

# Building Intelligent Robots from the Ground Up

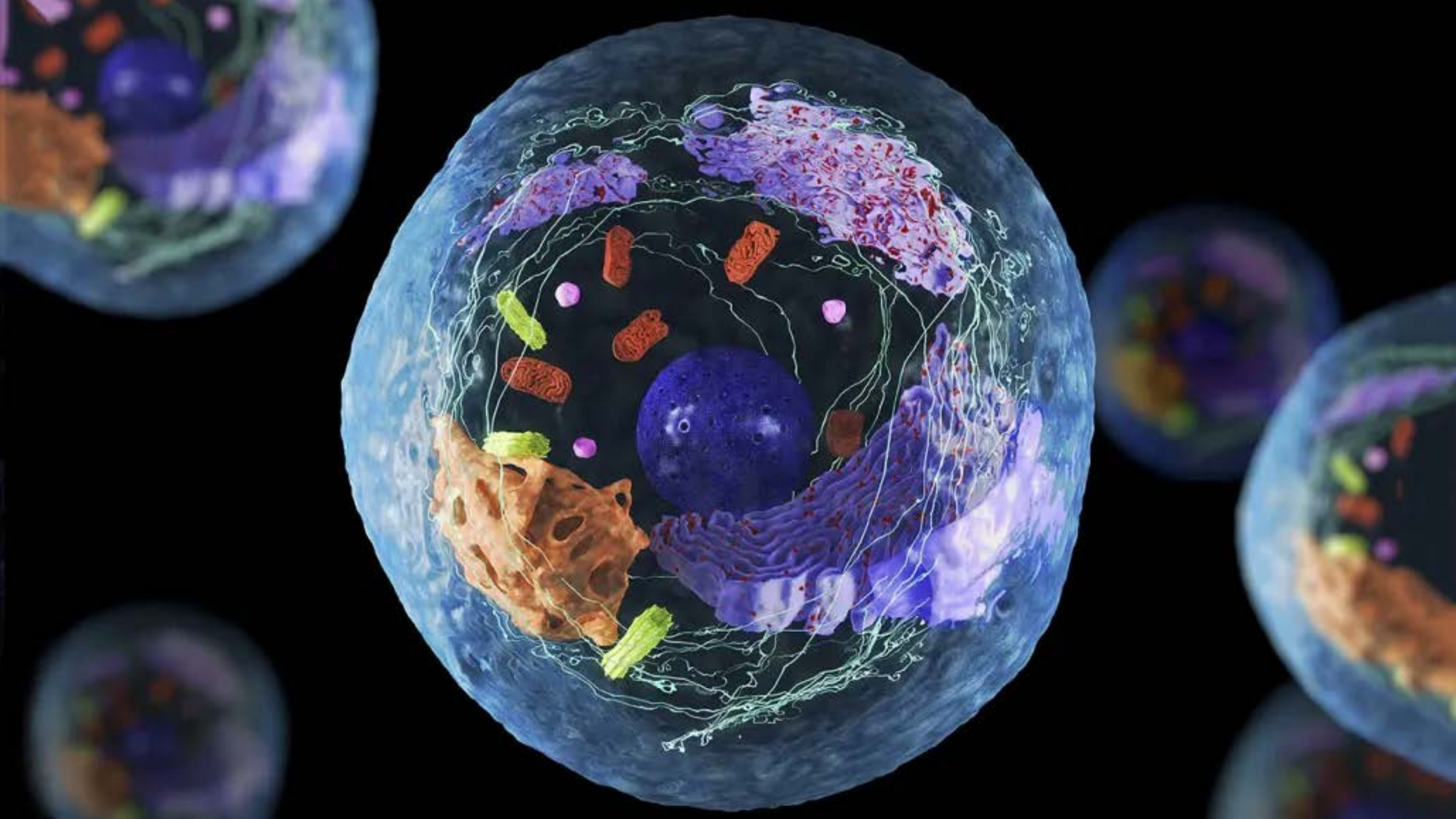
Boyuan Chen

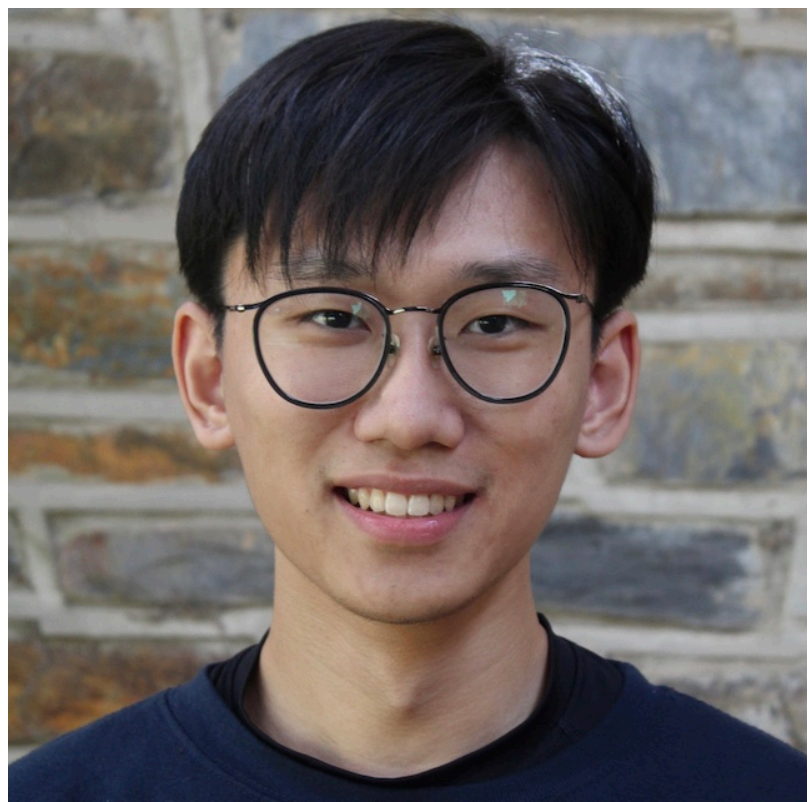
Dickinson Family Assistant Professor

MEMS, ECE, CS

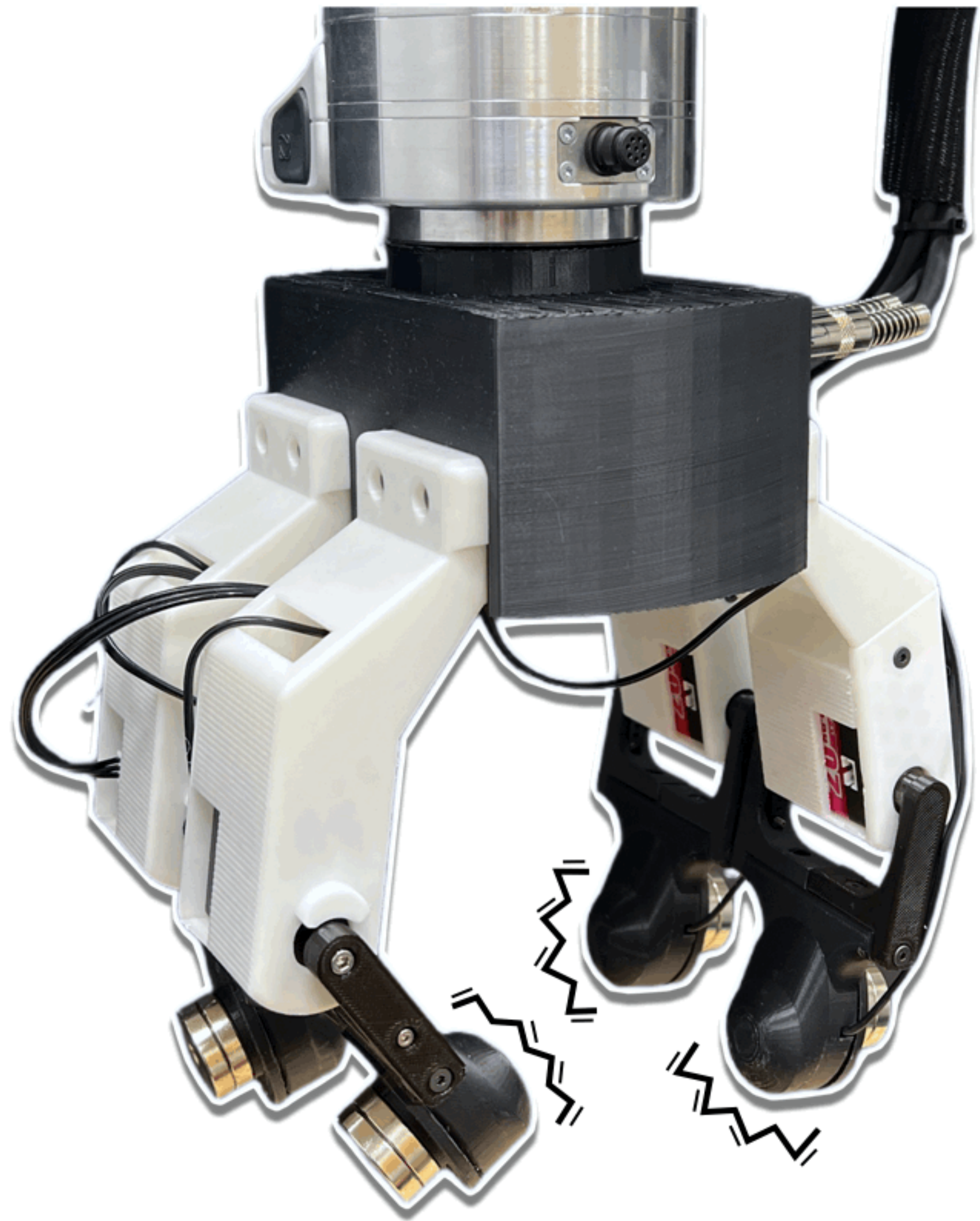
General Robotics Lab

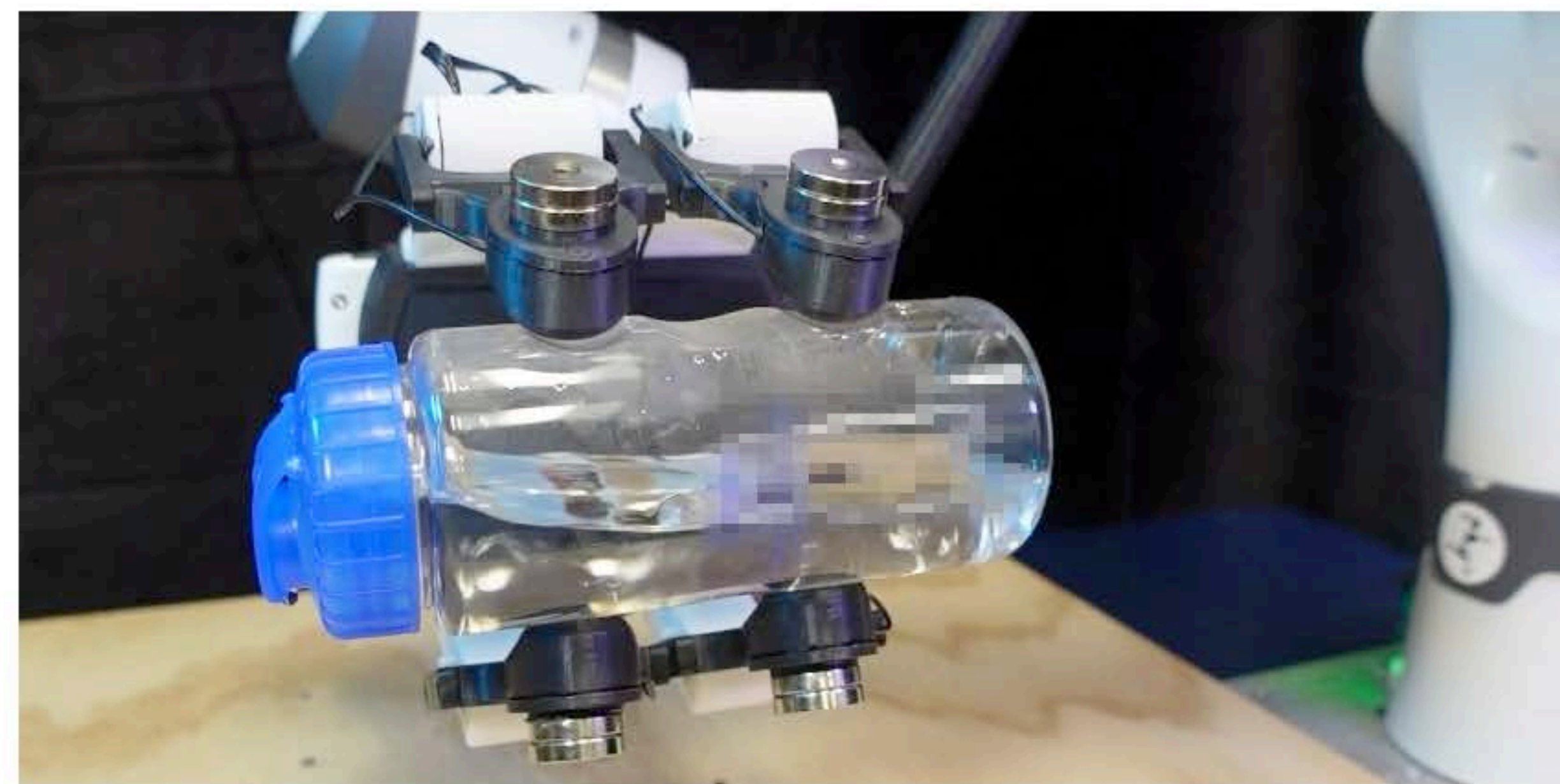
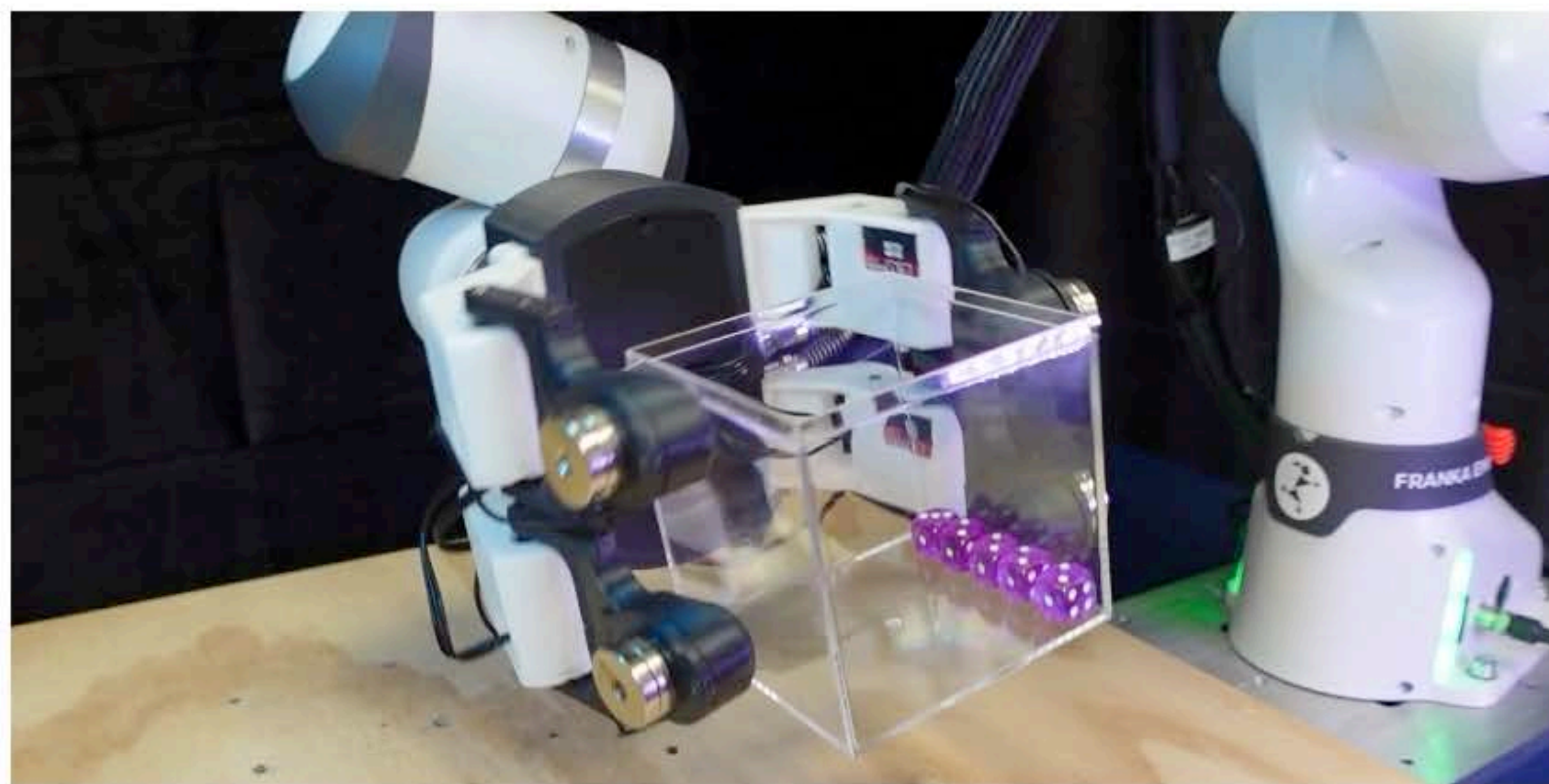
***building intelligent robots =  
breeding a new species***





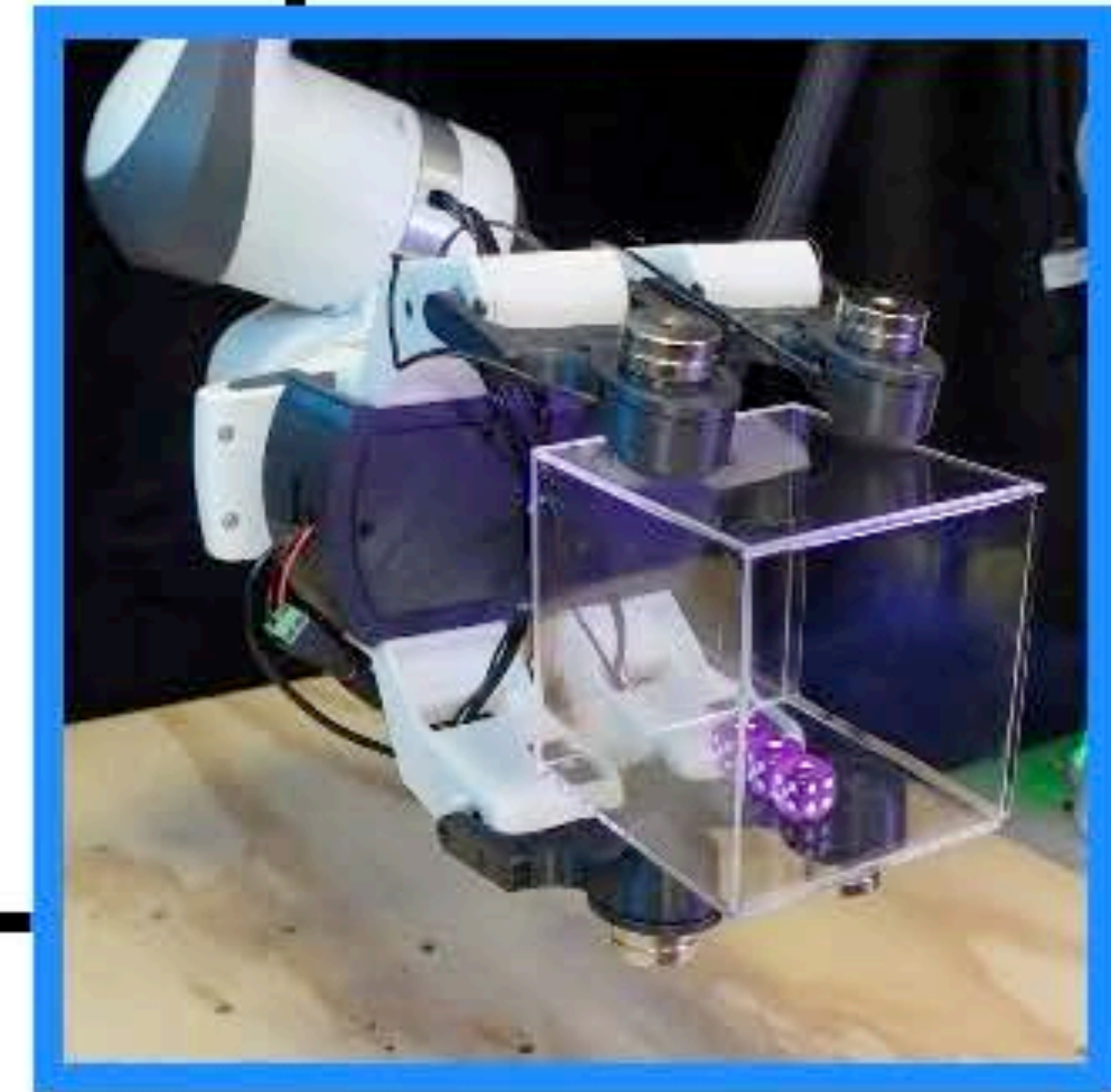
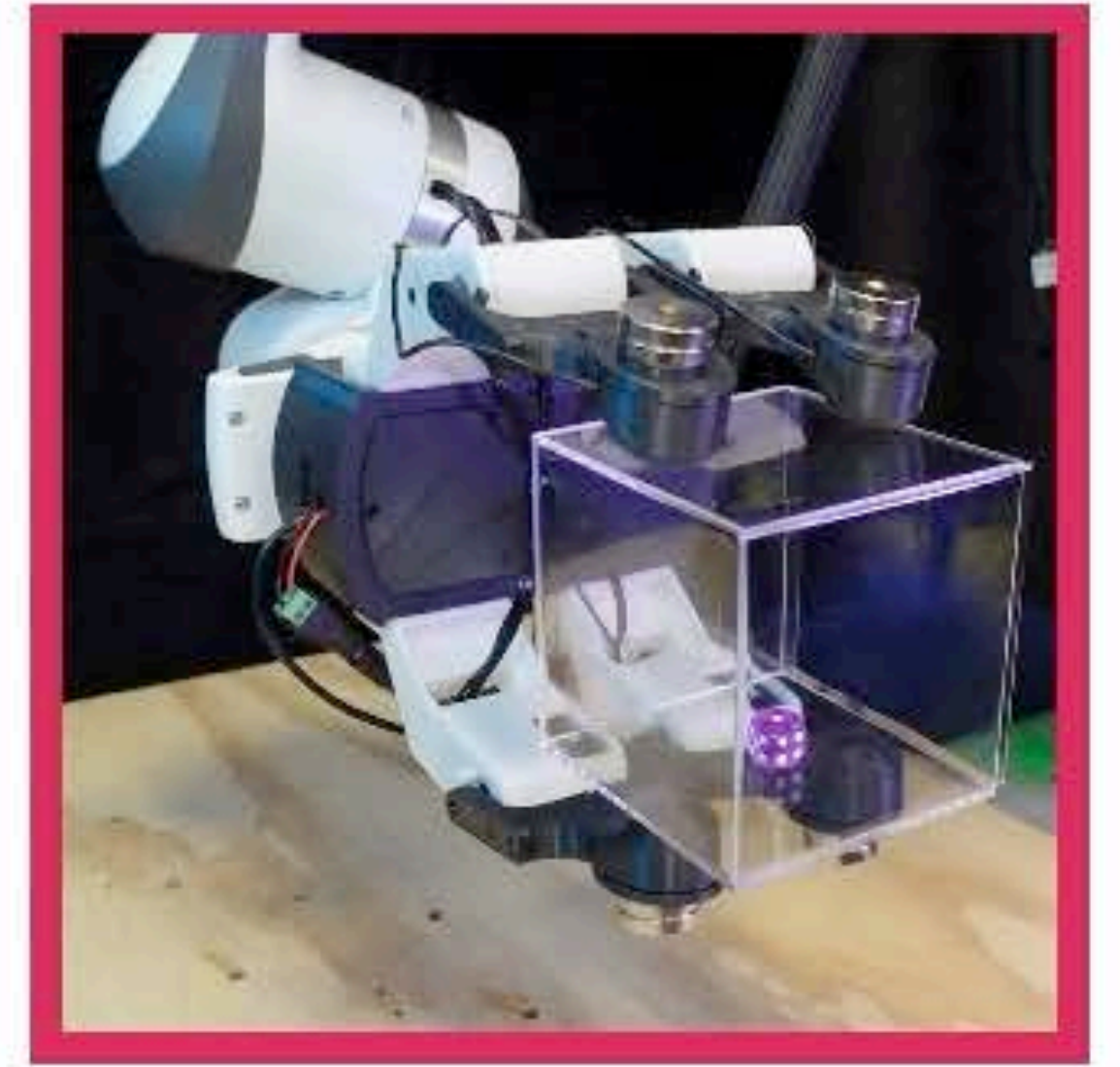
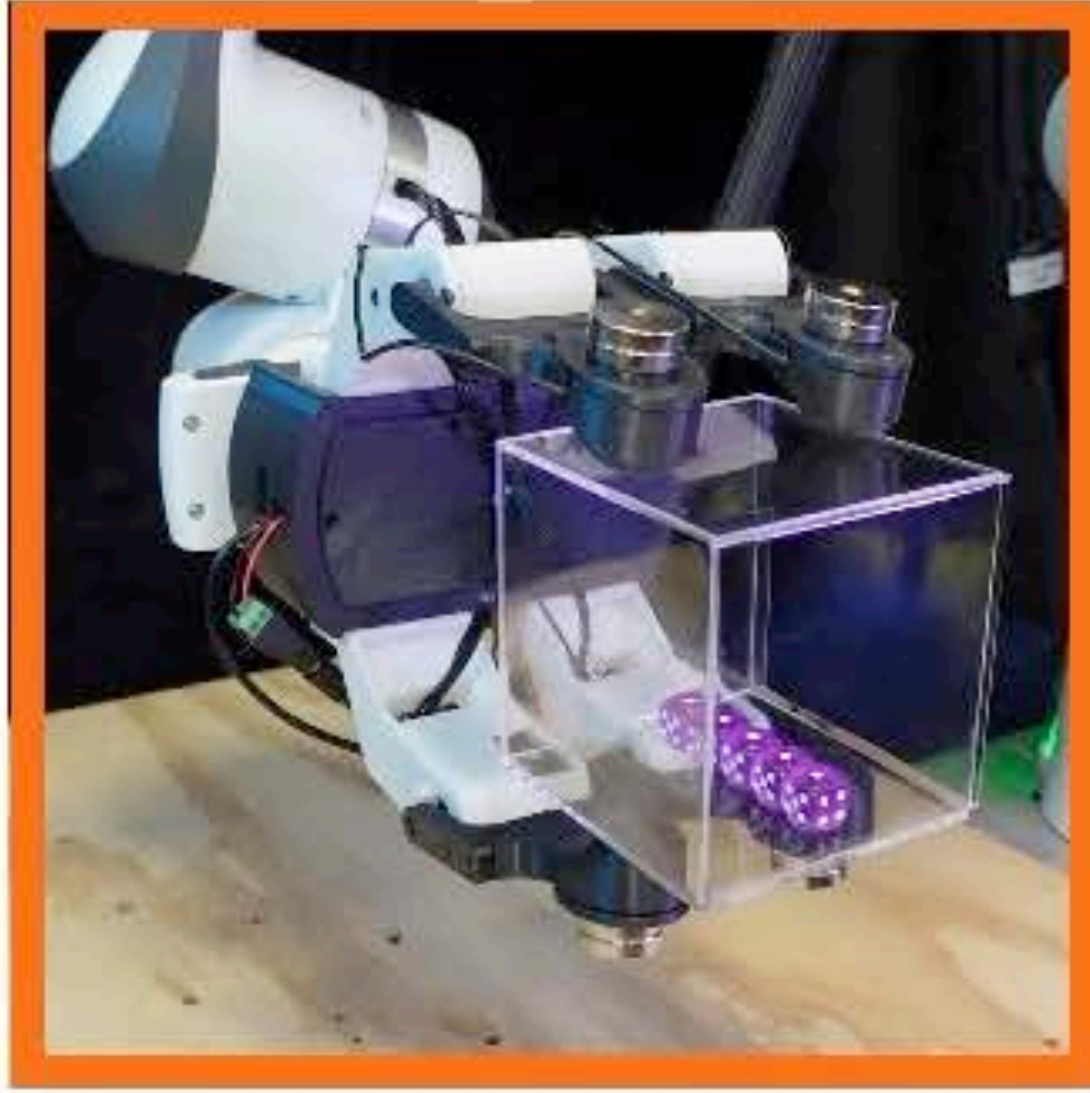
Jiaxun Liu

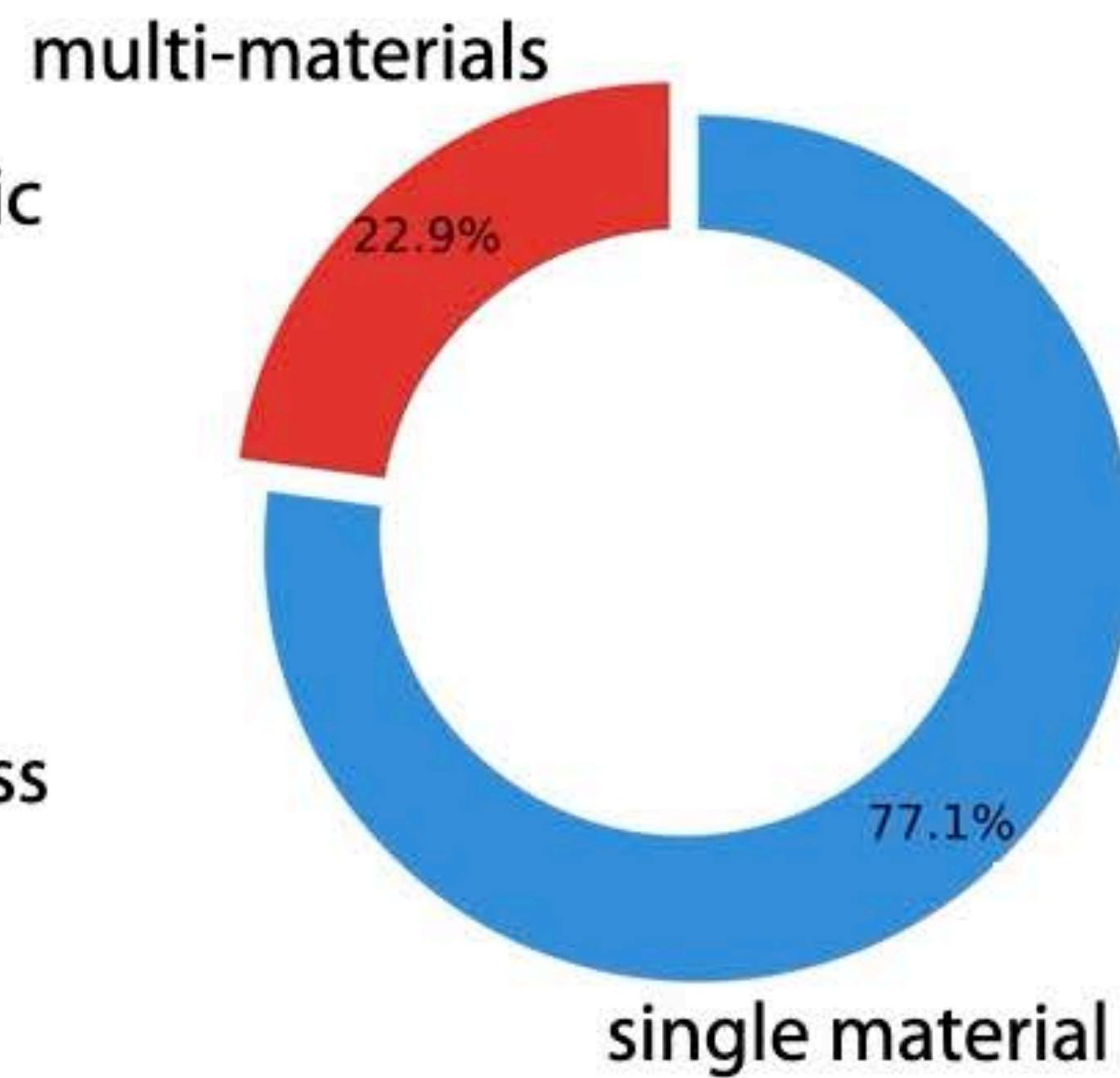
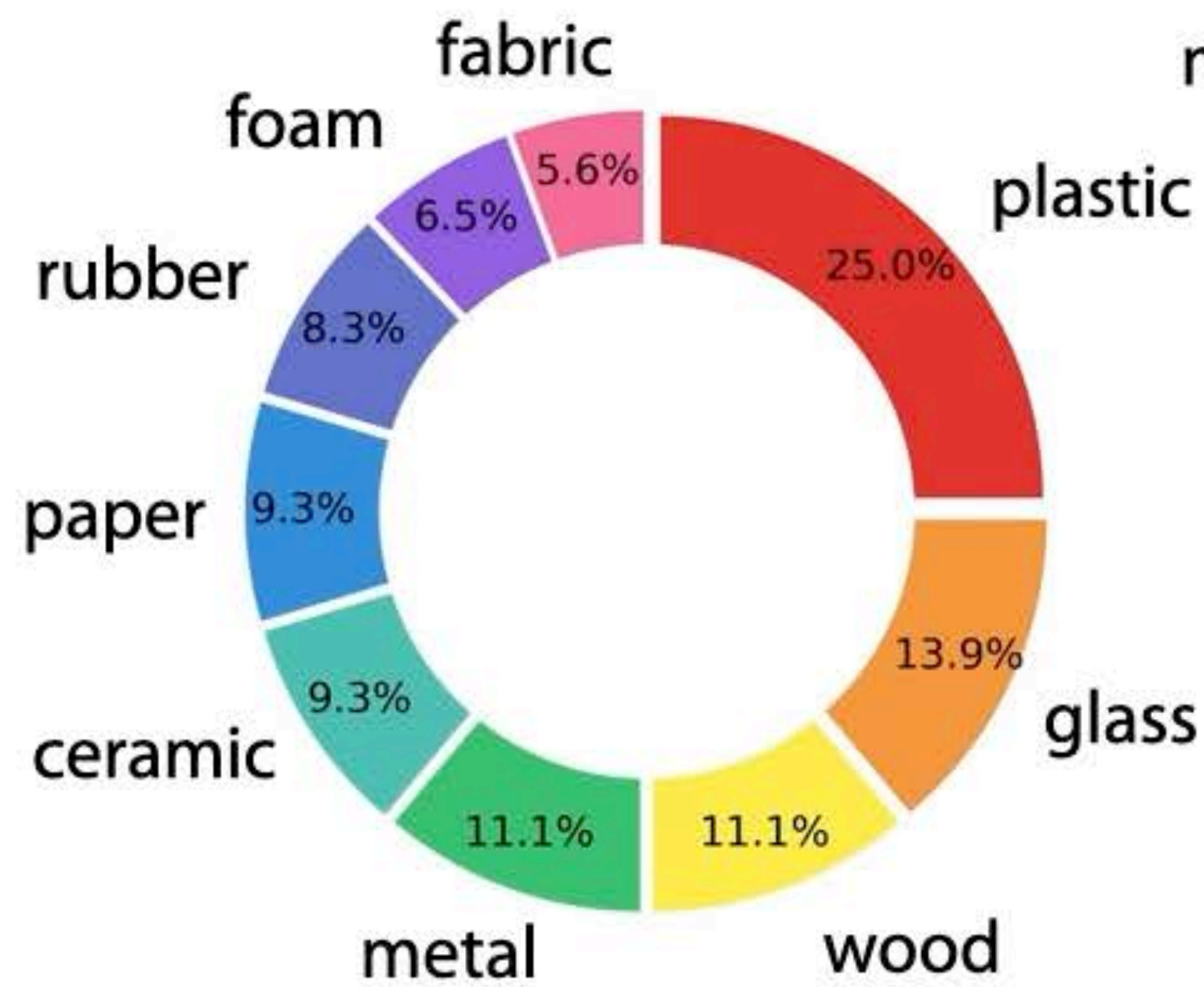




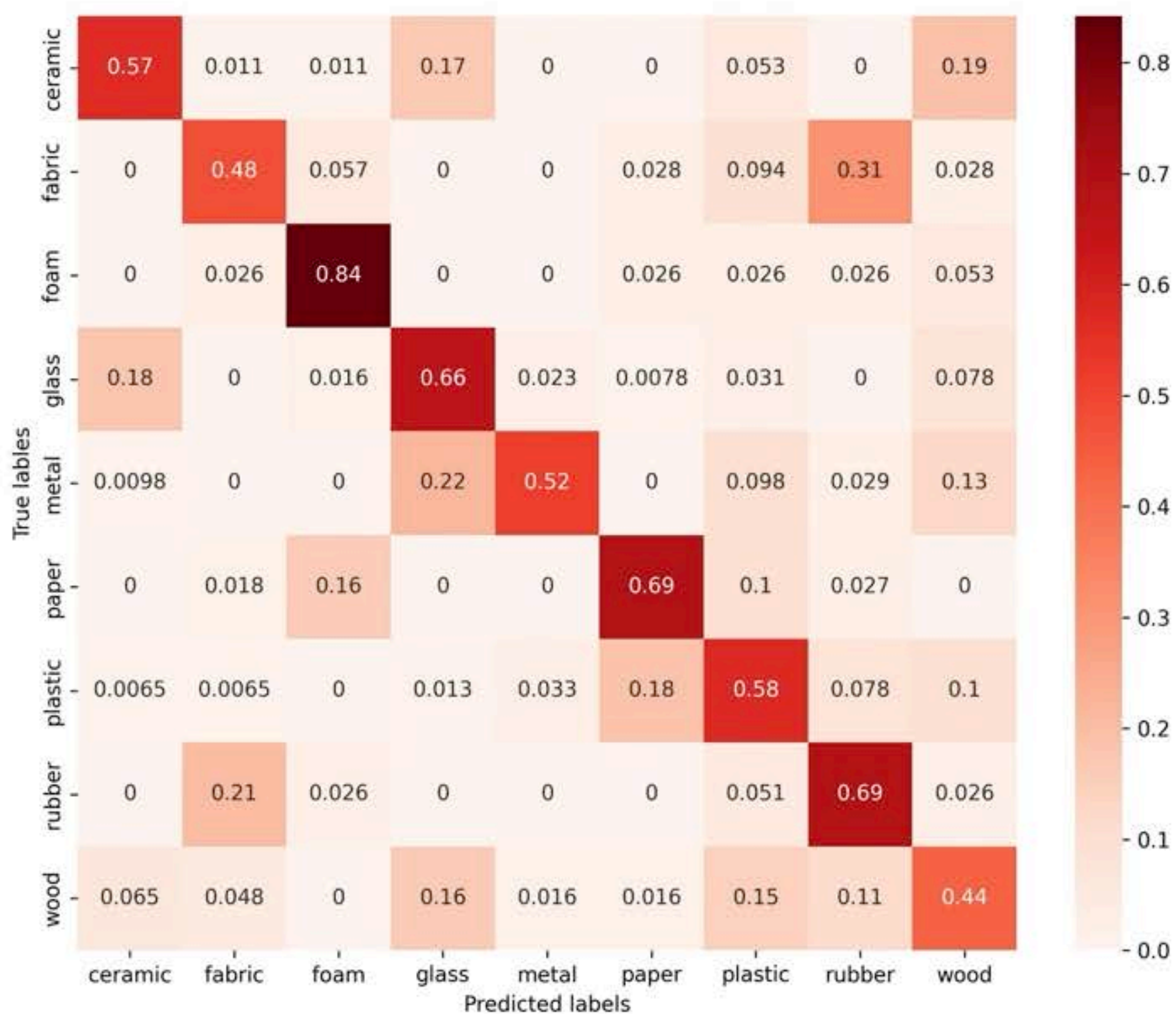
**SonicSense.** Liu and Chen. CoRL 2024

# t-SNE



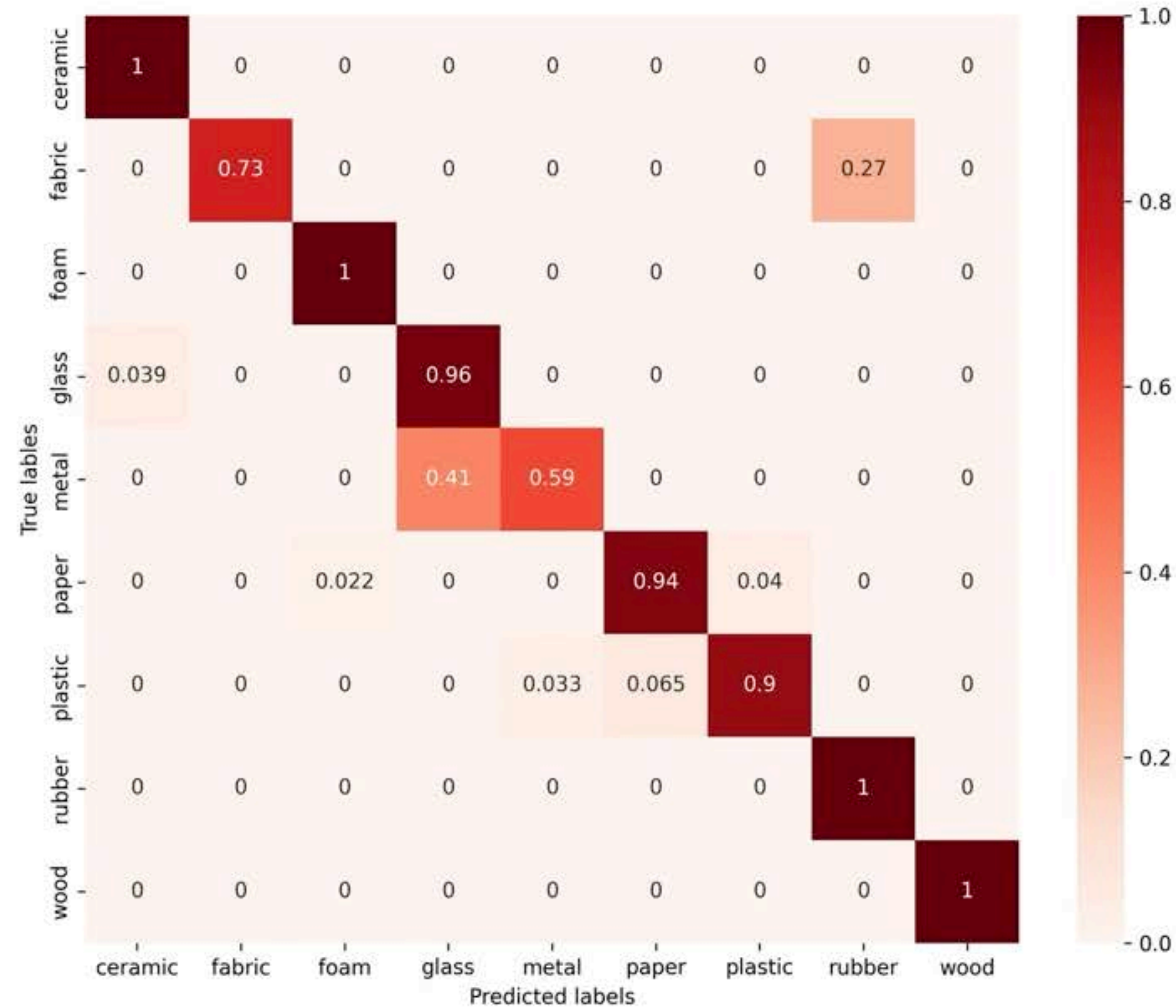


# Initial Confusion Matrix



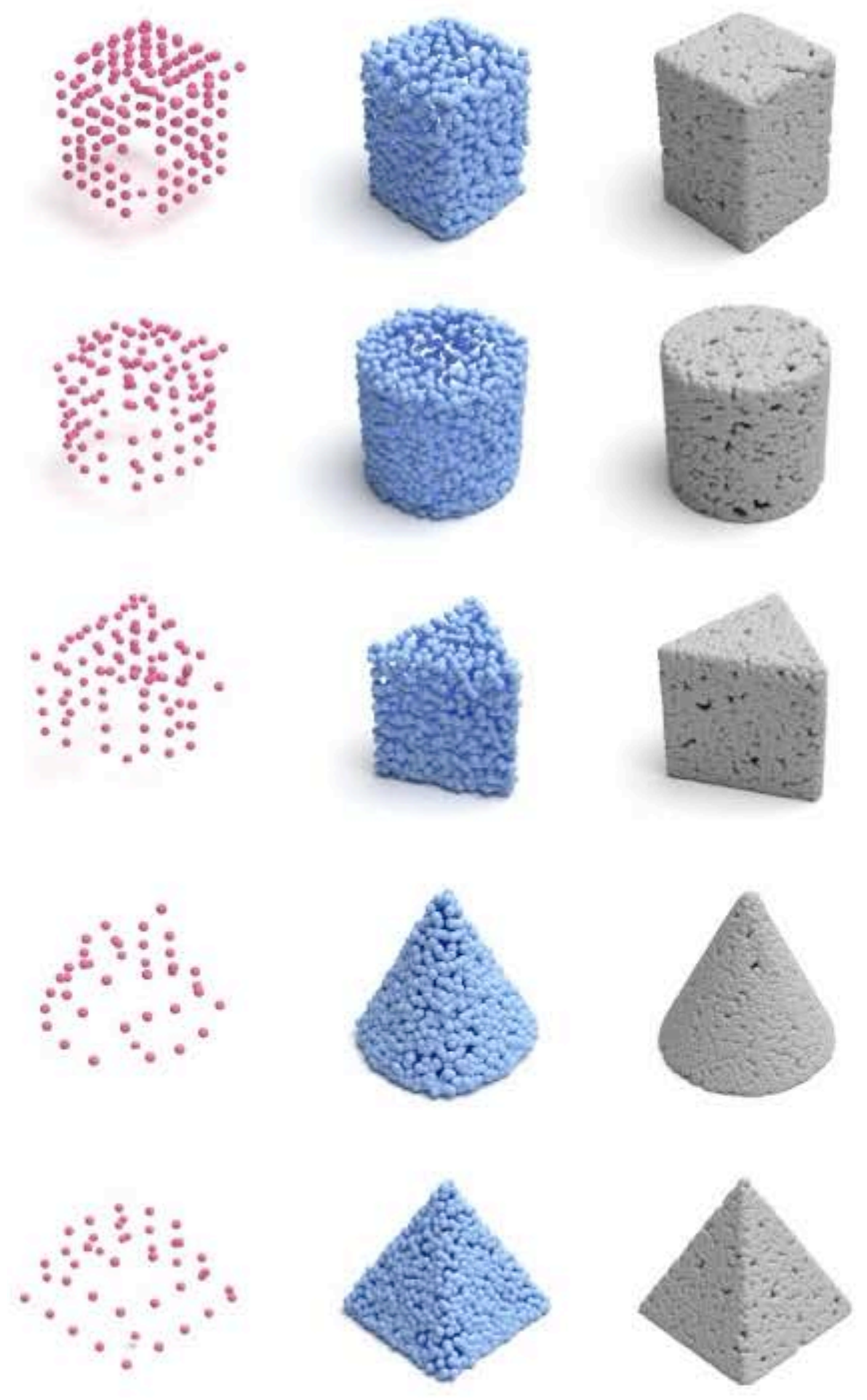
**F1 Score: 0.523**

# Confusion Matrix after Refinement



**F1 Score: 0.763**

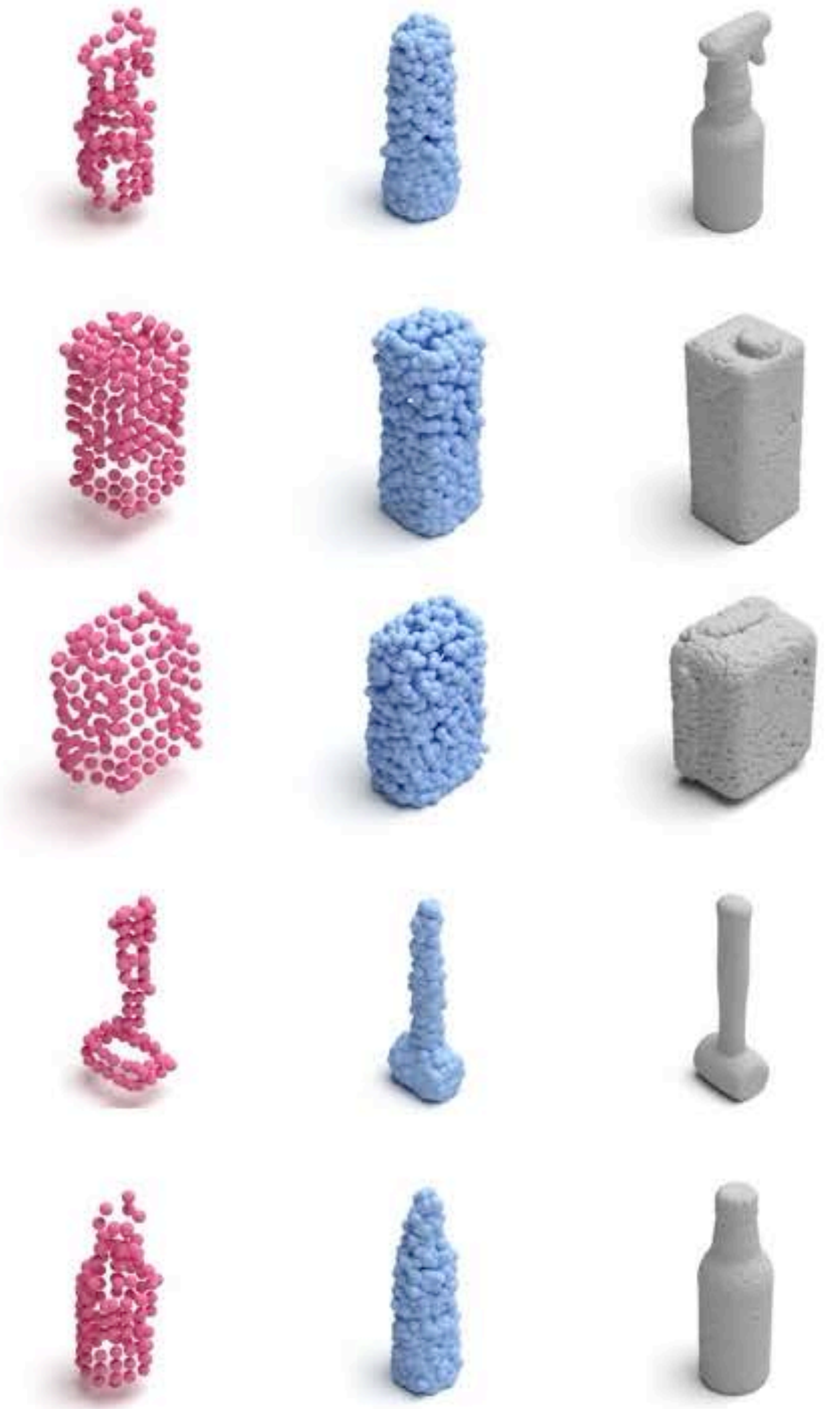
**Input Prediction Real**



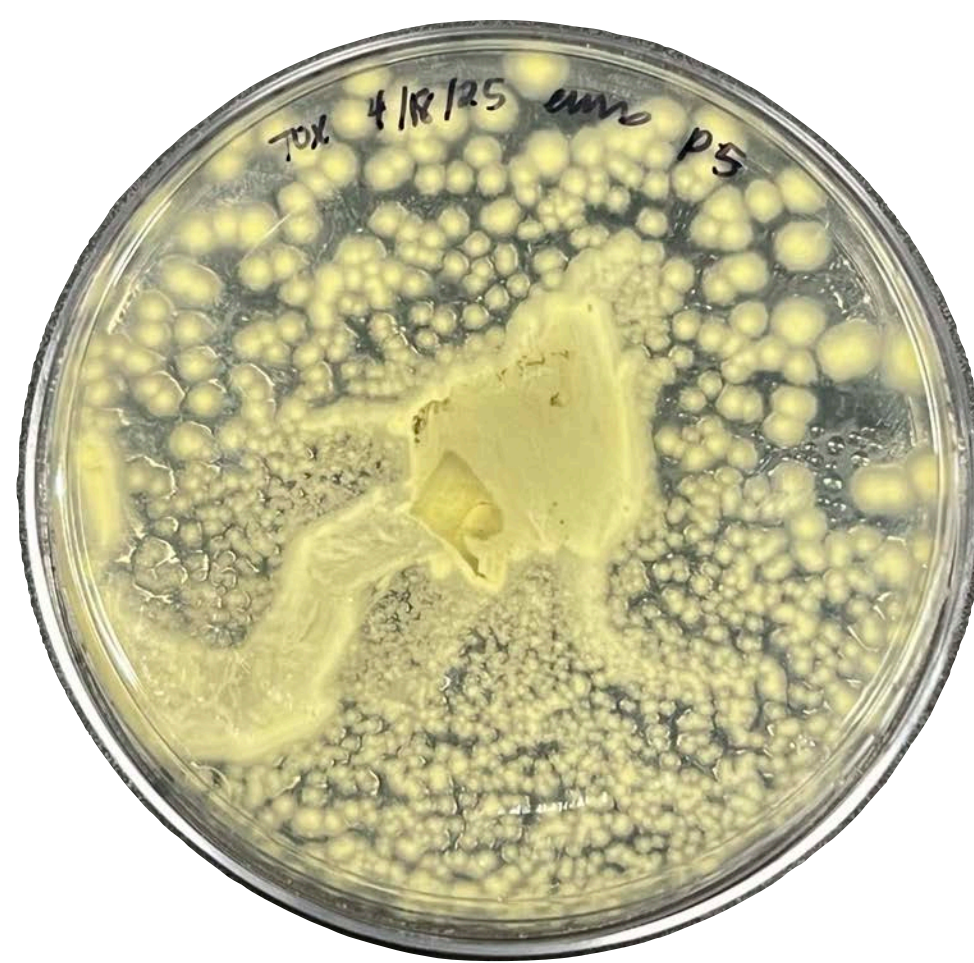
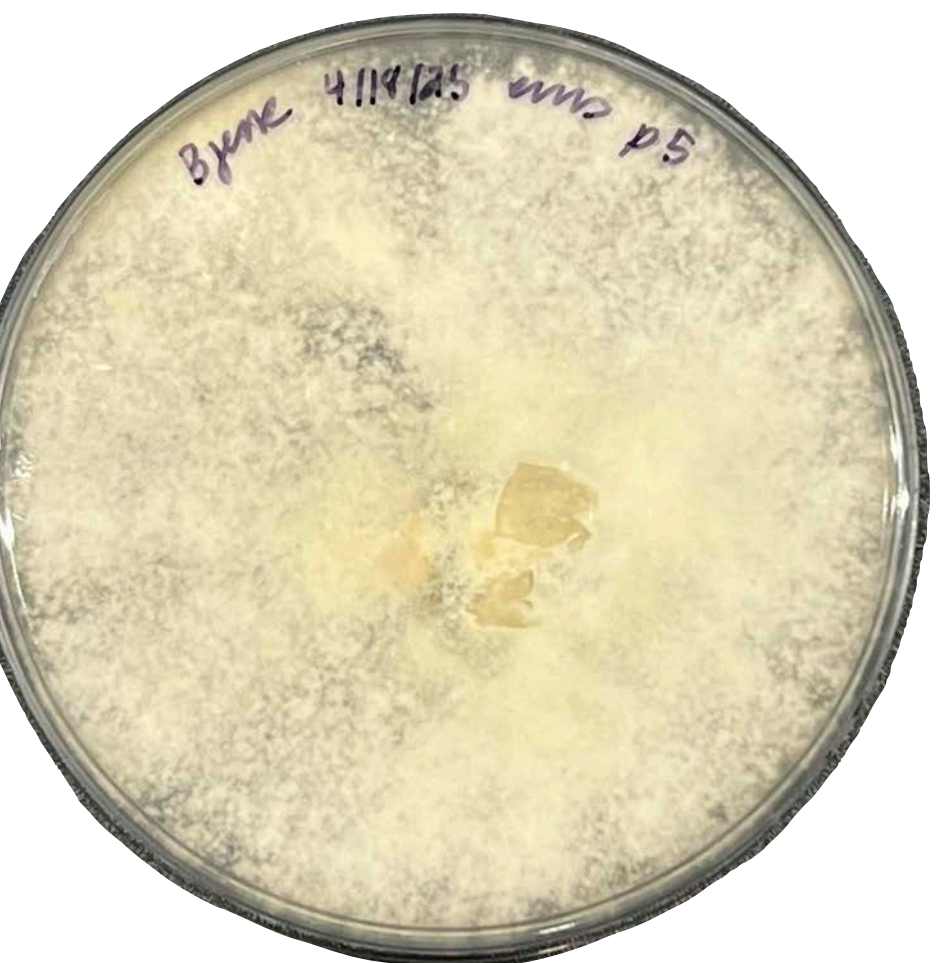
**Input Prediction Real**



**Input Prediction Real**







**B.adusta**

**Xylaria.501**

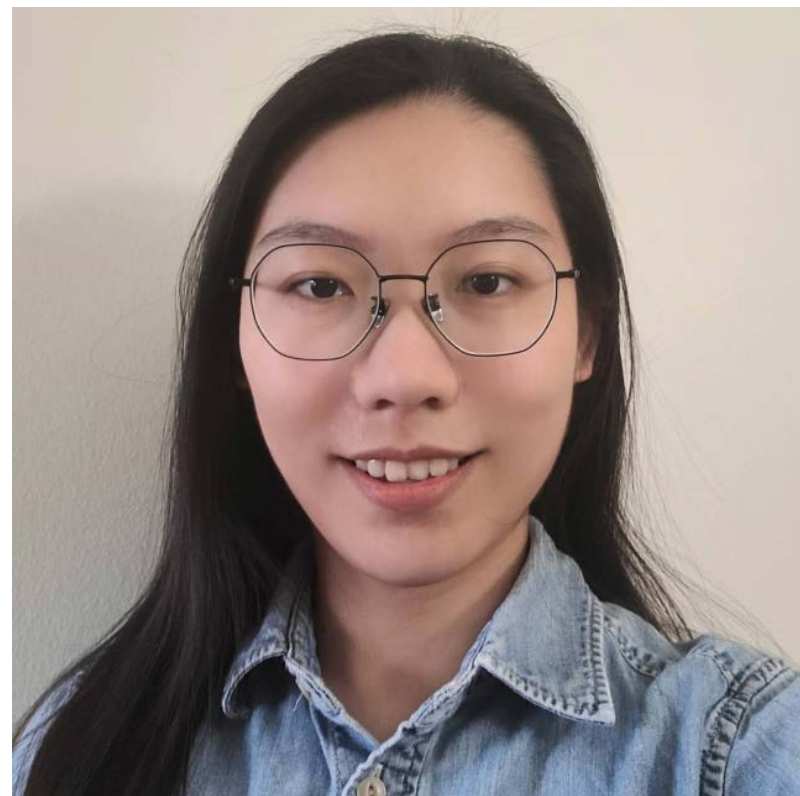
**P.toxicarium**

**P.513**

**T.508**

Decaying Wood

Built Environments



Yanbaihui (Evelyn) Liu



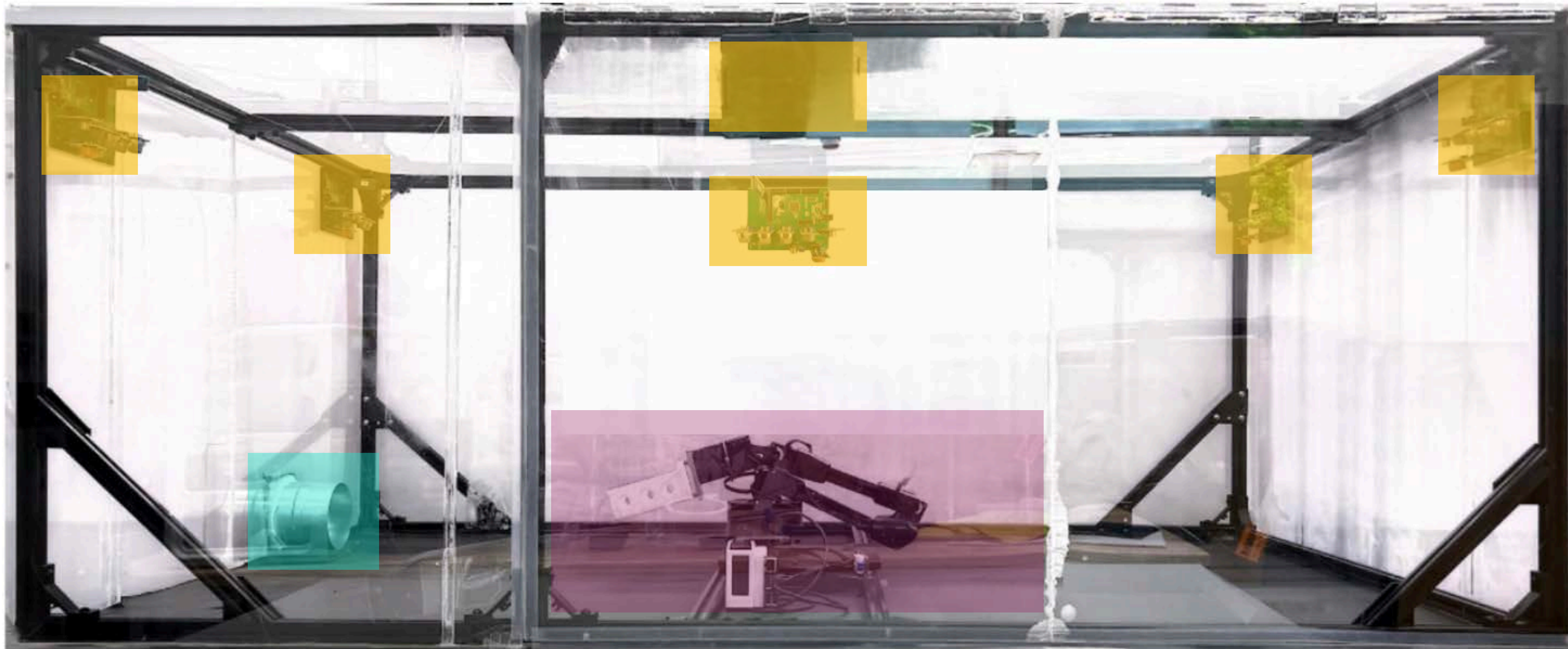
Erica Babusci



Claudia Gunsch



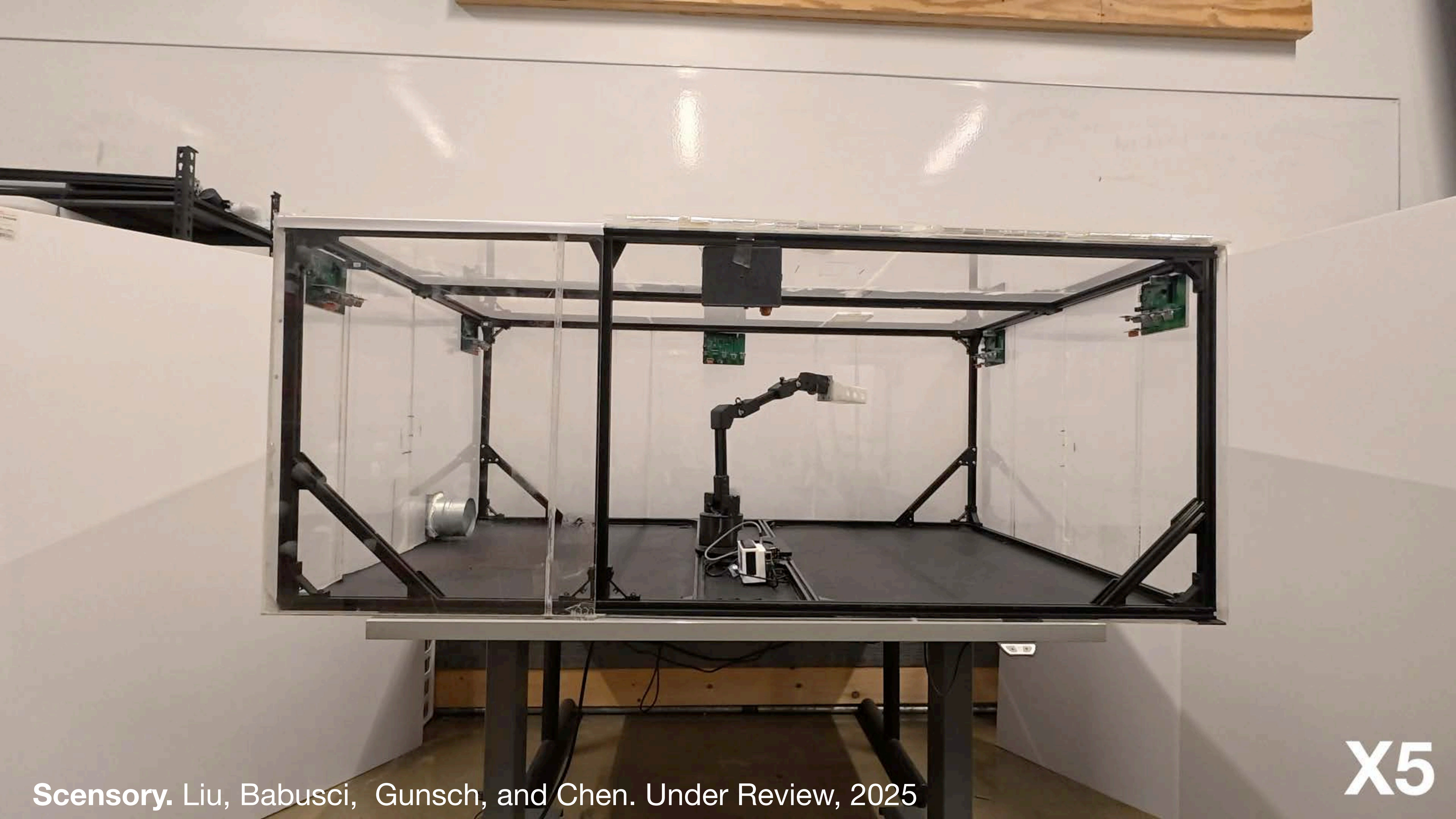
**Scensory.** Liu, Babusci, Gunsch, and Chen. Under Review, 2025

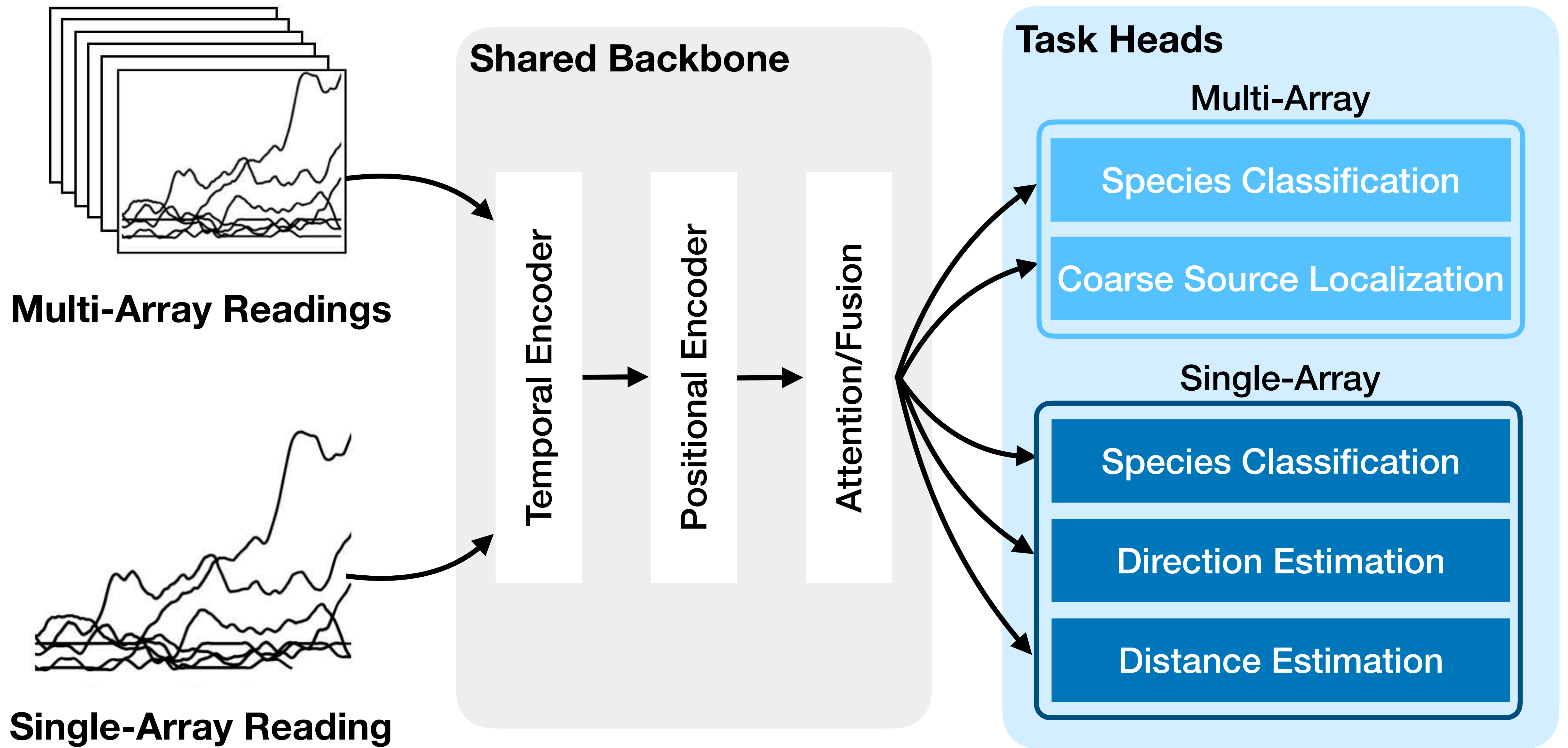


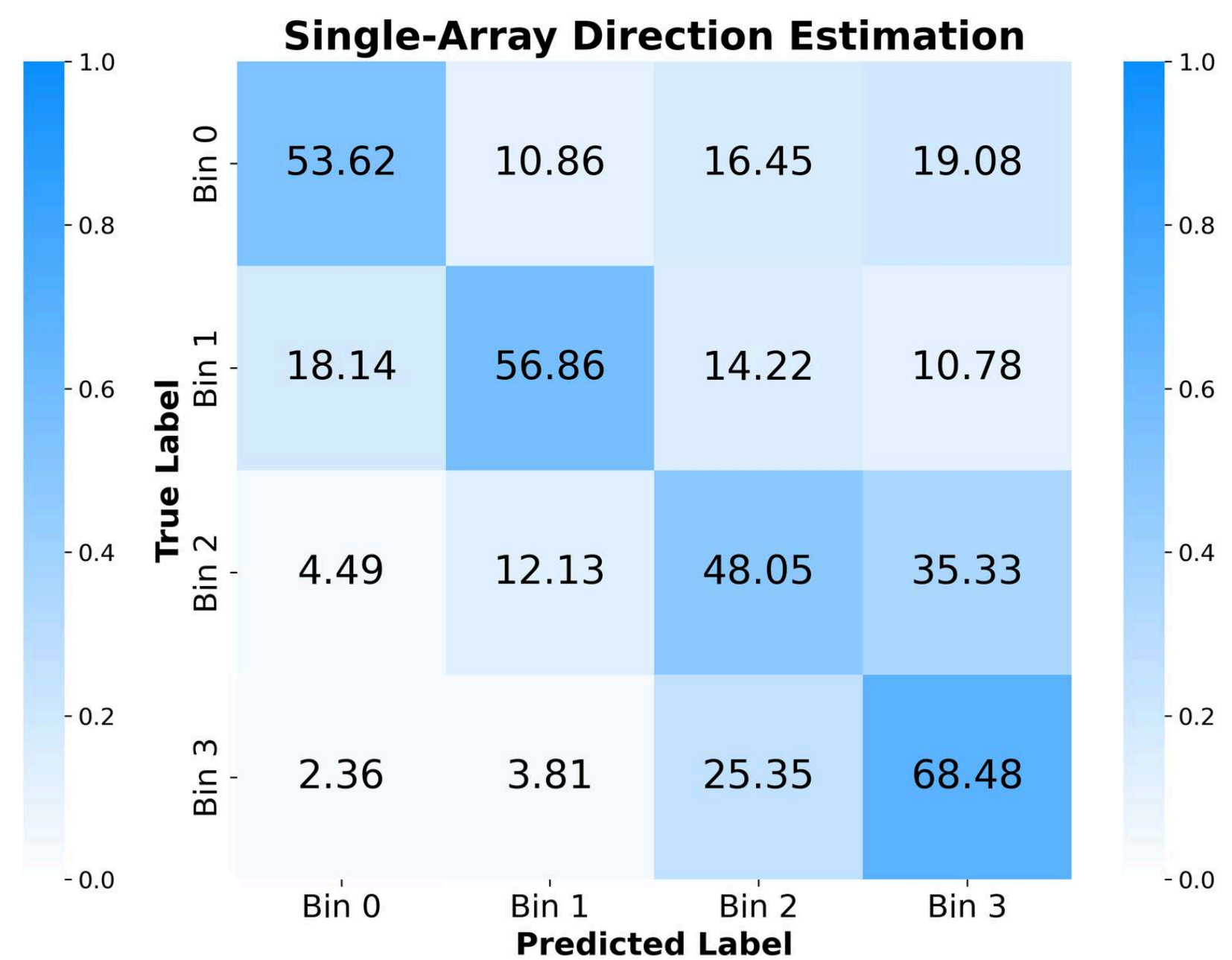
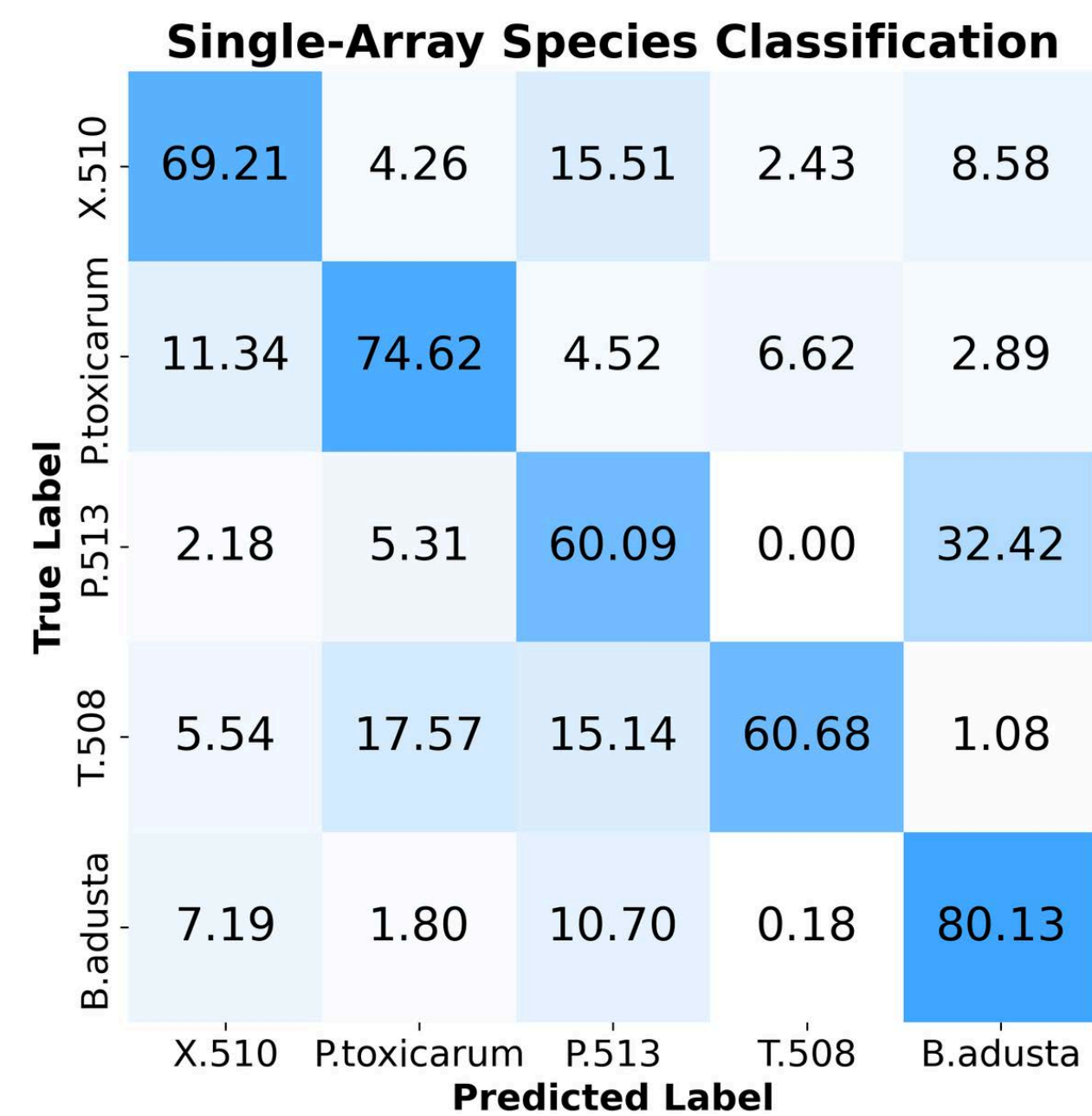
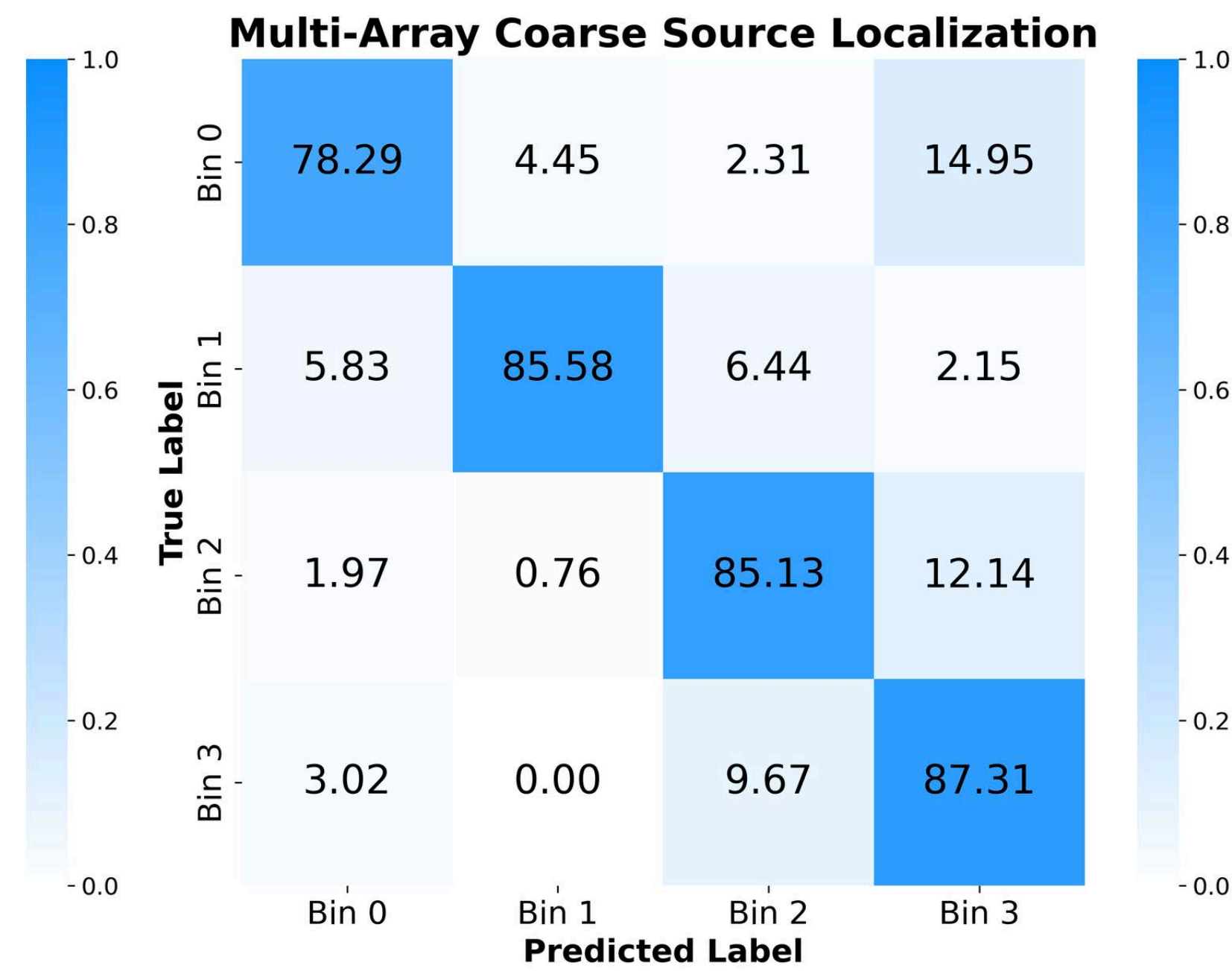
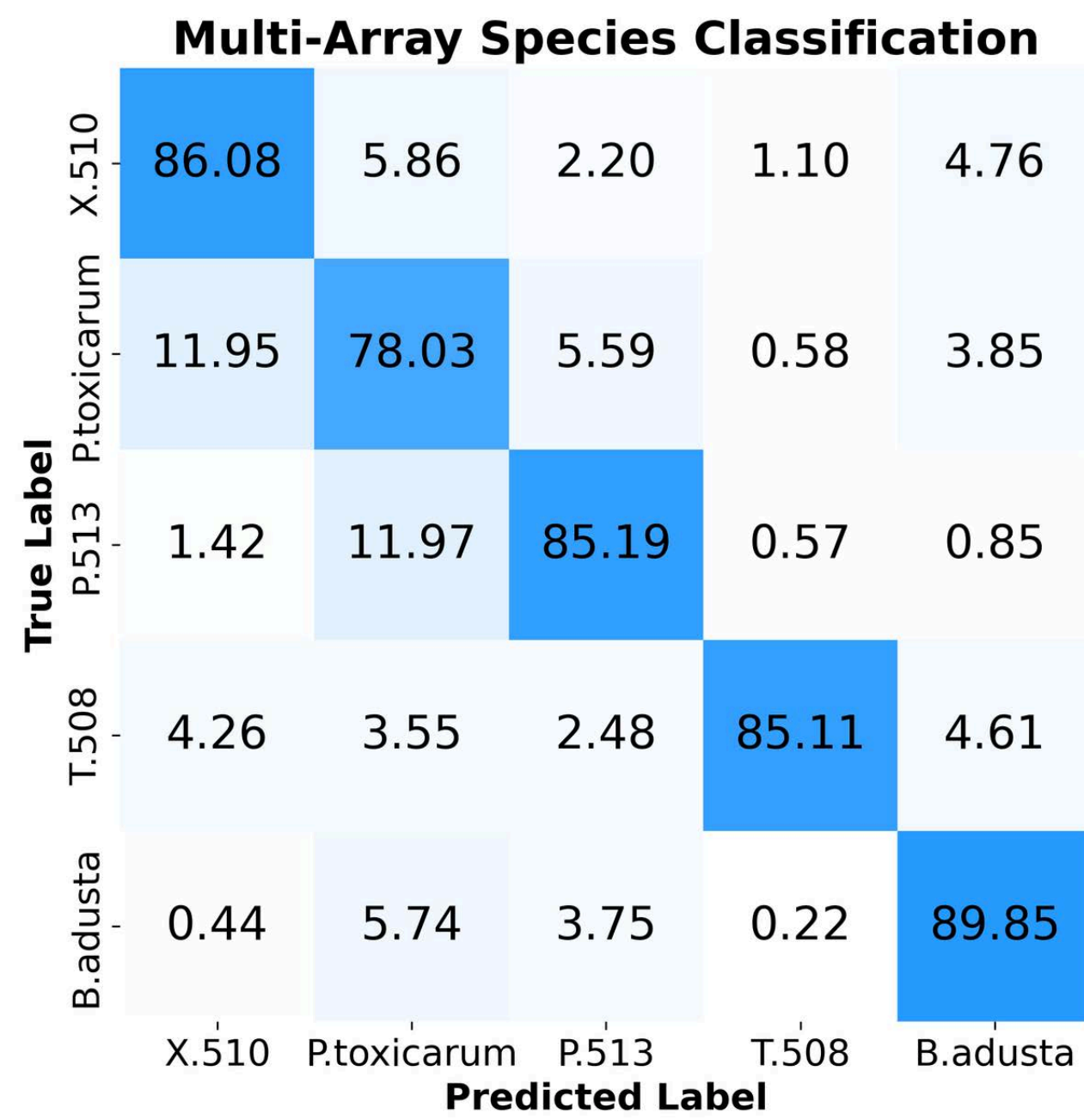
**Sensor arrays**

**Exhausted Fan**

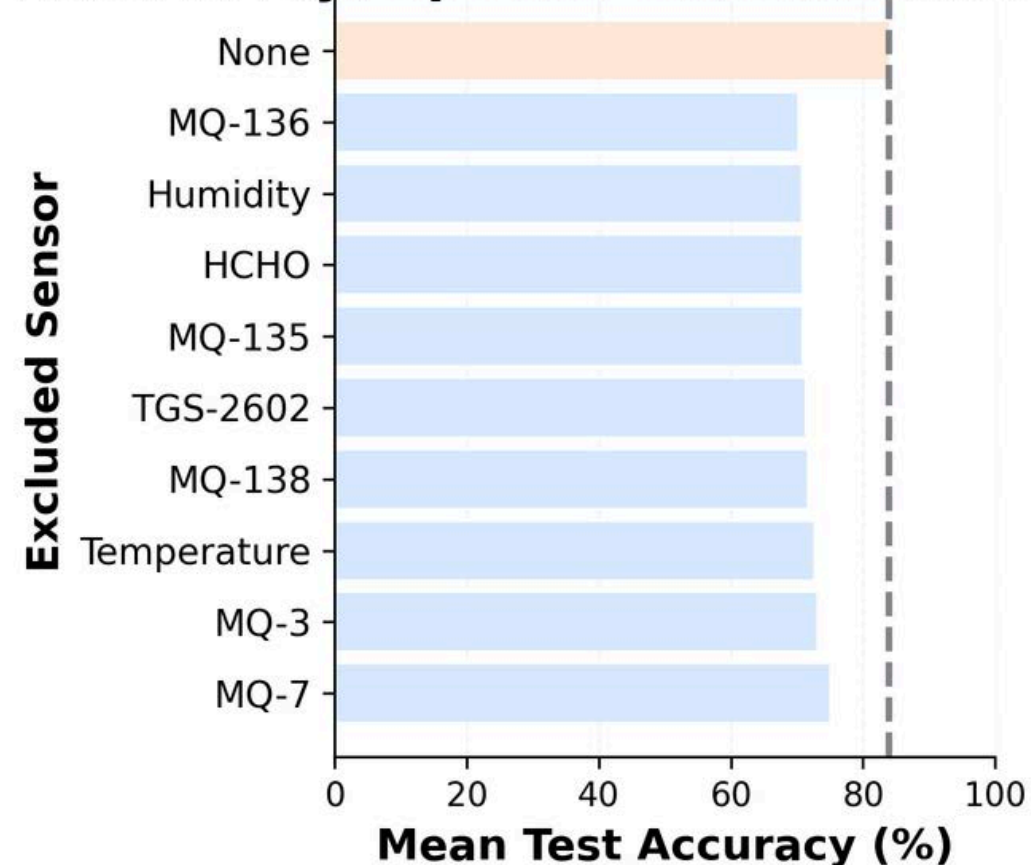
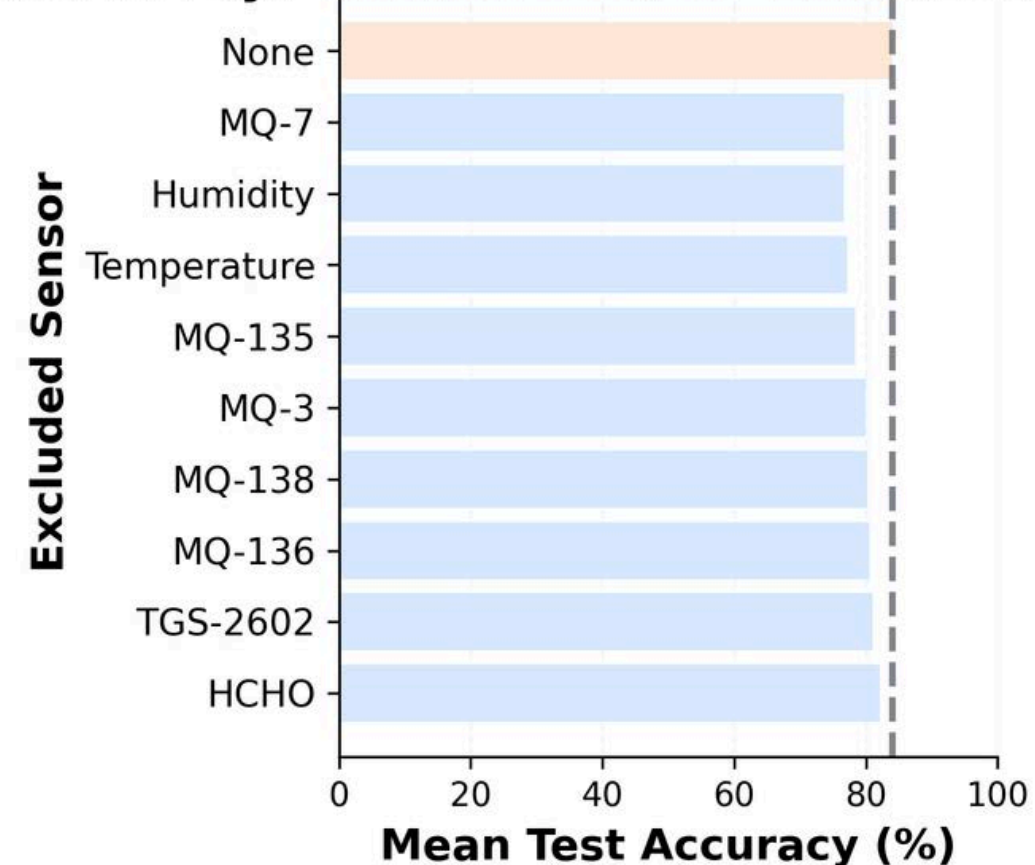
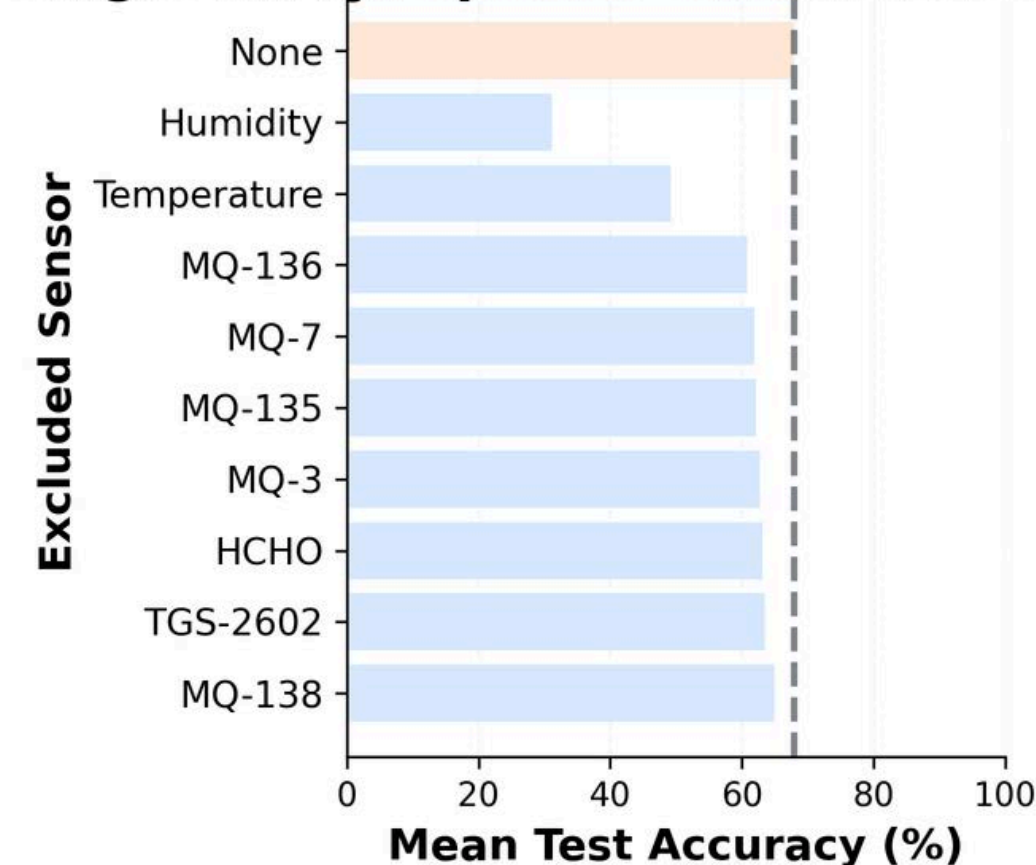
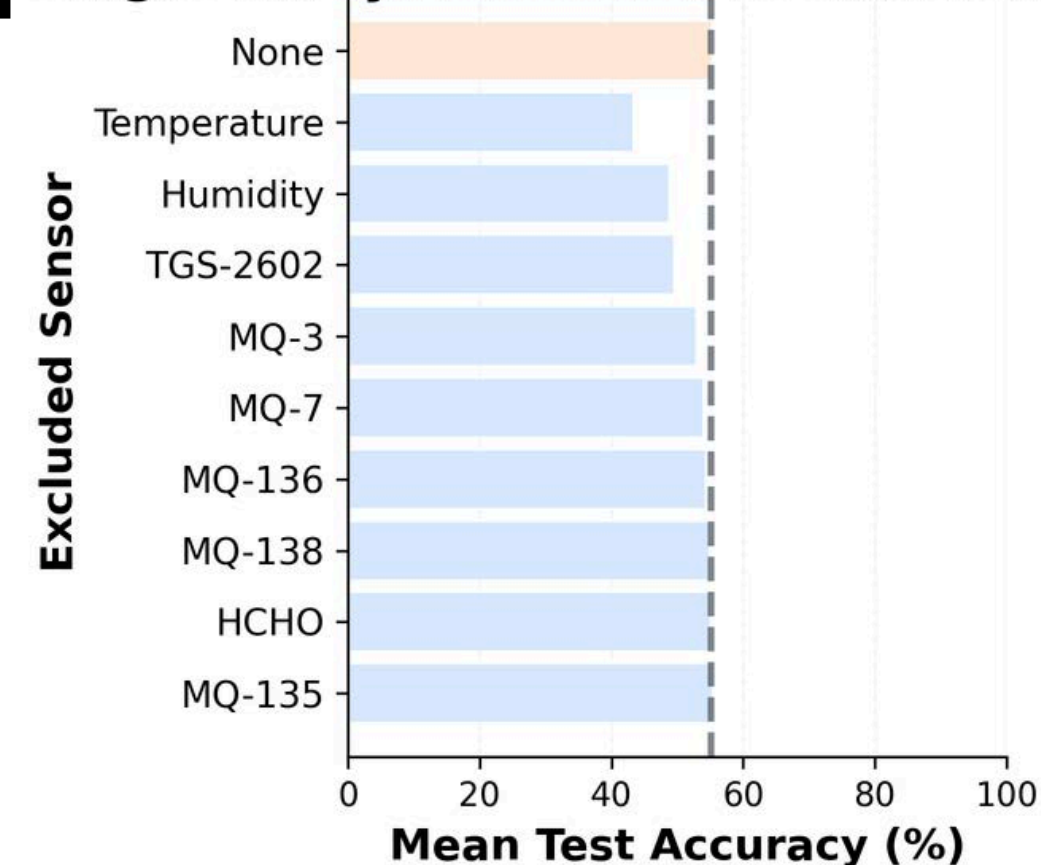
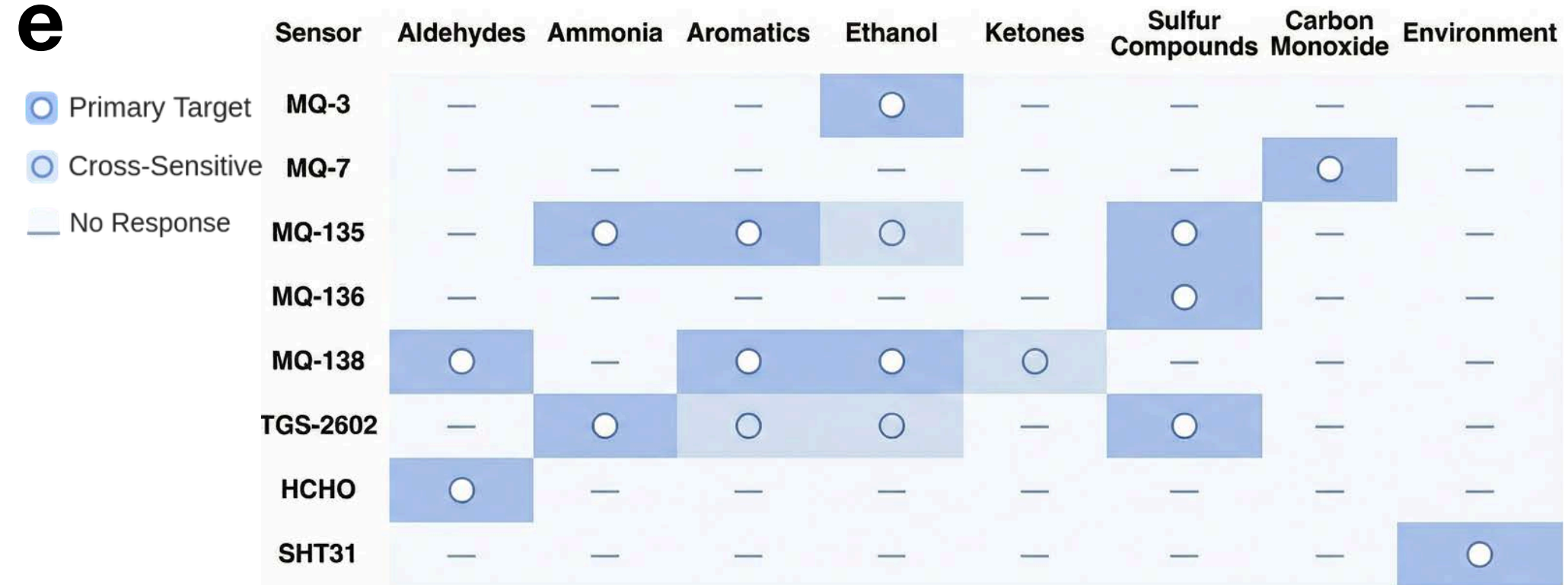
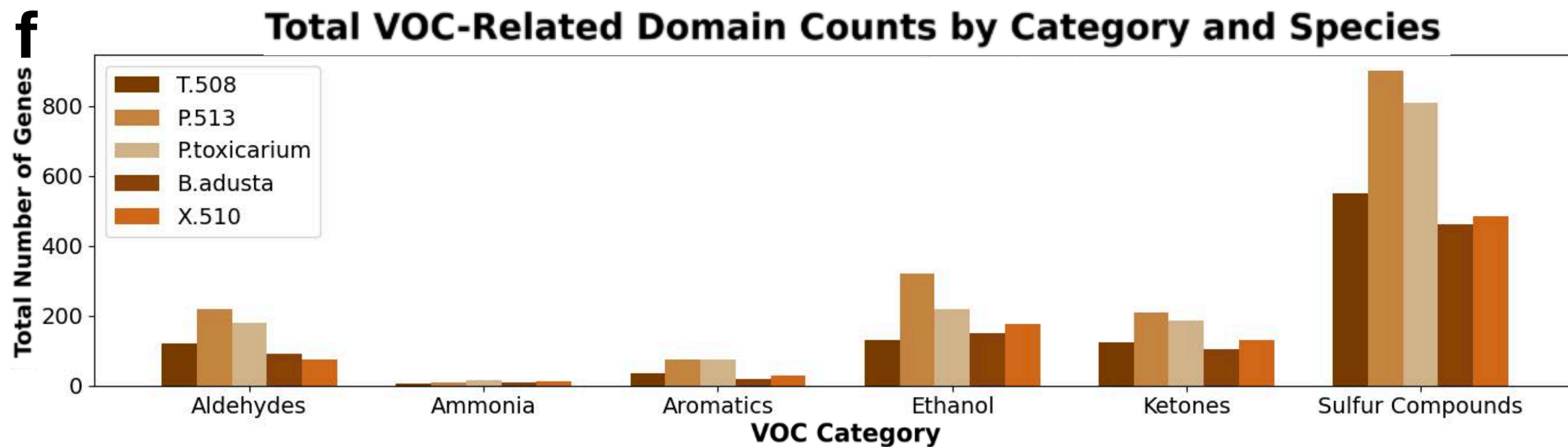
**Robot Arm**







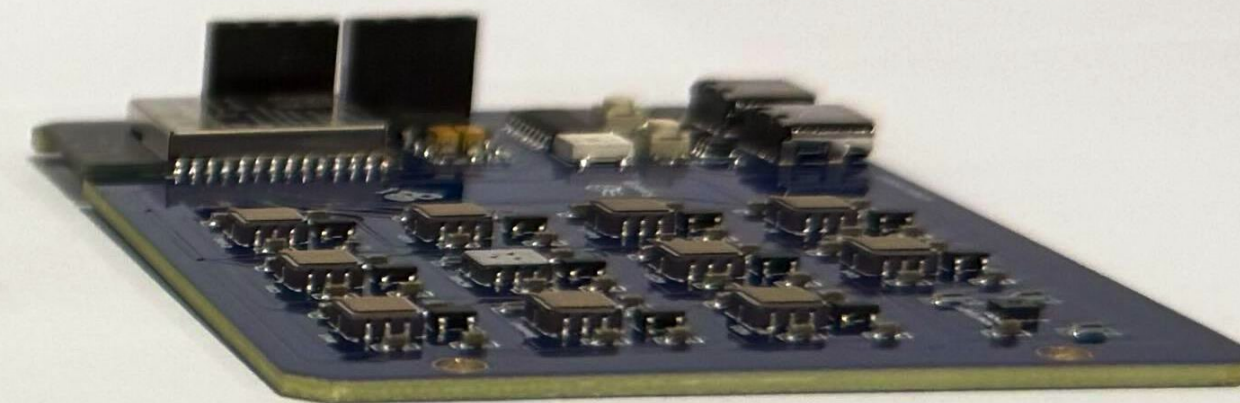
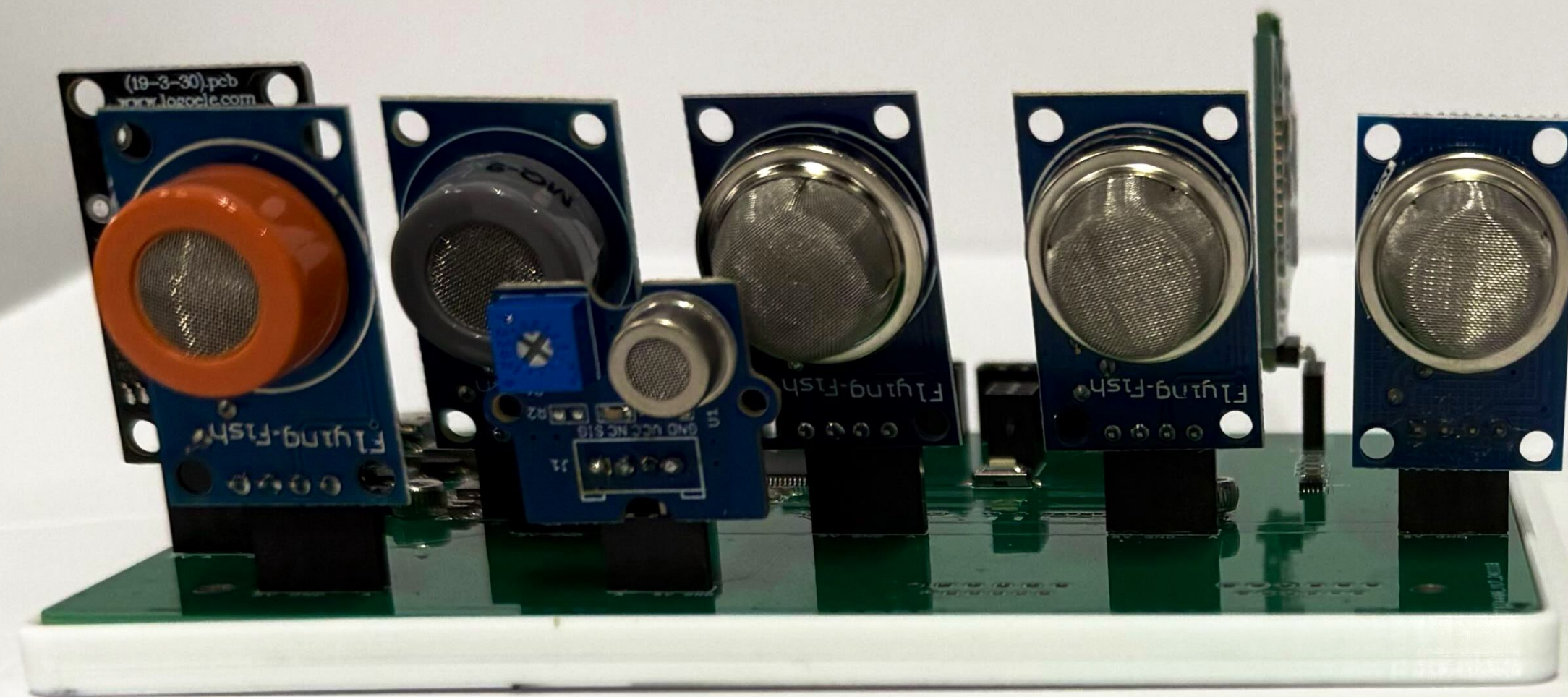
Species	MAE [m]	MSE [m <sup>2</sup> ]	RMSE [m]	Resolution Ratio
<i>X.510</i>	0.1246	0.0239	0.1513	0.36
<i>P. toxicarium</i>	0.1311	0.0258	0.1601	0.34
<i>P.513</i>	0.1198	0.0198	0.1388	0.38
<i>T.508</i>	0.1097	0.0182	0.1358	0.41
<i>B. adusta</i>	0.1169	0.0217	0.1467	0.39

**a Multi-Array: Species Classification****b Multi-Array: Coarse Source Localization****c Single-Array: Species Classification****d Single-Array: Direction Estimation****e****f**

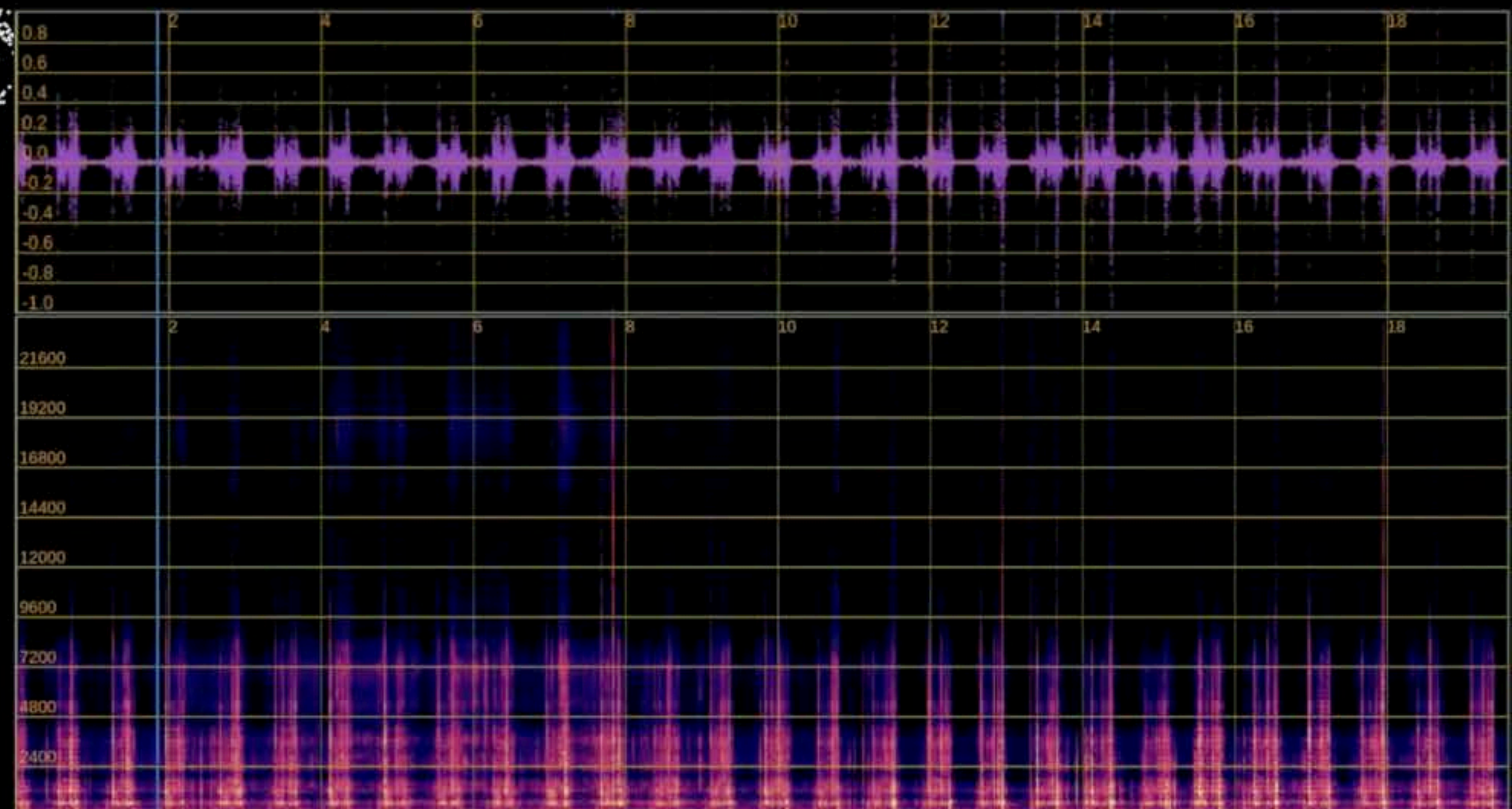
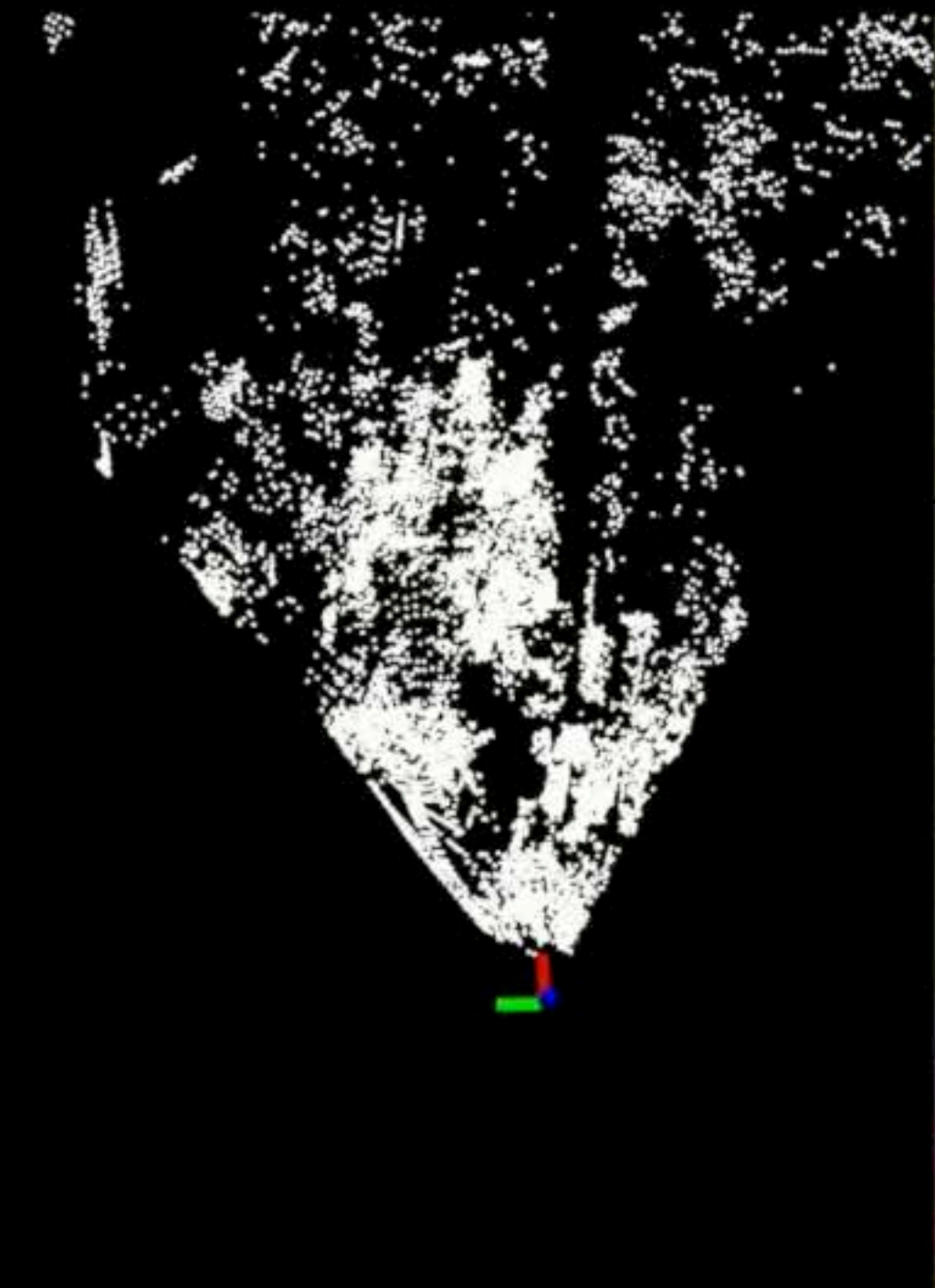
# Robot Perspective



Where the fungal plate located

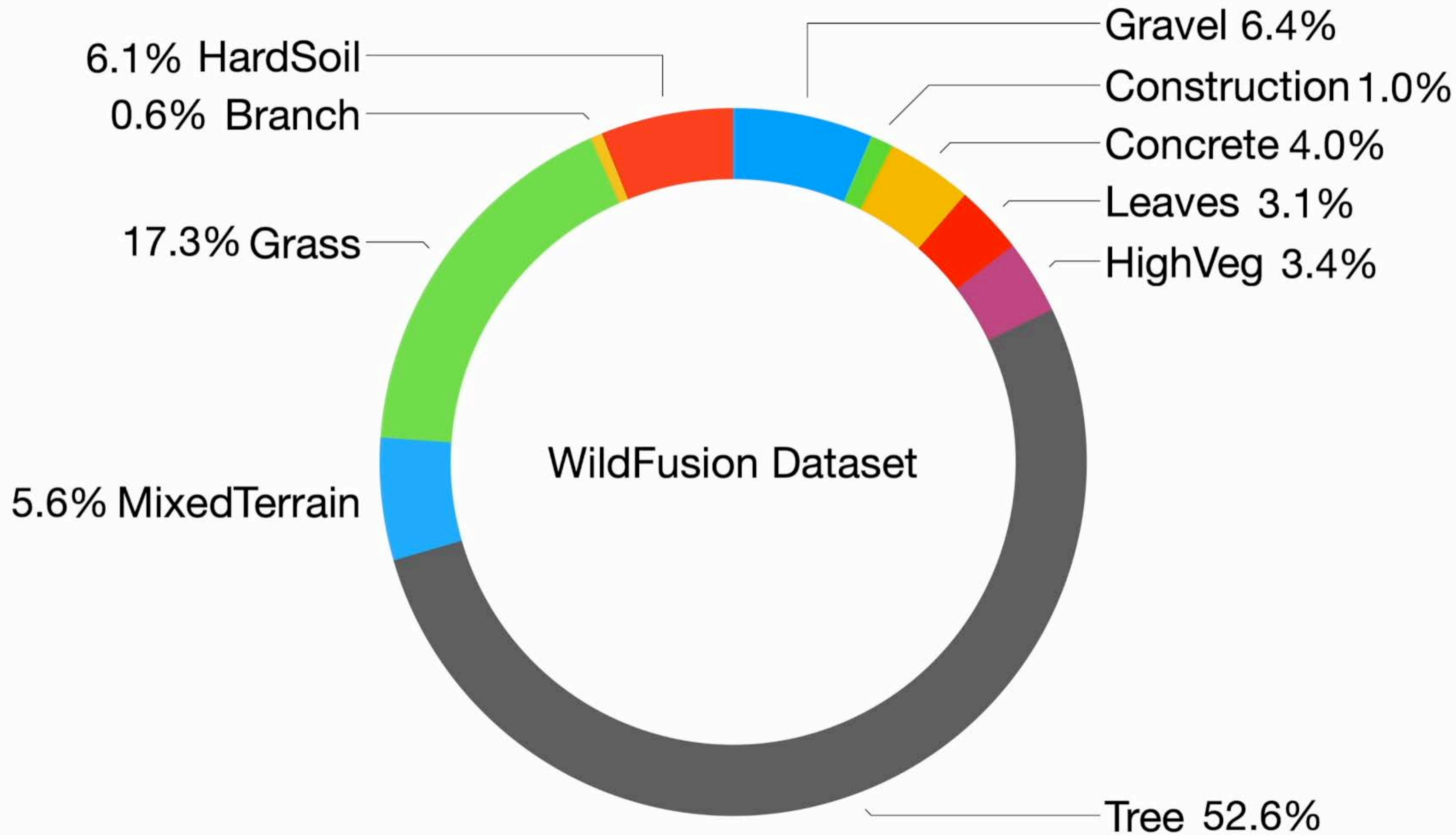








Yanbaihui (Evelyn) Liu



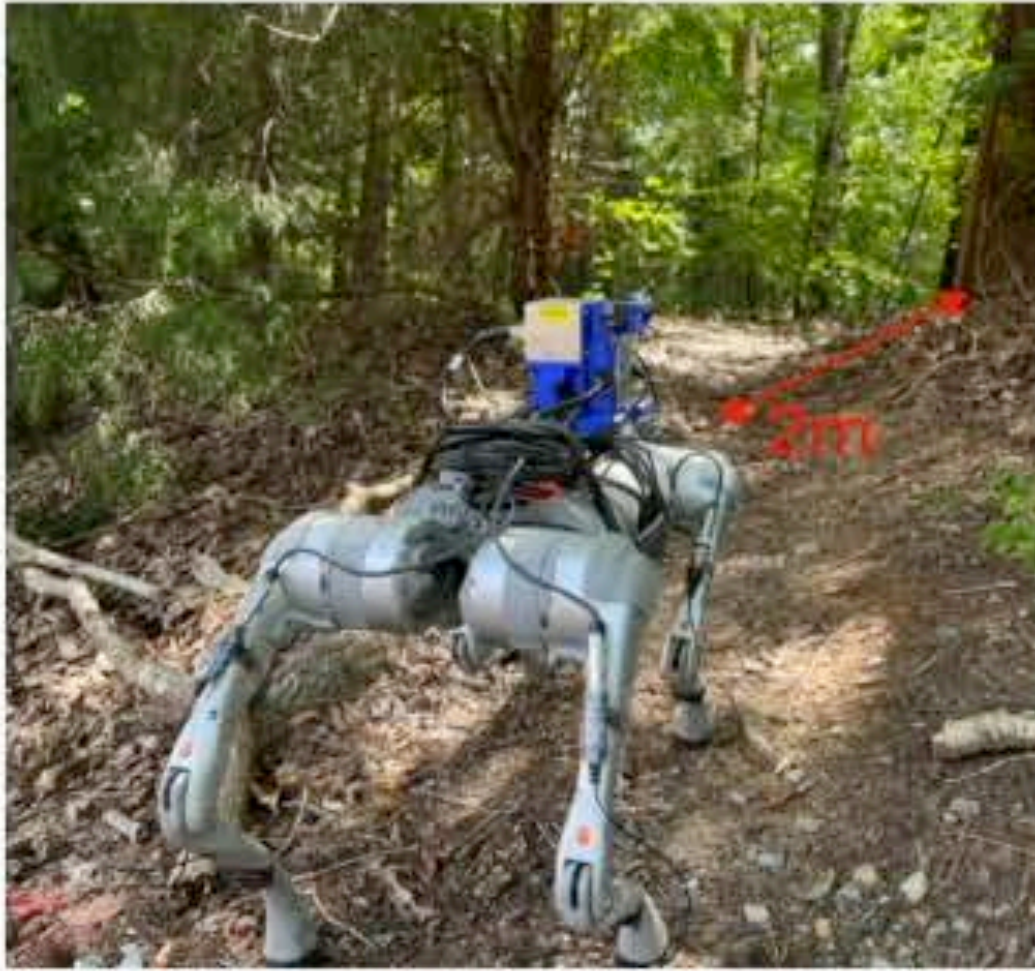
# Beyond Semantics

**Continuous** traversability score / frame =

Variance of normalized accelerometer reading

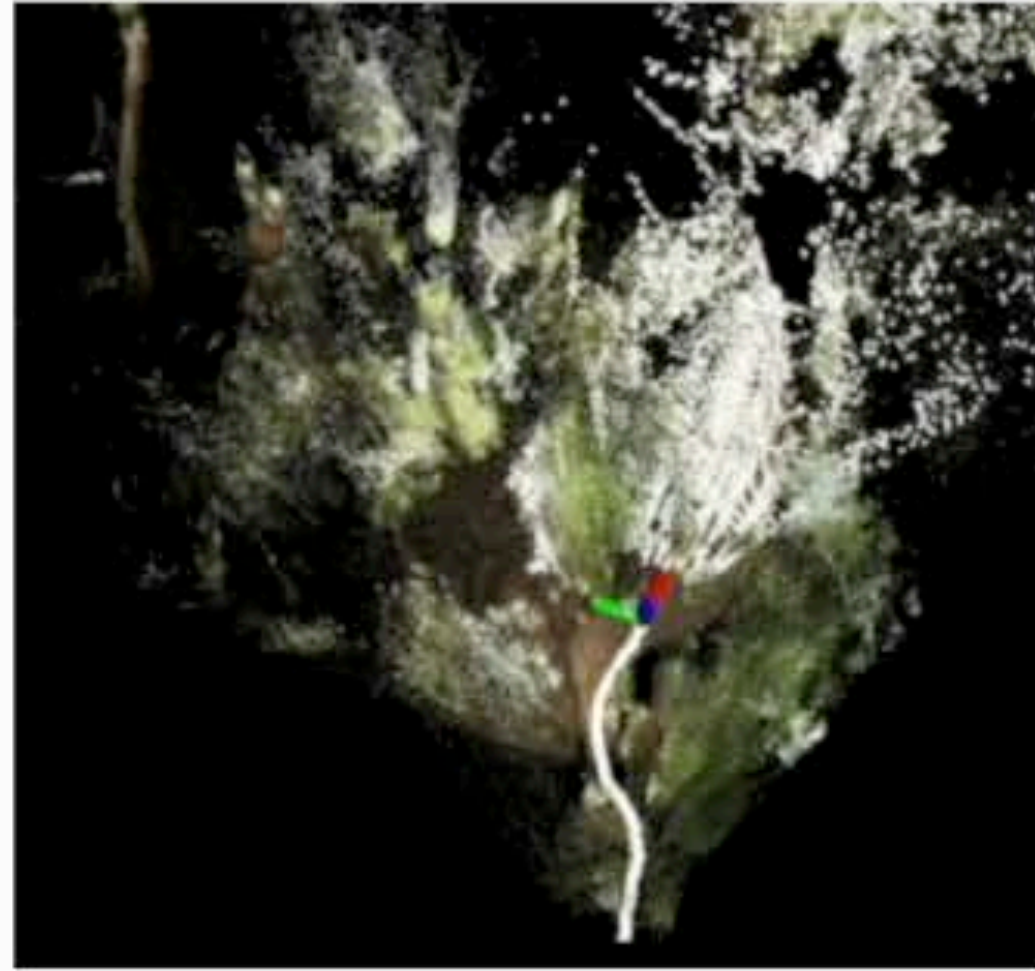
\* Deviation of tactile data from an ideal balanced pose

### 3D Spatial Reasoning



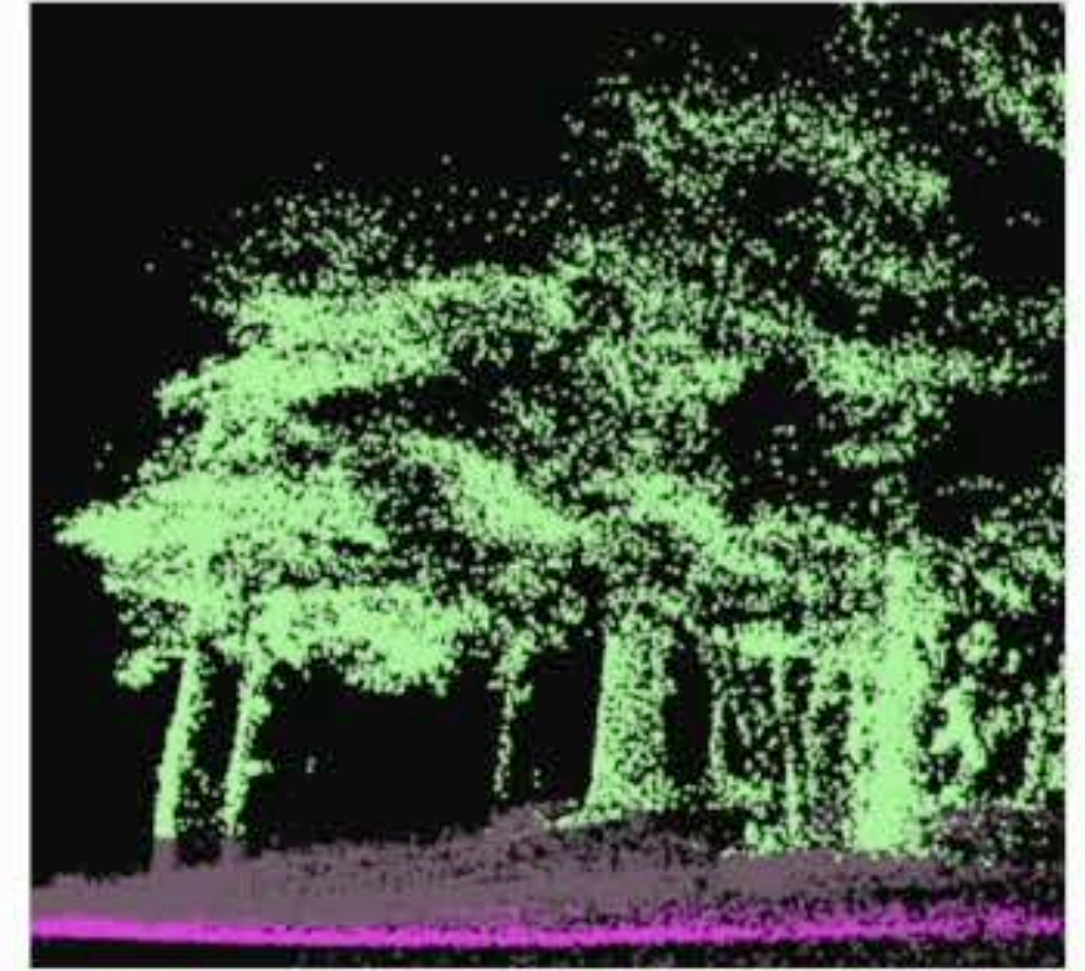
*How far am I from that?*

### Path Planning

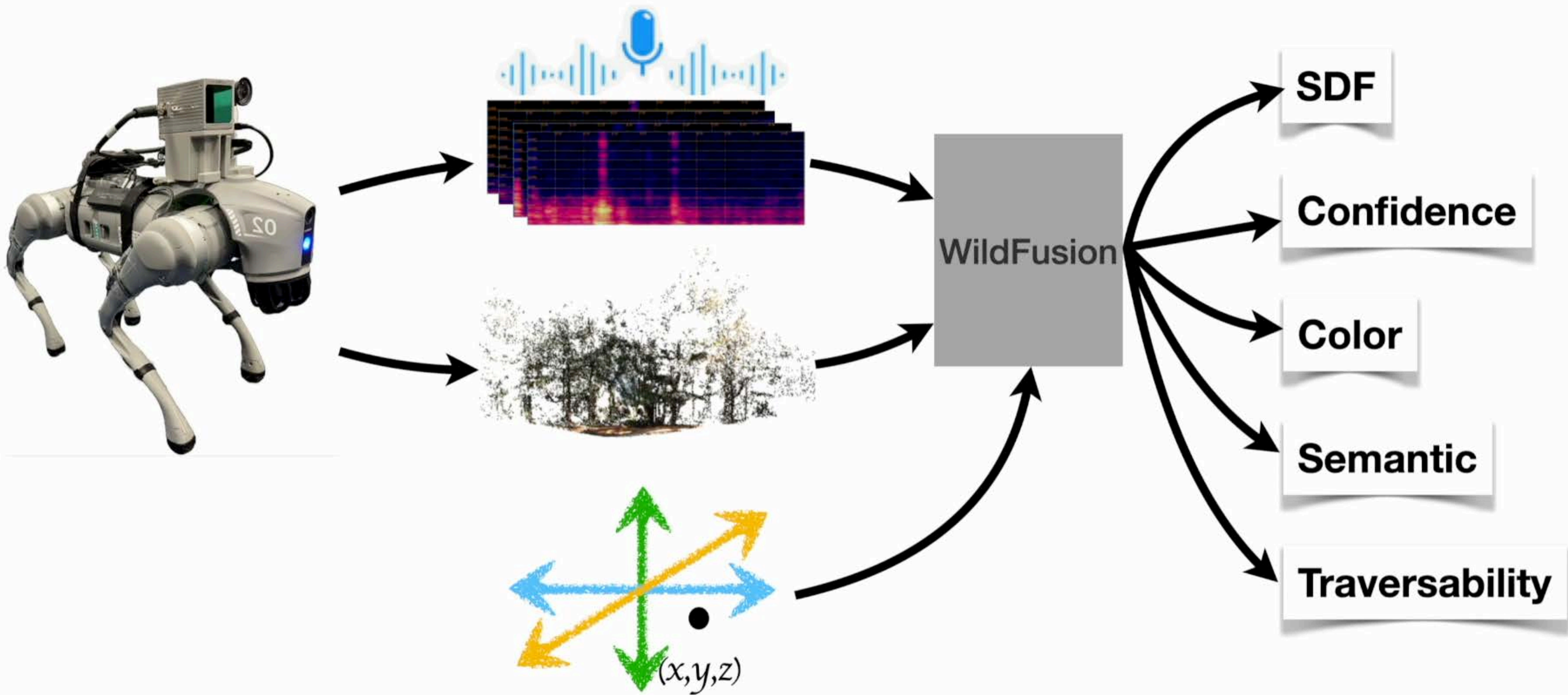


*How can I get there?*

### Semantic-Aware Queries



*Is the nearest object a tree or a rock?*



Ground Truth



Prediction



		Full mode	SDF, Semantic, Color	SDF, Conf. Color	SDF, Conf., semantic	SDF, Conf.
Color	MSE	0.060	0.061	0.066	-	-
	MAE	0.162	0.172	0.176	-	-
	PSNR	12.633	12.518	12.097	-	-
Geometry	Haus.	6.166	6.499	6.512	6.512	7.514
	Cha.	0.068	0.081	0.082	0.083	0.083
Semantic	Acc.	0.769	0.717	-	0.705	-
	Prec.	0.851	0.807	-	0.774	-
	Re.	0.763	0.717	-	0.705	-
	F1	0.770	0.694	-	0.693	-
	IoU	0.704	0.638	-	0.619	-
Confidence	ECE	0.205	-	0.79	0.228	0.778

# **Real World Experiments**

**Elevation Map vs WildFusion**







# Query-Based Self-Modeling

**Query  
(Input)**

Spatial Location

$$X = (x, y, z)$$

Joint Angles

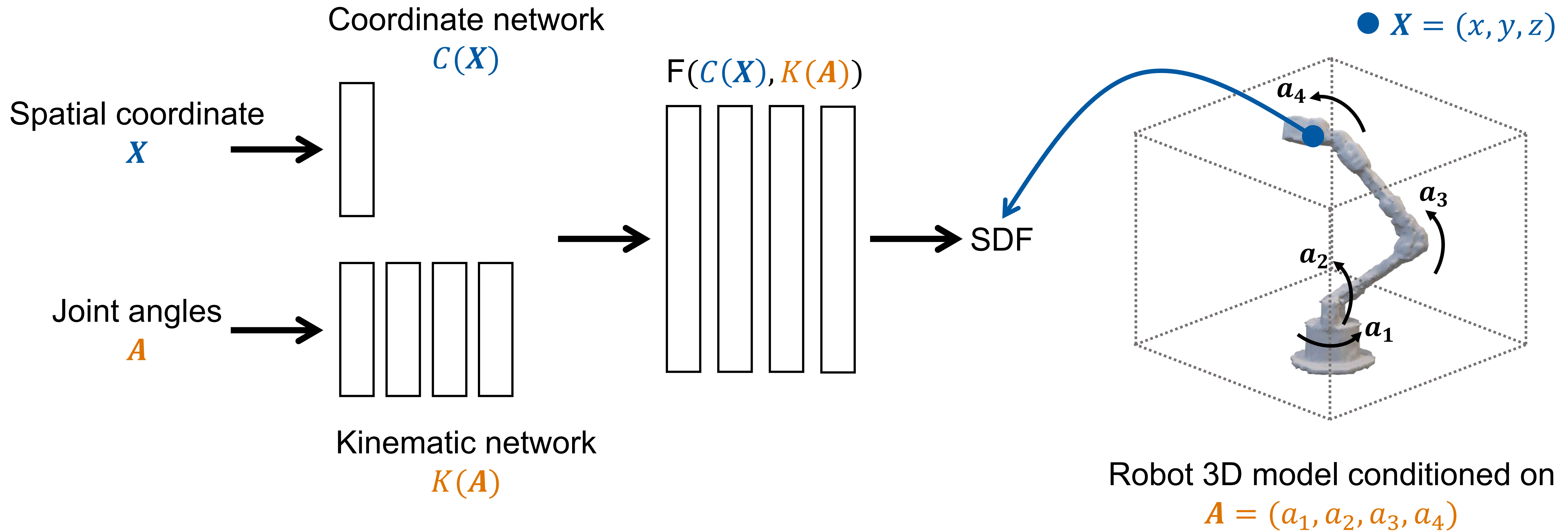
$$A = (a_1, a_2, a_3, a_4)$$

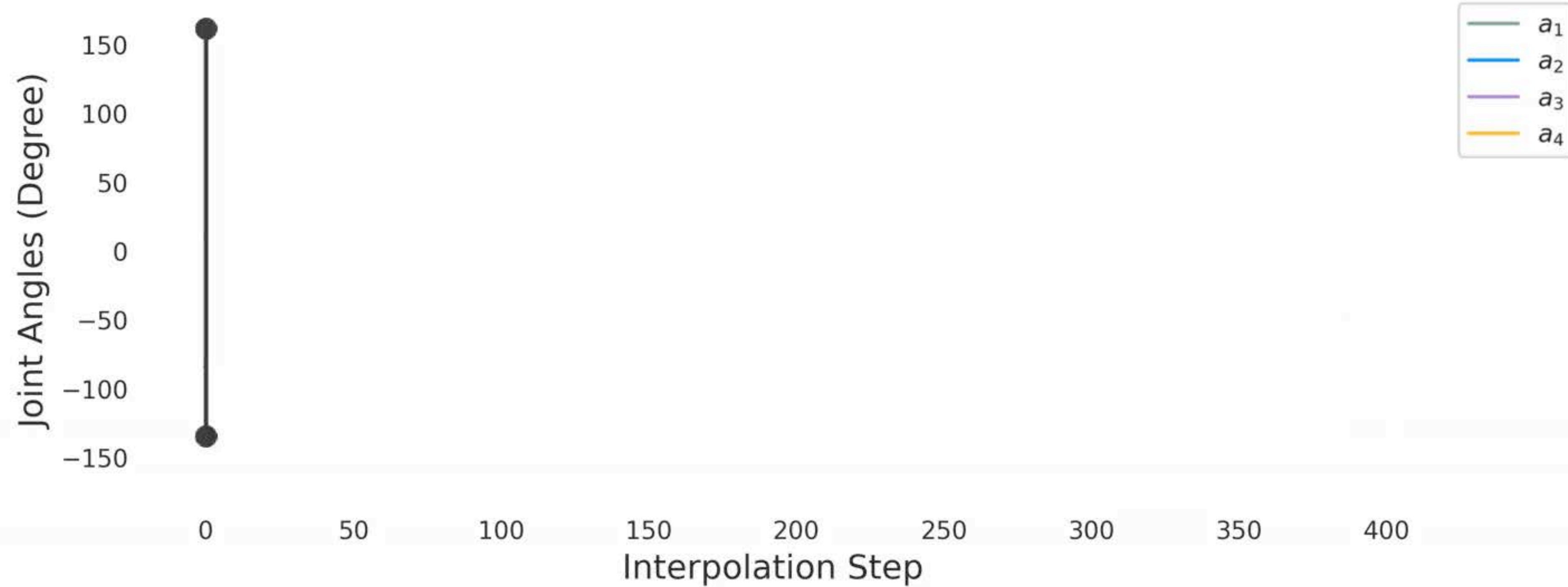
**Answer  
(Output)**

Occupancy



# Query-Based Self-Modeling



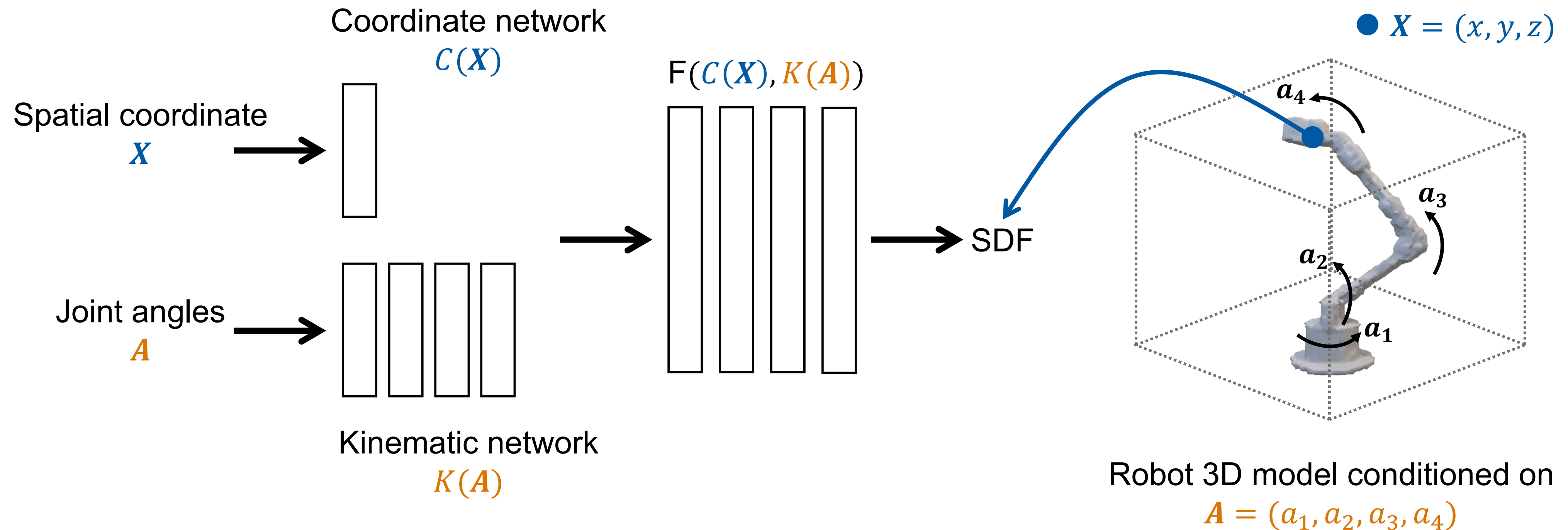


Ground Truth



Prediction

# For Motion Planning and Control



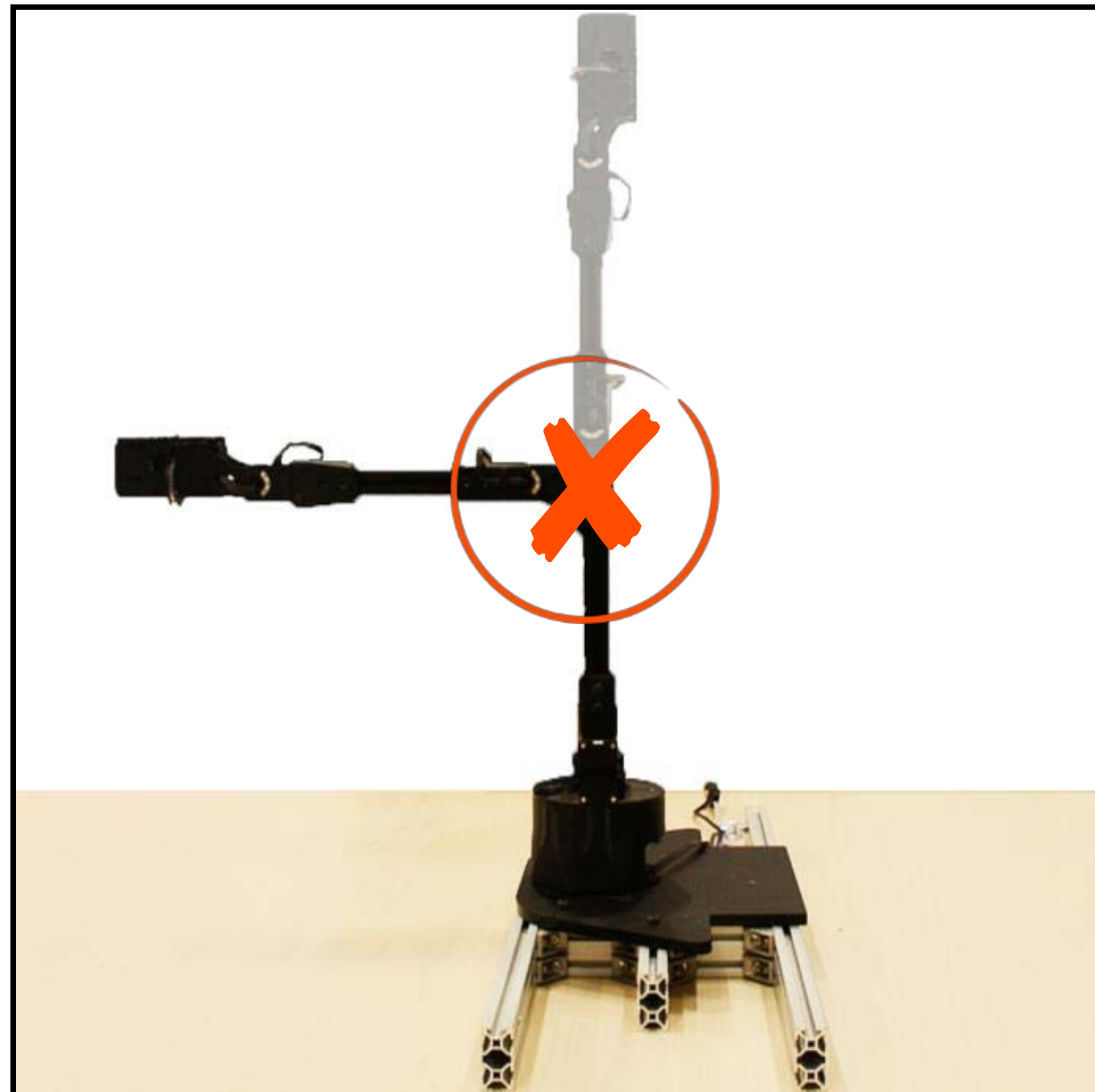
$$\mathbf{A}^* = \min \mathbb{E}_{\mathbf{A}^b} \left[ \sum_{\mathbf{T}^p} F(C(\mathbf{T}^p), K(\mathbf{A}^b)) \right] \quad \text{s.t.} \quad -\pi \leq A_i^b \leq \pi, i = 1, 2, 3, 4$$

↓  
Sampled points on the target object

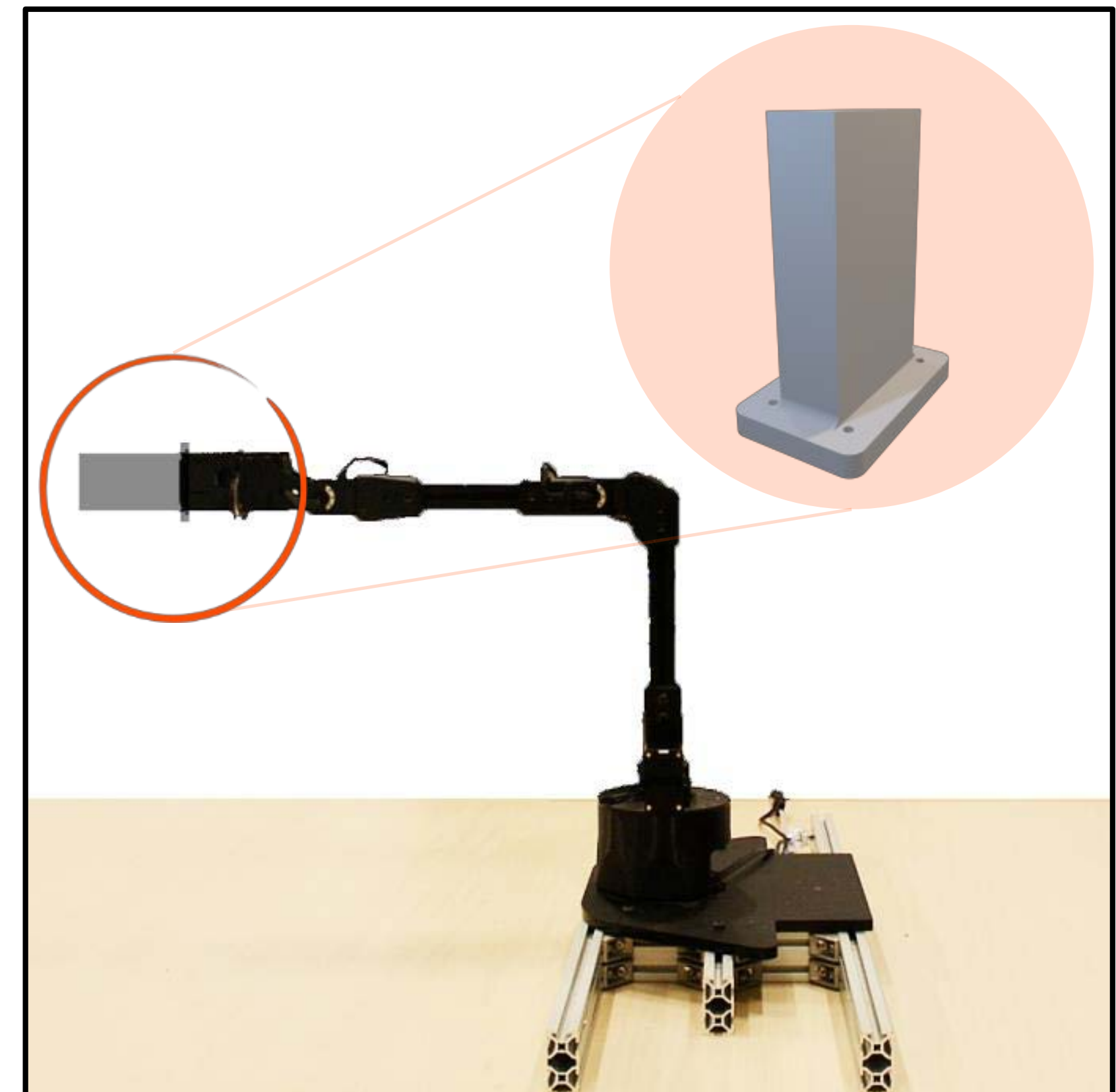


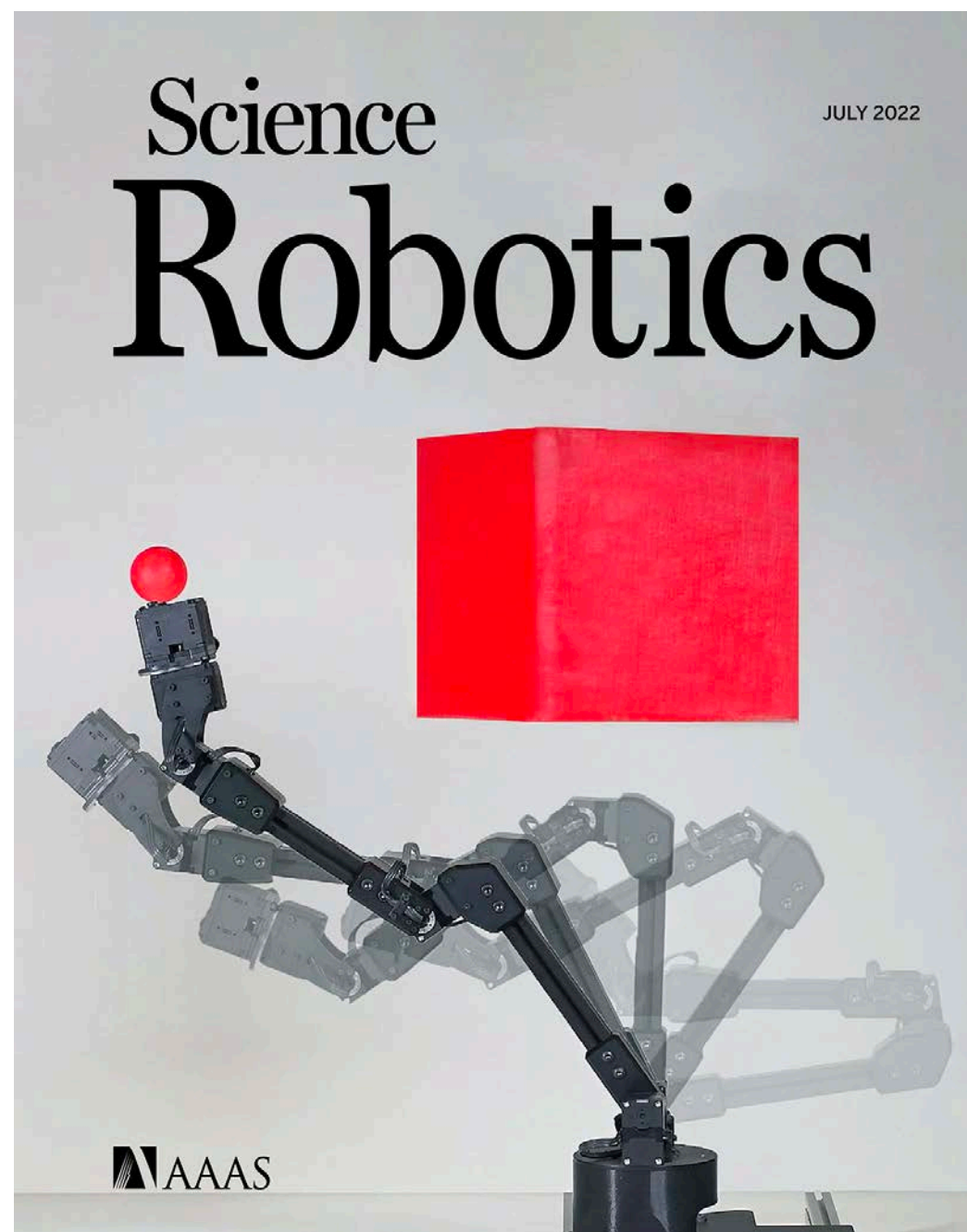
# Damage Assessment and Recovery

Motor broken

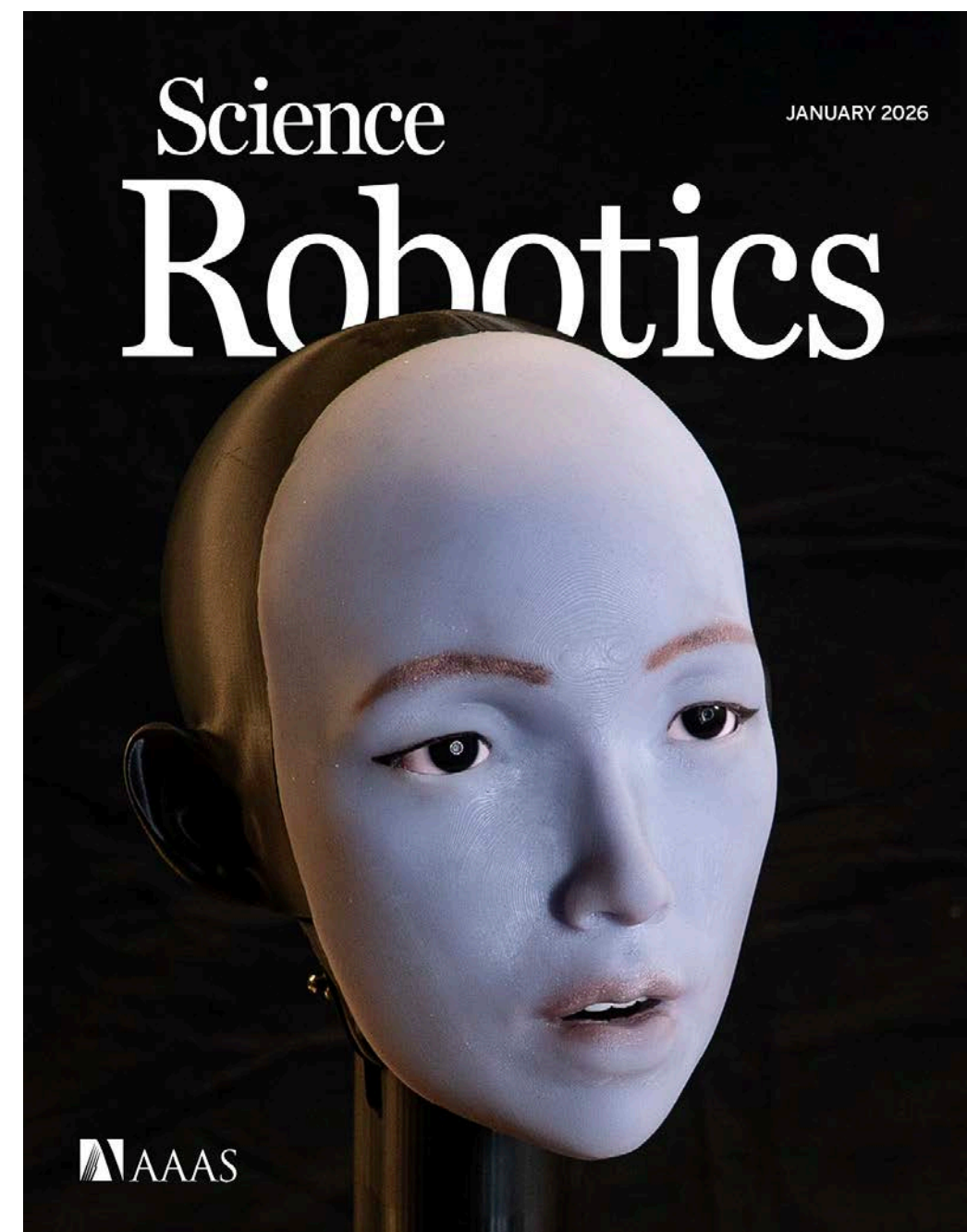


Attached gripper





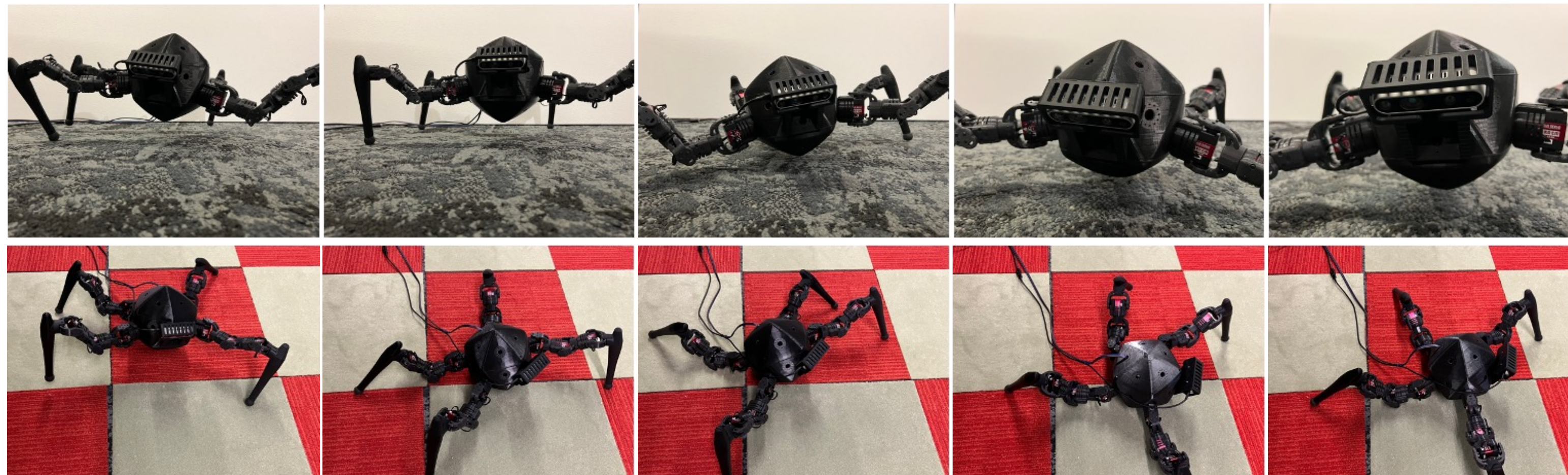
Science Robotics. 2022.



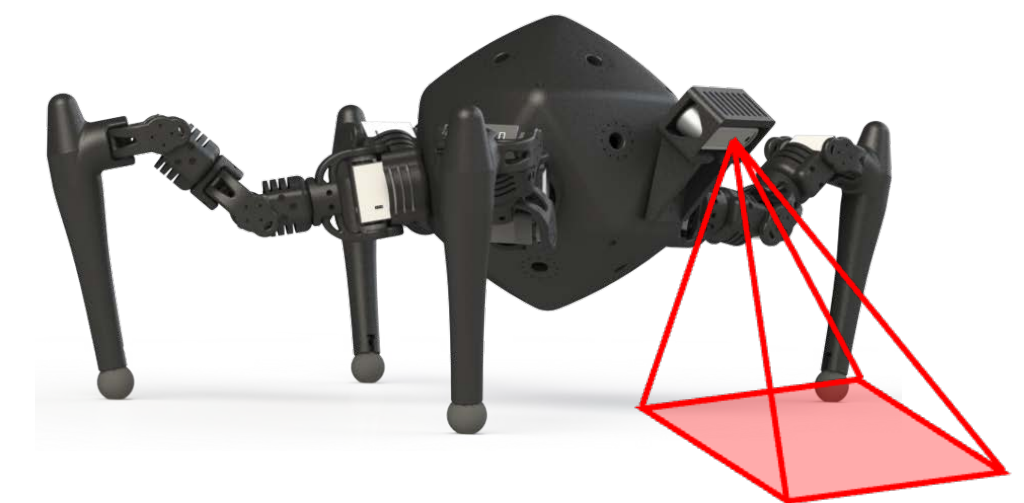
Science Robotics. 2024 & 2026



Nature Machine Intelligence. 2024.



npj Robotics. 2025

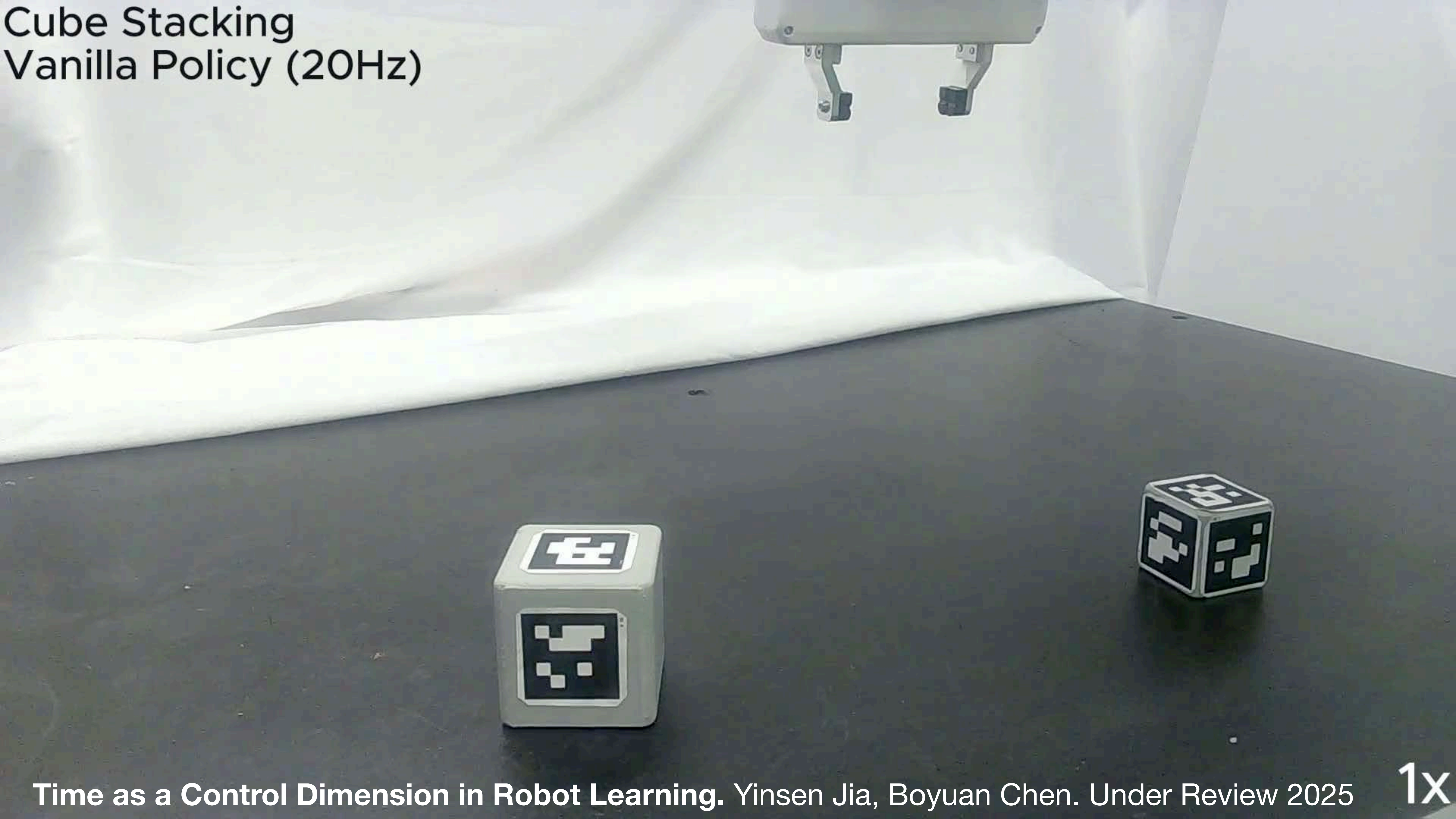


Front camera

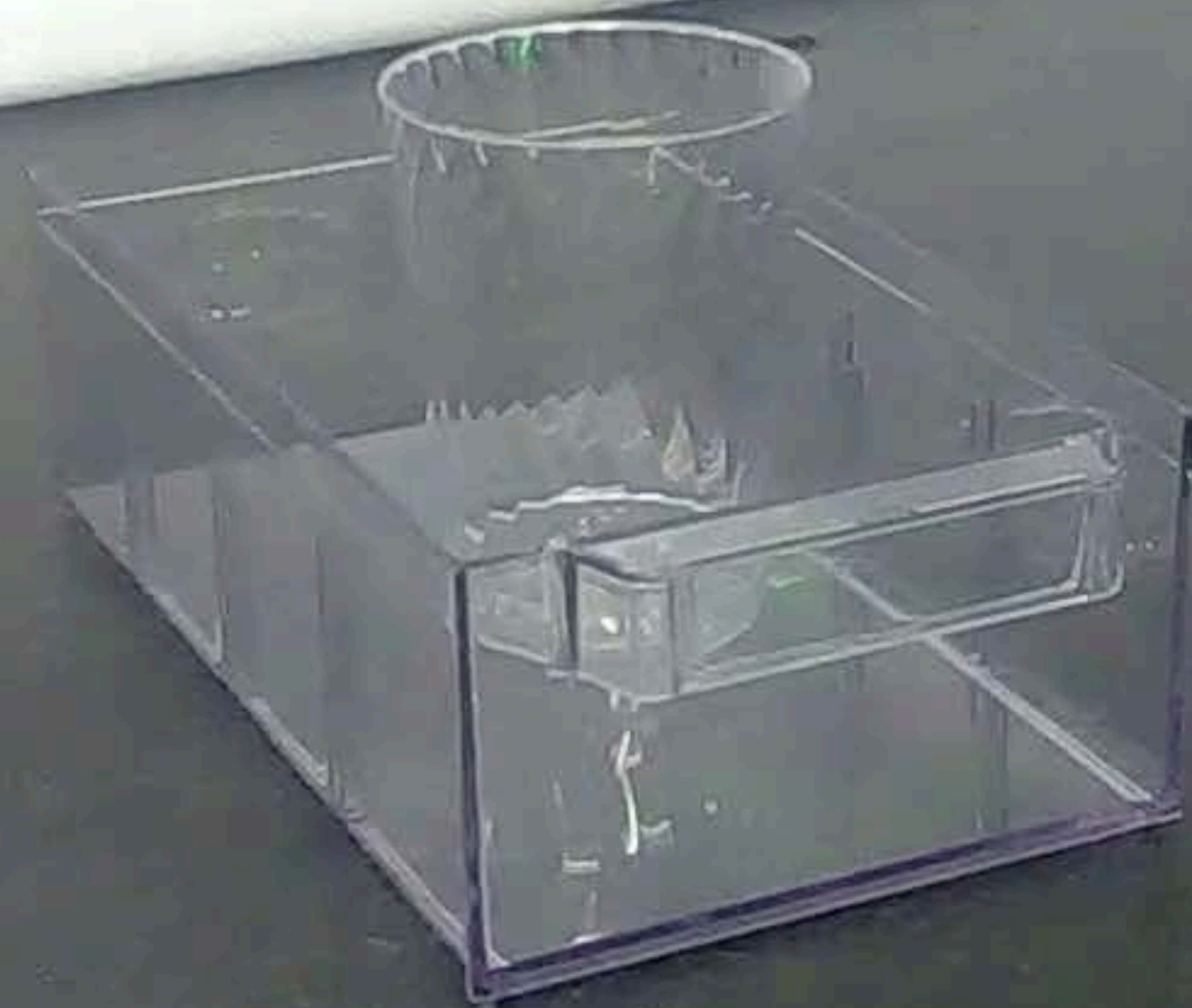




# Cube Stacking Vanilla Policy (20Hz)



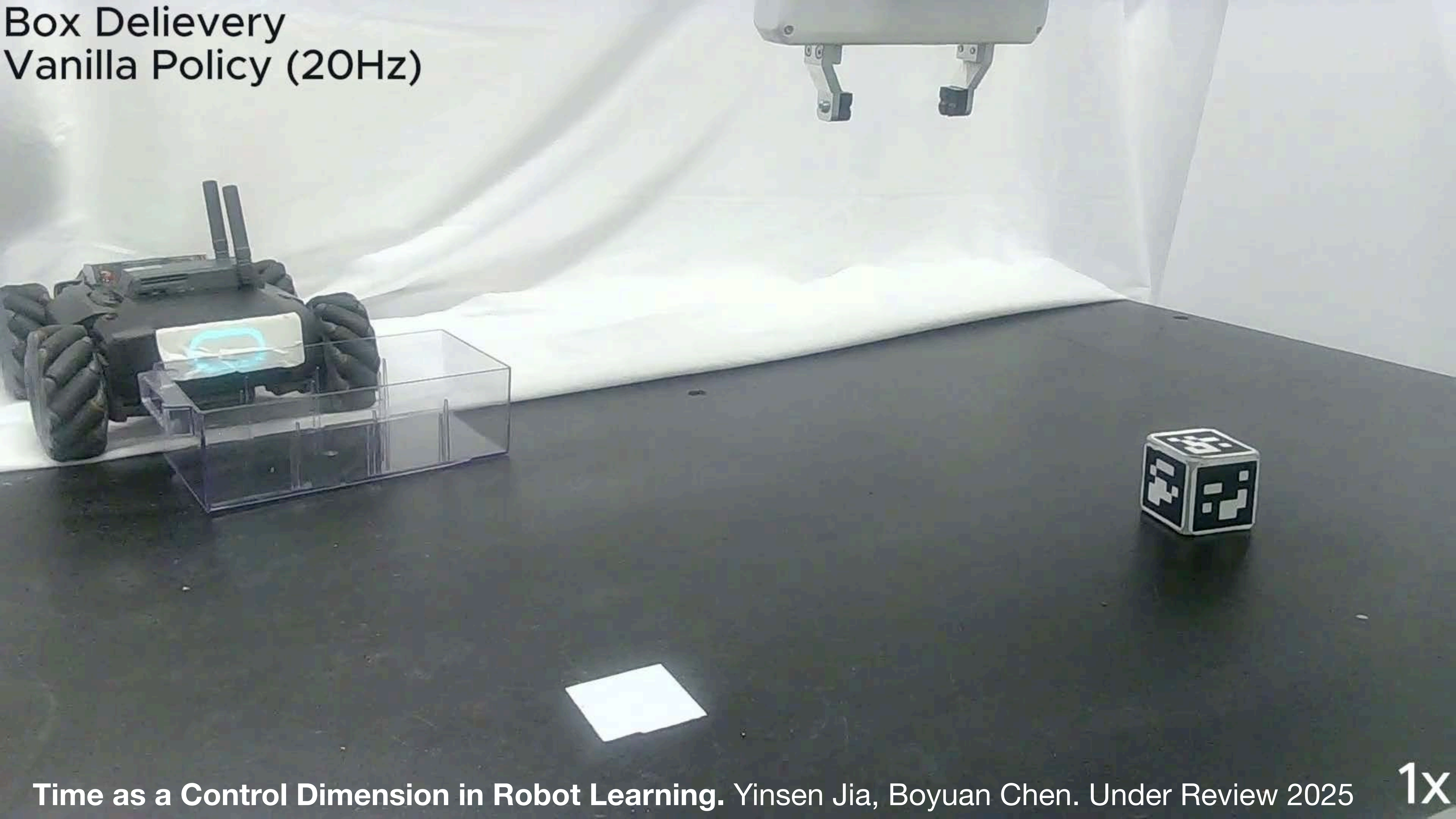
# Granular Media Pouring Vanilla Policy (20Hz)



The box is only used  
to re-collect beans.

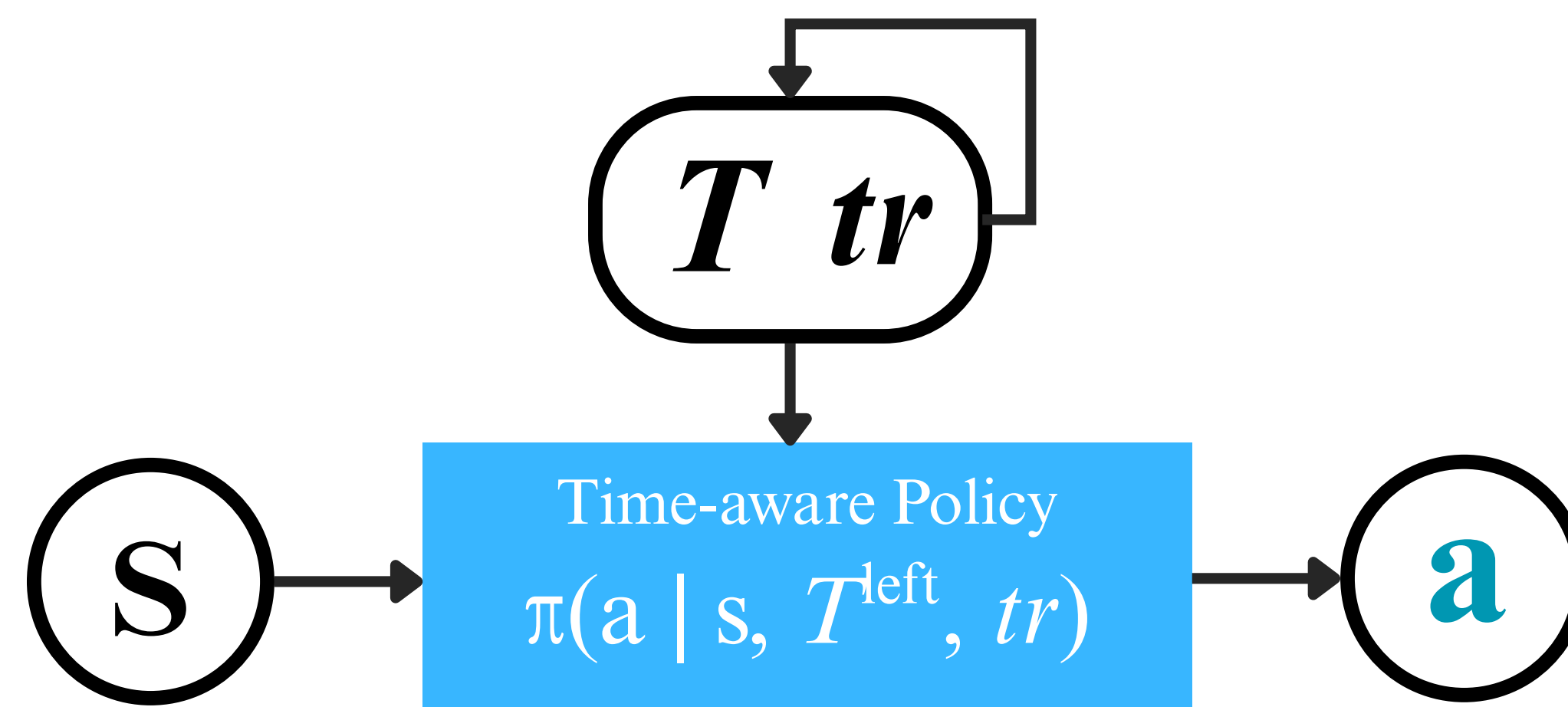
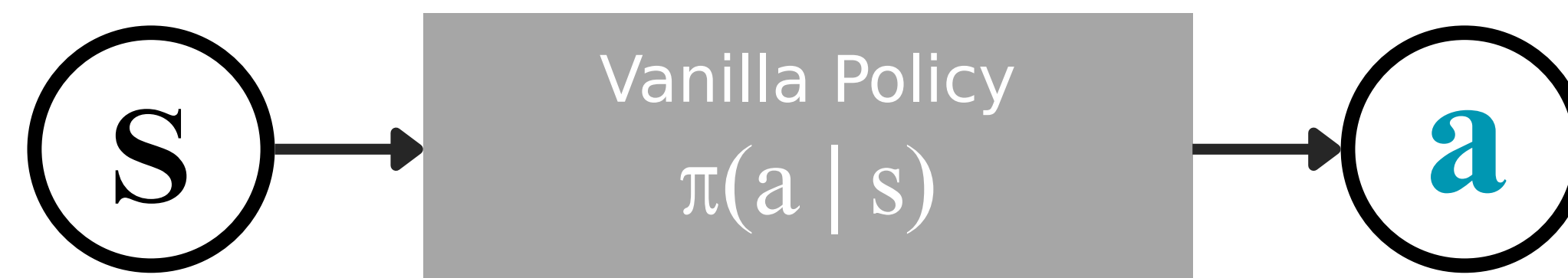


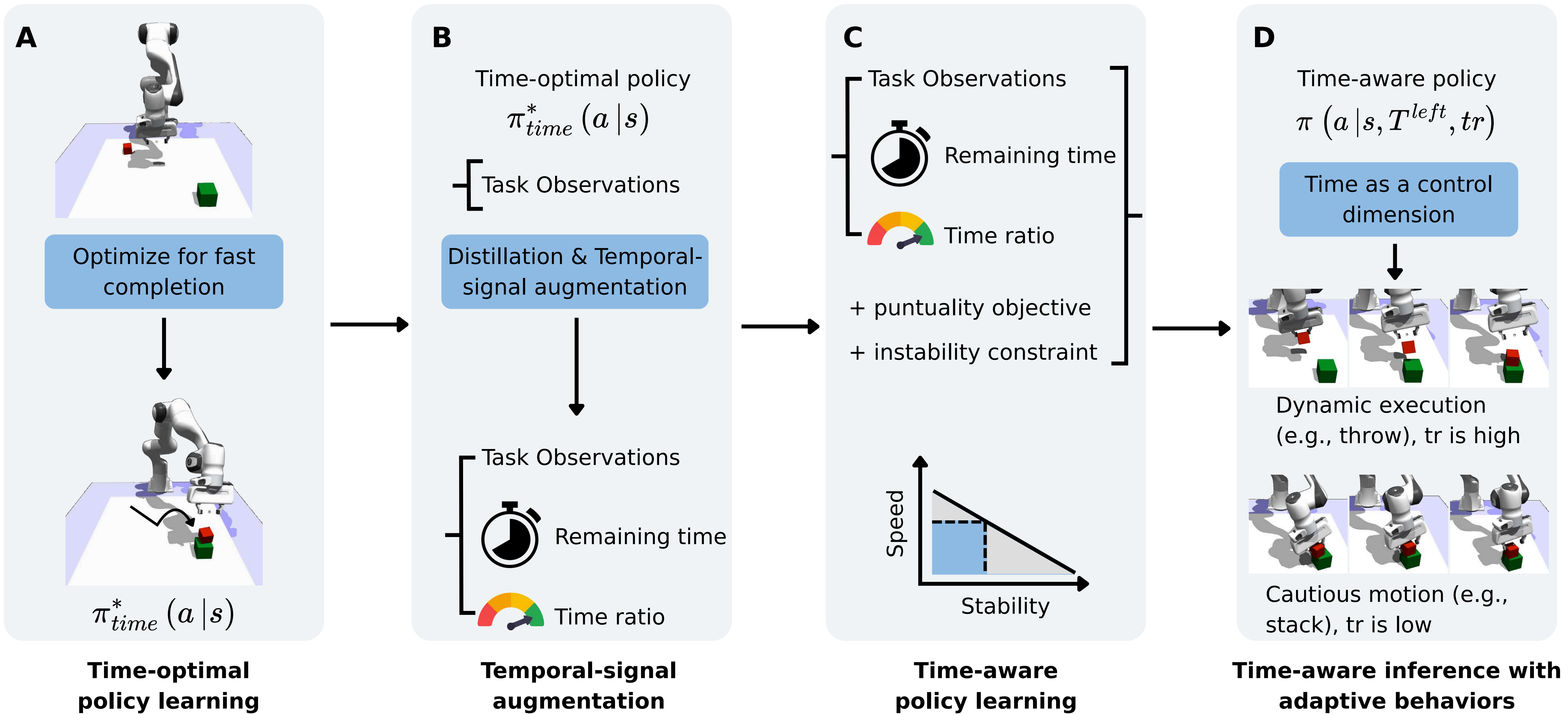
# Box Delivery Vanilla Policy (20Hz)





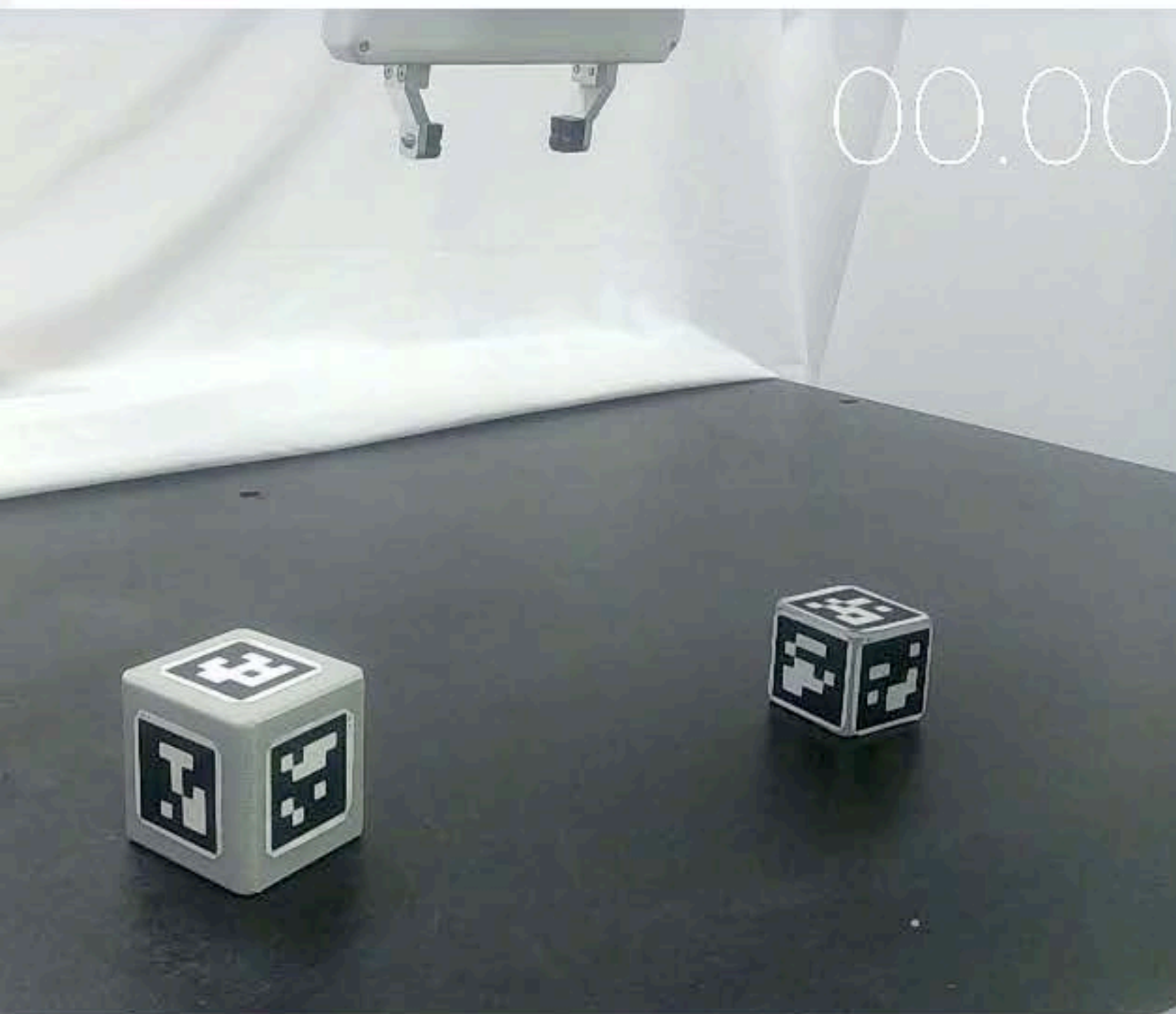
Yinsen Jia



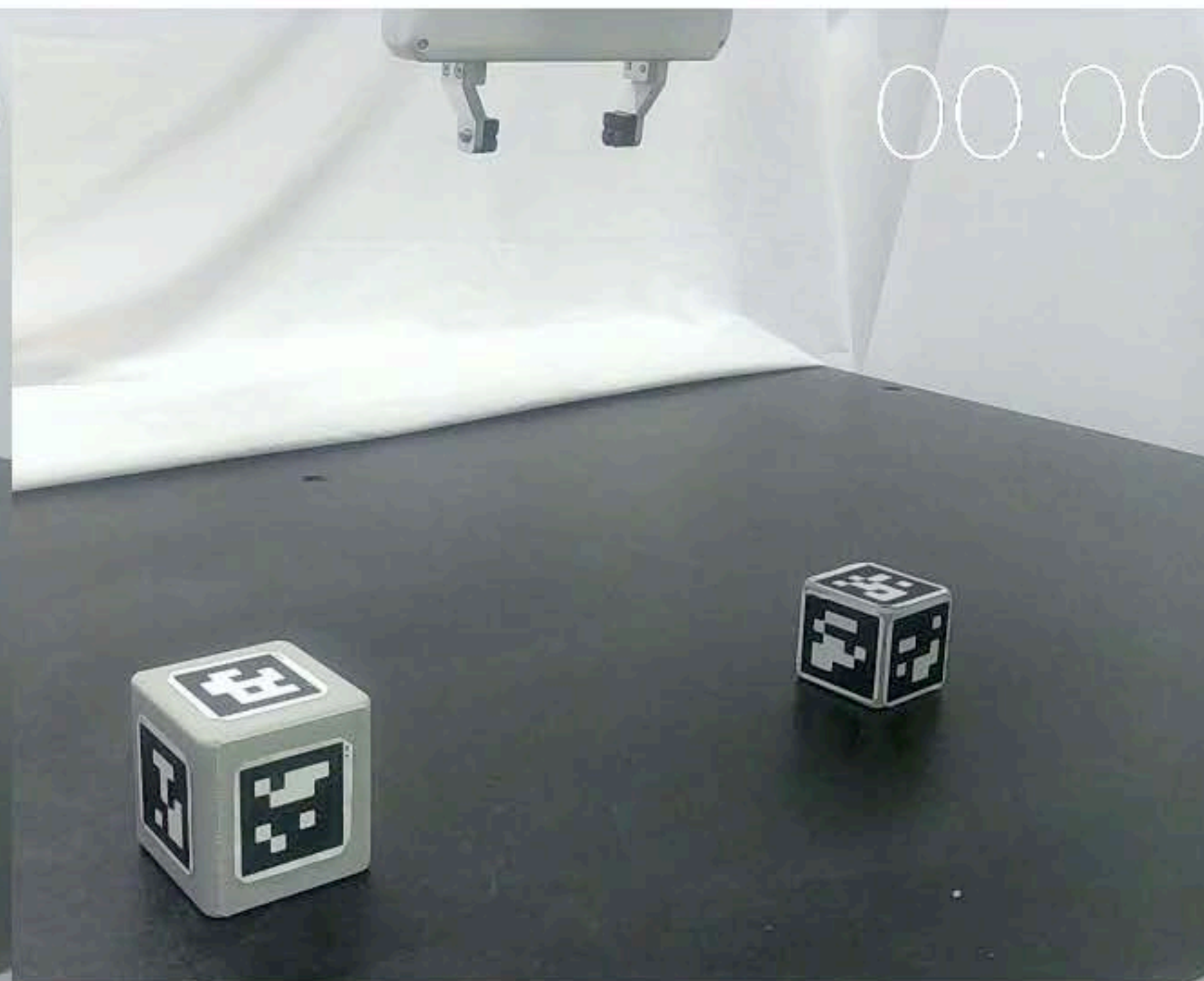


# Cube Placing

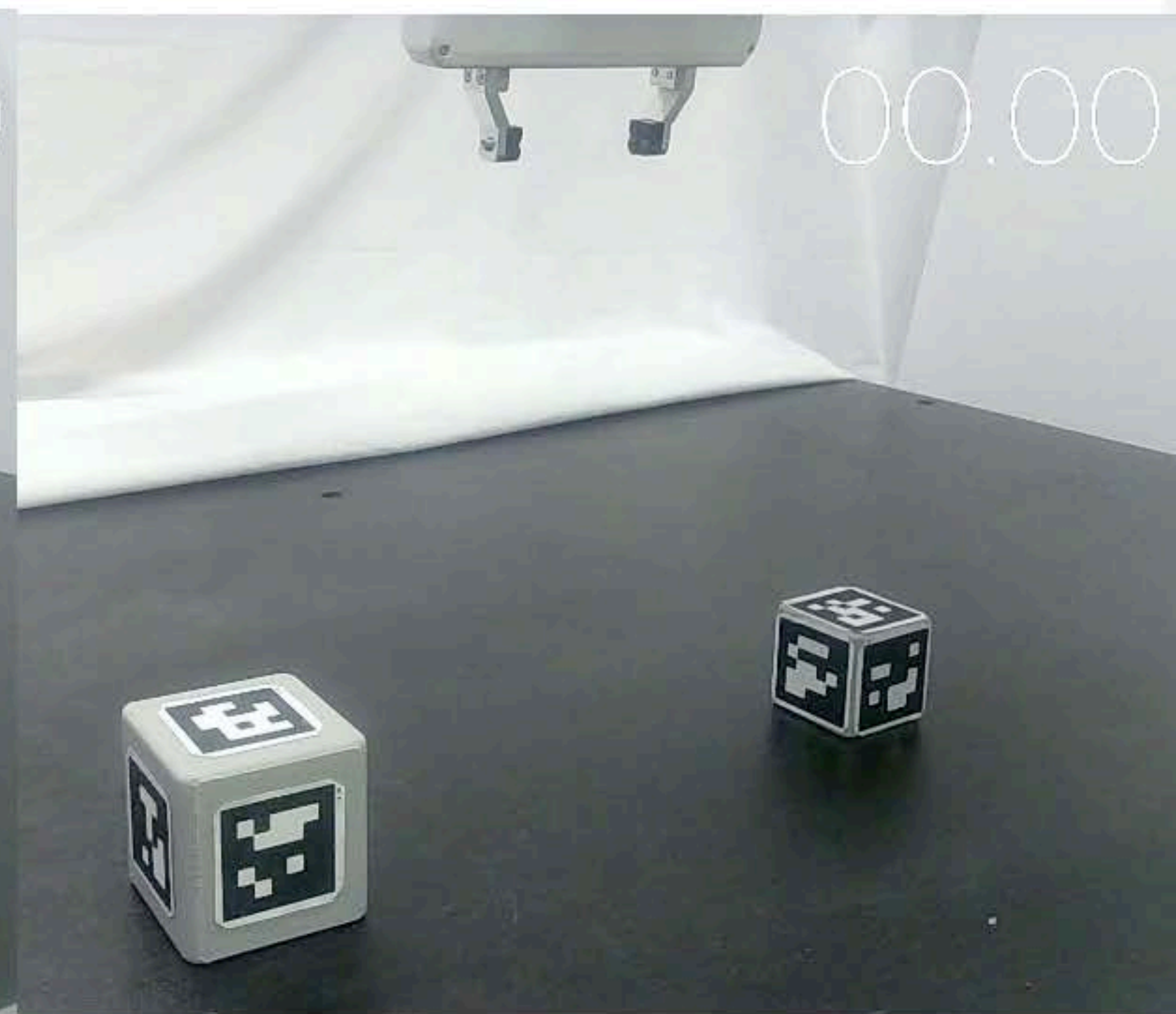
Various scheduled time



Time-aware Policy  
Scheduled Time: 5s



Time-aware Policy  
Scheduled Time: 7.5s



Time-aware Policy  
Scheduled Time: 10s

# Drawer Opening

Various scheduled time



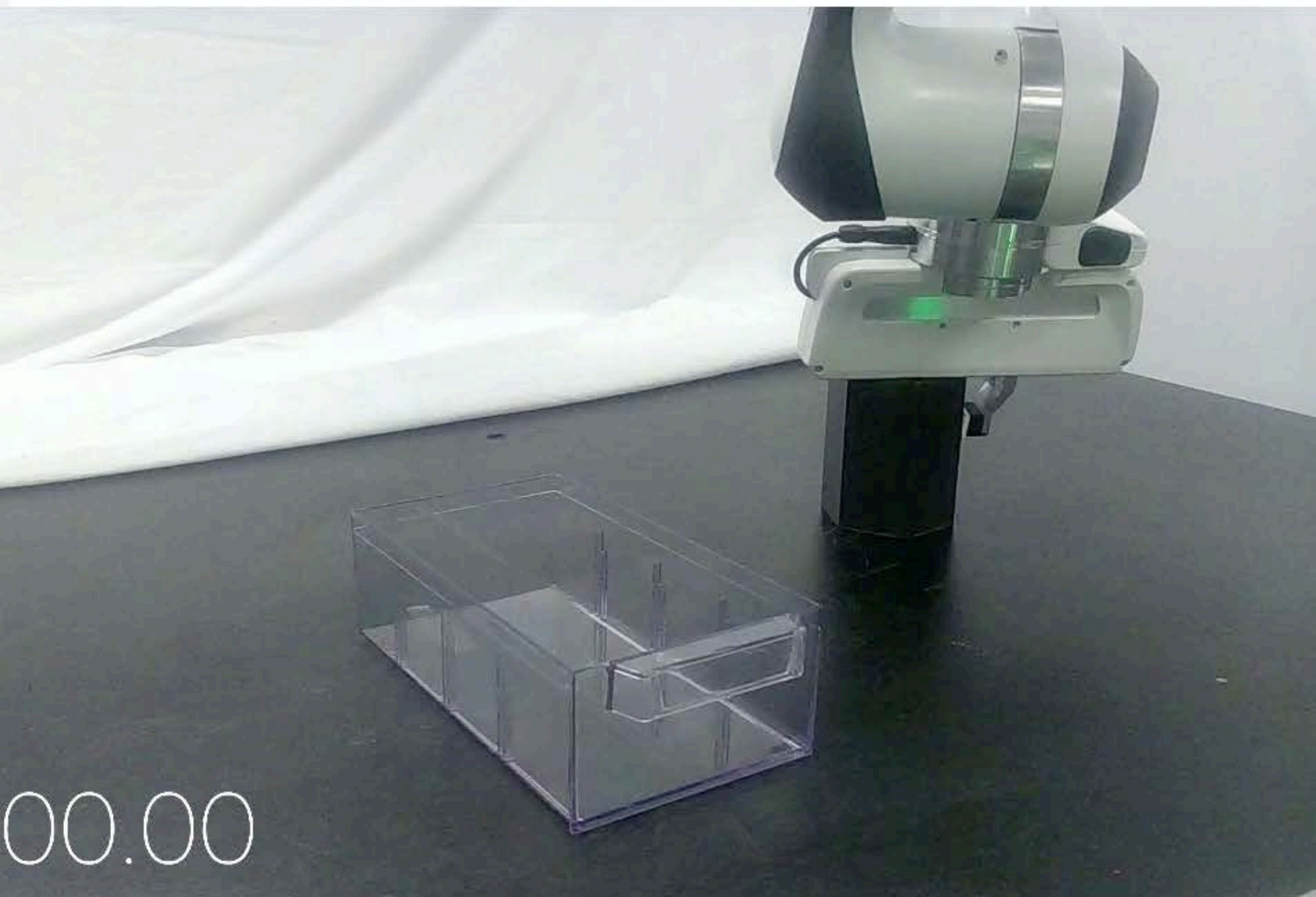
Time-aware Policy  
Scheduled Time: 7.5s

Time-aware Policy  
Scheduled Time: 10s

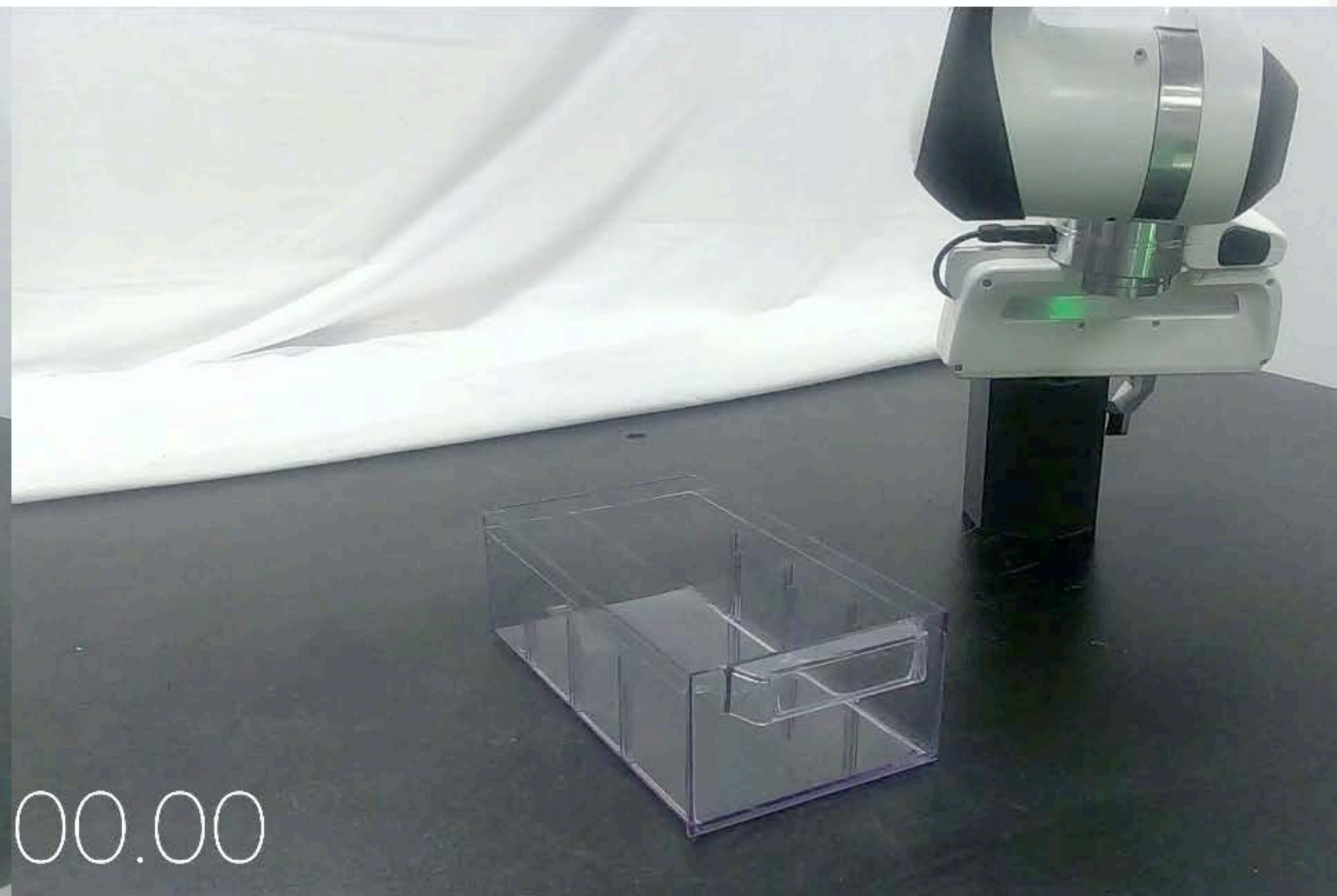
Time-aware Policy  
Scheduled Time: 12.5s

# Granular Media Pouring

Various scheduled time



Time-aware Policy  
Scheduled Time: 5s

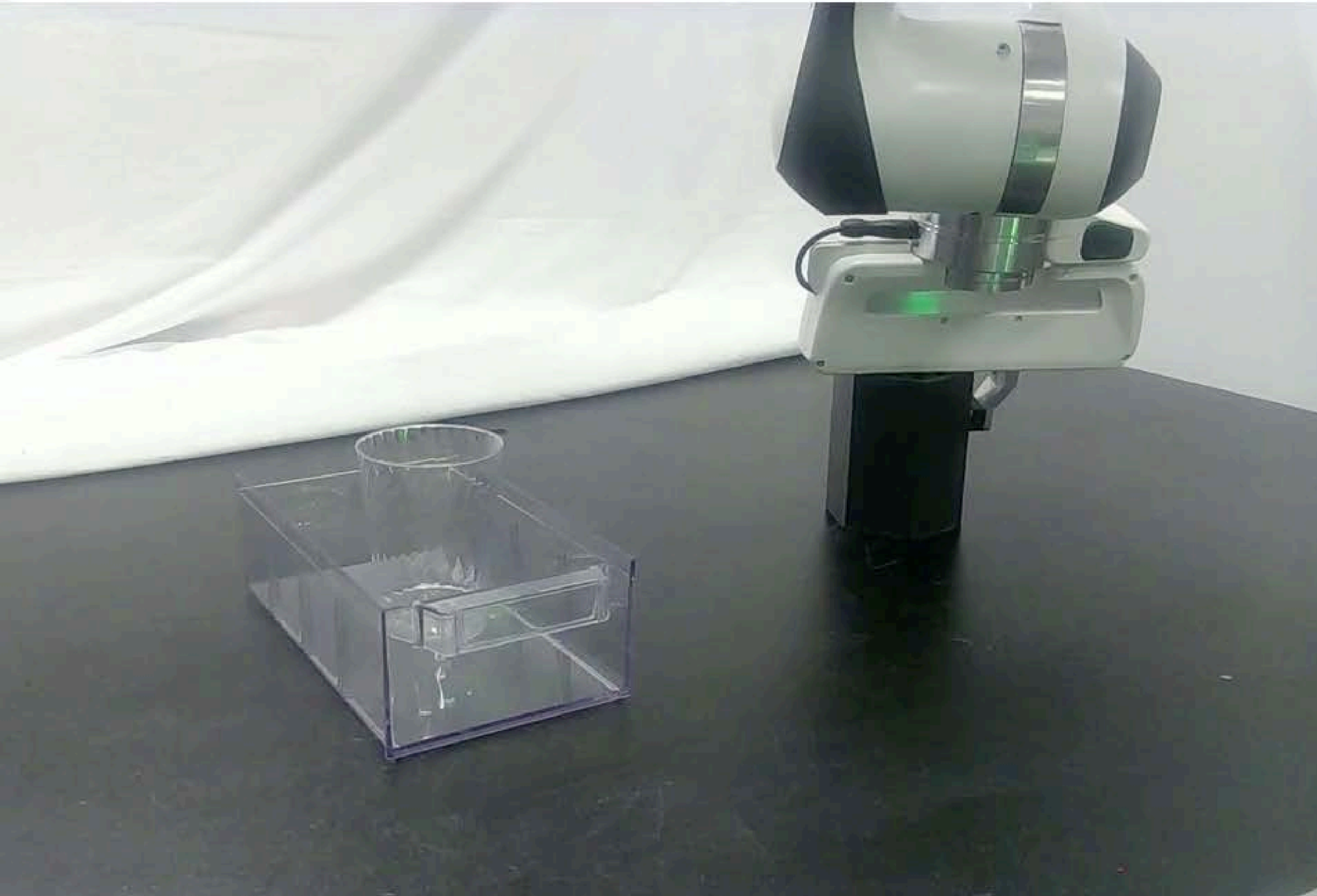


Time-aware Policy  
Scheduled Time: 6s

# Granular Media Pouring

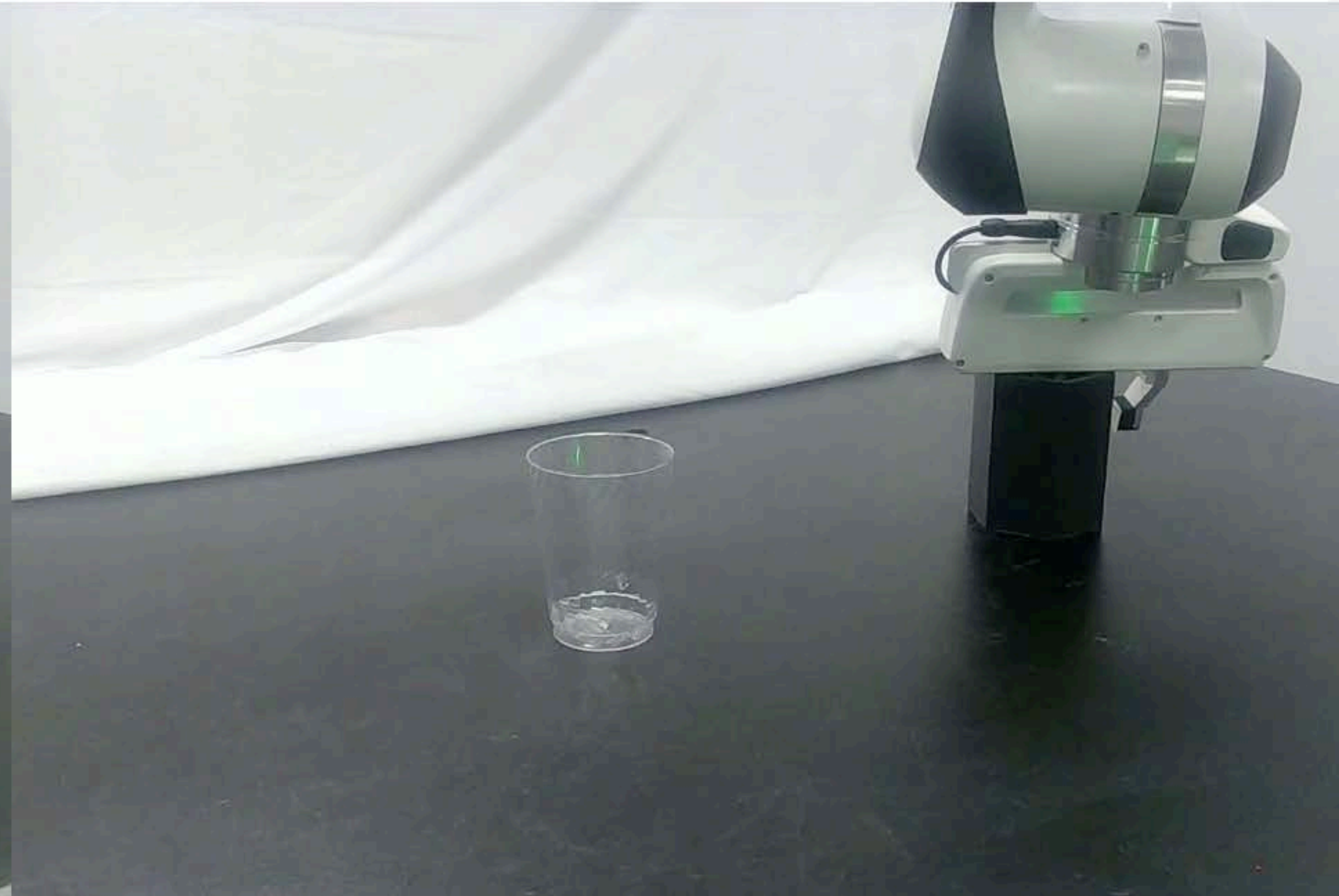
More granular medias during the test (40)

Increasing scheduled time enables stable behaviors



Vanilla Policy

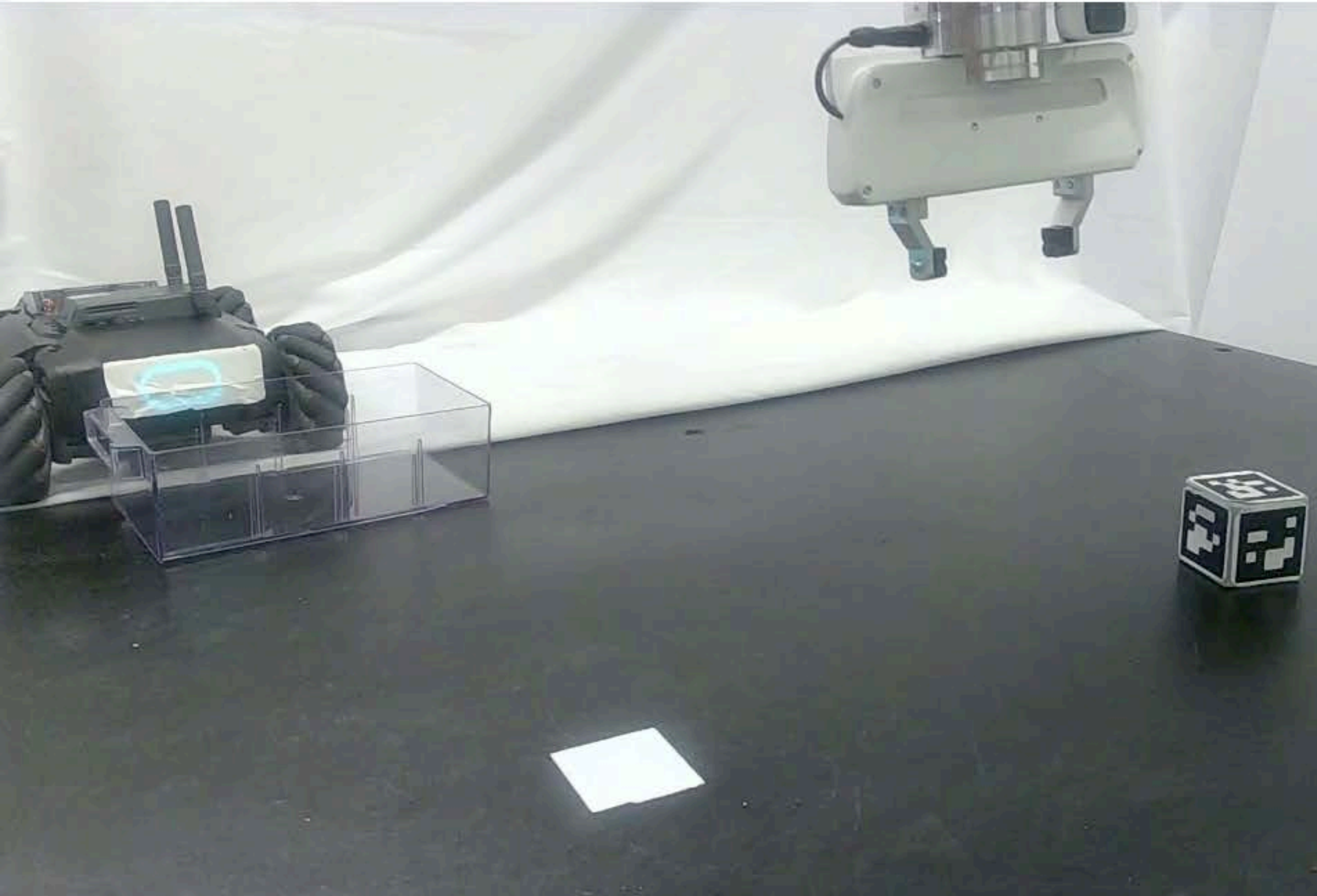
The box is used for re-collecting beans.



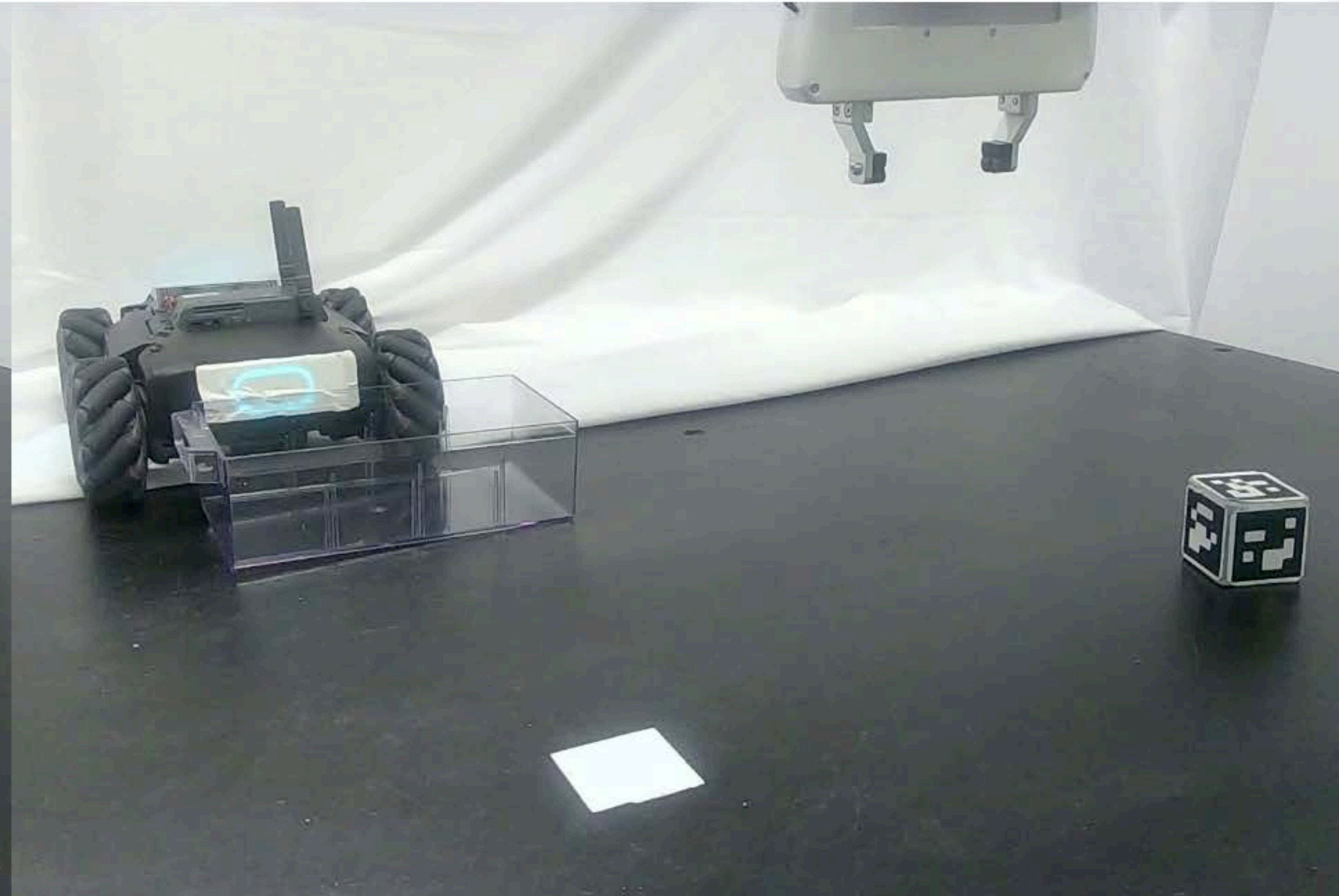
Time-aware Policy

Time Ratio: 0.5

# Multi-agent Object Delivery



Vanilla Policy: too early



Vanilla Policy: too late

# Staged-wise control

Time-aware Policy:

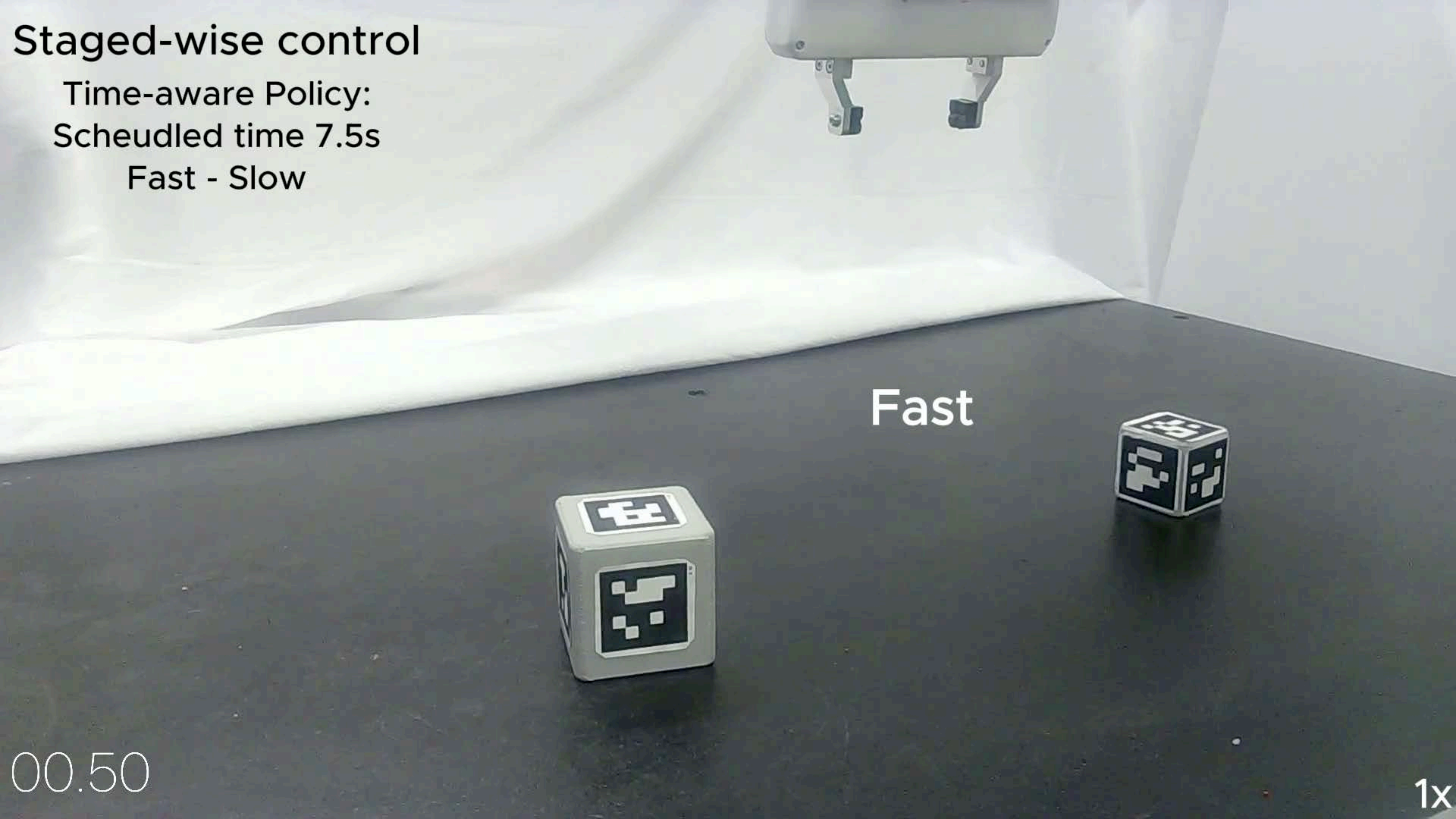
Scheduled time 7.5s

Fast - Slow

Fast

00.50

1x



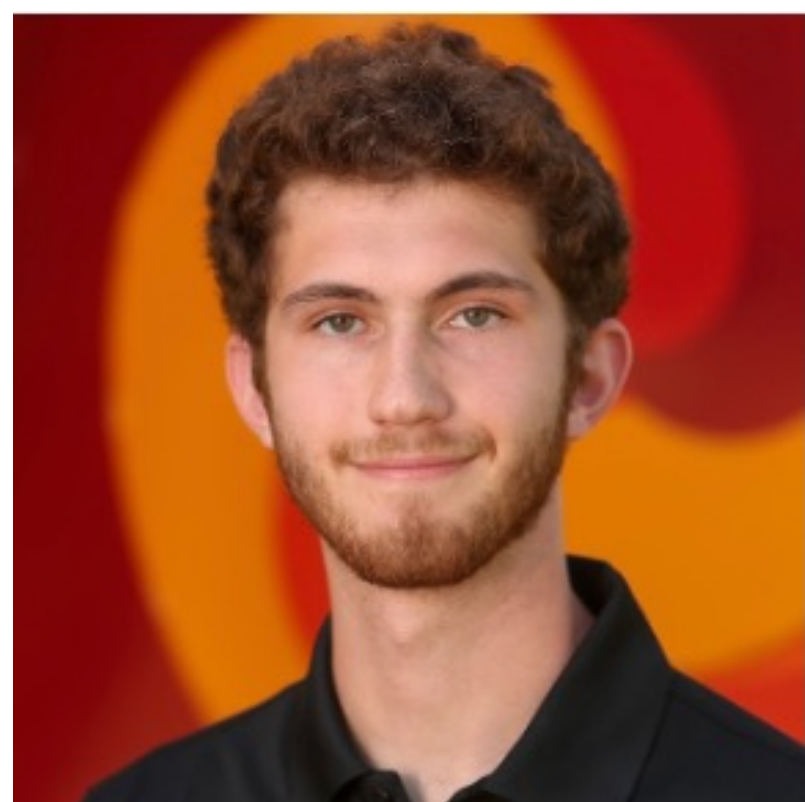


Robot Studio Class at Duke University

# 12 years ago...



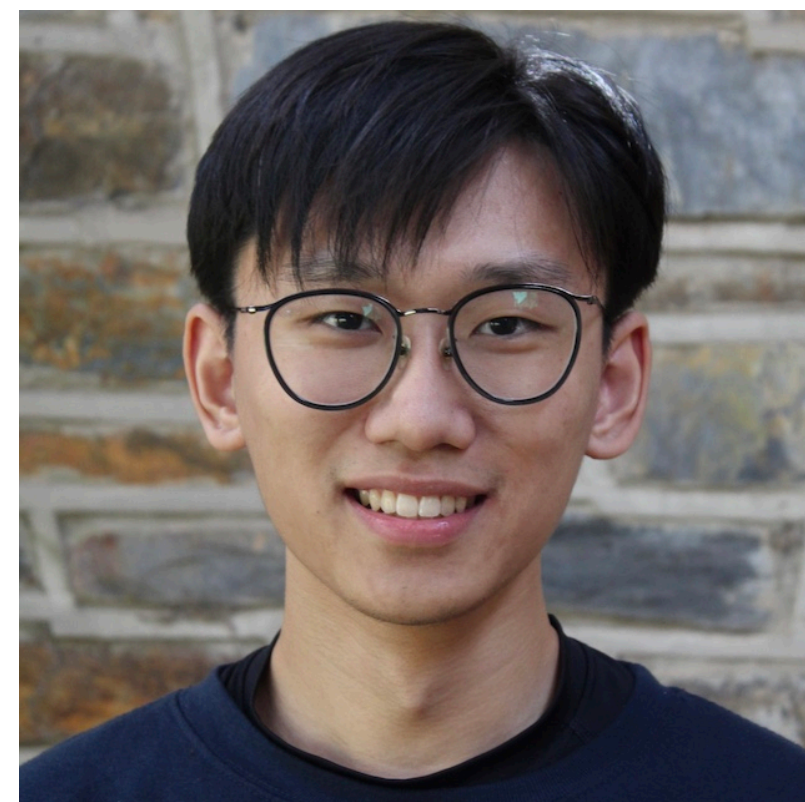
# Text2Robot



Ryan Ringel\*



Zach Charlick\*



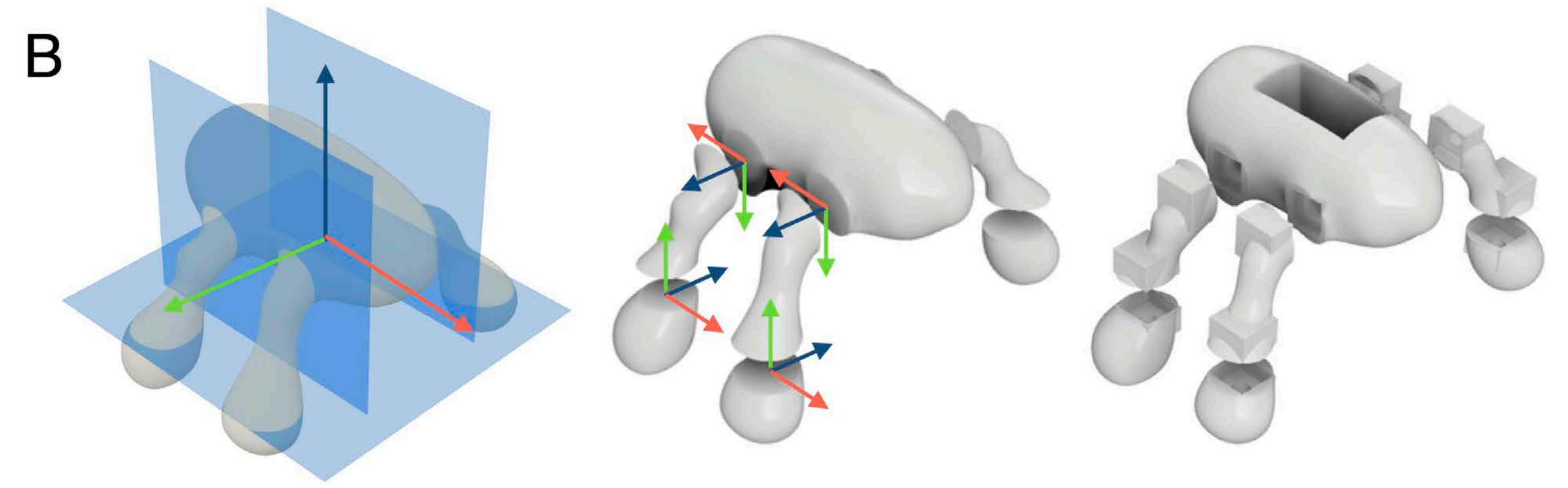
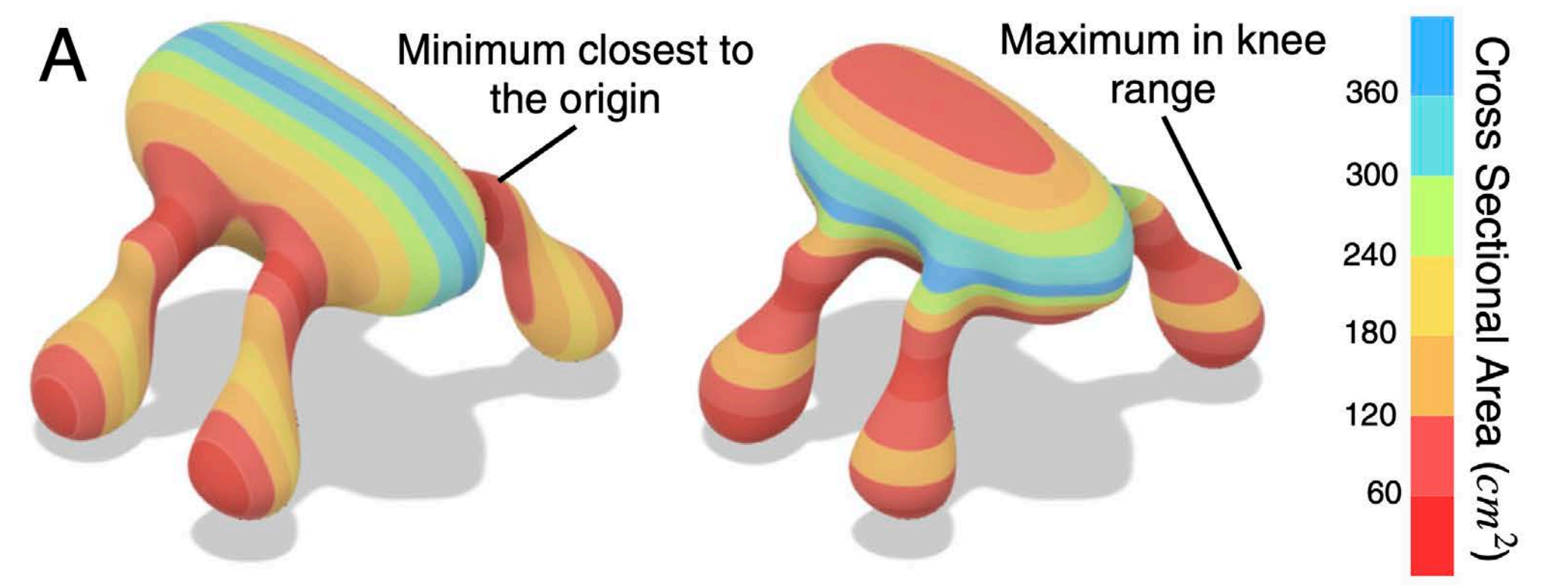
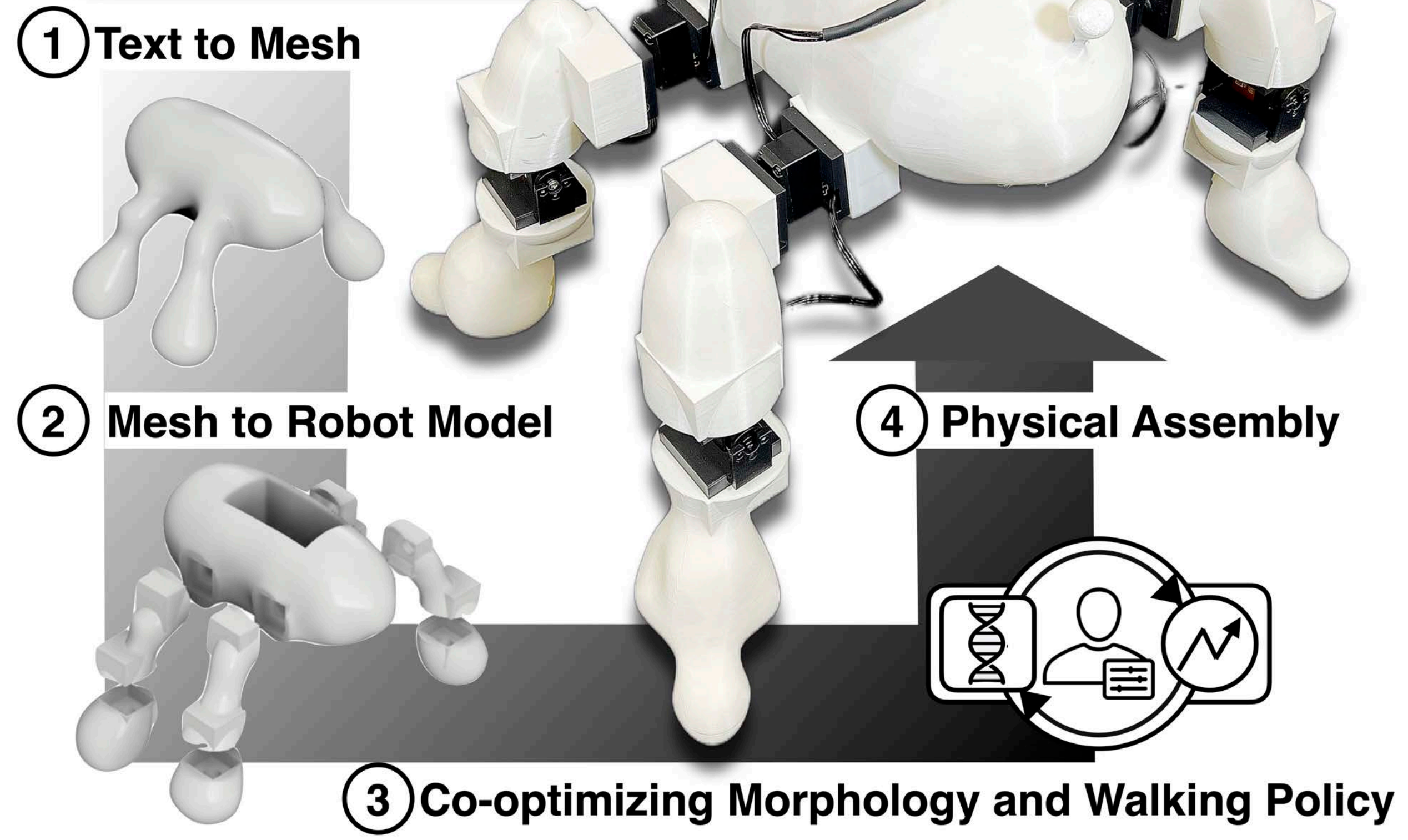
Jiaxun Liu\*

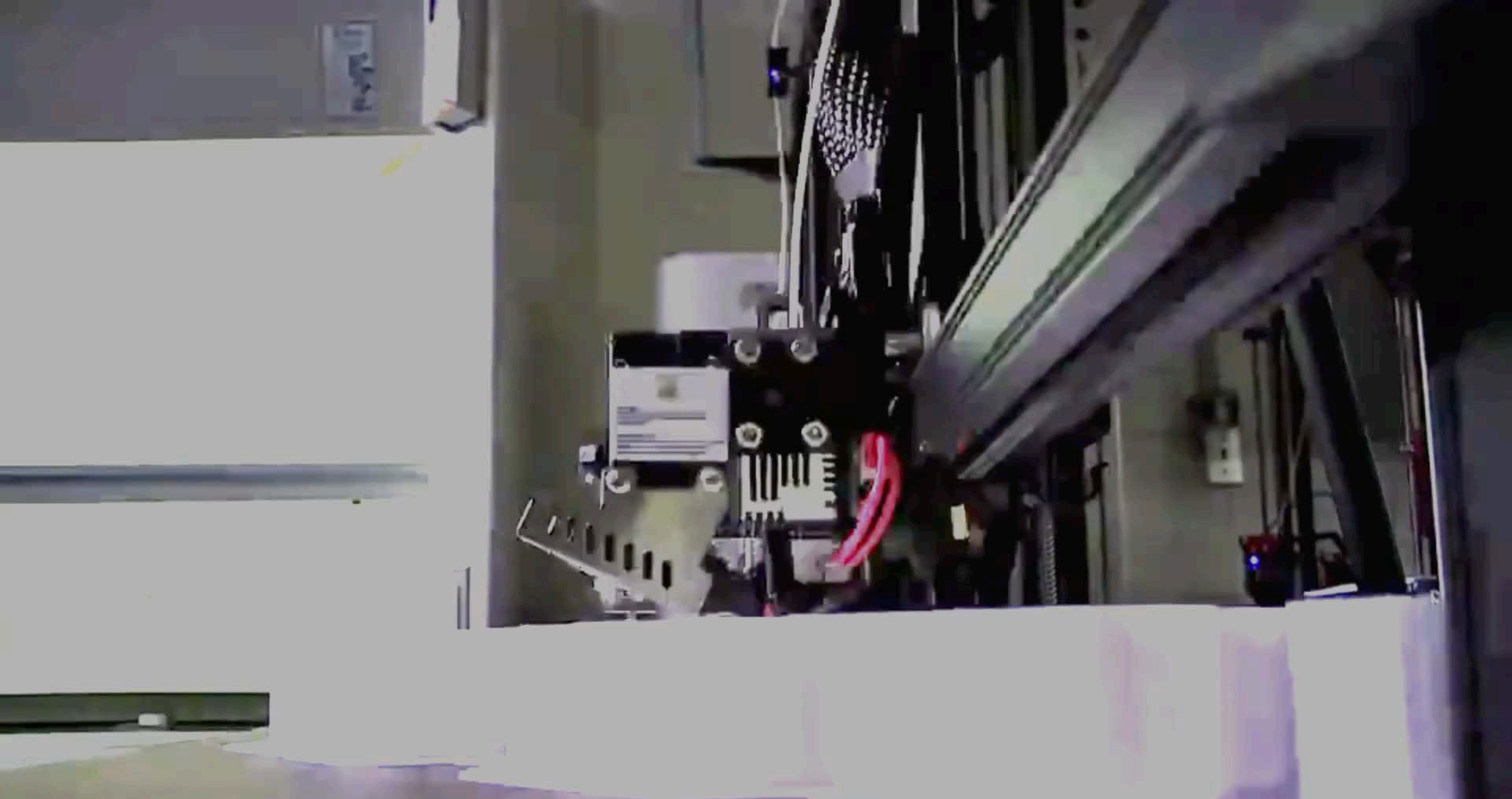


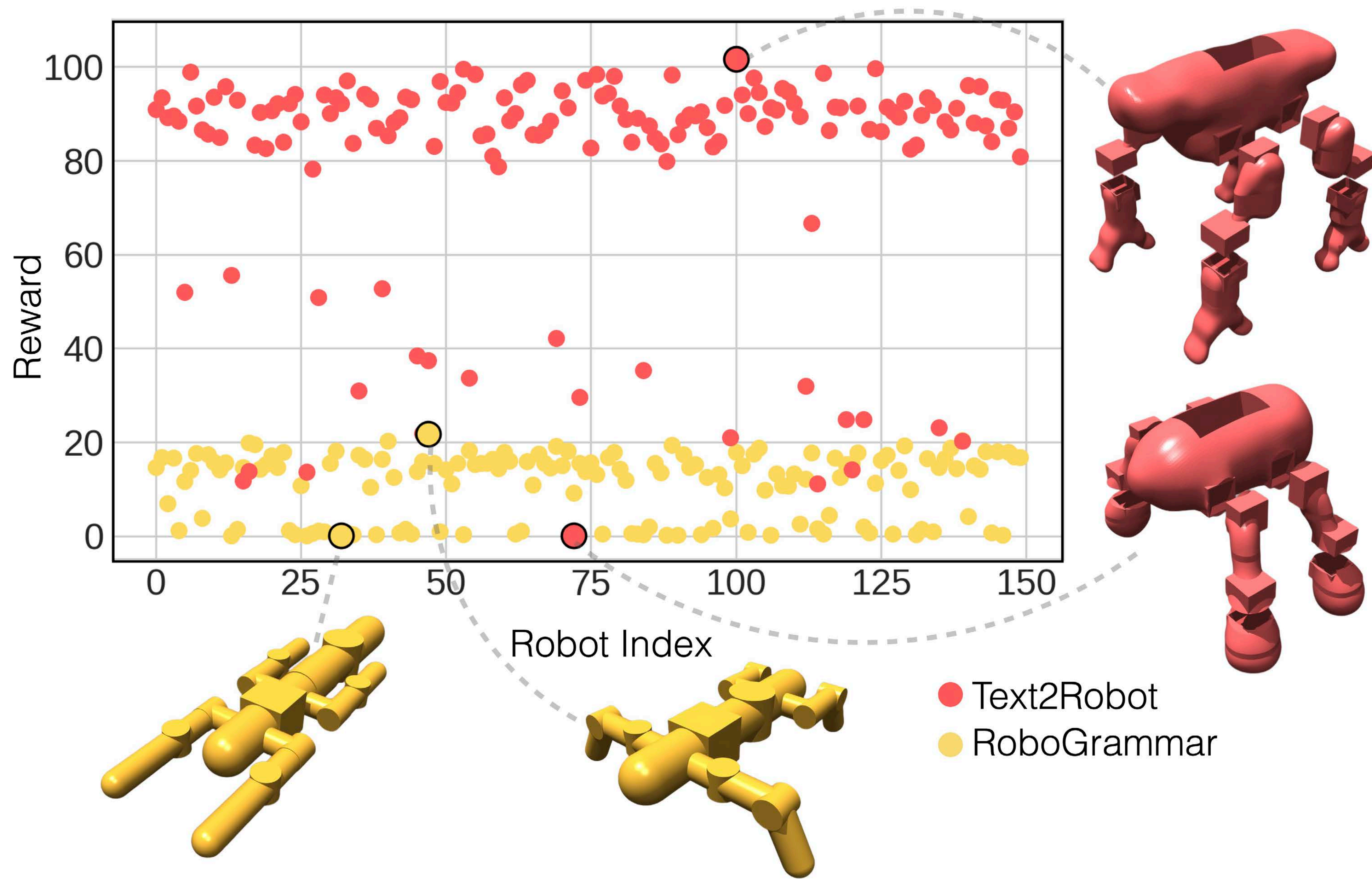
\* equal contribution

 **Quadrupedal walking robot resembling a bug.**

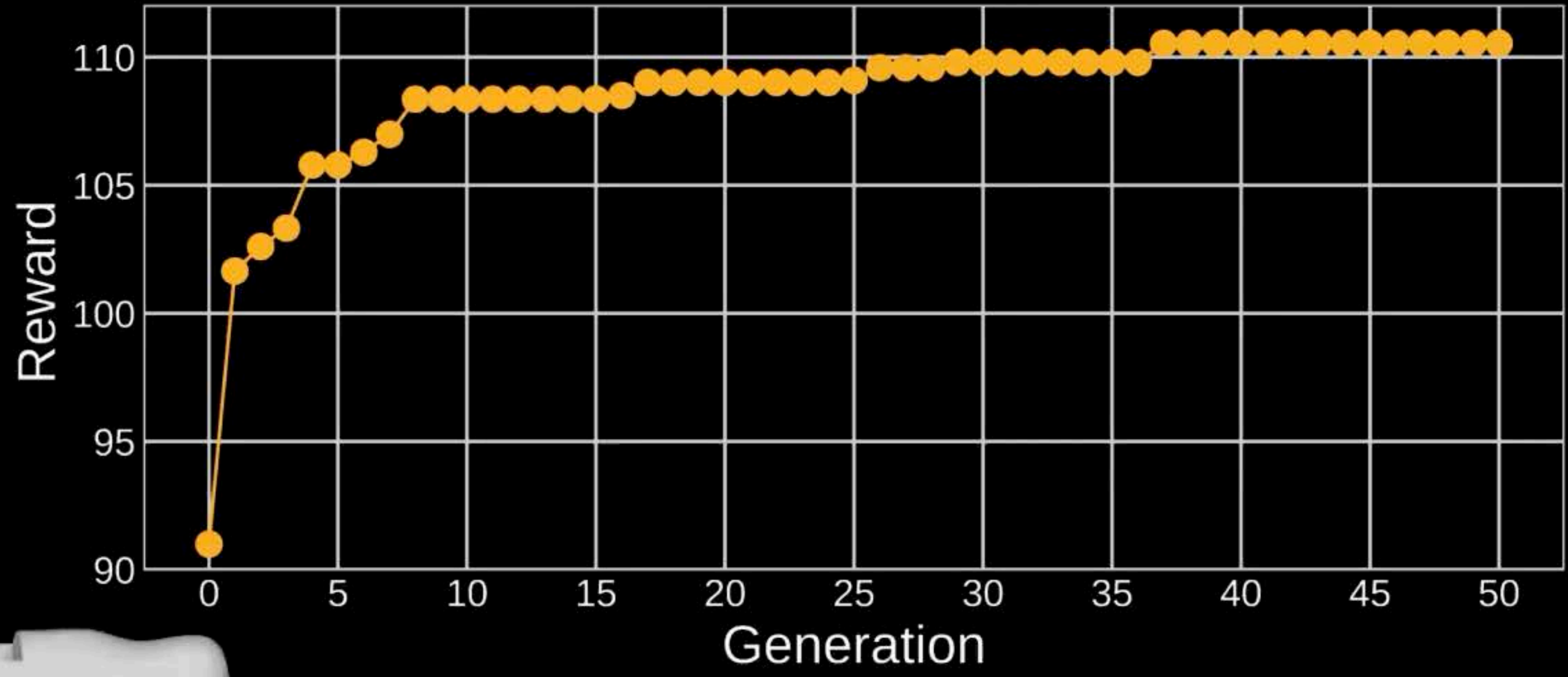
- Preference (select one):
- Match prompt aesthetic
  - Accurate velocity tracking
  - Energy efficiency







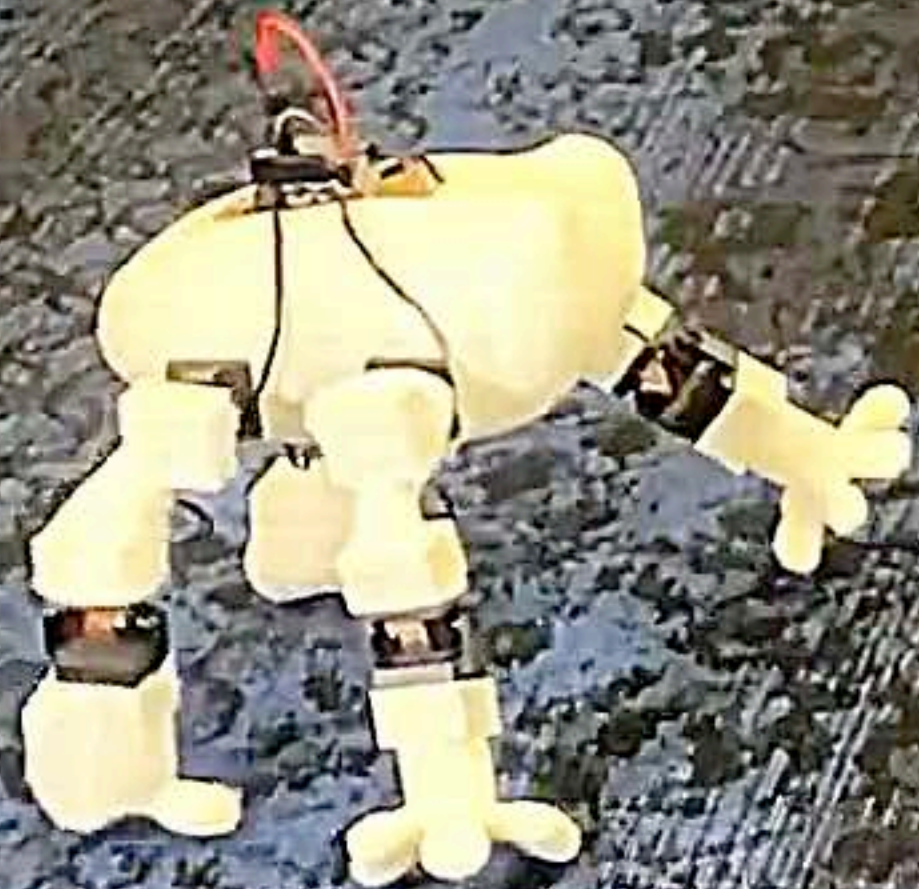
# Co-optimizing Morphology and Policy

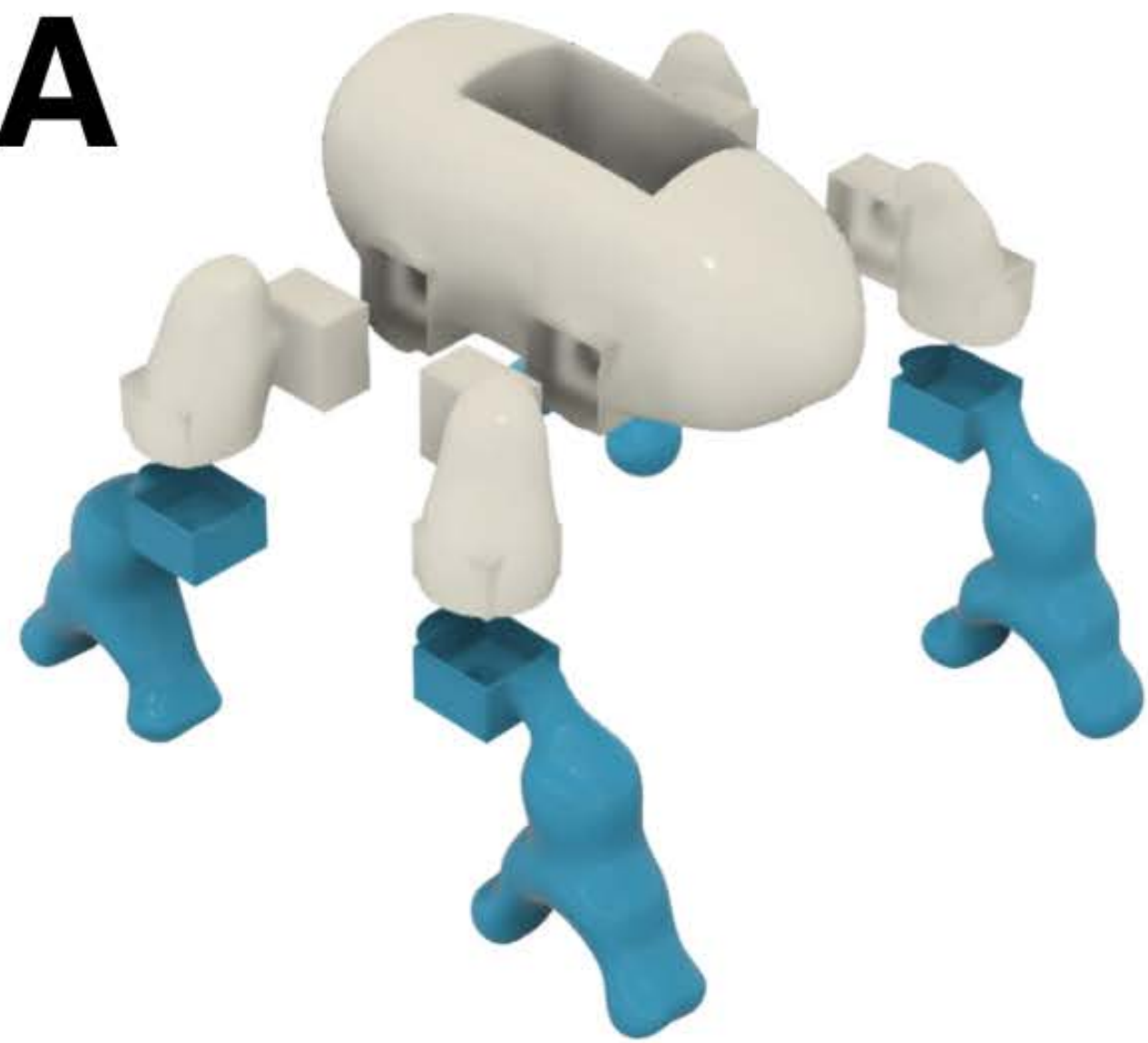


"Bug"



"Frog"

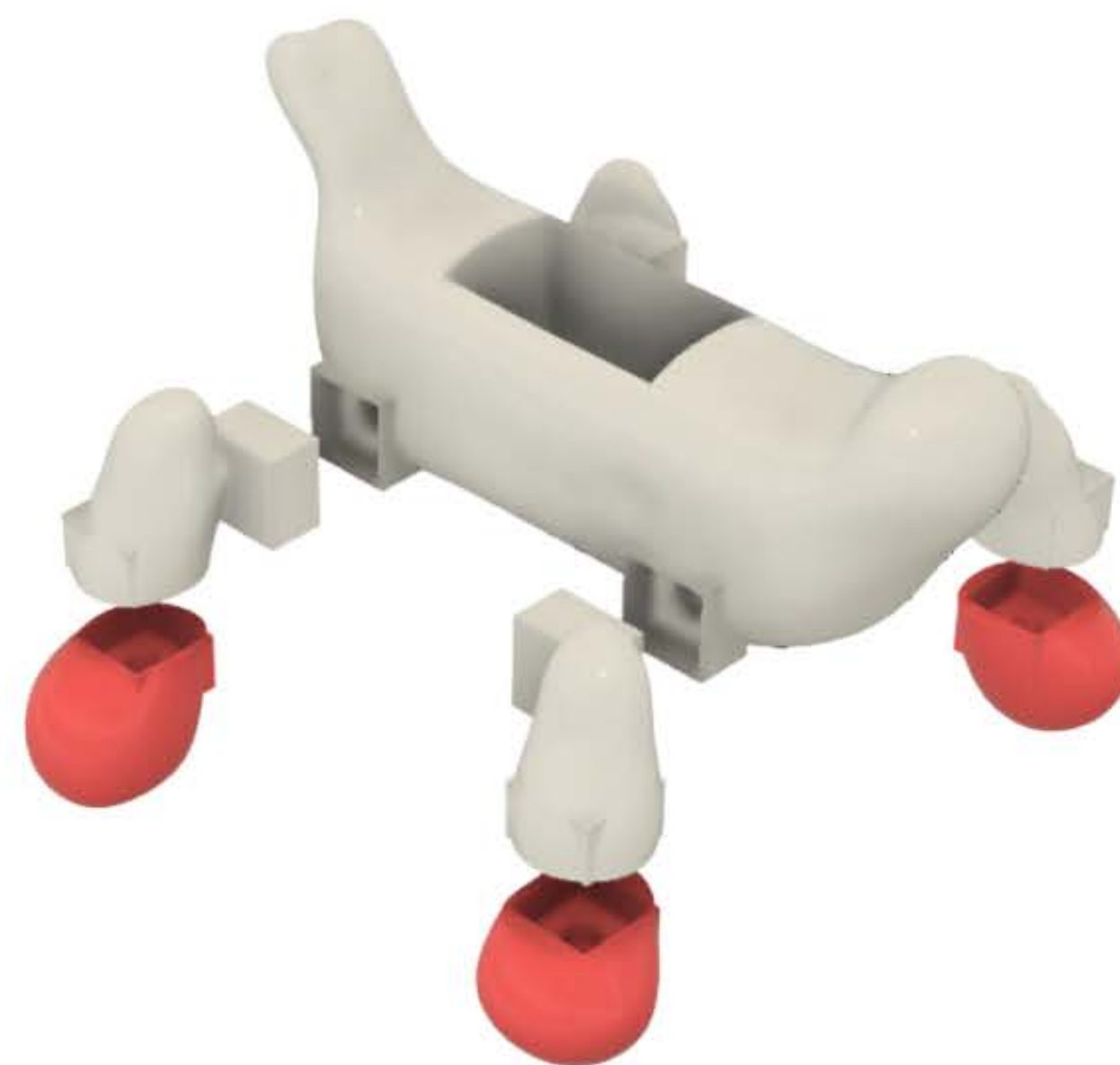


**A**

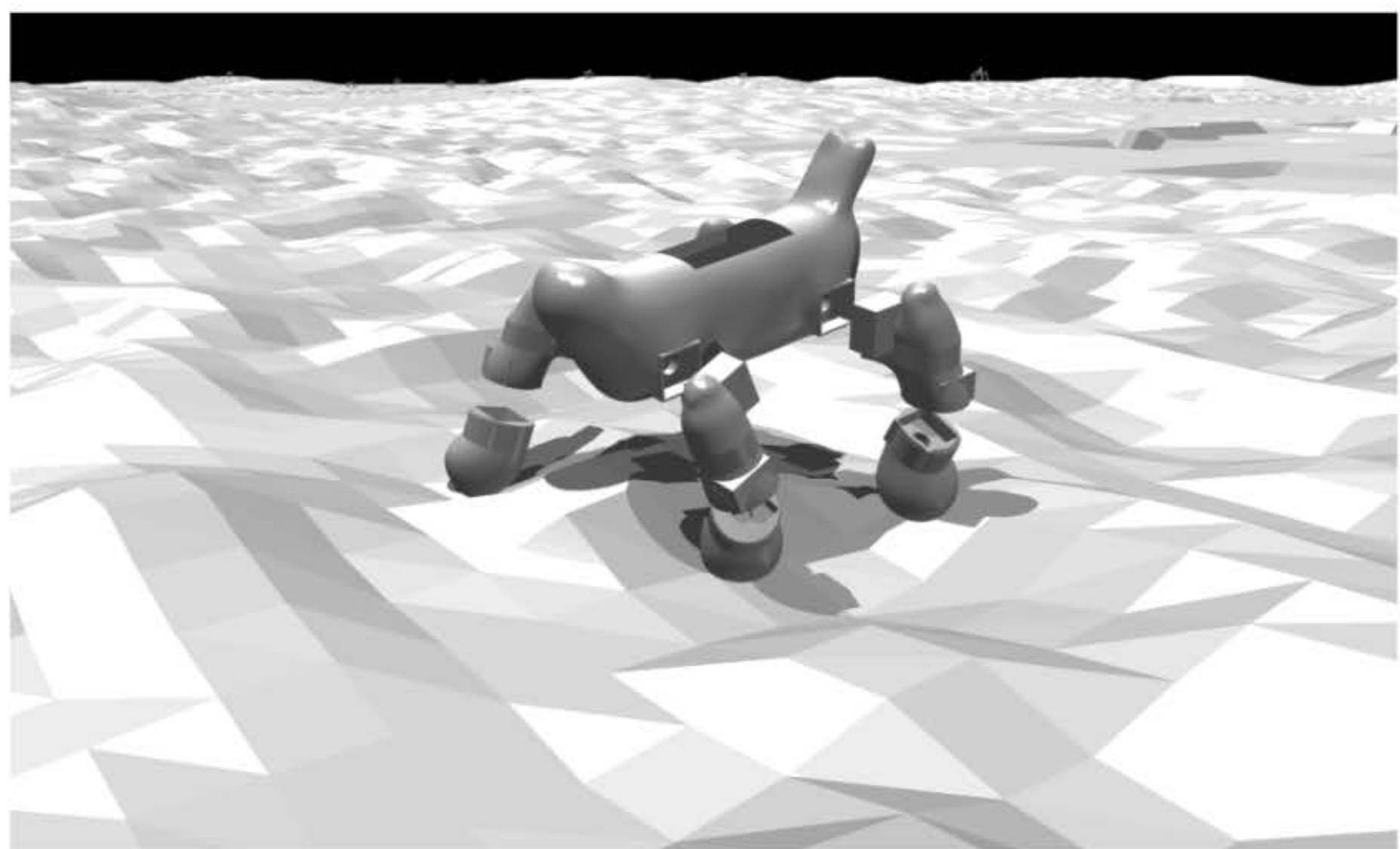
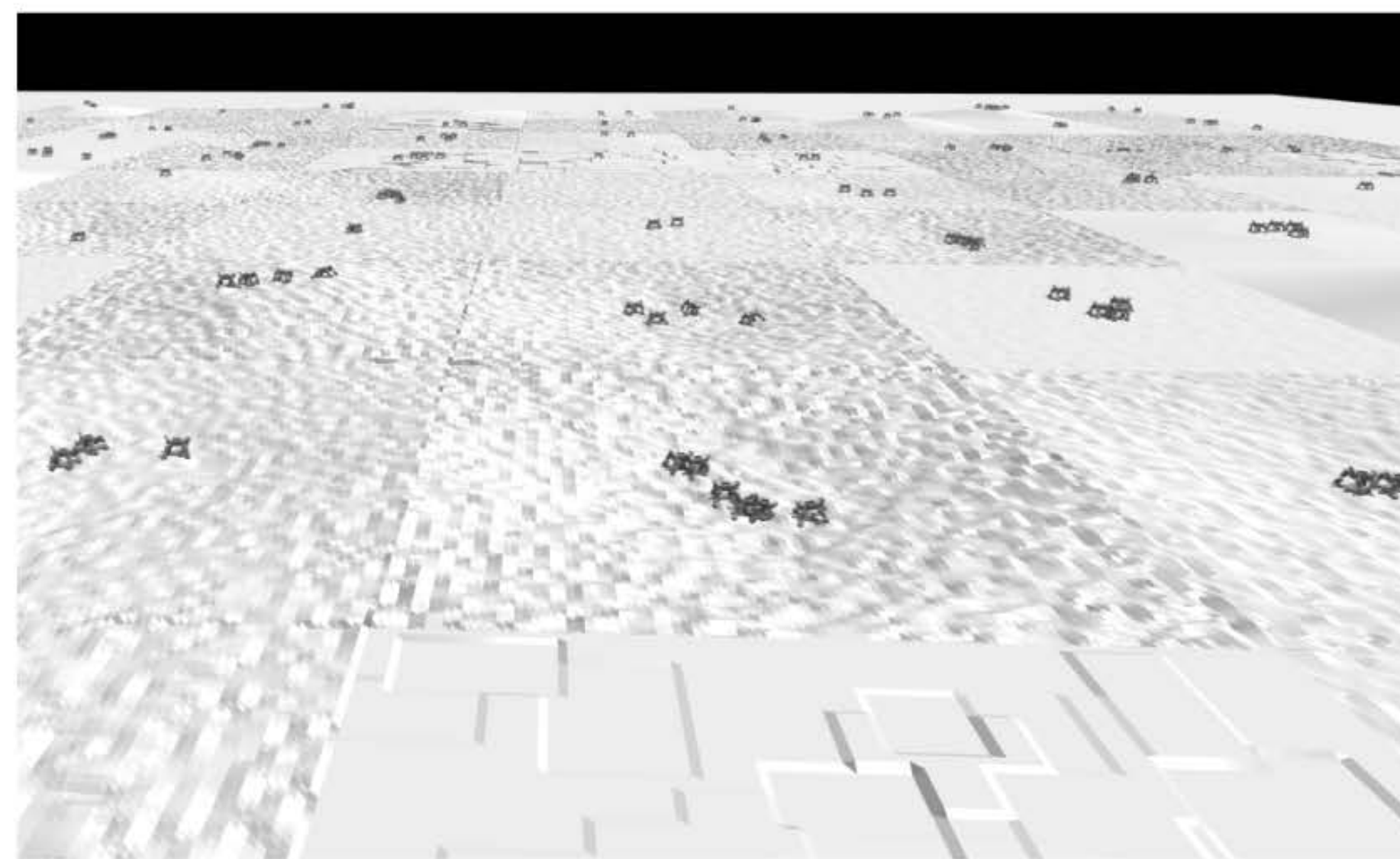
General

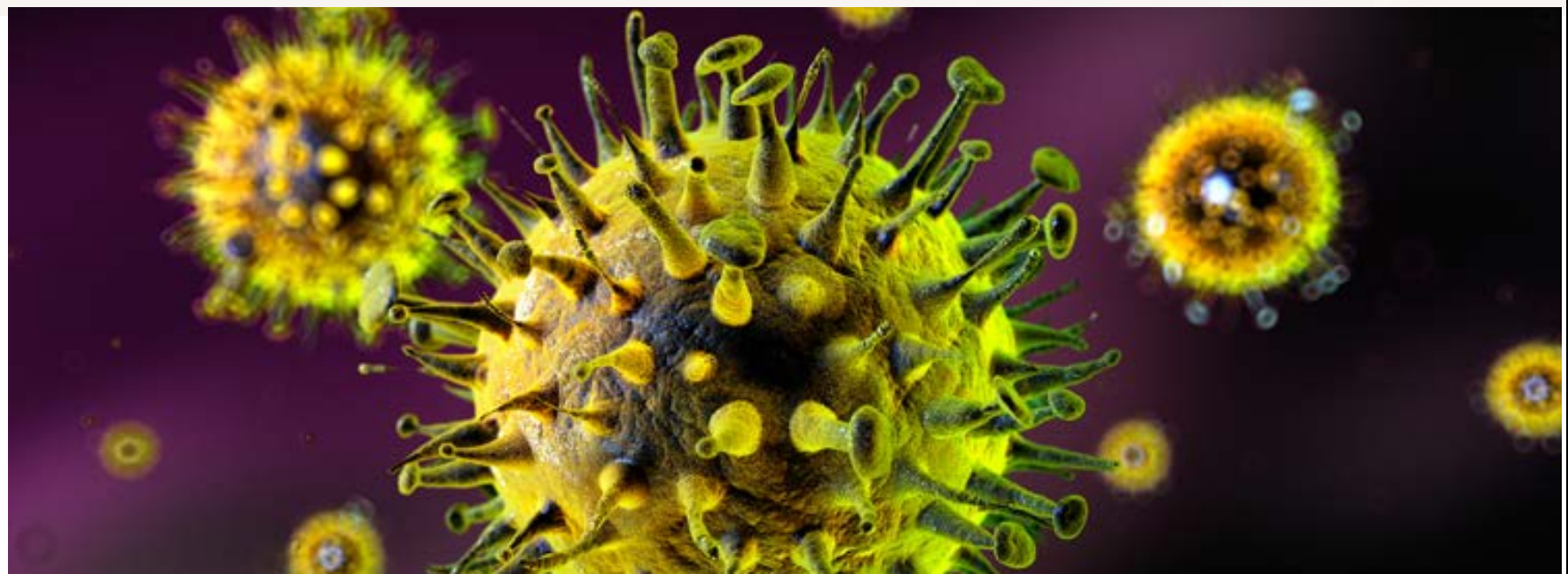


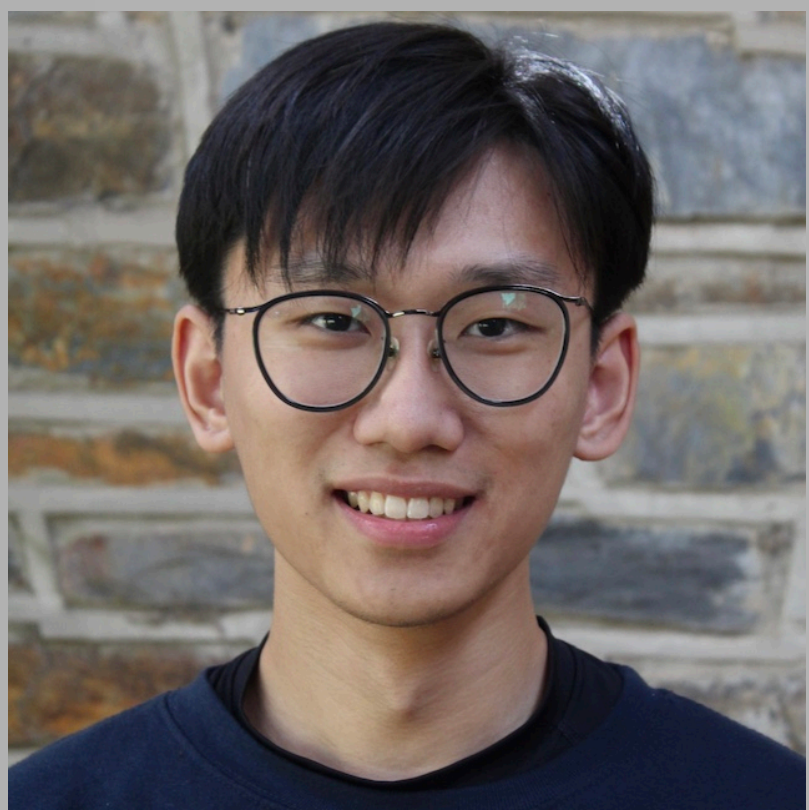
Velocity Tracking



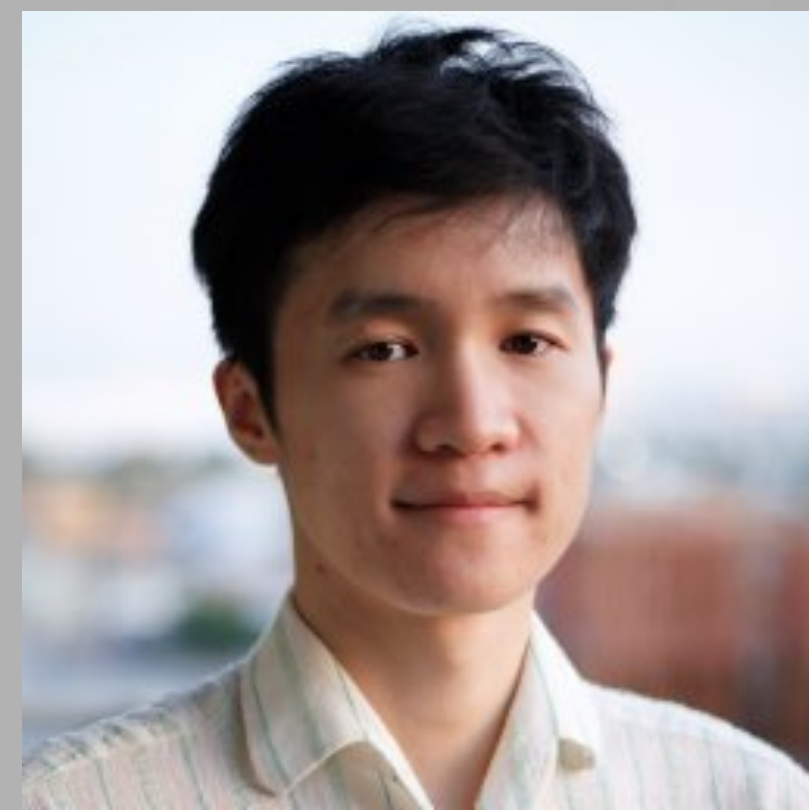
Rough Terrain

**B****C**



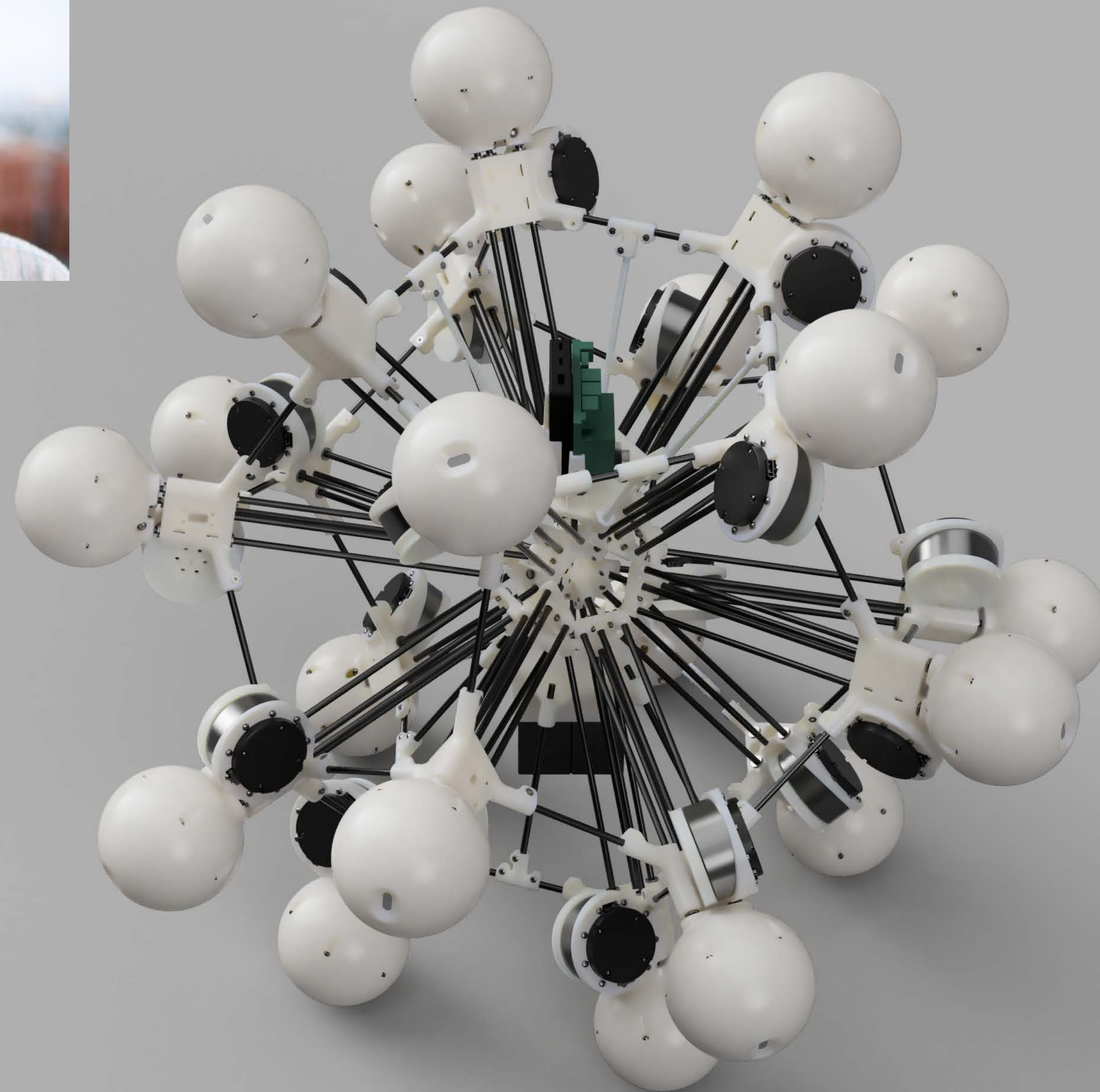


Jiaxun Liu\*

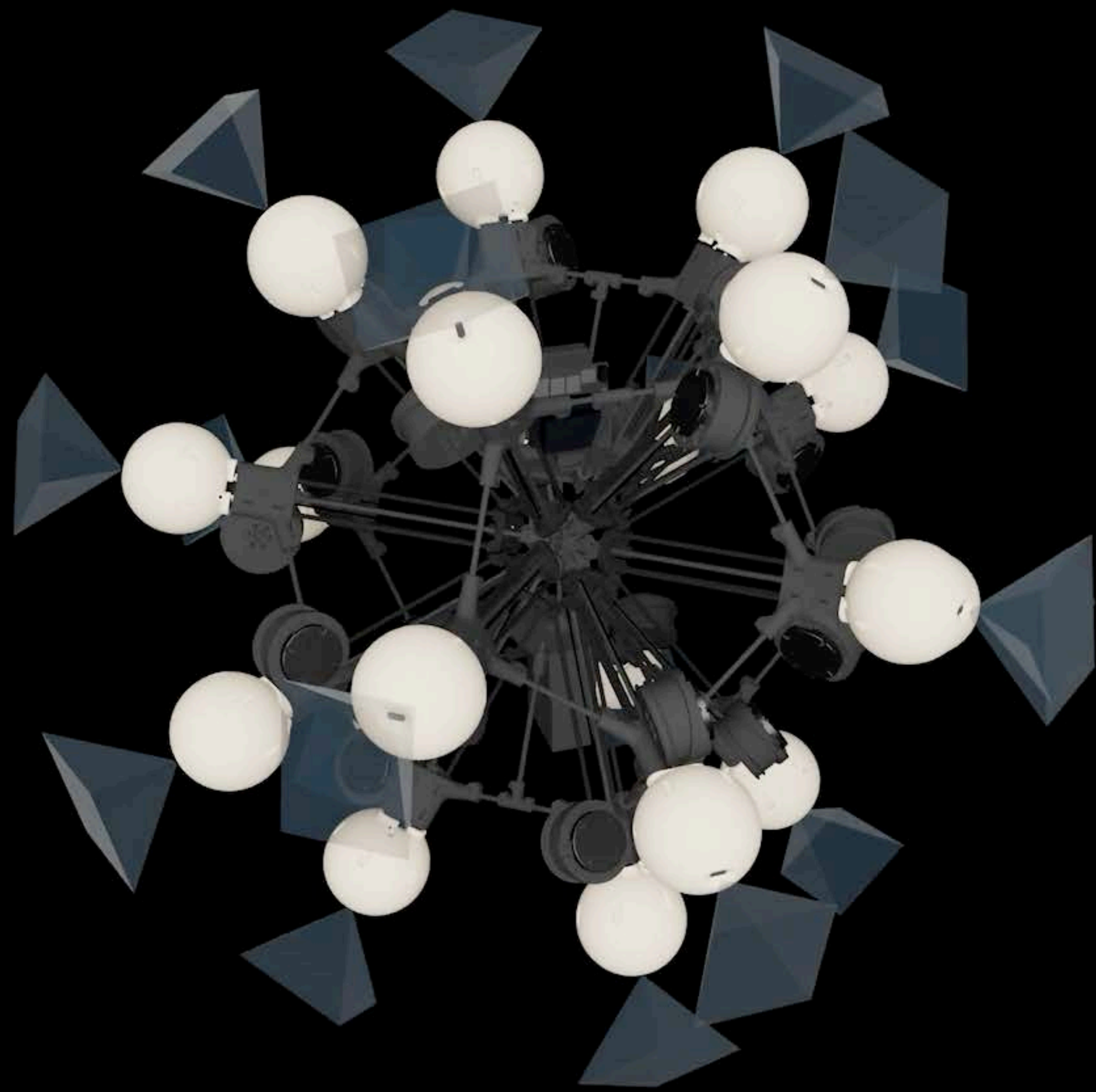


Boxi Xia\*

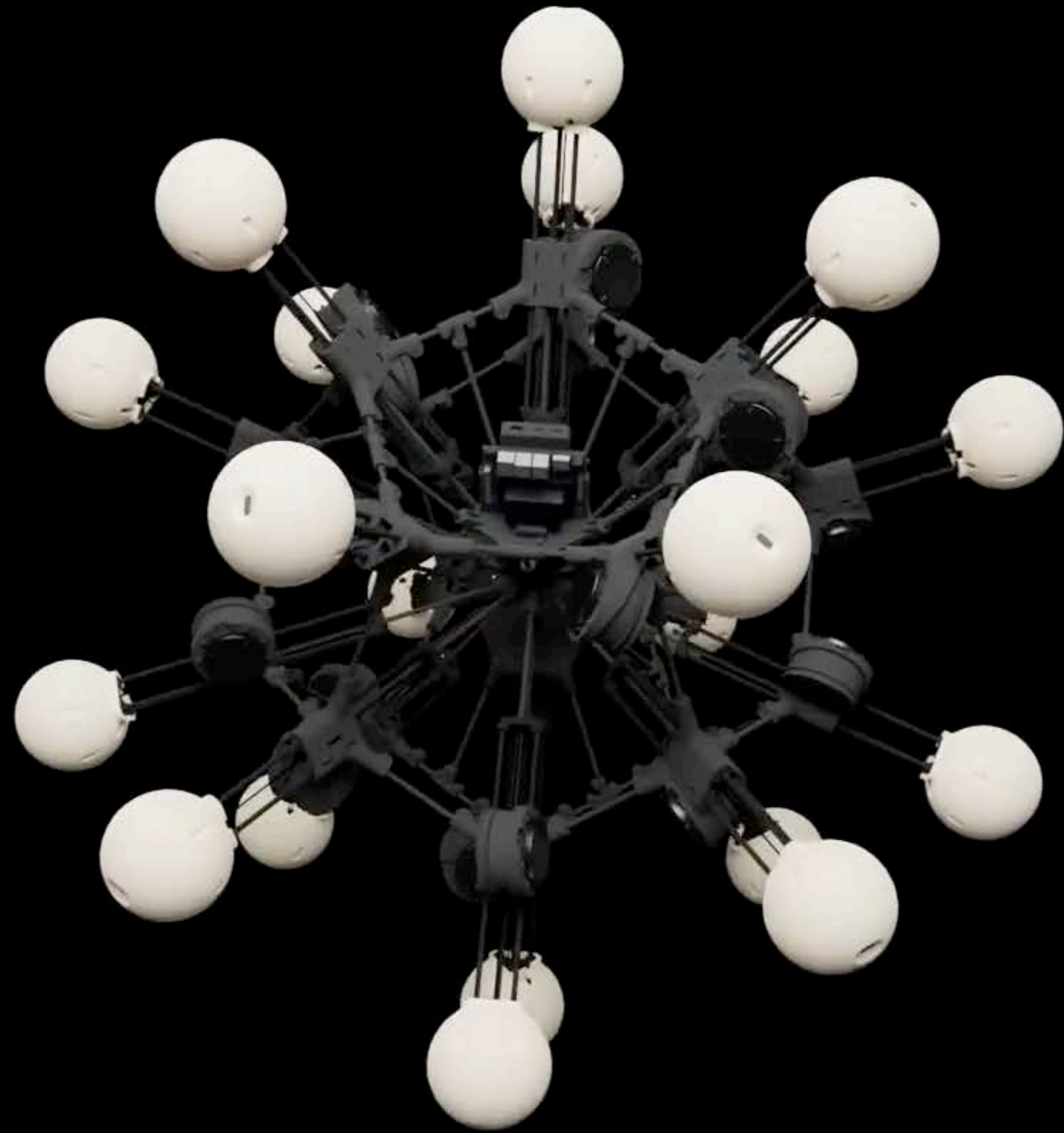
\* equal contribution



**Argus.** Boxi Xia, Jiaxun Liu, Boyuan Chen. In Press. Science Robotics. 2026.



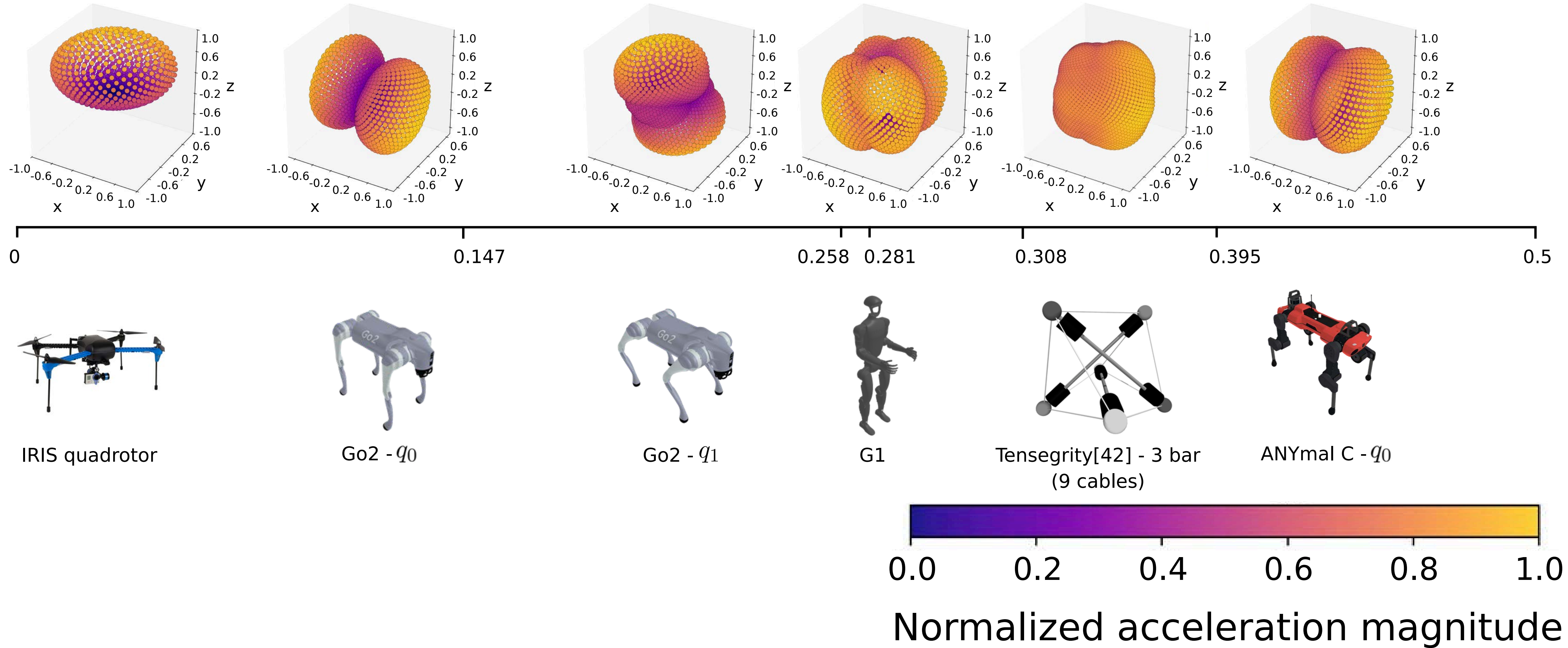
**Argus.** Boxi Xia, Jiaxun Liu, Boyuan Chen. In Press. Science Robotics. 2026.



**Argus.** Boxi Xia, Jiaxun Liu, Boyuan Chen. In Press. Science Robotics. 2026.

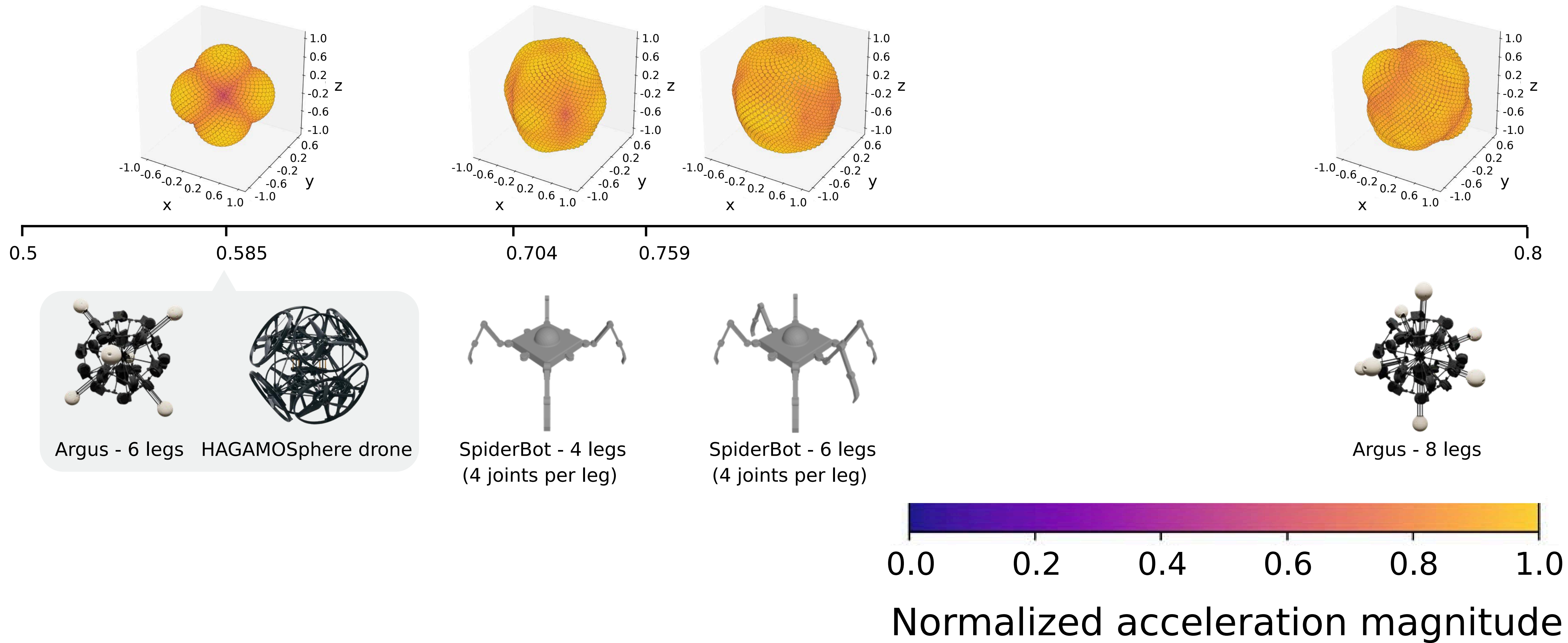
# Dynamic Isotropy

$$\eta = \frac{a_{\min}}{a_{\max}}$$



# Dynamic Isotropy

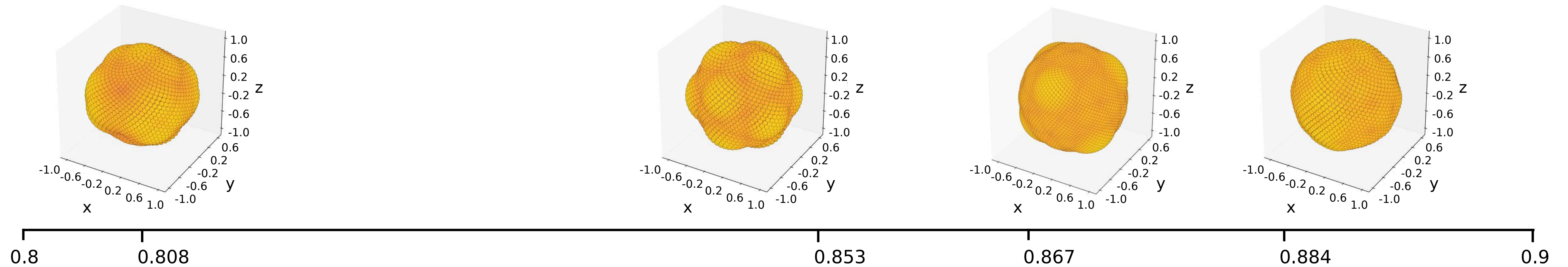
$$\eta = \frac{a_{\min}}{a_{\max}}$$



**Argus.** Boxi Xia, Jiaxun Liu, Boyuan Chen. In Press. Science Robotics. 2026.

# Dynamic Isotropy

$$\eta = \frac{a_{\min}}{a_{\max}}$$



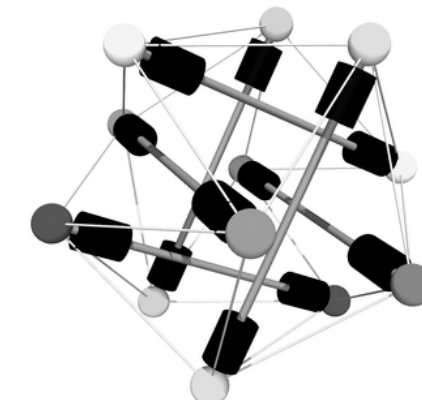
ANYmal C -  $q_1$



Argus - 12 legs



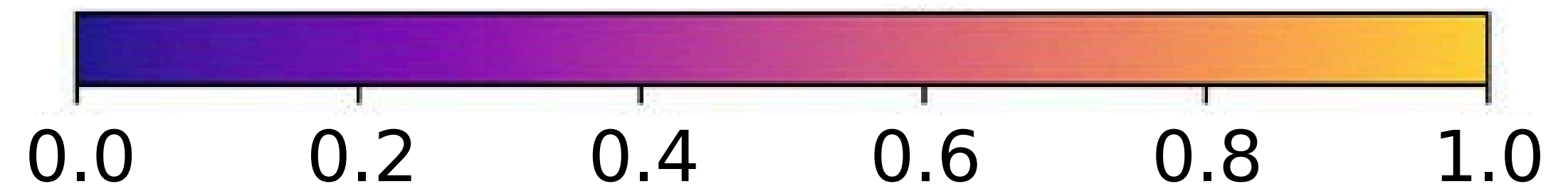
Spiny[53] - 12 legs



Tensegrity[42] - 6 bar  
(24 cables)



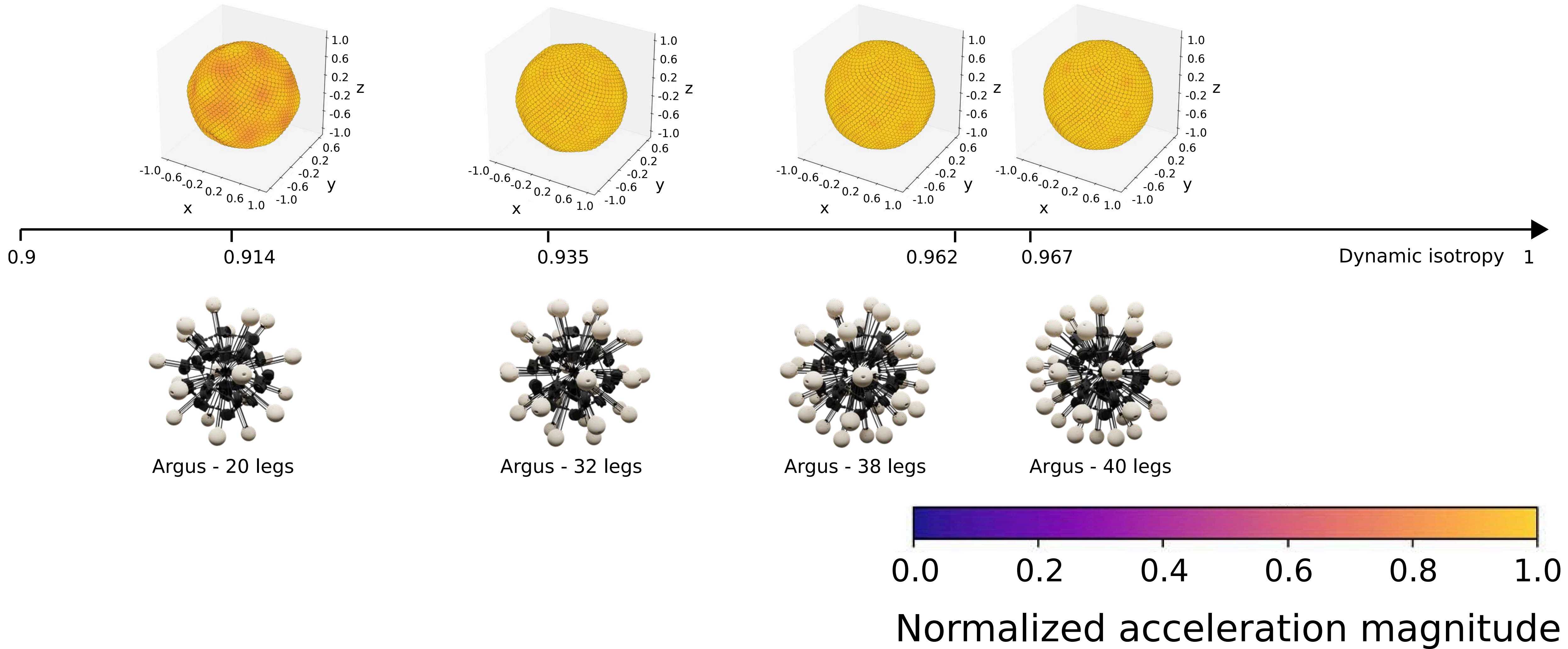
Mochibot[33] - 32 legs



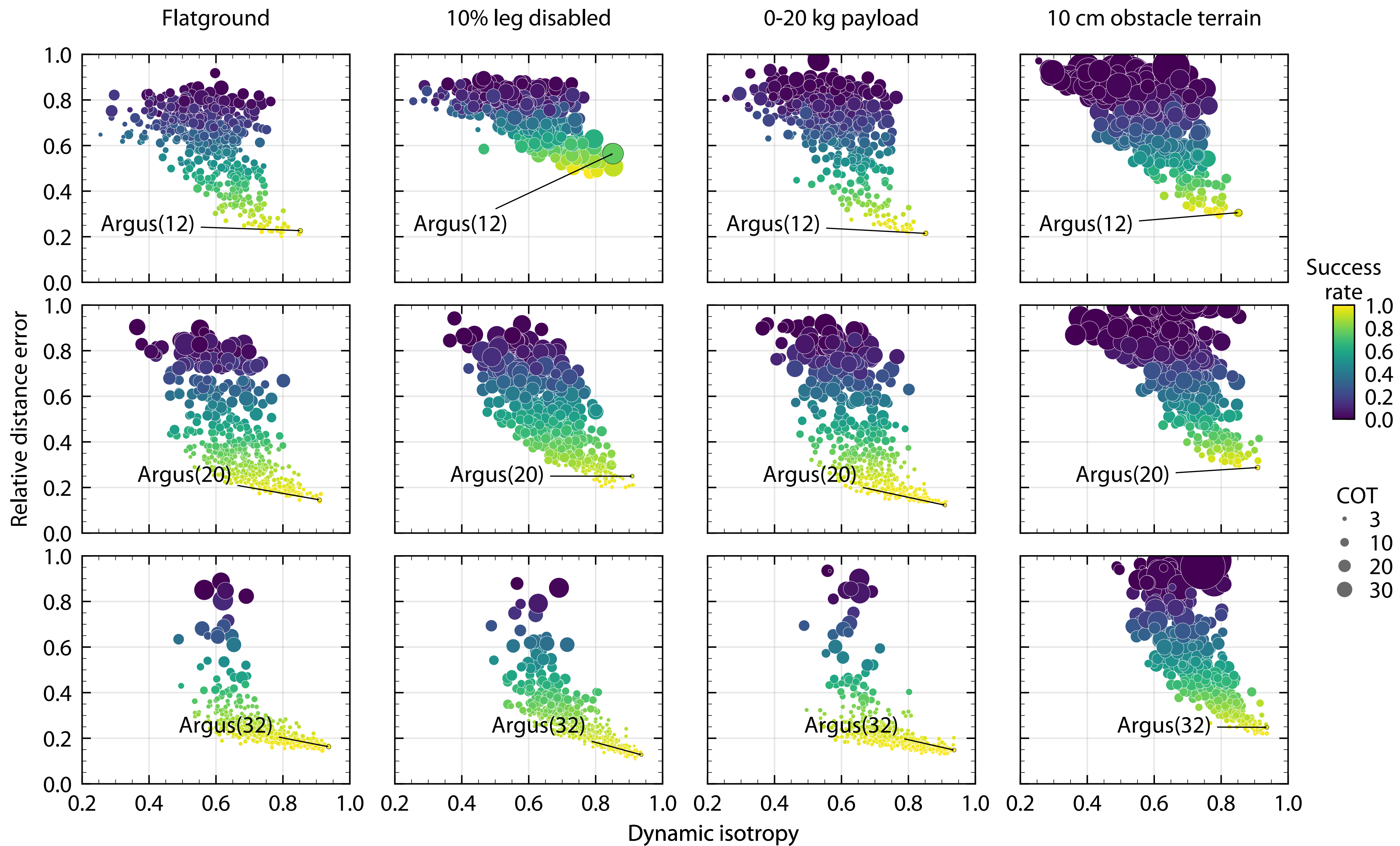
Normalized acceleration magnitude

# Dynamic Isotropy

$$\eta = \frac{a_{\min}}{a_{\max}}$$



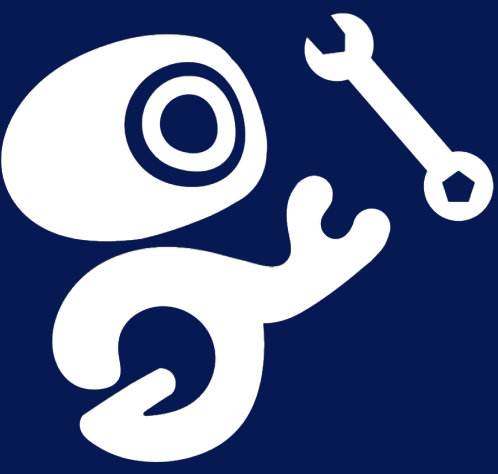
**Argus.** Boxi Xia, Jiaxun Liu, Boyuan Chen. In Press. Science Robotics. 2026.



**Argus.** Boxi Xia, Jiaxun Liu, Boyuan Chen. In Press. Science Robotics. 2026.

***building intelligent robots =  
breeding a new species***

Sense → Adapt → Connect → Machine Scientists



# Building Intelligent Robots from the Ground Up

Boyuan Chen

Dickinson Family Assistant Professor

MEMS, ECE, CS

General Robotics Lab