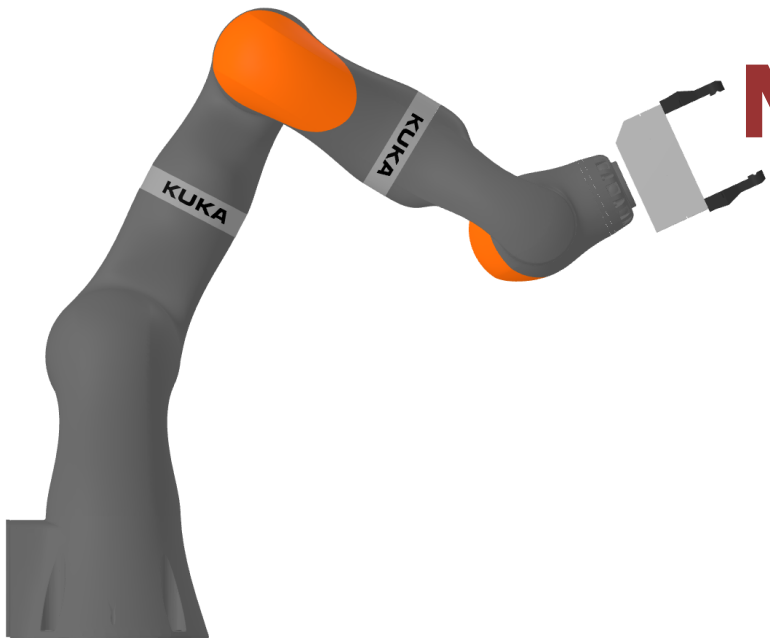
Introduction: Anatomy of a Manipulation System



MIT 6.4210/2: Robotic Manipulation

Fall 2025, Lecture 1

Massachusetts Institute of Technology

Course Info

https://manipulation.csail.mit.edu/Fall2025/

Website: http://manipulation.mit.edu

6.4210 is a CI-M (Communication Intensive in the Major)

Communications Instructors from Comparative Media Studies/Writing

Recitations Fridays afternoons (starting Sept 12)

Project-related (CI) assignments for 6.4210 students

1. Journal club presentation *(3 pts)*
2. Project preproposal *(1 pt)*
3. Project proposal final revision *(4 pts)*
4. Project final report *(10 pts)*
5. Project final video *(3 pts)*
6. Peer reviews *(2 pts)*
7. Writing conferences *(2 pt)*
8. CI-M participation & pre-writing tasks *(3 pts)*

CI-M Enrollment Limit

- 6.4210 has an enrollment cap.
- Fill in the form found on the course home page by tomorrow (Thu) noon.
- If you responded to the previous form we mailed around, you do not need to re-explain your situation. Just confirm you still want to take the course.
- If you did not previously respond, then please explain your situation.
- We will contact you with a decision by this Friday.

6.4210 vs 6.4212

- Mostly same assignments, quiz, project
- Higher expectations on 6.4212 projects
- 6.4212 has an extra assignment
  - Create a tutorial notebook on some relevant topic
  - See description on website

Logistics

- Make sure you're on Piazza and Gradescope
- CI-M (6.4210) material on Canvas.
- Review the course guidelines.
- Read the lecture notes
- ~ weekly problem sets throughout the class, due Thurs.
  - Problem Set 1 released today (on the course calendar).
- Midterm quiz on Nov 5 (evening)
- Final project:
  - Group Report
  - Group Video and
  - Individual Summary (in-class)

Class Time and Location

Fall semester (September - December, 2025)
Lectures: Monday, Wednesday 9:30 -11:00 am in 45-230
Recitations are only for the undergrad version (6.4210):

- R1: Friday at 12-1pm in 4-149,
- R2: Friday at 1-2pm in 4-149, or
- R3: Friday at 1-2pm in 66-168.
- R4: Friday at 2-3pm in 66-168.

See class schedule for complete details.

Office Hours

See Piazza posts for our office hours schedule.

Class Forums

Forums are on Piazza (sign up with your @mit.edu email address).

For 6.4210, communication on CI-M material will primarily happen through Canvas.

We will use Gradescope for problem set submission and grading.

Grading Policy

Late assignments will be penalized 10% every 24 hours. Additionally, we will grant a one time (one pset) extension of up to one week without penalty. This will automatically be applied at the end of the term to whichever pset will earn you the most points; there is no need to request it. All psets will be be assigned equal weight when determining final grade.

6.4210 grade distribution
Assignments: 15%
Midterm: 25%
Journal club/peer reviews: 5%
CI-M participation, pre-writing tasks & writing conferences: 5%
Project proposal: 10% (5% tech grade + 5% CI grade)
Project report and summary: 30% (20% tech grade + 10% CI grade)
Project video: 10% (7% tech grade + 3% CI grade)

6.4212 grade distribution
Assignments: 15%
Midterm: 25%
Project proposal: 5%
Project updates: 10%
Project report and summary: 35%
Project video: 10%

Policy on Generative AI: Download the policy (PDF)

https://manipulation.csail.mit.edu/intro.html

https://people.csail.mit.edu/russt/uploads/yellow_spot.html

Today

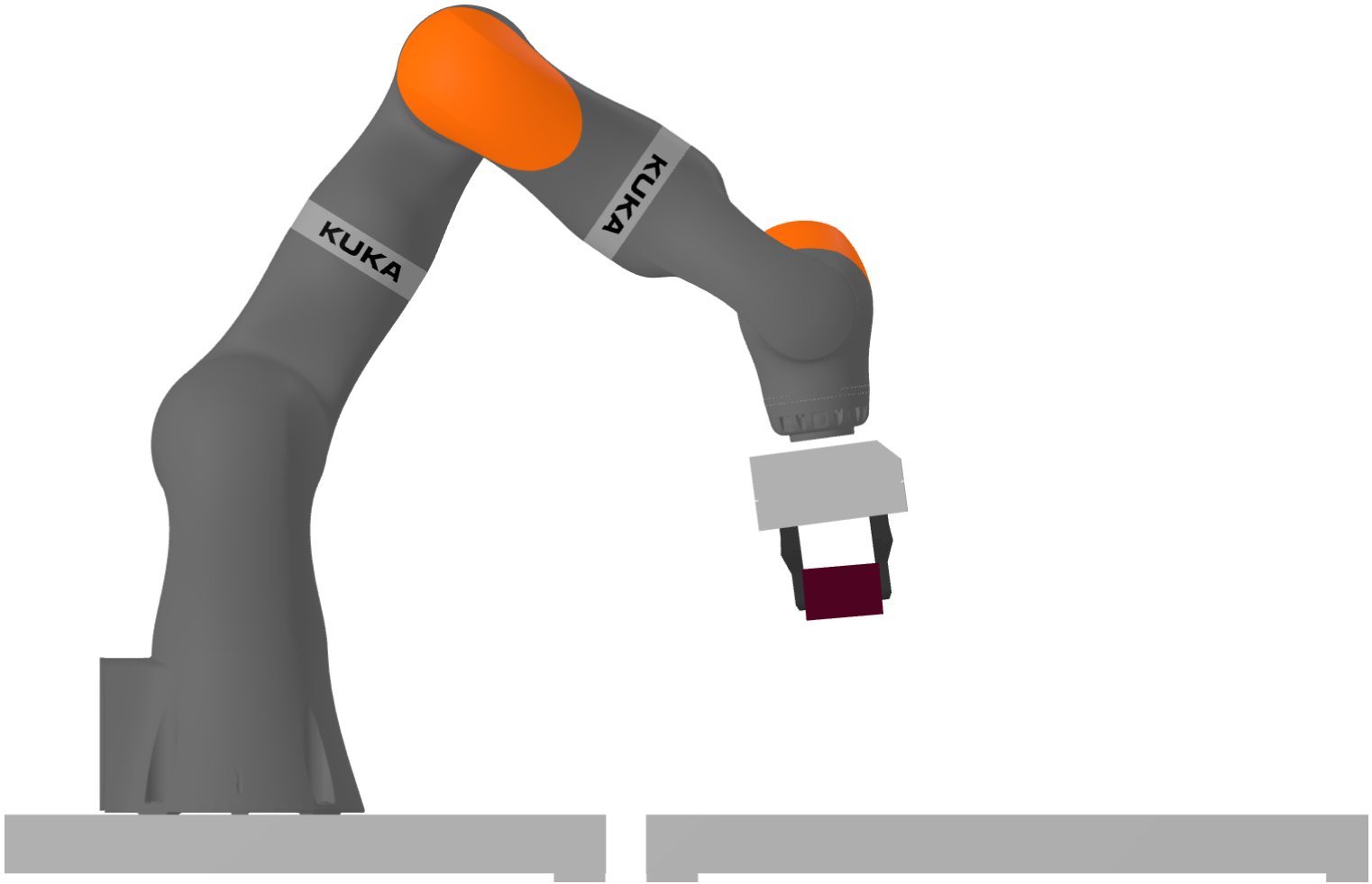
- What do we mean by "***manipulation***"? (with examples!)
- Anatomy of a manipulation system
- Goals for the course

Matt Mason says

- *Definition 1 (etymological).* Manipulation refers to the activities performed by hands.
- ...
- *Definition 5.* Manipulation refers to an agent's control of its environment through selective contact.

Matthew T. Mason. Toward Robotic Manipulation. *Annual Review of Control, Robotics, and Autonomous Systems*, 1:1-28, 2018.

https://www.youtube.com/embed/hxsWeVtb-JQ?enablejsapi=1


KUKA
KUKA

https://www.youtube.com/embed/1RbaIo4VdbA? enablejsapi=1&start=112&mute=1

Autonomous "Open-world" Manipulation

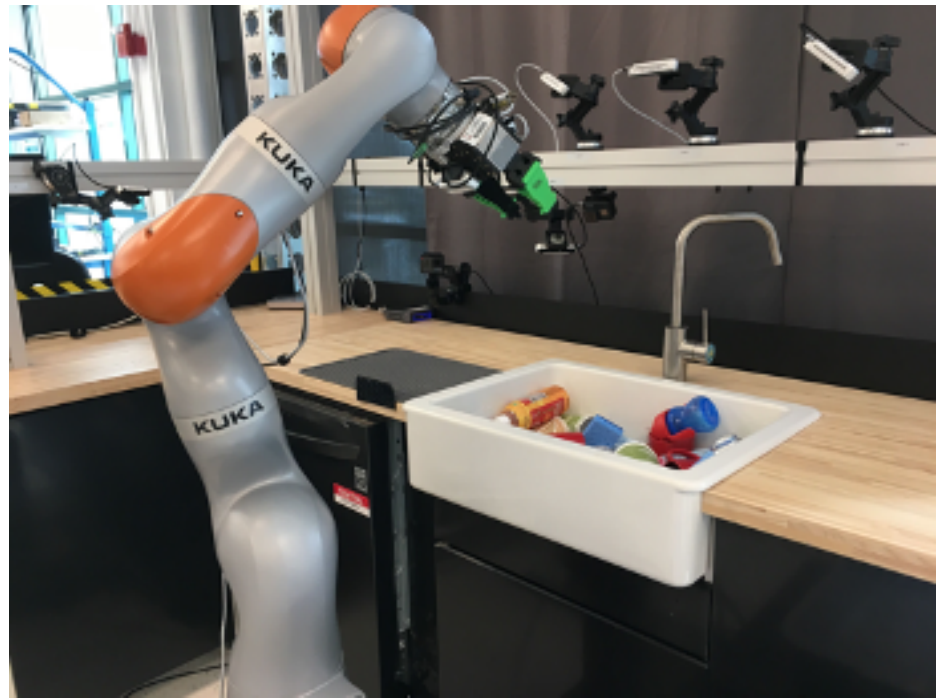
- *Definition 5.* Manipulation refers to an agent's control of its environment through selective contact.

- *Even broader:* "Open-world" manipulation requires:
  - rich perceptual understanding of the environment,
  - "common-sense" understanding of objects,
  - the ability to make long-term (task-level) plans, and combine them with fine (joint-level) motions.

Motivation

Consider the task of loading a dishwasher…

(from TRI Robotics)



The world is even more "open" when the manipulation system goes *mobile.*

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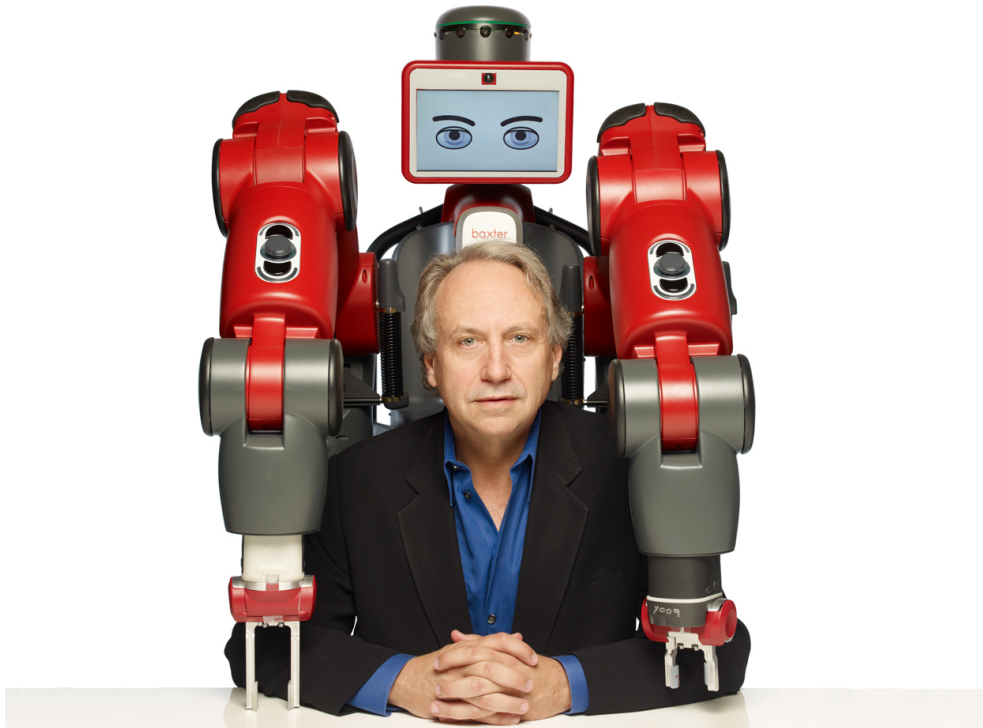
Basic components

- Links
- Joints (Revolute, Prismatic)
- Sensors
  - Proprioception (position, torque)
  - Force and/or tactile
  - Vision: RGB(D), Laser Scan
- Actuation
  - Motors (electric, hydraulic)
  - Transmission (gear reduction, backlash, friction)
  - Motor drivers
    - Position control [most robots]

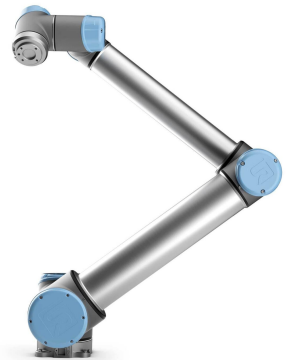
Exploring robot arms

https://www.infineon.com/cms/en/discoveries/robotics-systems-safety-security/

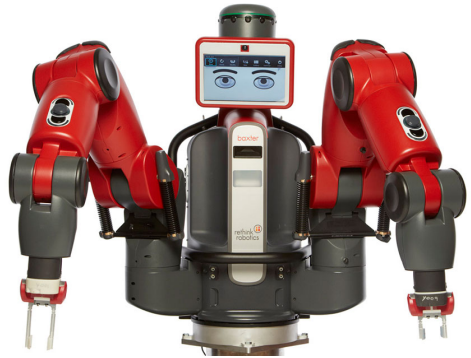


https://spectrum.ieee.org/robotics/industrial-robots/rethink-robotics-baxter-robot-factory-worker

Universal Robots



Rethink Baxter



Kuka iiwa

Kinova Jaco

ABB Yumi

Franka Panda

https://www.youtube.com/embed/dnUwqngH0bM?start=35&mute=1&enablejsapi=1

https://www.youtube.com/embed/P-d-yTcxdzw?enablejsapi=1

Schunk WSG 50

Force-controlled planar gripper

https://www.youtube.com/embed/oyHWkQcin7I?enablejsapi=1&mute=1

http://personalrobotics.stanford.edu/

Hands

Shadow hand

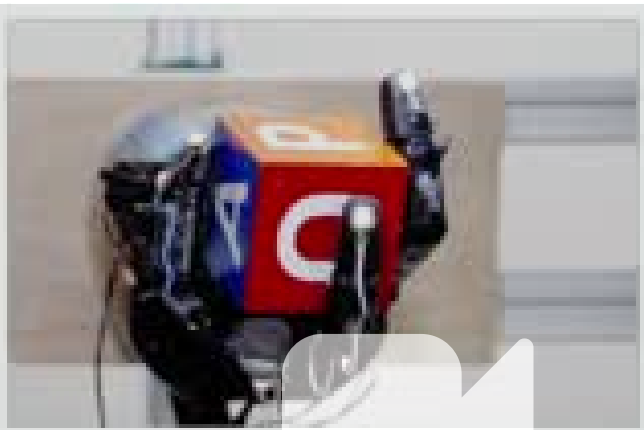
iHY (i-Robot, Harvard, Yale)

Robotiq 3-fingered gripper

Allegro Hand

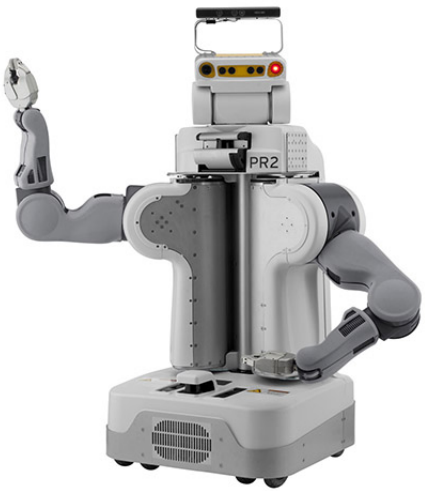
FINGER PIVOTING

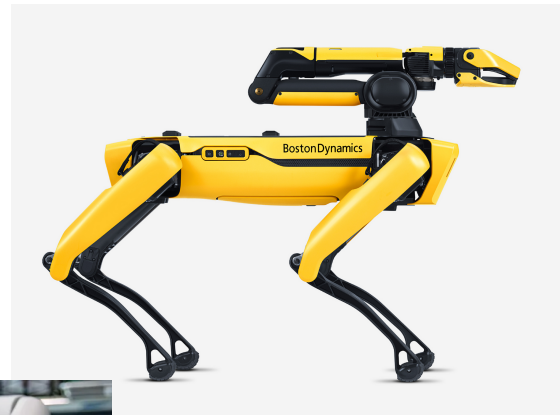
SLIDING

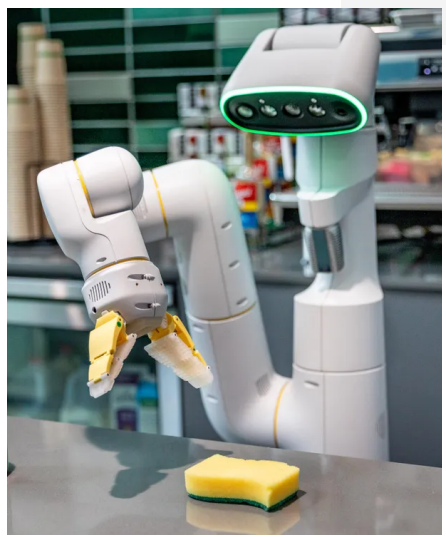


FINGER GAITING

Mobile Manipulators







New mobile manipulators

https://www.youtube.com/embed/I3_GIb7W5UQ?enablejsapi=1&mute=1

Rainbow RBY1

New humanoids (w/ dexterous hands)

Sanctuary AI

New humanoids (w/ dexterous hands)

https://www.youtube.com/embed/0SRVJaOg9Co?enablejsapi=1&mute=1

Figure

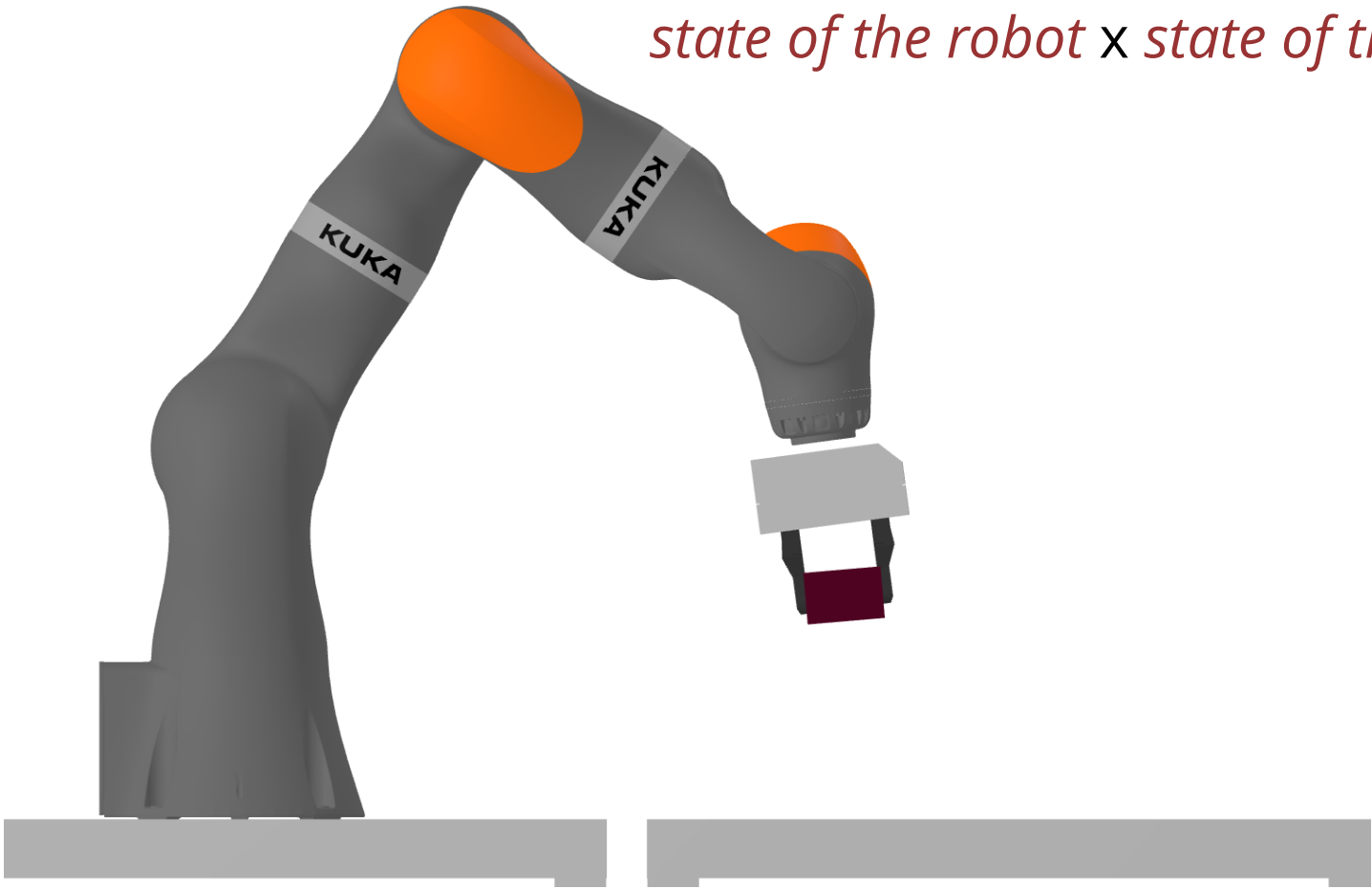
This class

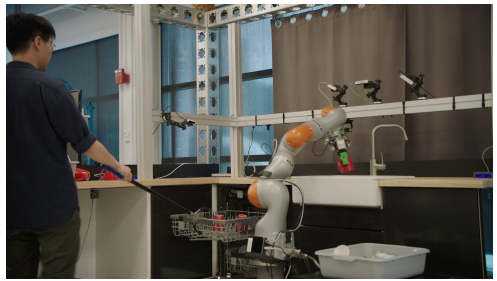
- Robot ***arms***.
  - The hardware matters.
  - We'll often use *Kuka iiwa*
- Robot ***hands***.
  - We'll often use *Schunk WSG*

The *anatomy* of a modern manipulation system

To be clear: we're not just controlling the arm

state of the robot x *state of the environment*

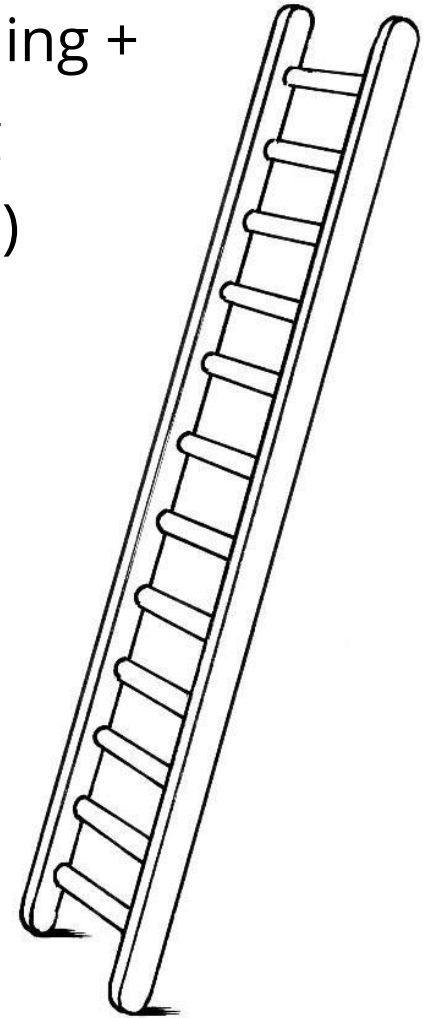


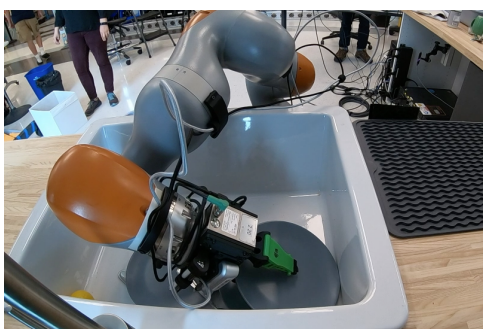


Scene-understanding +

Task-level Planning

(discrete/symbolic)

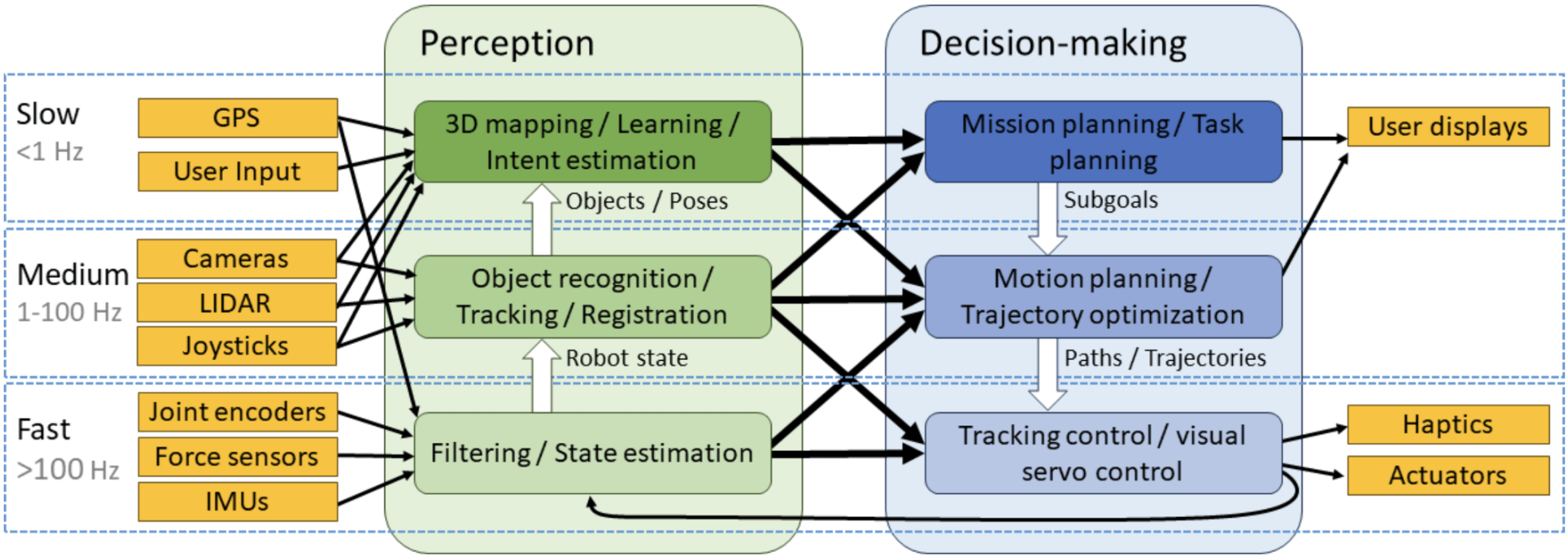




Low-level feedback control from cameras / sensors

(continuous time/state/action)

Robot System Architecture



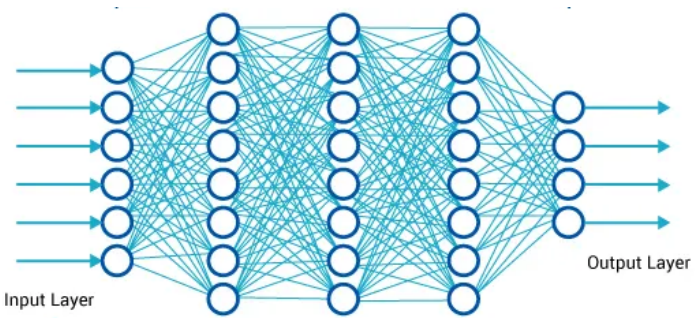
From Kris Hauser - Robotic Systems (online)

https://www.youtube.com/embed/0LJb66aYtG8?start=111&mute=1&enablejsapi=1&controls=0&rel=0&modestbranding=1

Visuomotor policies

perception network

(often pre-trained)



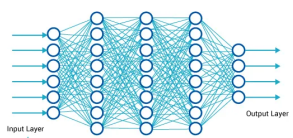
$\mathbb{R}^{640\times480\times3}$

$\approx \mathbb{R}^{32}$

z

learned state representation

policy network



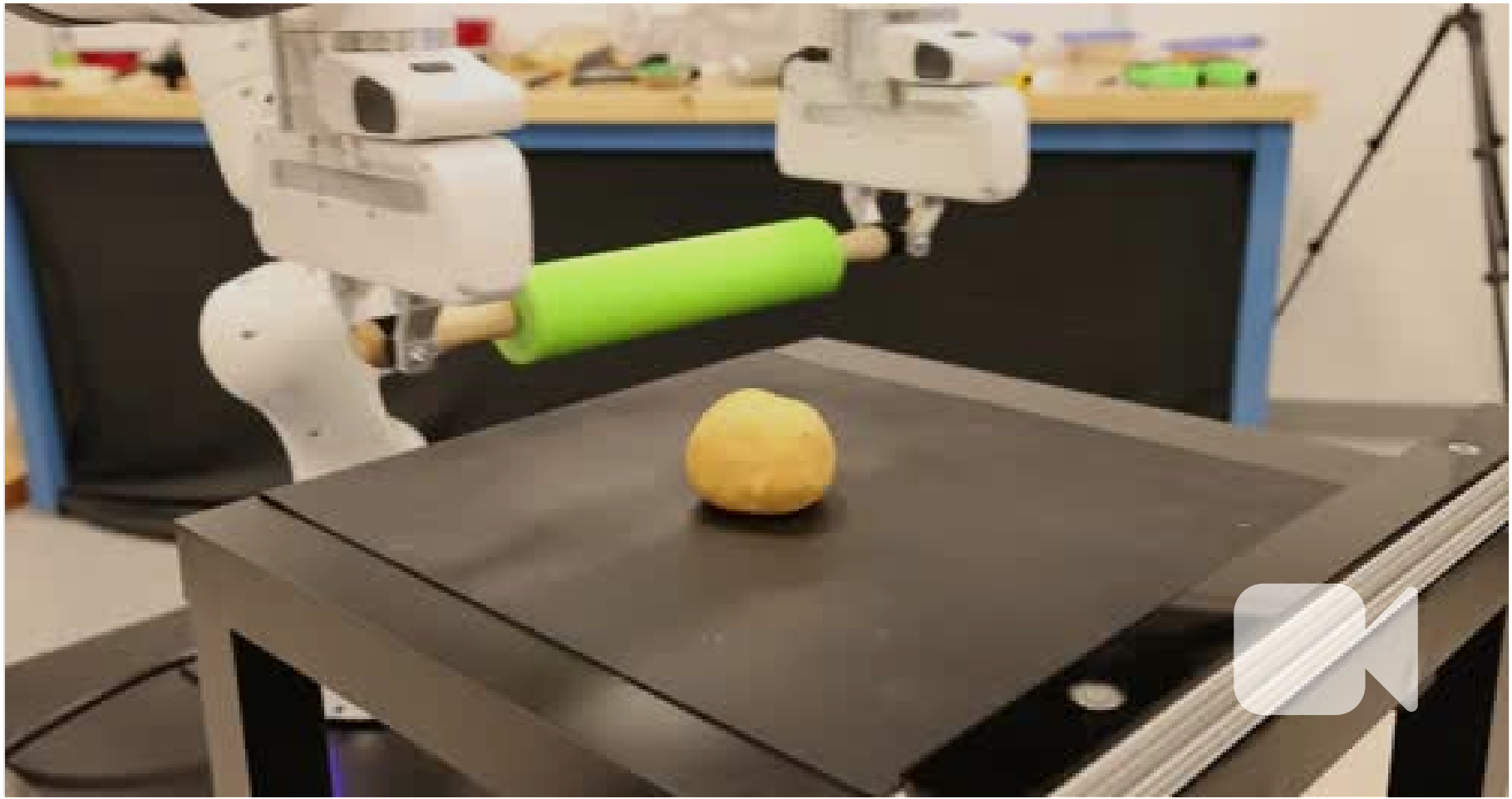
$\approx \mathbb{R}^{7}$

actions

other robot sensors

$\approx \mathbb{R}^{13}$

Levine*, Finn*, Darrel, Abbeel, JMLR 2016



Manipulation is much more than "pick and place"!

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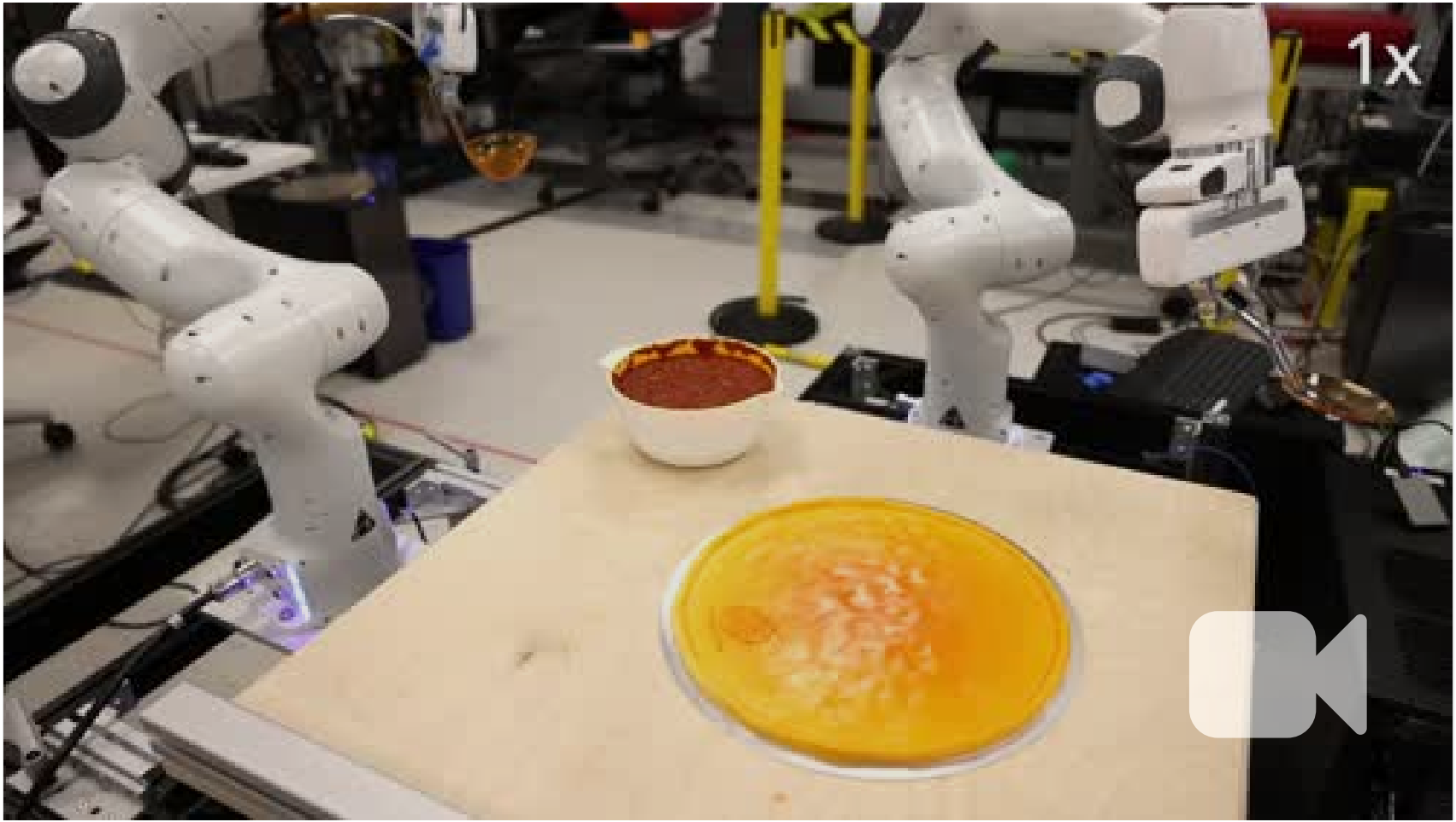

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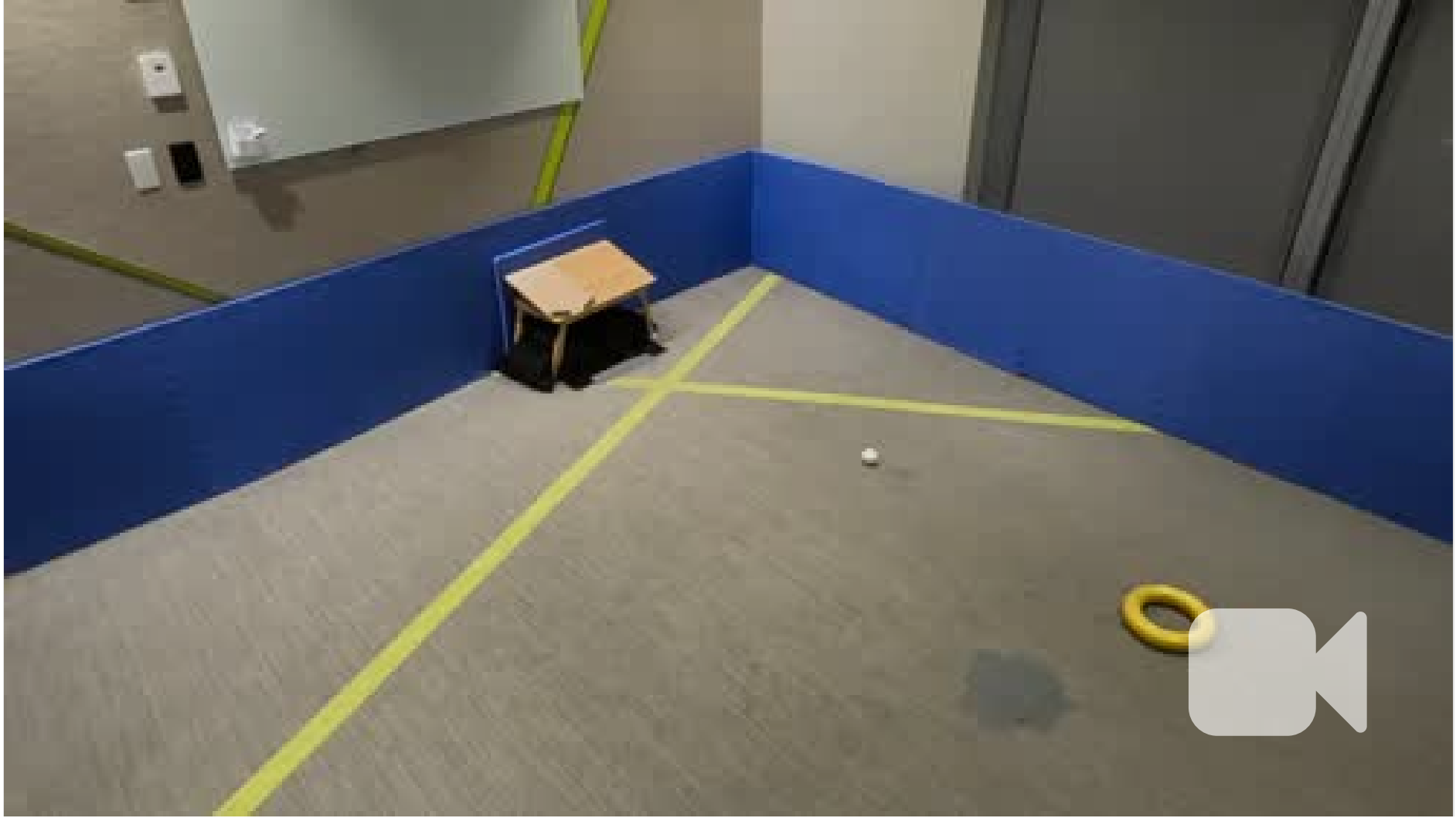
https://www.youtube.com/embed/HYwekersccY?enablejsapi=1

But even pick and place is challenging in the general case



Kumar, Silver, McClinton, et al 2024

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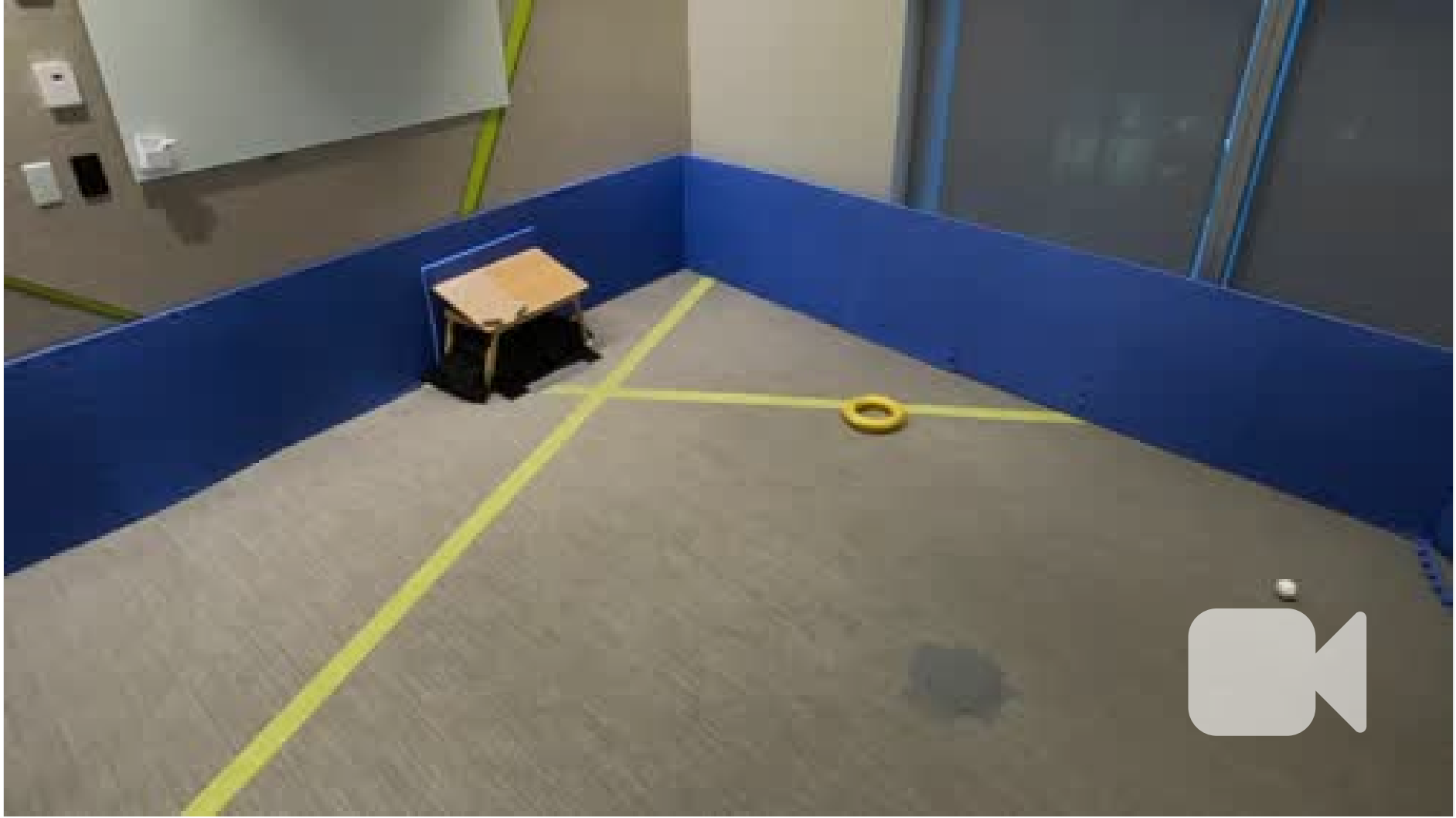

Kumar, Silver, McClinton, et al 2024

A. Curtis, X. Fang, L. Kaelbling, T. Lozano-Perez, C. Garrett 2022

C. Garrett, C. Paxton, T. Lozano-Perez, L. Kaelbling, D. Fox 2020

https://manipulation.csail.mit.edu/Fall2025/schedule.html

What is Drake?

CORE LIBRARY

Modeling Dynamical Systems	Solving Mathematical Programs	Multibody Kinematics and Dynamics
API | TUTORIAL	API | TUTORIAL	API

drake.mit.edu

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