

Planning for Multi-Stage Forceful Manipulation

Rachel Holladay
Tomás Lozano-Pérez
Alberto Rodriguez

ICRA 2021

Forceful Manipulation

Opening a Childproof Bottle



Opening a Childproof Bottle

- Push down on the cap



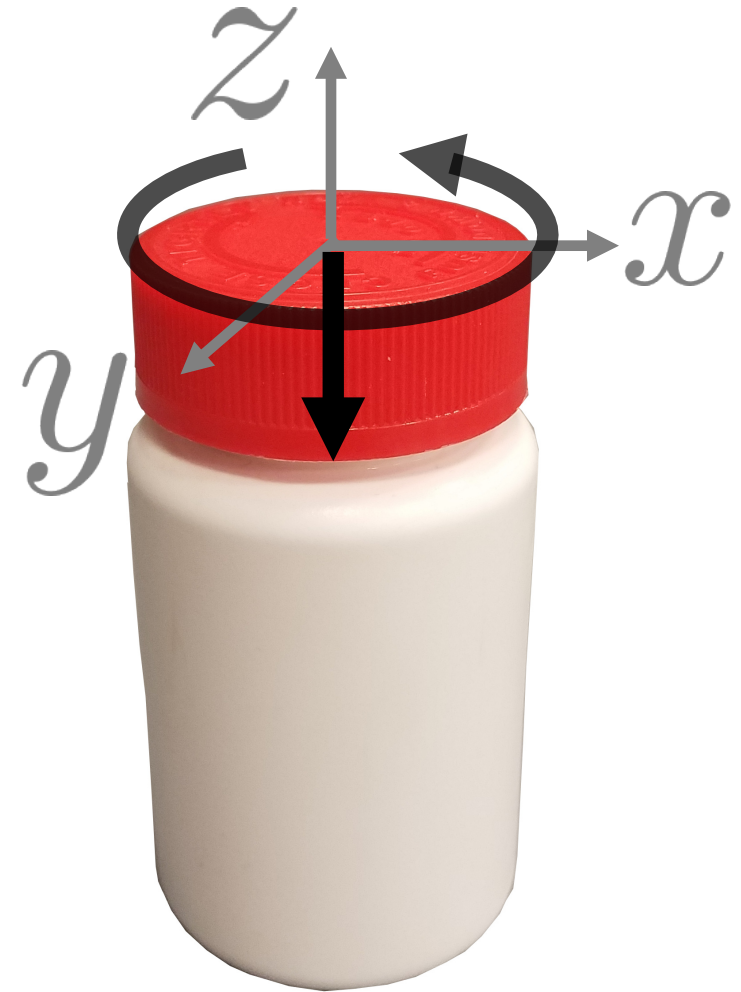
Opening a Childproof Bottle

- Push down on the cap
- Twist the cap



Opening a Childproof Bottle

- Push down on the cap
- Twist the cap



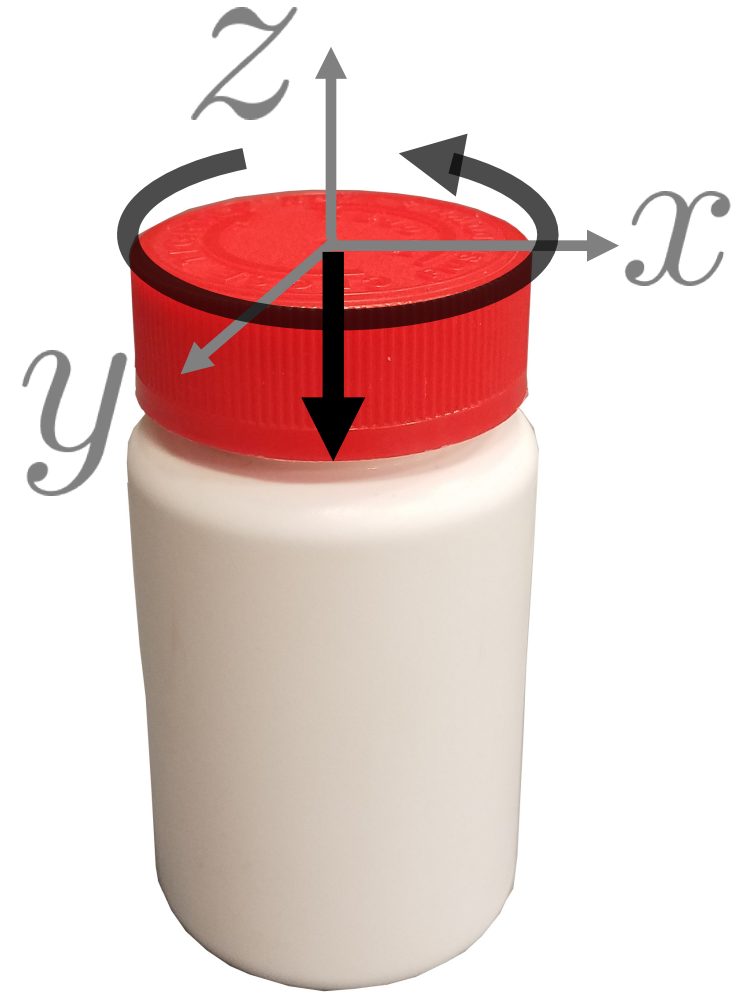
$$(0, 0, -f_z, 0, 0, t_z)$$

Opening a Childproof Bottle

- Push down on the cap
- Twist the cap

$$(0, 0, -f_z, 0, 0, t_z)$$

Forceful Operation



Opening a Childproof Bottle

- Push down on the cap
- Twist the cap
- Secure the bottle

$$(0, 0, -f_z, 0, 0, t_z)$$

Forceful Operation



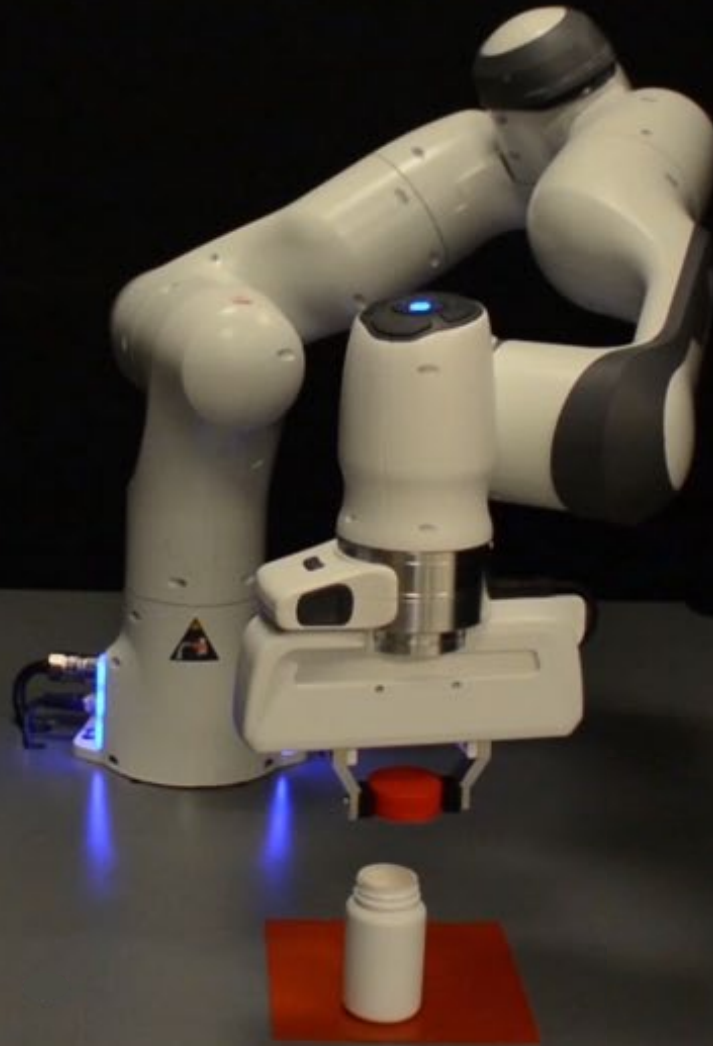






Force as a limiting factor?

Forceful Kinematic Chain

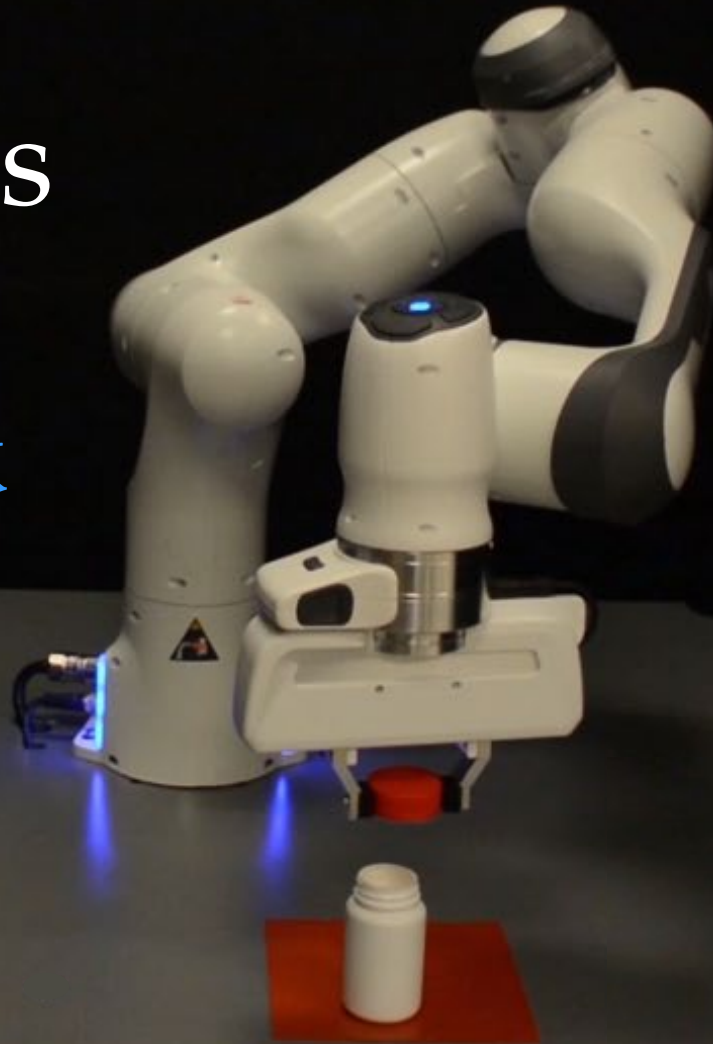


Force as a limiting factor?

Forceful Kinematic Chain

Planning sequences
of actions?

TAMP Framework



Force as a limiting factor?

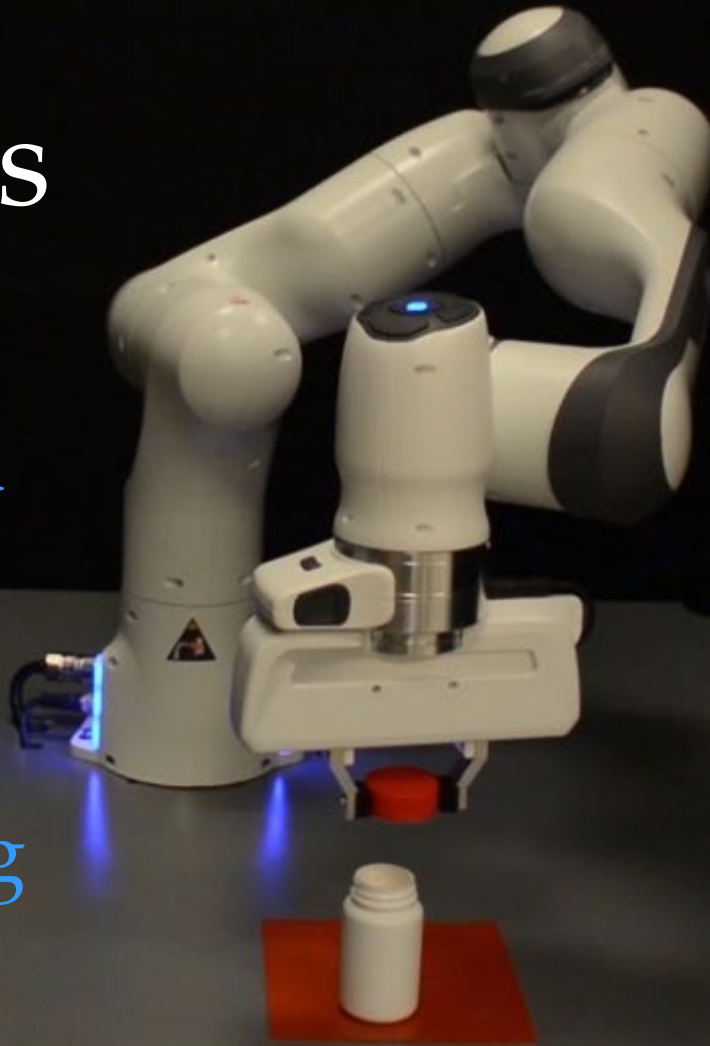
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TAMP Framework

Robust sequences?

Cost-Sensitive Planning



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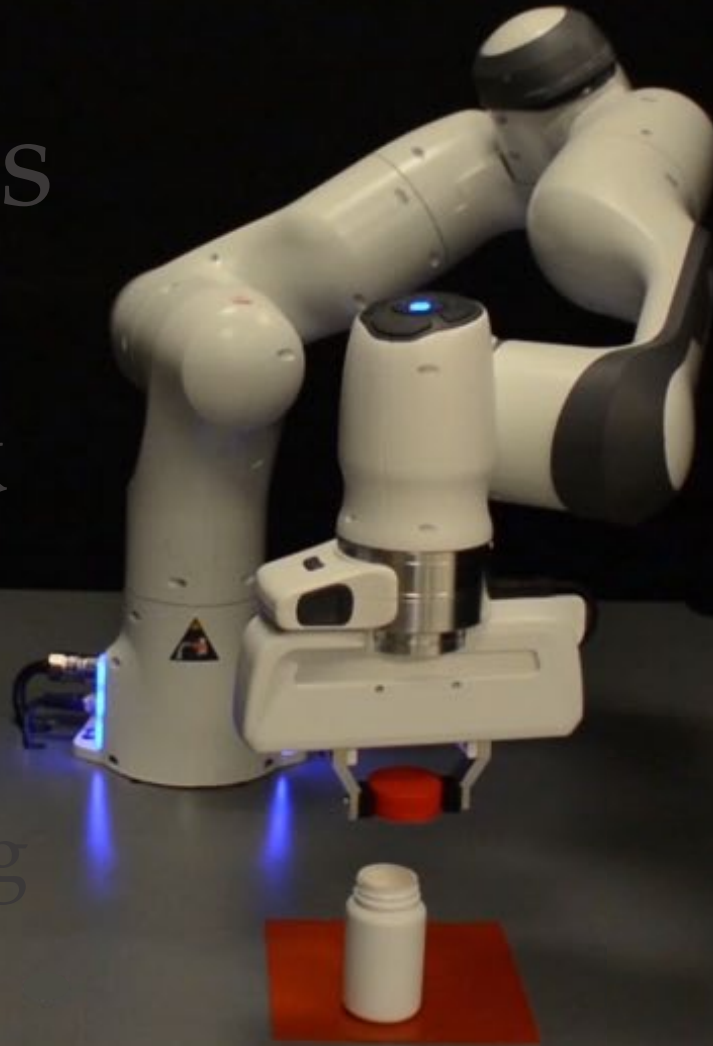
Forceful Kinematic Chain

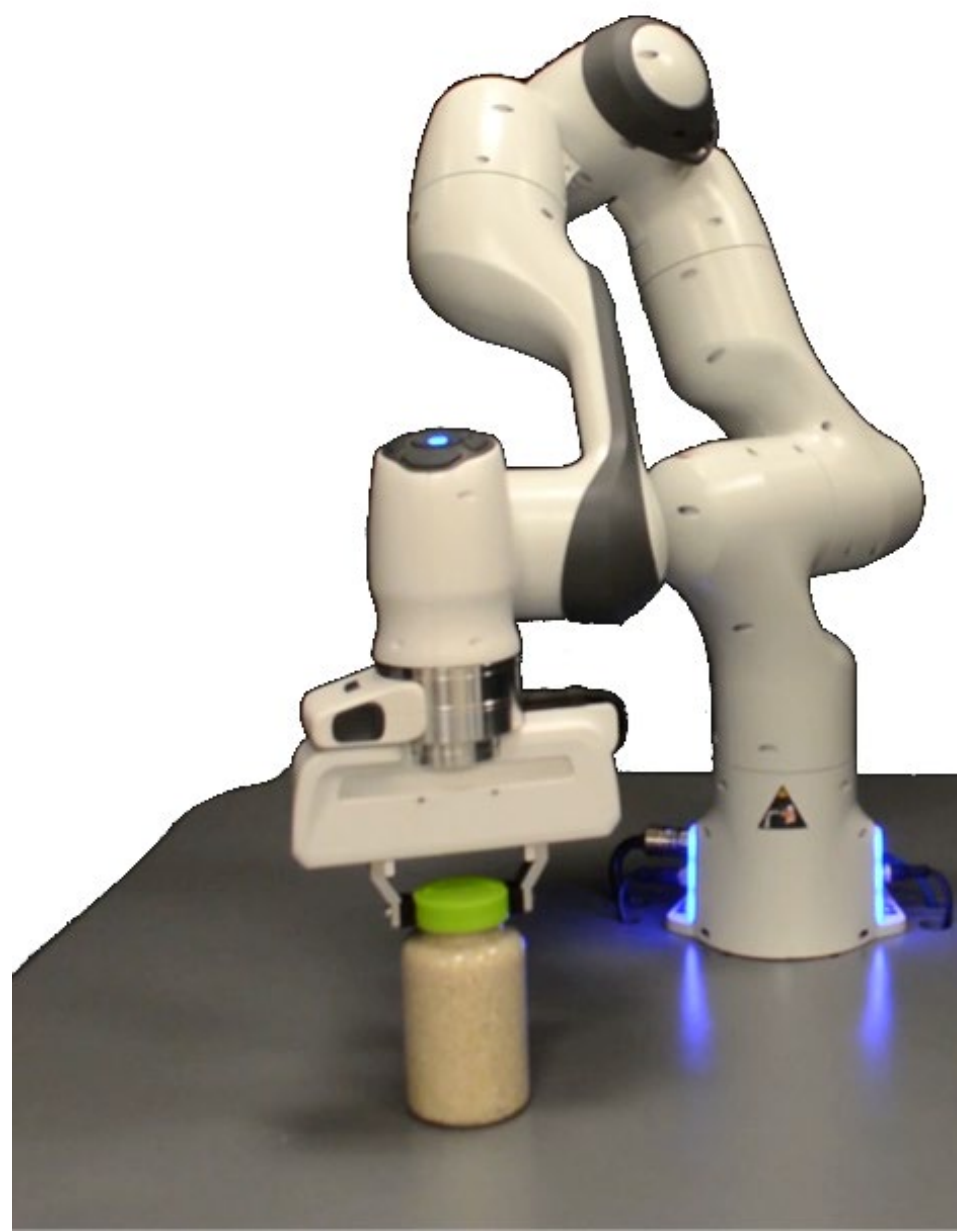
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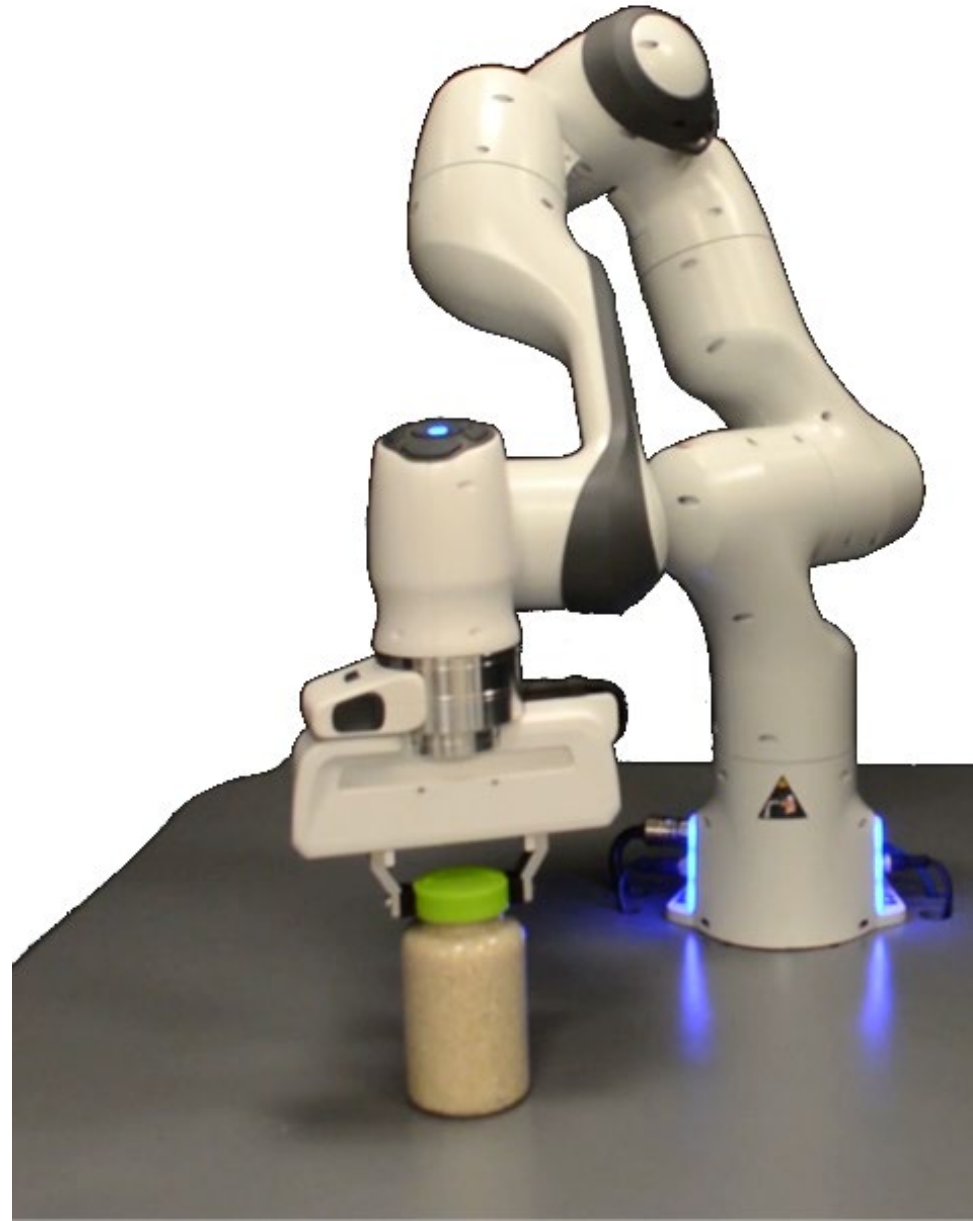
Robust sequences?

Cost-Sensitive Planning

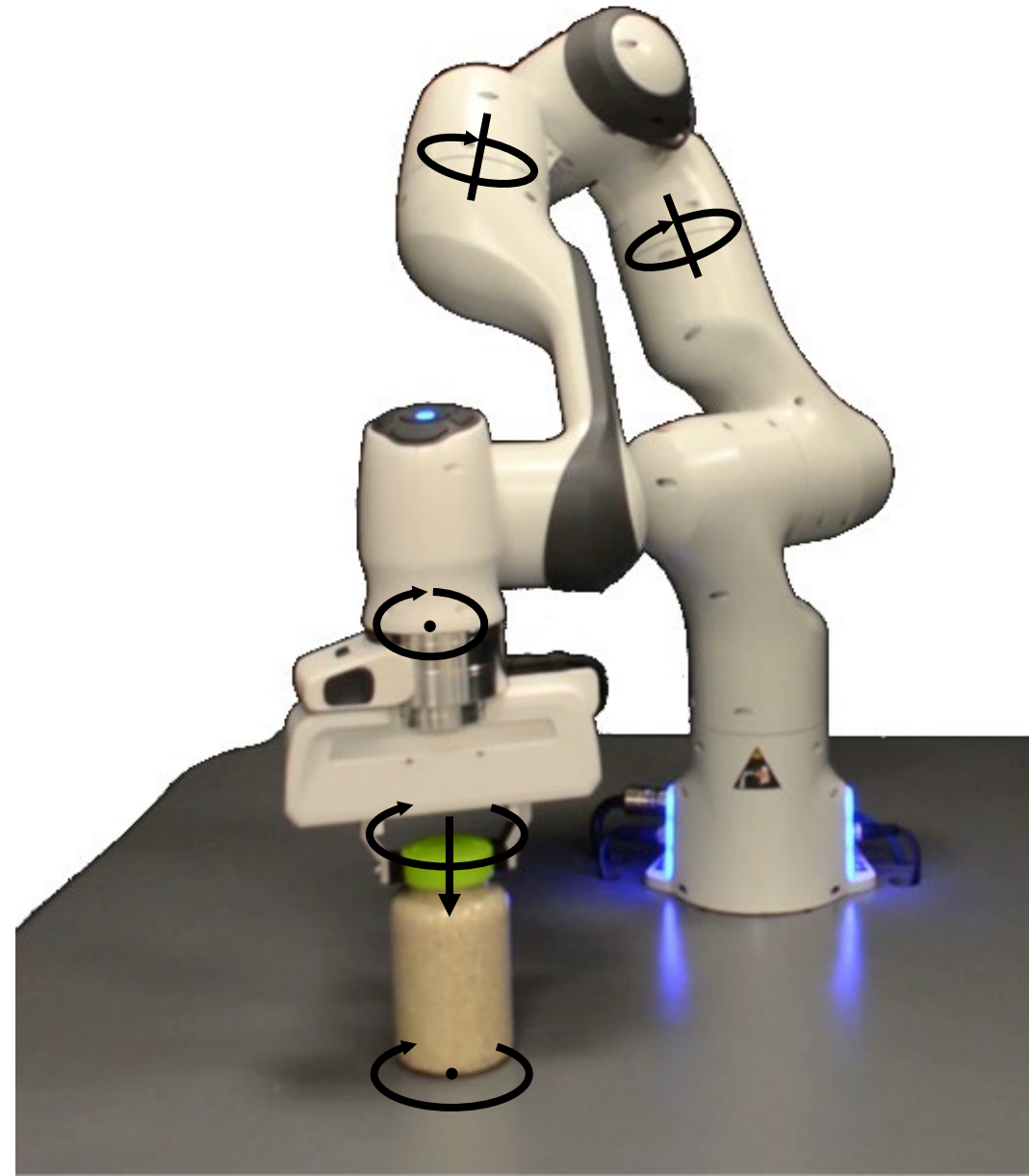




Kinematic Chain

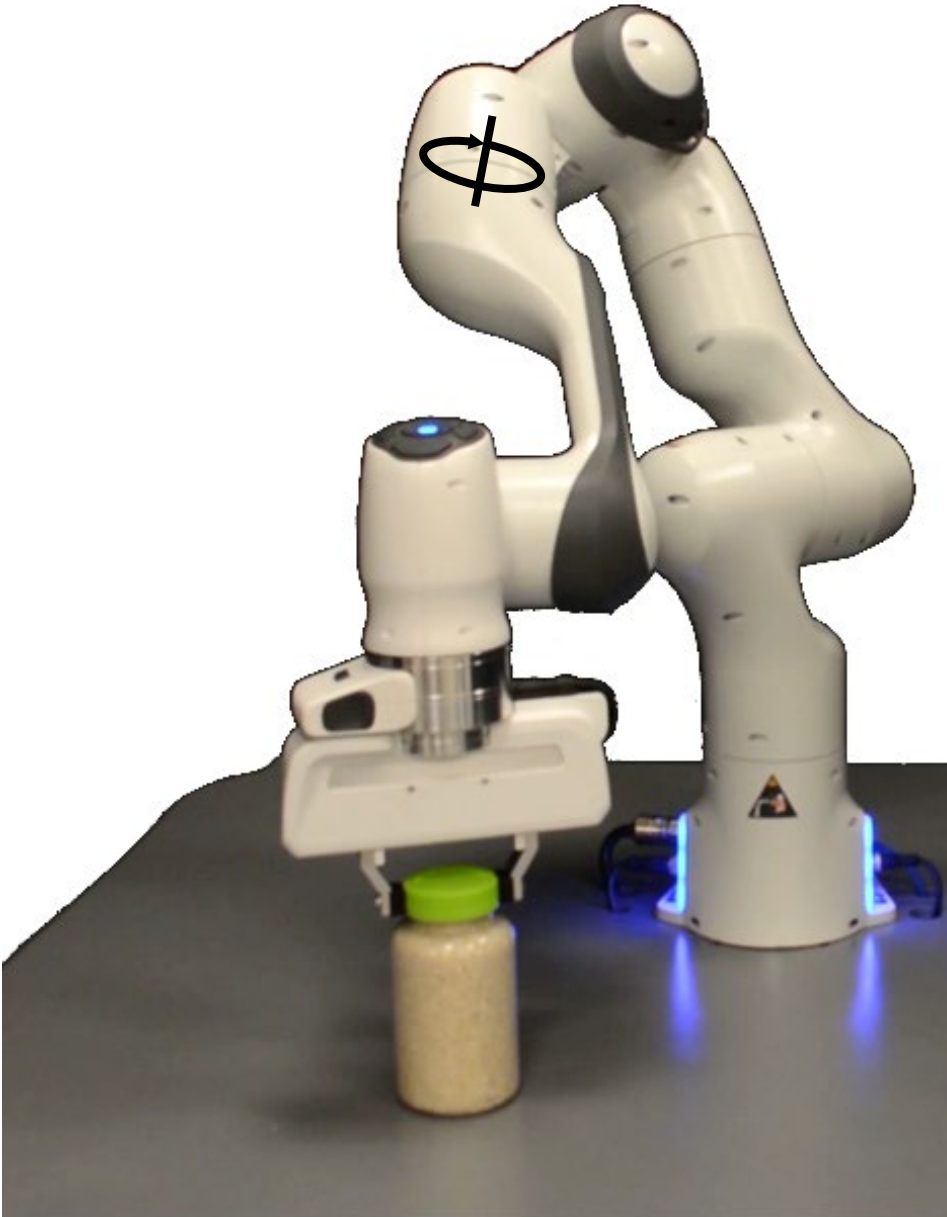


Kinematic Chain

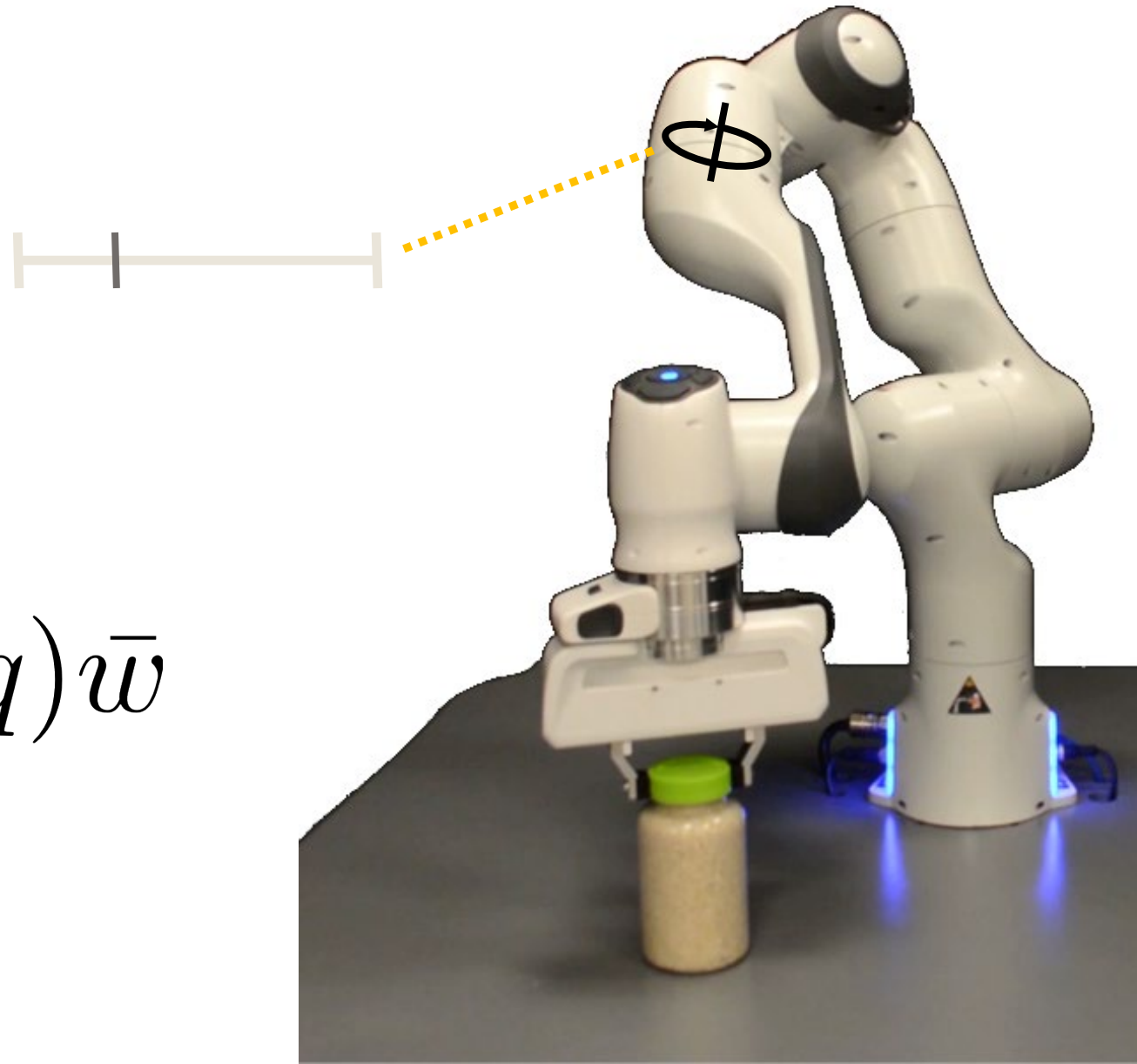


Forceful Kinematic Chain



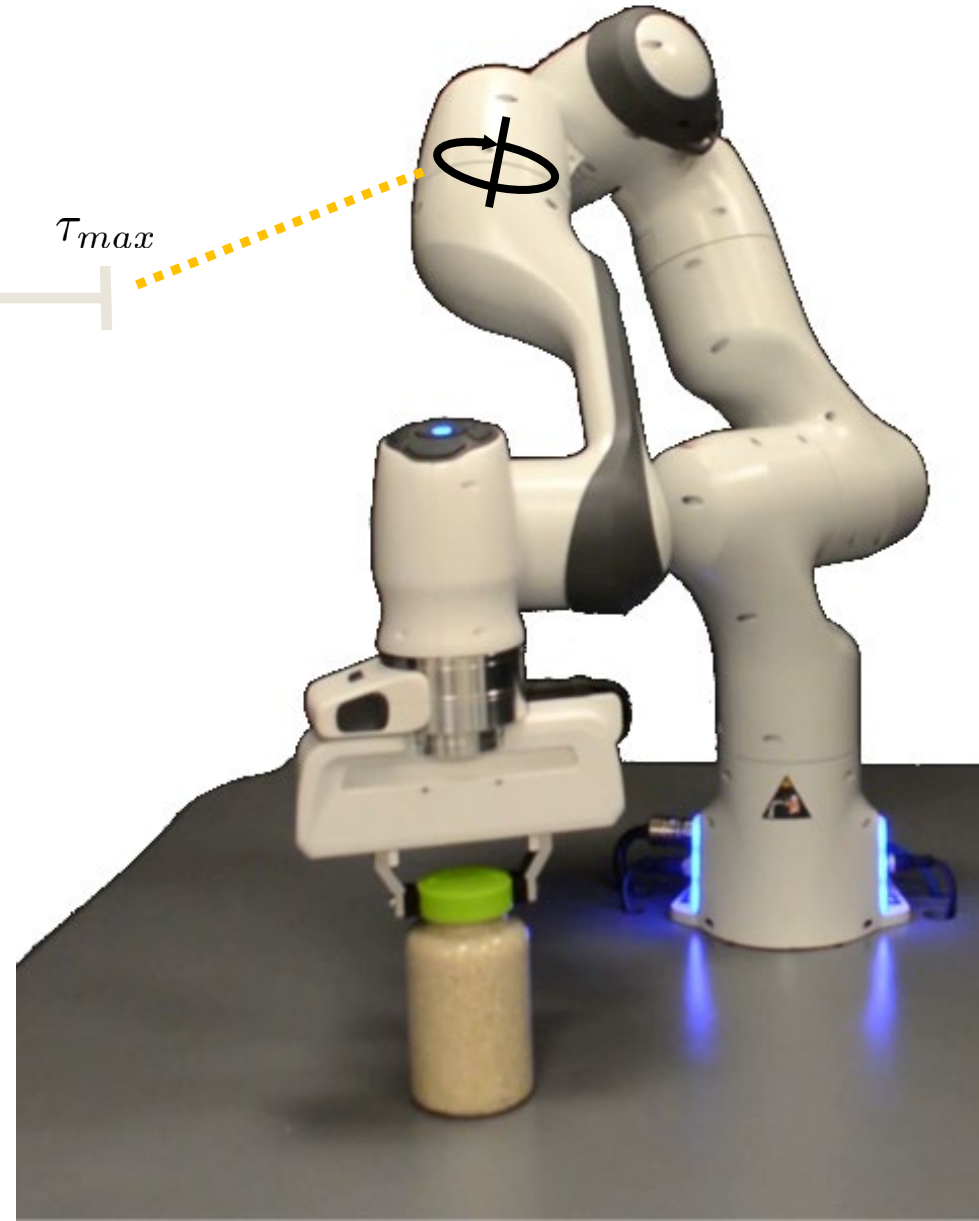


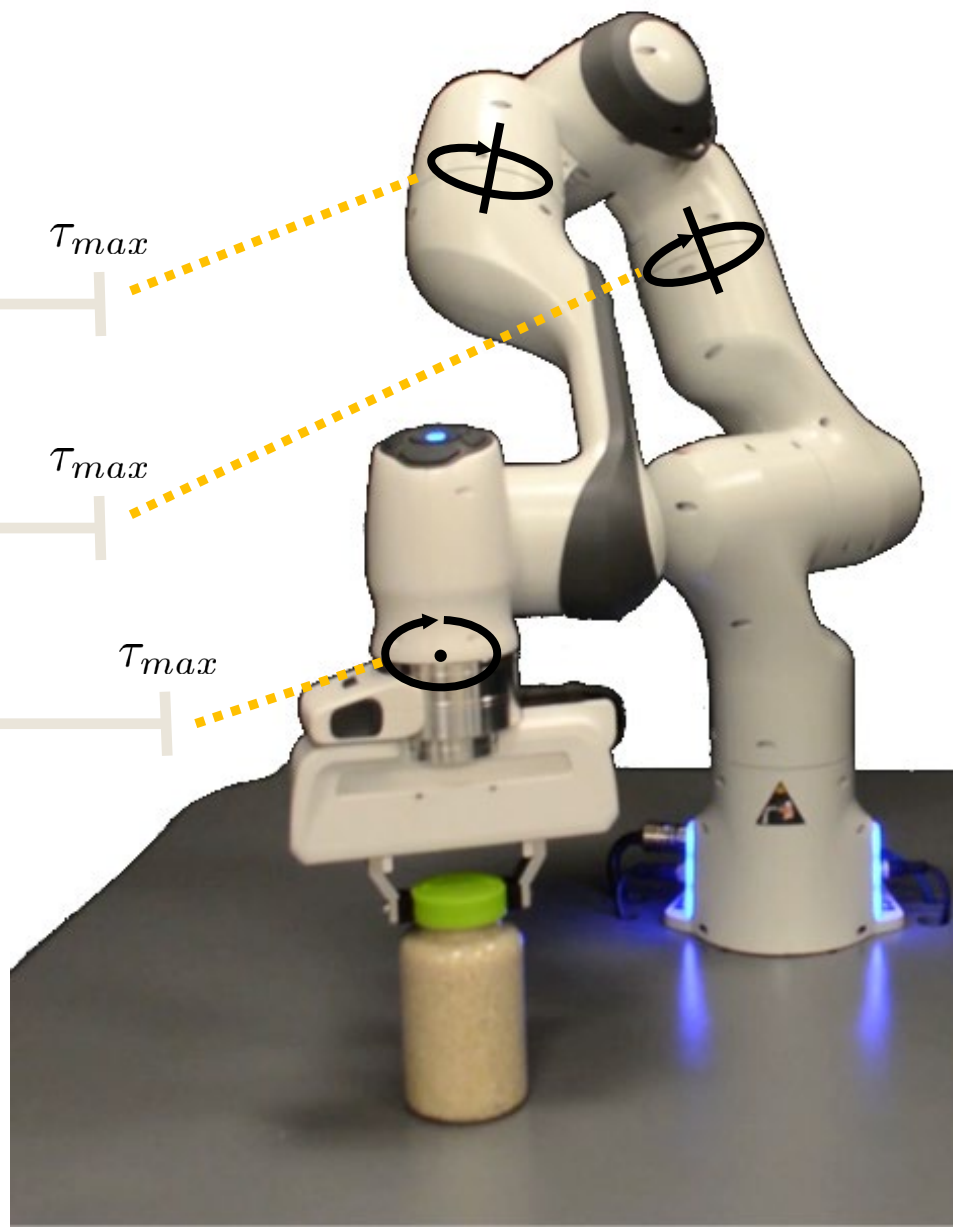
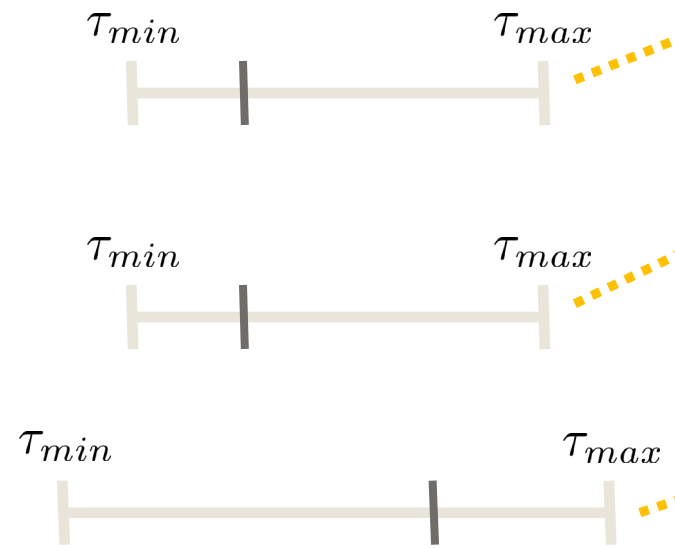
$$\tau = J_m^T(q) \bar{w}$$

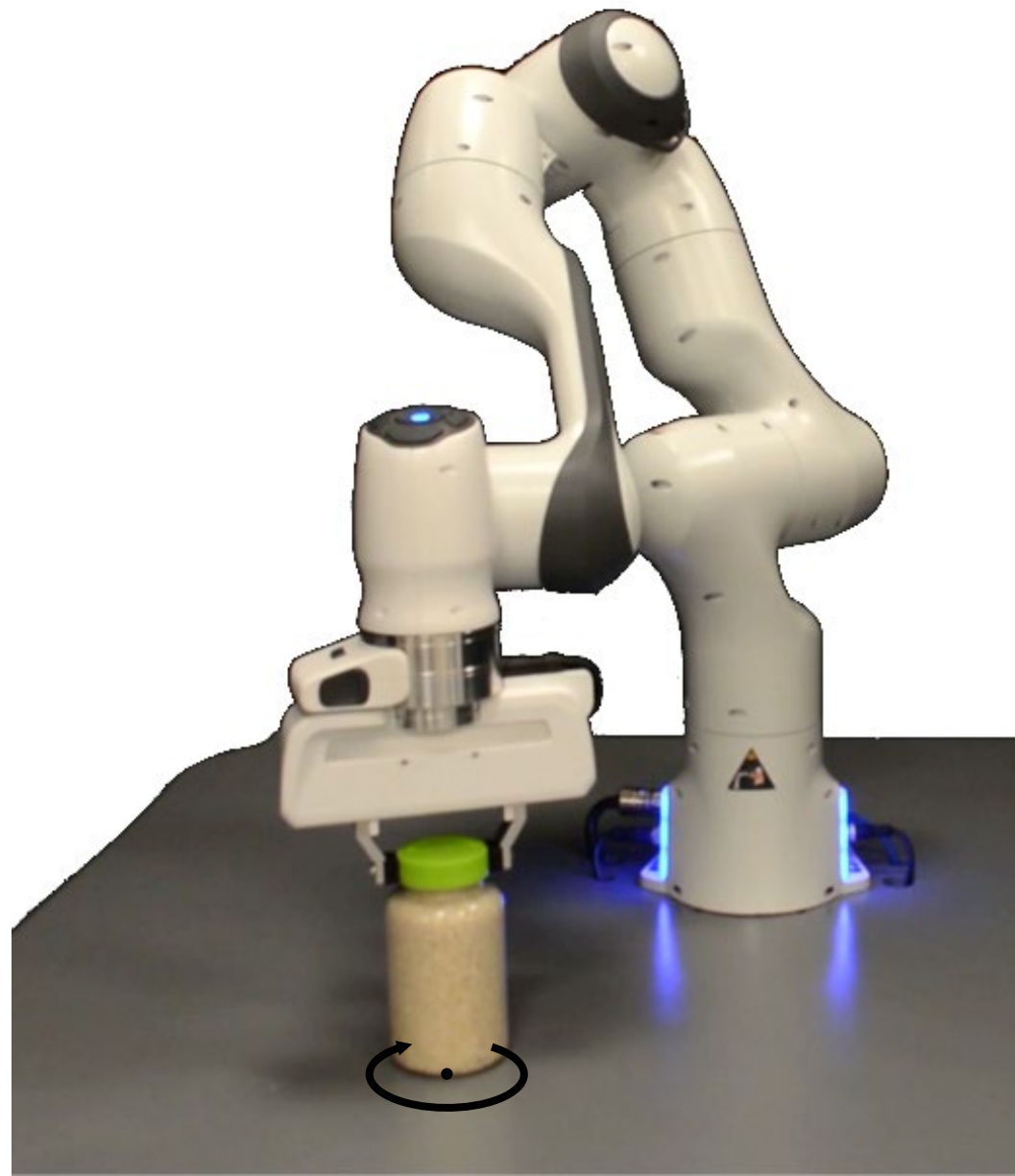


Torque Limits

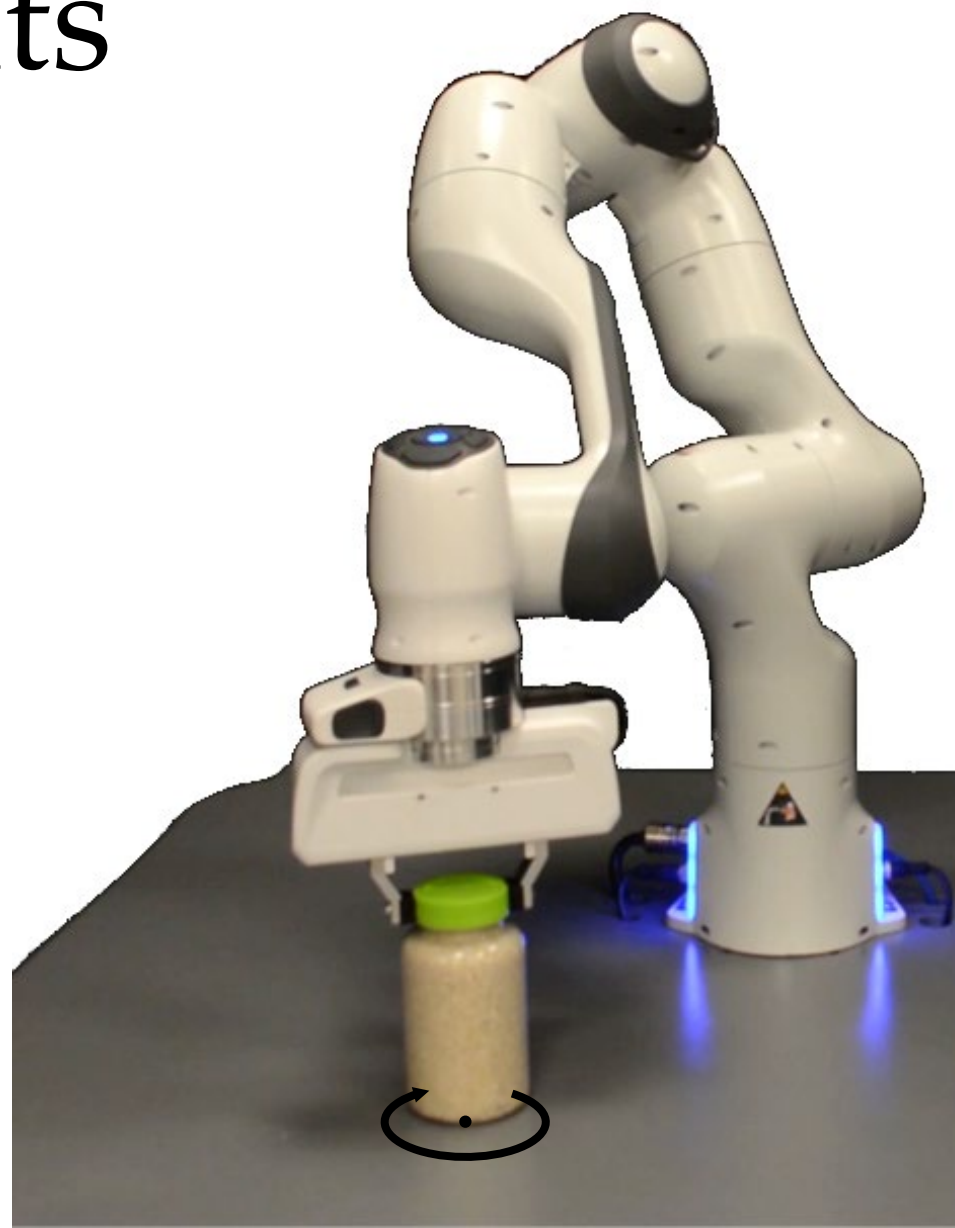
$$\tau_{lim} > \tau = J_m^T(q) \bar{w}$$



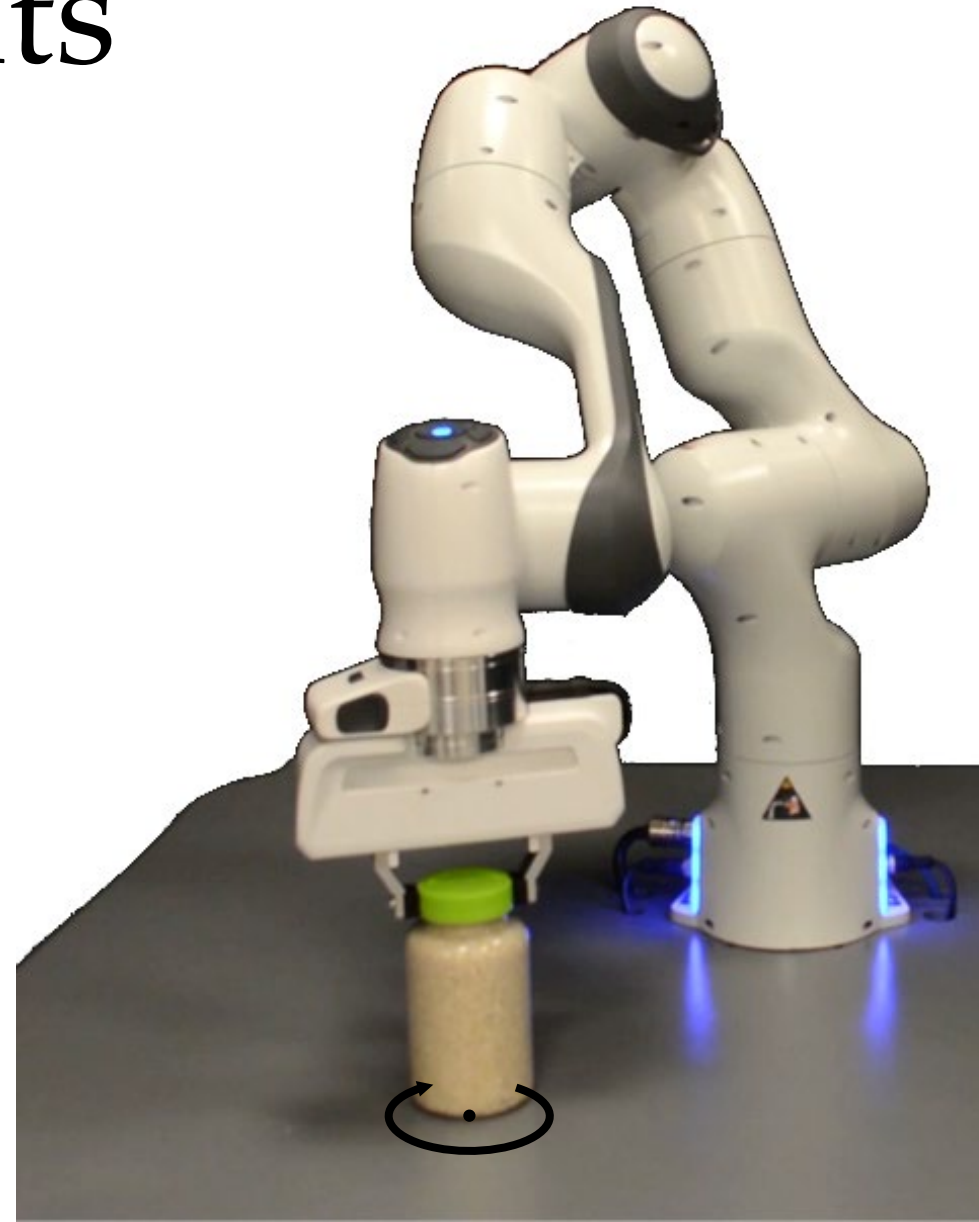




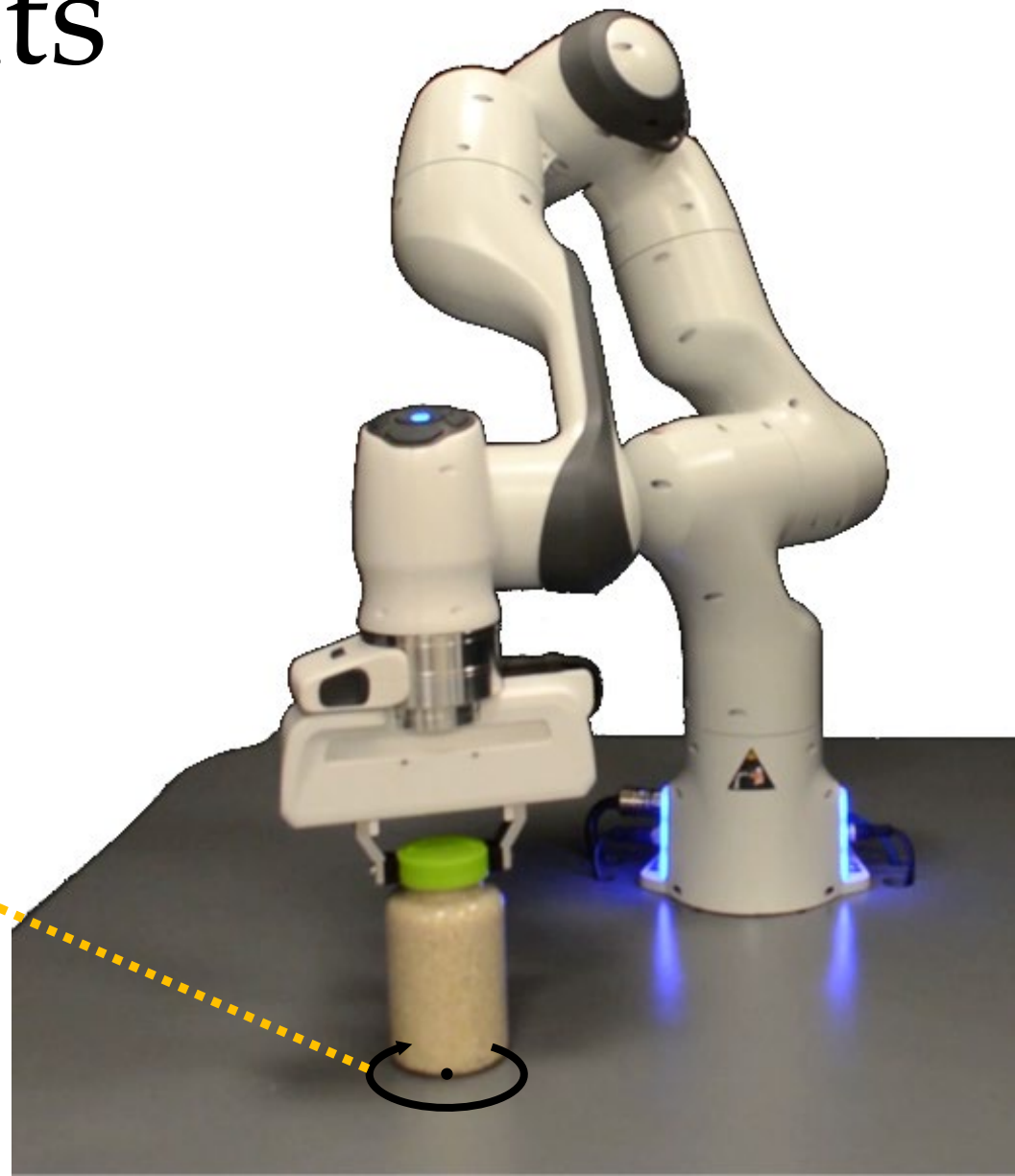
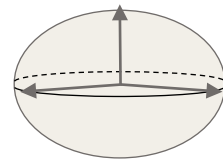
Non-Penetration Limits



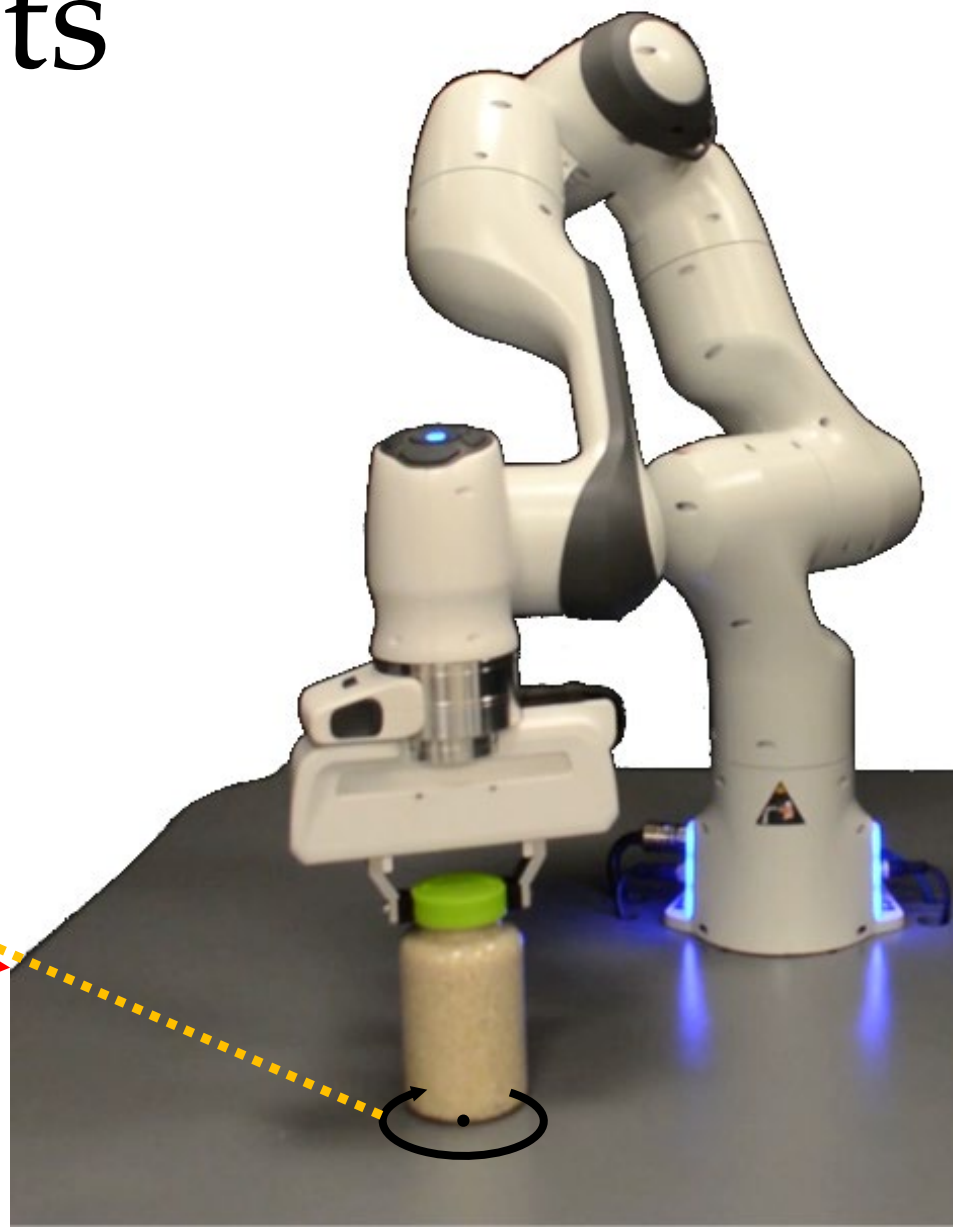
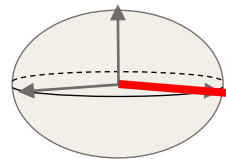
Non-Penetration Limits + Limit Surface



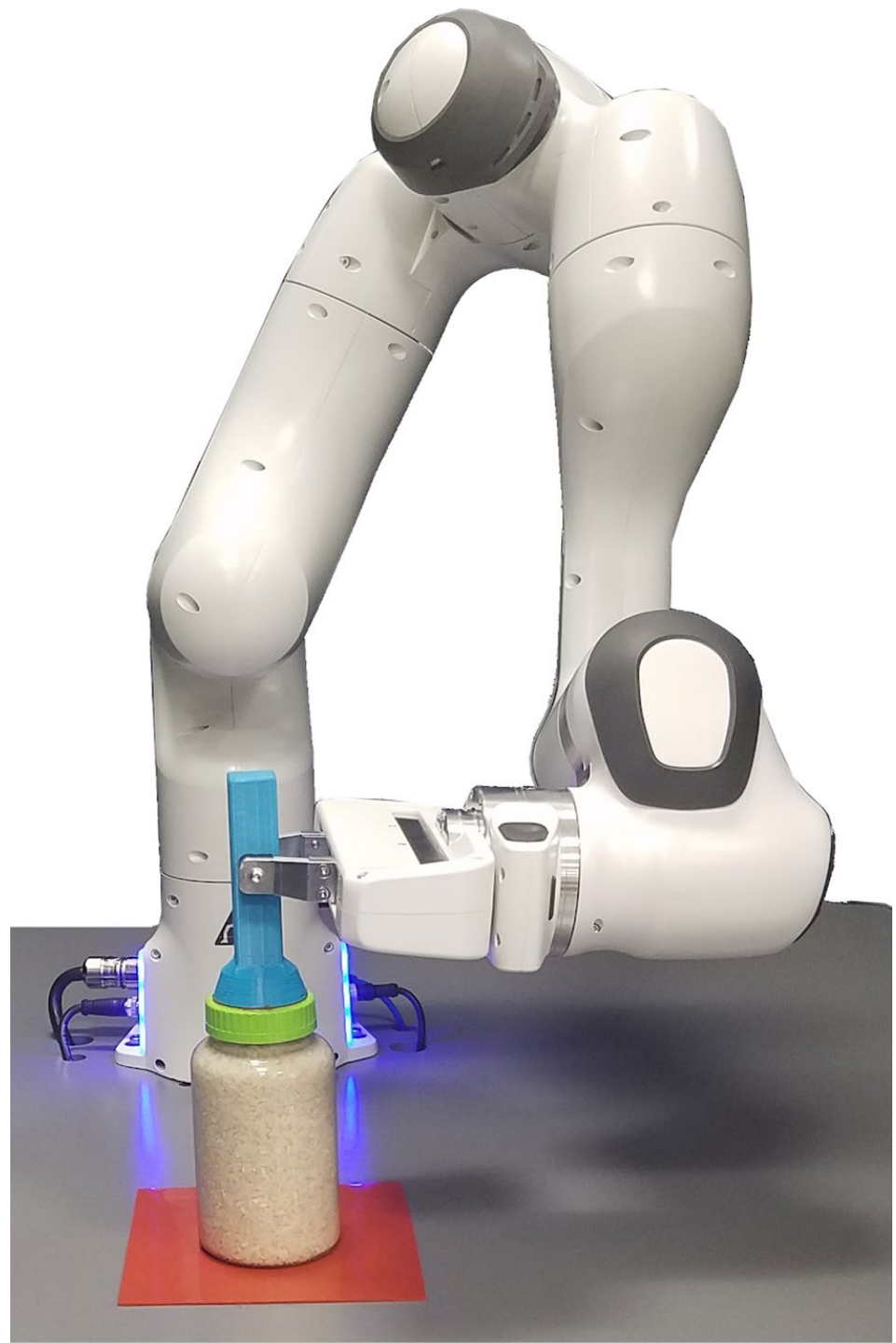
Non-Penetration Limits + Limit Surface

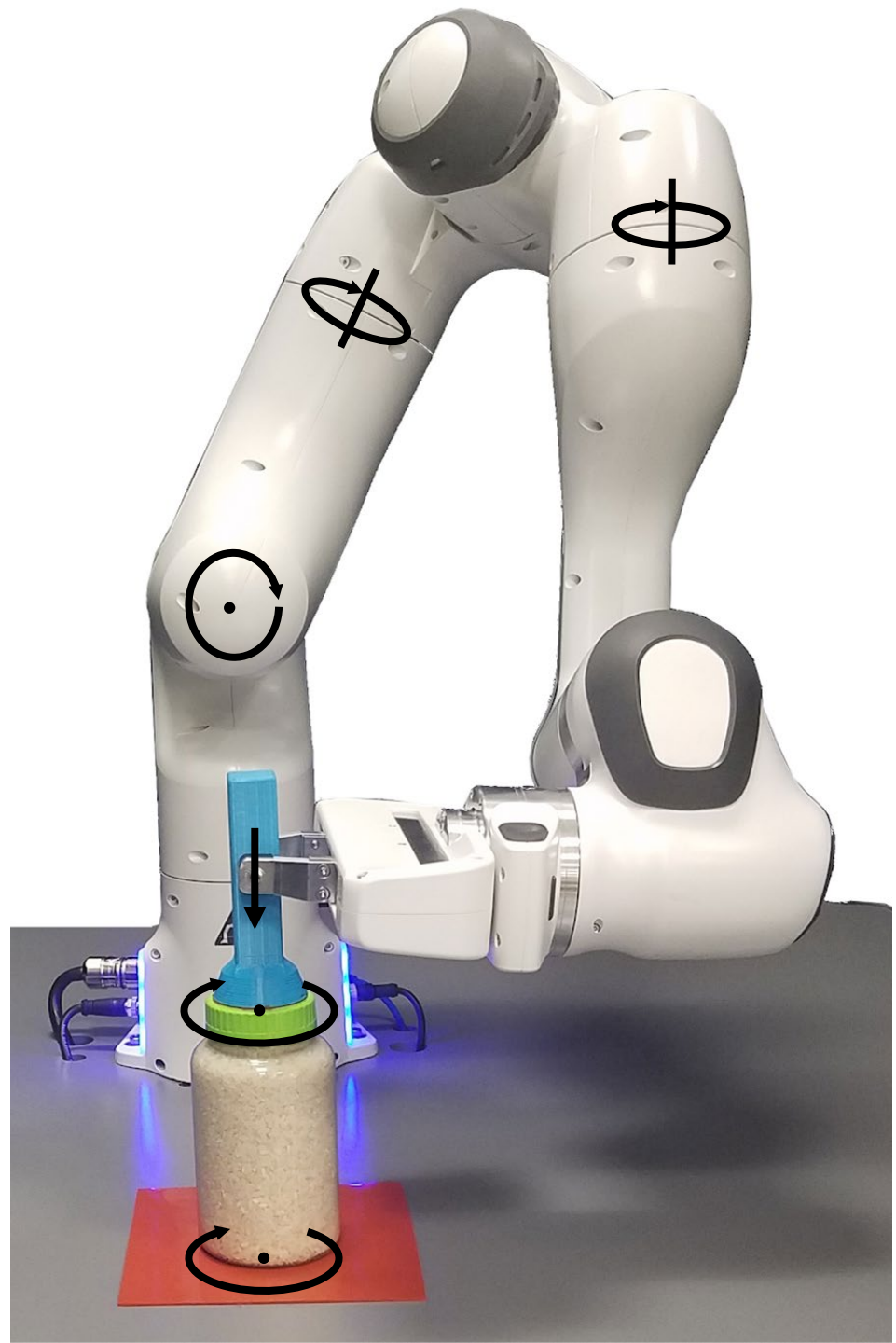


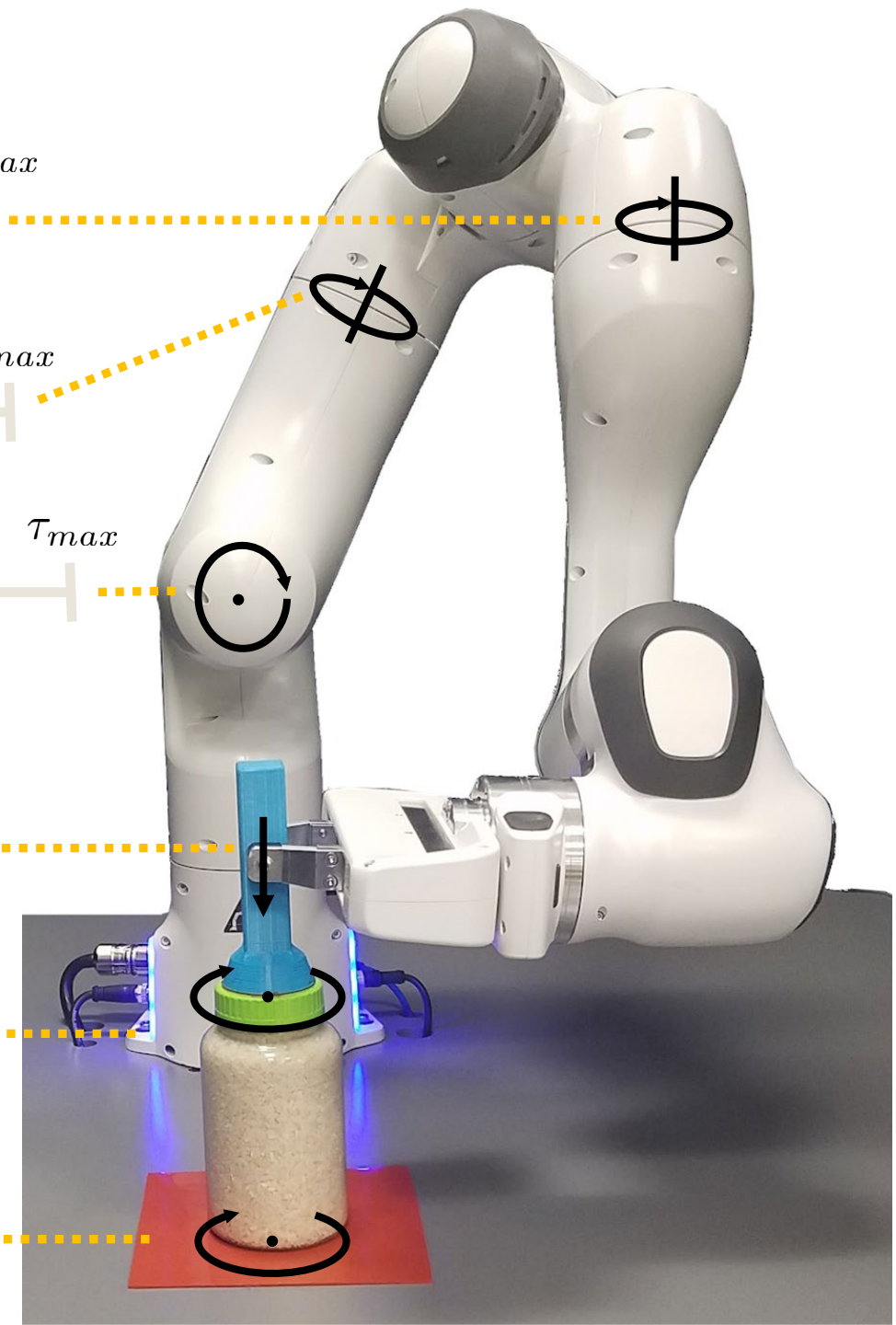
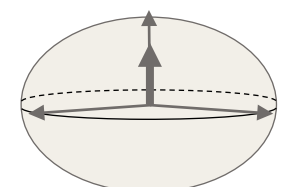
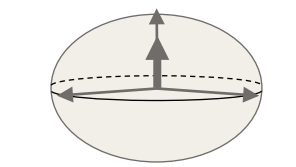
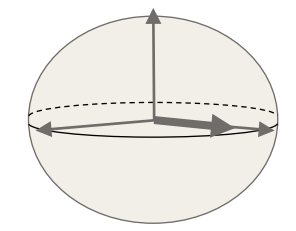
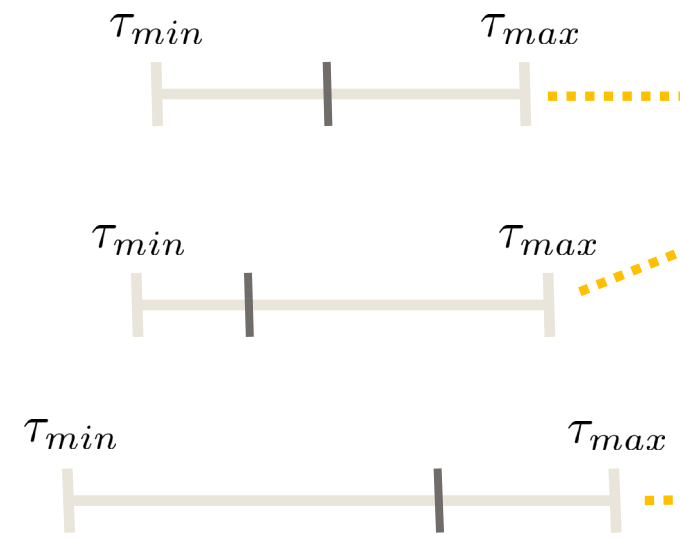
Non-Penetration Limits + Limit Surface













Force as a limiting factor?

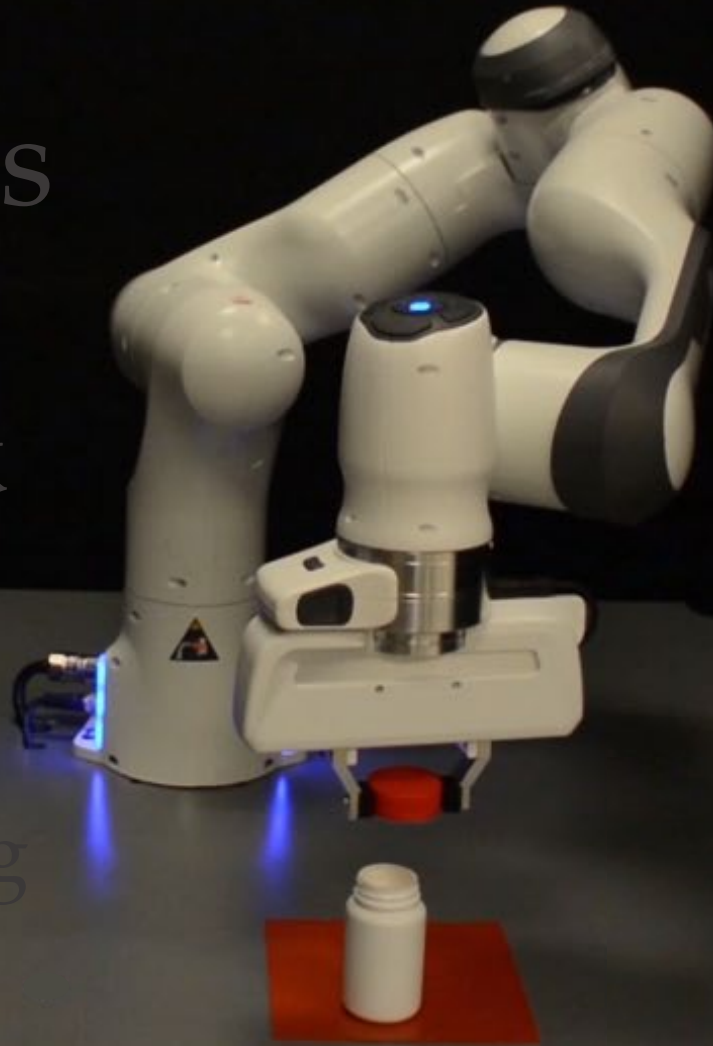
Forceful Kinematic Chain

Planning sequences
of actions?

TAMP Framework

Robust sequences?

Cost-Sensitive Planning



Force as a limiting factor?

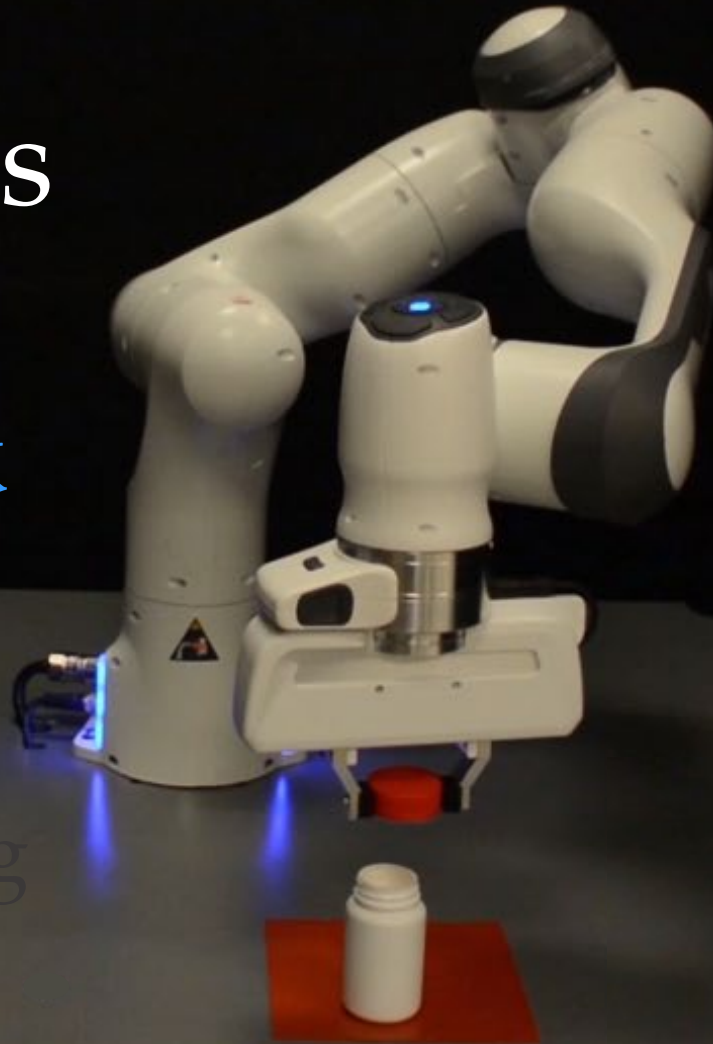
Forceful Kinematic Chain

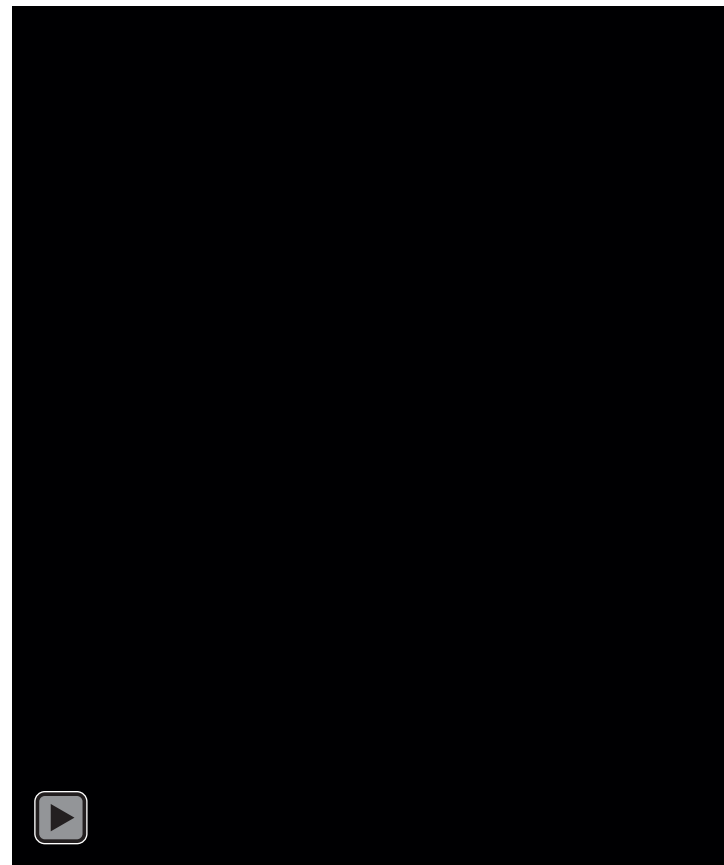
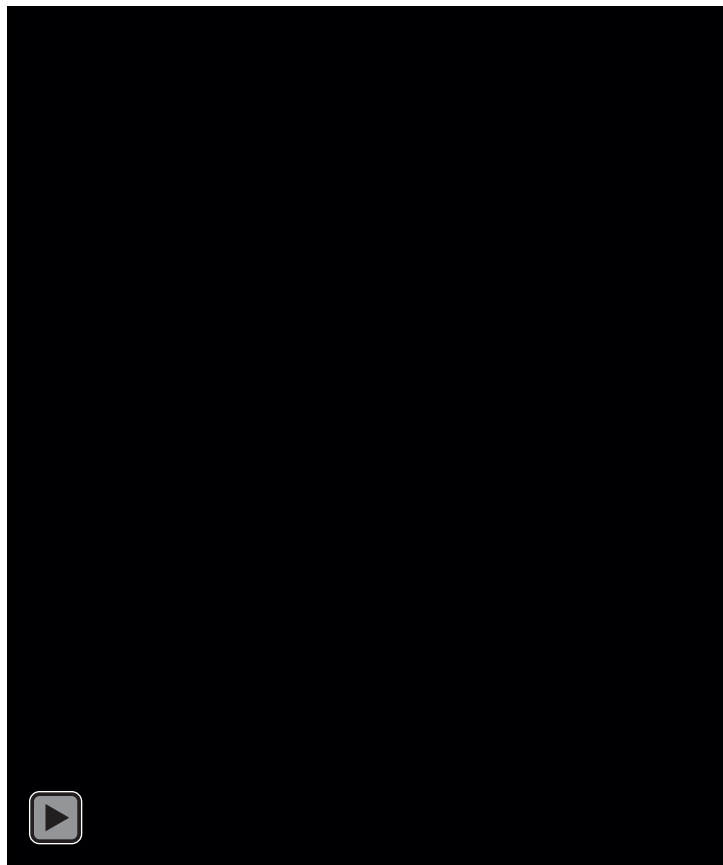
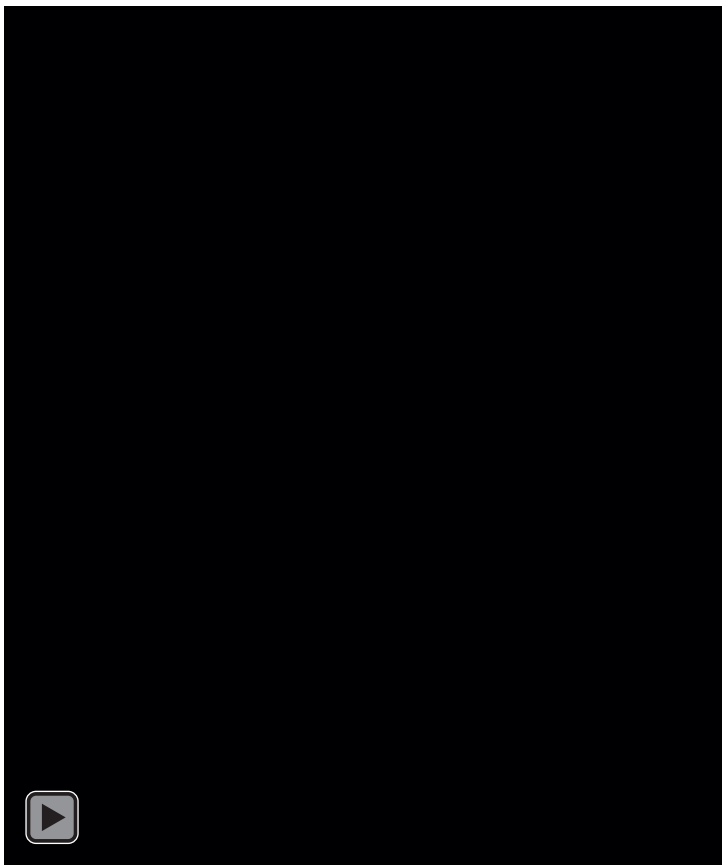
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Find a **sequence of actions** and the parameters of those actions, subject to constraints

place



move

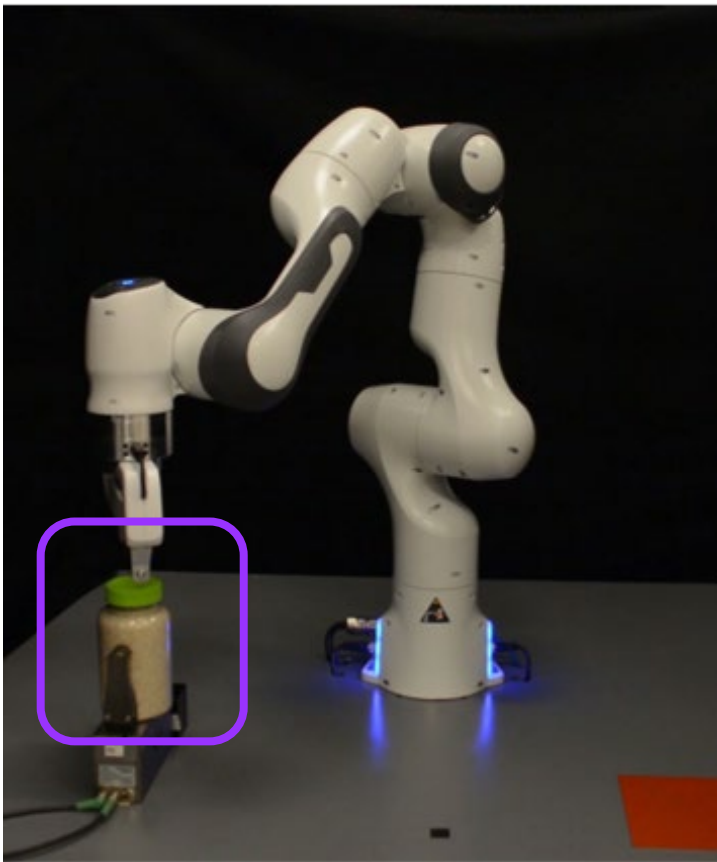


pushtwist



Find a sequence of actions and the **parameters of those actions**, subject to constraints

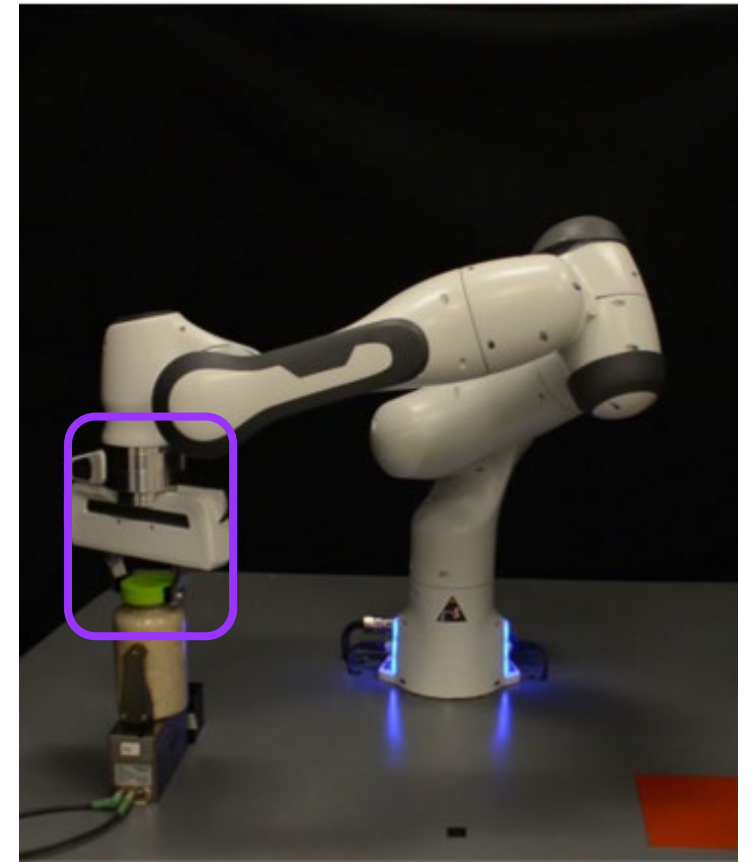
place



move



pushtwist



Find a sequence of actions and the parameters of those actions, subject to **constraints**

place



move



pushtwist



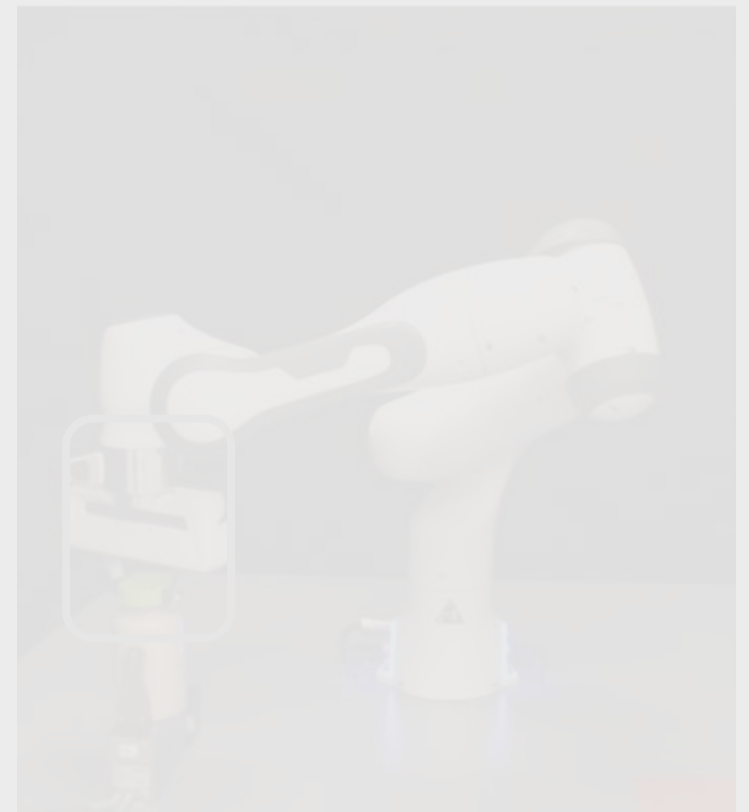
TAMP Framework: PDDLStream

Find a sequence of actions, subject to constraints

place

move

pushtwist

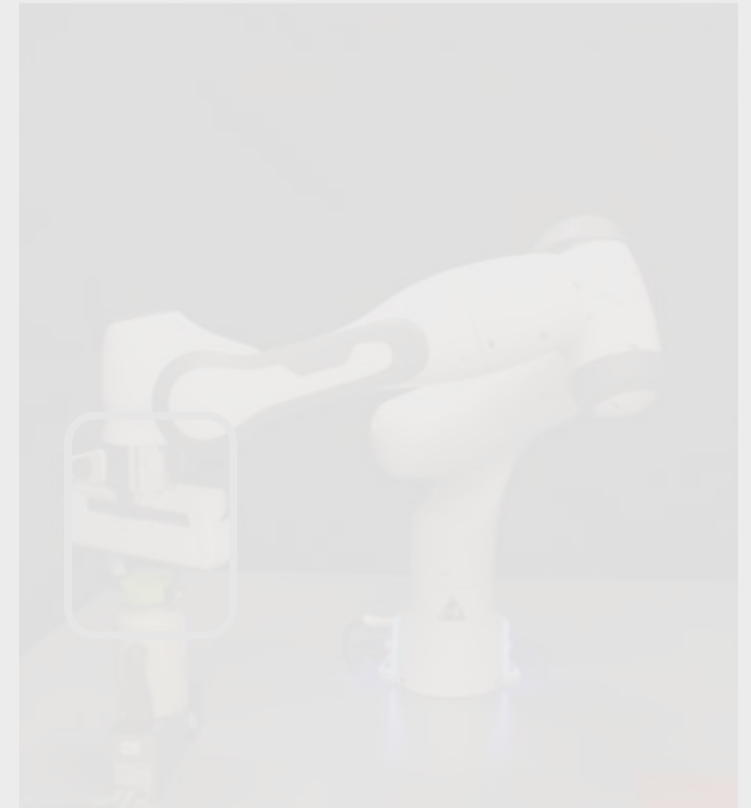


TAMP Framework: PDDLStream

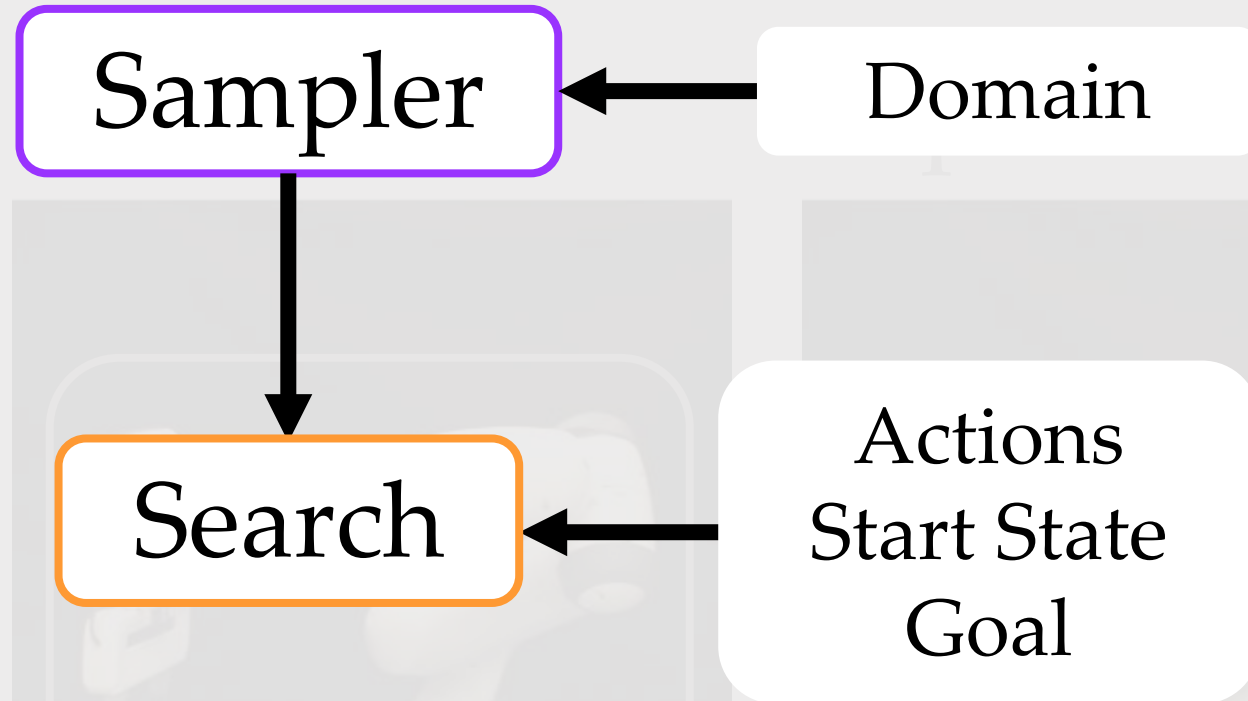
Find a sequence of actions, subject to constraints

Sampler

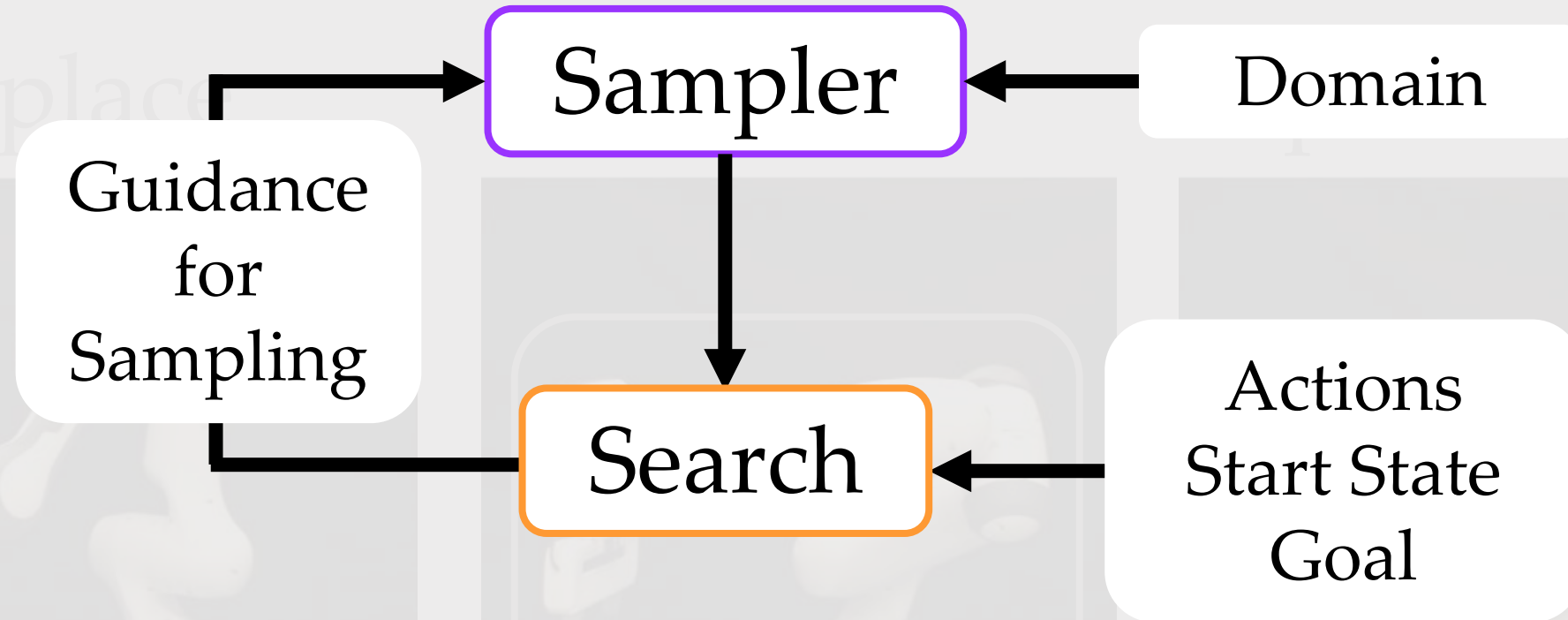
Domain



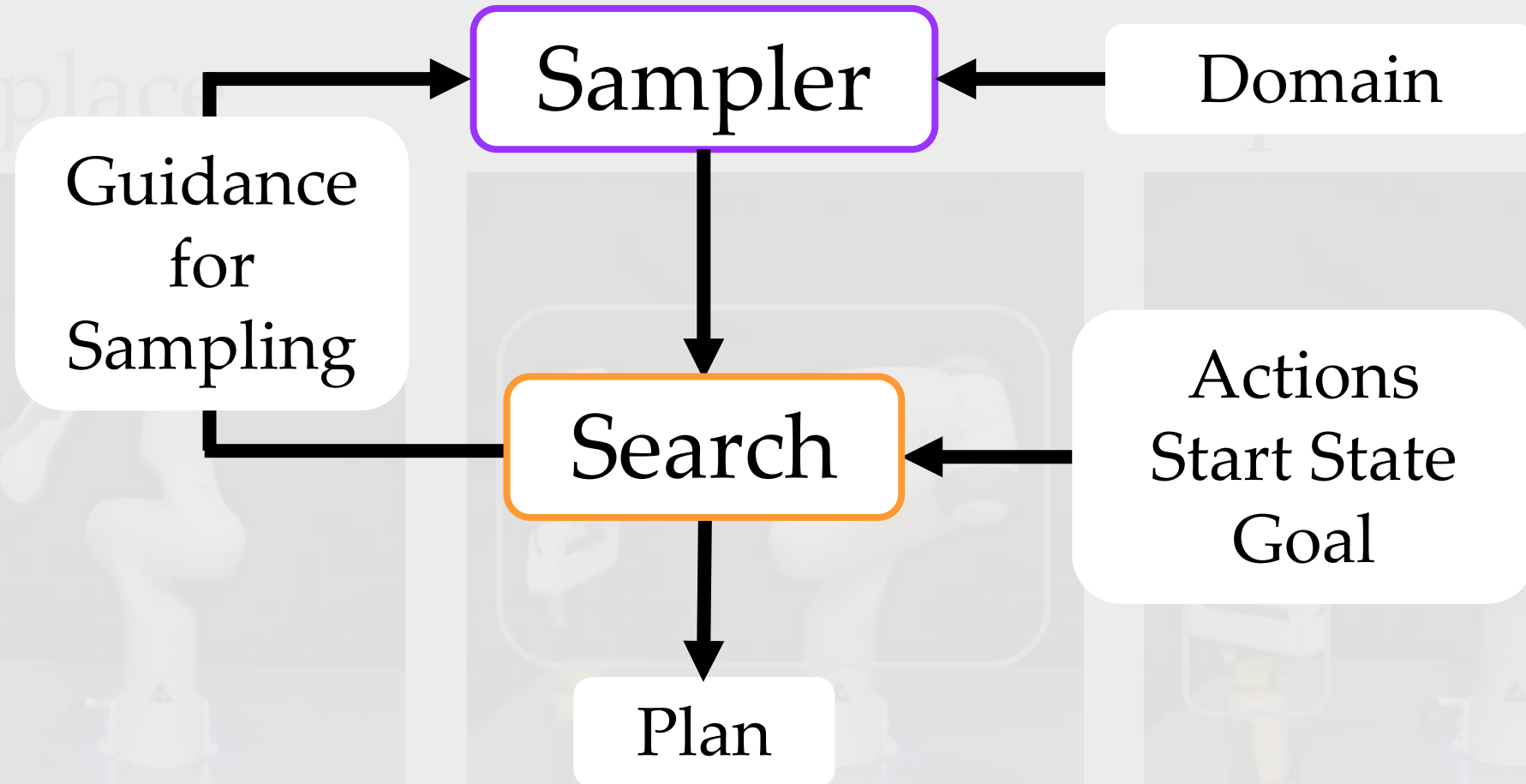
TAMP Framework: PDDLStream



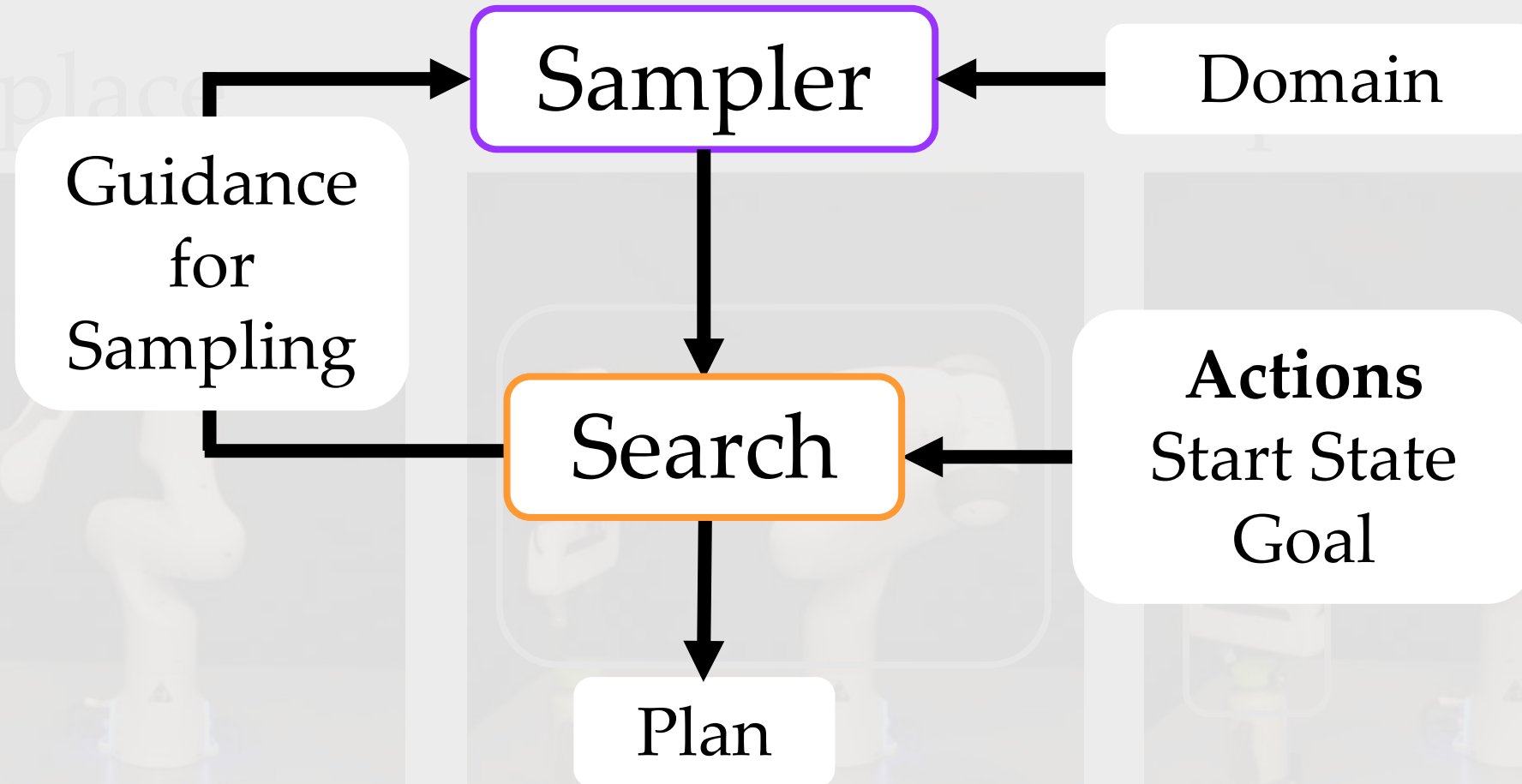
TAMP Framework: PDDLStream



TAMP Framework: PDDLStream



TAMP Framework: PDDLStream



place



move



pushtwist



Controller
Preconditions
Effects



place

Controller
Preconditions
Effects



move

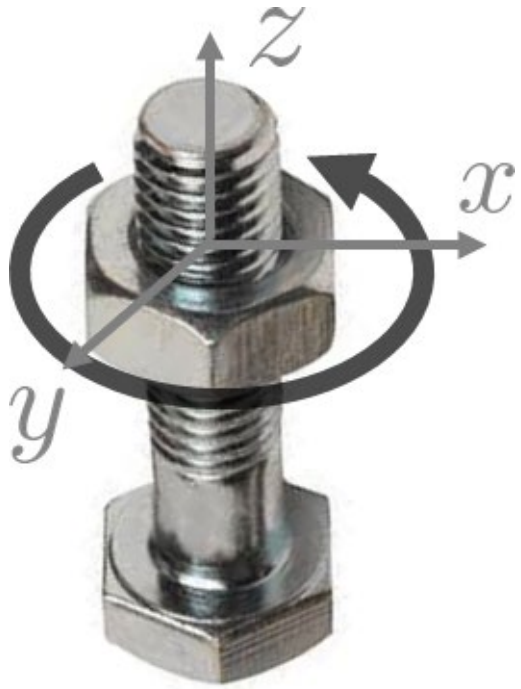
Controller
Preconditions
Effects



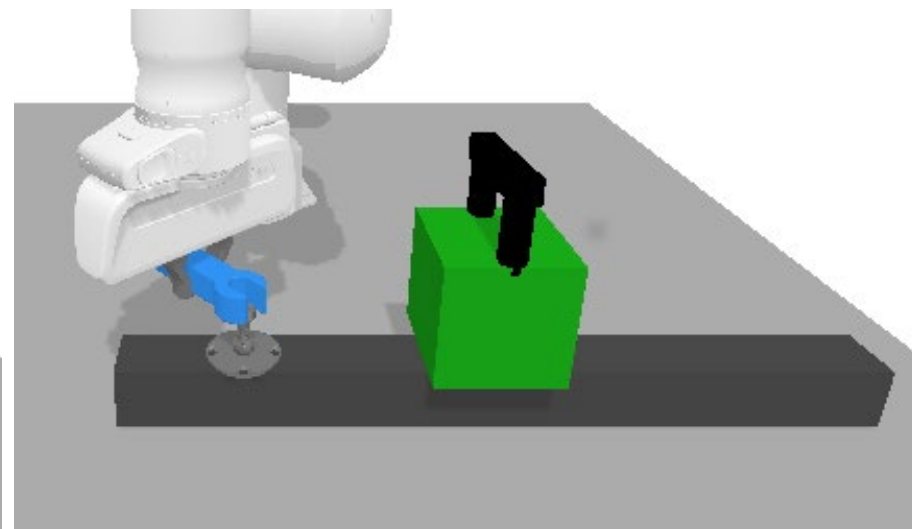
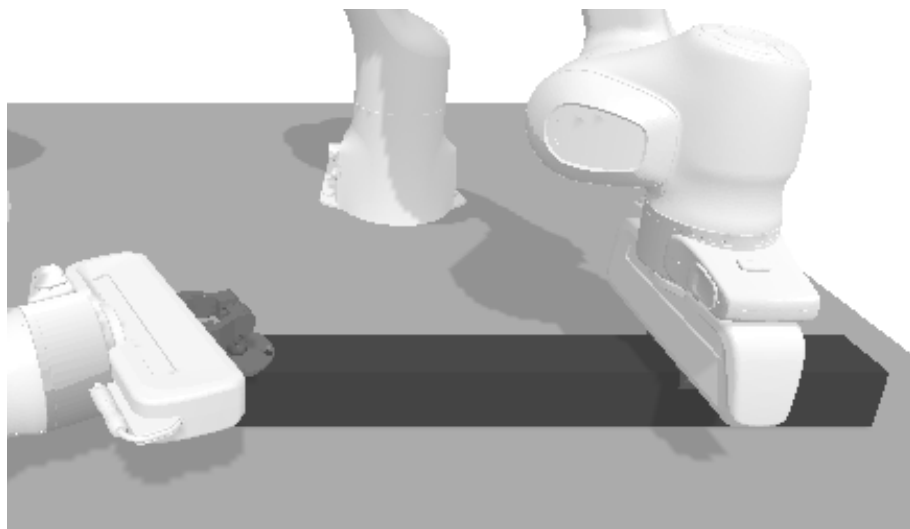
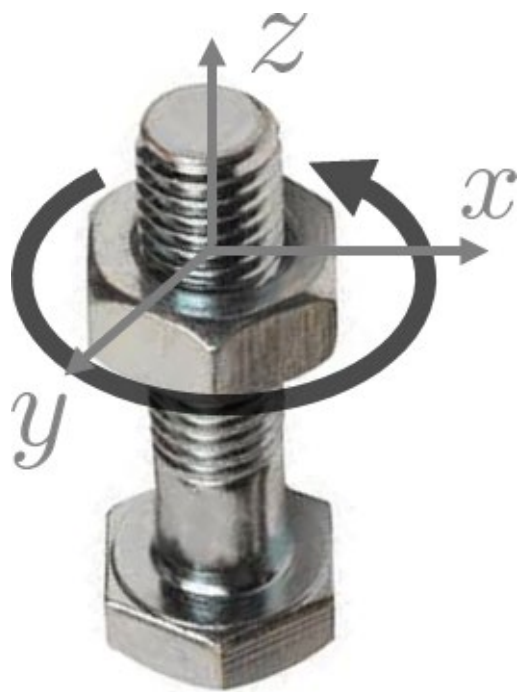
pushtwist



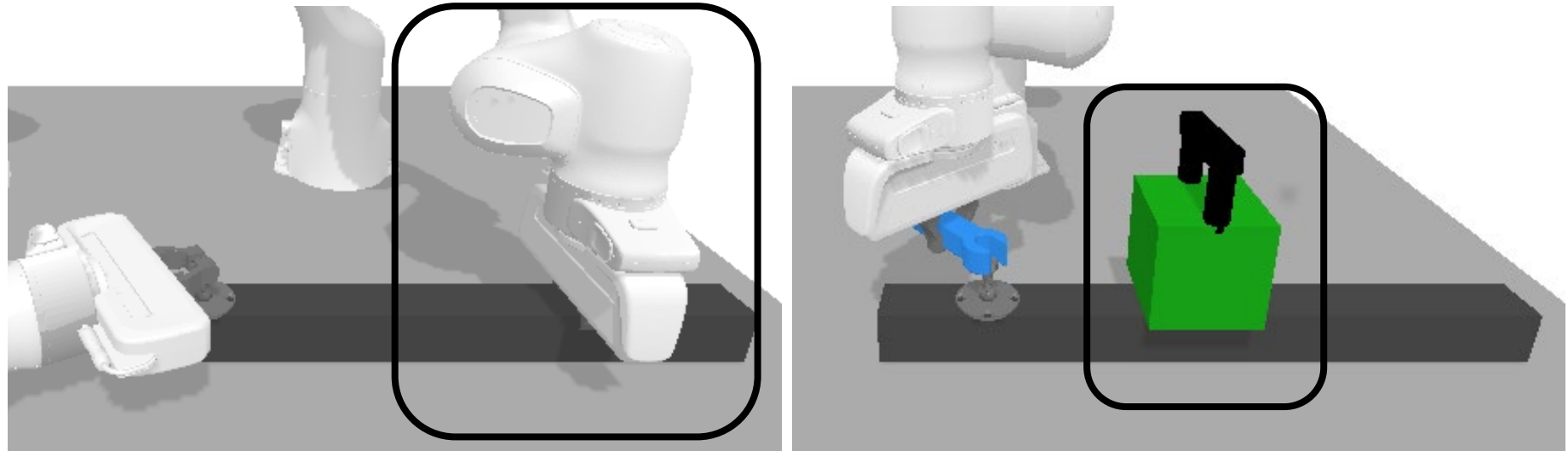
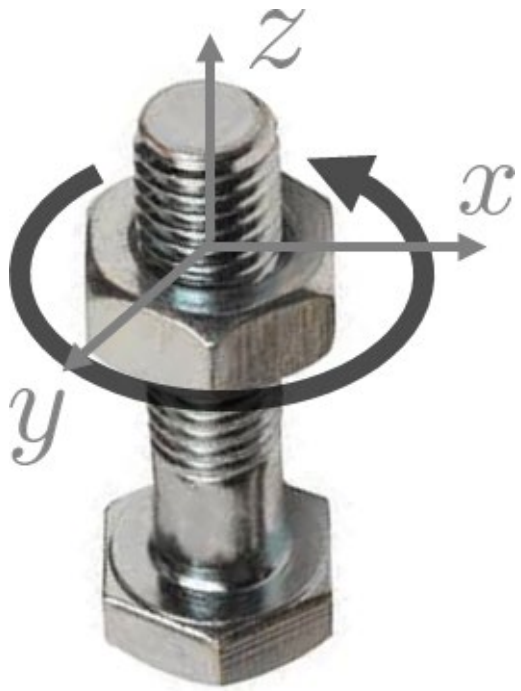
Second Domain: Nut Twisting



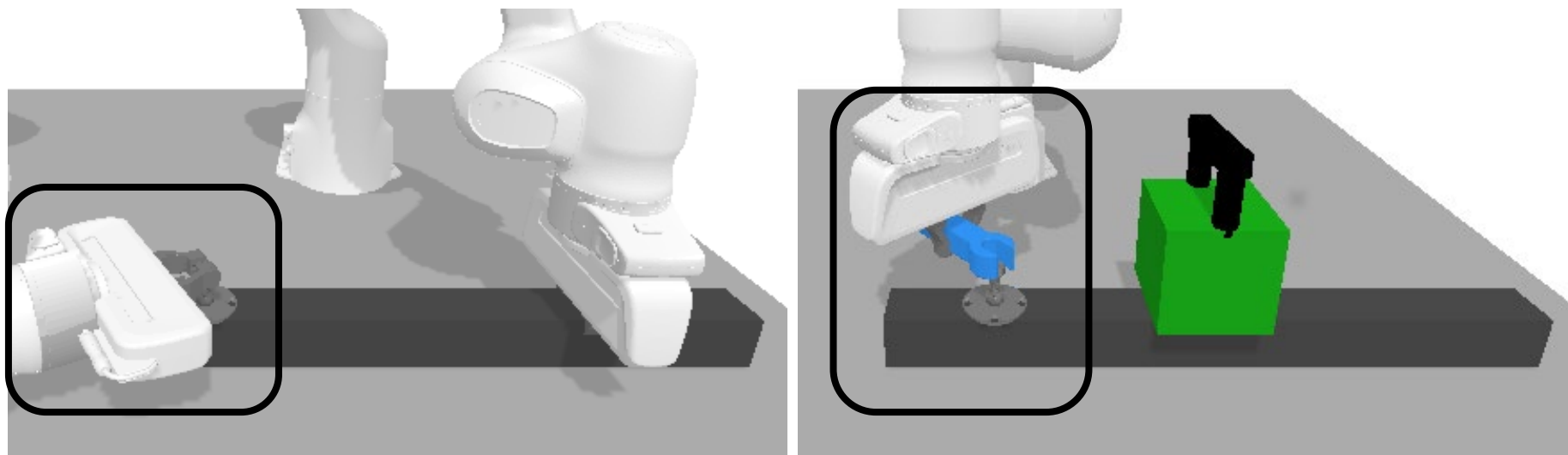
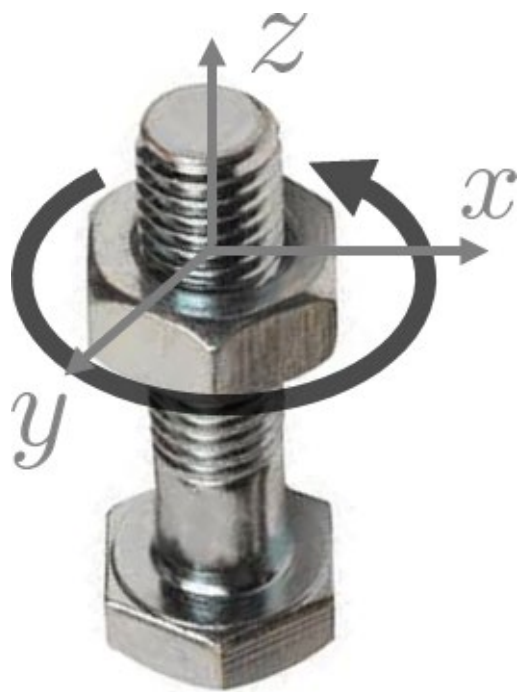
Second Domain: Nut Twisting



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Second Domain: Nut Twisting





Force as a limiting factor?

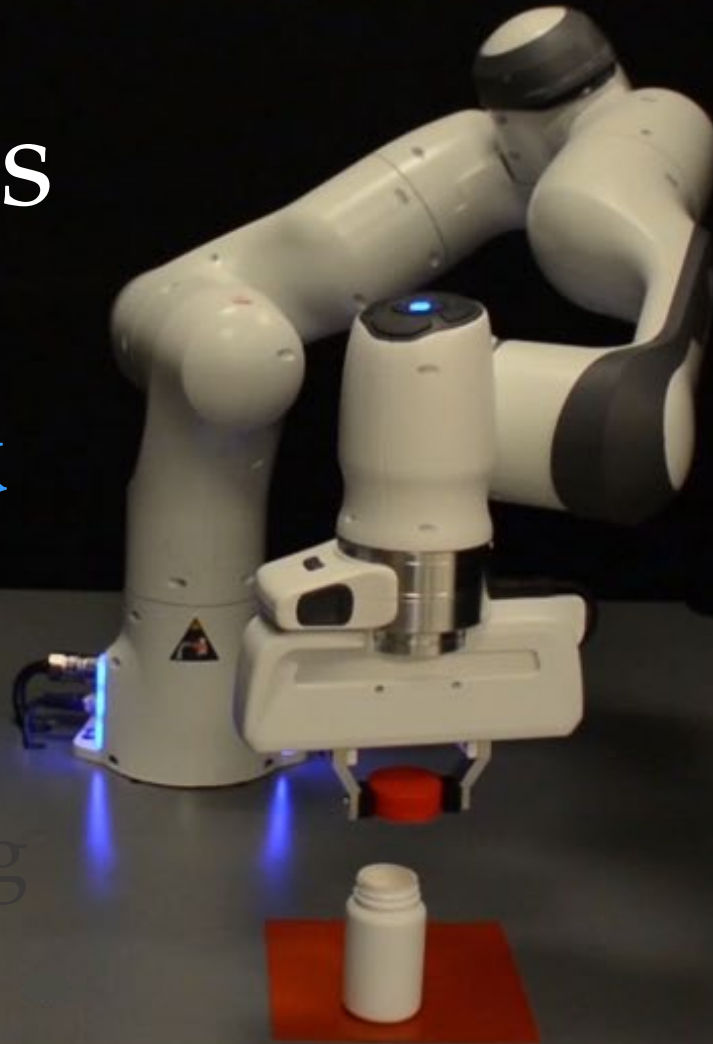
Forceful Kinematic Chain

Planning sequences
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Robust sequences?

Cost-Sensitive Planning



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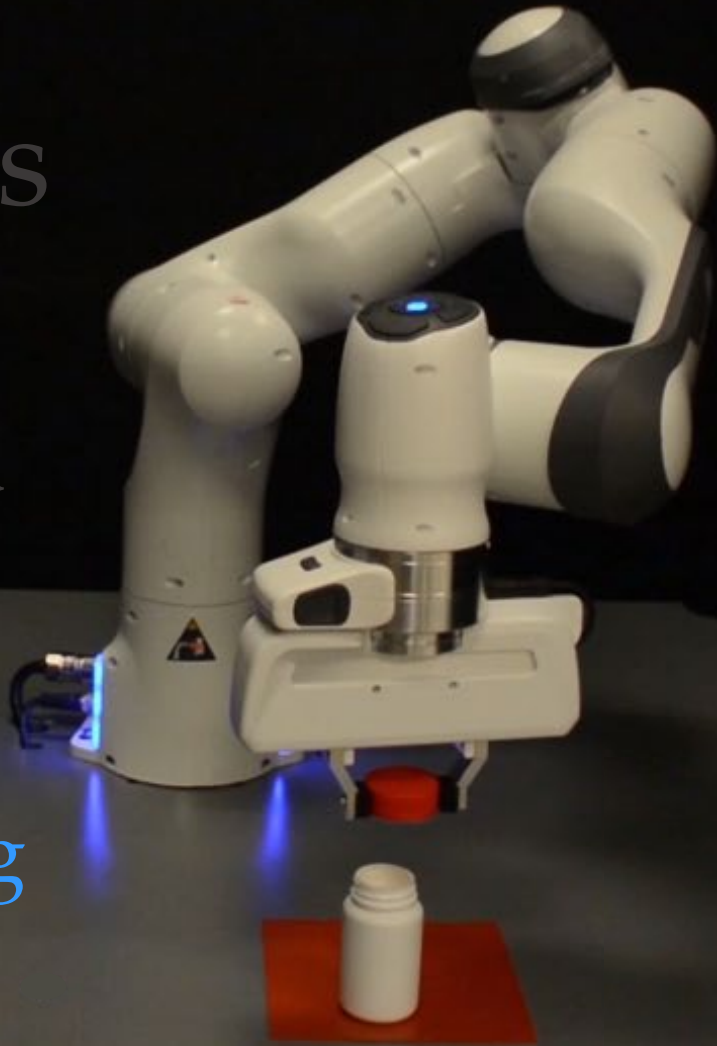
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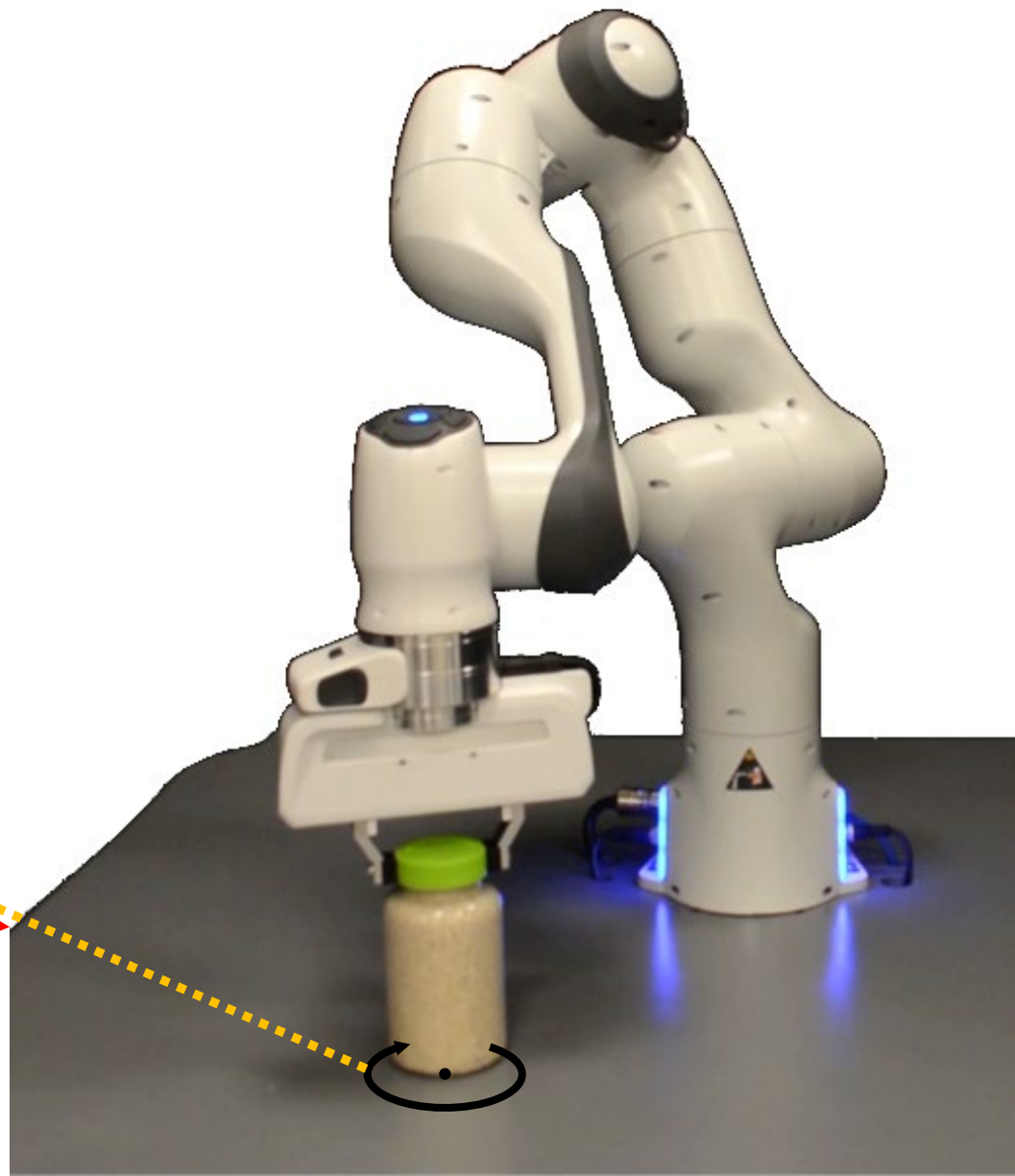
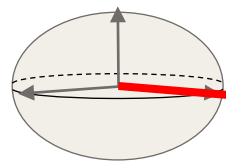
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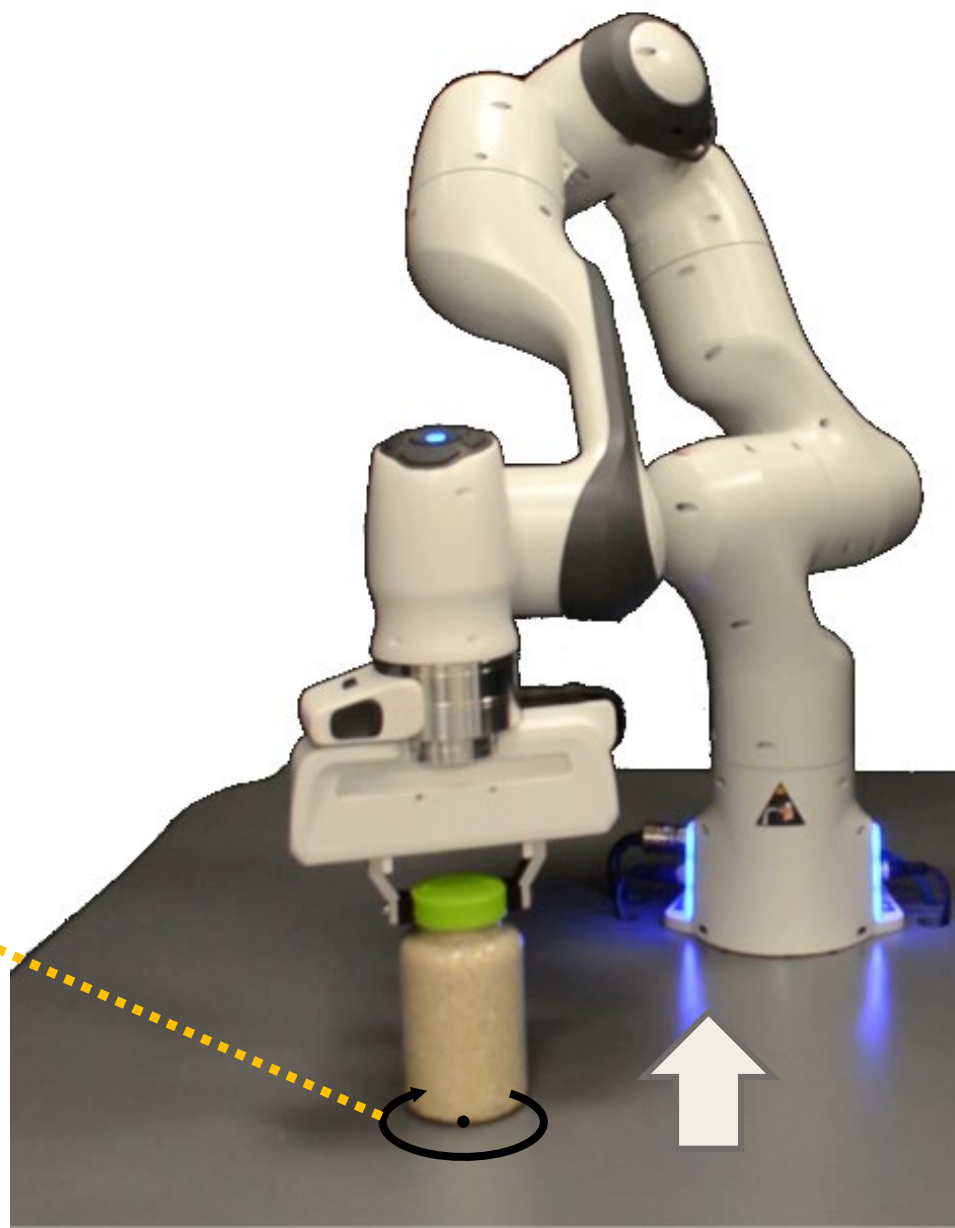
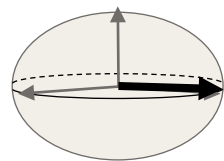
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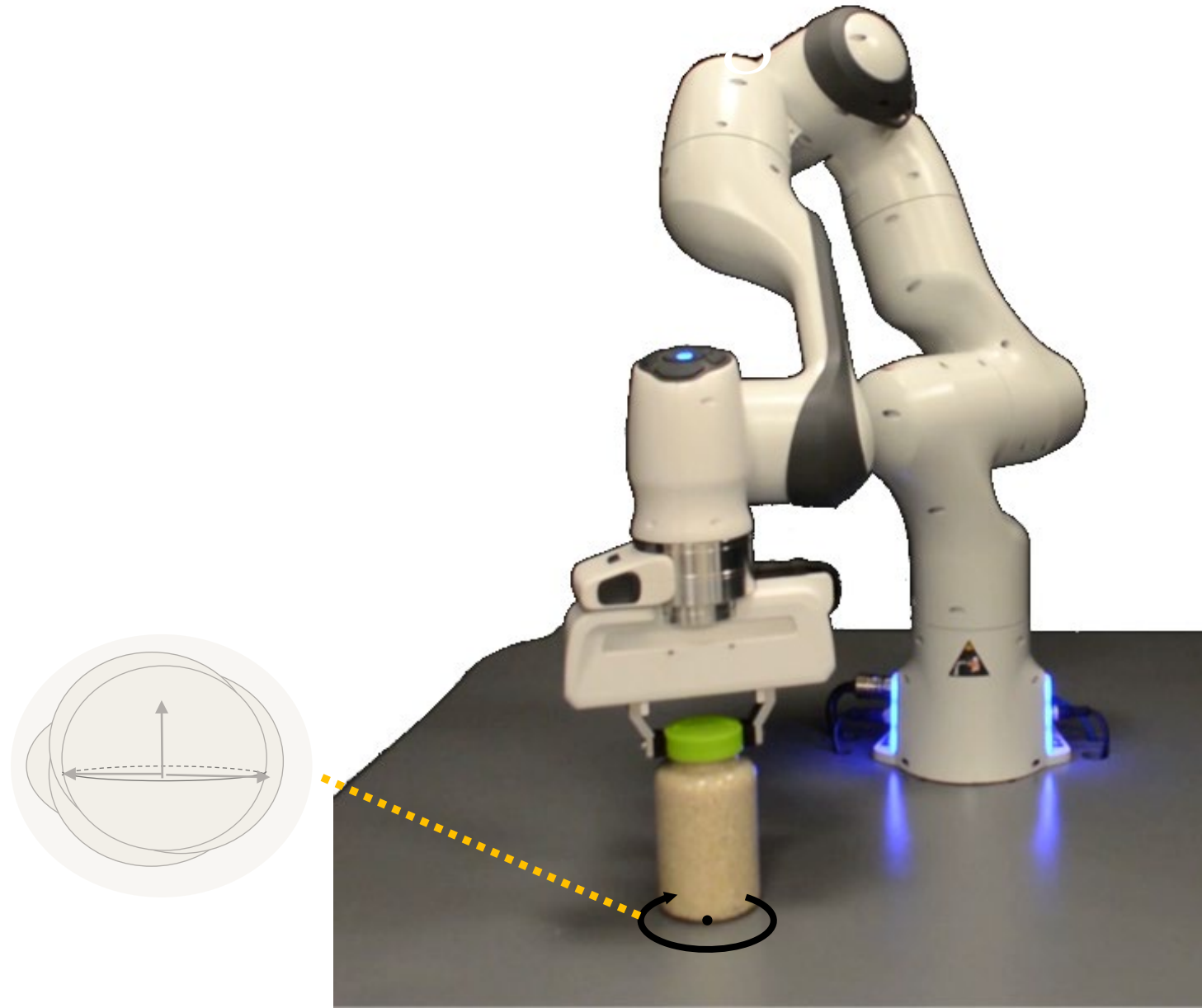
Cost-Sensitive Planning





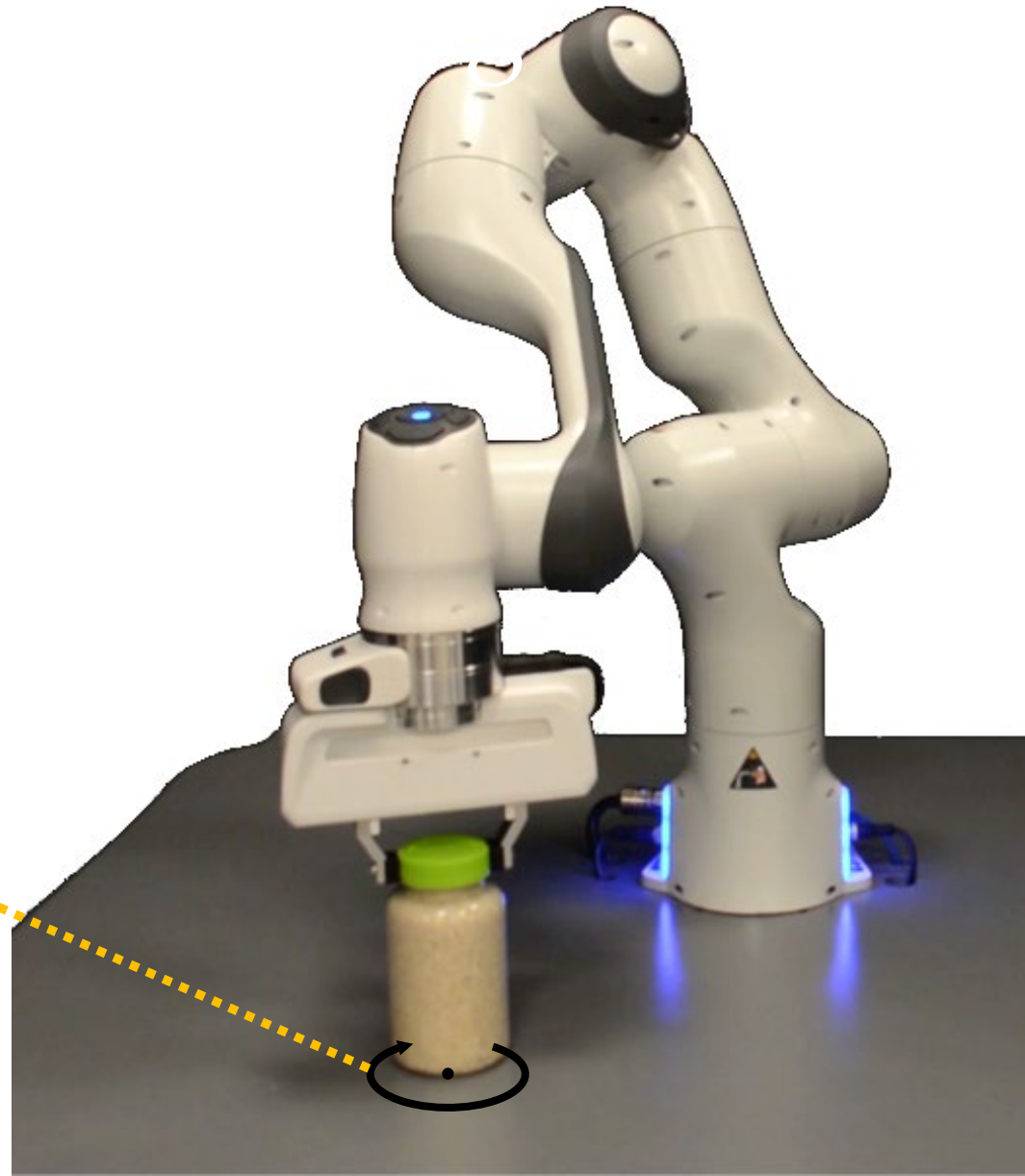
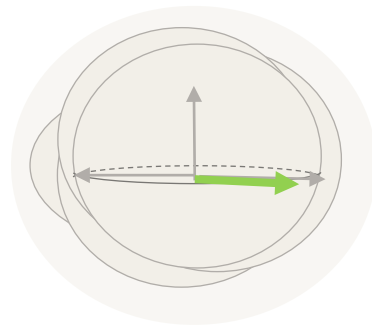


Robust to Variations in the Physical Parameters



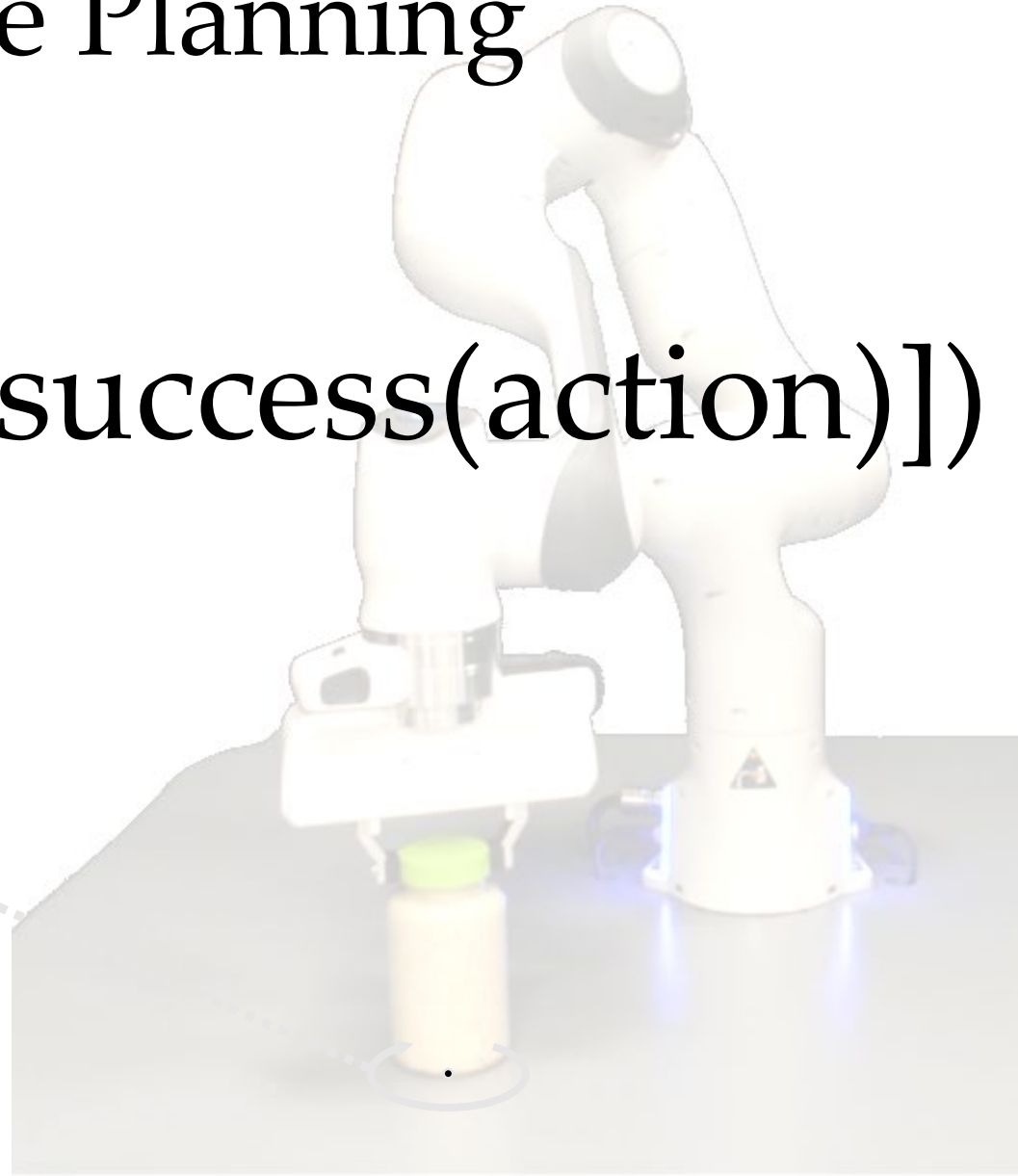
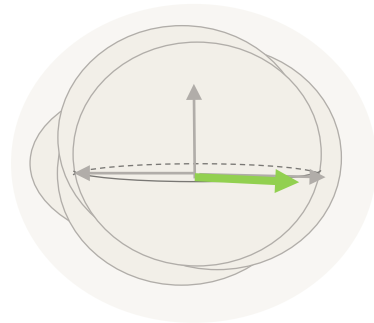
Robust to Variations in the Physical Parameters

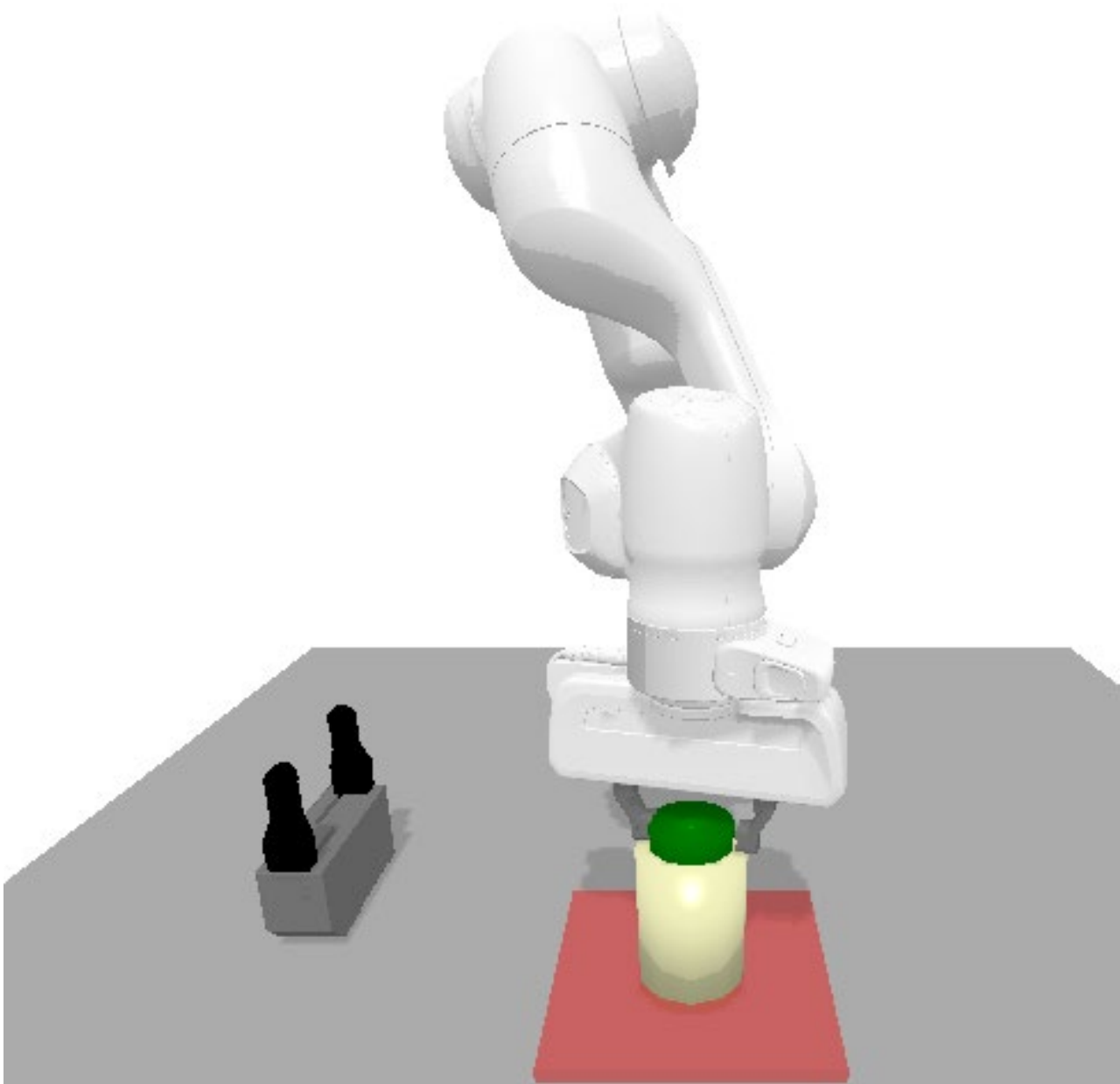
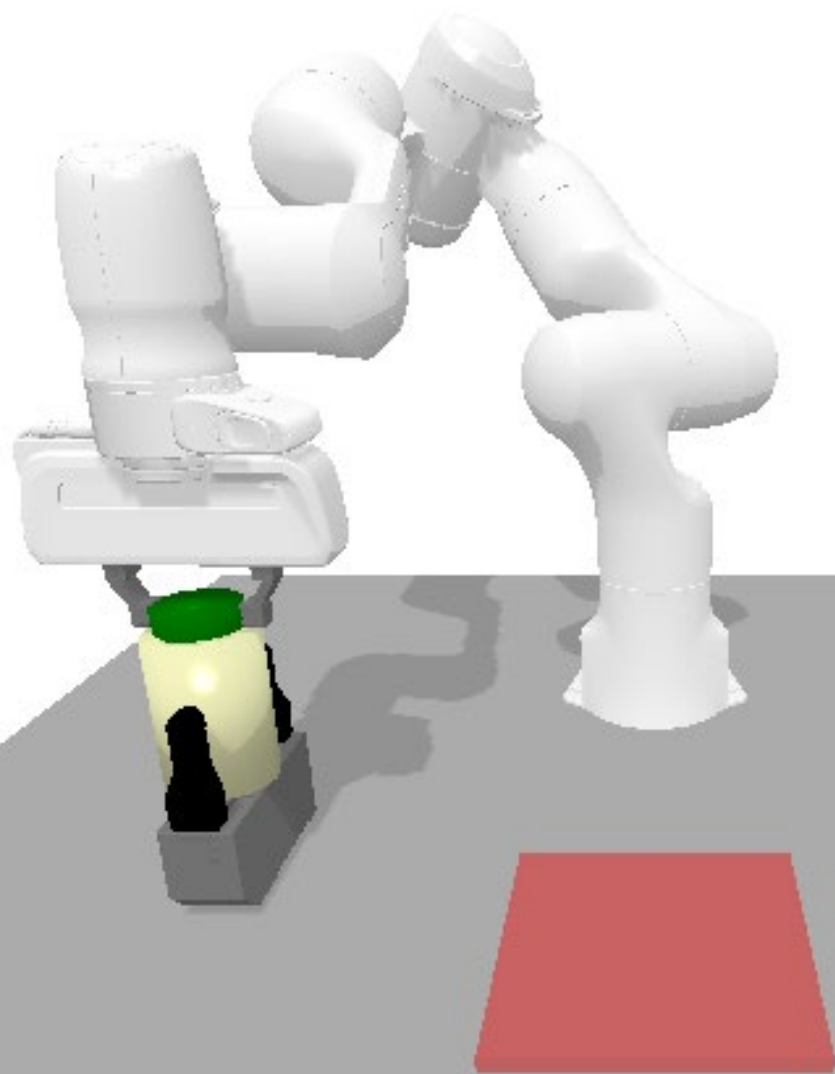
$\Pr[\text{success}(\text{action})]$

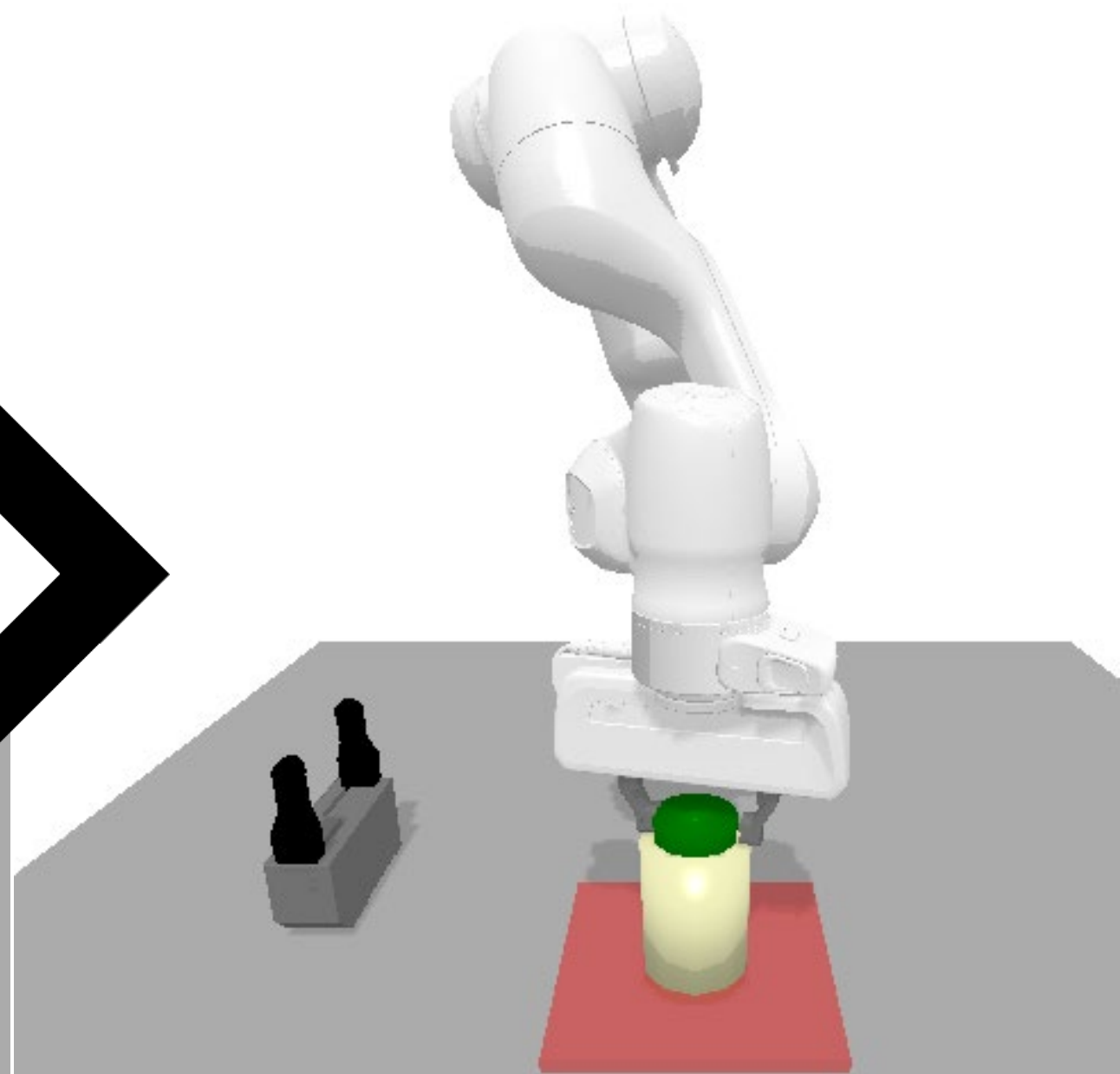
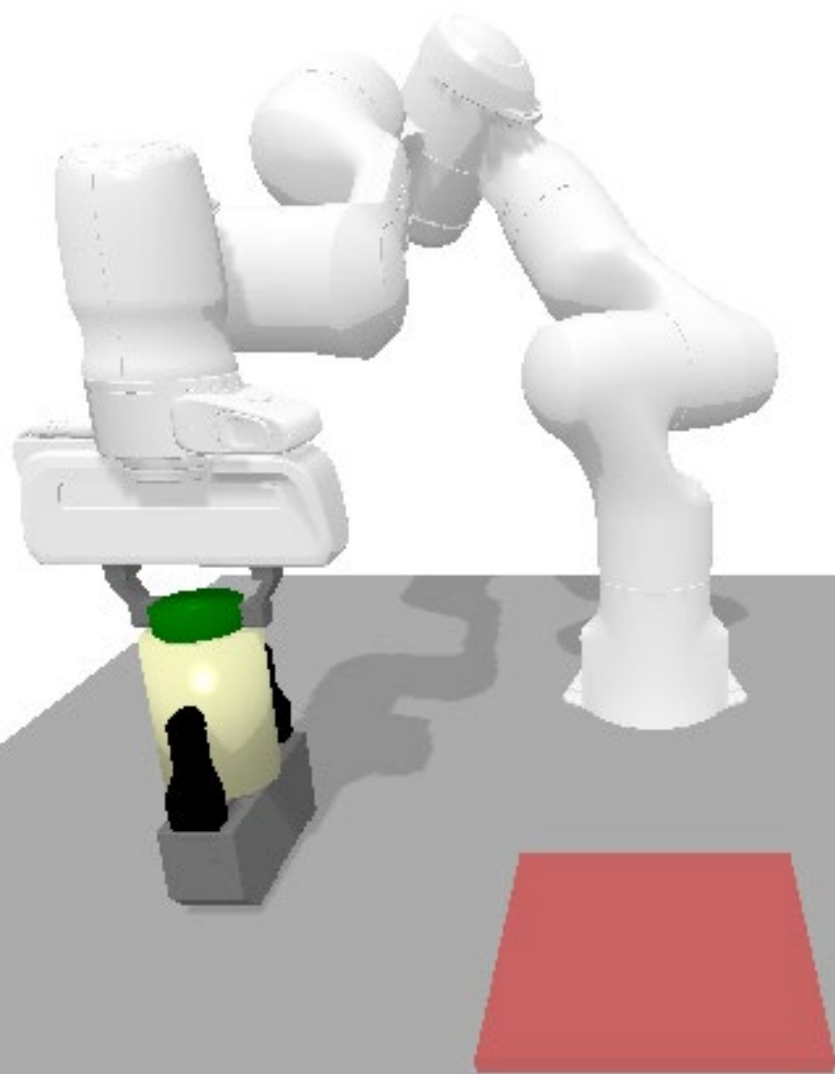


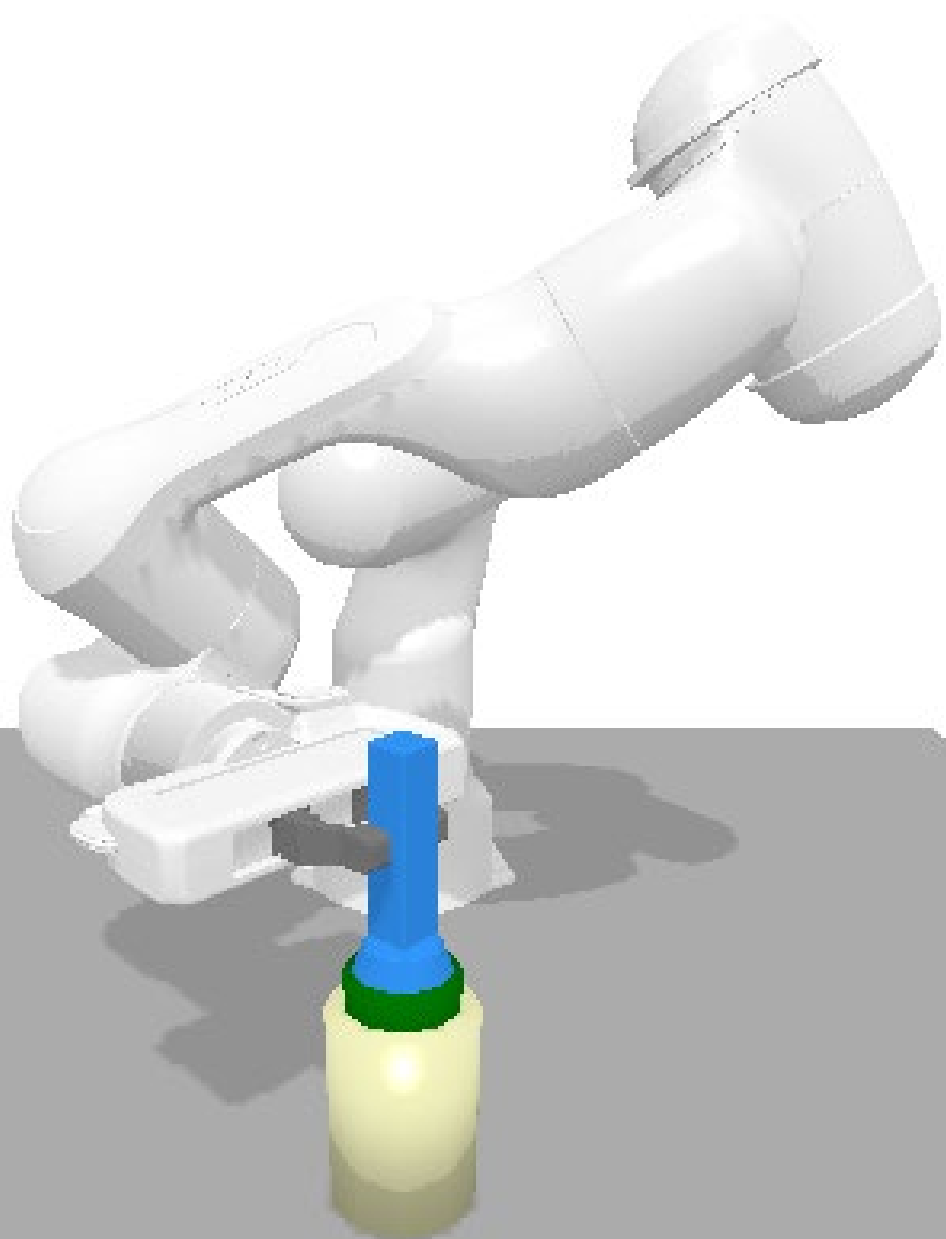
Robust to Variations in the Physical Parameters via Cost-Sensitive Planning

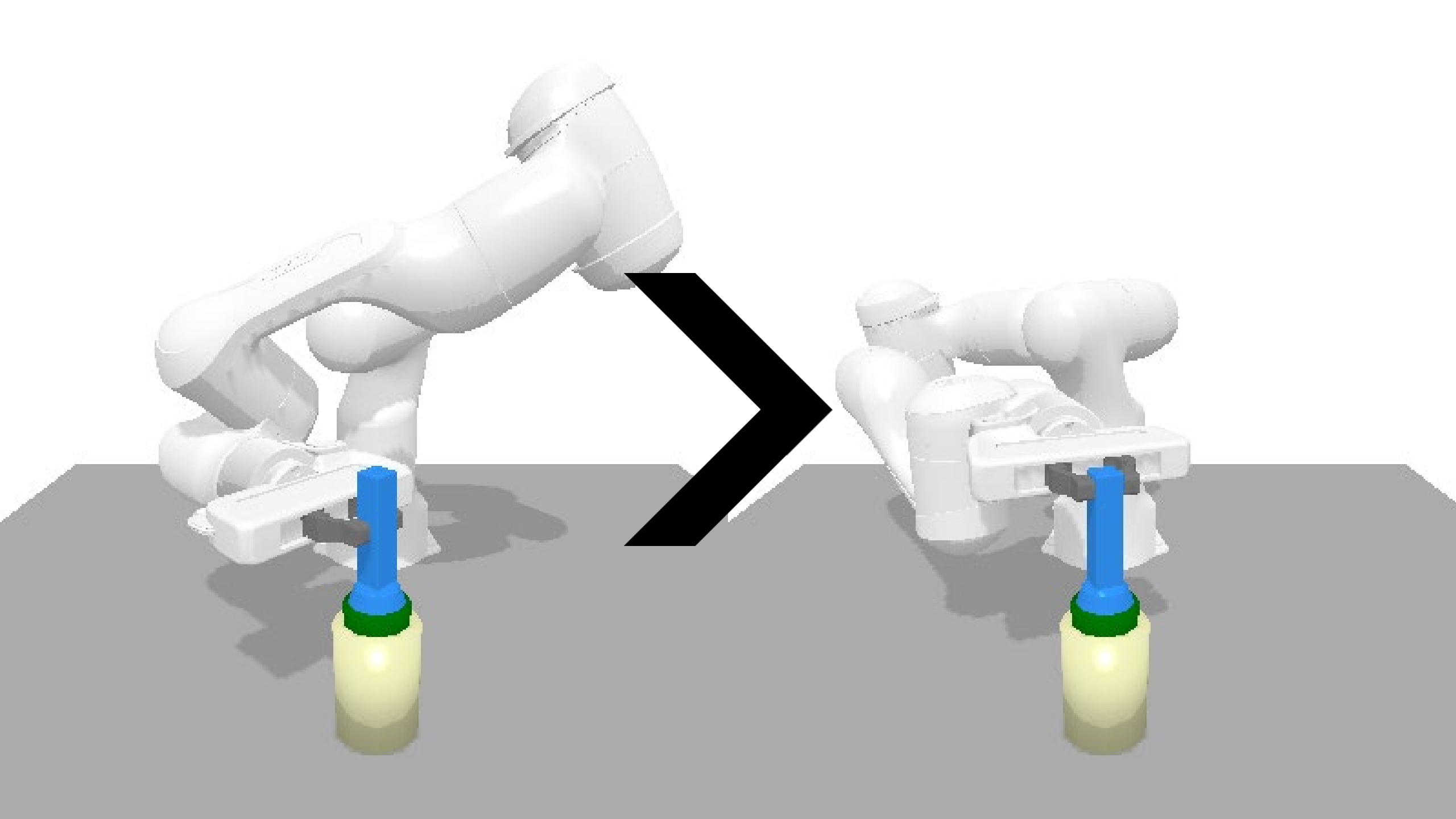
$$\text{cost}(\text{action}) = -\log(\text{Pr}[\text{success}(\text{action})])$$











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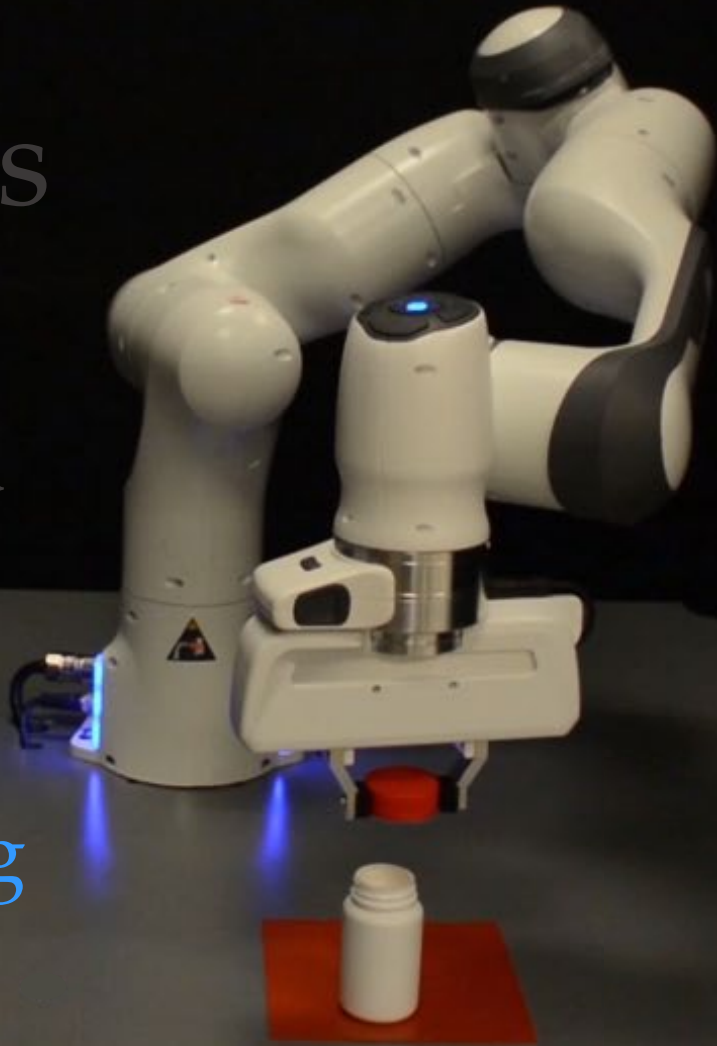
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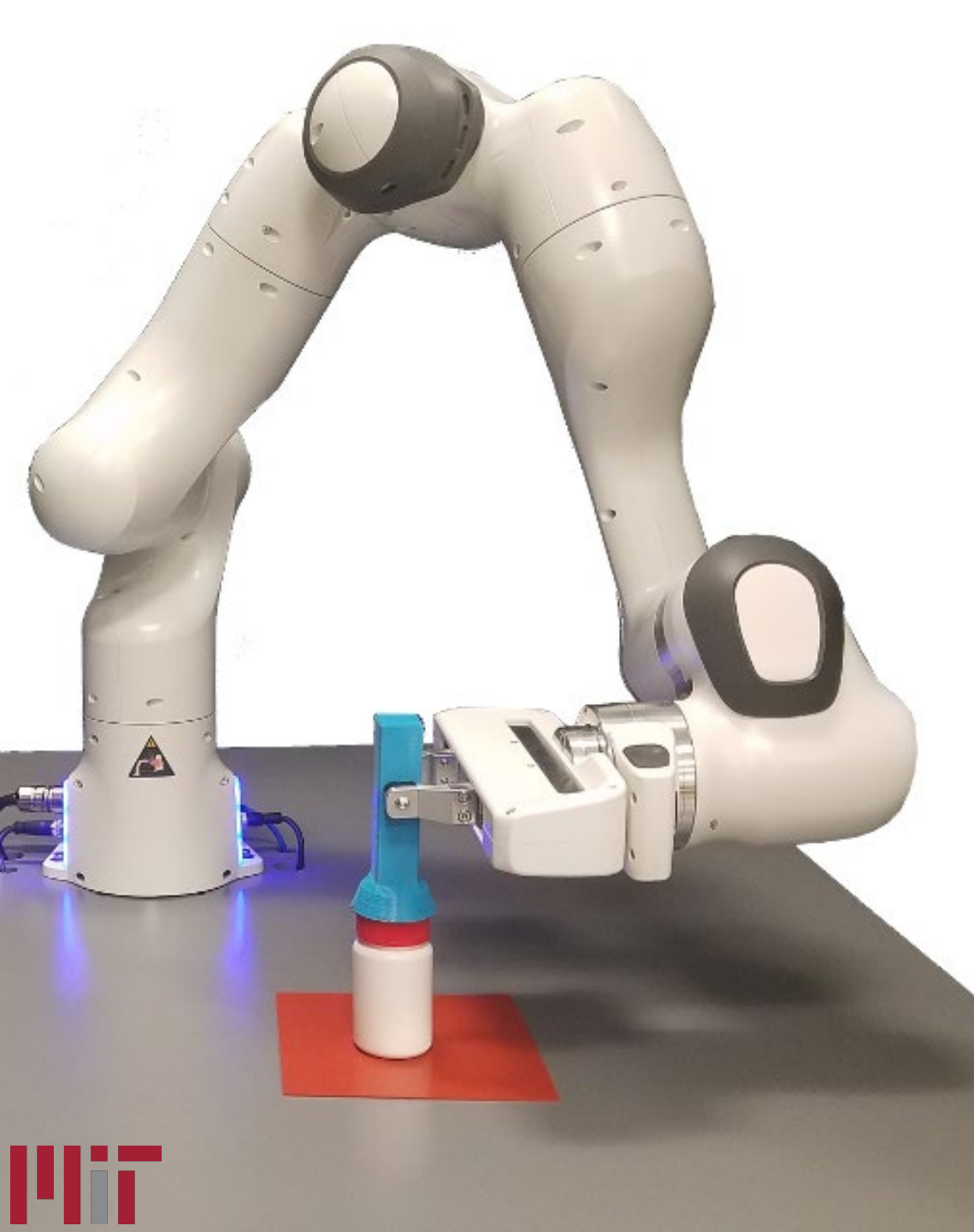
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mcube.mit.edu/forceful-manipulation/