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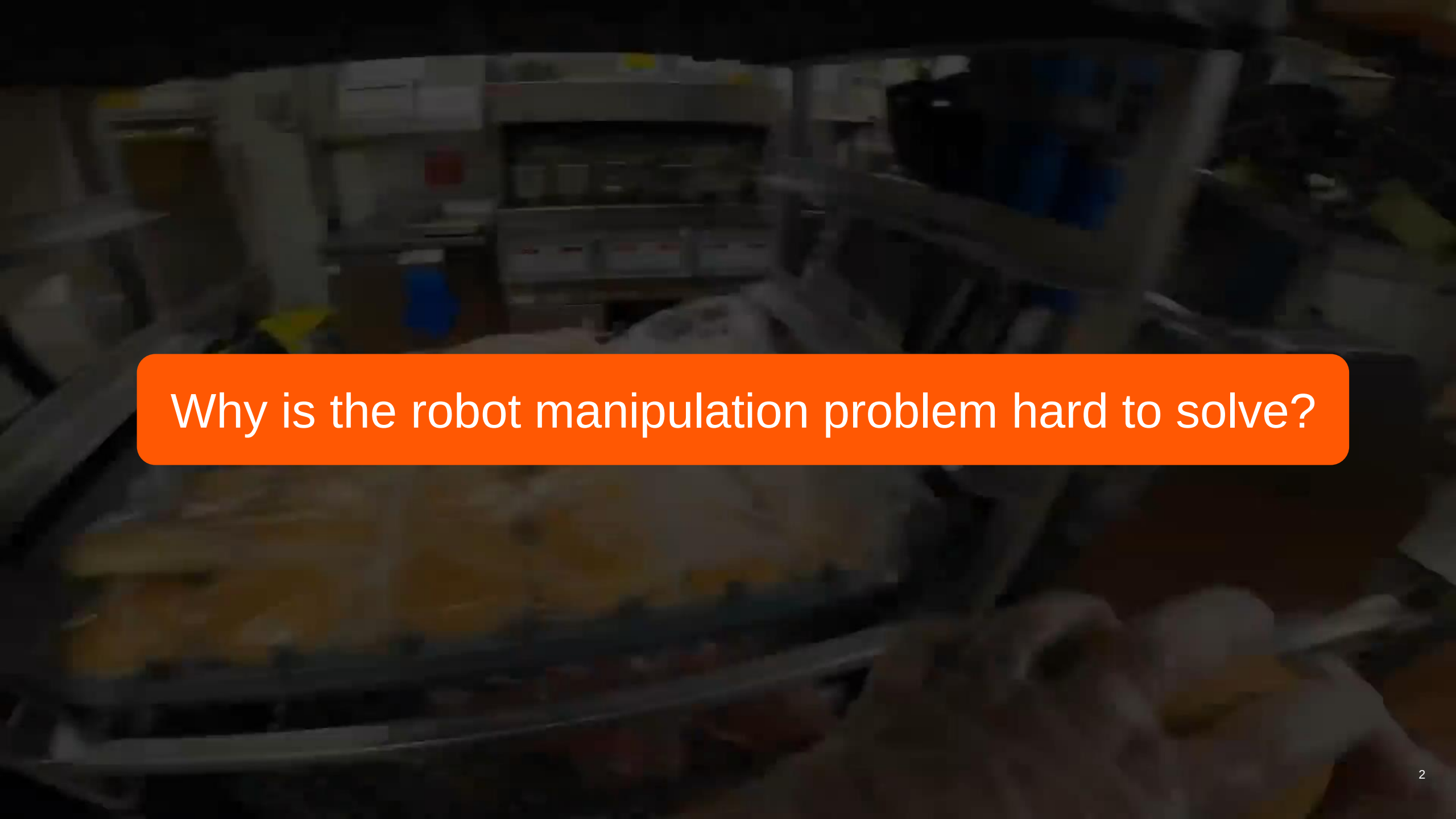
Class Wrap-Up + Q&A

Robert Katzschmann

SoftRobotics Laboratory


Why is the robot manipulation problem hard to solve?

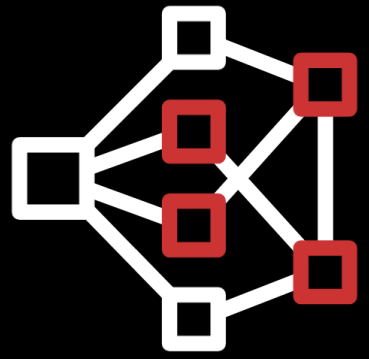
The Real World Robotics (RWR) class topics

Design and Fabrication

Kinematics, Dynamics and Control

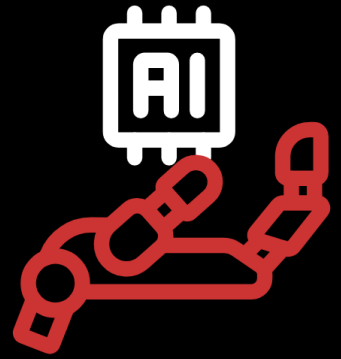
Sensors

Simulation

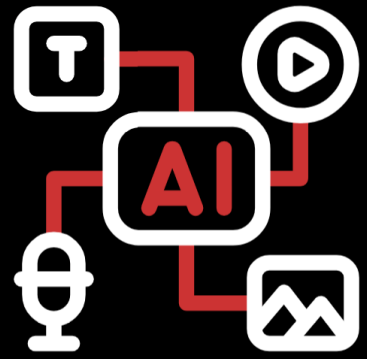


Reinforcement Learning

Teleoperation and Data Collection



Imitation Learning



VLAs and Foundation models

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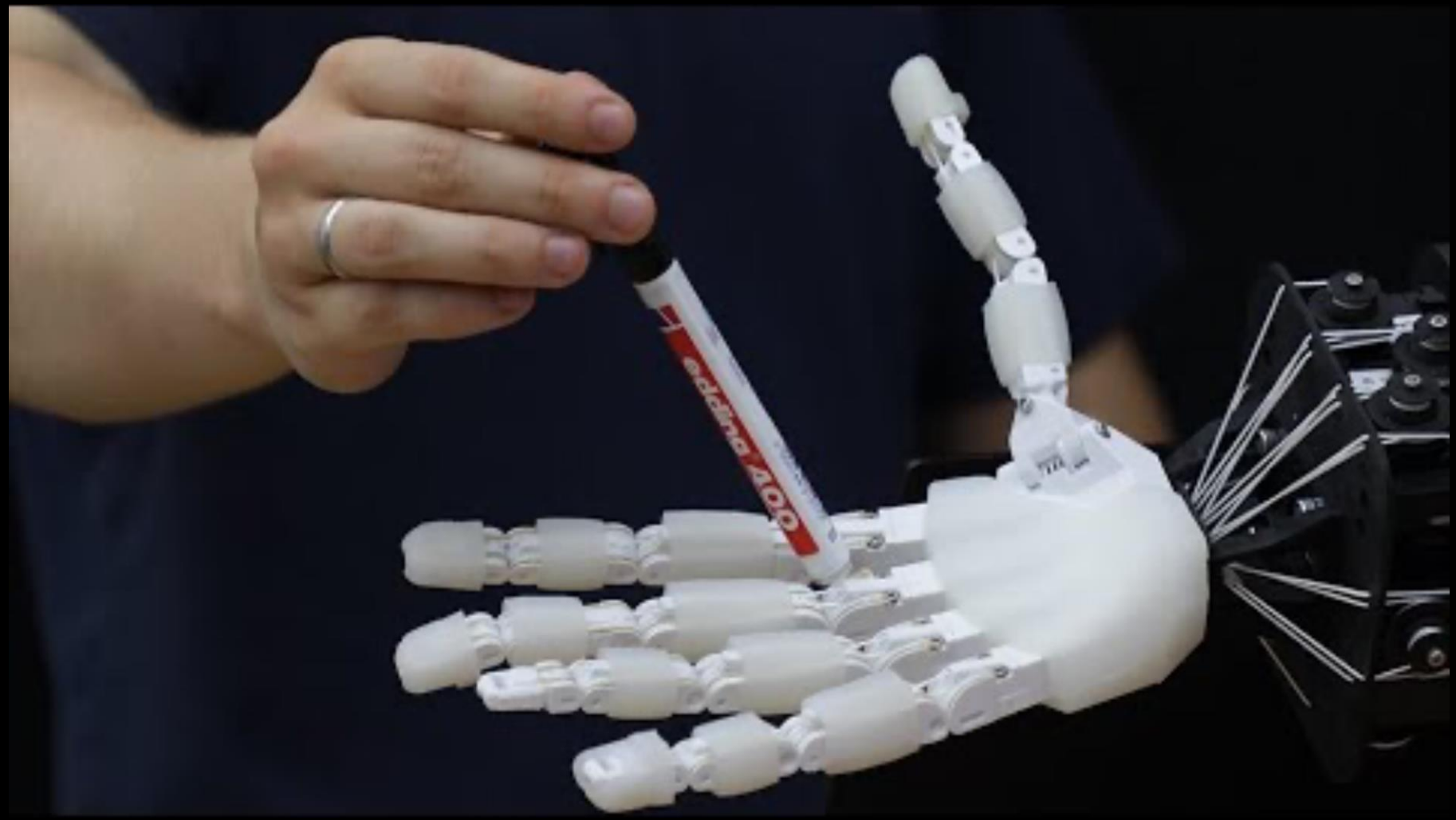
The Challenge for an Anthropomorphic Hand

Design and Fabrication



The Challenge for an Anthropomorphic Hand

Design and Fabrication

The Challenge

Conventional robotic grippers **lack versatility**

Humanoid robotic hands are **expensive** and complex

Humanoid robotic hands are **complicated** and require programming expertise

The Desired Solution

Versatile & Dexterous
One universal robotic hand for a large range of use-cases with different grasp types and re-orientation motions

Cost-Efficient
Simplified joint design optimized for easy and cost-effective fabrication

Easy-to-use
Reduced programming effort by using gesture-based control

Actuation Modality for a Robotic Gripper

Design and Fabrication

At joint

- Inflating bellows introduce bending motion
- Highly integrated
- Intrinsic compliance
- Bulky

Away from joint

- Move joint with tendons
- Modularity
- Shown to be stronger
- More anthropomorphic

1. Images source (from left to right):
2. https://cdn0.tnwcdn.com/wp-content/blogs.dir/1/files/2017/10/SoftRobotics_Picking_Tomato.jpg
3. Tavakoli, M., Batista, R., & Sgrigna, L. (2016). The UC softhand: Light weight adaptive bionic hand with a compact twisted string actuation system. Actuators, 5(1). https://doi.org/10.3390/ACT5010001

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Fabrication Techniques for Robotic Hands

Design and Fabrication

Summary

Machining

1. Drilling
2. Tapping
3. Laser cutting
4. Water jet cutting
5. Milling
6. Turning

…

Joining

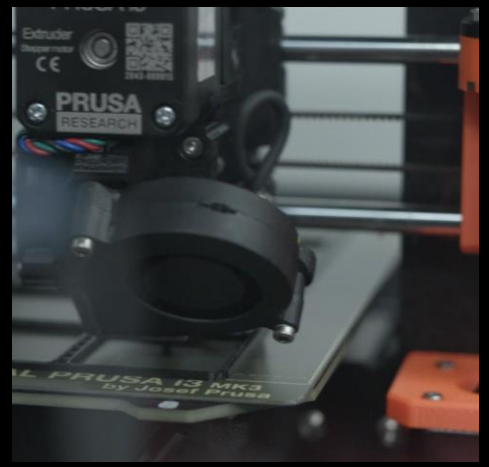
1. Adhesive Bonding
2. Fastening
3. Soldering

…

Casting / Molding

1. Soft Stereolithography
2. Lost Wax Molding
3. Injection Molding

...



3D Printing / Additive Manufacturing

1. Fused deposition modeling (FDM)
   Fused filament fabrication (FFF)
2. Direct Ink Writing (DIW)
3. Selective Laser Sintering (SLS)
4. Stereolithography (SLA)
5. 3D Inkjet printing

…

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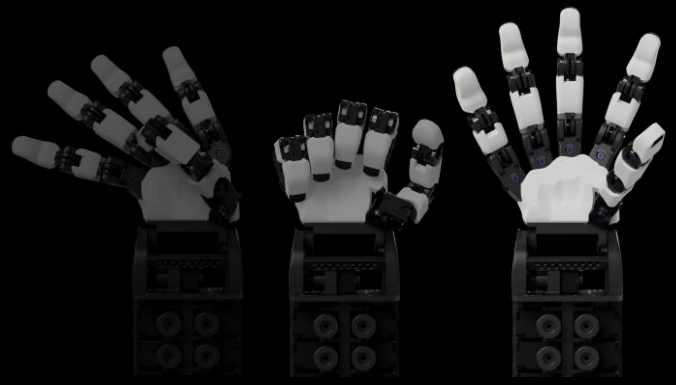
Many more manufacturing technique: https://en.wikipedia.org/wiki/List_of_manufacturing_processes


rca

Provided Hand Platform

Design and Fabrication

Auto-Calibration

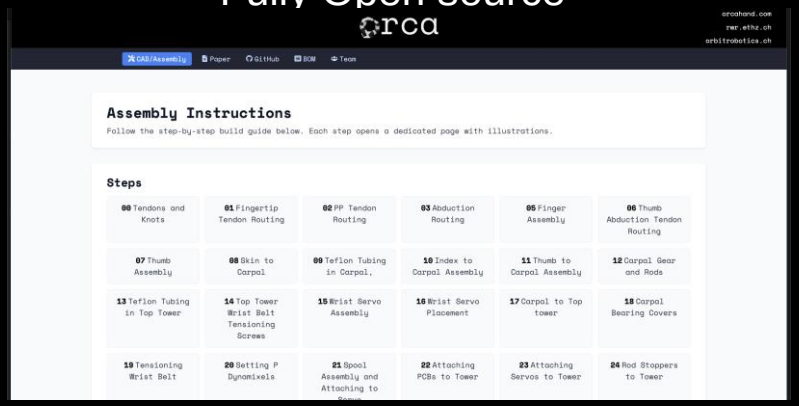


1 2 calibrated

1 2 calibrated

Easy to Assemble

Fully Open source



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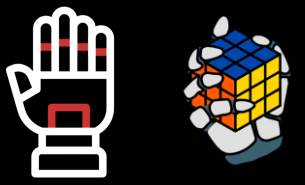
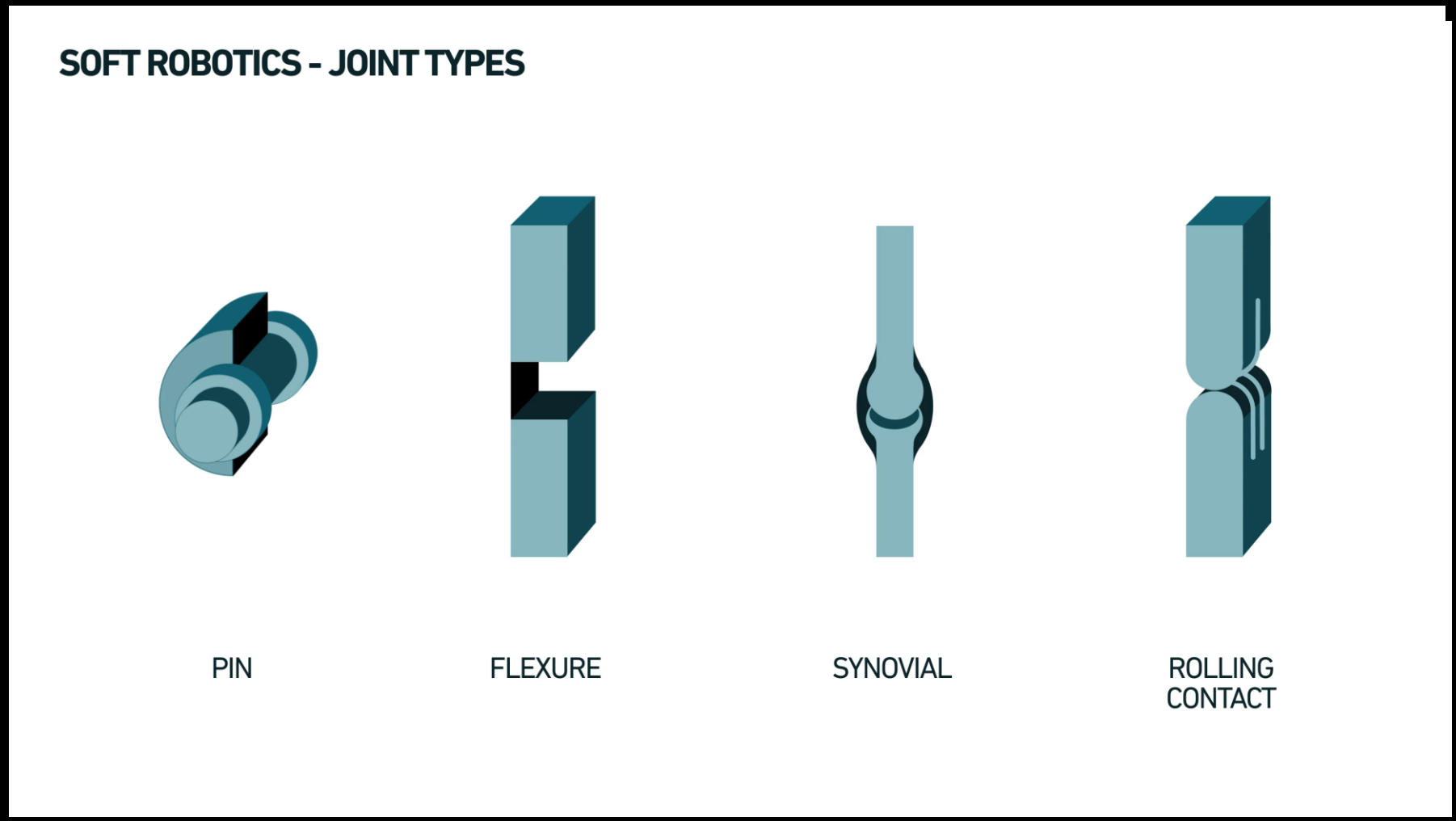
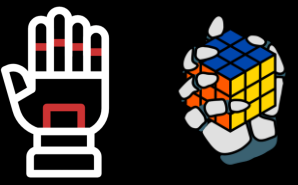
https://orca.ethz.ch

Different Types of Joints

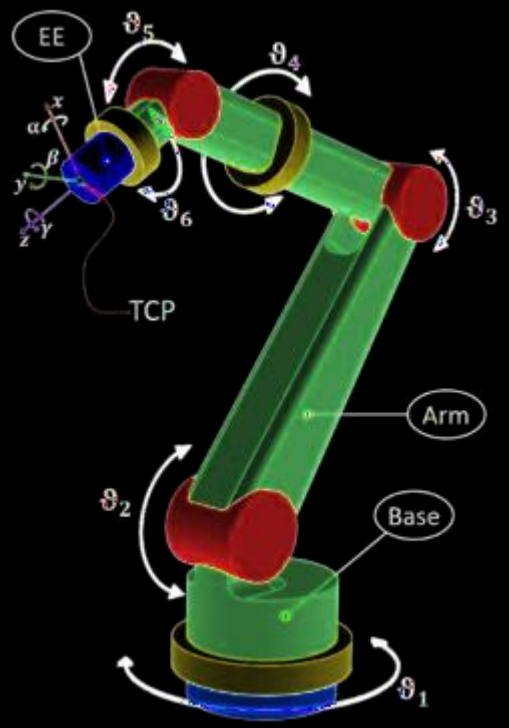




Robot Kinematics and Dynamics

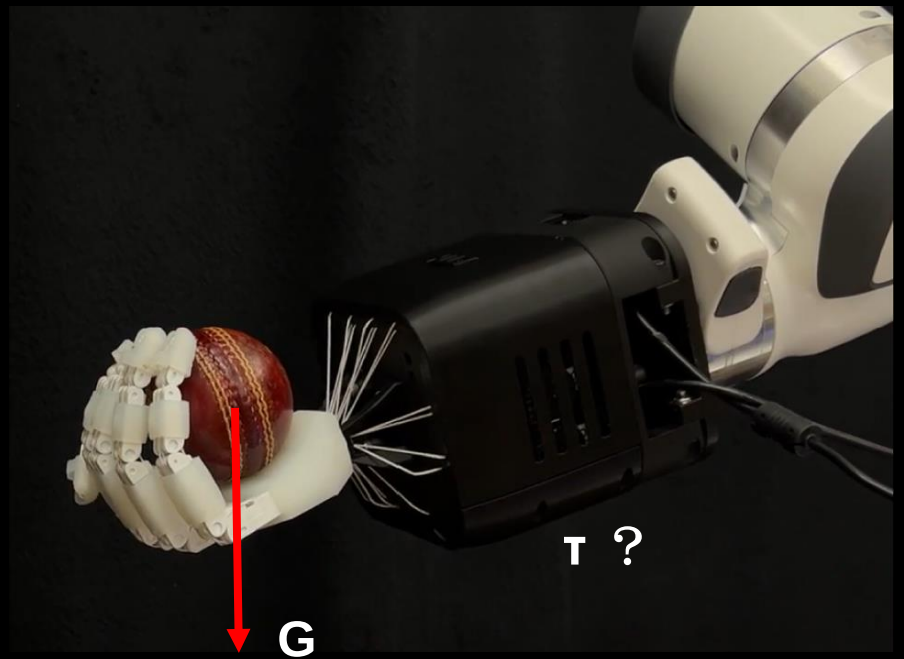


Kinematics, Dynamics and Control



researchgate.net

Kinematics



Toshimitsu et al. (2023) https://srl-ethz.github.io/get-ball-rolling/

Dynamics

Simulation
reaction to certain actuator commands

Control
invert of simulation, want to get somewhere, what to command?

Design
how are the loads distributed?

Optimization
what dimension should I have?

Actuation
torque, speed, powder etc.

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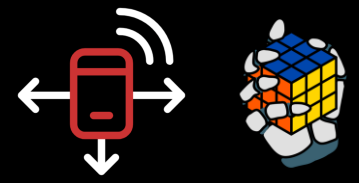
Classification of Robotic Sensors



Sensors

1. Exteroceptive Sensor

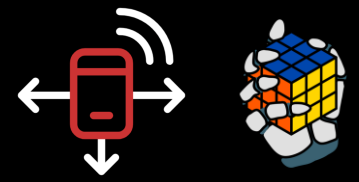
- Acquire information from the robot's environment.
- Tactile sensors, proximity sensors, light intensity, and sound amplitude.

2. Proprioceptive Sensor

- Measure values internal to the system (robot).
- Motor speed, wheel load, joint angles, bending sensor, and battery voltage.

Roland Siegwart; Illah Reza Nourbakhsh; Davide Scaramuzza, "Perception," in *Introduction to Autonomous Mobile Robots* , MIT Press, 2011, pp.101-263.

Sensing the pose: two methods

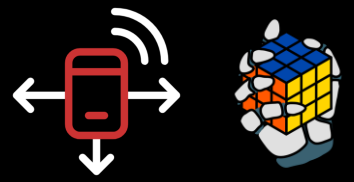


Sensors

- Direct methods: Direct reference to the world reference frame
  - The sensors obtain the absolute value of the state we are measuring

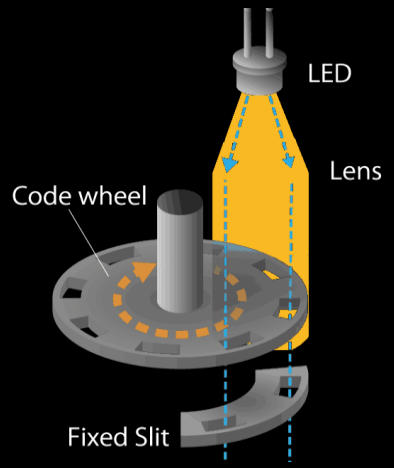
- Indirect methods: Obtain a measurement with reference to a second frame
  - The sensors will estimate a relative measurement that can be transformed into an absolute measurement

Sensor options



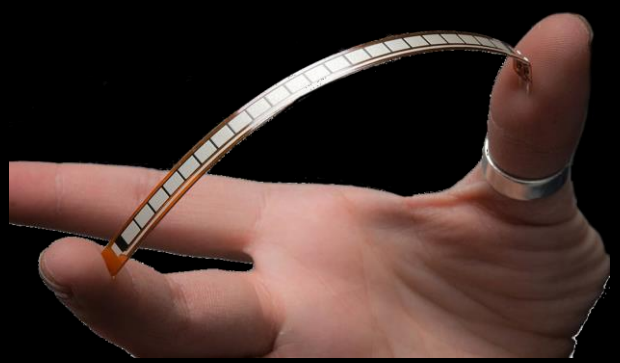
Sensors

Rotary Encoders



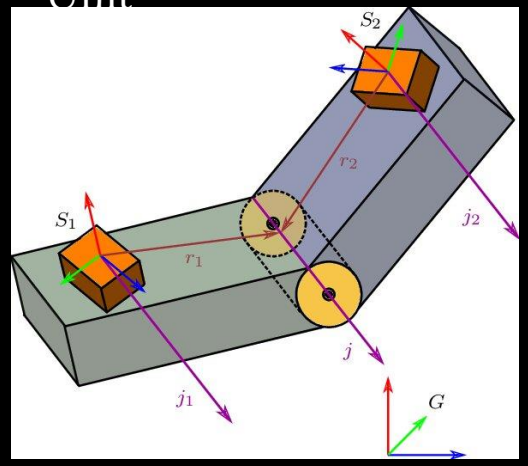
Asahi Kasei Microdevices

Flex Sensors



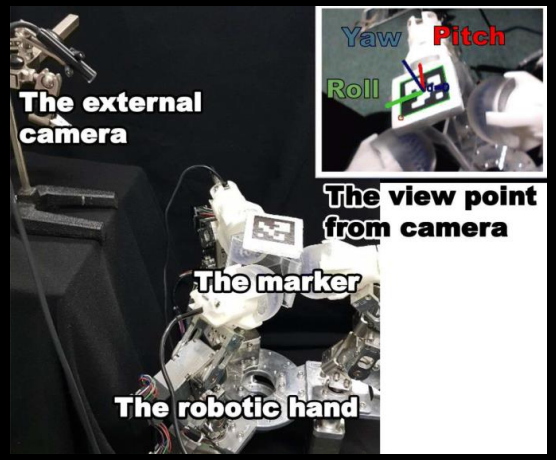
AdaFruit

Inertial Measurement Unit



Olsson et al. *FUSION 2019*

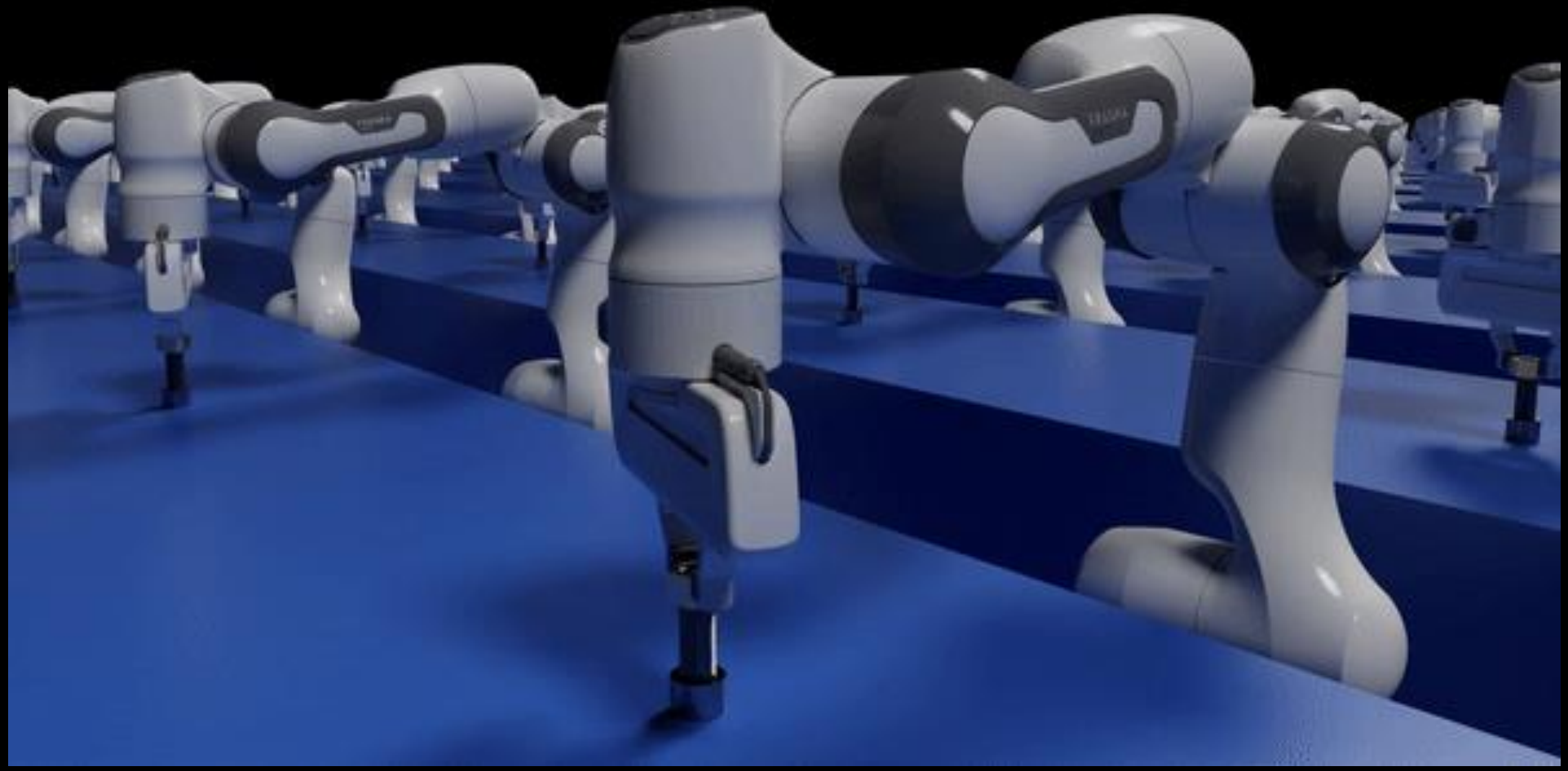
Camera



Choi, Tahara. Robomech Journal (2020)

Simulation for Massively parallel RL

Simulation



Advancing Robotic Assembly with a Novel Simulation Approach Using NVIDIA Isaac: Technical Blog

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What simulators are out there? (2025 ver.)

Simulation

Important questions for simulators:
Stability and accuracy?
GPU parallelization (i.e. speed)?
Open source?
Extensive documentation / large community?

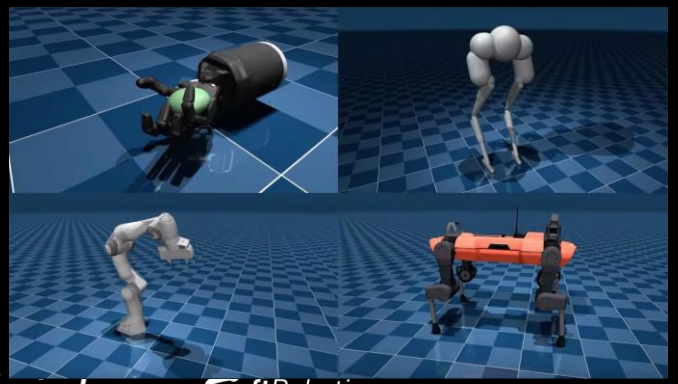
“Team Google”

Google DeepMind

(but not really)

“Team NVIDIA”

MuJoCo



Isaac Sim / NVIDIA Omniverse

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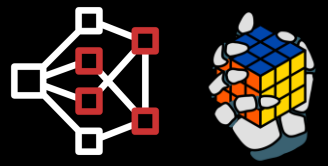
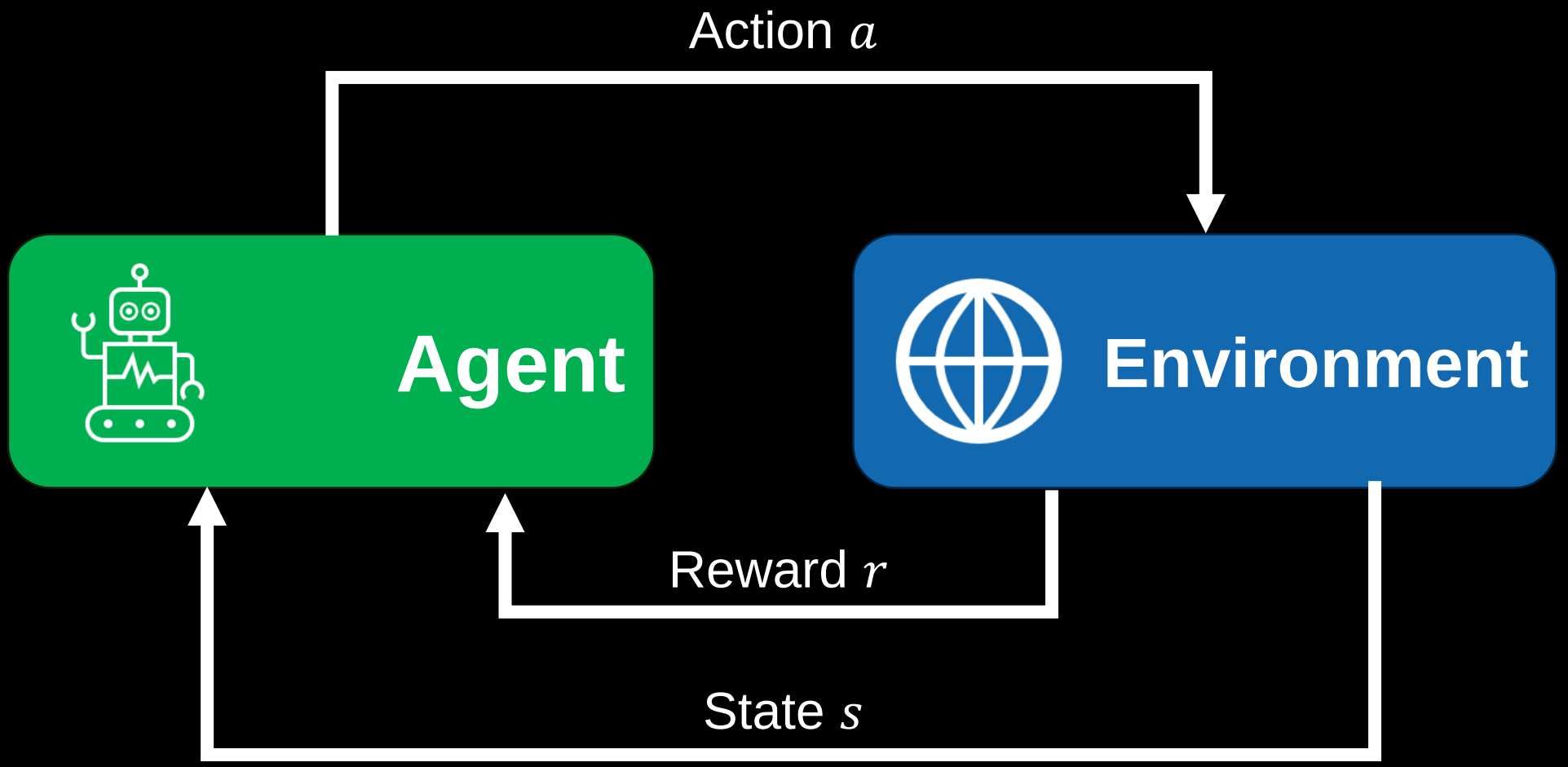
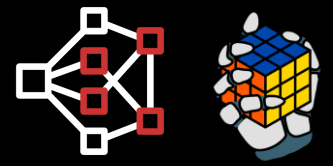
RL: Definitions



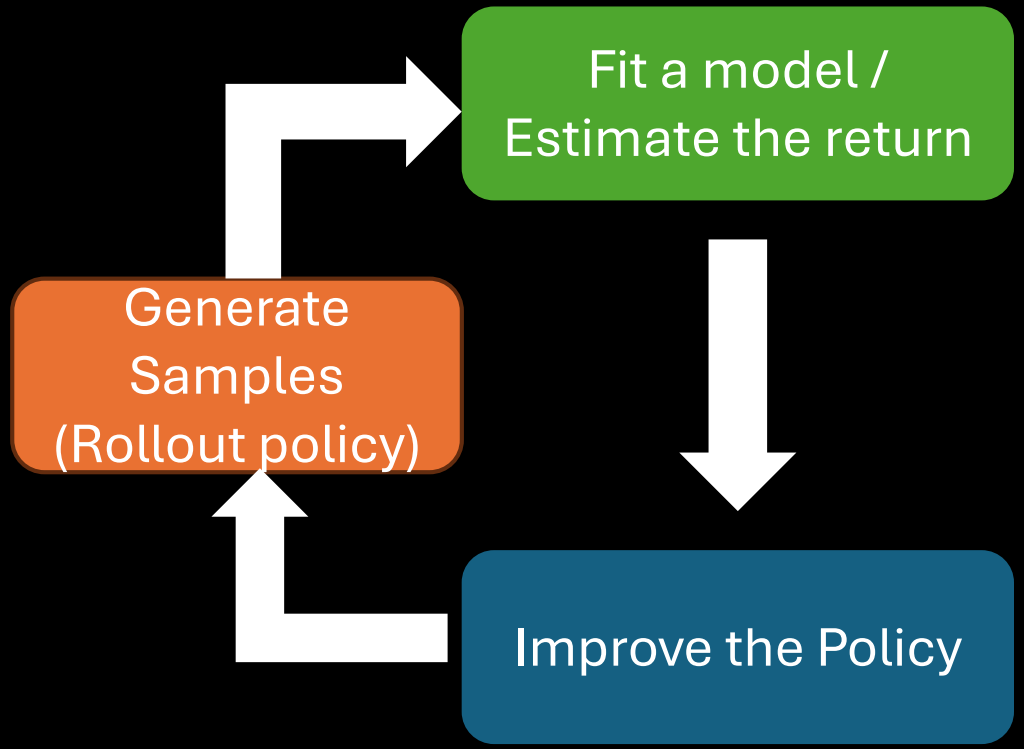
Reinforcement Learning



The anatomy of a reinforcement learning algorithm



Reinforcement Learning

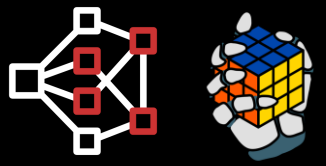


Learn the dynamics model

- $p(s'|s,a)$
- $r(s,a)$

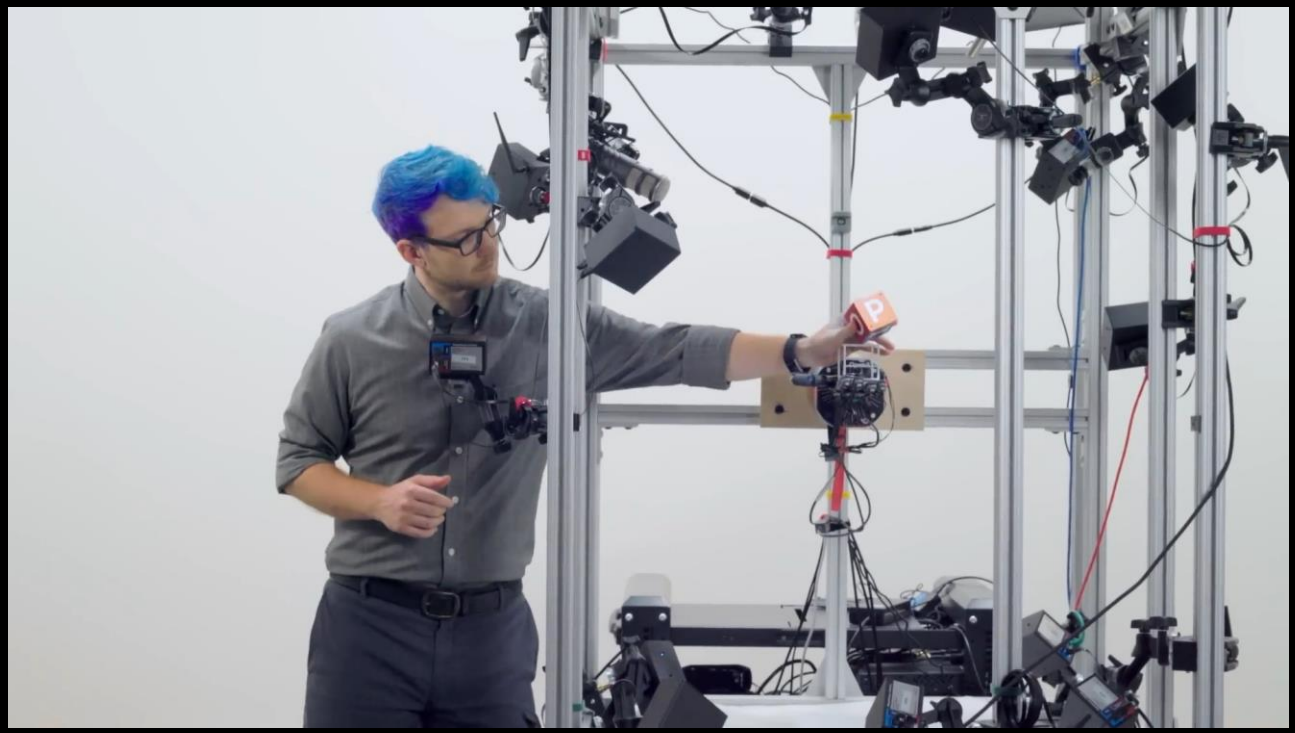
Optimal control from the model

Sim2Real: Domain randomization



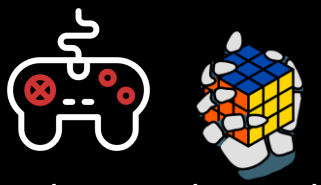
Reinforcement Learning

Increase the diversity in simulation domains so that the real world **may** look like another simulator.



resource: Learning dexterous in-hand manipulation
OpenAI, IJRR 2020 https://openai.com/index/learning-dexterity/

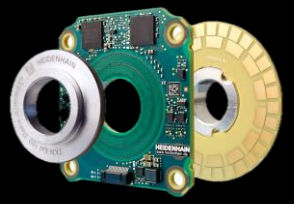
Robotics data is highly multimodal



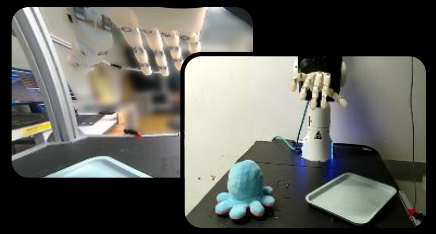
Teleoperation and Data Collection

Observations

Proprioception



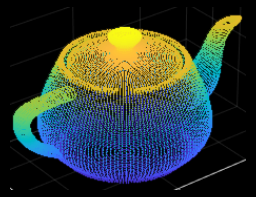
Wrist/Workspace RGBs



Language Command

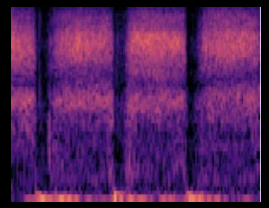
"put the plush on the tray"

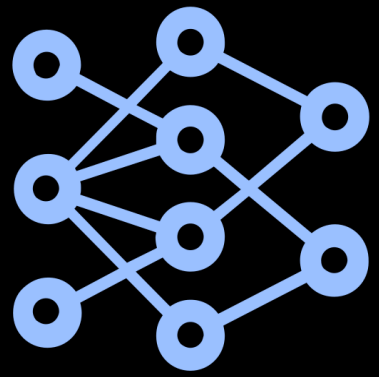
3D



Tactile Sensing

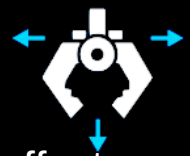
Audio





Actions

Different Meanings



end-effector space

Joint space

Different Dimensions

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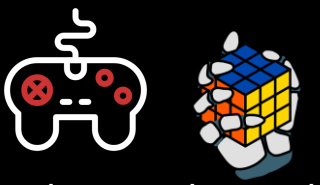
Data Sources for Robotic Manipulation

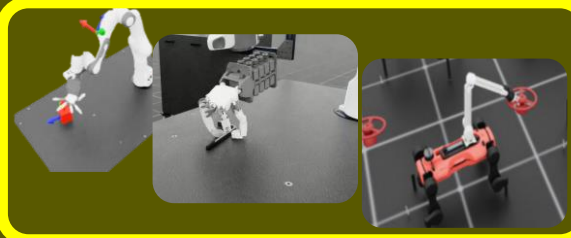


Teleoperation and
Data Collection

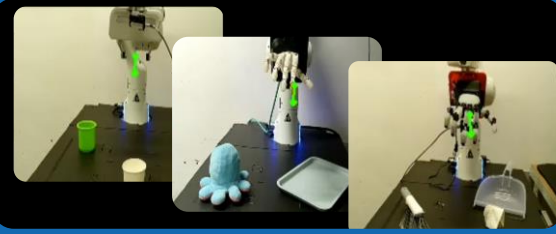
Scalability

Human Data

Simulation



Teleoperation

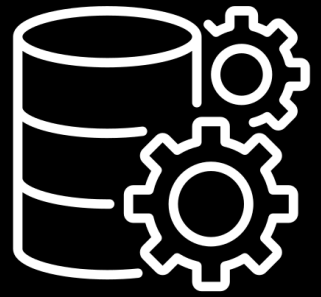


Quality

Imitation Learning (IL)

aka Behavior Cloning (BC), aka Learning from Demonstrations (LfD)

Imitation Learning

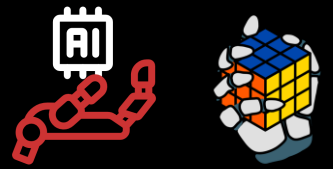


Given a dataset of "Expert transitions"

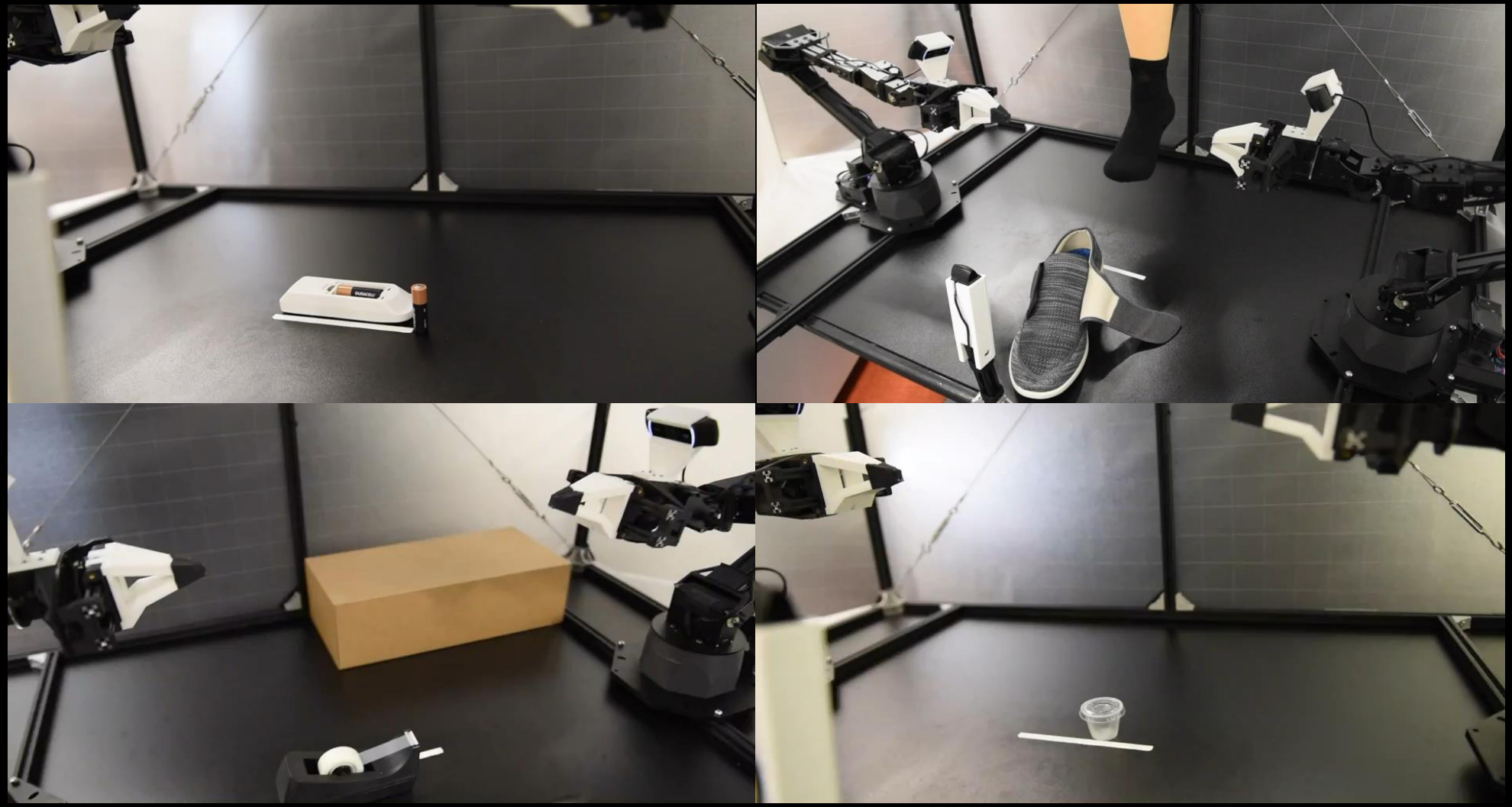
$$\mathfrak{D} = \{(o_t, a_t)\}_{t=1}^{N}$$

Simple supervised regression : $\pi = \arg\min \ \mathbb{E}_{(o,a) \sim \mathfrak{D}} [\|a - \pi(o)\|^2]$

ACT (Action Chunking Transformers)



Imitation Learning



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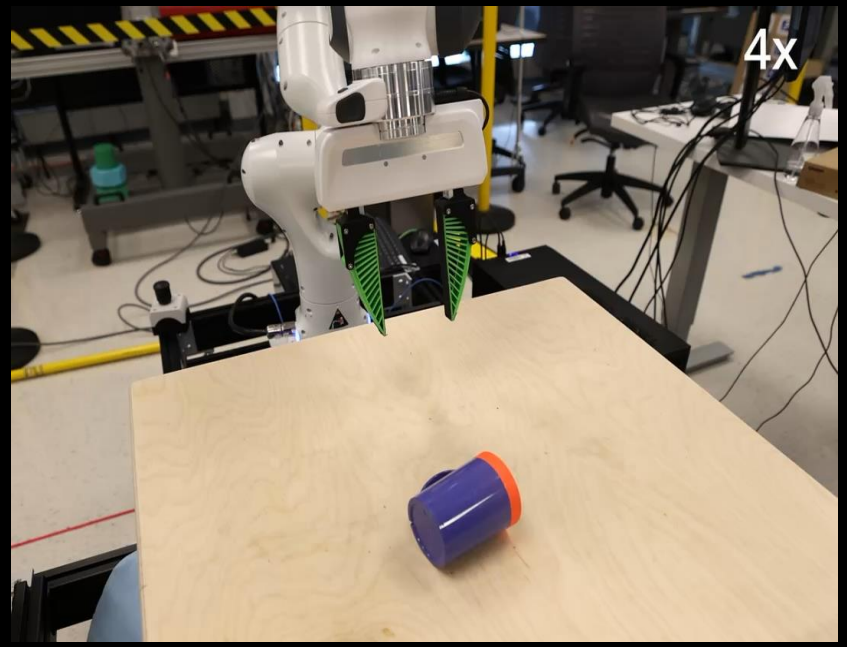
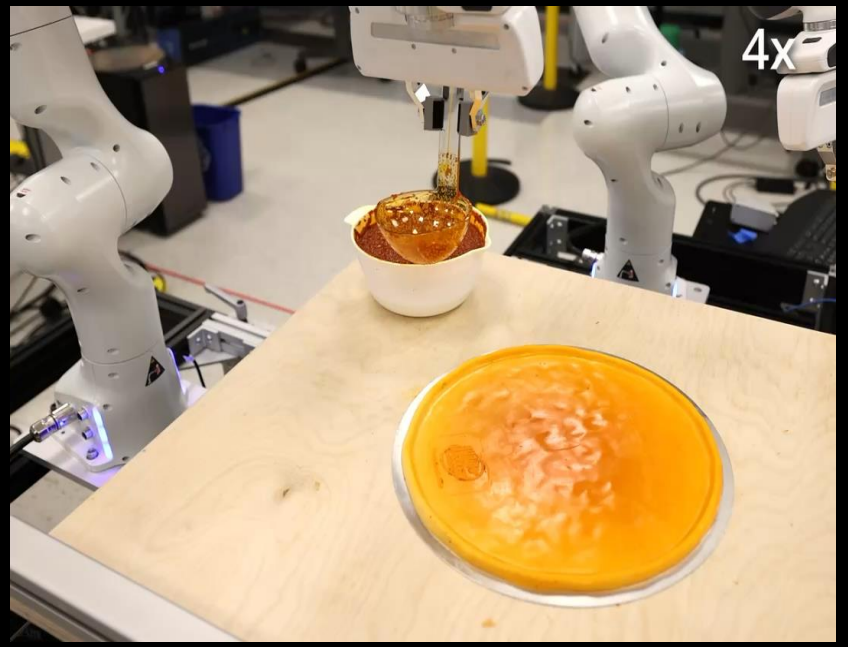
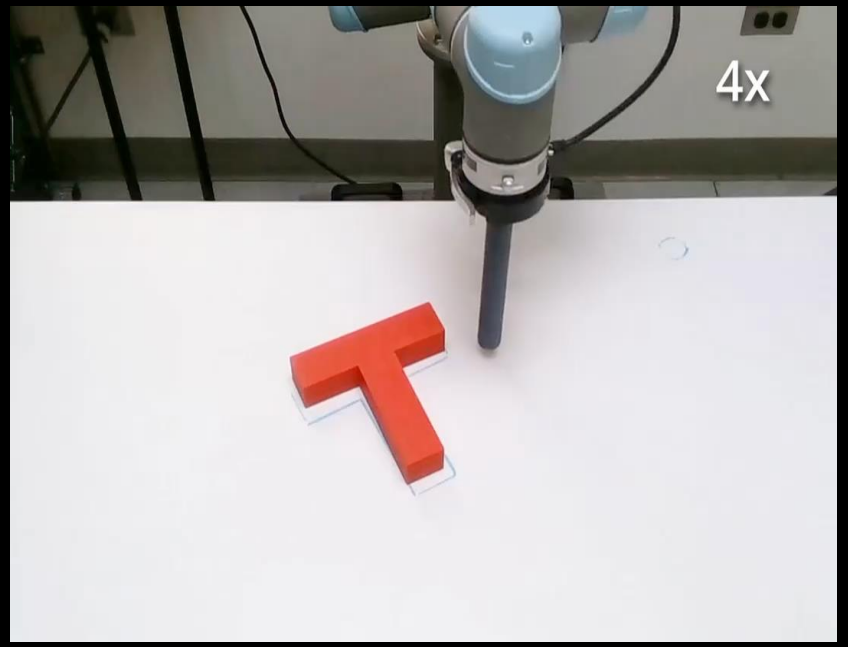
Zhao, T. Z., Kumar, V., Levine, S., Finn, C. (2023).
Learning Fine-Grained Bimanual Manipulation with Low-Cost Hardware

Diffusion Policy

Imitation Learning







Chi, C. et al. (2023). *Diffusion Policy: Visuomotor Policy Learning via Action Diffusion*

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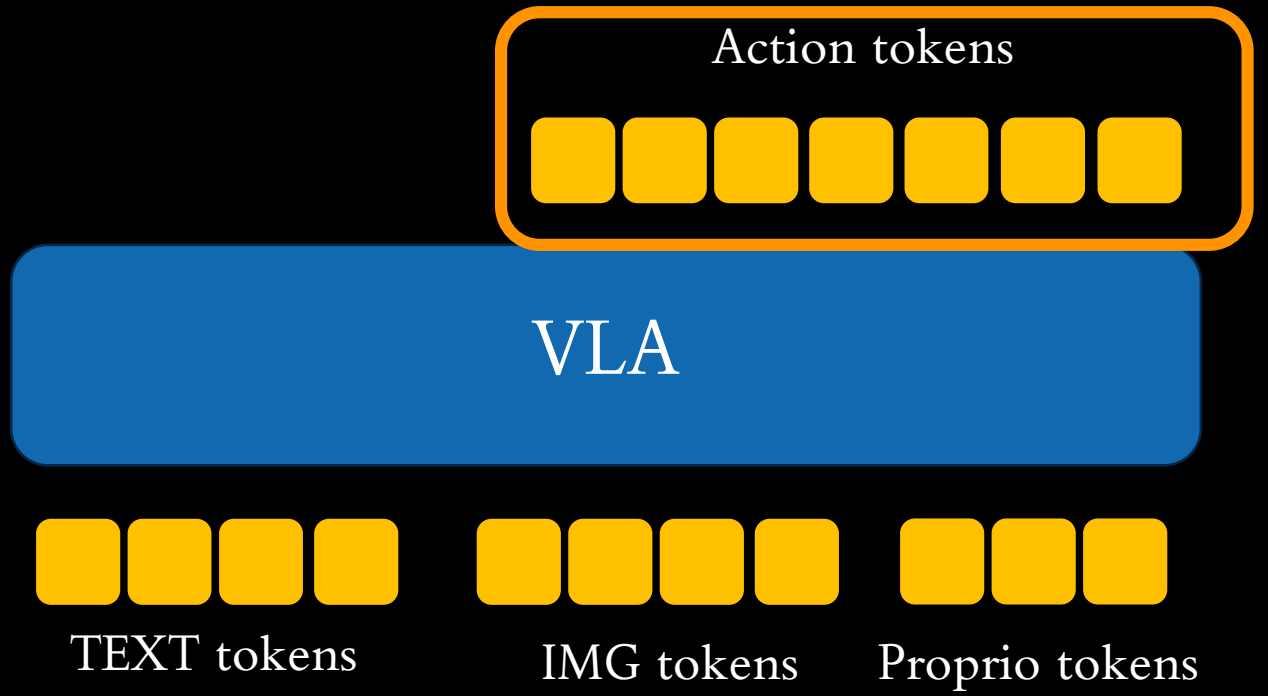
What are VLAs?

VLAs and
Foundation models

Extend VLMs with Actions

How to tokenize the Actions?
Can we afford slow autoregressive inference?



Bottlenecks for generalist robotics

VLAs and
Foundation models

Data

Cannot simply scrape internet
→ Human videos
→ Synthetic Data
→ Simulation

Control Frequency

Need real time control
→ System 1/ System 2
→ Chunk Quantization (FAST)

Cross-embodiment

Observation and Action Space depends on the Robot Embodiment
→ Scaling Data
→ Latent Actions

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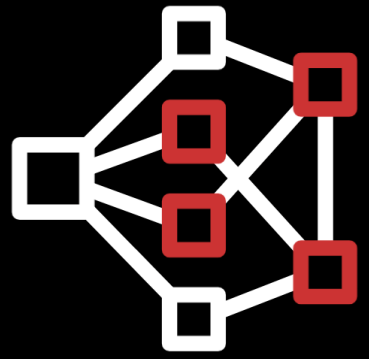
Questions?

Design and Fabrication

Kinematics, Dynamics and Control

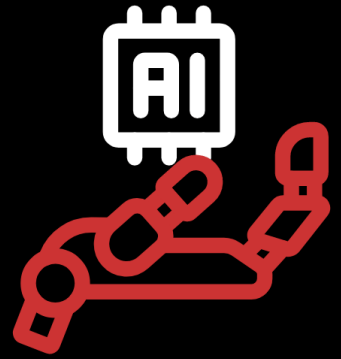
Sensors

Simulation

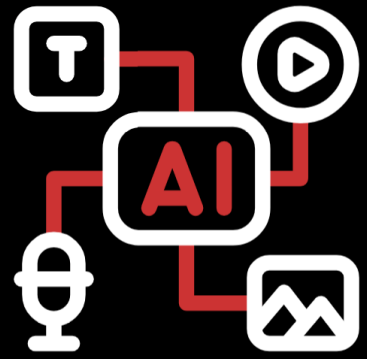


Reinforcement Learning

Teleoperation and Data Collection



Imitation Learning



VLAs and Foundation models

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