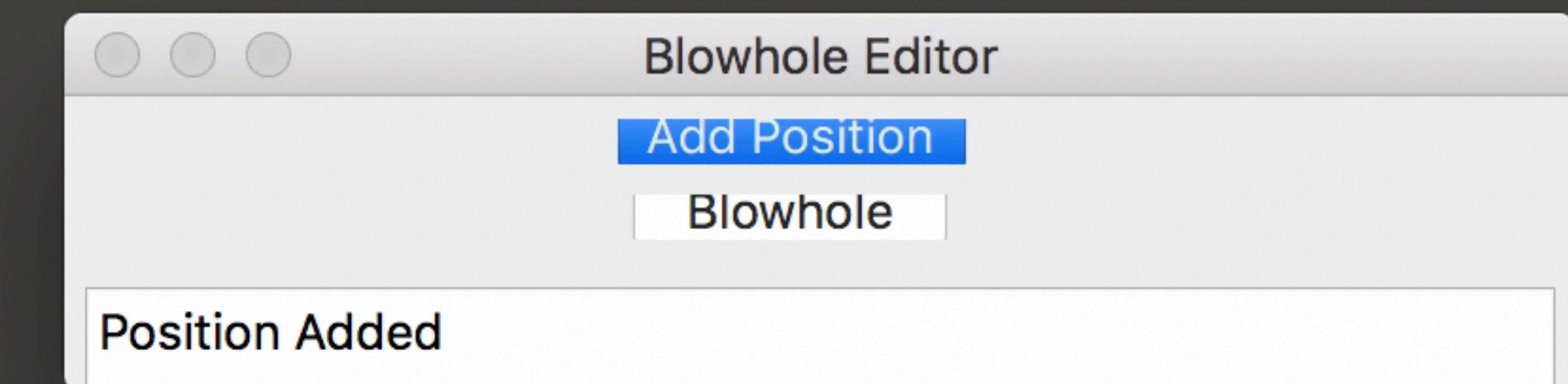
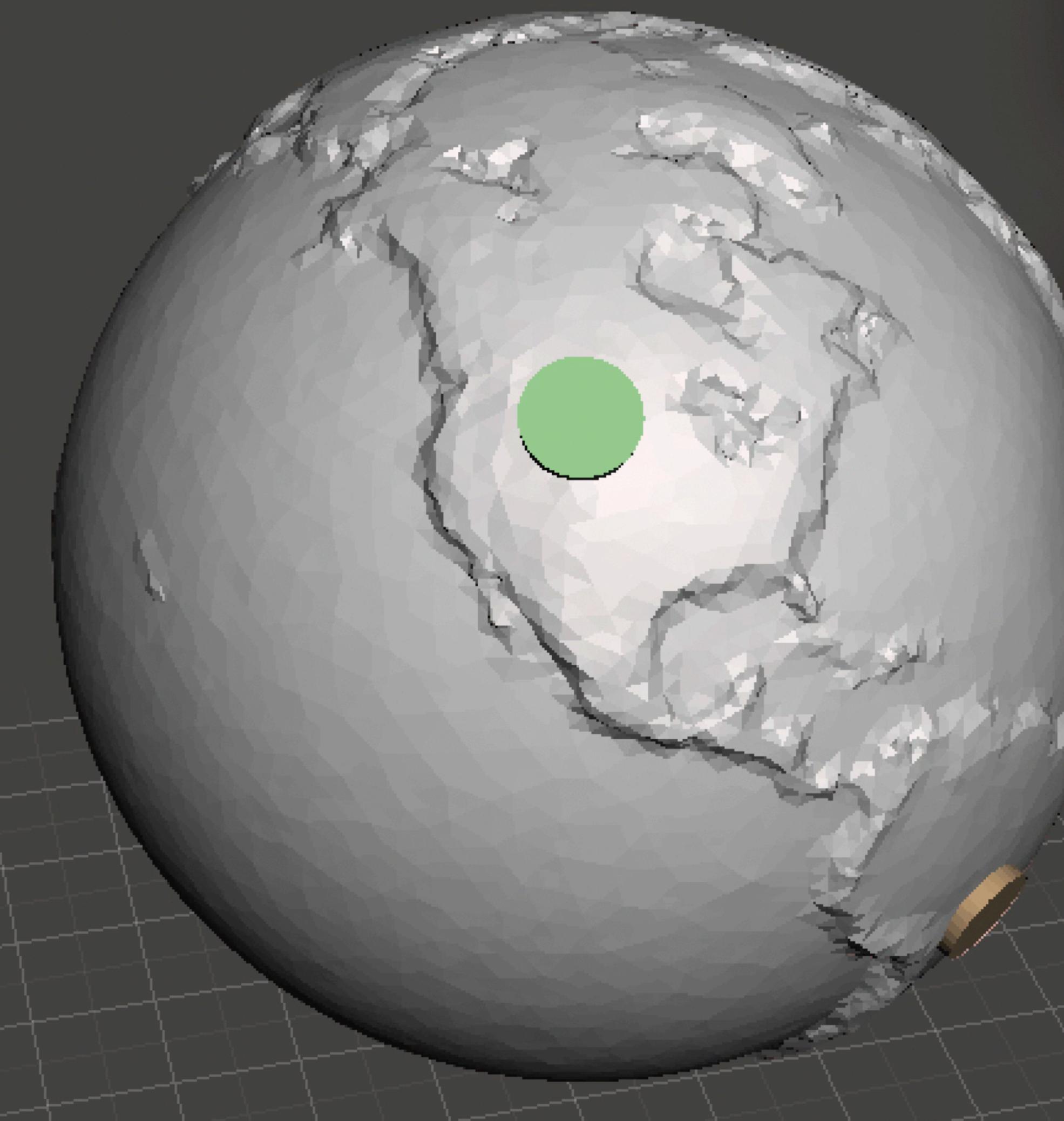


Blowhole Characterization

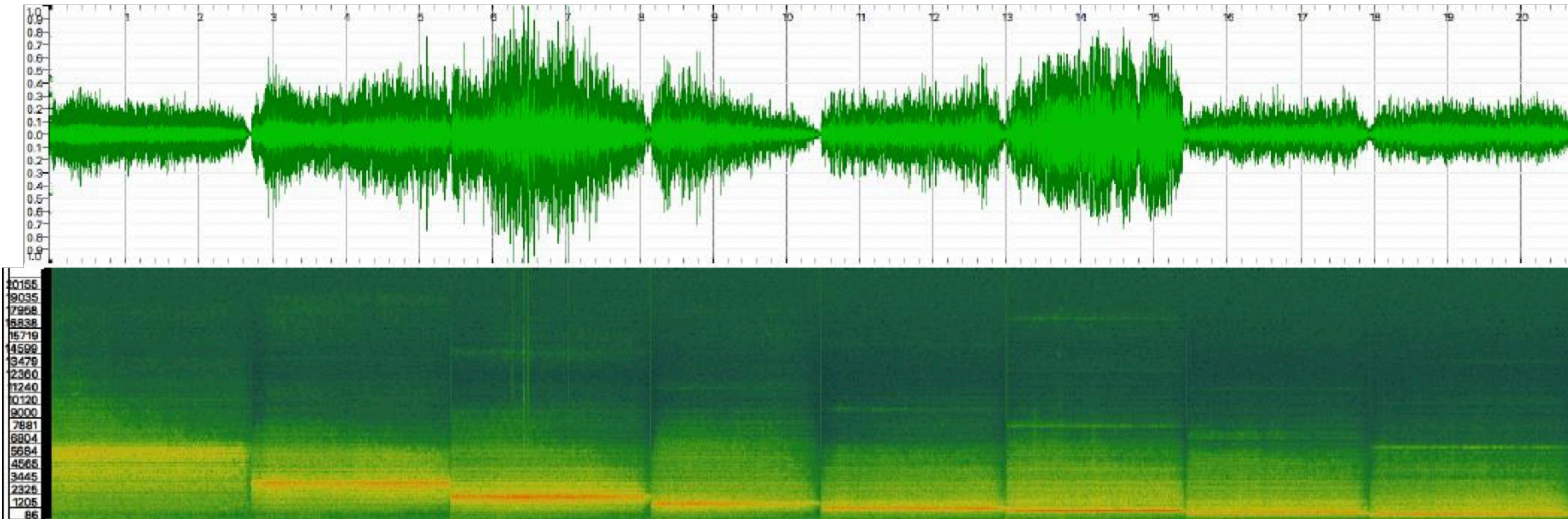
- 12 participants
- Ask to gently blow on our test objects.
 - Recorded fundamental frequencies.



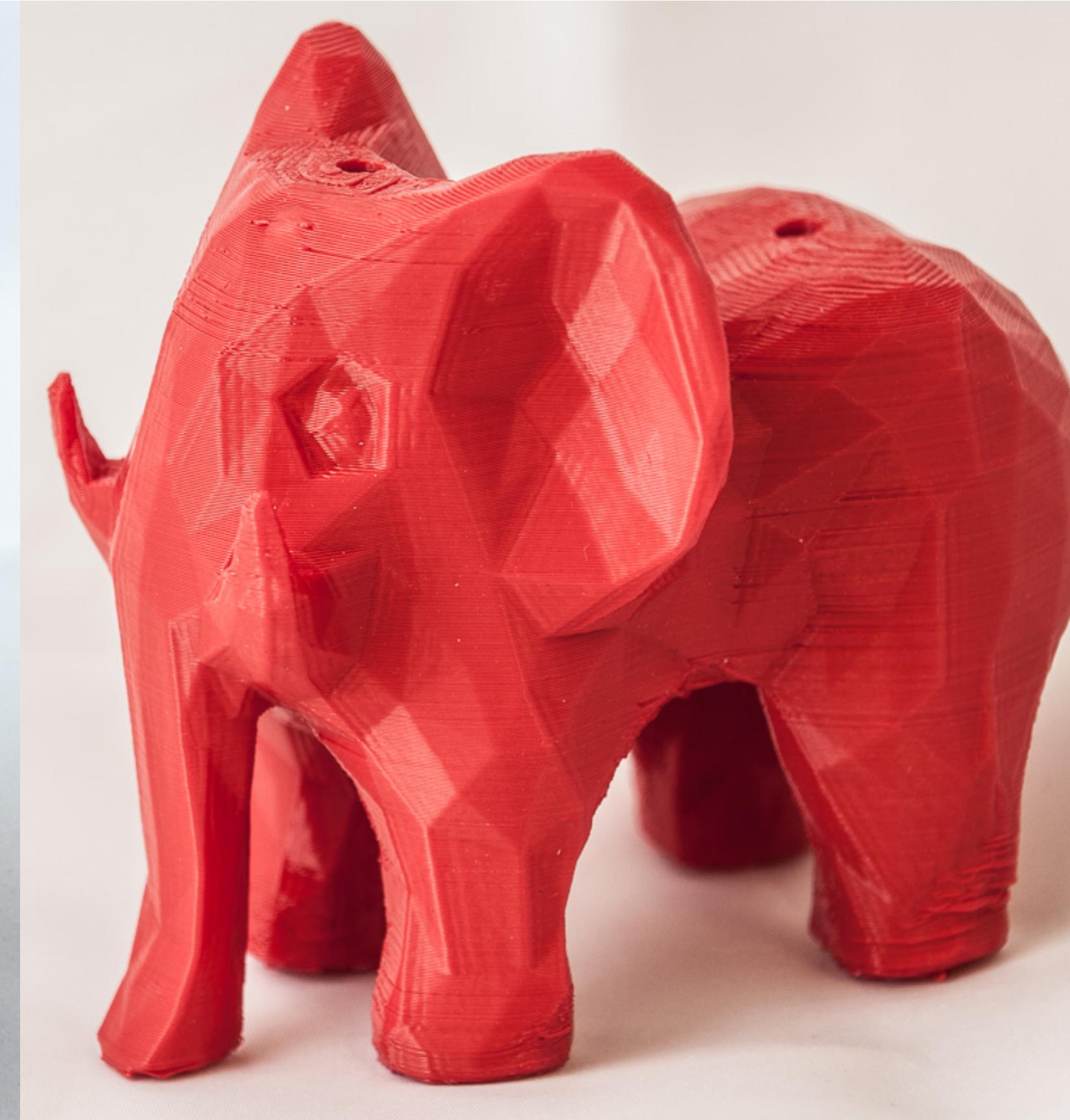
System Implementation



System Implementation



System Implementation



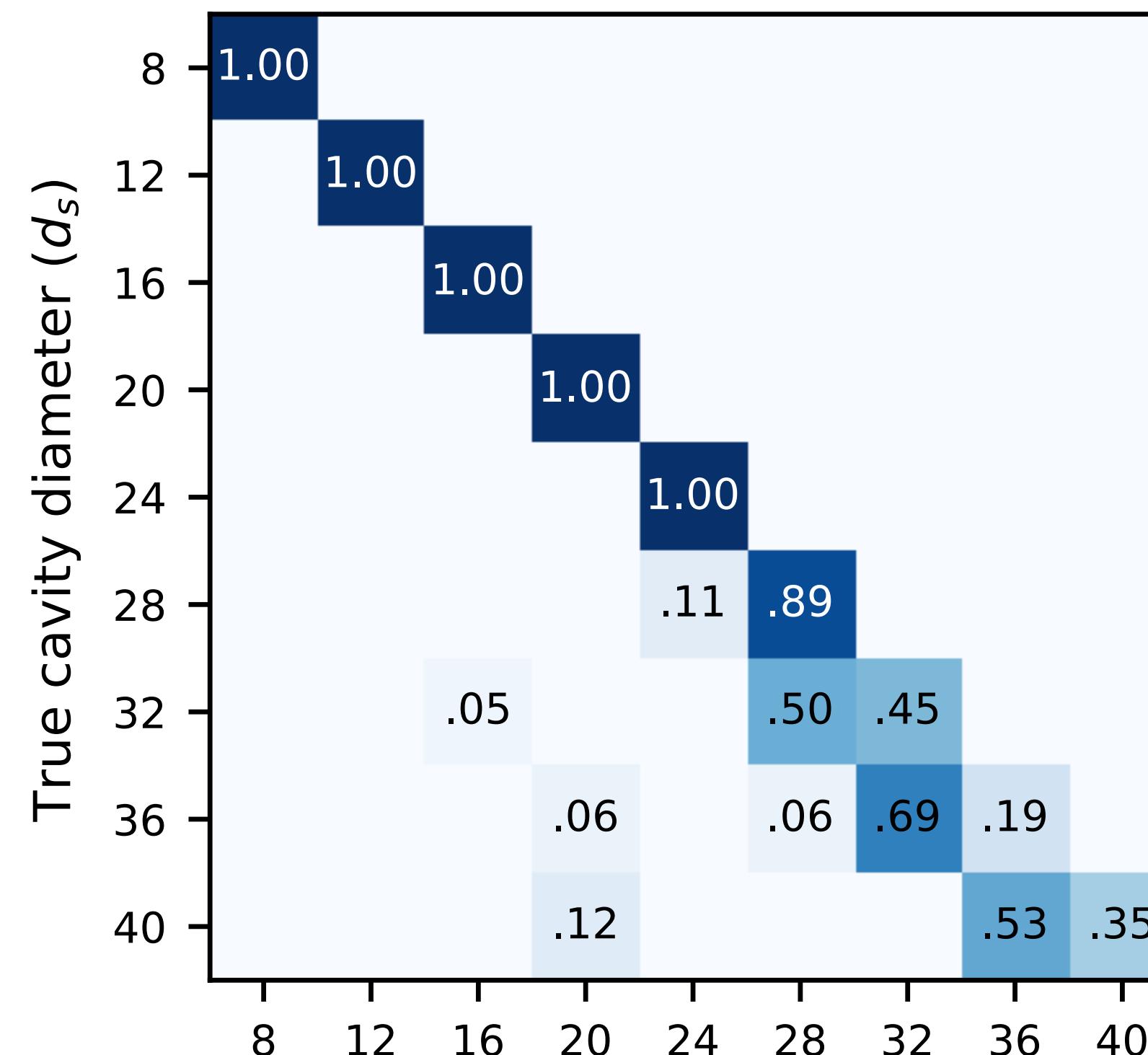
Performance Testing

Performance Testing

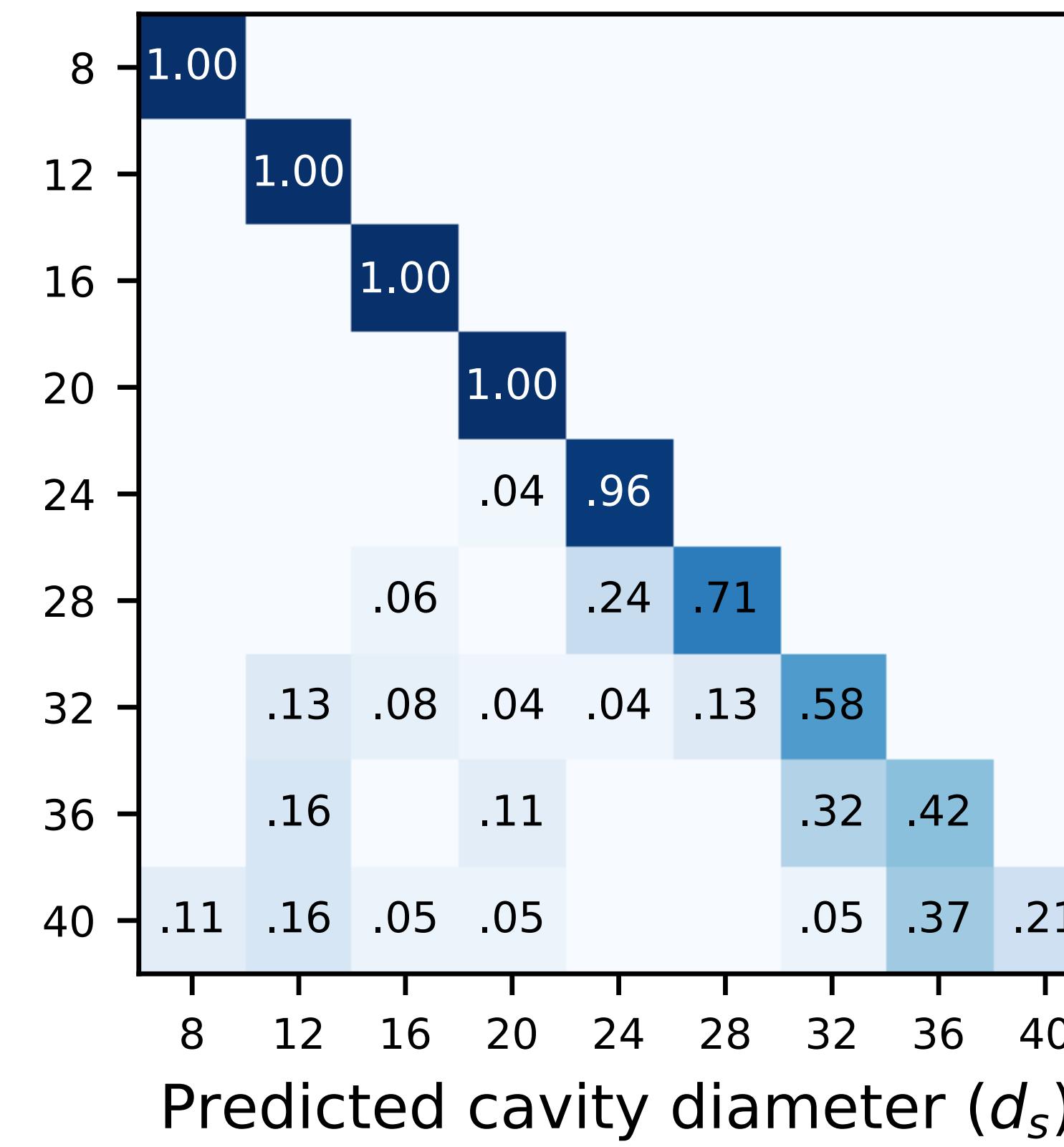
- Collected 830 blow segments.
- 10 participants.
- Tested both overall and per-user.

Performance Testing

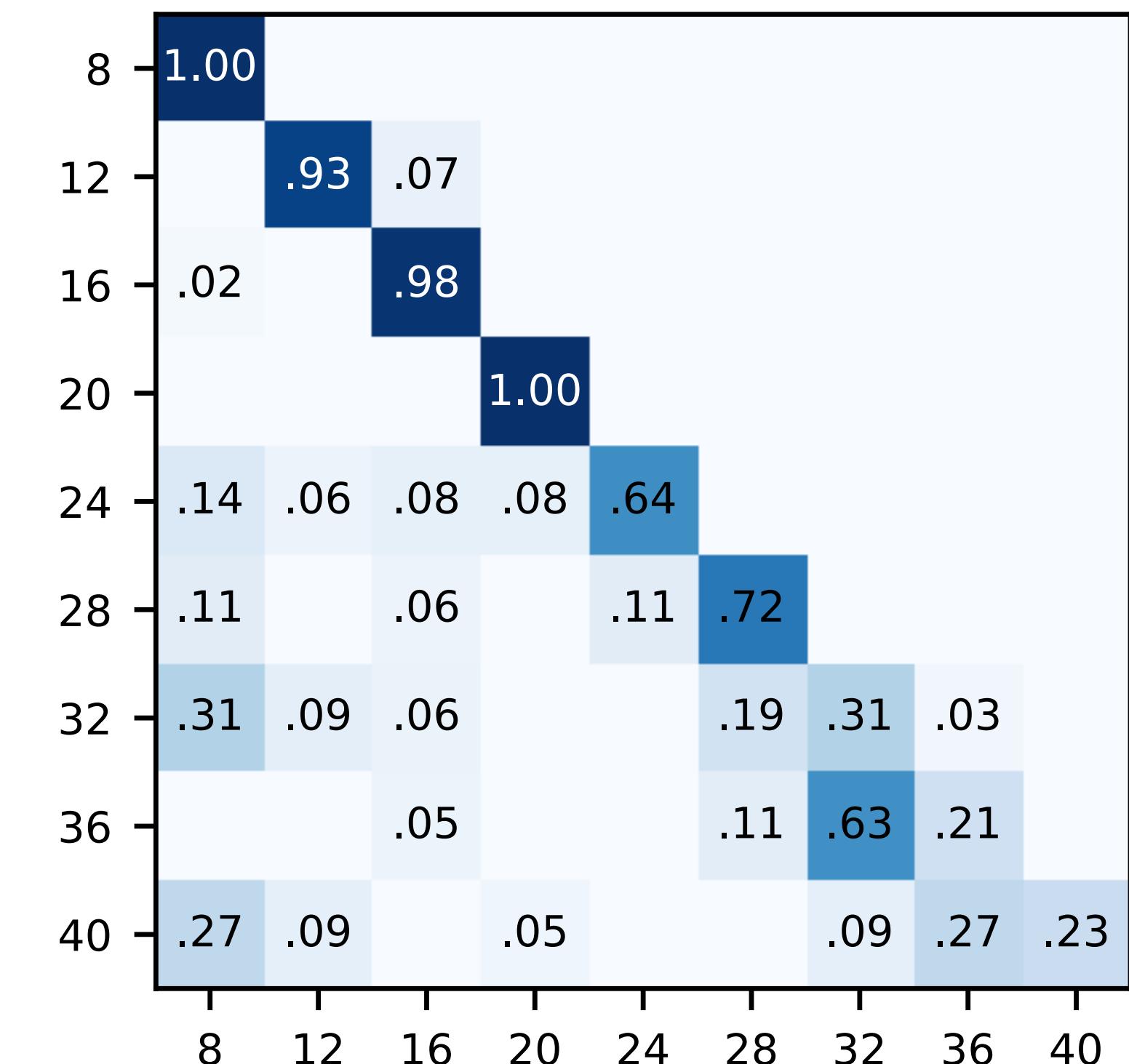
2.5 mm tube



5 mm tube



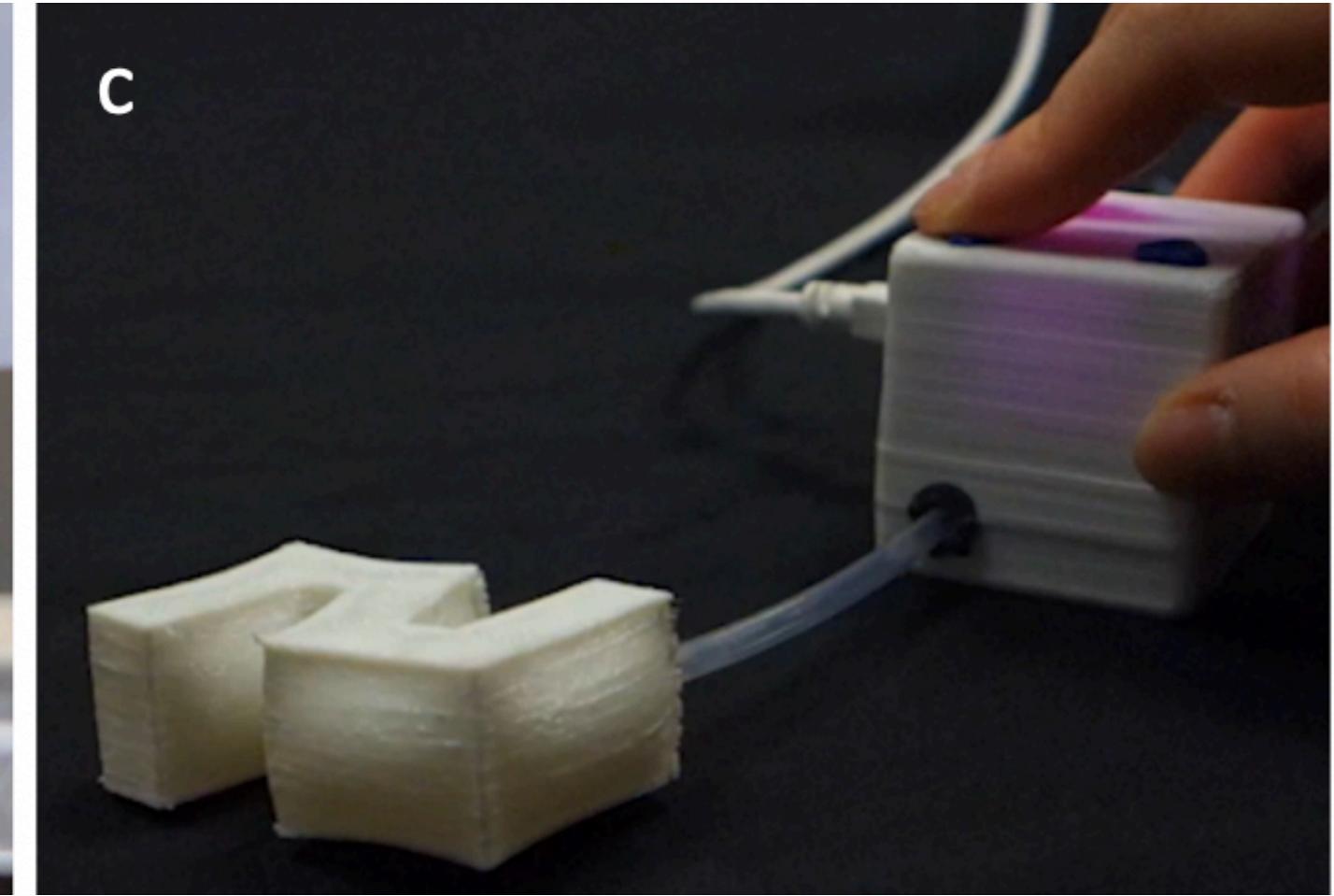
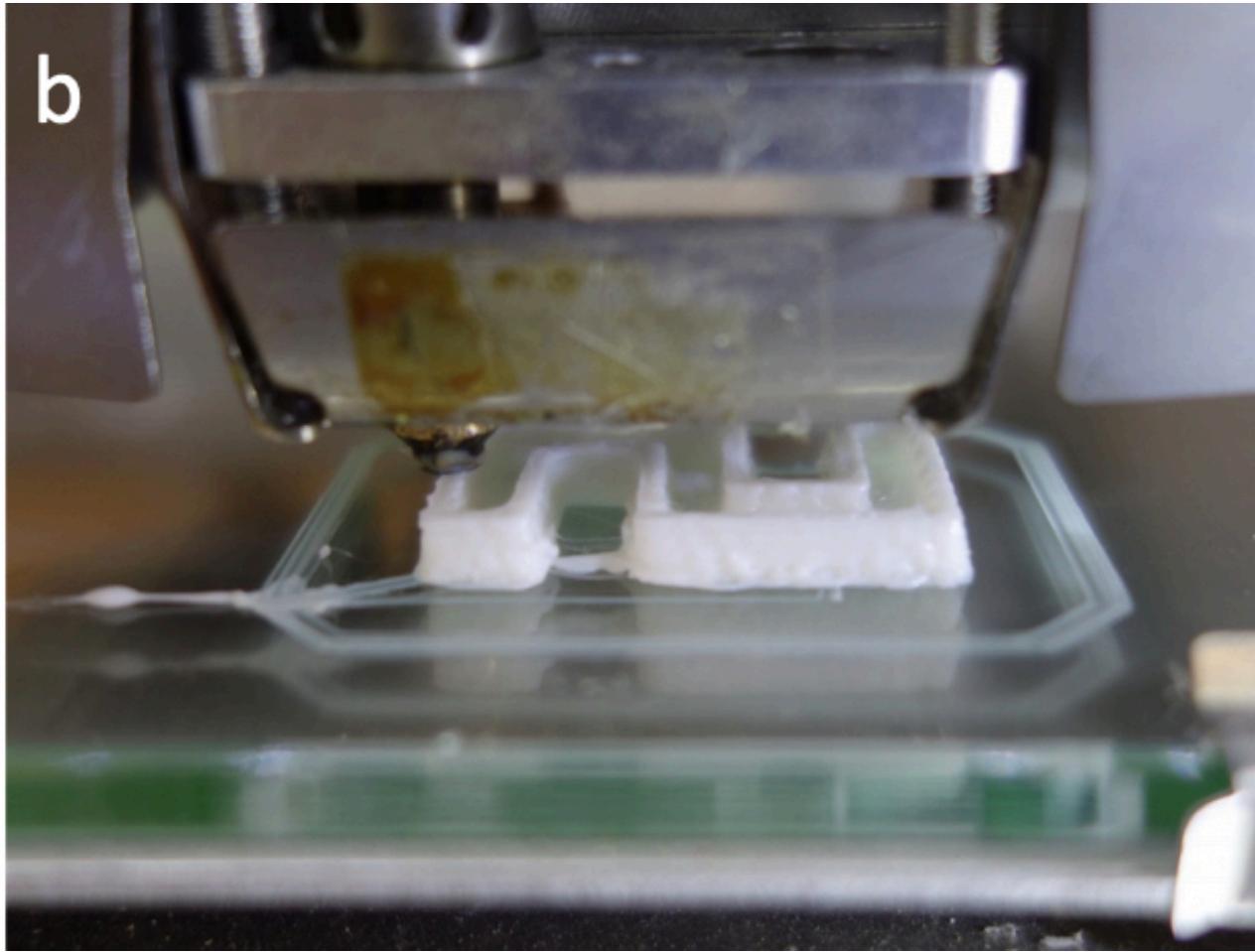
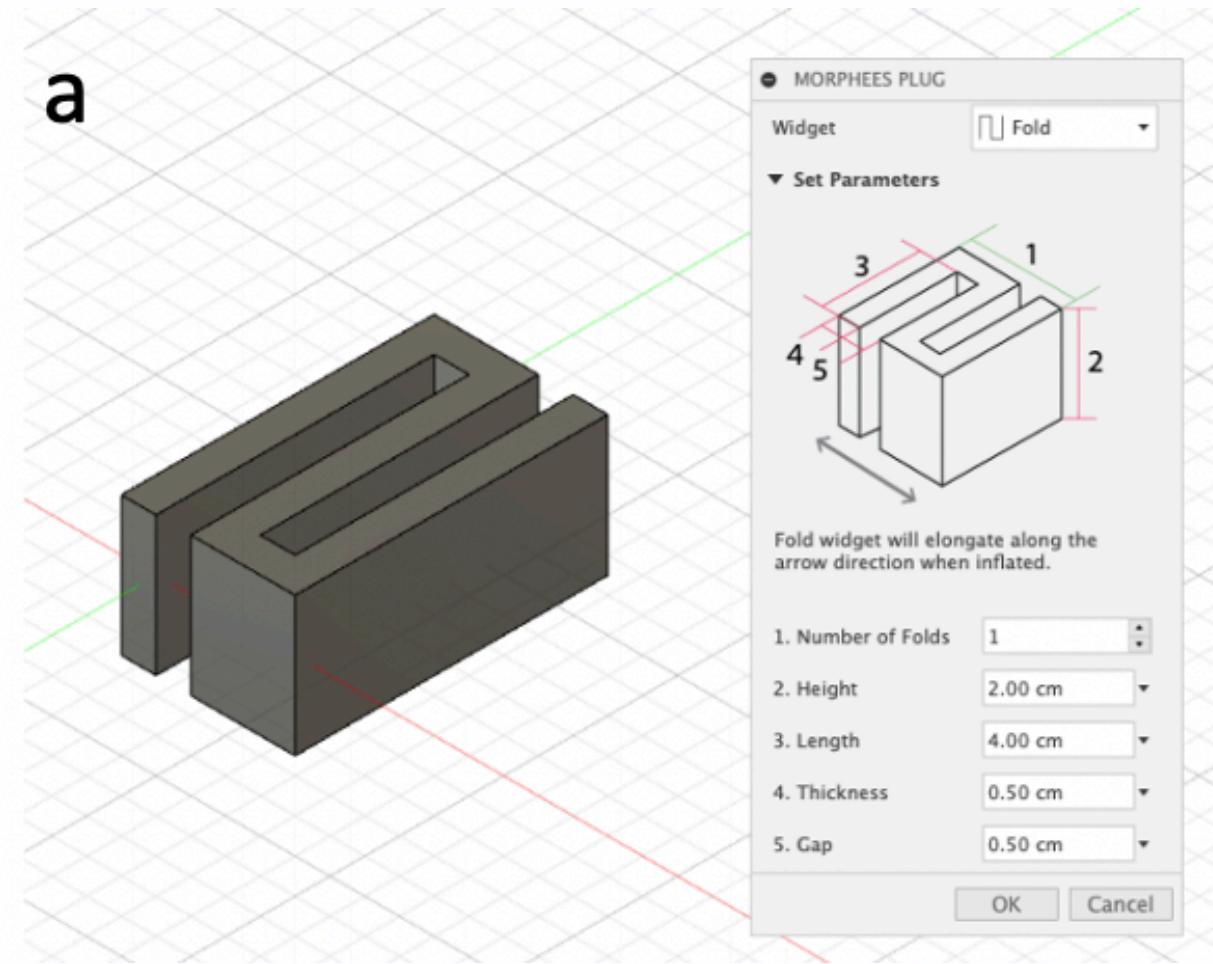
10 mm tube





Blowhole

Blowing-Activated Tags for Interactive 3D-Printed Models



CHI '21
MorpheesPlug

A Toolkit for Prototyping Shape-Changing Interfaces

Hyunyoung Kim



Aluna Everitt



Carlos Tejada

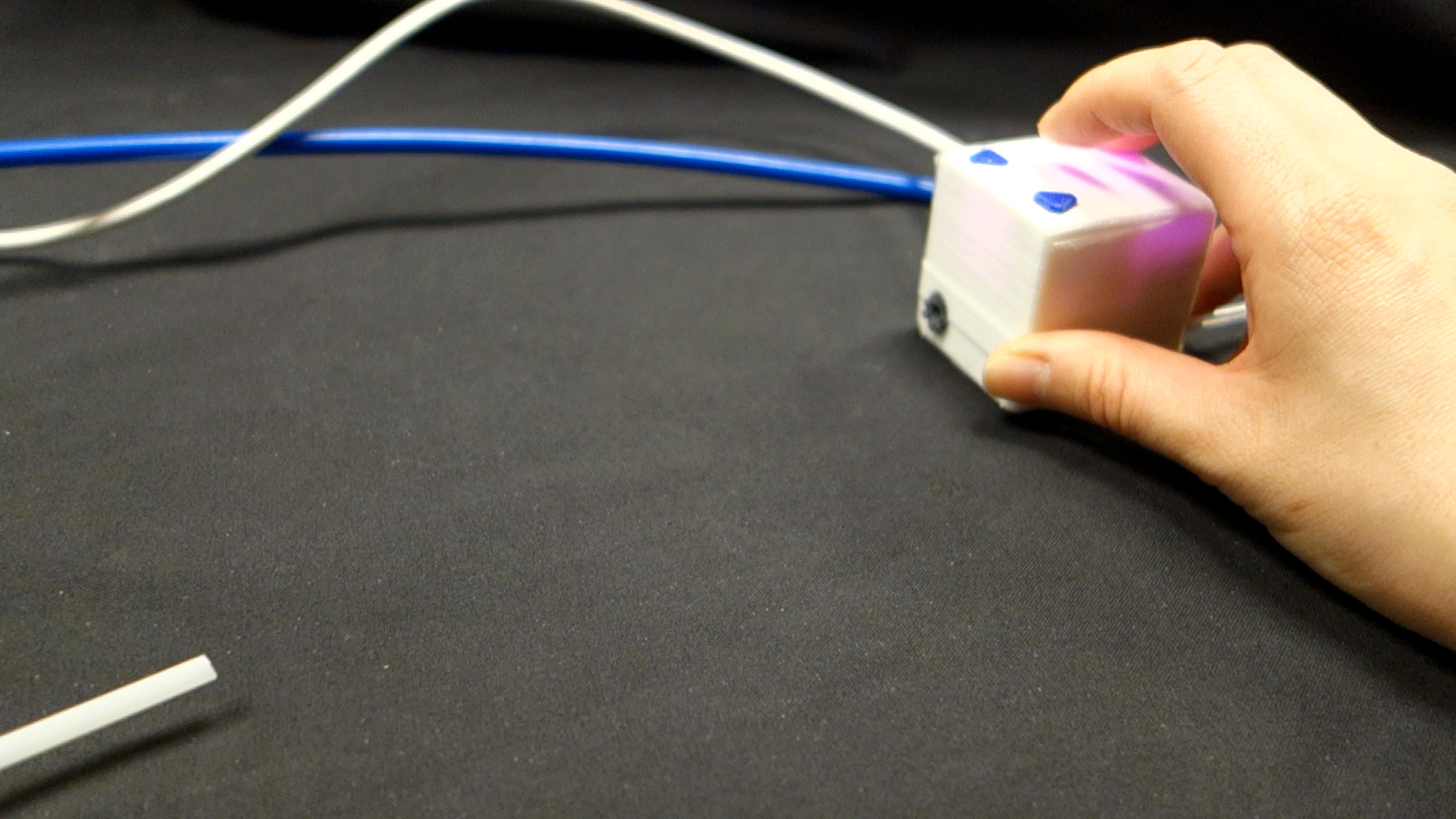


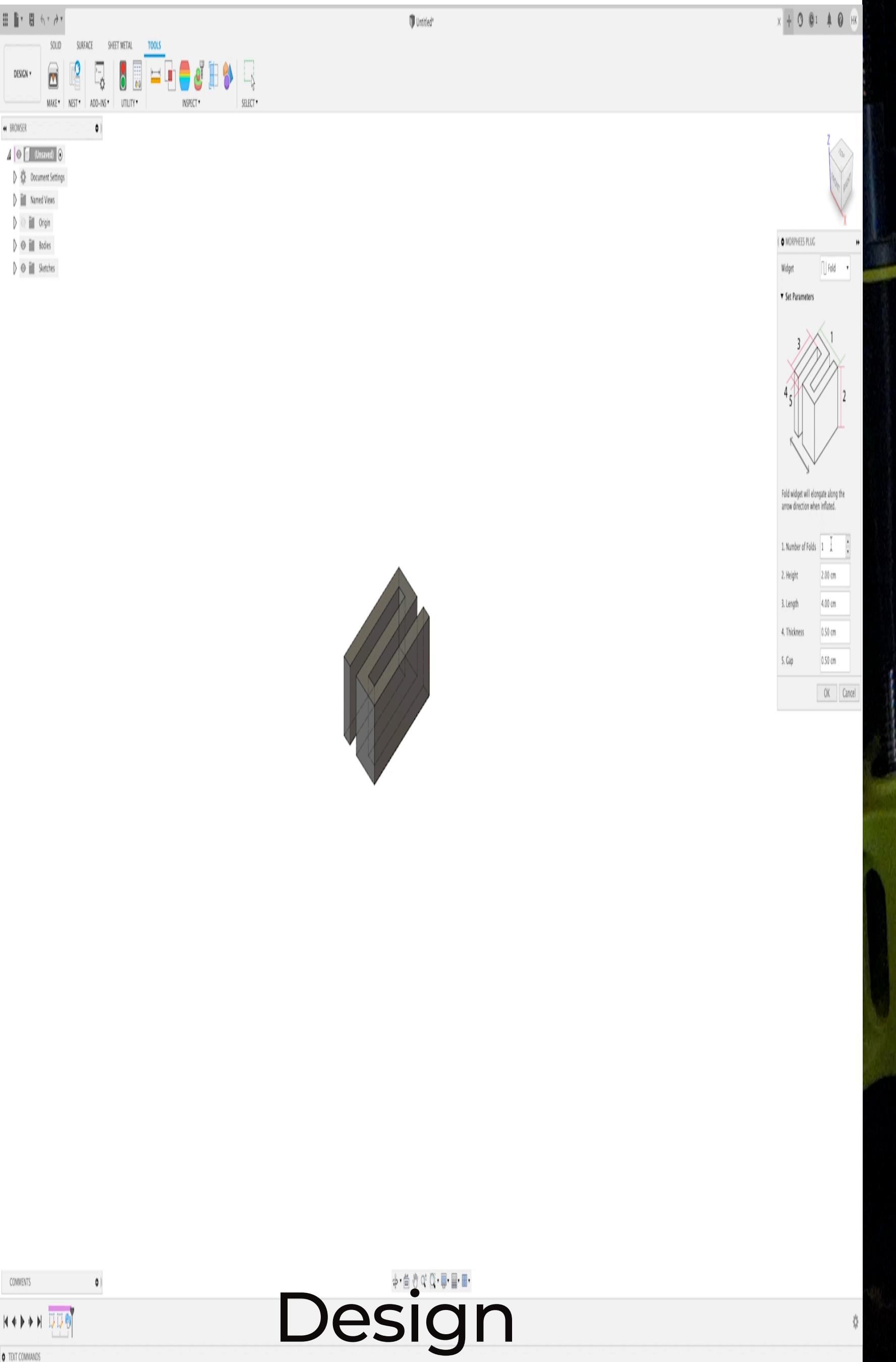
Mengyu Zhong



Daniel Ashbrook







Design

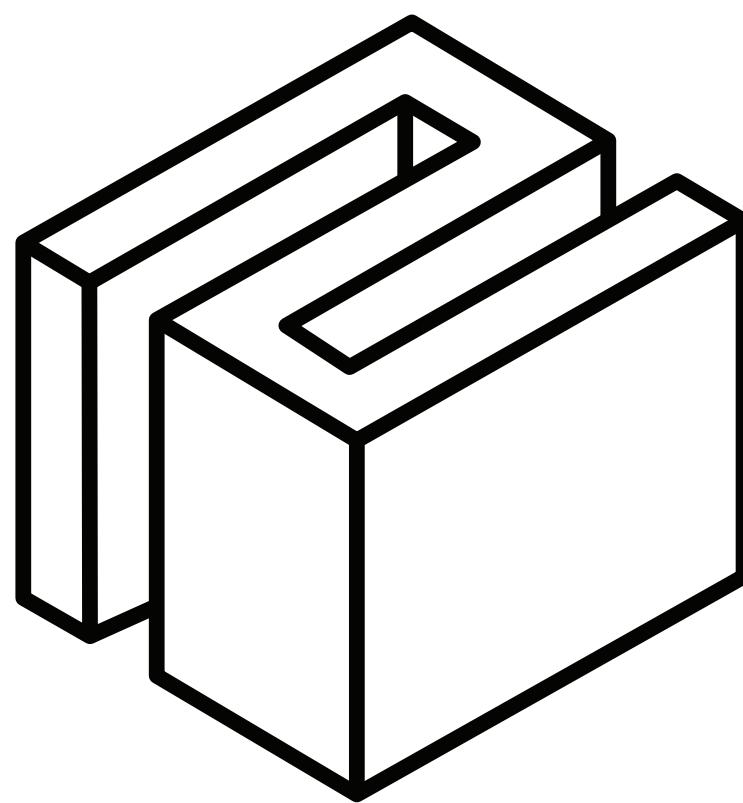


Fabrication

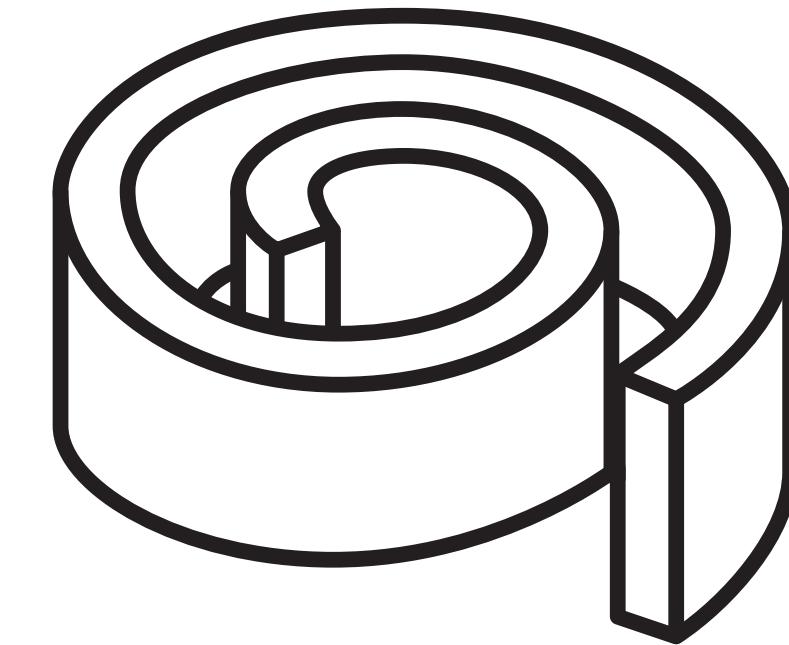


Actuation

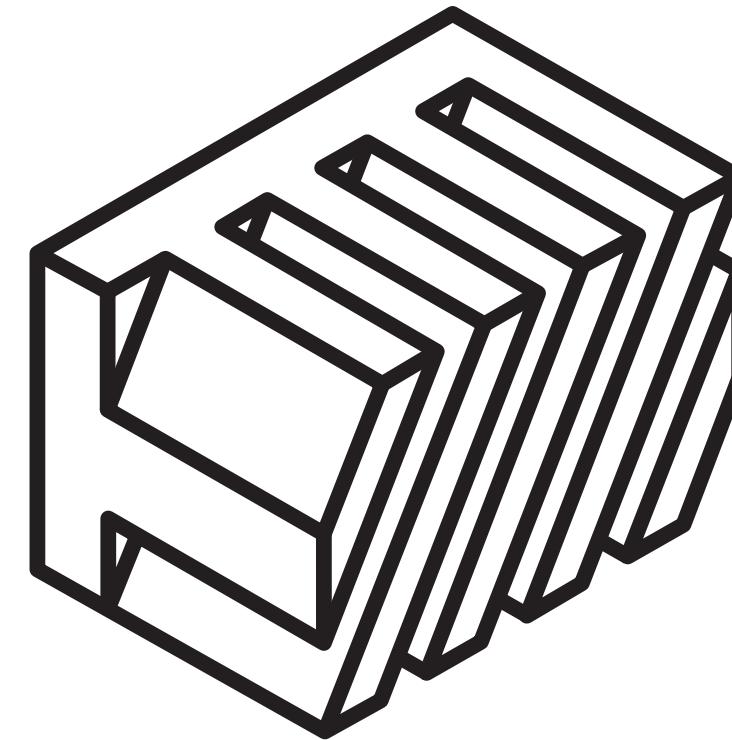
Design



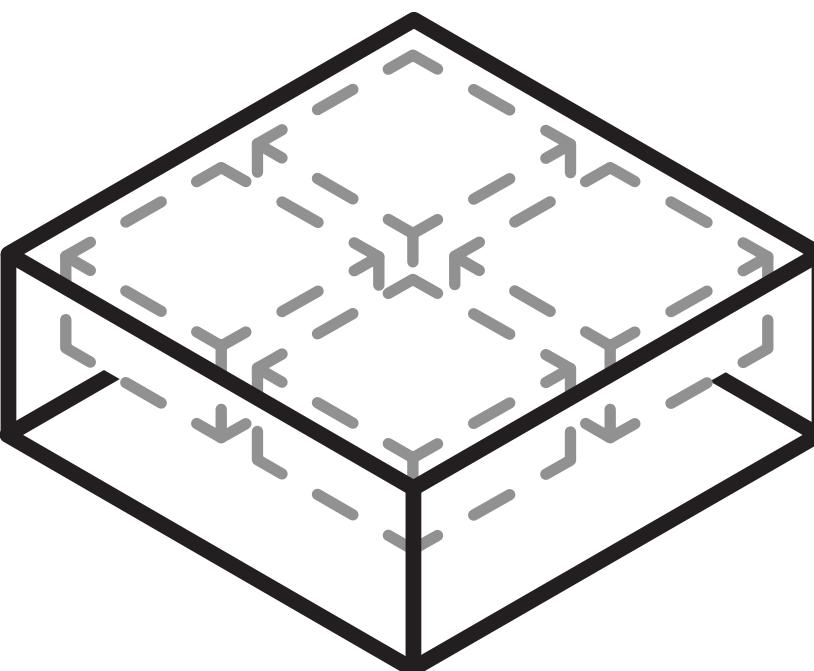
Fold



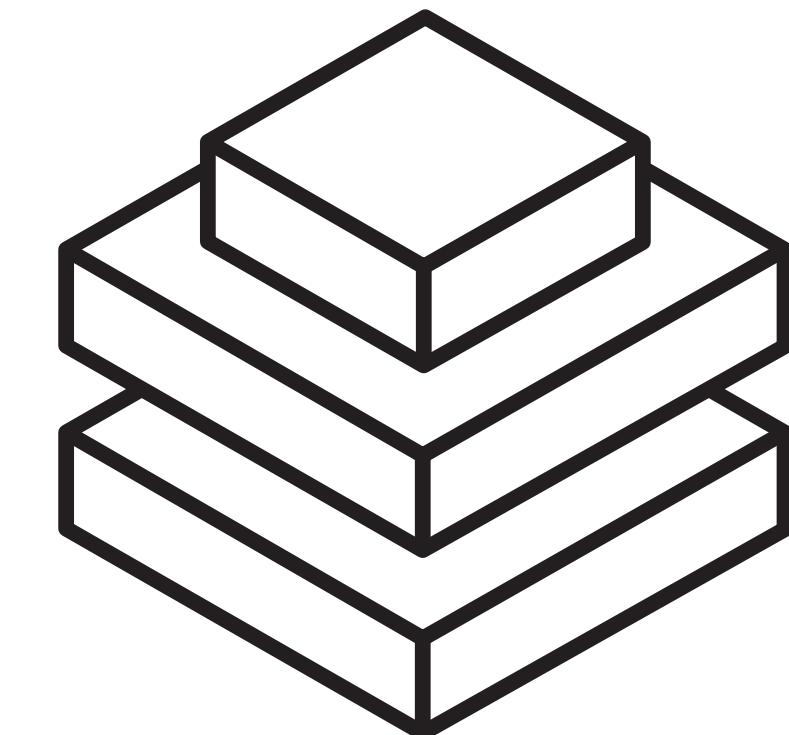
Spiral



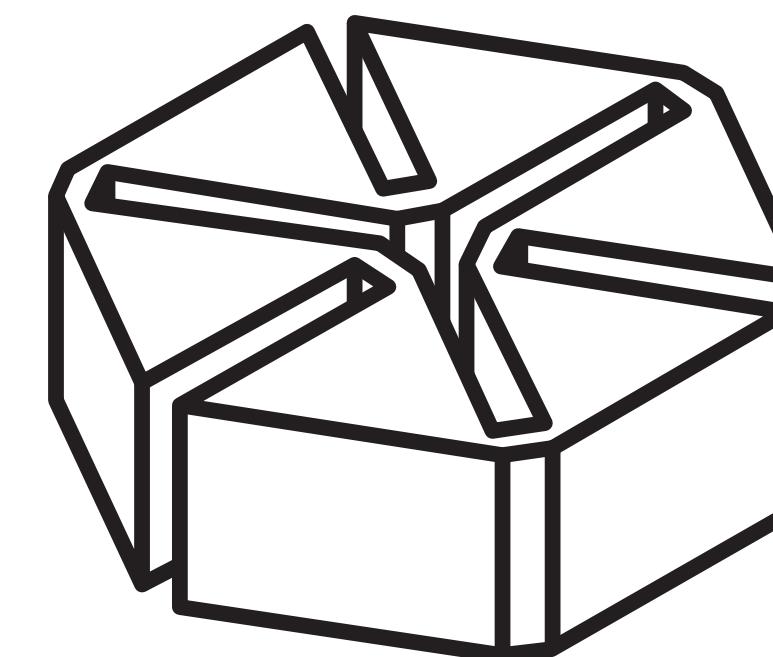
Teeth



Bump

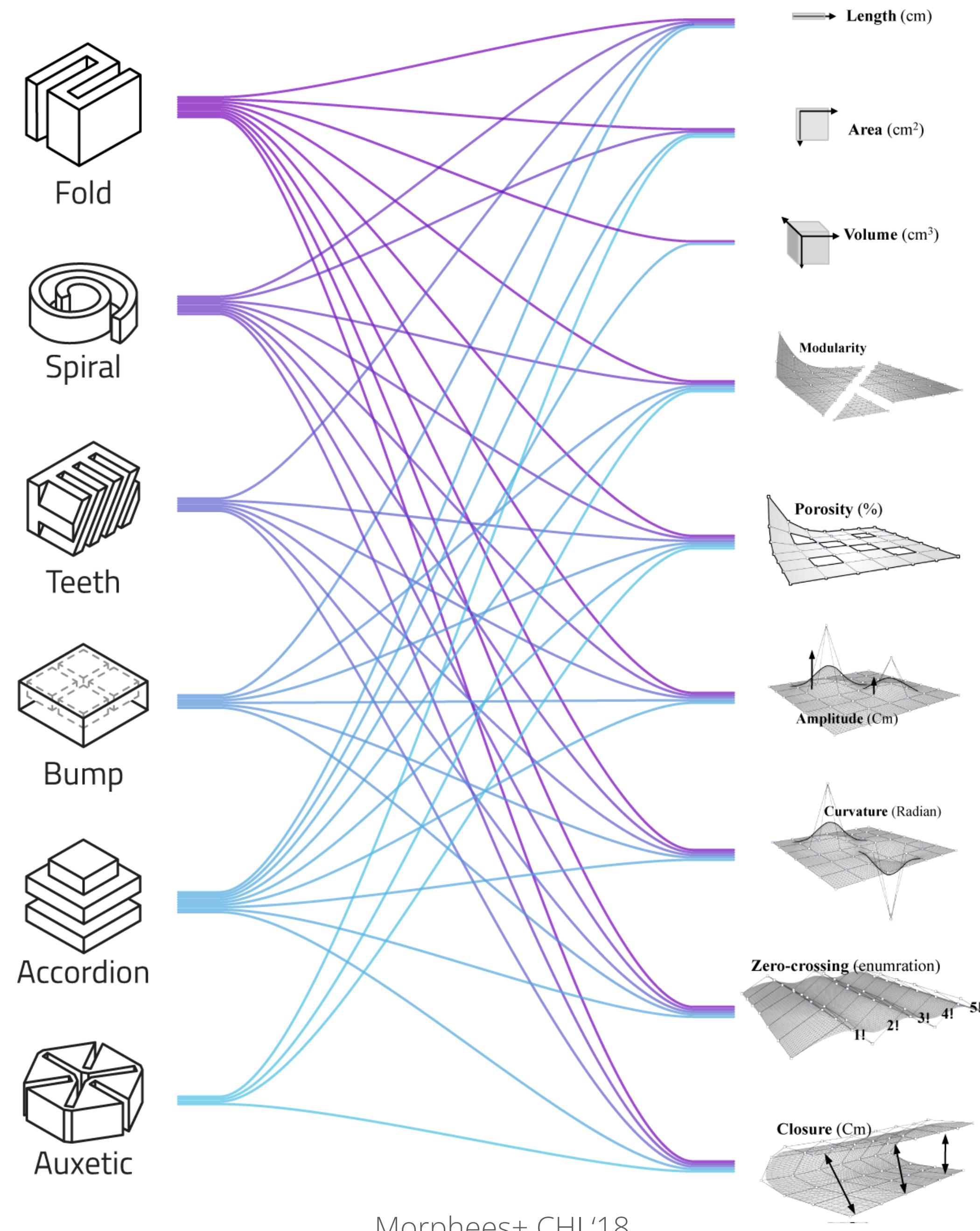


Accordion

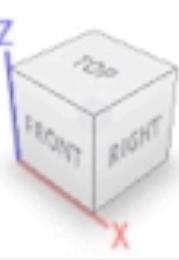


Auxetic

Design



Design



MORPHEES PLUG

Widget Fold

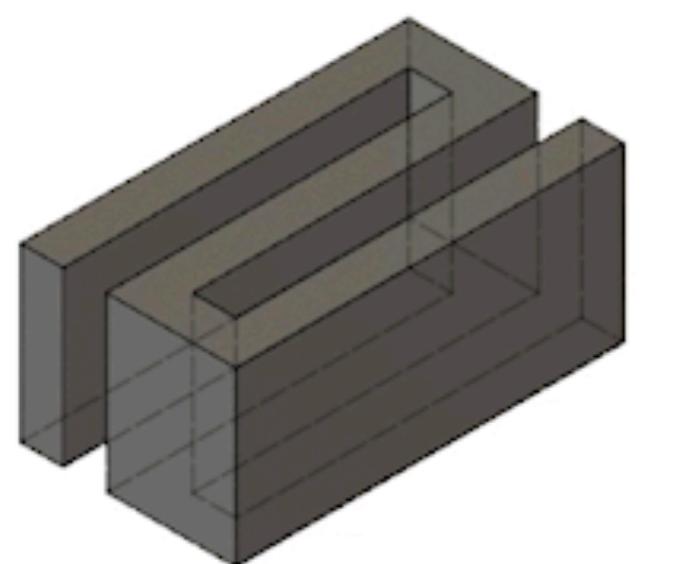
▼ Set Parameters

Fold widget will elongate along the arrow direction when inflated.

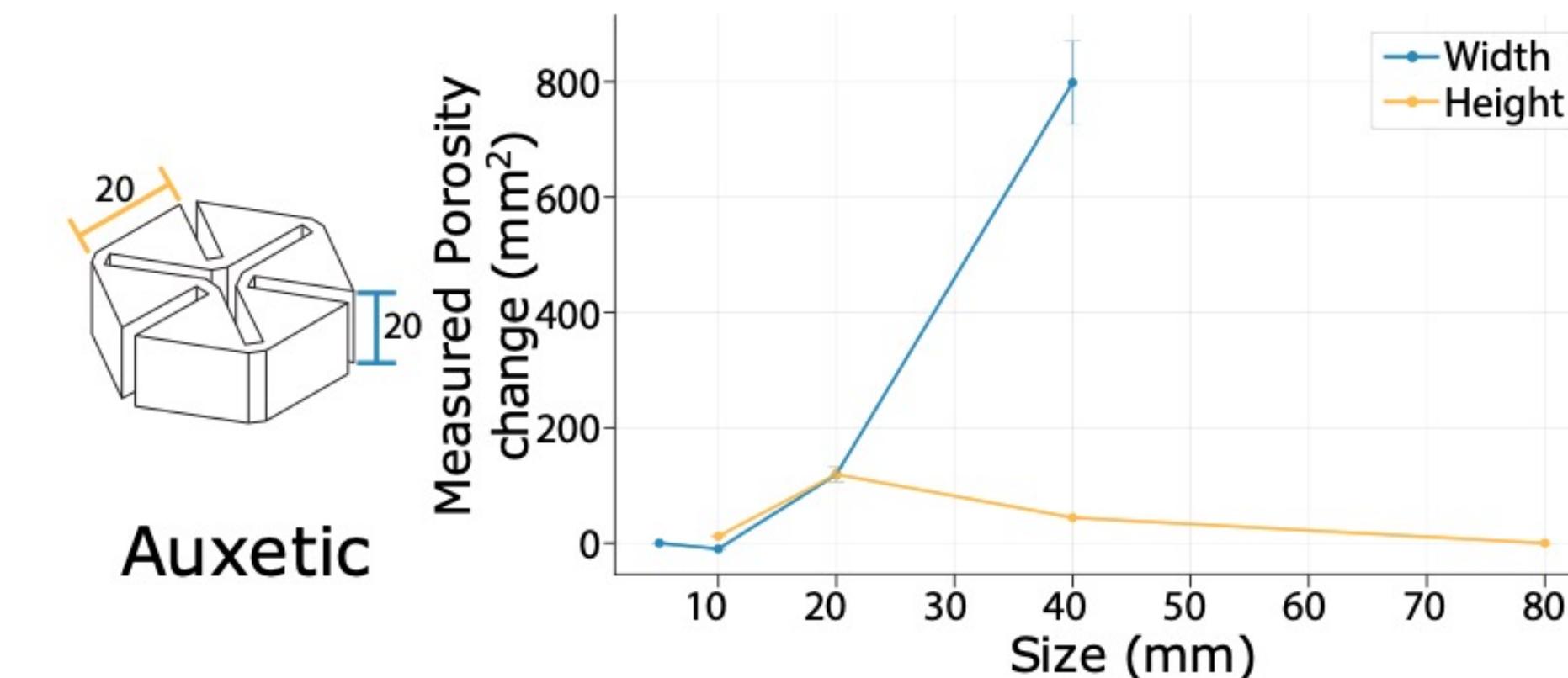
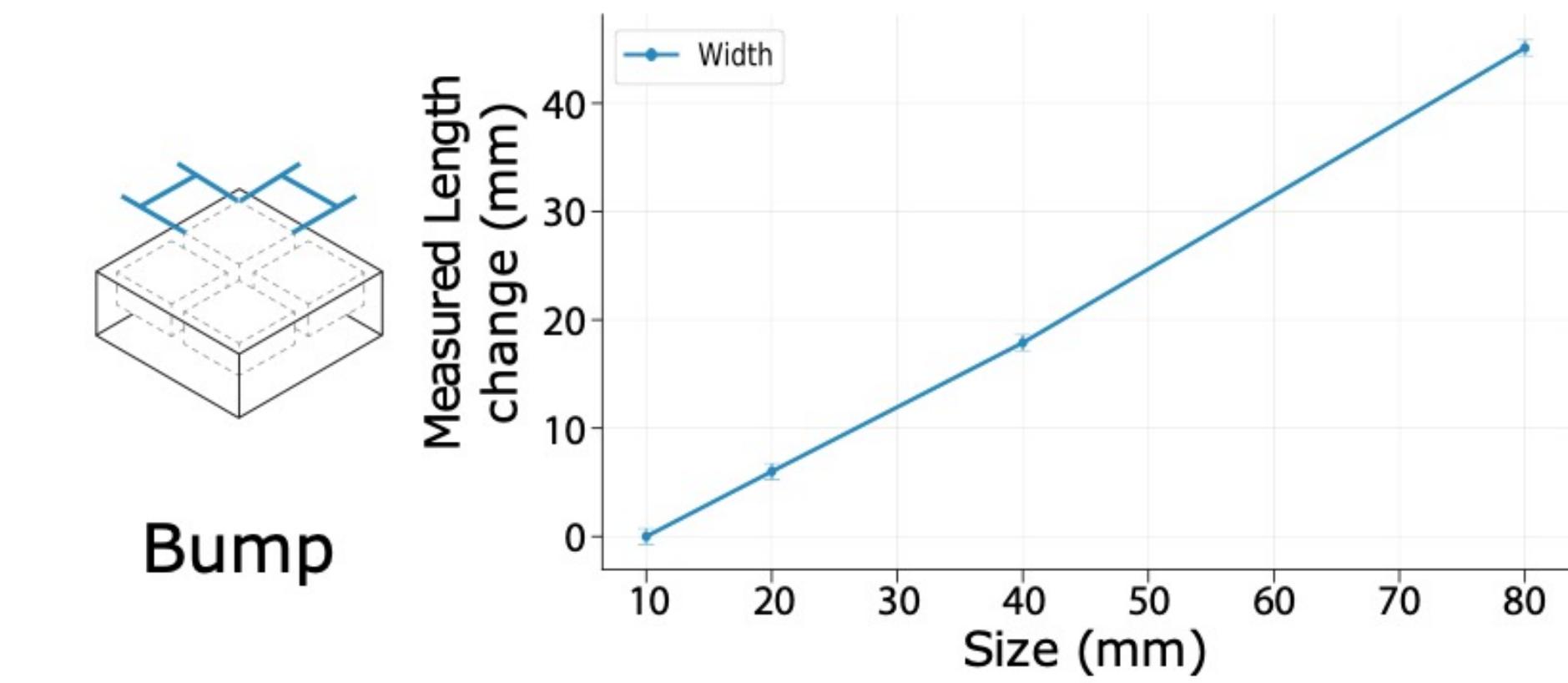
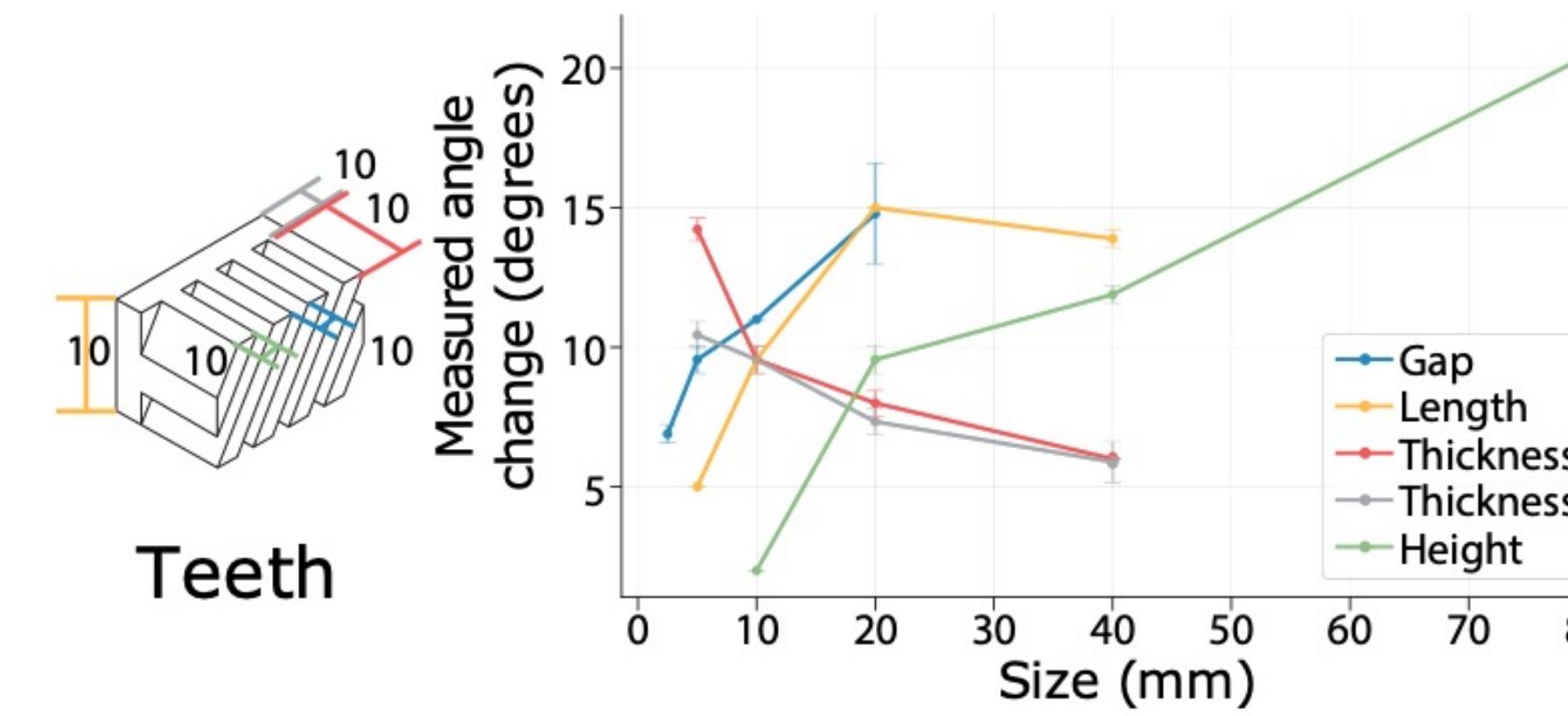
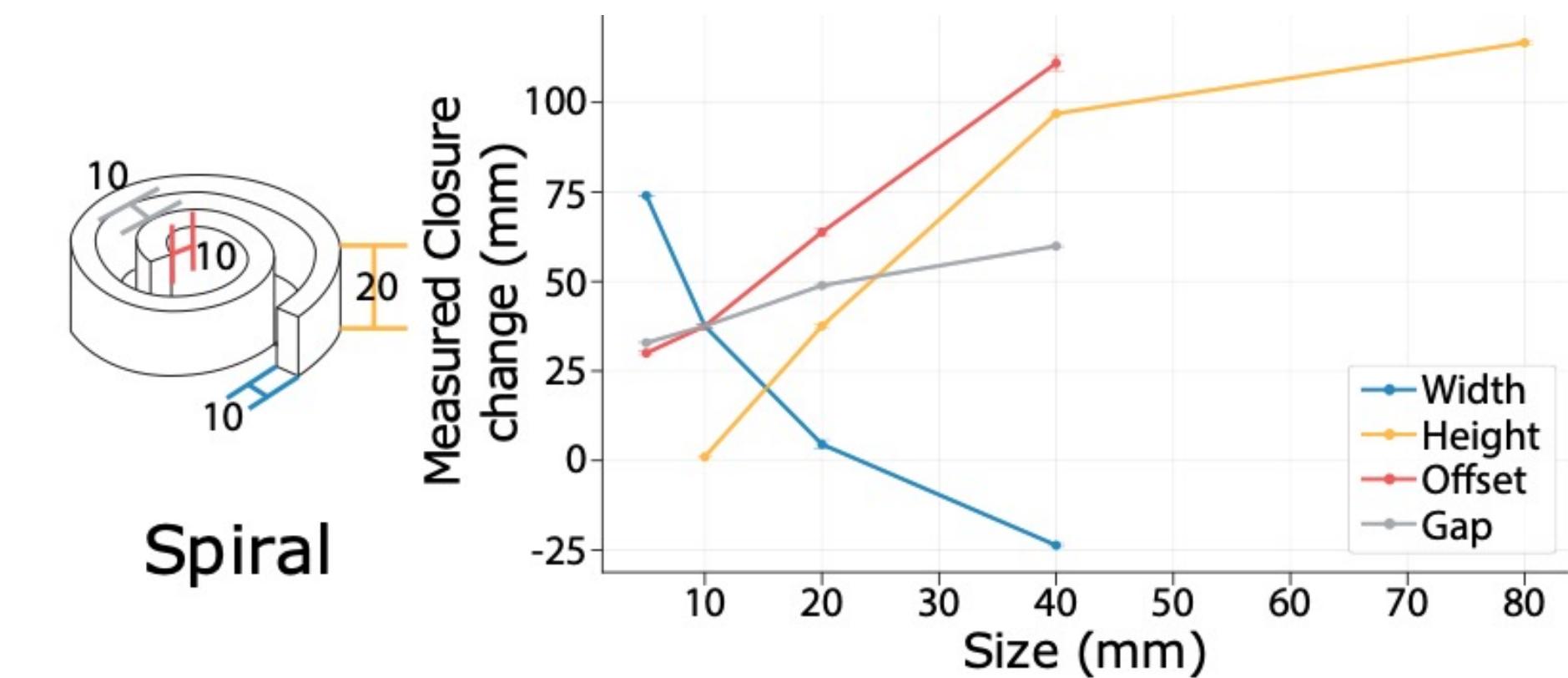
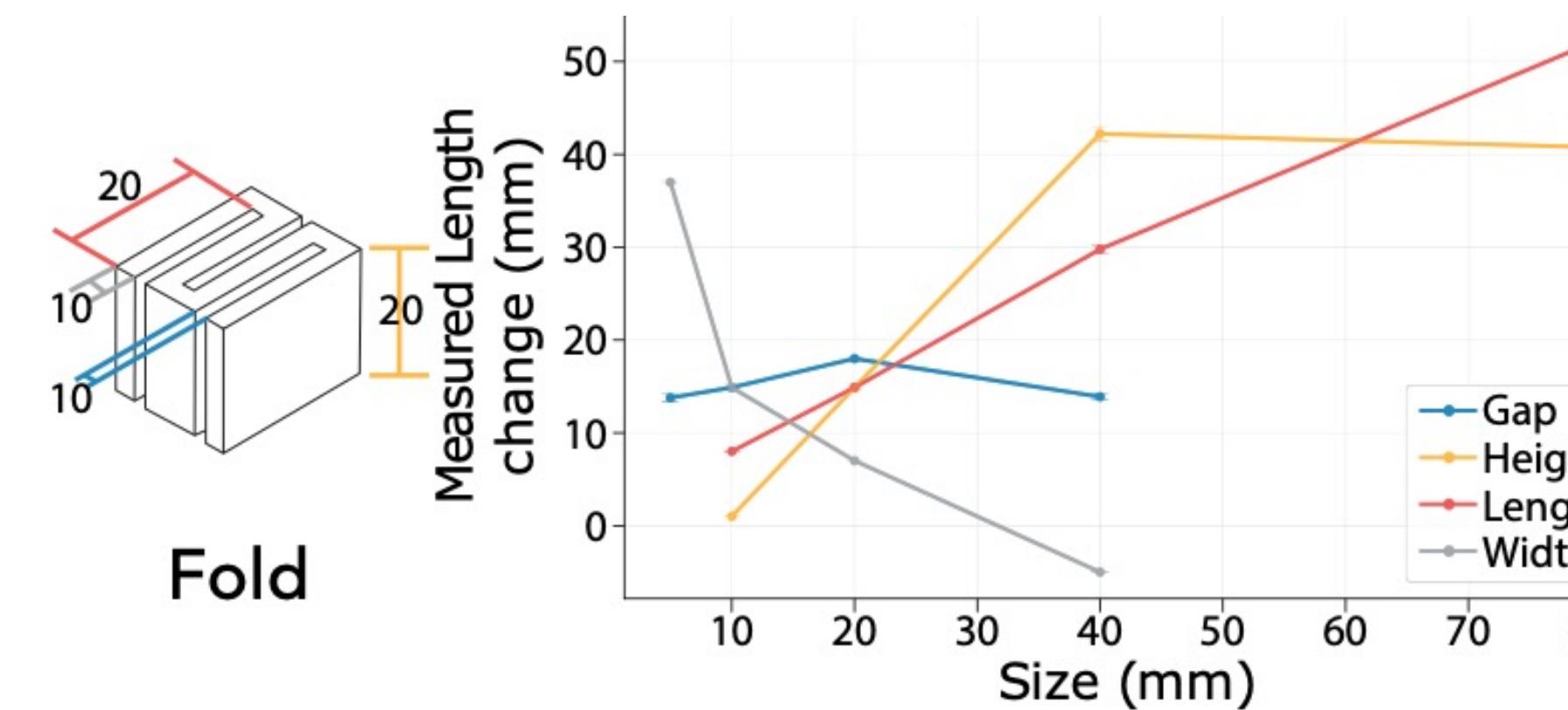
1. Number of Folds	1
2. Height	2.00 cm
3. Length	4.00 cm
4. Thickness	0.50 cm
5. Gap	0.50 cm

OK Cancel

1
2
3
4
5



Design



Fabrication

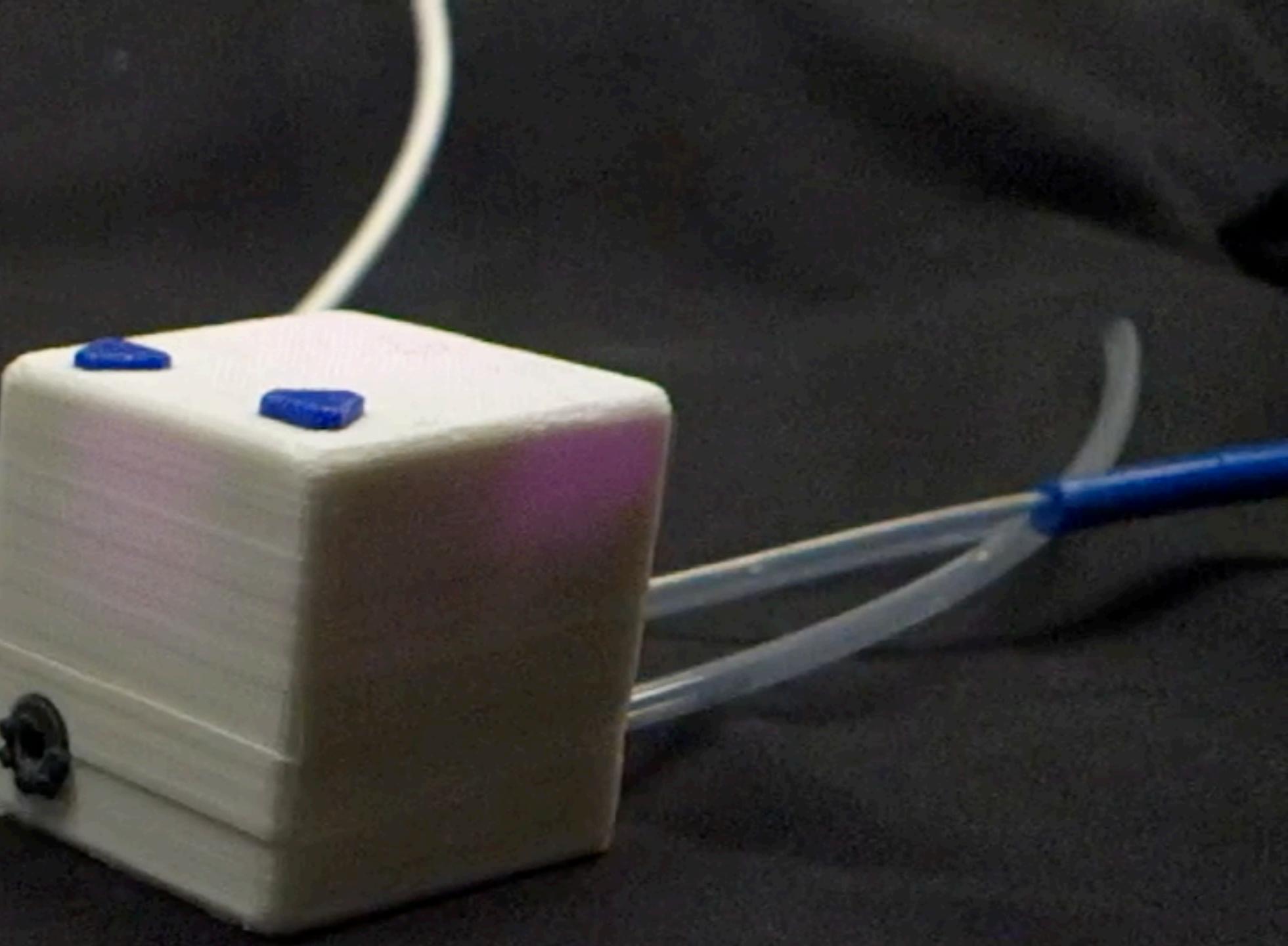
TPU (NinjaFlex 85A)

Tested with 3 printers

Tips for airtight print

- Low print speed
- More number of shells
- Over extrusion

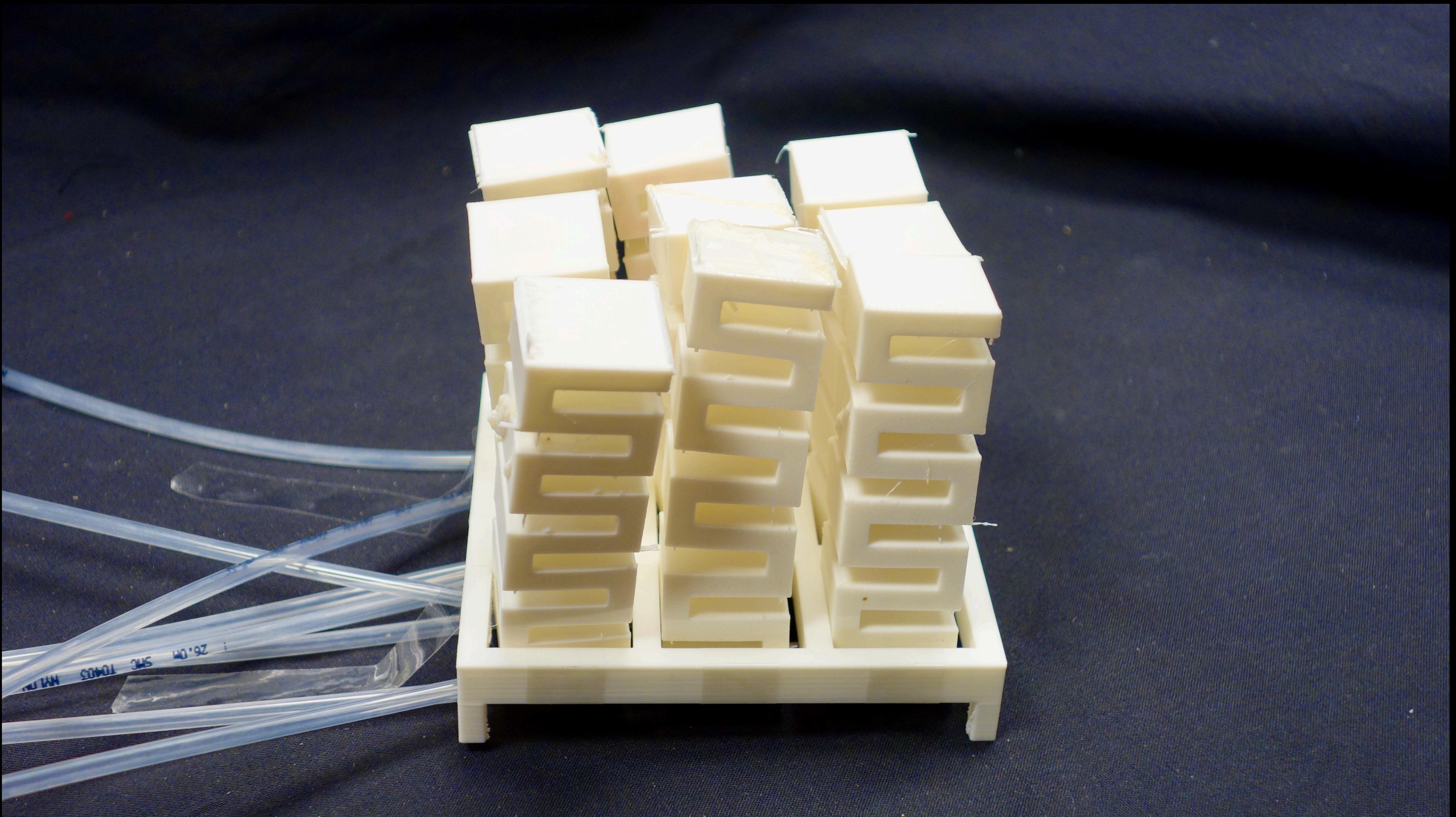
Actuation

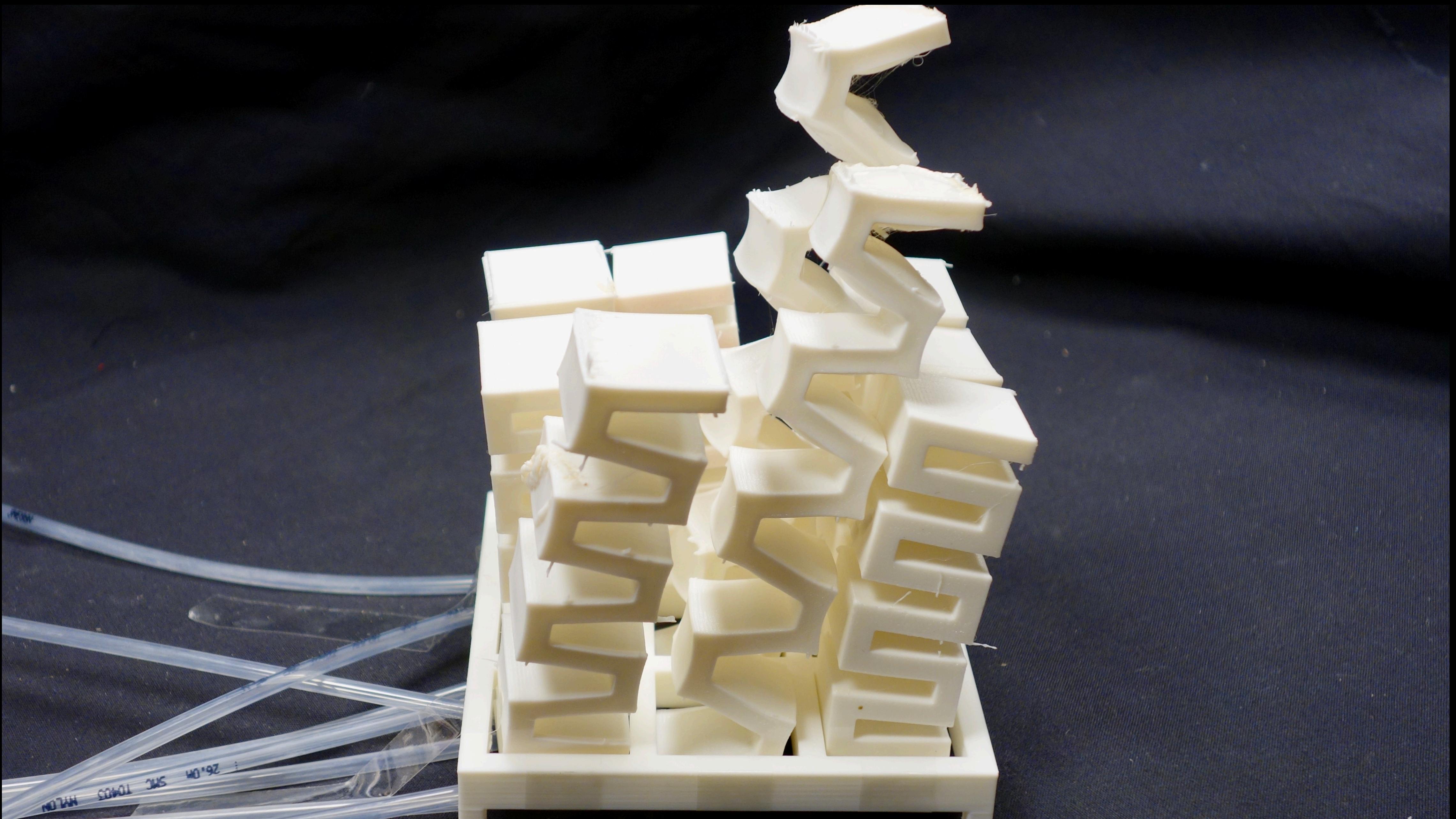


- Connected to air compressor
- Press to inflate/deflate widgets
- Can be programmed















In manuscript

AirLogic

A Toolkit for 3D-printing Stand-Alone, Interactive Objects

Carlos Tejada

University of Copenhagen



Hyunyoung Kim

University of Copenhagen



Raf Ramakers

Hasselt University



Mengyu Zhong

Uppsala University



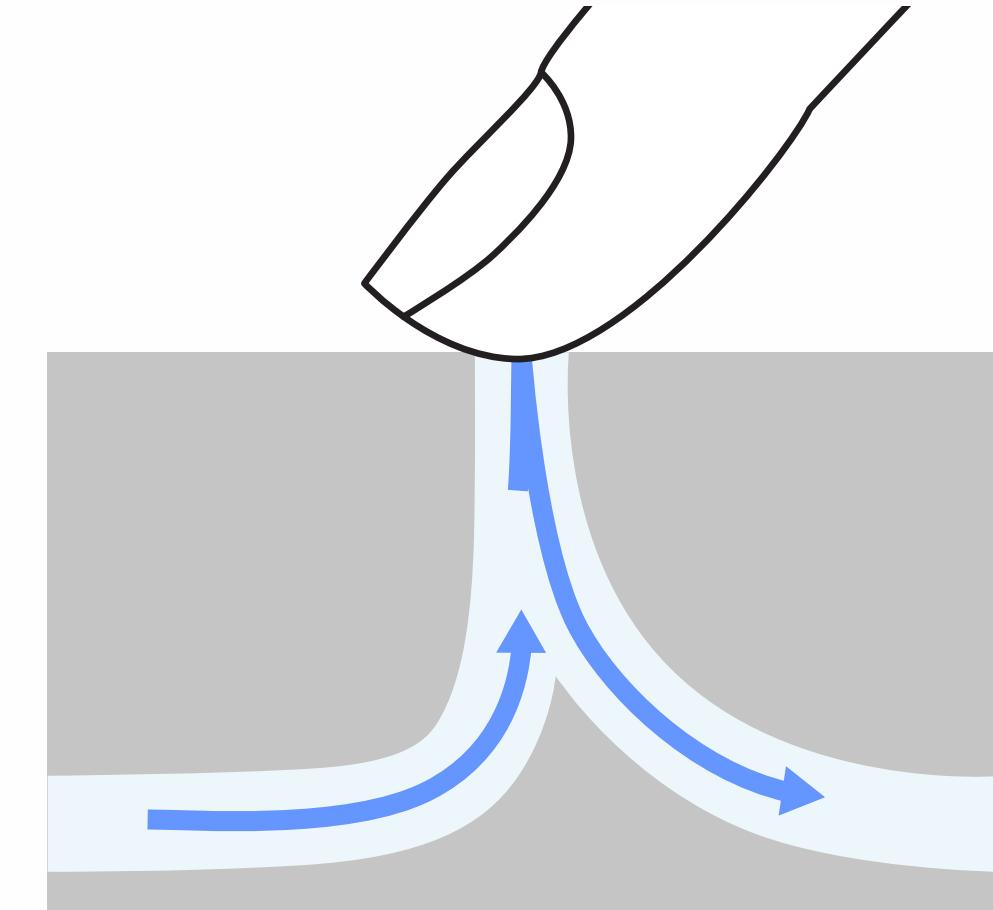
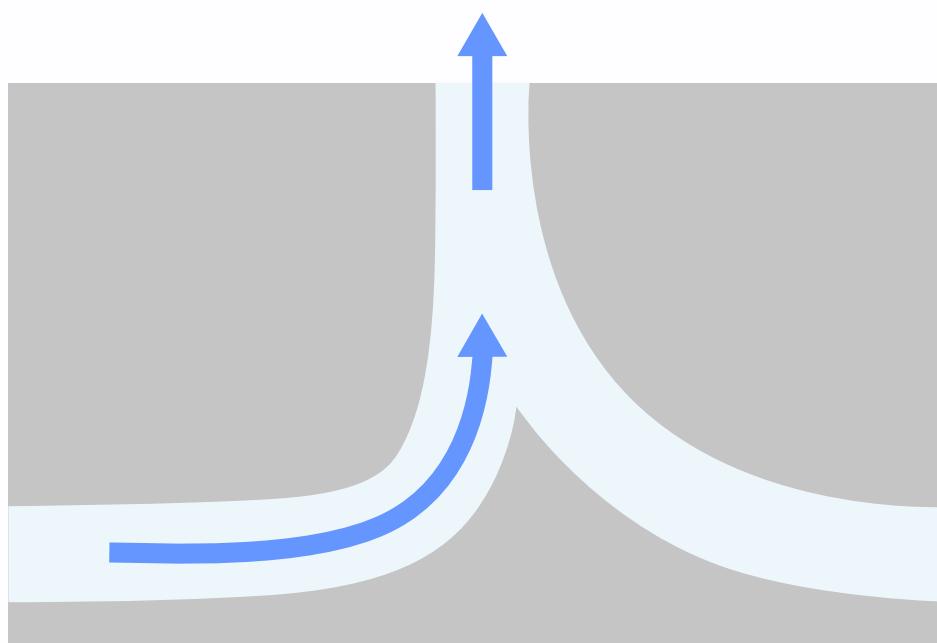
Daniel Ashbrook

University of Copenhagen

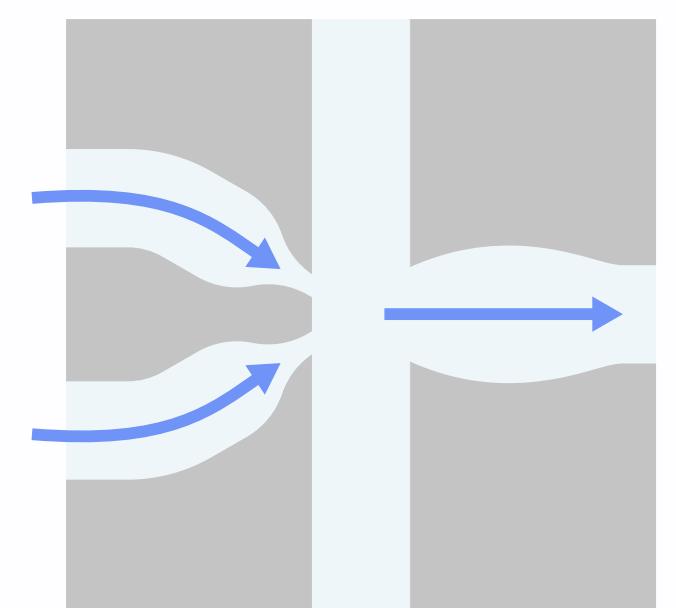
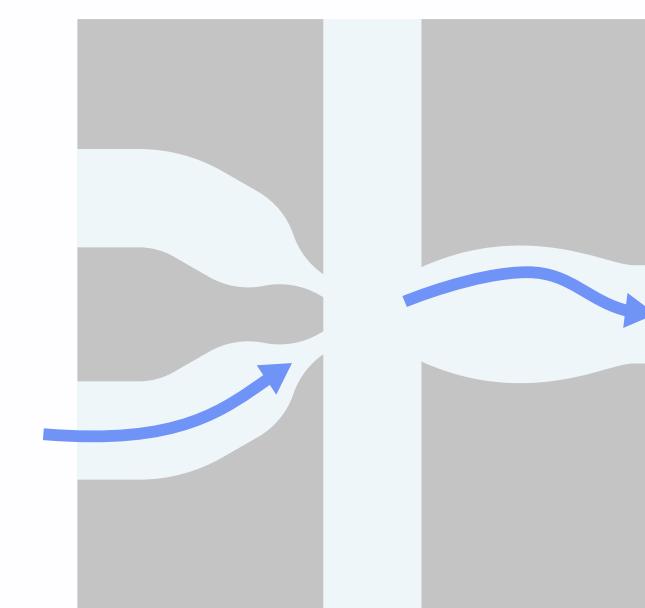
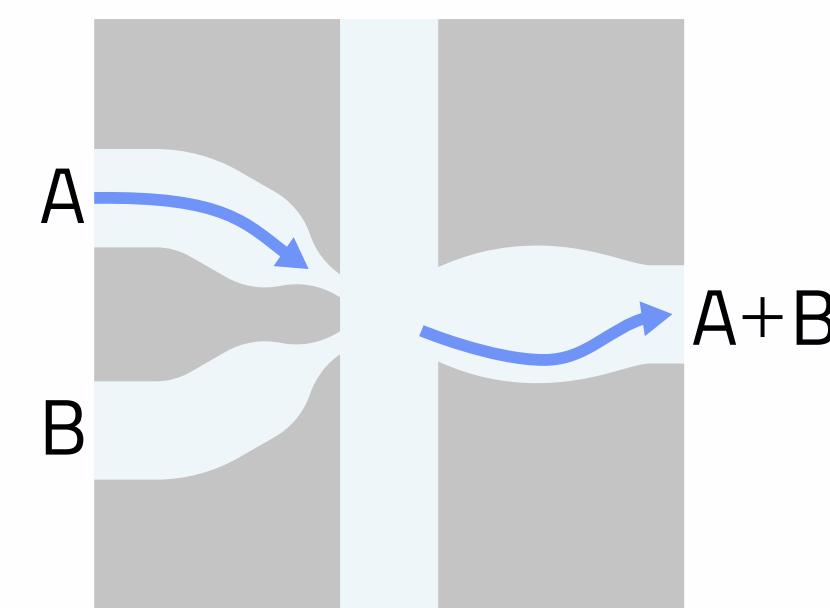




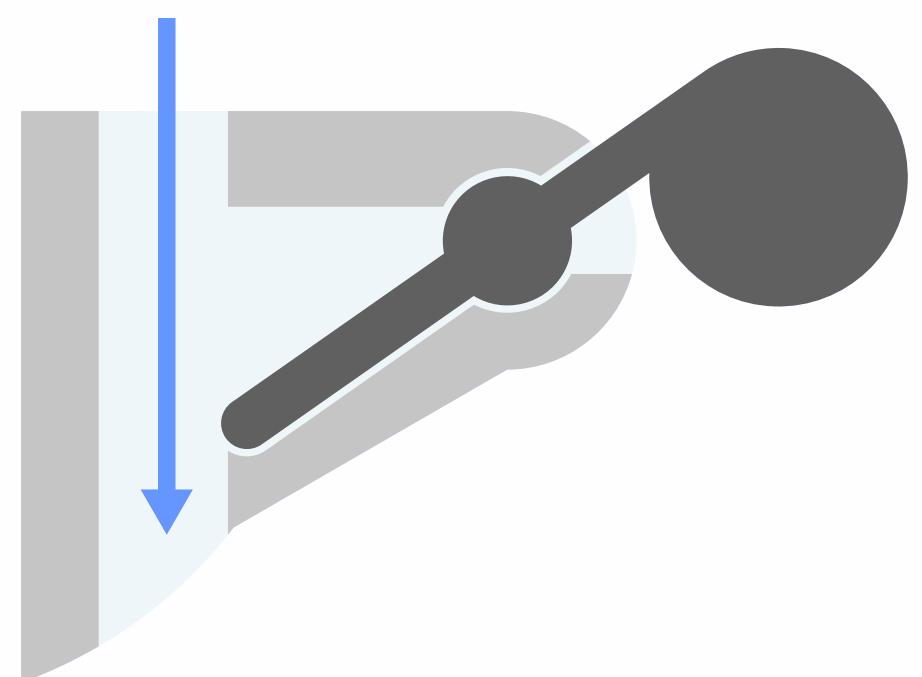
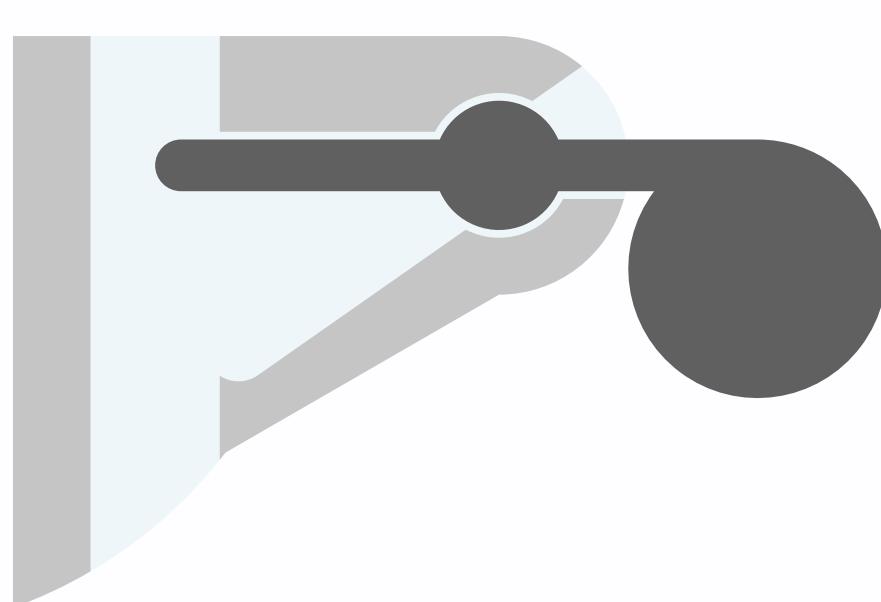
Input



Processing



Output



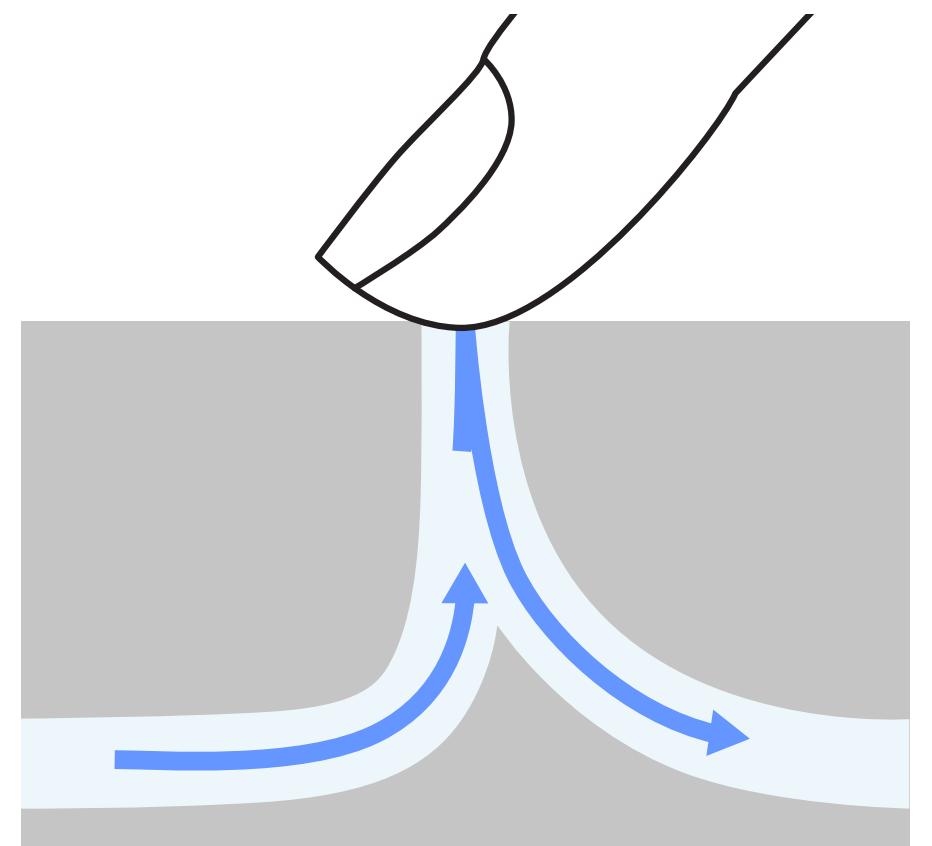
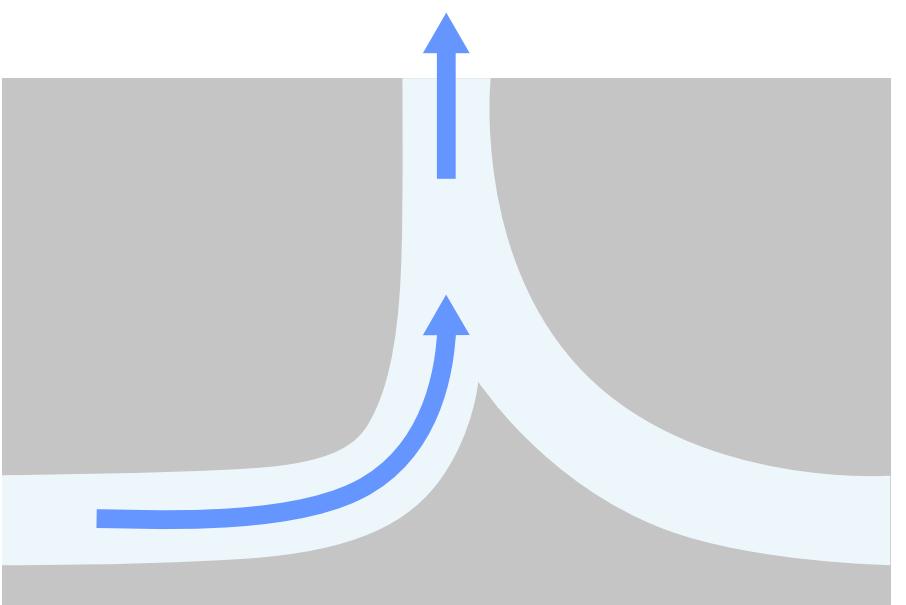
AirLogic Toolkit

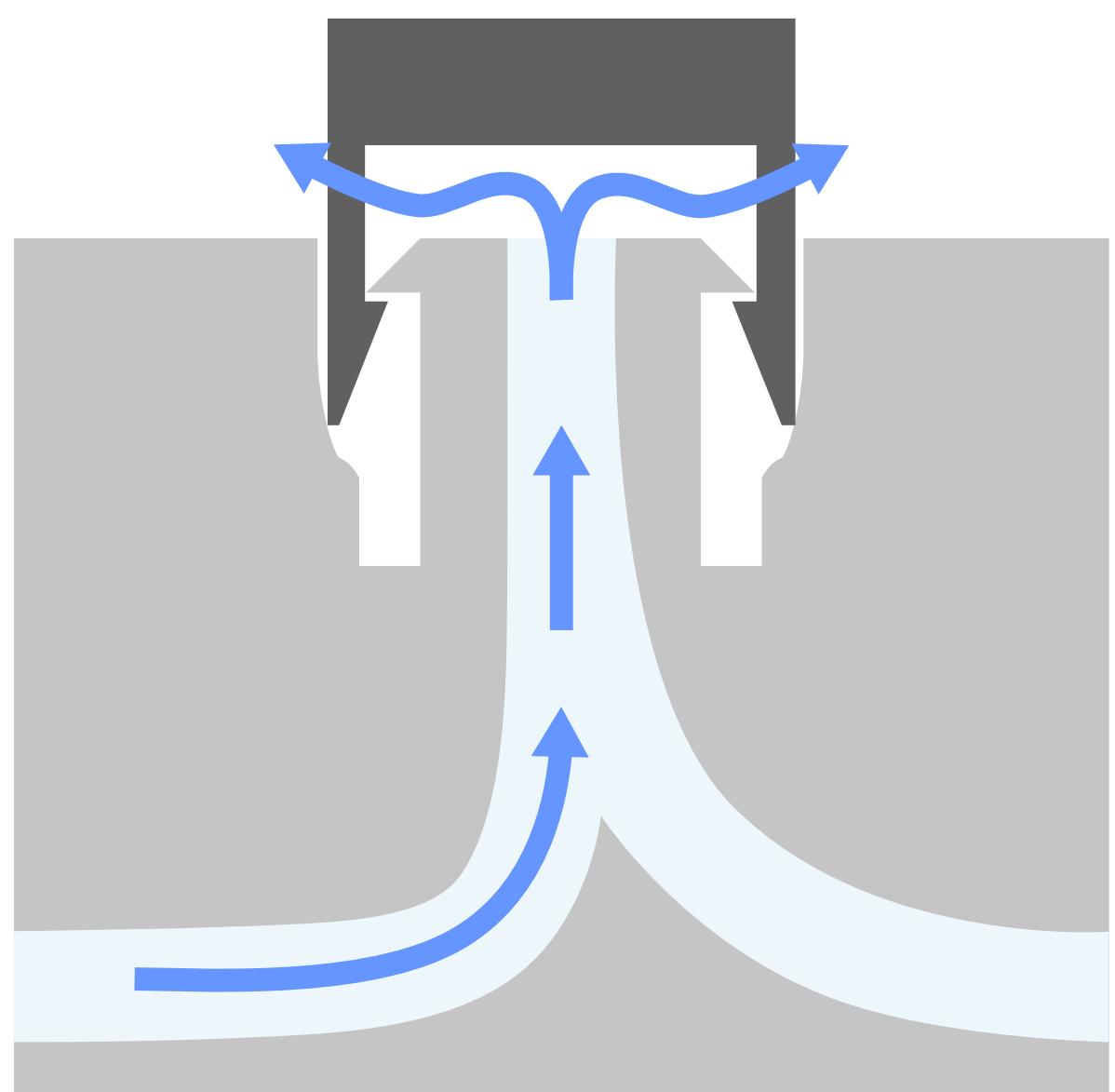
- Physical toolkit comprised of 13 widgets.
- Input, logic, output widgets.
 - Interconnected using standard tubing.
 - Embedded into existing three-dimensional designs.

AirLogic Toolkit

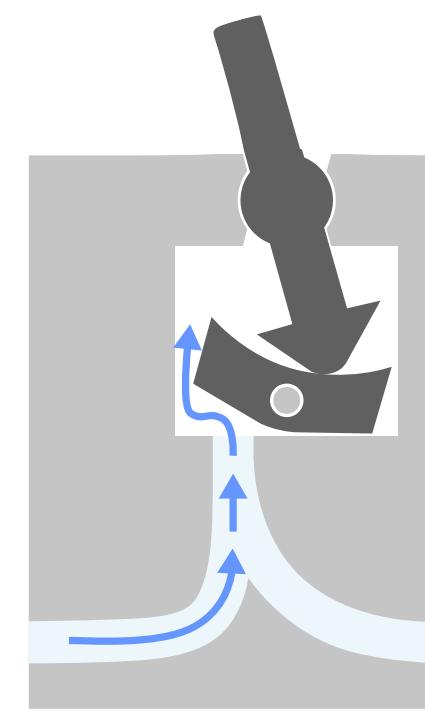
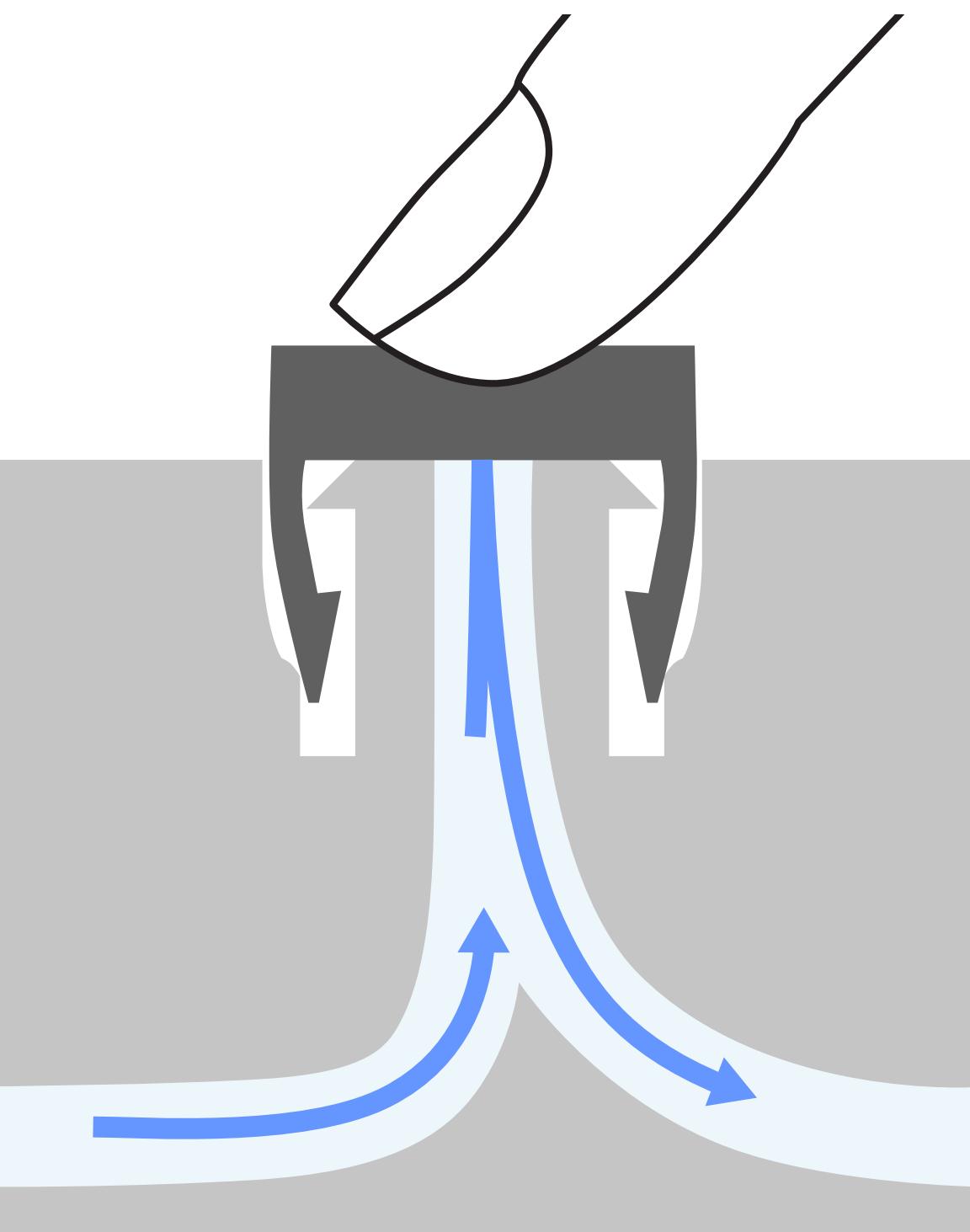
Input widgets

- Operates similarly to an electronic switch.
- Based on an inverted T-joint.
- Air exits the design unless obstructed.
- When obstructed, the air continues through the conducts.

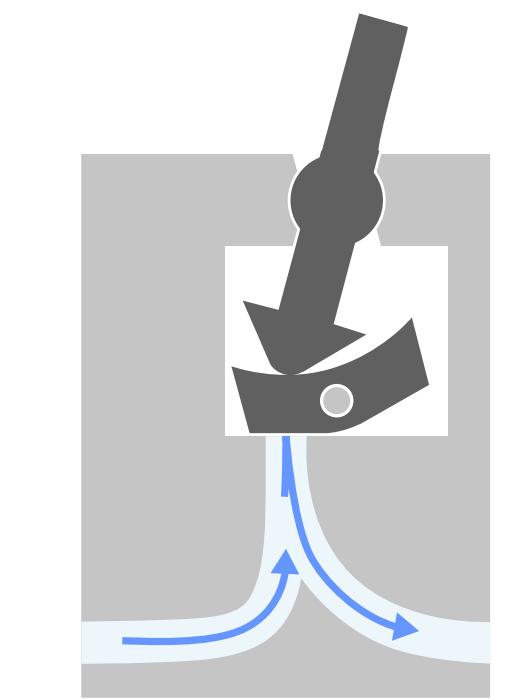
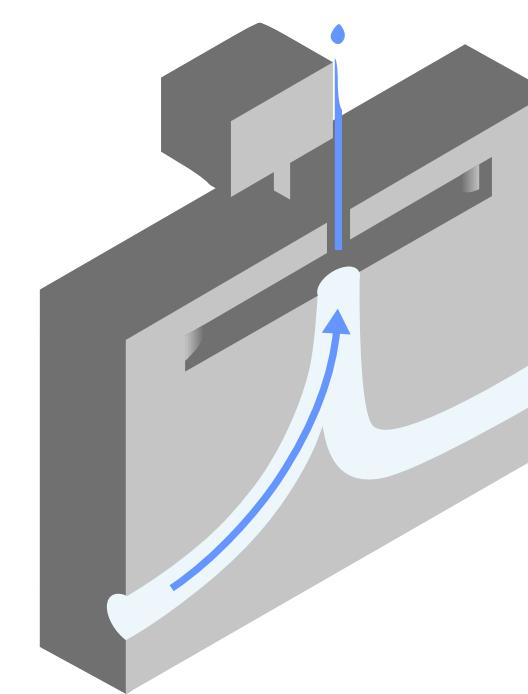




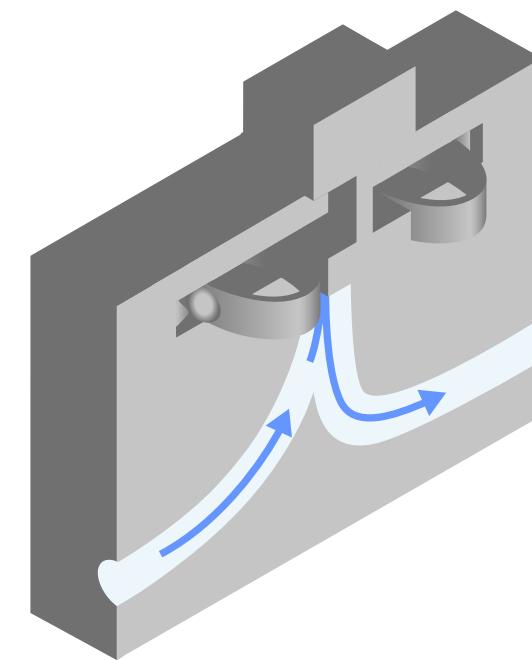
Buttons

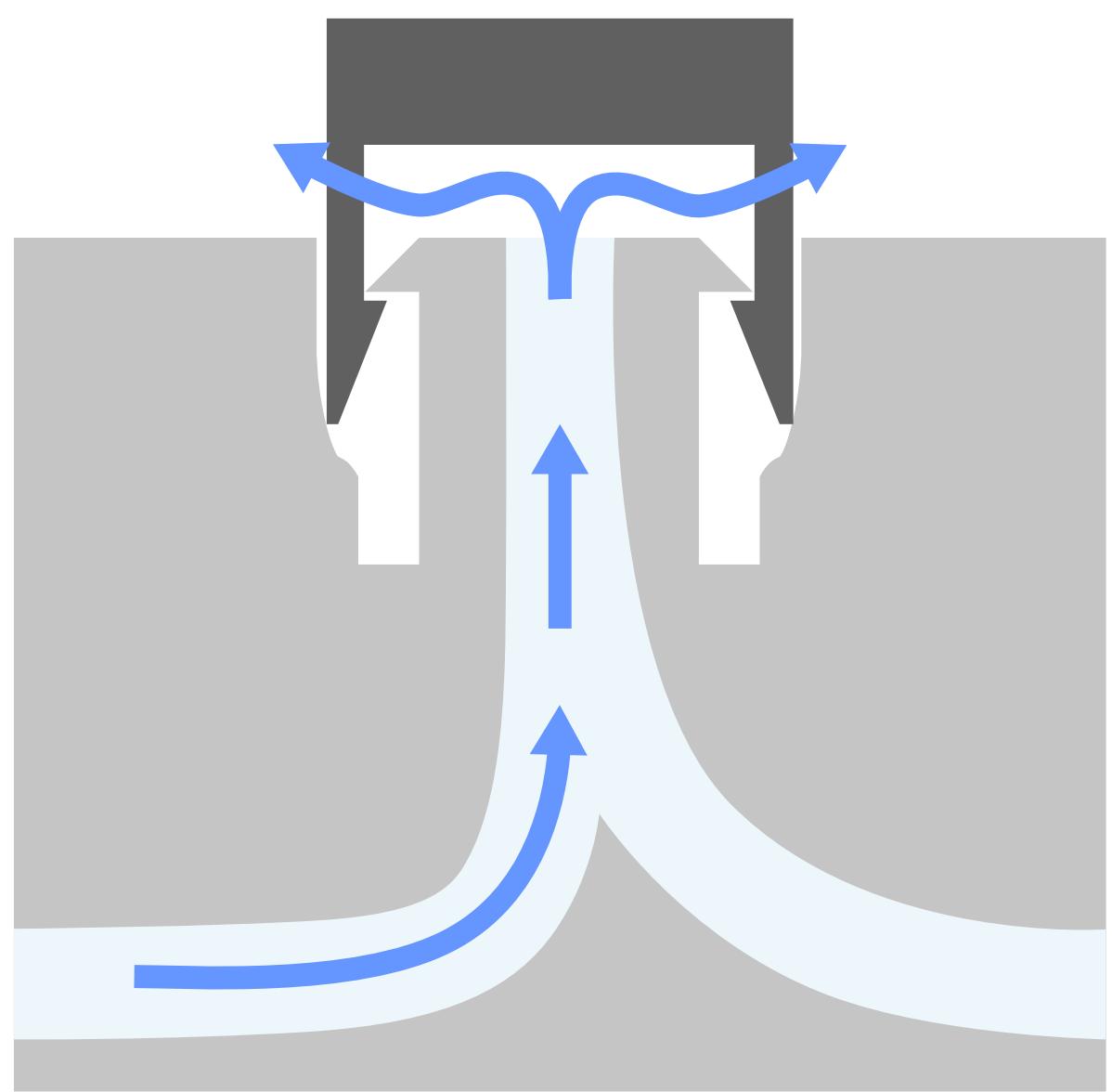


Switches

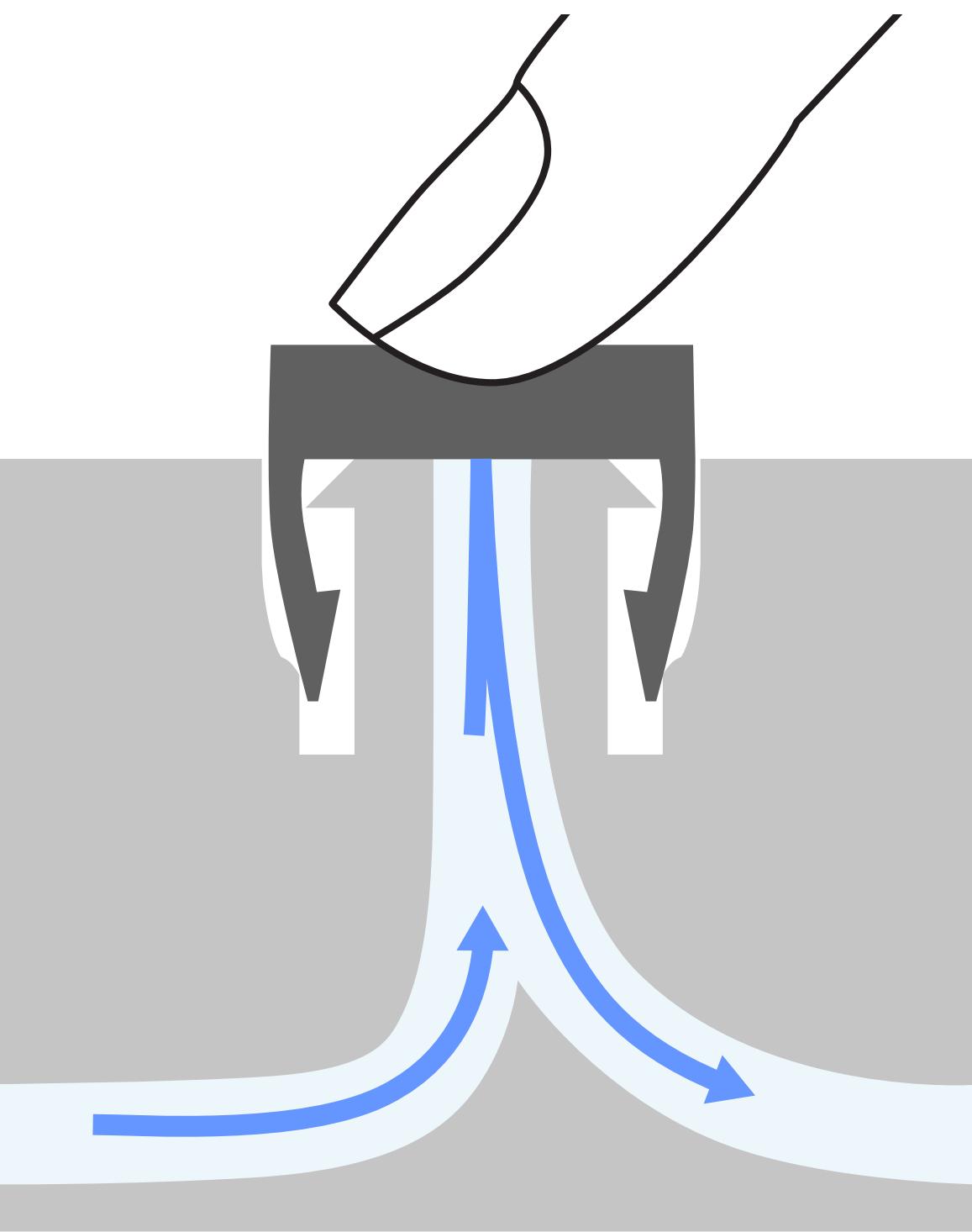


Sliders

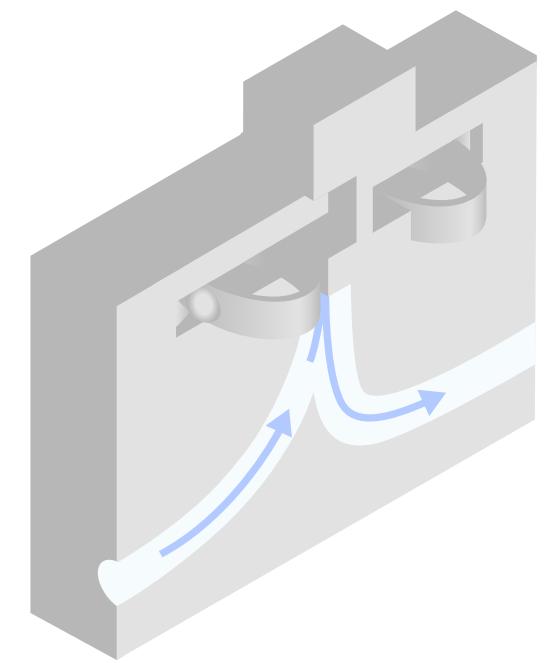
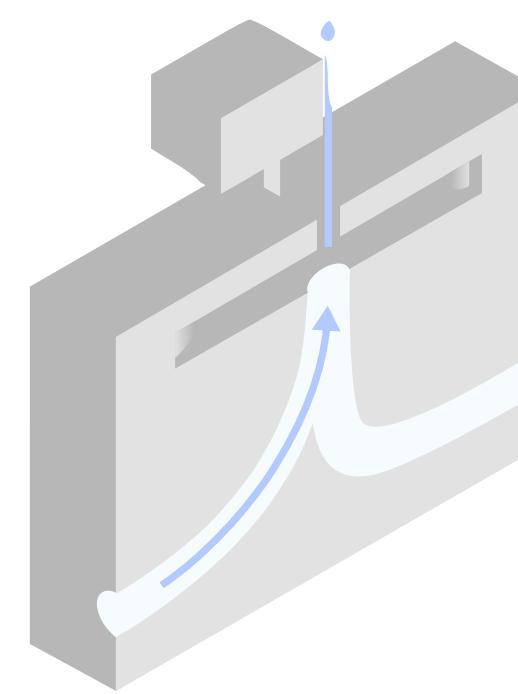




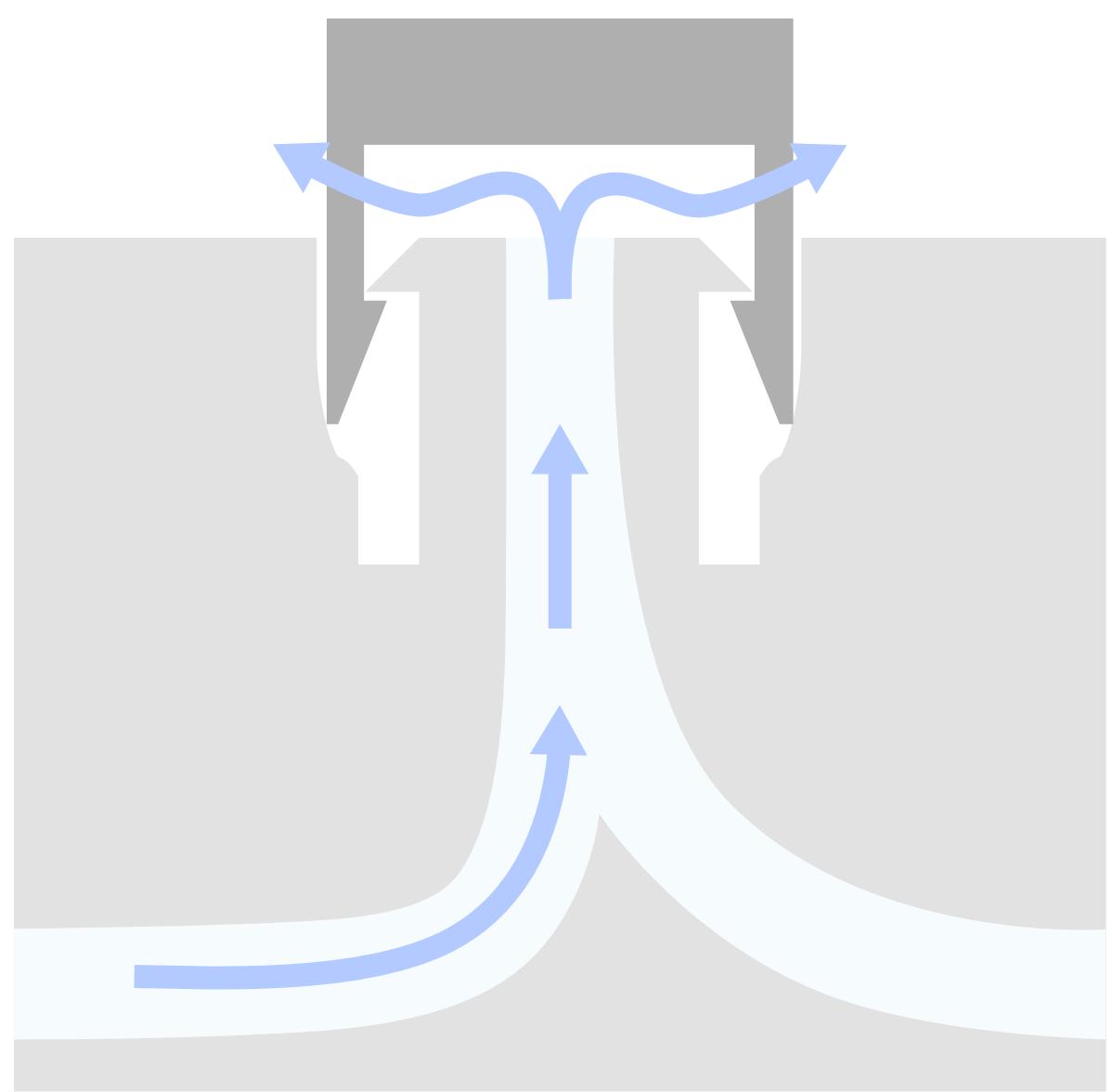
Buttons



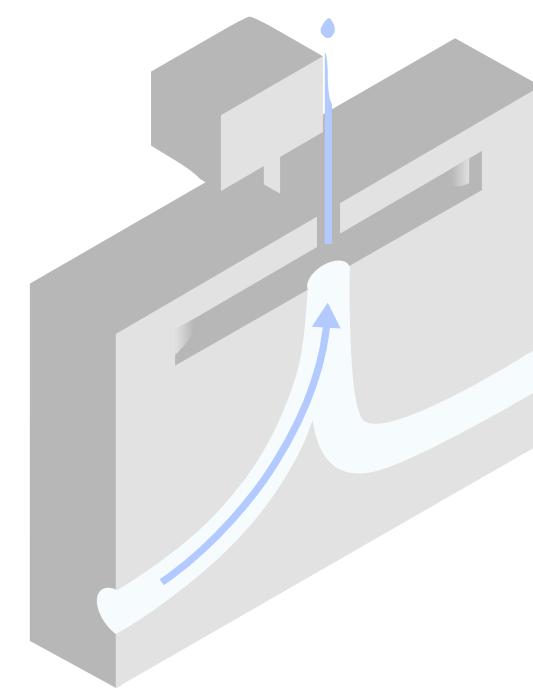
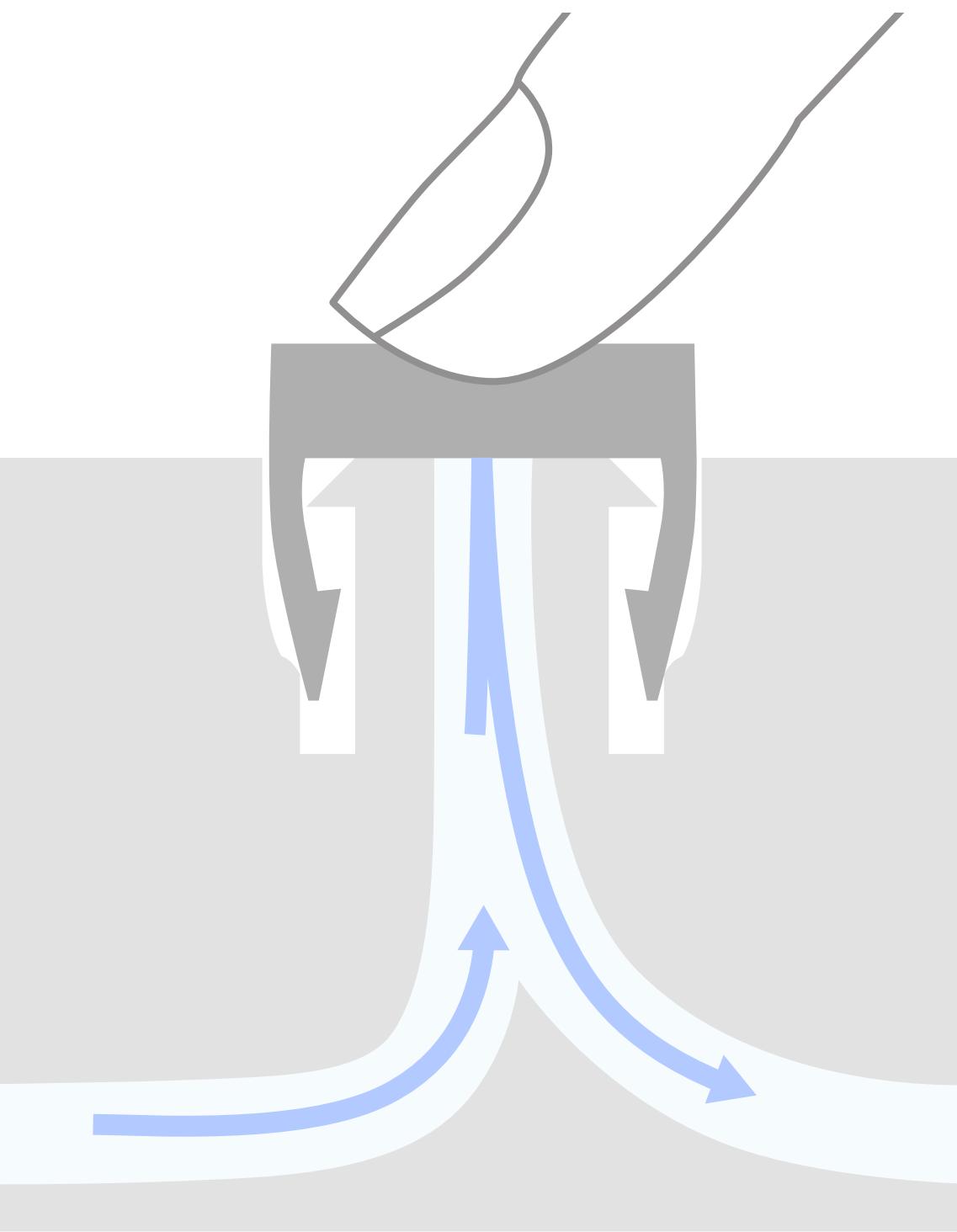
Switches



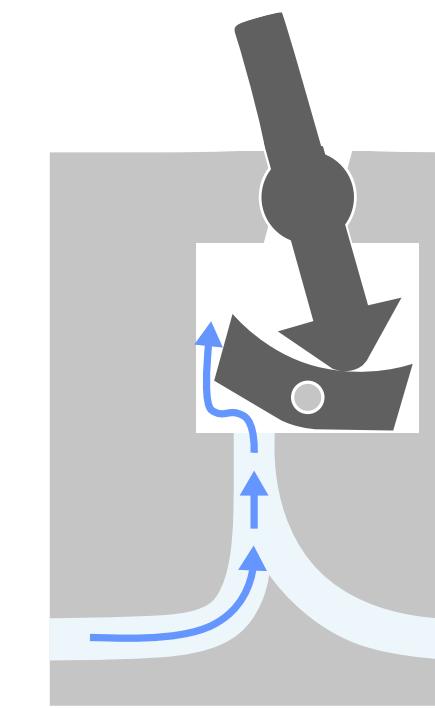
Sliders



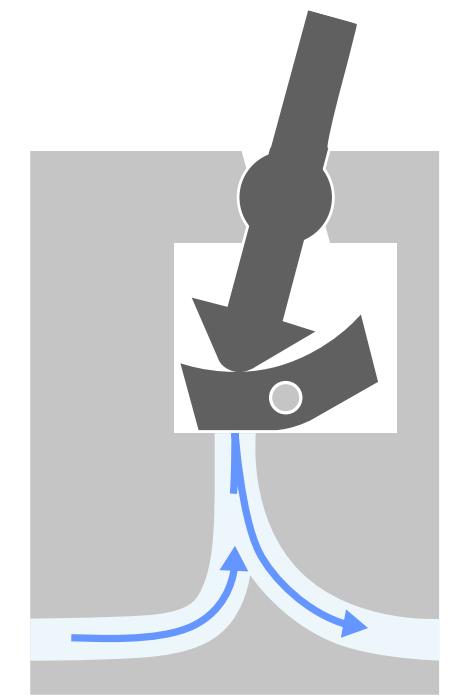
Buttons

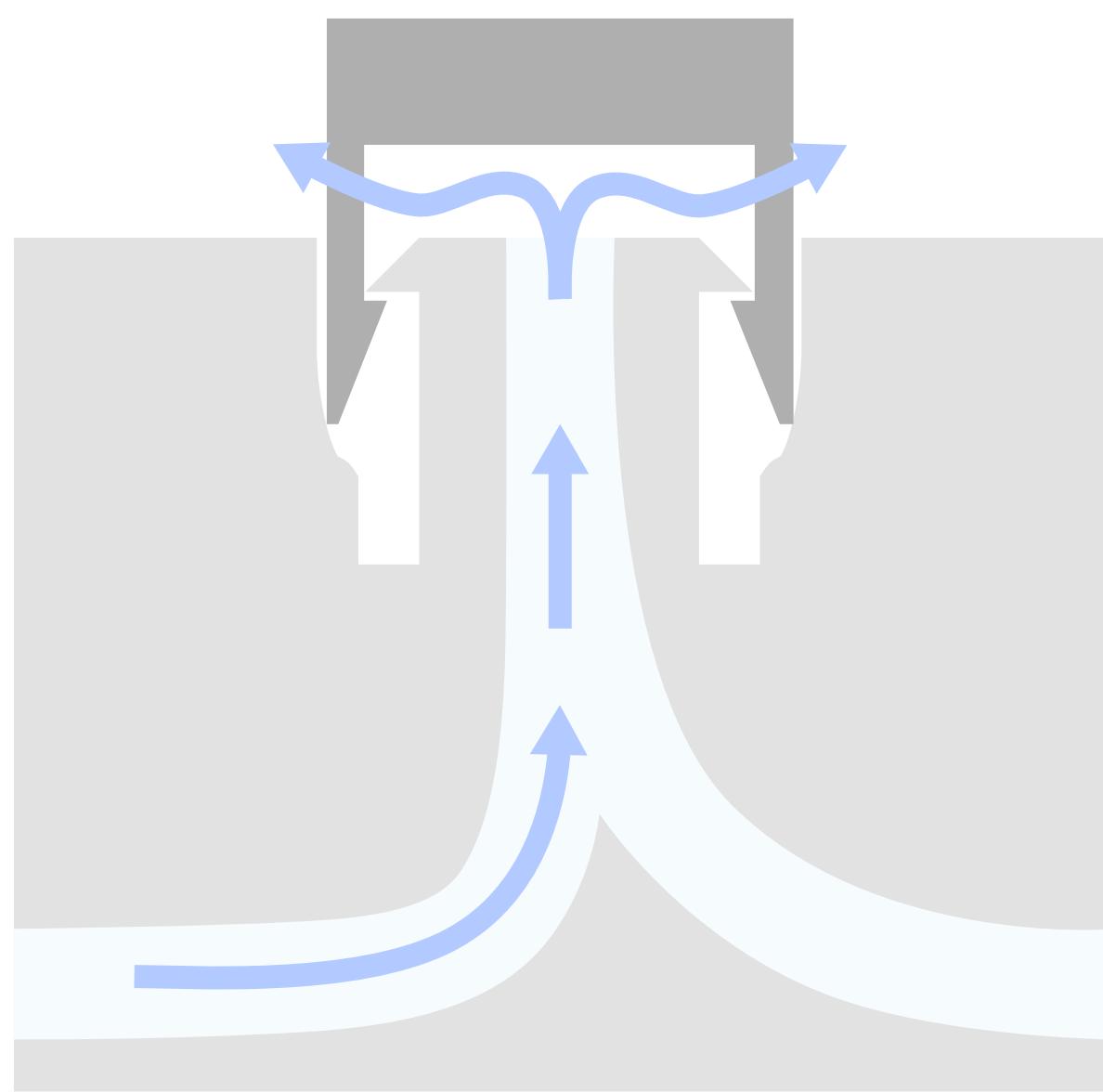


Sliders

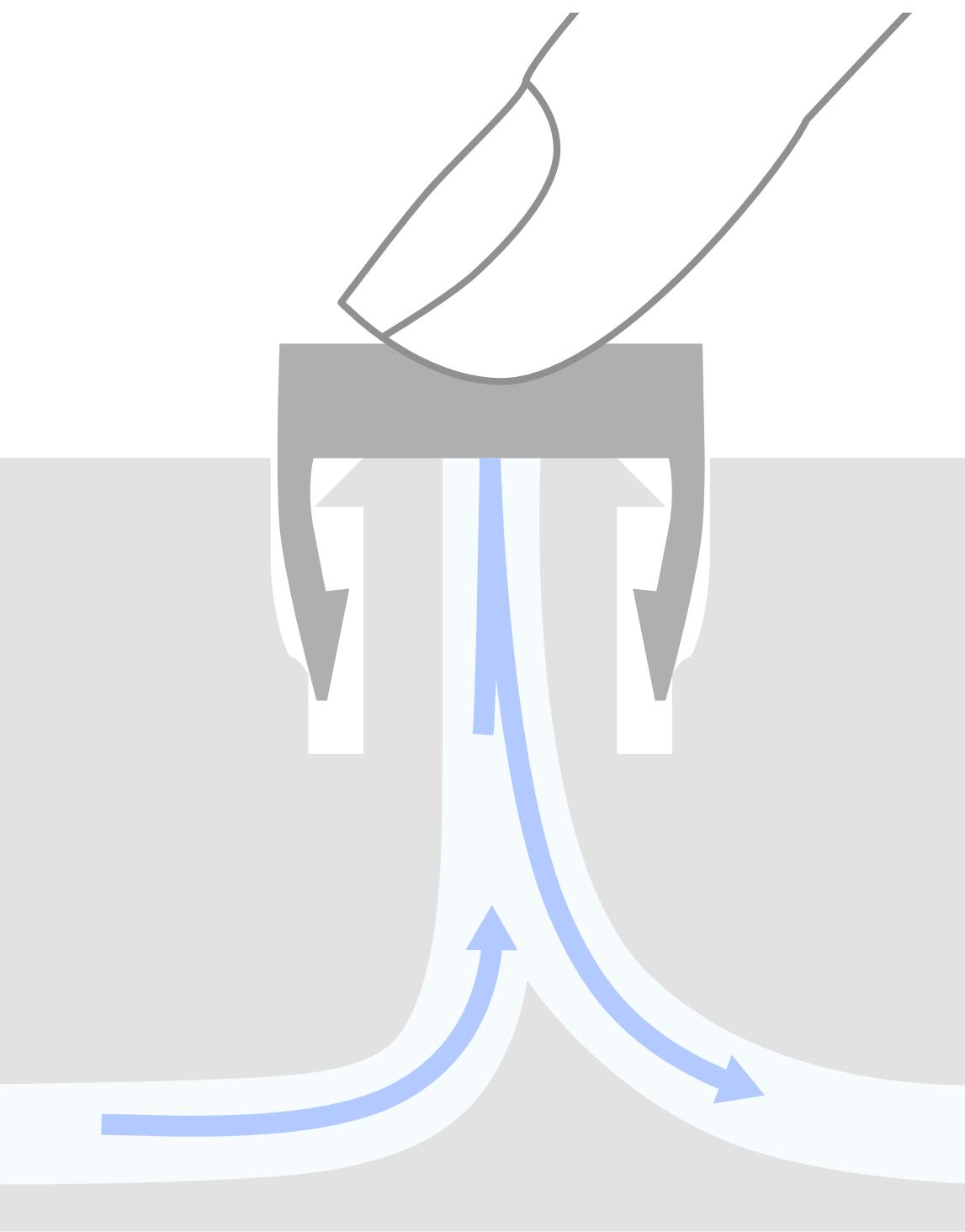


Switches

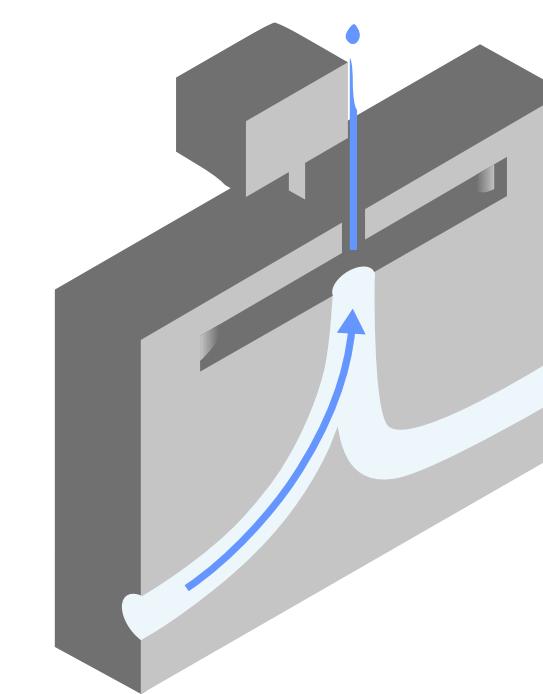




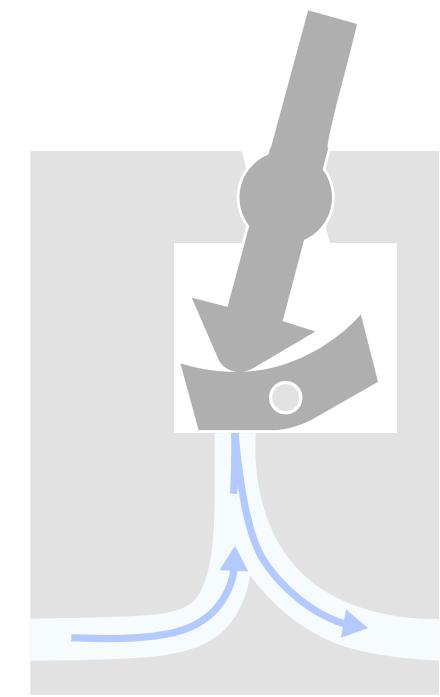
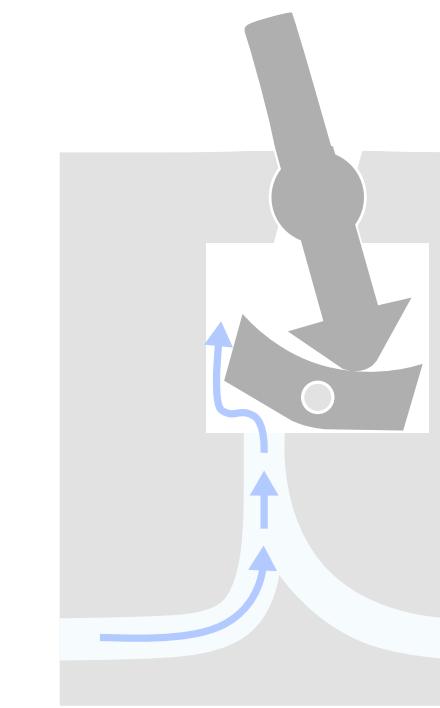
Buttons



Switches



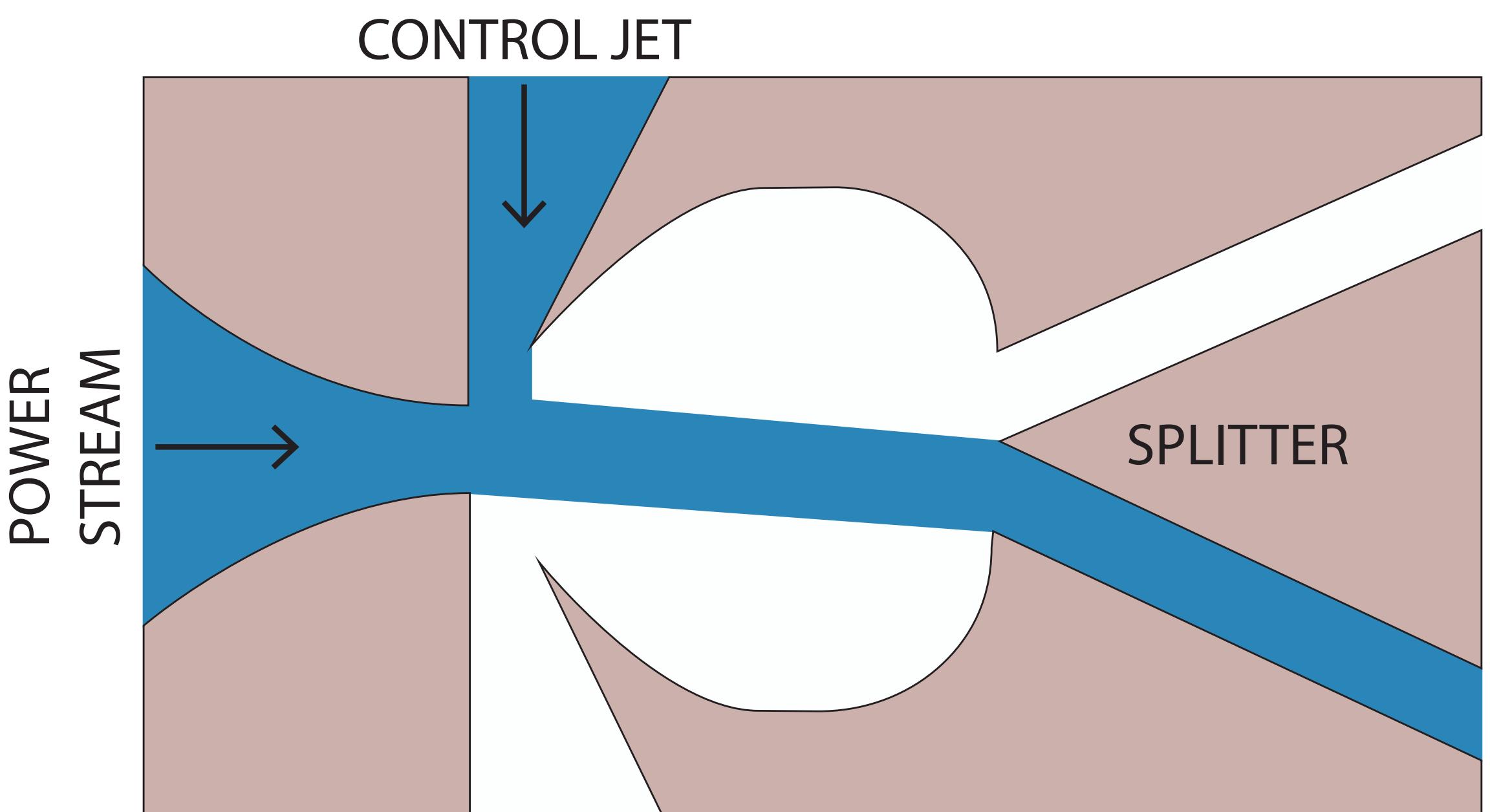
Sliders



AirLogic Toolkit

Logic widgets

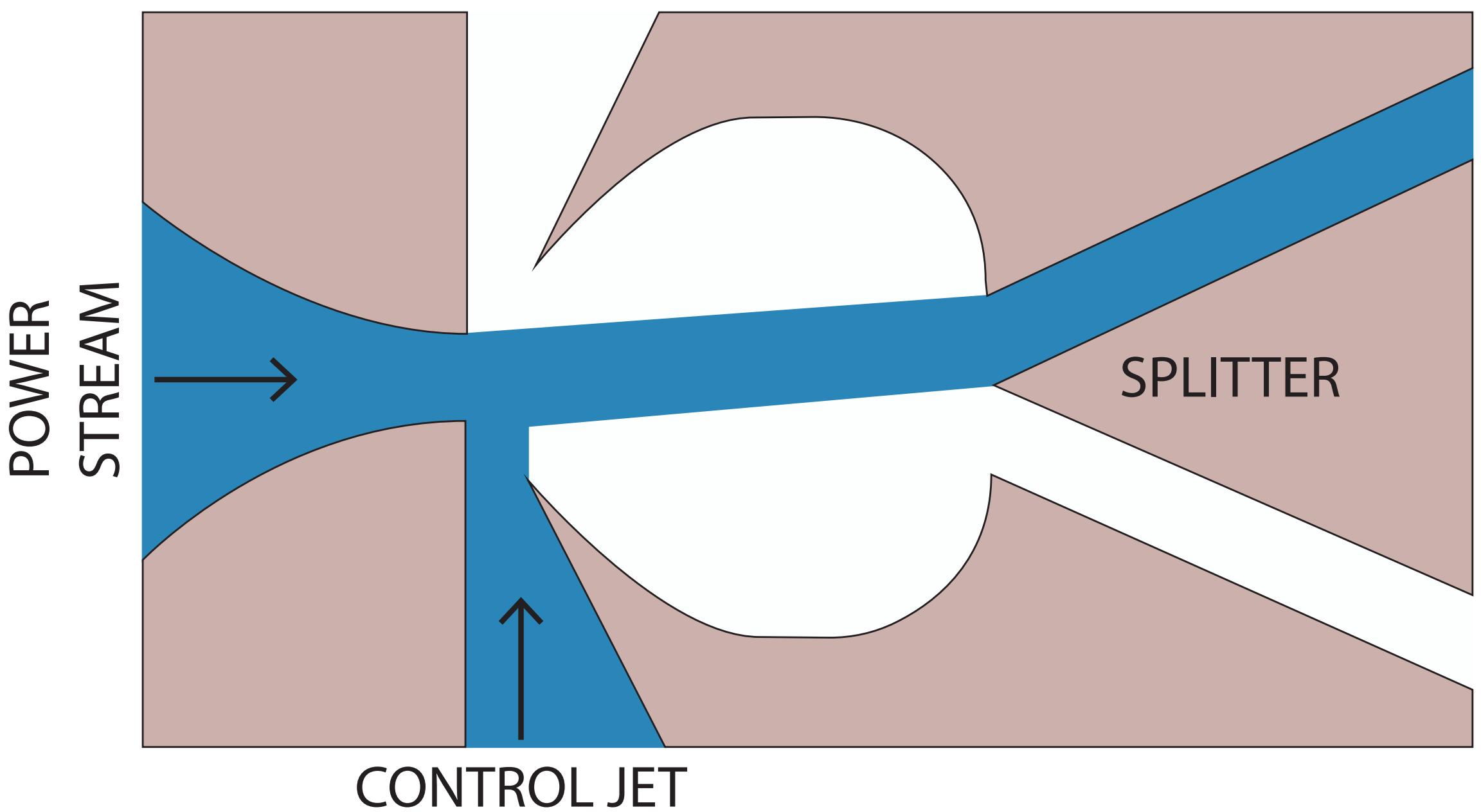
- Based on fluid deflection principles.
- By arranging specific geometries, we can represent a variety of operational elements.
- Logic gates: AND, OR, XOR, NOT.



AirLogic Toolkit

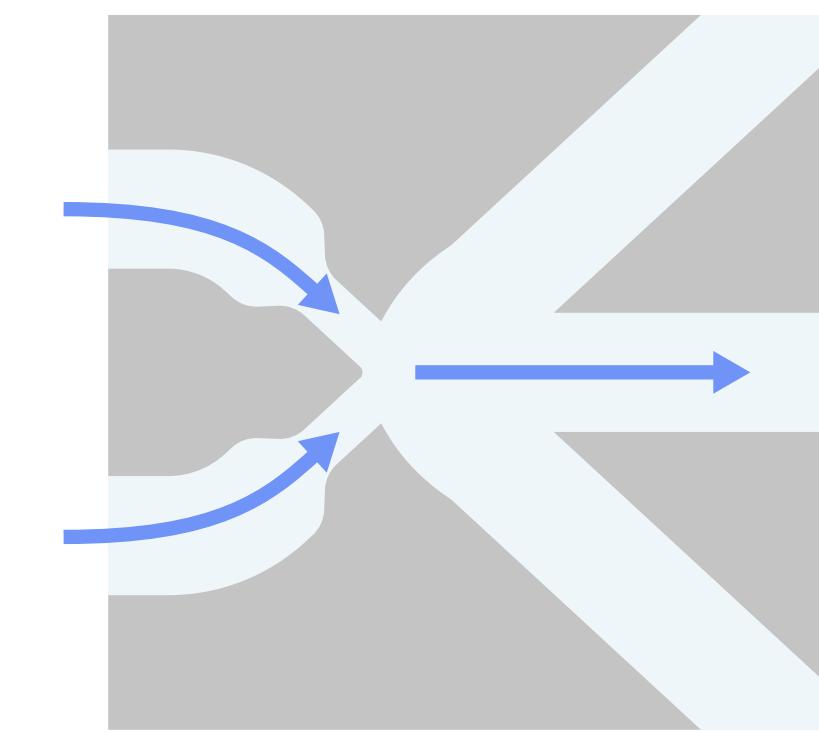
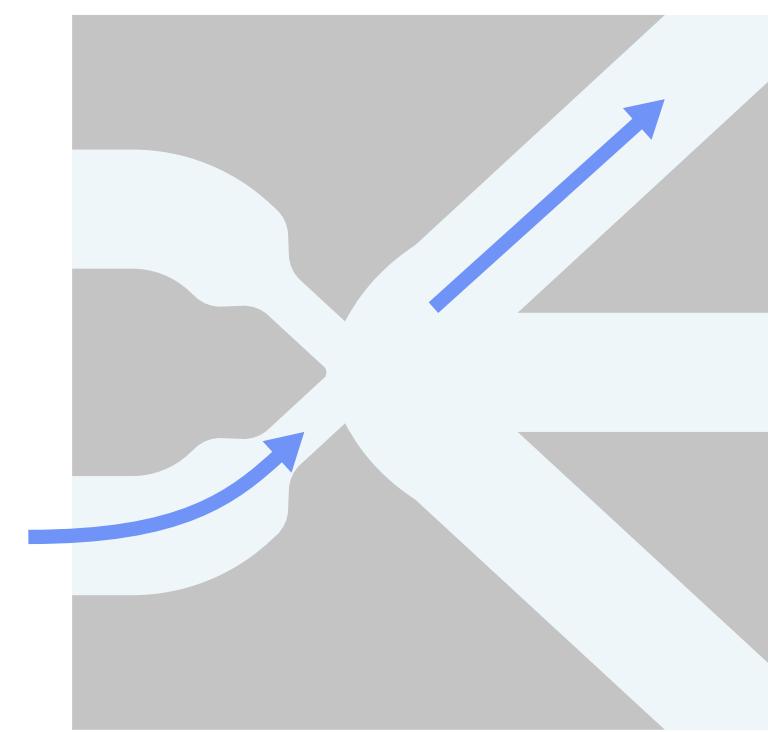
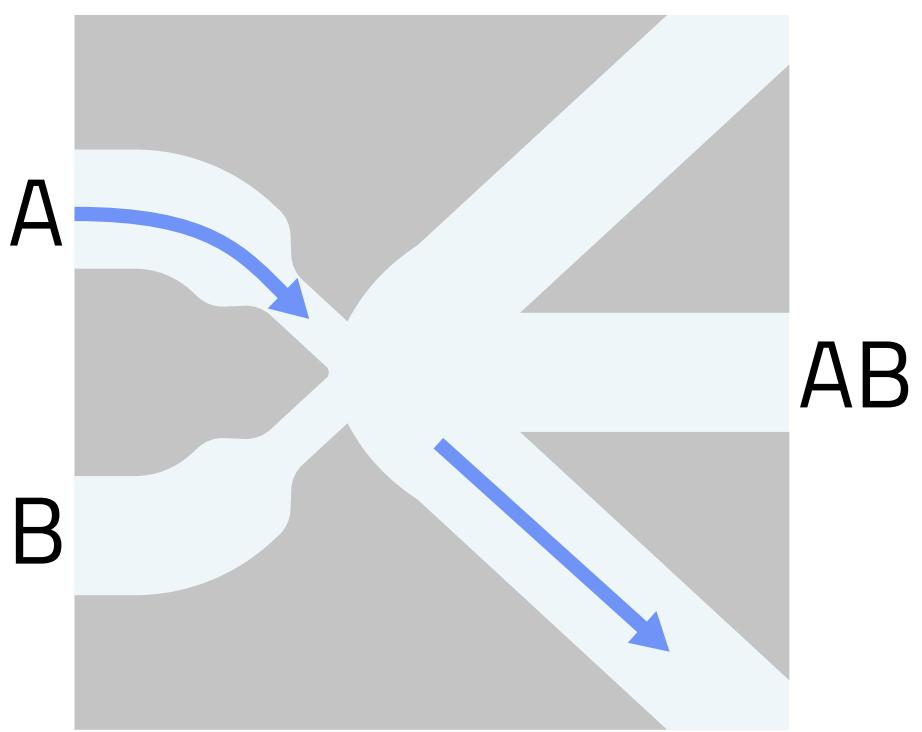
Logic widgets

- Based on fluid deflection principles.
- By arranging specific geometries, we can represent a variety of operational elements.
- Logic gates: AND, OR, XOR, NOT.



AND

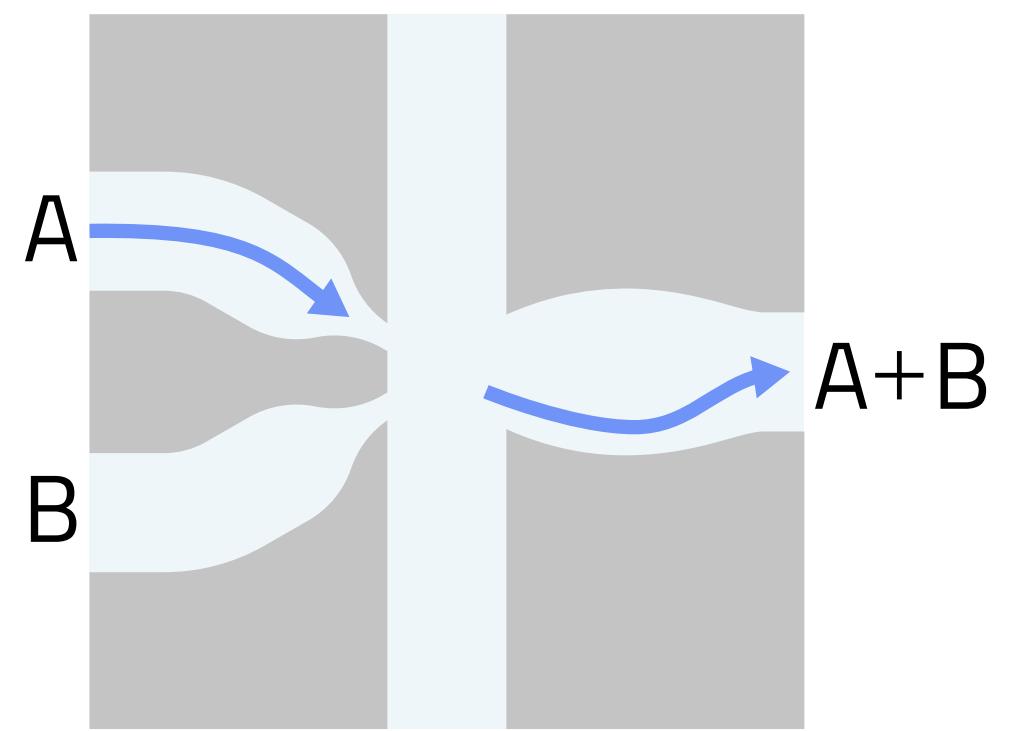
A	B	0
0	0	0
0	1	0
1	0	0
1	1	1



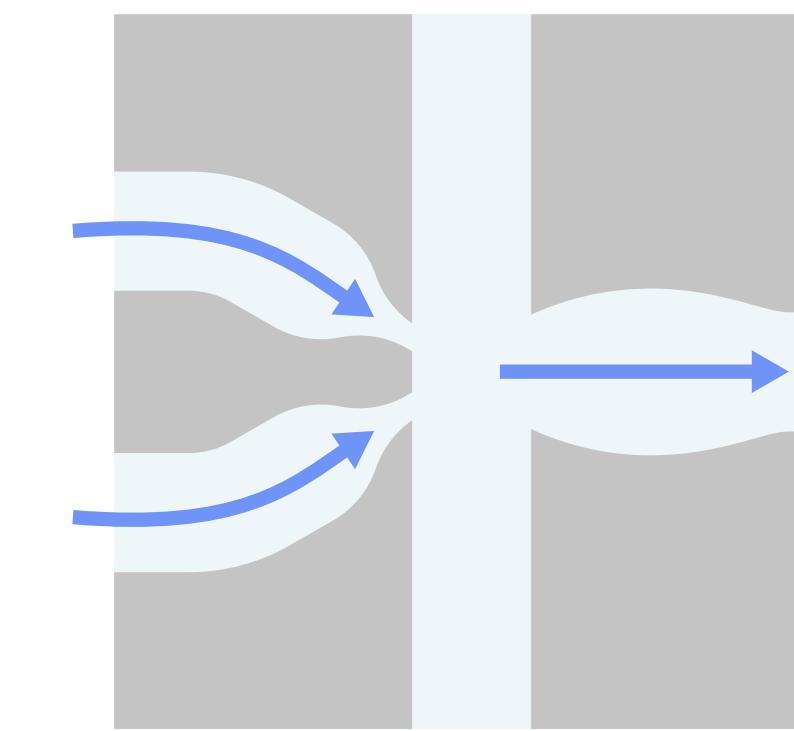
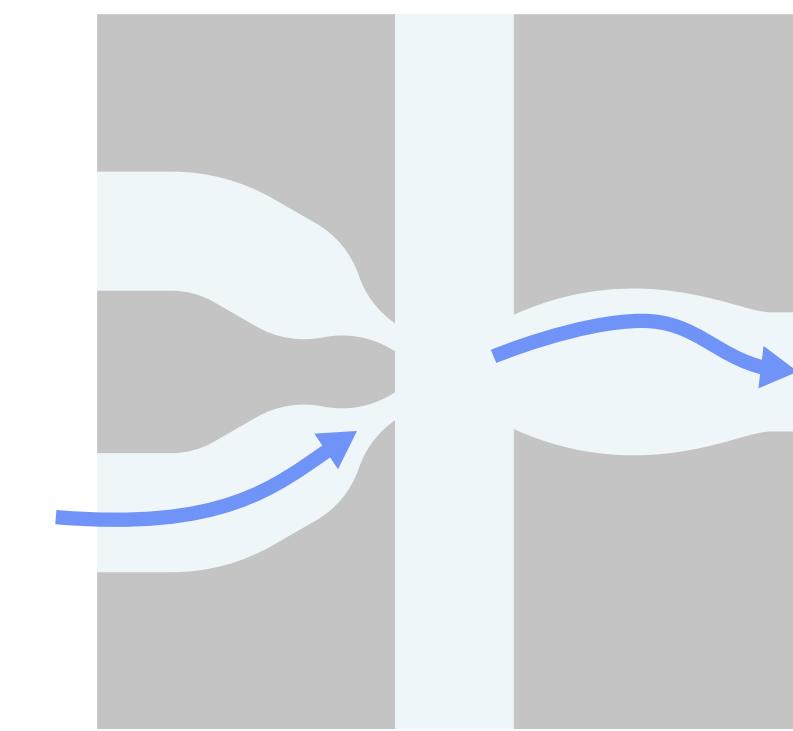
AND

OR

A	B	0
0	0	0
0	1	1
1	0	1
1	1	1

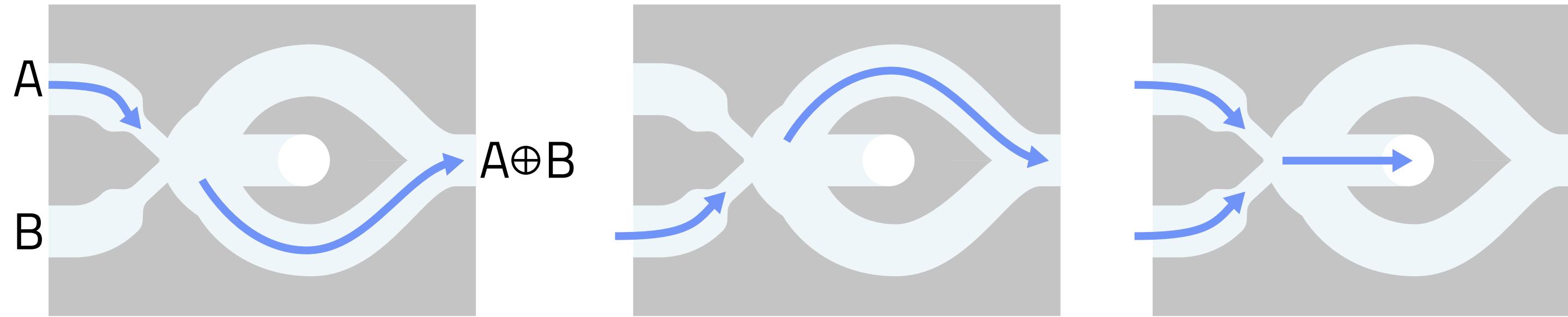


OR



XOR

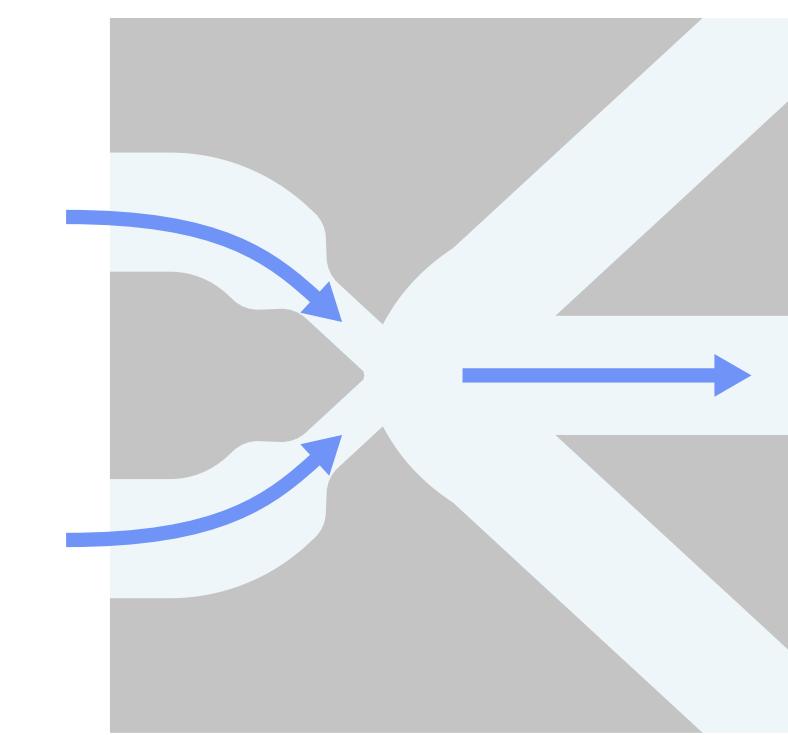
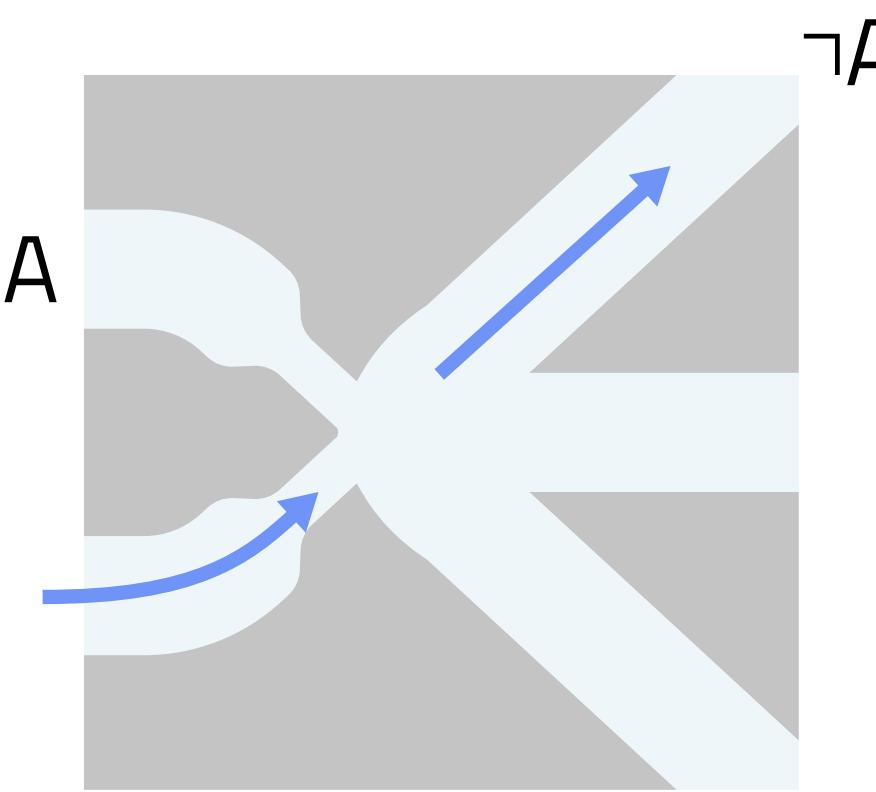
A	B		0
0	0		0
0	1		1
1	0		1
1	1		0



XOR

NOT

	A 0
A	0 1
	1 0

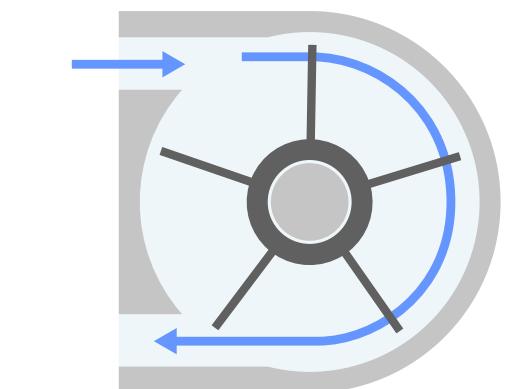
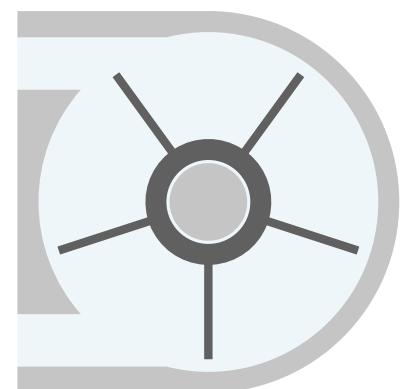
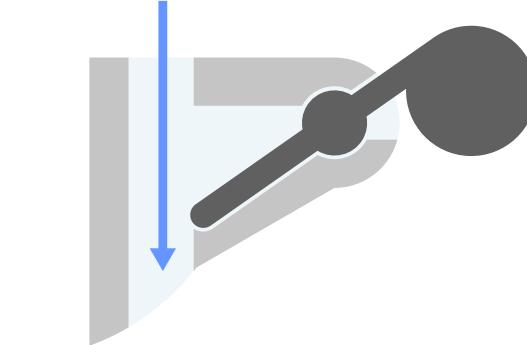
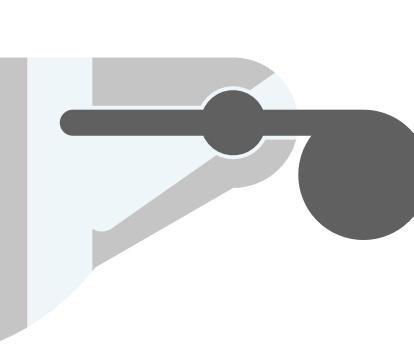
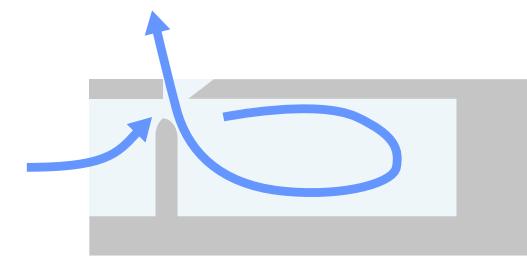
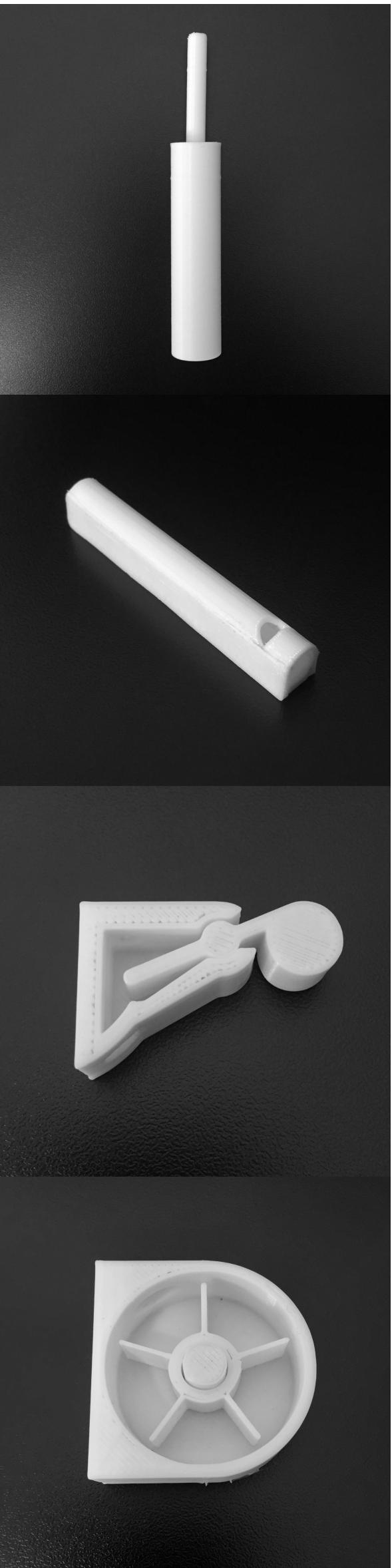
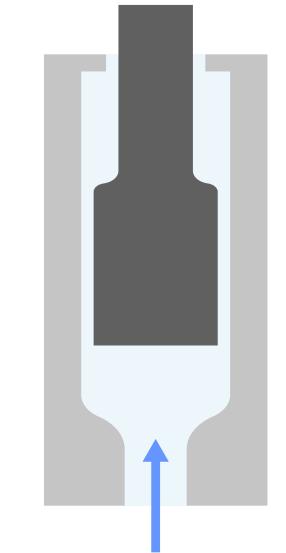


NOT

AirLogic Toolkit

Output widgets

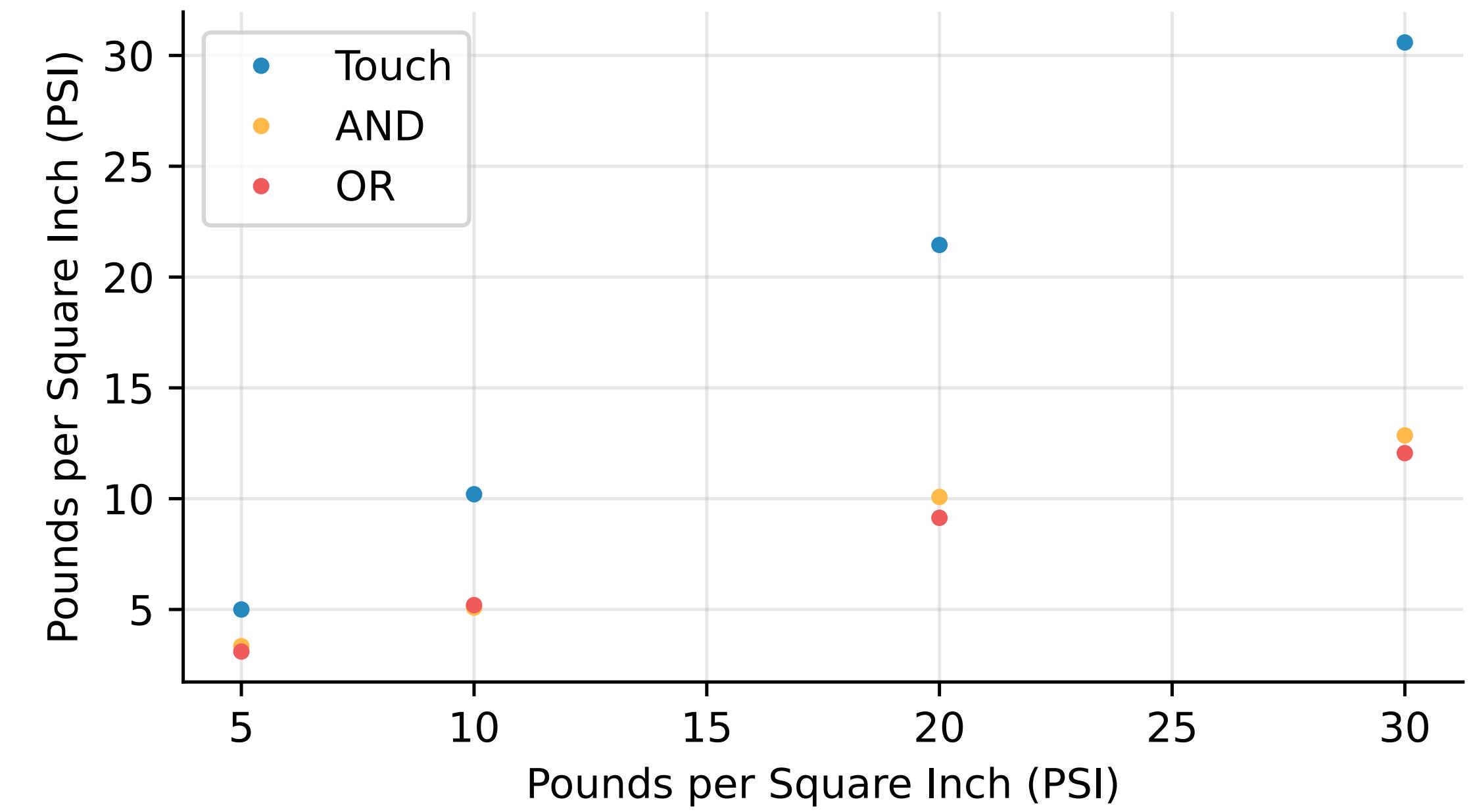
- Multi-modality output:
 - Visual
 - Acoustic
 - Vibrotactile



Validation

Technical evaluation

- Pressure losses on widgets
 - Only analyzed input, and logic widgets.
 - Input widgets exhibit very little pressure loss.
 - Logic widgets lose about half of the supplied pressure.



Validation

Example applications

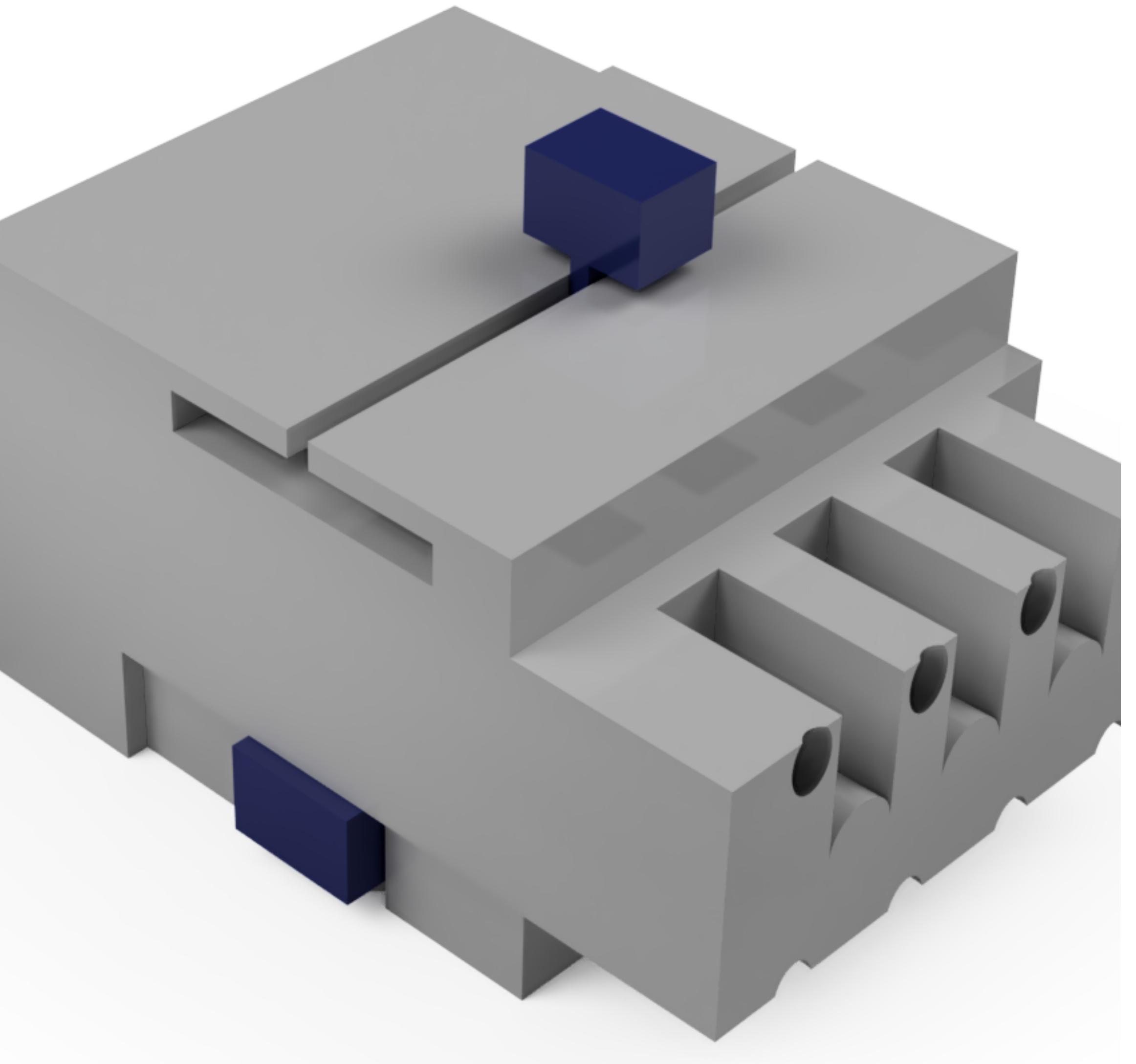
- Interactive bunny
 - Touch input
 - OR gate
 - Wiggle output



Validation

Example applications

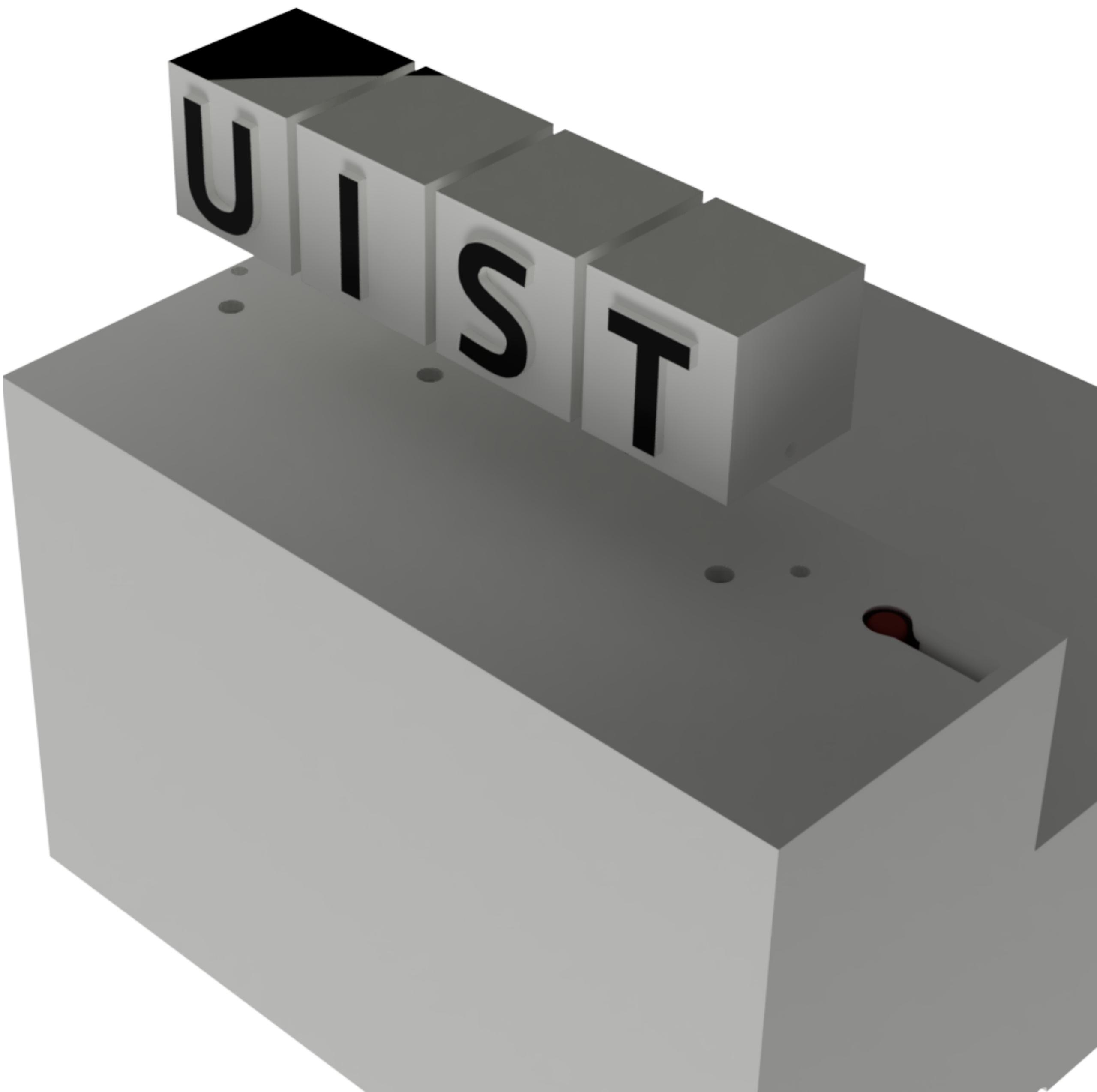
- Pitch slider
 - Slider and button
 - AND gates
 - Whistles of different pitches



Validation

Example applications

- Interactive puzzle
 - Block input
 - AND gates
 - Pin output



In manuscript

AirLogic

A Toolkit for 3D-printing Stand-Alone, Interactive Objects

Carlos Tejada

University of Copenhagen



Hyunyoung Kim

University of Copenhagen



Raf Ramakers

Hasselt University



Mengyu Zhong

Uppsala University

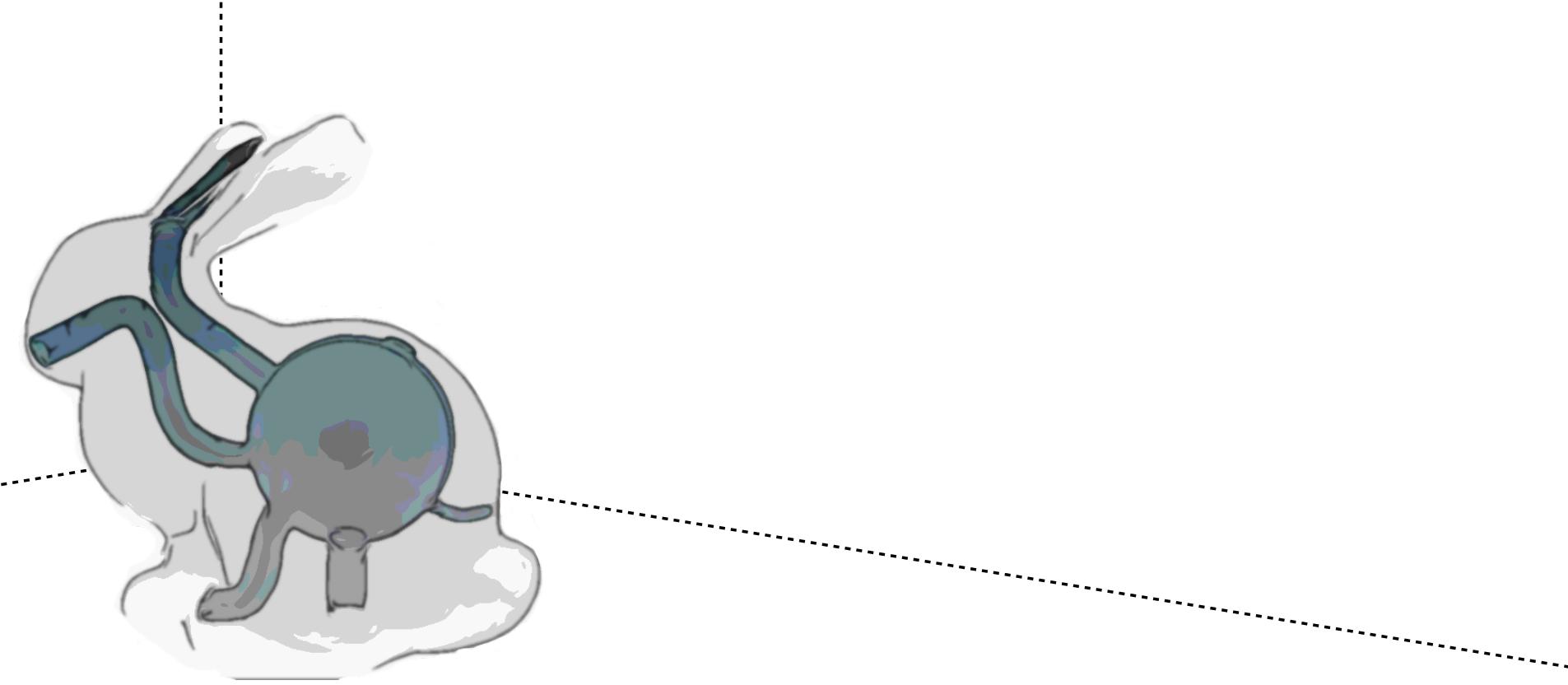
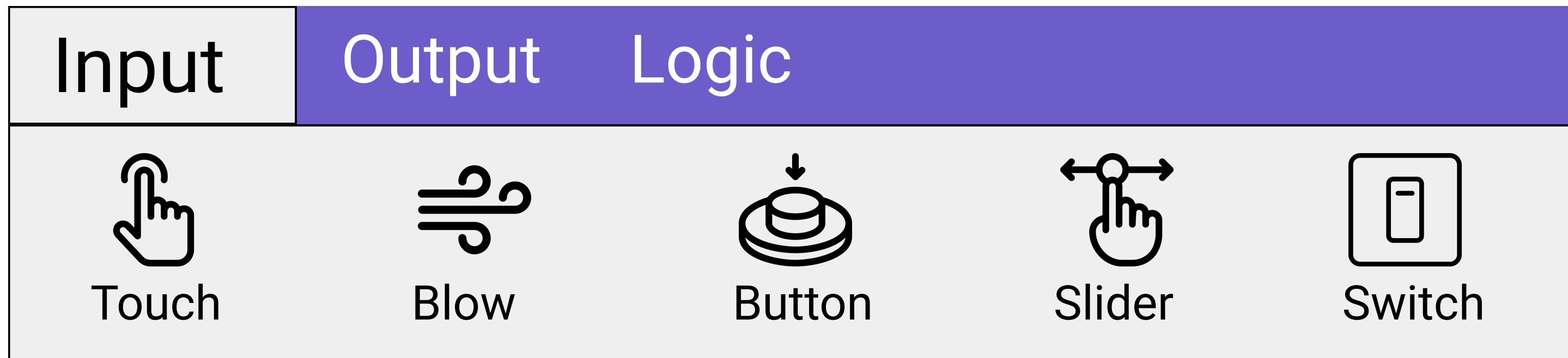


Daniel Ashbrook

University of Copenhagen

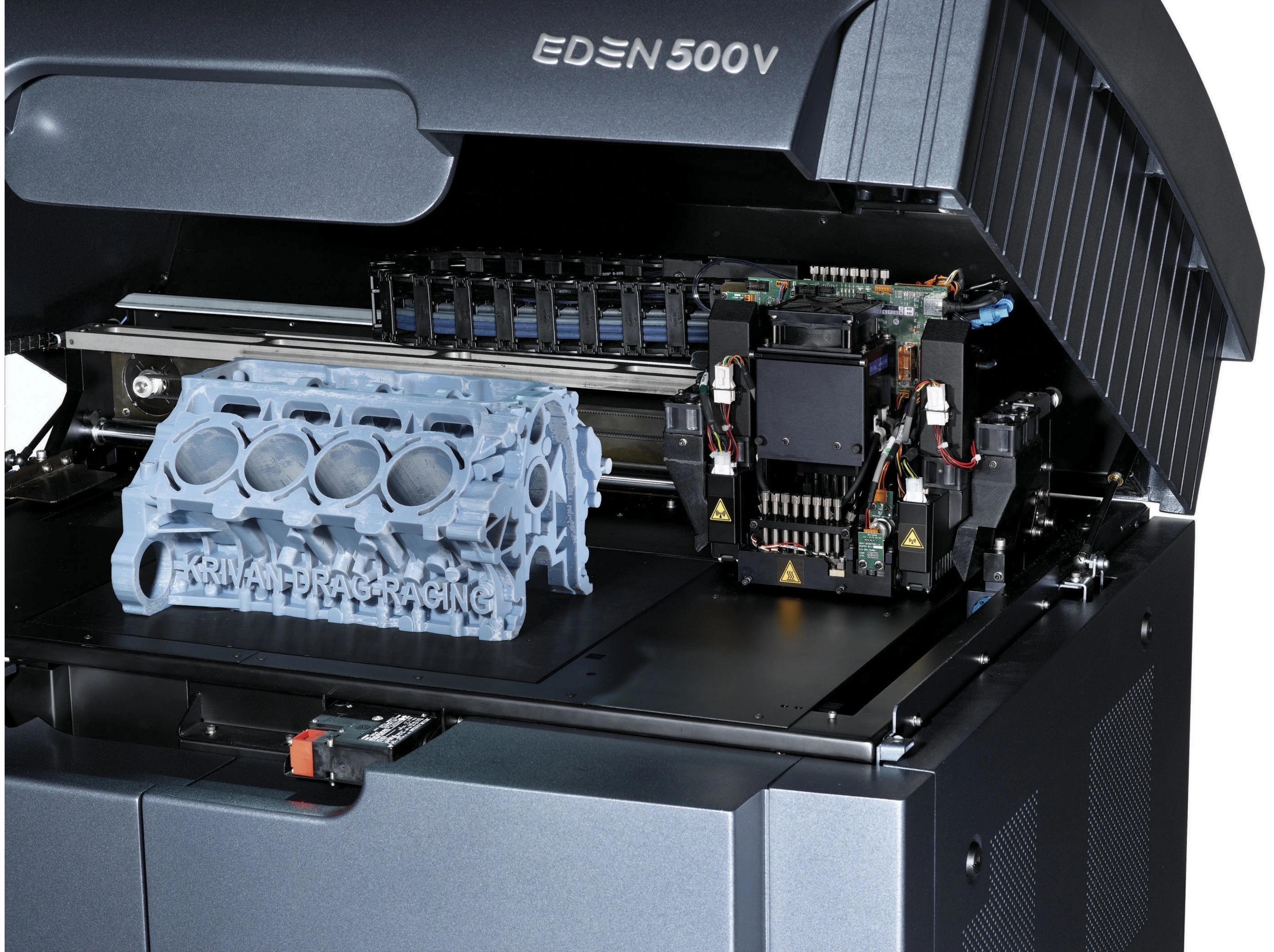


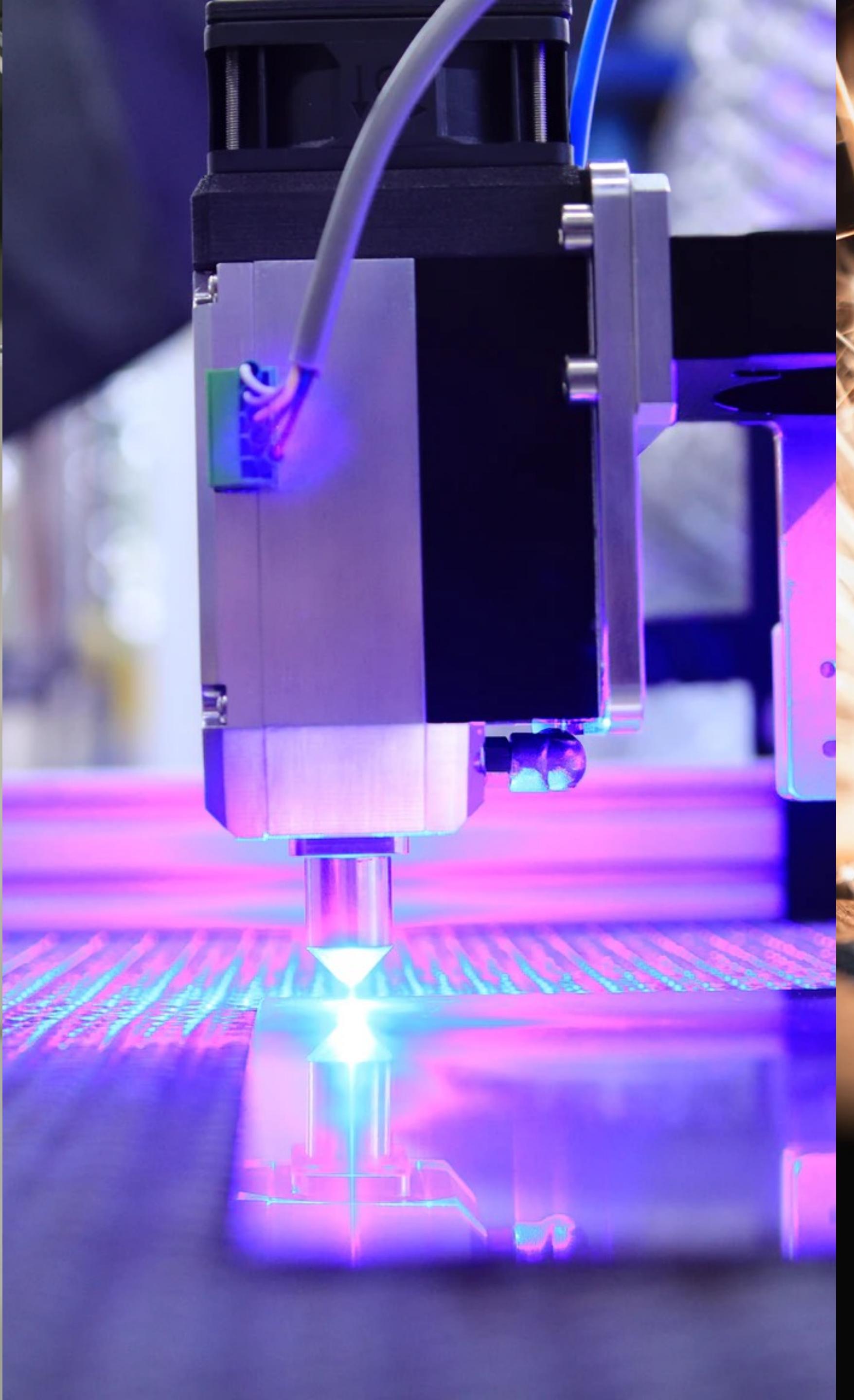
Discussions & Implications

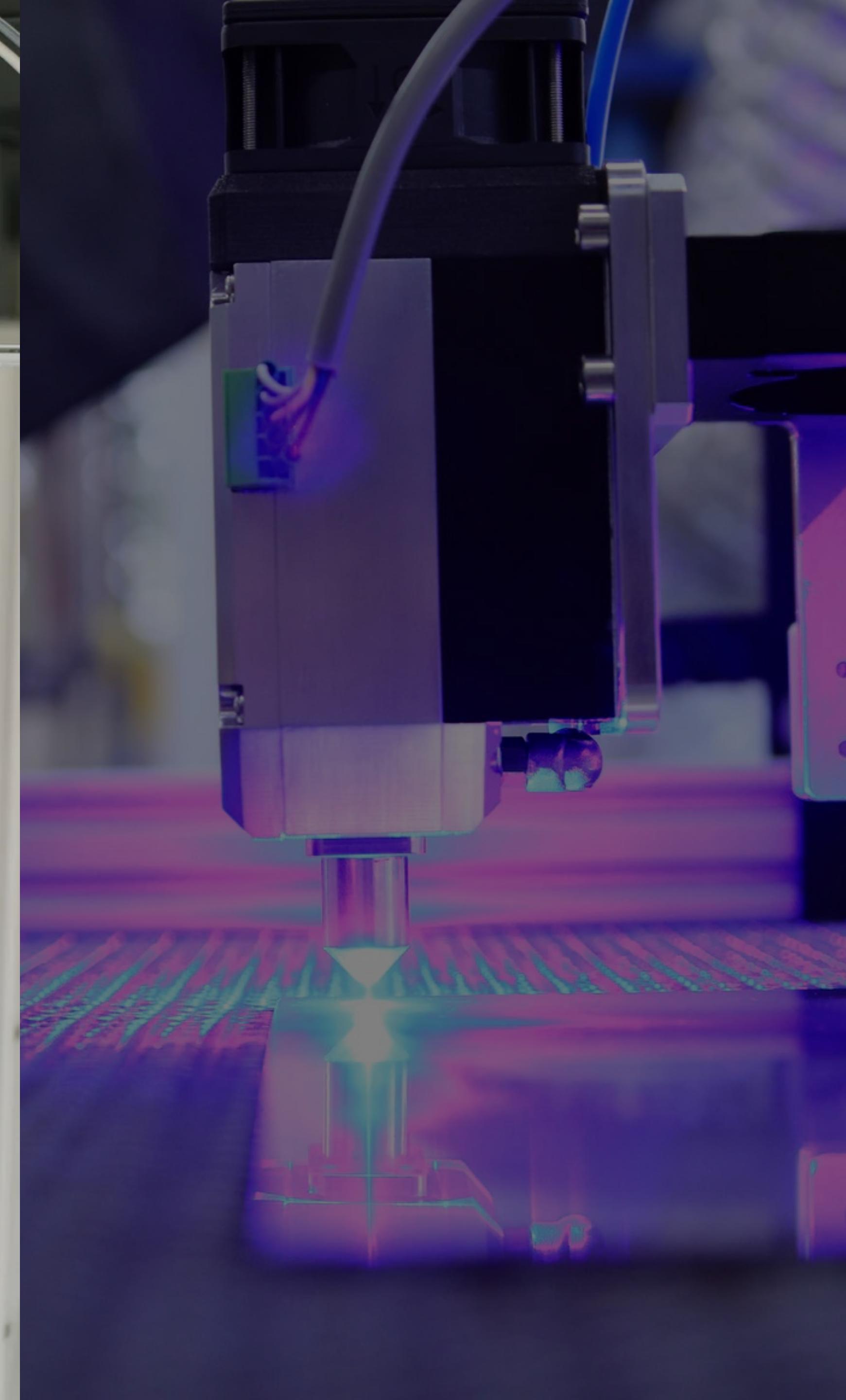


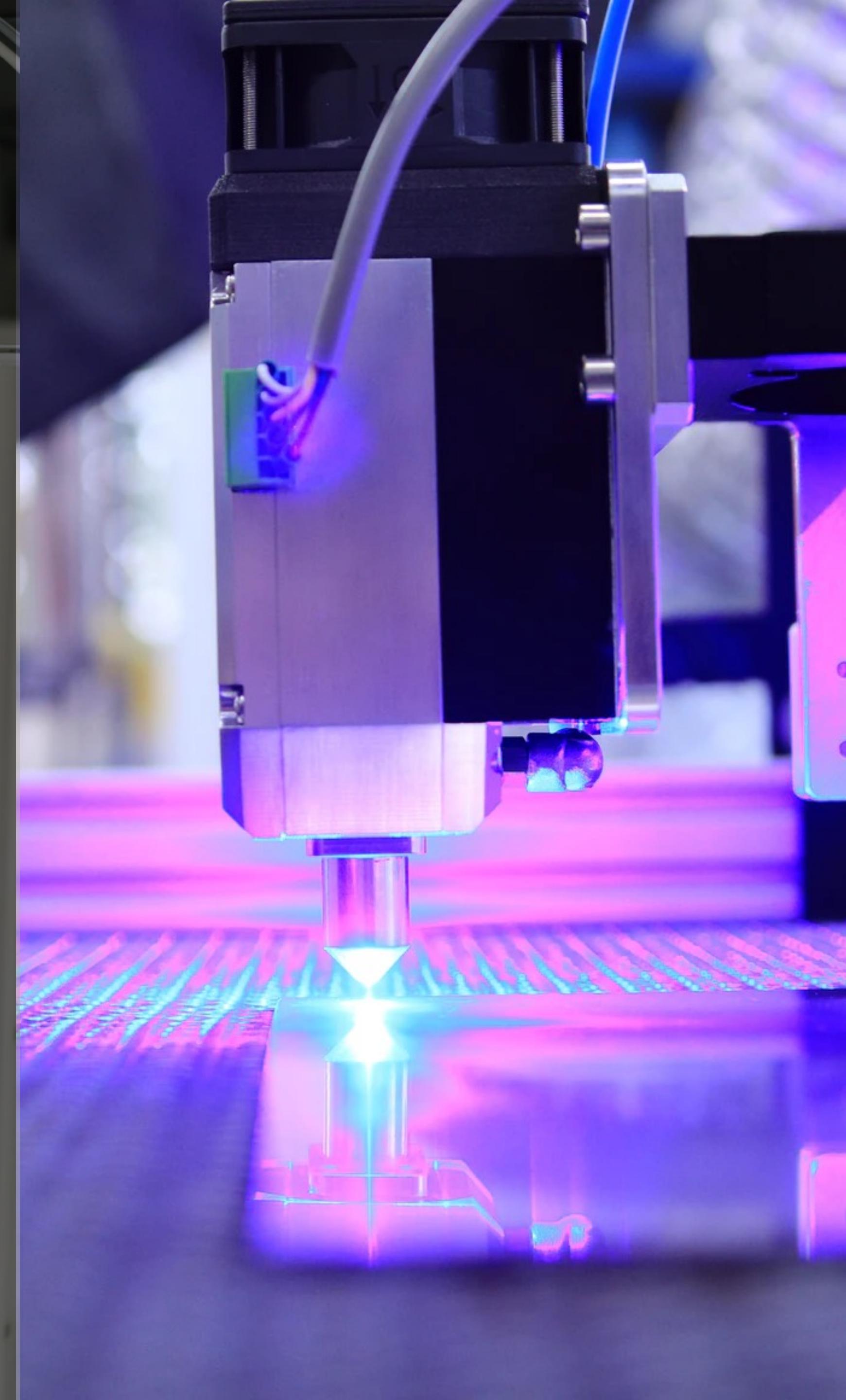
Discussion of Projects

Print-and-Play Fabrication Toolkit









Directions for Future Work

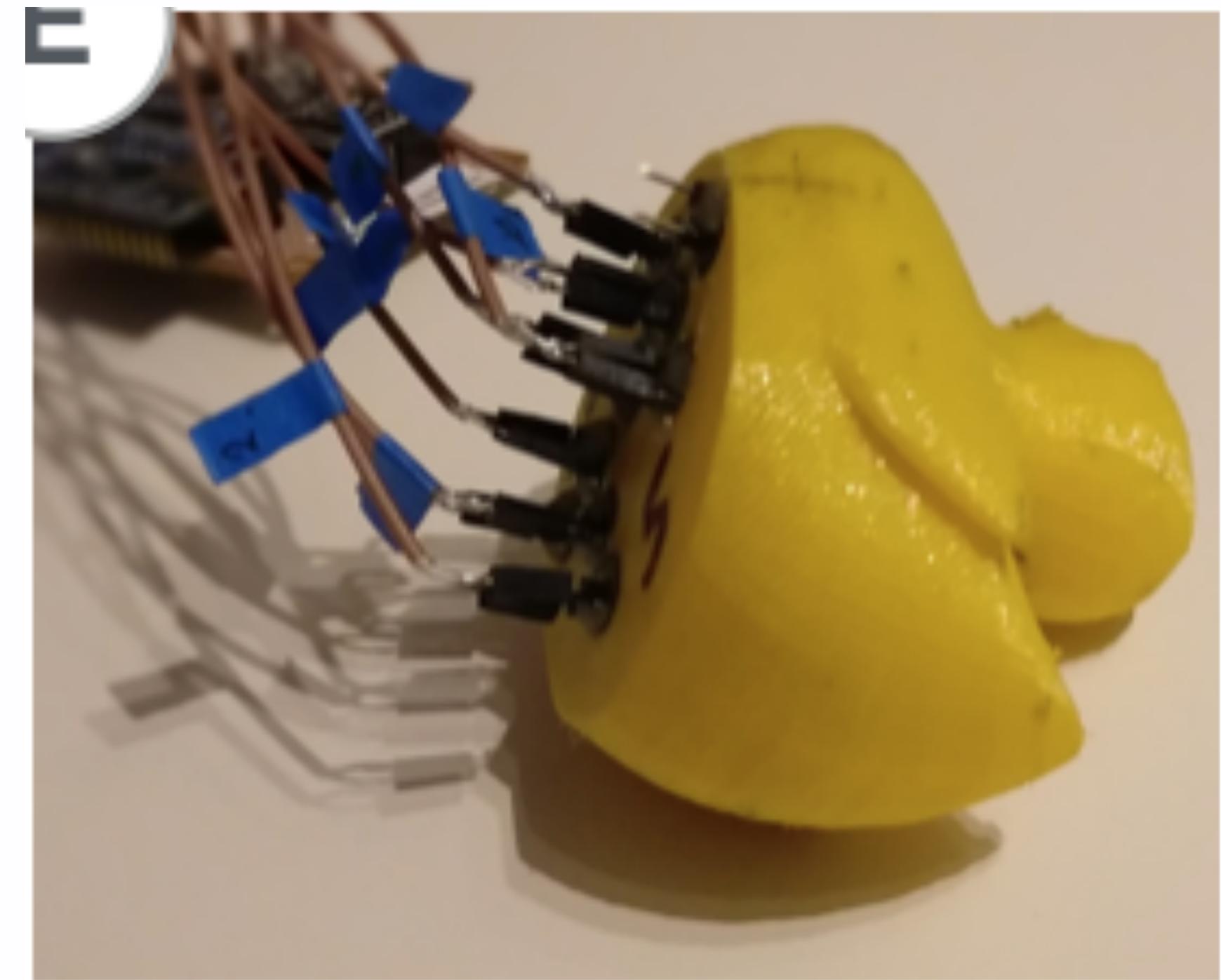
Support for multi-material printing



Capricate
Schmitz et al.

Directions for Future Work

Support for multi-material printing

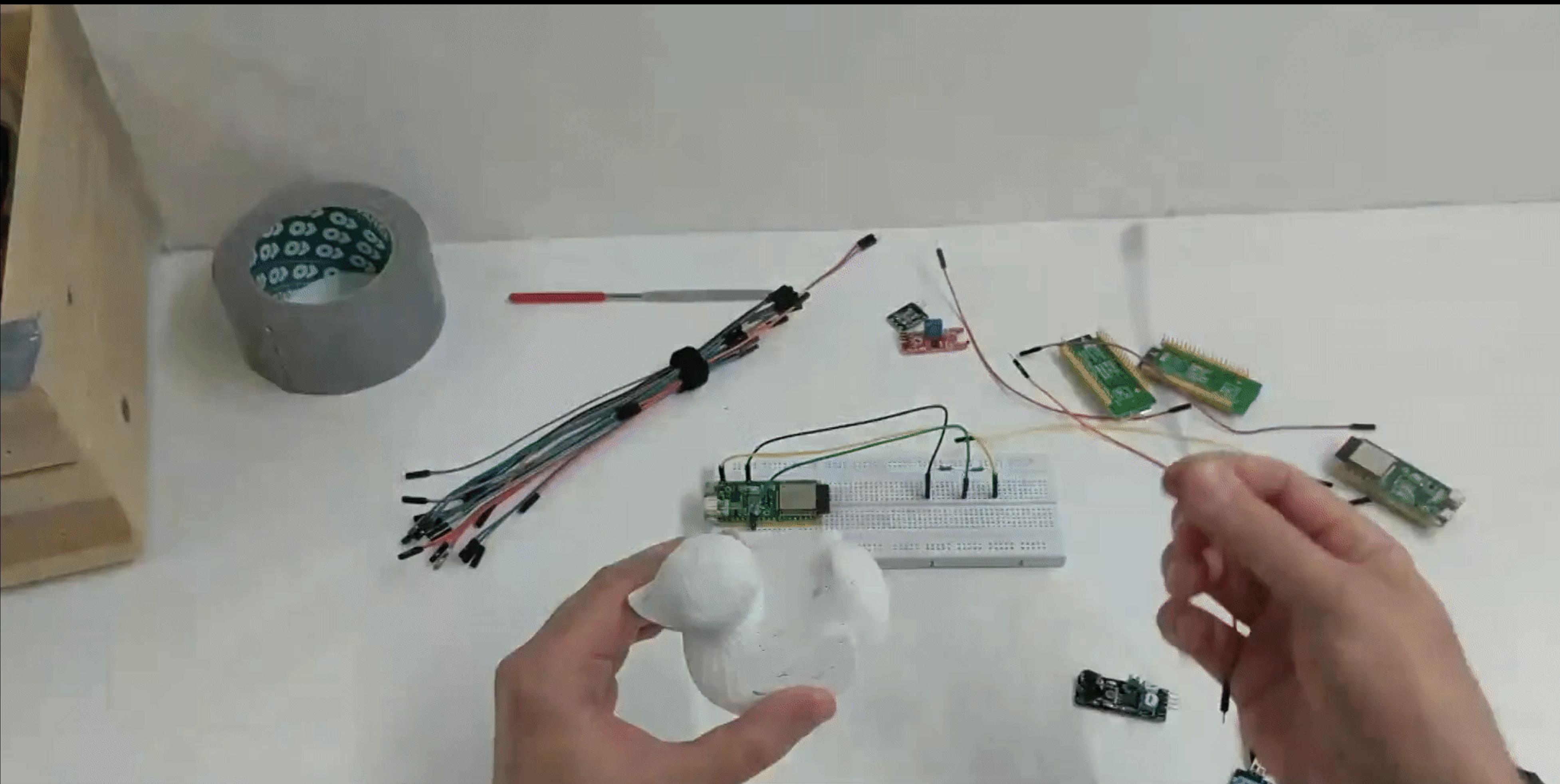


./trilaterate
Schmitz et al.

Resumen en Español







CHI '20

AirTouch

3D-printed Touch-Sensitive Objects Using Pneumatic Sensing

Carlos Tejada

University of Copenhagen



Raf Ramakers

Hasselt University



Sebastian Boring

Aalborg University



Daniel Ashbrook

University of Copenhagen





Blowhole

Blowing-Activated Tags for Interactive 3D-Printed Models

Carlos Tejada

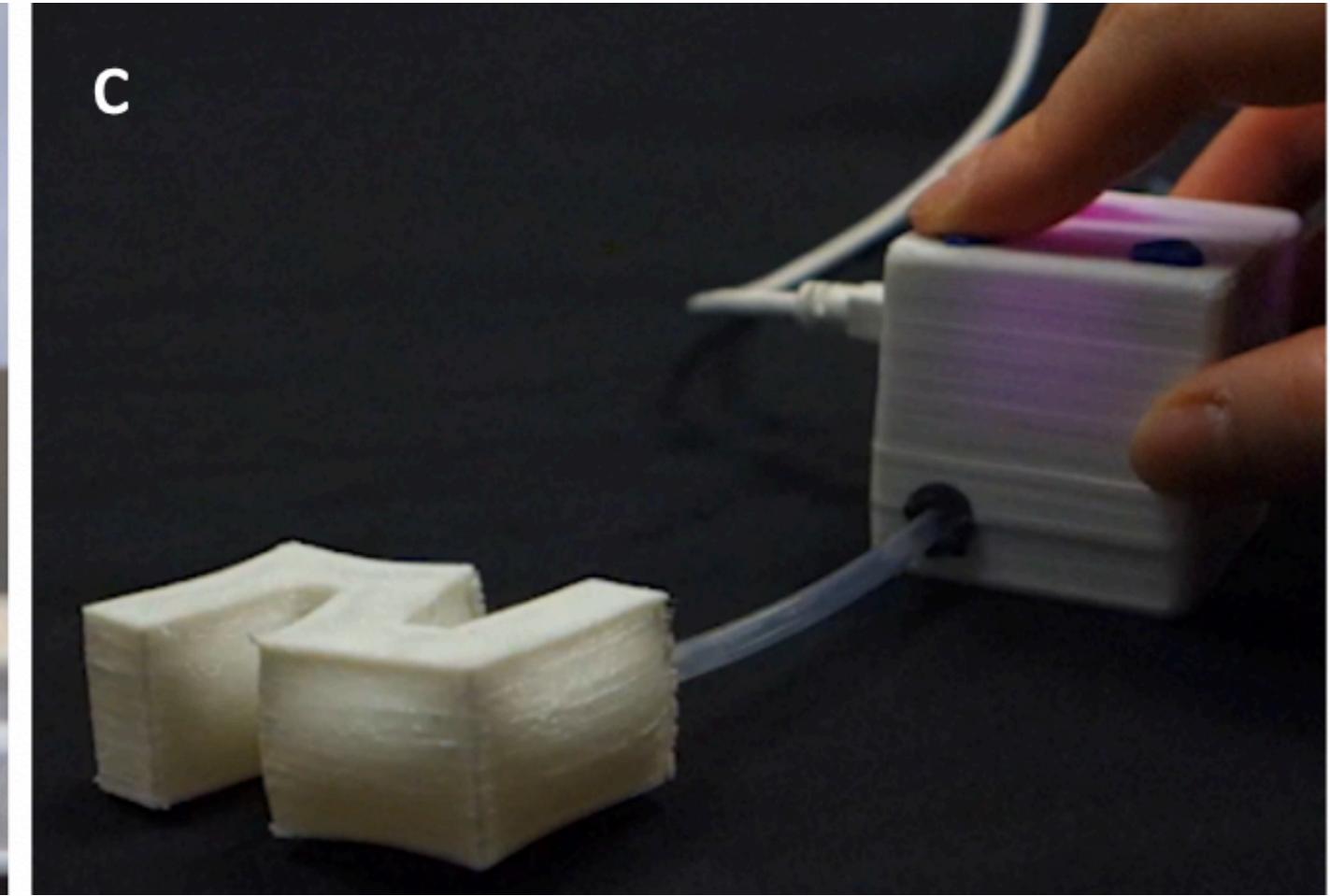
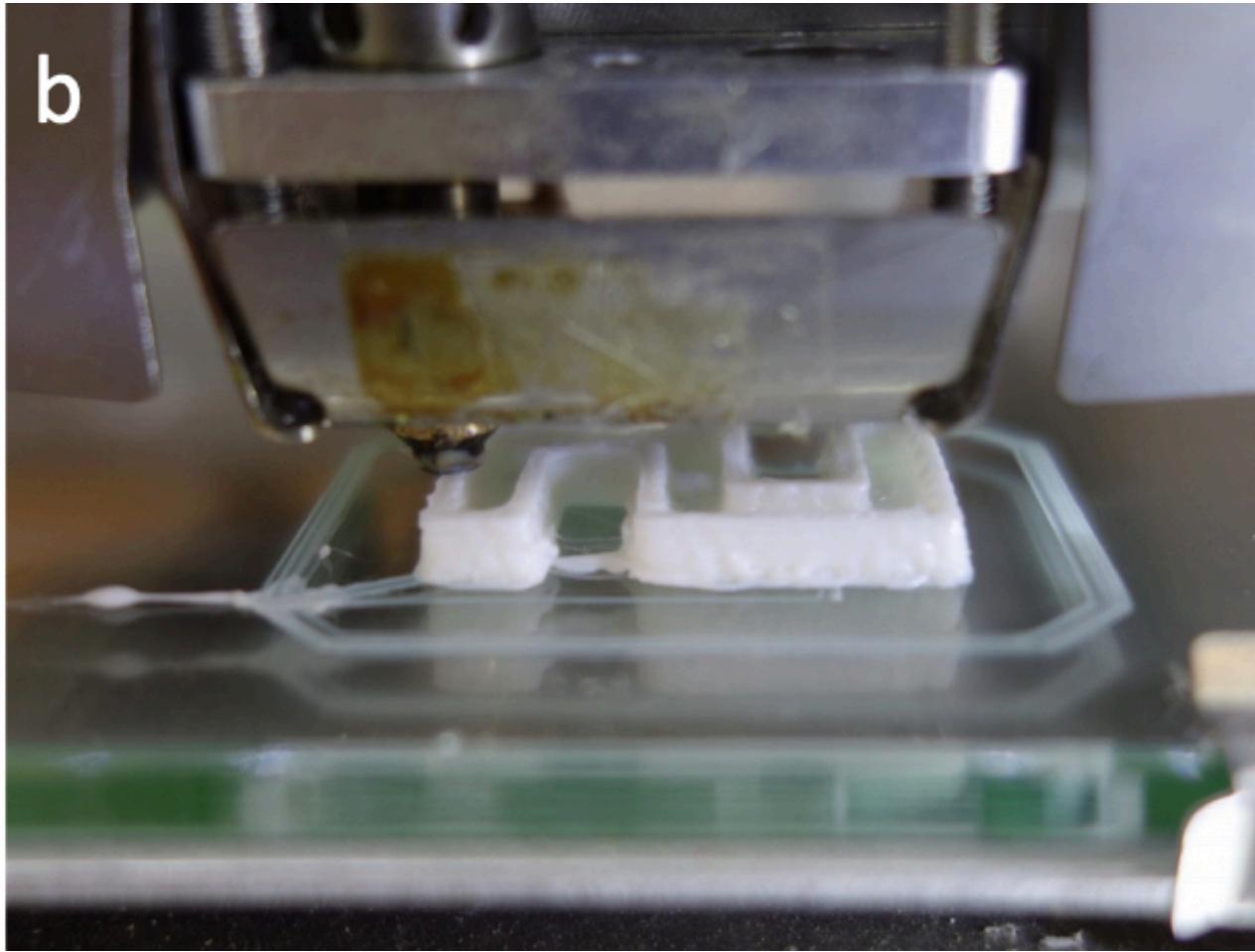
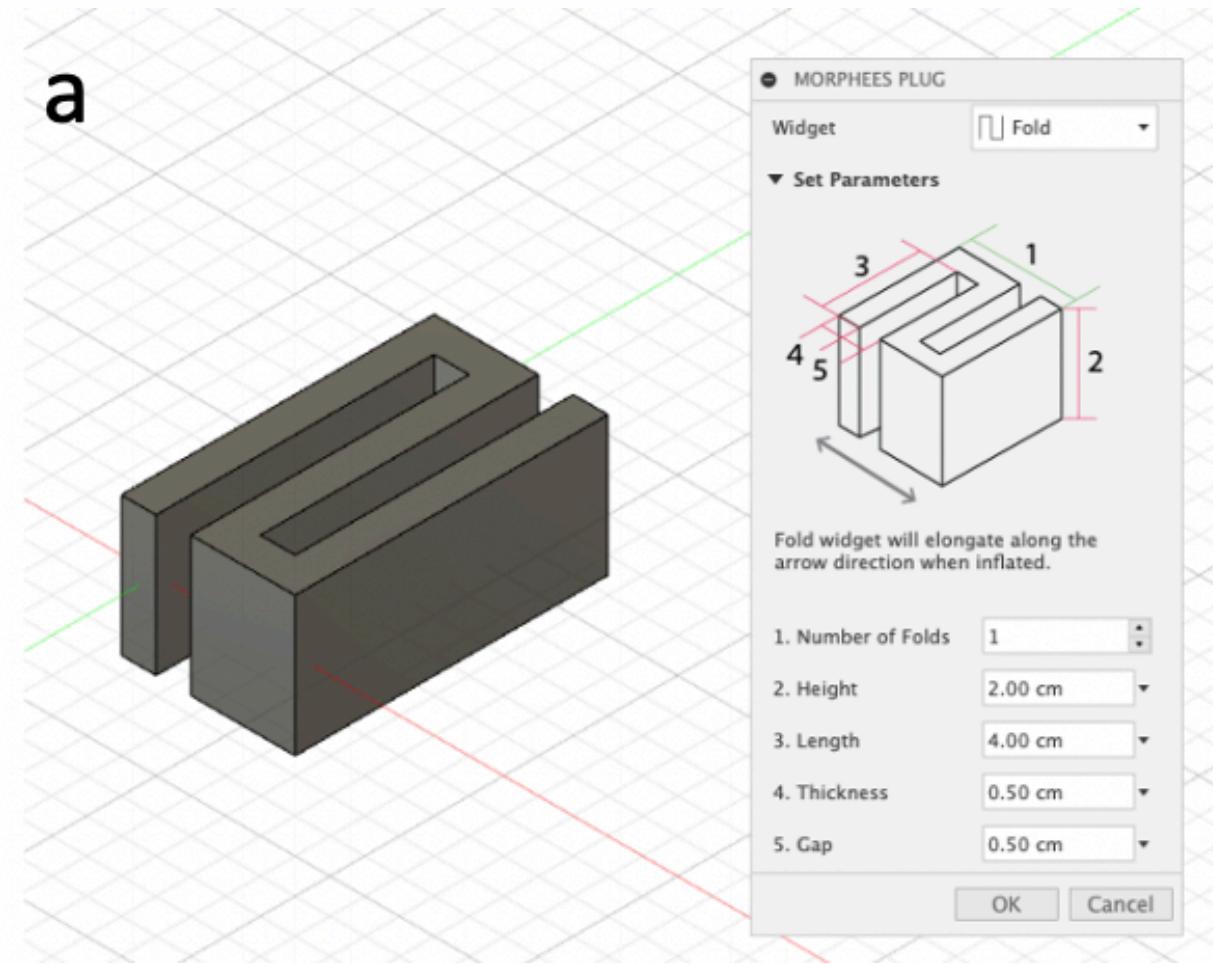
Osamu Fujimoto

Zhiyuan Li

Daniel Ashbrook



GI '18



CHI '21
MorpheesPlug

A Toolkit for Prototyping Shape-Changing Interfaces

Hyunyoung Kim



Aluna Everitt



Carlos Tejada



Mengyu Zhong



Daniel Ashbrook



In manuscript

AirLogic

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Raf Ramakers

Hasselt University



Mengyu Zhong

Uppsala University



Daniel Ashbrook

University of Copenhagen



Closing Remarks

Closing Remarks

- Print-and-Play Fabrication
 - Interactive devices are printed, not assembled.
- Four new techniques.
- Air-powered techniques, making use of custom internal geometries.
- Can be used to create tangible devices using commodity 3D-printers.

Print-and-Play Fabrication

Carlos E. Tejada