3rd Class / Jan 15 (Wed)

Modern Robot Learning: Hands-on Tutorial

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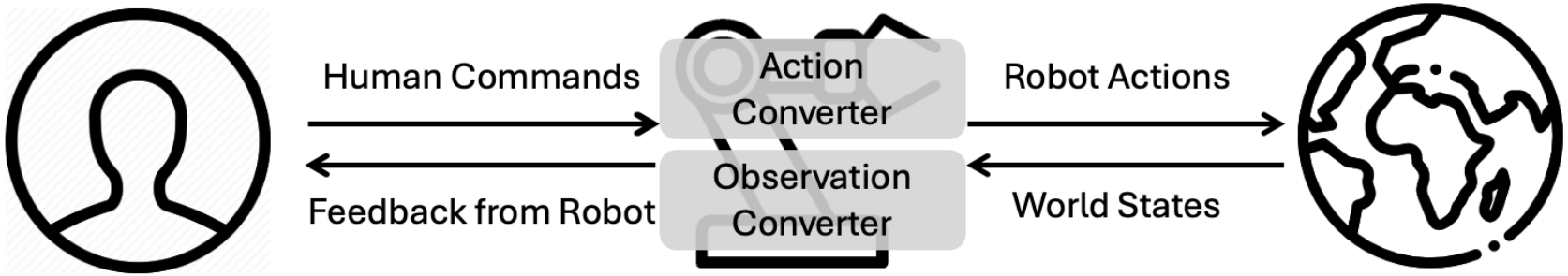
Last Week…

Robot Teleoperation

4 Key Elements of Teleoperation System

1. **Designing** command space for humans
2. **Converting** commands to robot actions
3. **Designing** feedback space for humans
4. **Converting** robot perceptions to human feedback



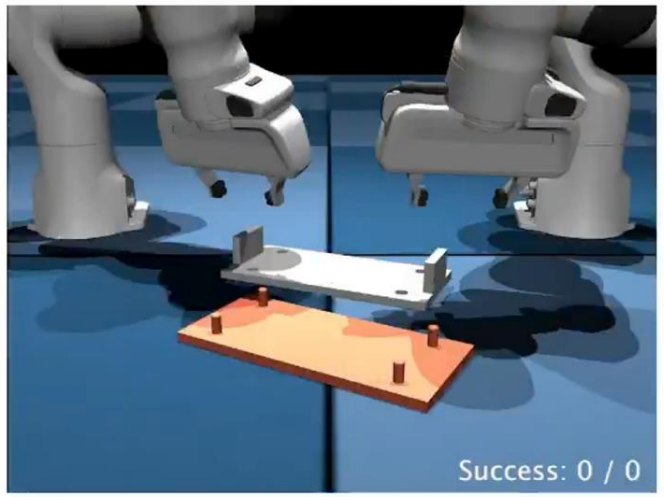
Most of the robot datasets are created by ***"teleoperation"***

Last Week…

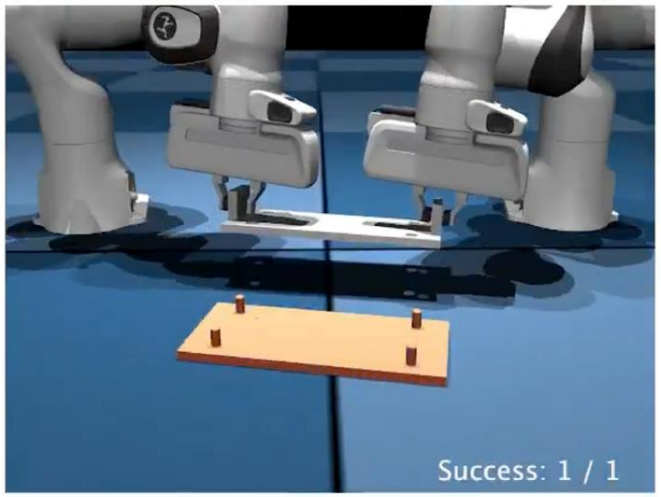
Role of Simulation

Demos collected in simulation supports
last-mile performance improvement through **RL finetuning.**

Imitation only



With a sprinkle of reactivity



*How **simulation** can help data collection*

Today

Collecting Robot **Data** in Virtual World

Learning from Videos

Interaction Interfaces

Today

- Learning from videos
  - Policy learning from human video
    - Observation mismatch
    - Get action
  - World modeling
    - Data and learning
    - How to apply to robots
- Drawbacks of three different methods
- Interaction interface Case Studies: In-Depth Analysis
  - Policy learning with interaction interface

Today

- **Learning from videos**
  - Policy learning from human video
    - Observation mismatch
    - Get action
  - World modeling
    - Data and learning
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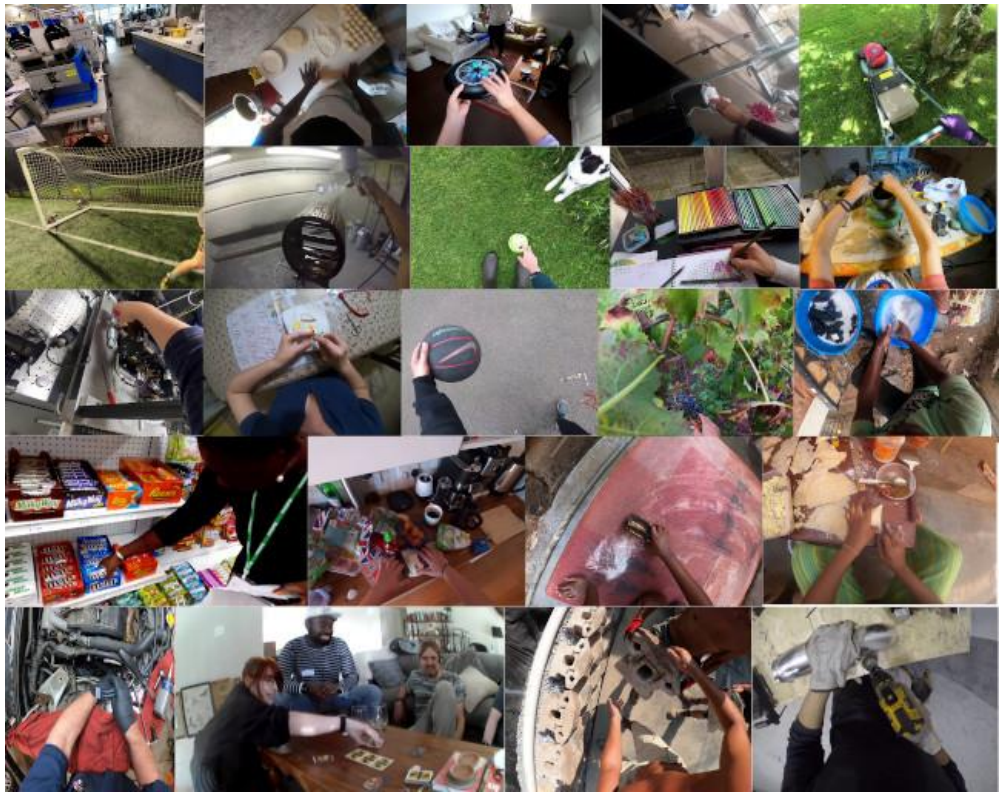
Learning from videos

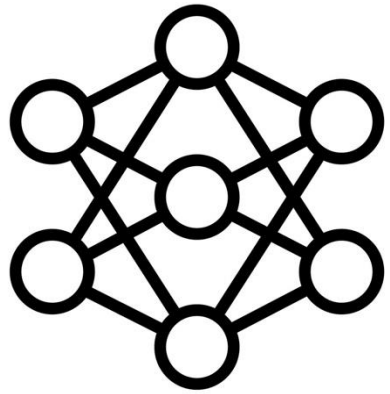
[A] Policy learning from human videos



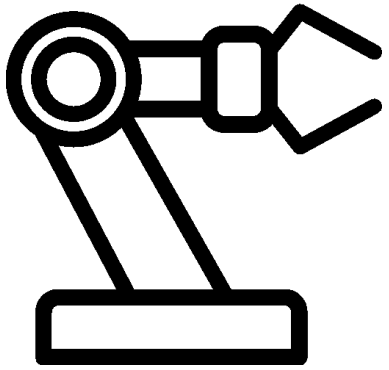
[B] World modeling from all videos

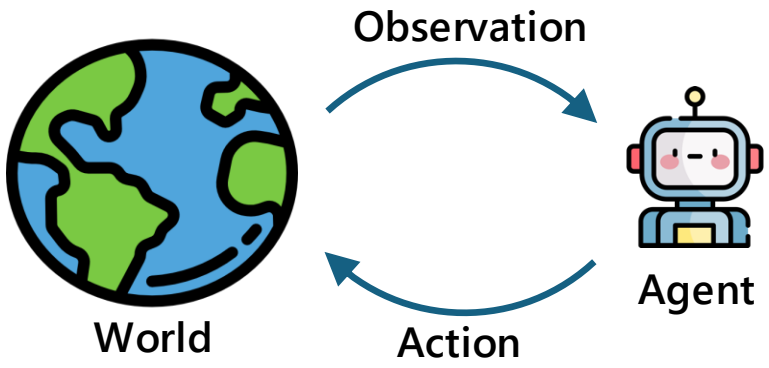
Policy learning

World / Robot States
from Sensors

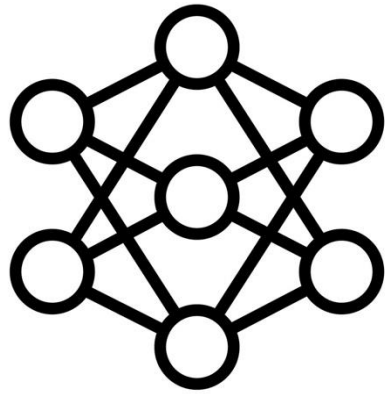
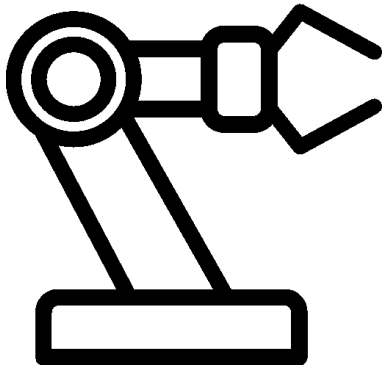


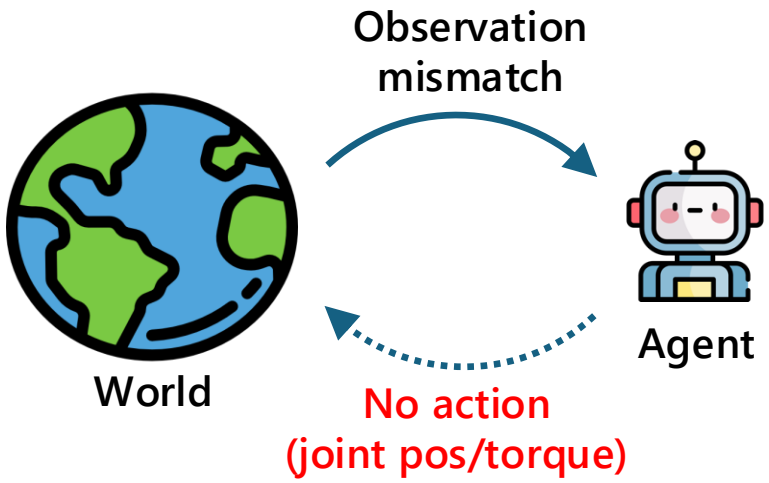
Robot Actions





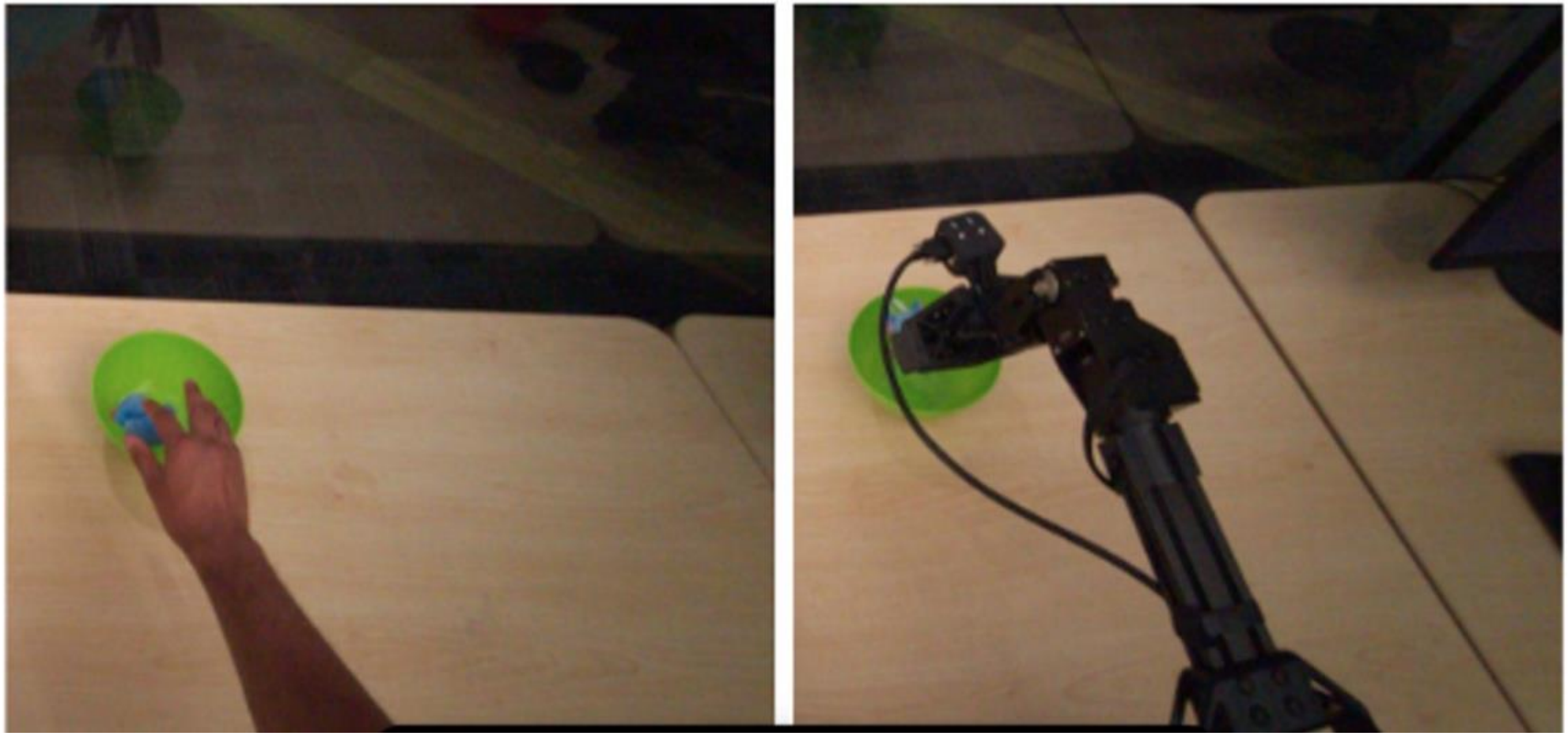
Policy learning

World / Robot States from Sensors →  → Robot Actions 

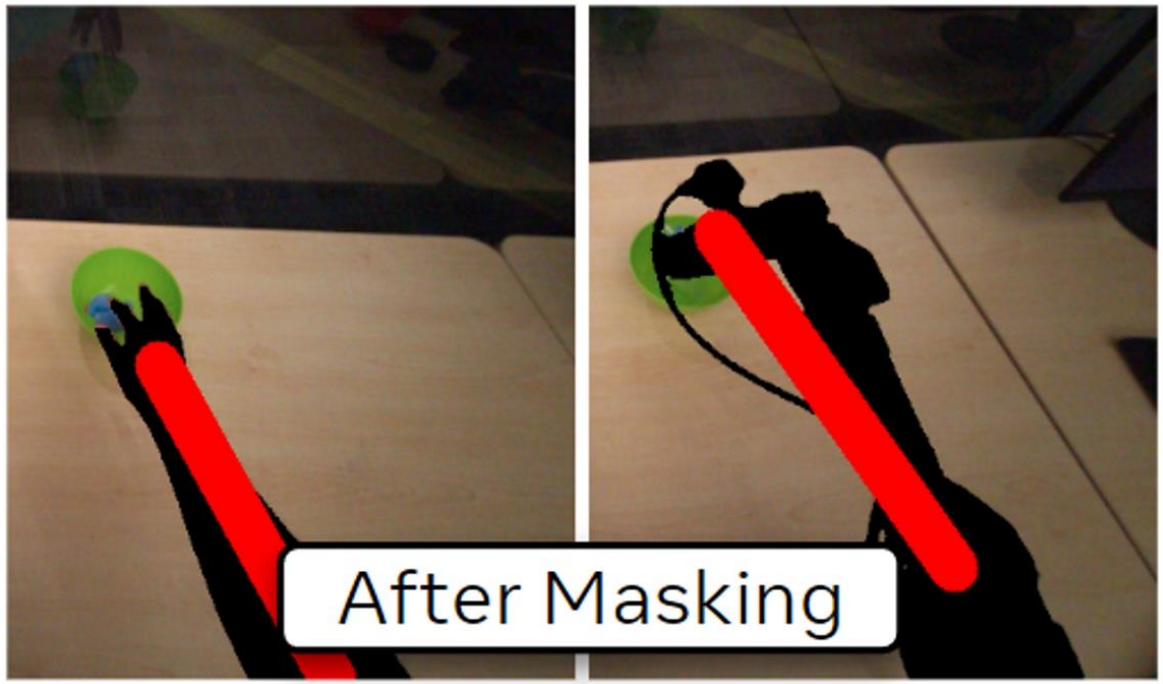


EPIC-KITCHENS

Observation mismatch

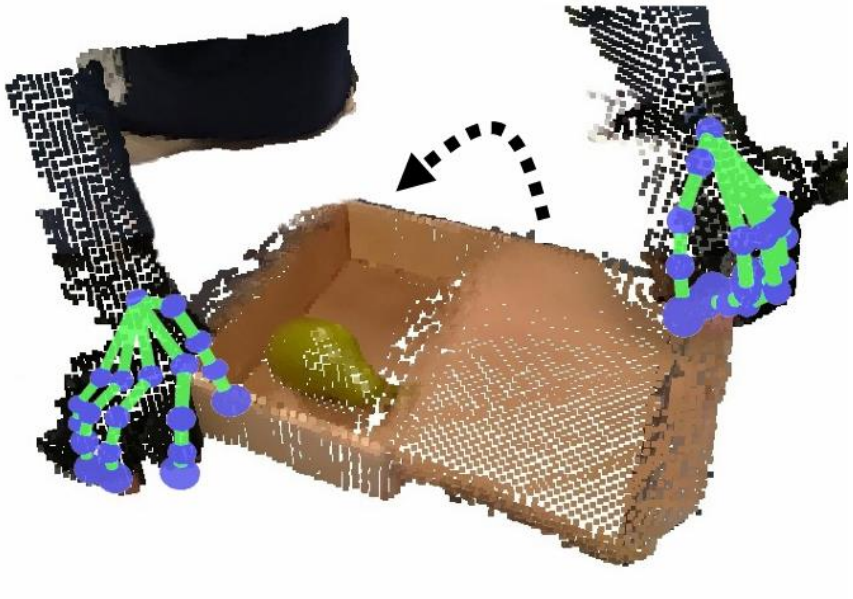


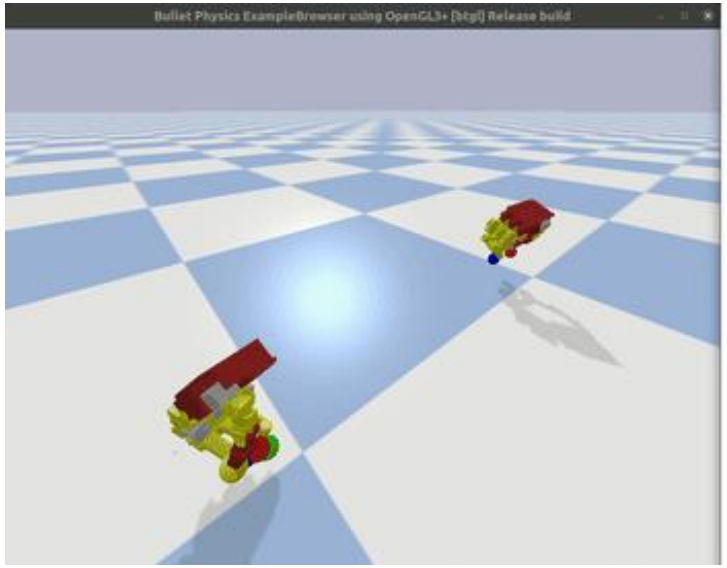
Observation retargeting



**Mask out both human and robot arms,
replace with a red line**

Overlay based on hand pose

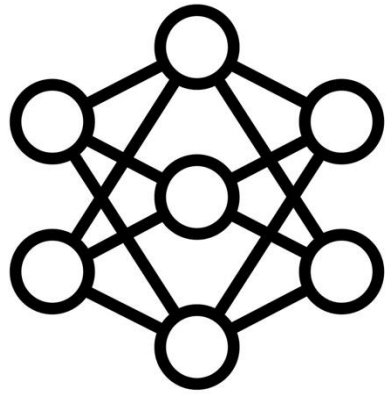




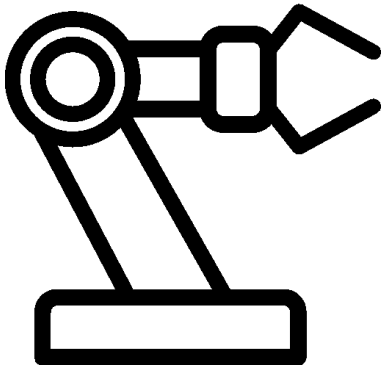
DexCap: Scalable and Portable Mocap Data Collection System for Dexterous Manipulation

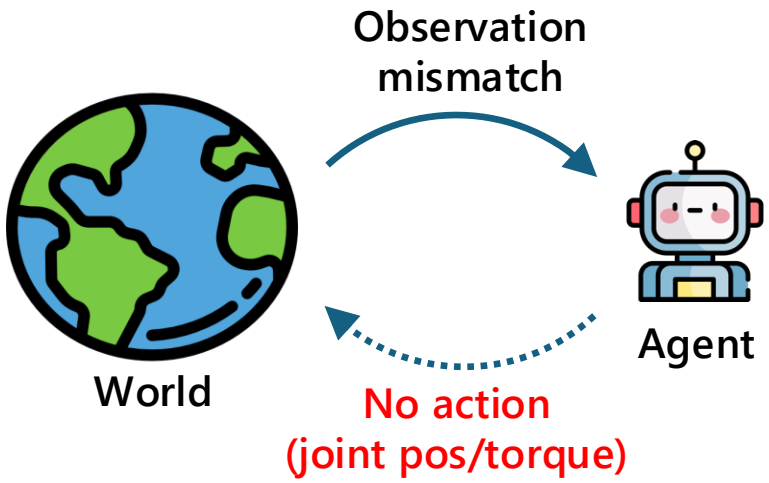
Policy learning

World / Robot States
from Sensors



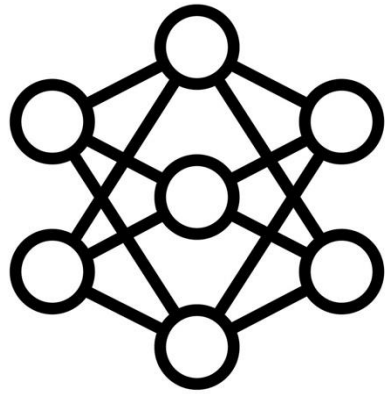
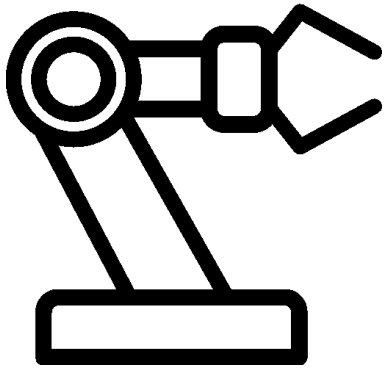
Robot Actions

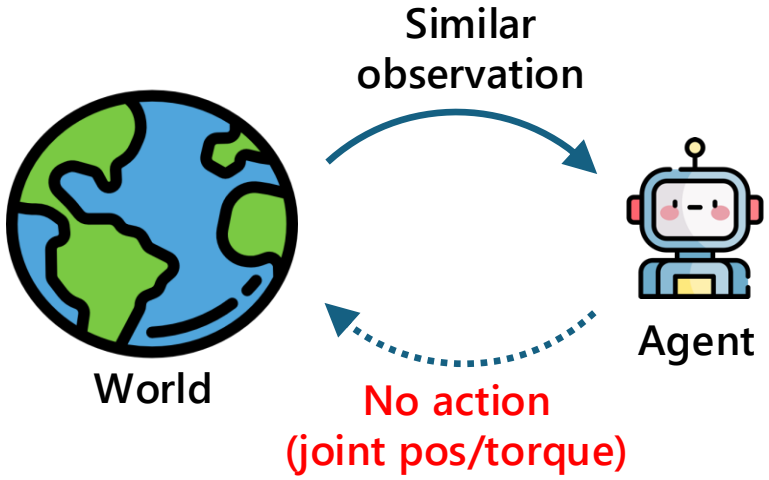




By retargeting, we can get an observation close to the robot would have.

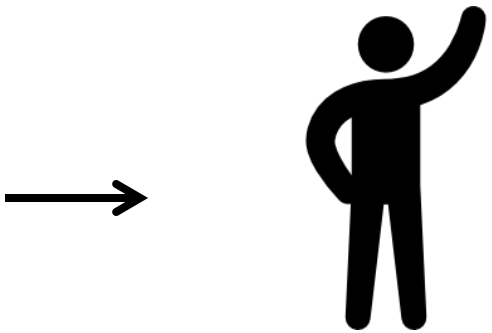
Policy learning

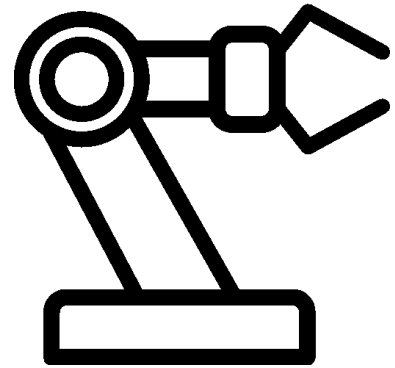
World / Robot States from Sensors →  → Robot Actions 



EPIC-KITCHENS

Action generation from videos





Human video

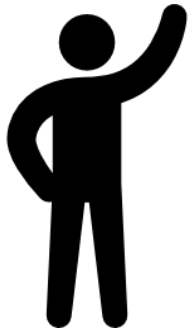
Human action

Robot action

$$D_1 = \{(s_0, s_1, \dots, s_n)\} \quad D_2 = \{(s_0, a_0, s_1, a_1, \dots, s_n)\} \quad D_3 = \{(s_0, \hat{a}_0, s_1, \hat{a}_1, \dots, s_n)\}$$

$$a_t = \boldsymbol{g}(s_t, s_{t+1}) \qquad \hat{a}_t = \boldsymbol{h}(a_t)$$

From videos to human action



Human video

Human action

$$D_1 = \{(s_0, s_1, \dots, s_n)\} \qquad D_2 = \{(s_0, a_0, s_1, a_1, \dots, s_n)\}$$

$$a_t = \boldsymbol{g}(s_t, s_{t+1})$$

From videos to human action

AlphaPose

OpenPose

Human pose estimation

ITALIAN HAND GESTURE:

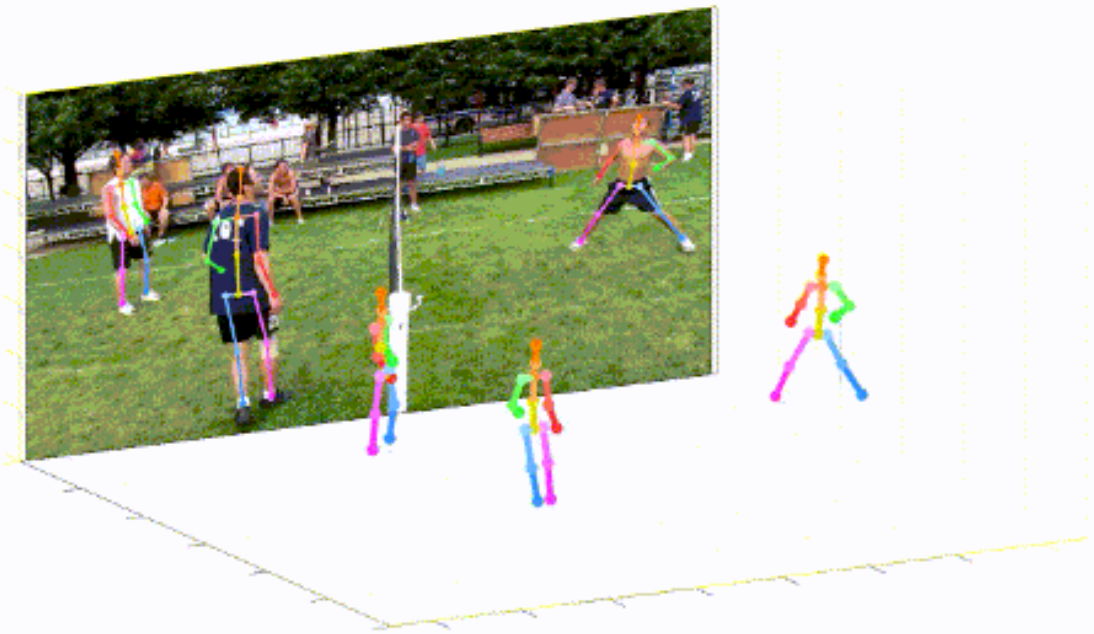
I AM FULL

Right hand
Top view

Left hand
Top view

Reconstructing Hands in 3D with Transformers

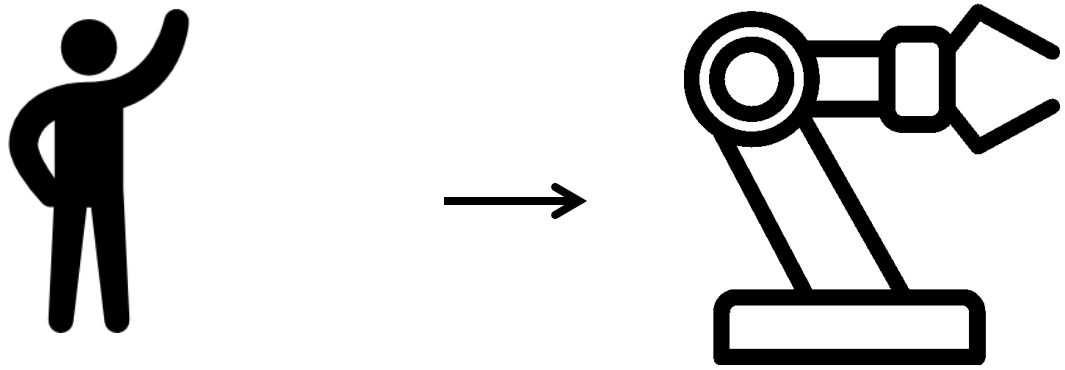
From videos to human action



3D Human pose estimation

Camera Distance-aware Top-down Approach for 3D Multi-person Pose Estimation from a Single RGB Image

Action generation from videos



Human action

Robot action

$$D_2 = \{(s_0, a_0, s_1, a_1, \dots, s_n)\} \qquad D_3 = \{(s_0, \hat{a}_0, s_1, \hat{a}_1, \dots, s_n)\}$$

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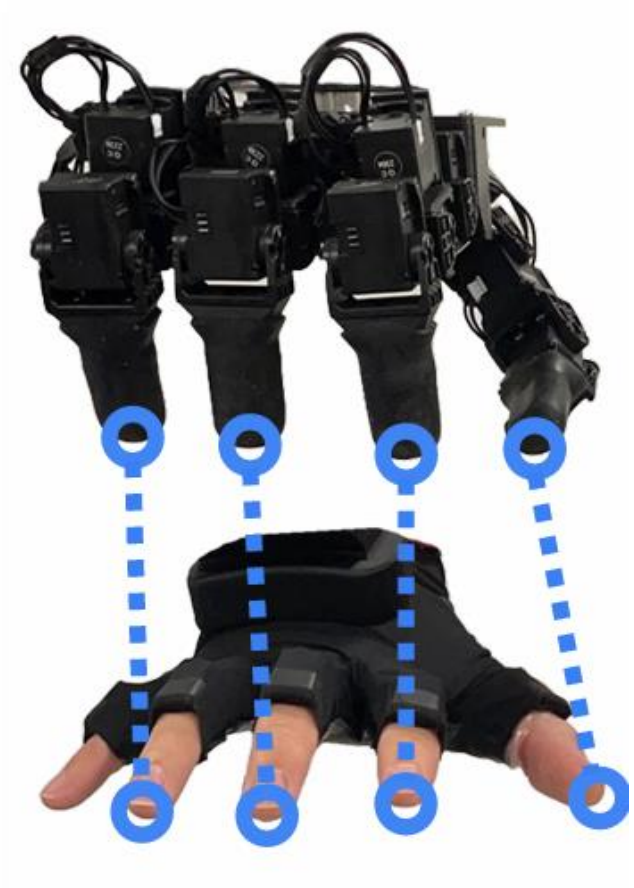
Action retargeting



Human hand

LEAP robot hand (**1.5x** larger in size)

DexCap: Scalable and Portable Mocap Data Collection System for Dexterous Manipulation

Policy learning

World / Robot States
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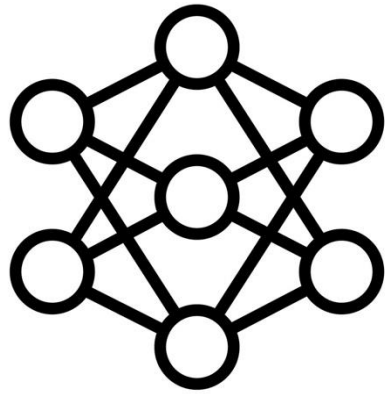

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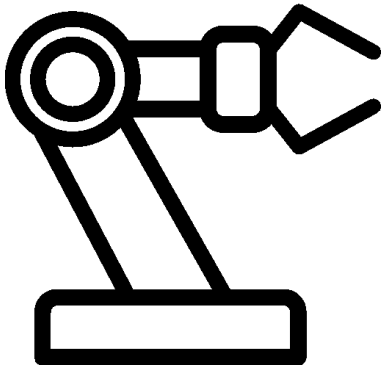
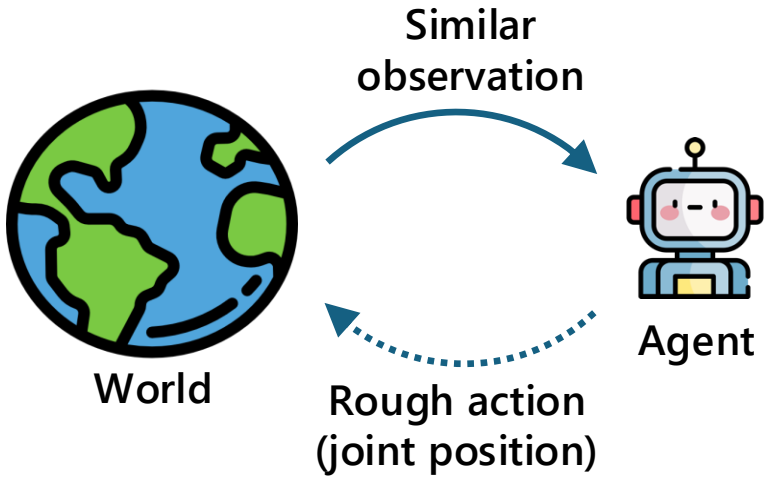
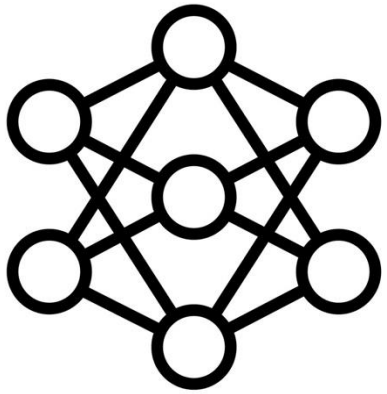




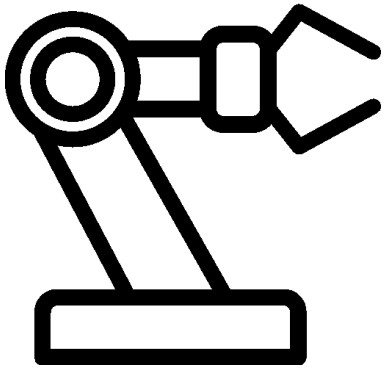
By action retargeting, we can get rough robot action (joint position)

Policy learning

World / Robot States
from Sensors

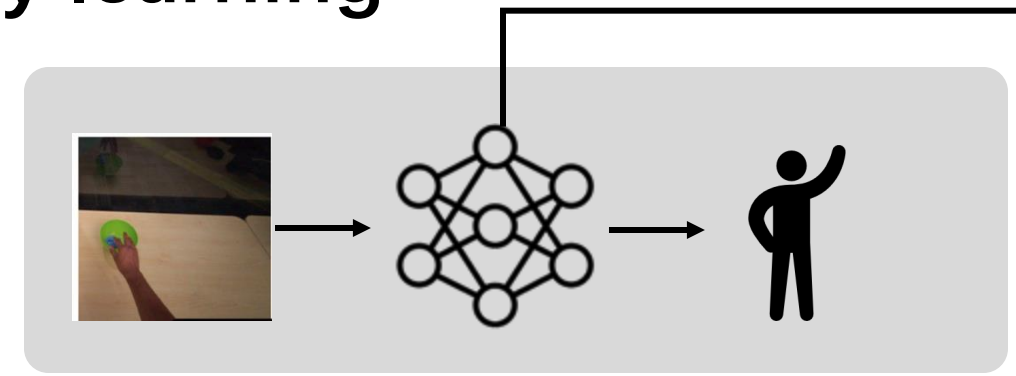


Robot Actions

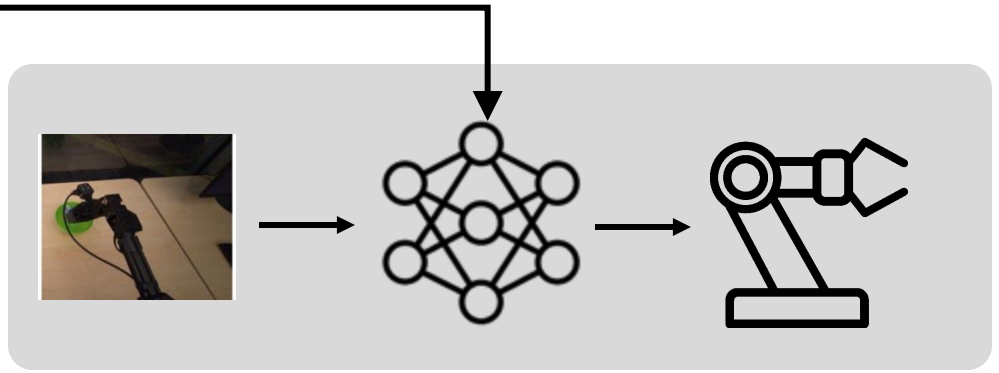


How to learn from these data?

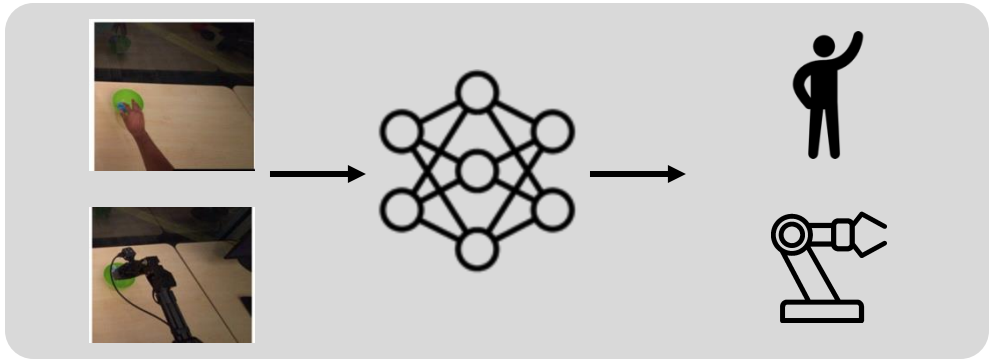
Policy learning



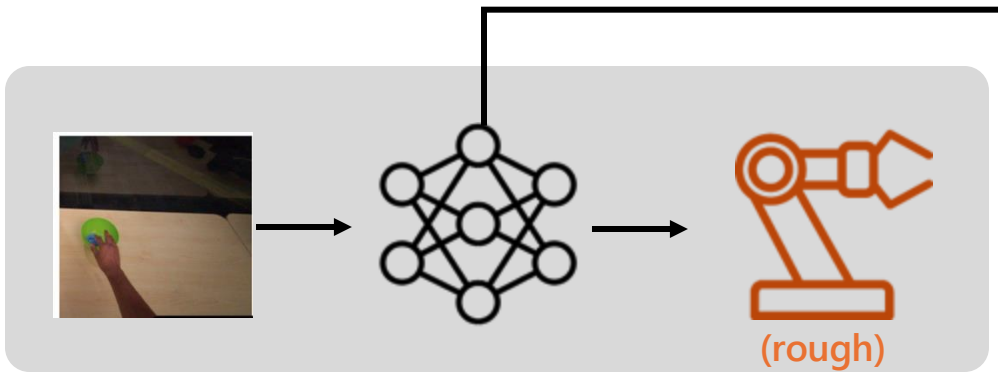
Pretrain

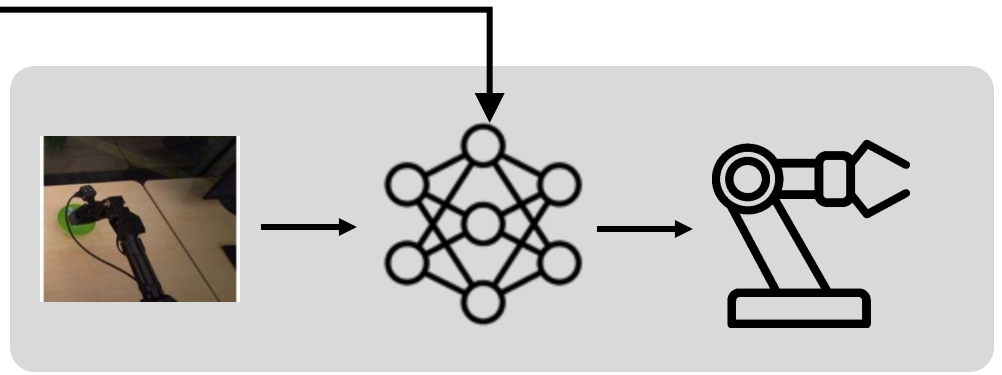


Finetune



Mix training

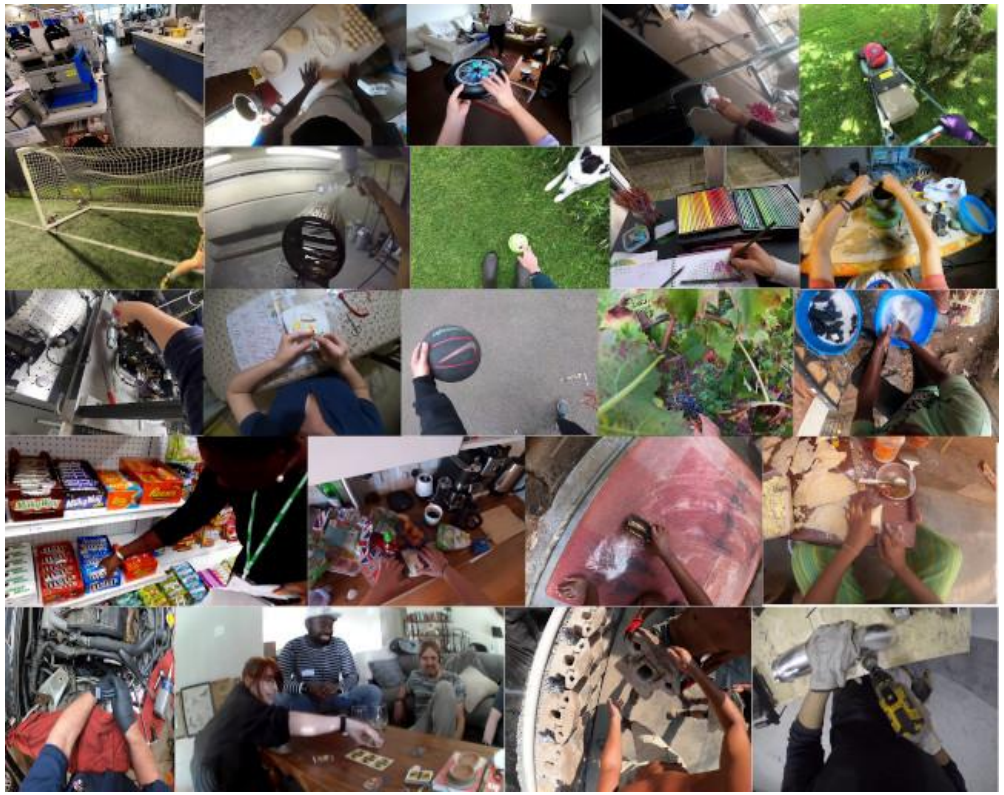




Human-in-the-loop correction

Learning from videos

[A] Policy learning from human videos



[B] World modeling from all videos

Learning from videos

GenAI

Sora - OpenAI

Data and learning

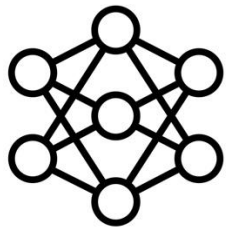
Data: all internet videos/games

An otter is surfing

Text instruction

And/Or

Current frame



Future frames

Learning: future video generation

Cosmos

Fold a green fabric item on a table.

Organize books by placing them vertically on a shelf.

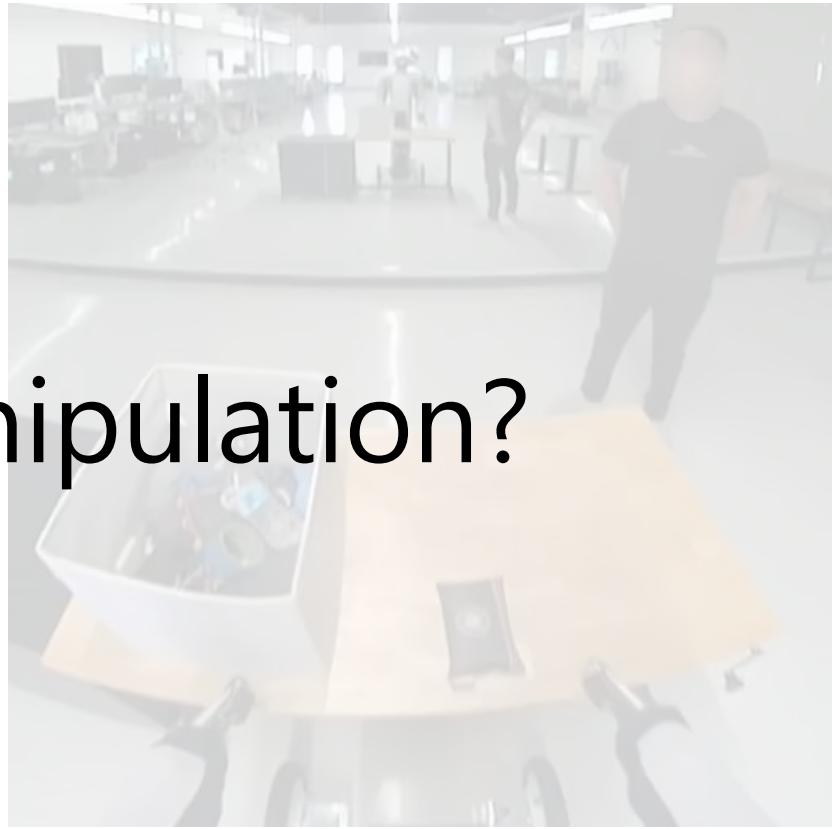
Pick up an electronic device from a table and place it in a bin.

https://www.nvidia.com/en-us/ai/cosmos/

Cosmos

Fold a green fabric item on a table.

Organize books by placing them vertically on a shelf.

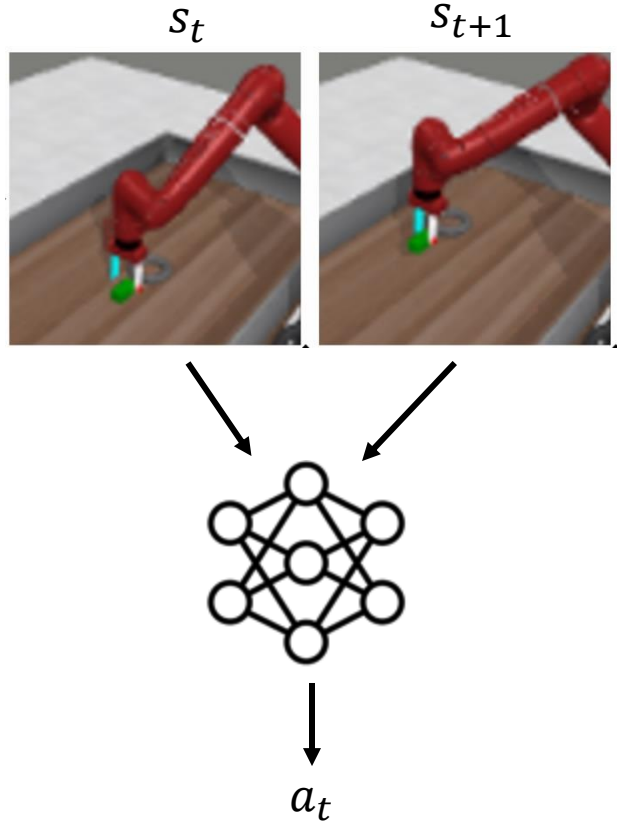


Pick up an electronic device from a table and place it in a bin.

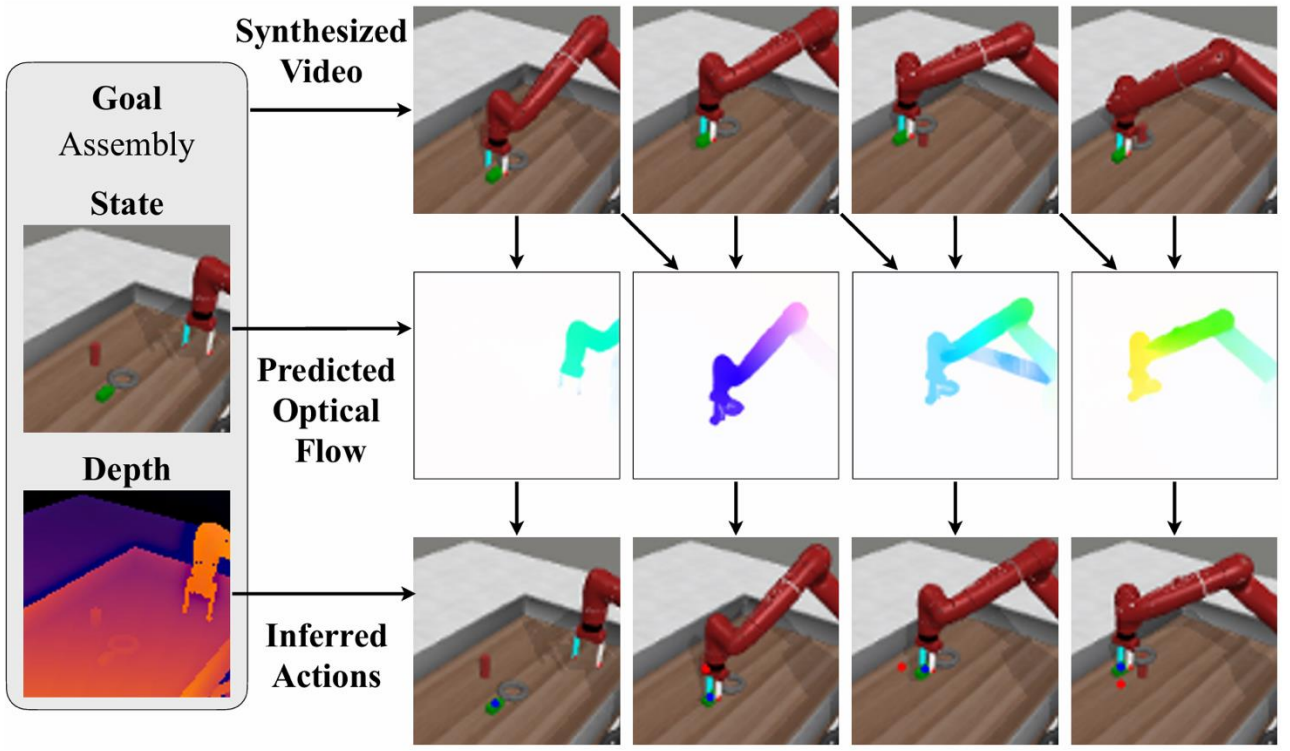
Problem of applying to manipulation?
No action!

https://www.nvidia.com/en-us/ai/cosmos/

Applying to manipulation



Inverse dynamic model

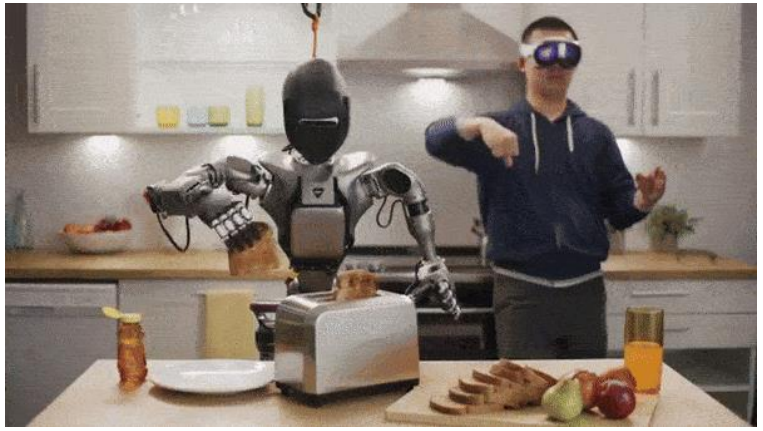


Correspondence

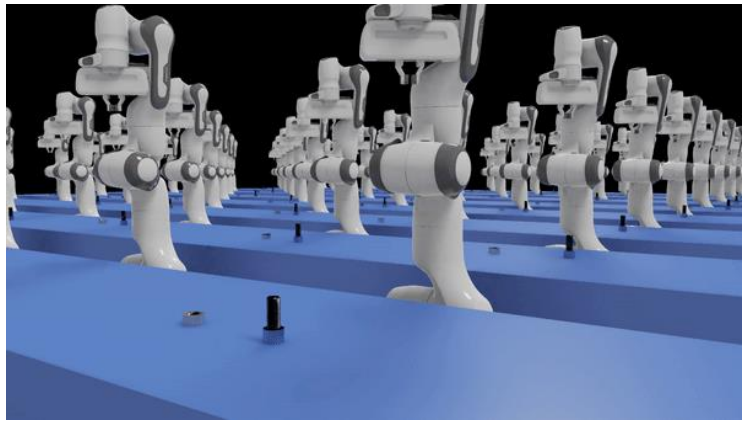
Today

- Learning from videos
  - Policy learning from human video
    - Observation mismatch
    - Get action
  - World modeling
    - Data and learning
    - How to apply to robots
- **Drawbacks of three different methods**
- Interaction interface Case Studies: In-Depth Analysis
  - Policy learning with interaction interface

How to collect robotic data?



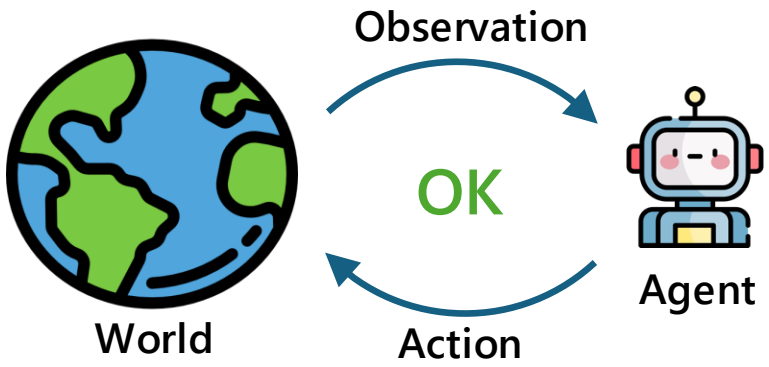
Teleoperation



Simulation

YouTube

Video



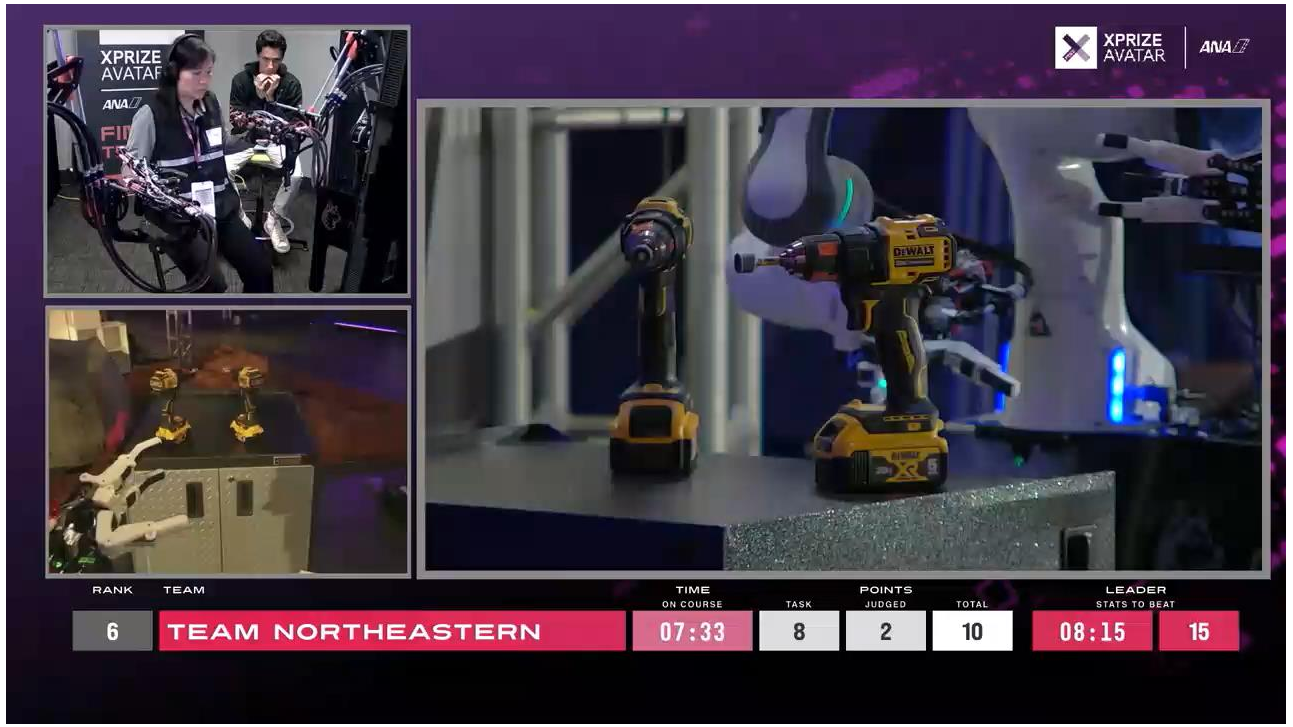
Is teleoperation good?

$$$$$

Expensive

Inefficient

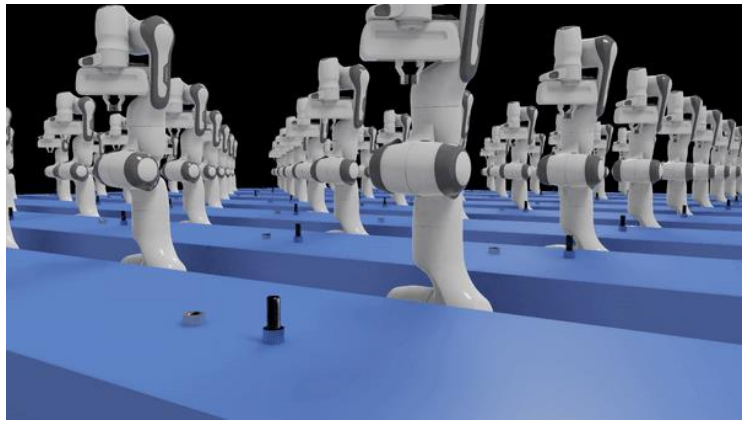
Limited capability



Top teleoperation platform motivated by $10M prize:
Took 40 seconds to adjust the drill and failed

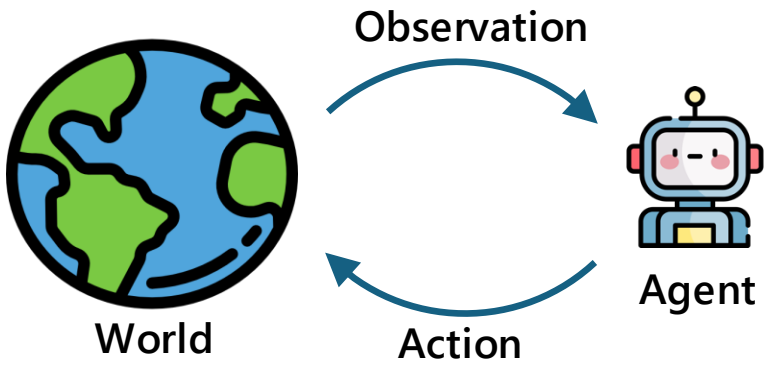
How to collect robotic data?

Teleoperation



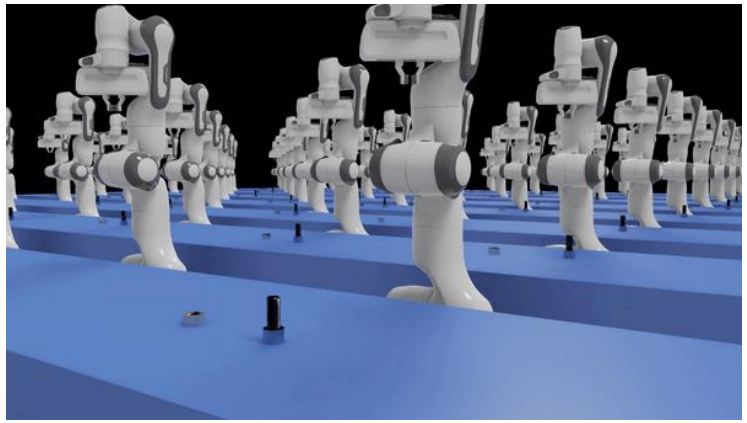
Simulation

Video



How to collect robotic data?

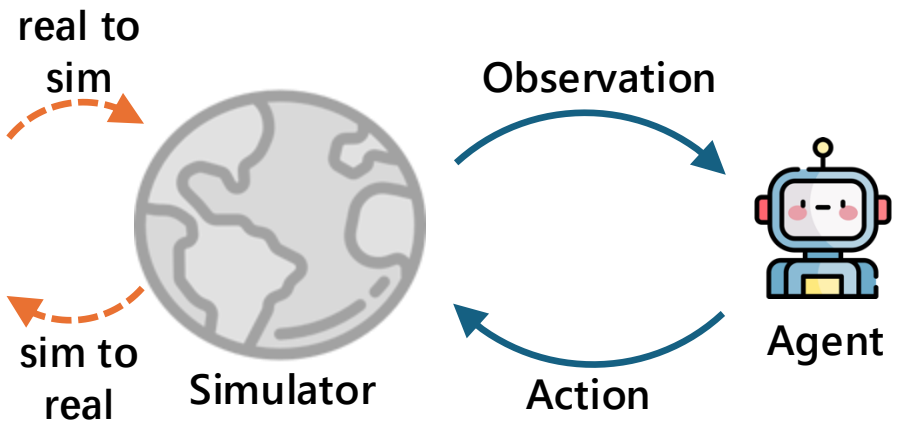
Teleoperation



Simulation

YouTube

Video



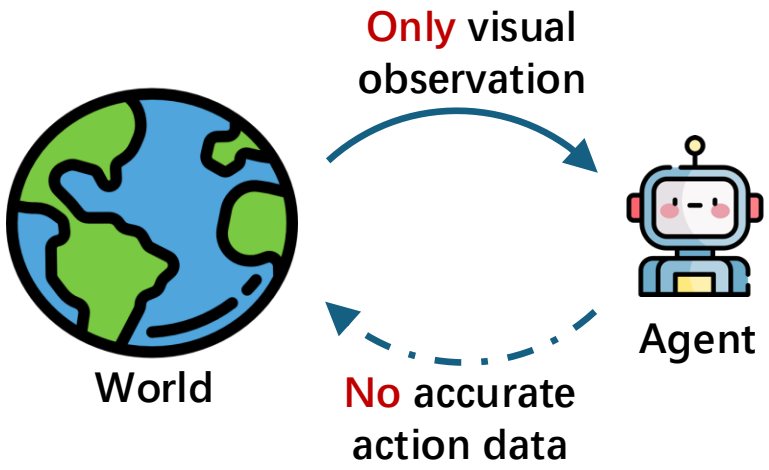
How to collect robotic data?

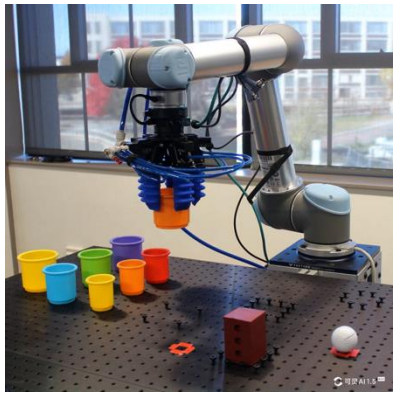
Teleoperation

Simulation

Video

Heavily occluded
Tactile is needed





The robotic arm pushes the red block - KlingAI

How to collect robotic data?

Expensive

Limited capability

Teleoperation

real to sim

sim to real

Simulation

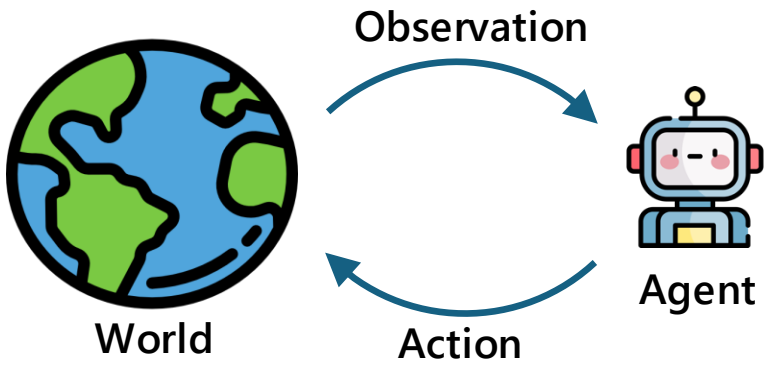
Only visual observation

No accurate action data

Video

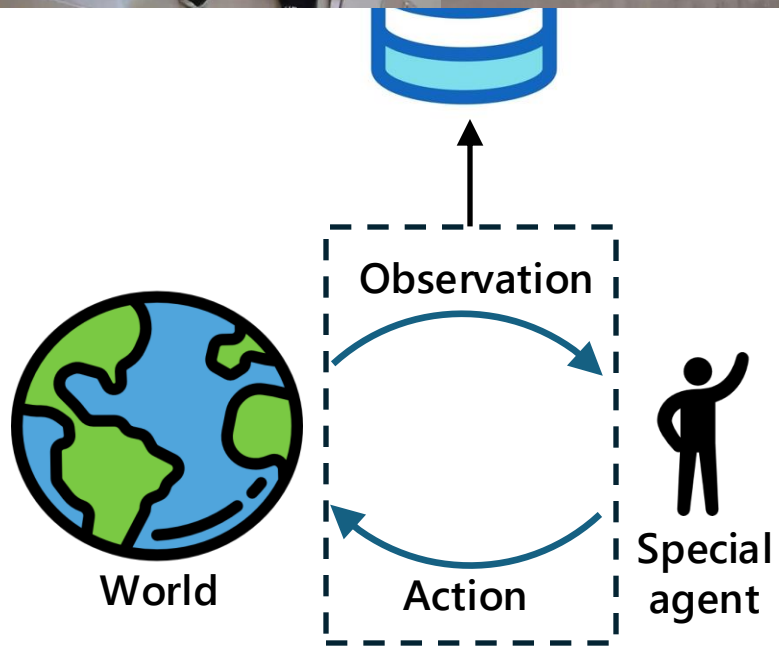
A new paradigm is needed for data collection!

How to collect robotic data?

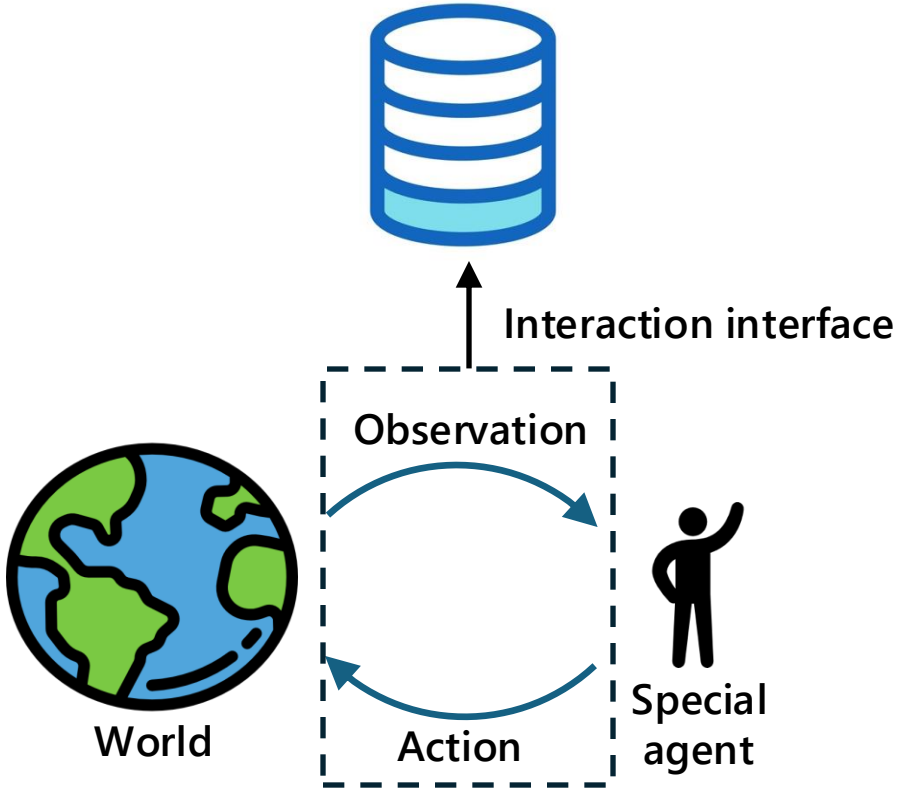


How to collect robotic data?



Interaction interface



Devices that can record observation and action data when humans are interacting with the world

Today

- Learning from videos
  - Policy learning from human video
    - Observation mismatch
    - Get action
  - World modeling
    - Data and learning
    - How to apply to robots
- Drawbacks of three different methods
- **Interaction interface Case Studies: In-Depth Analysis**
  - Policy learning with interaction interface

Interaction interface

AirExo

UMI

DEXO

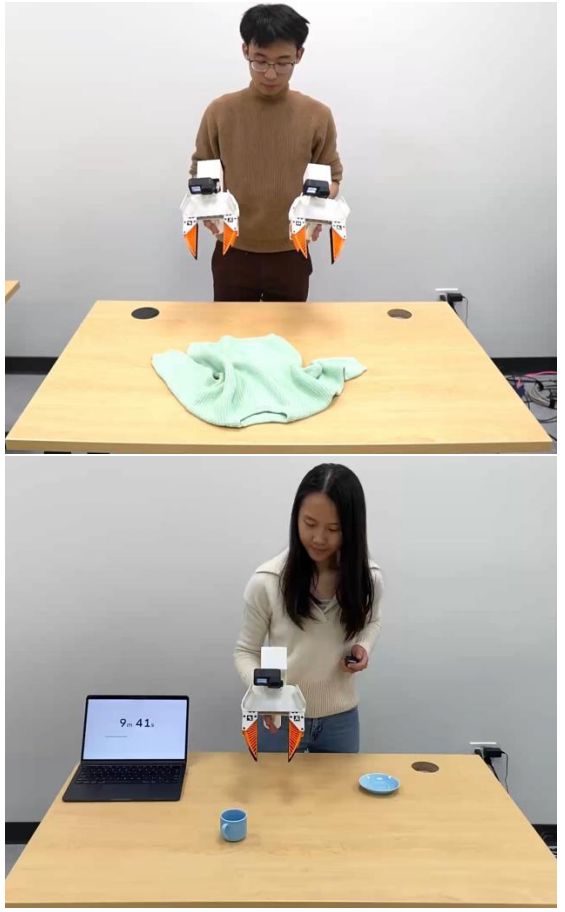
AirExo: Low-Cost Exoskeletons for Learning Whole-Arm Manipulation in the Wild

Universal Manipulation Interface: In-The-Wild Robot Teaching Without In-The-Wild Robots

DEXO: Hand Exoskeleton System for Teaching Robot Dexterous Manipulation In-The-Wild

Interaction interface

AirExo



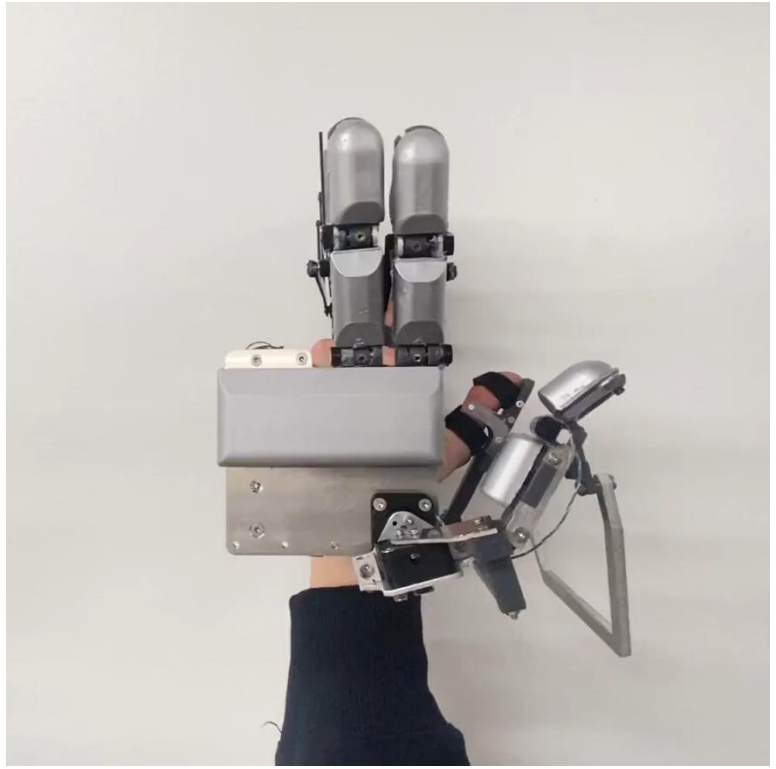
UMI

AirExo: Low-Cost Exoskeletons for Learning Whole-Arm Manipulation in the Wild

Universal Manipulation Interface: In-The-Wild Robot Teaching Without In-The-Wild Robots

Dexterous interaction interface

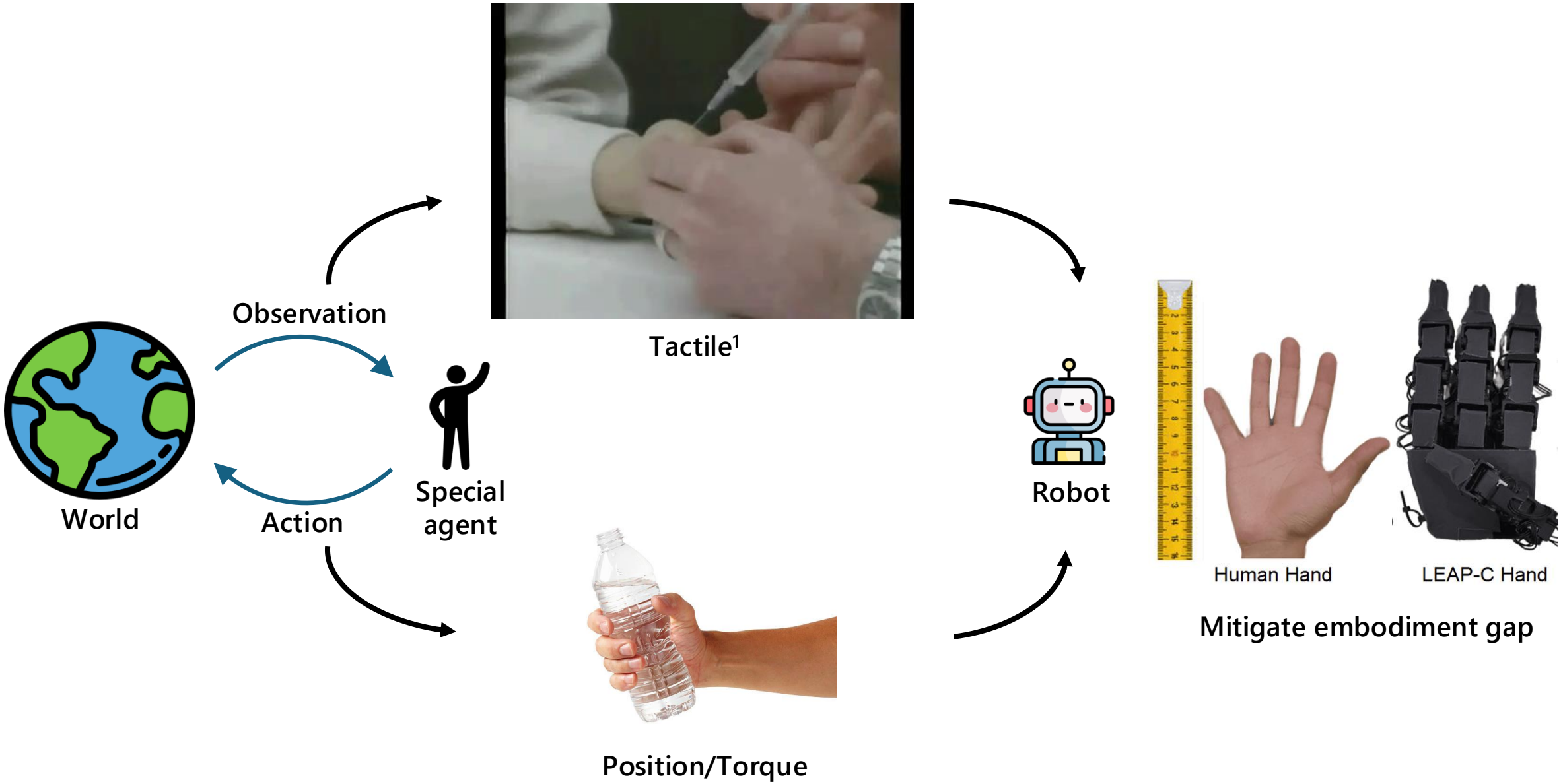
What is needed?
How to achieve?
Why is it better?



DEXO

DEXO: Hand Exoskeleton System for Teaching Robot Dexterous Manipulation In-The-Wild, Fang et al, in submission

What is needed?

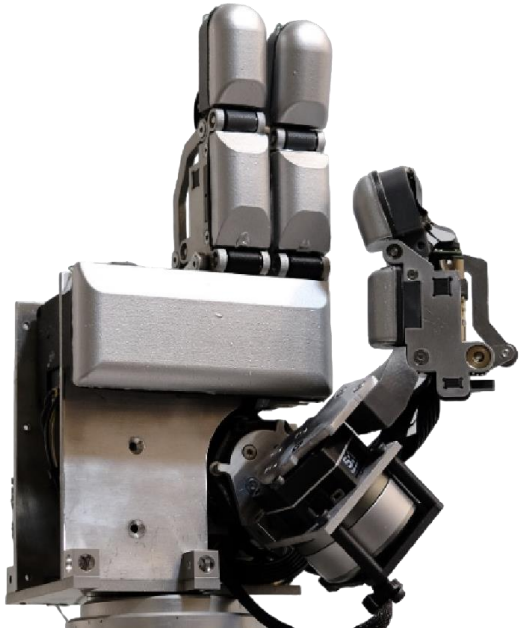


1: In courtesy of Johansson et al.

How to achieve?

Constraints

Constraints



Human hand

Interaction interface

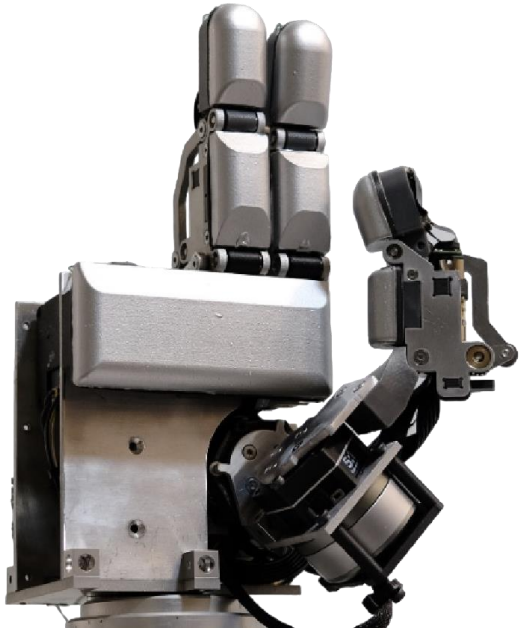
Robotic hardware

Co-design

How to achieve?

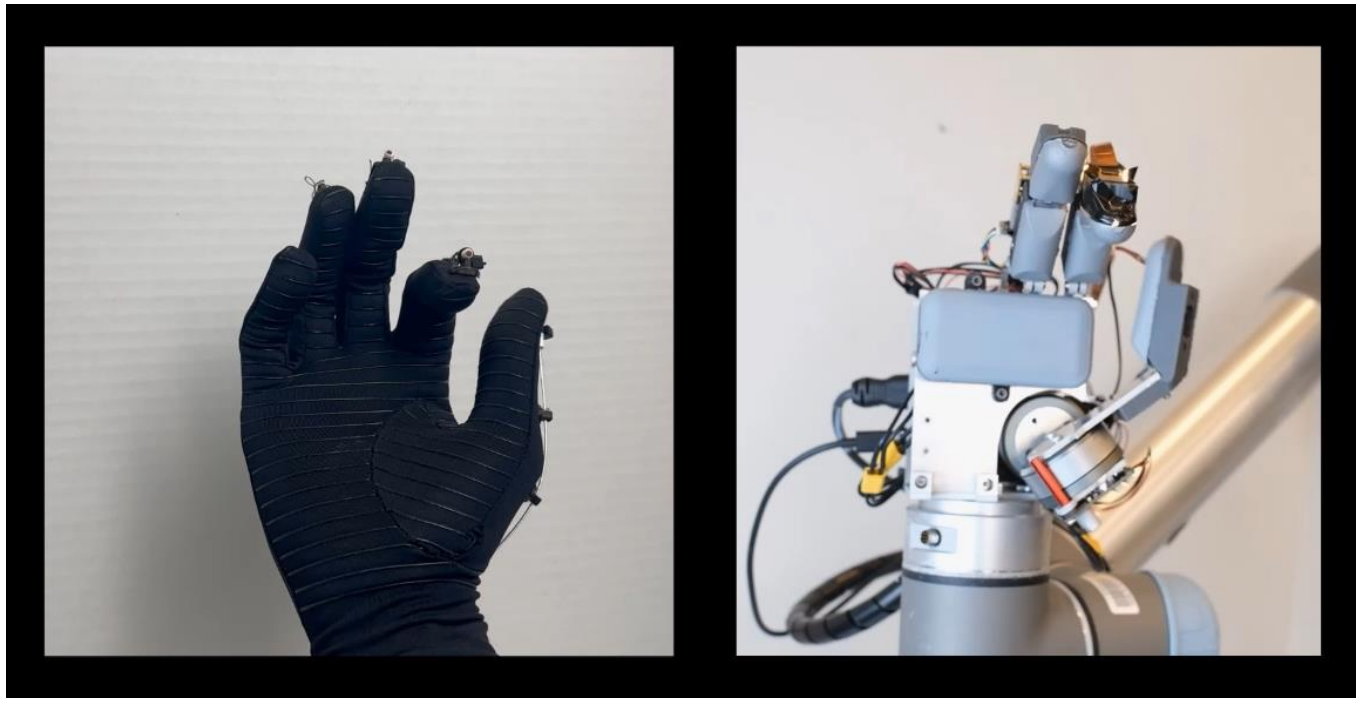
Human hand

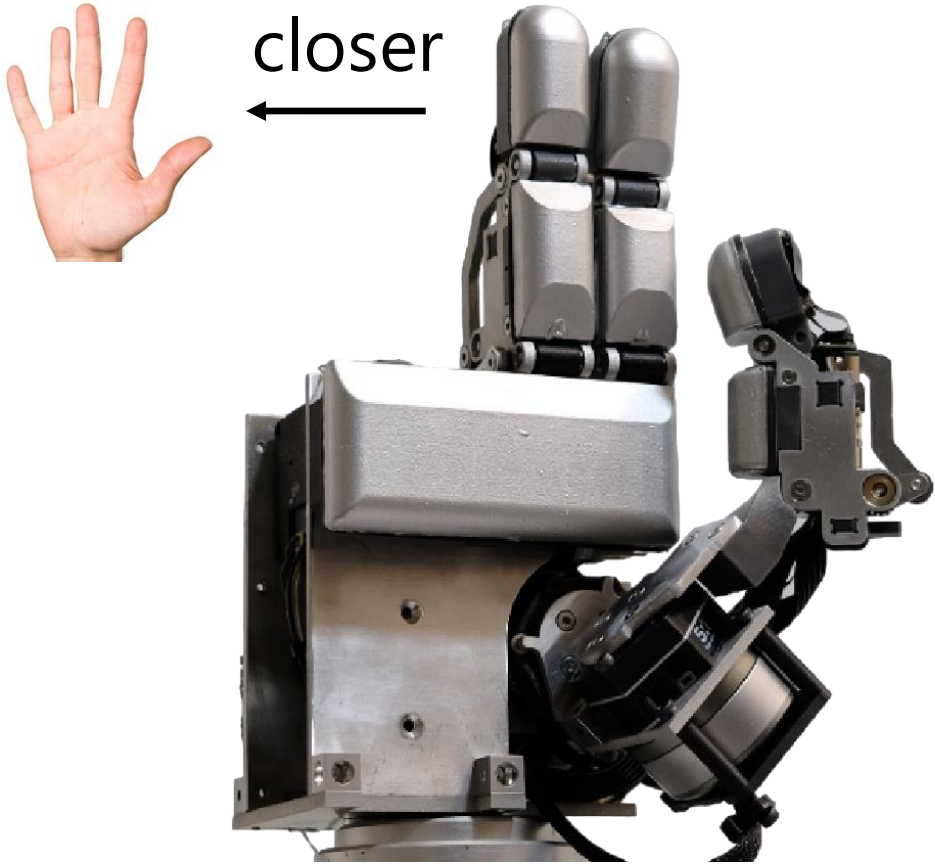
Closer to human hand



Robotic hardware

How to achieve?

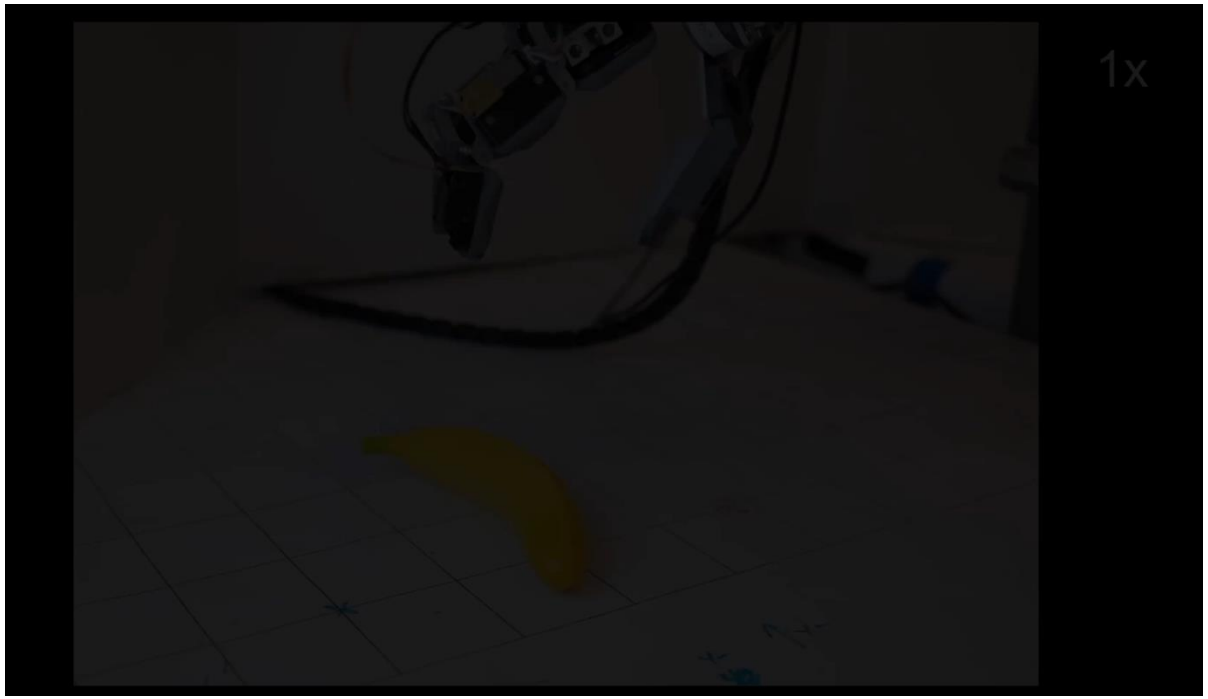


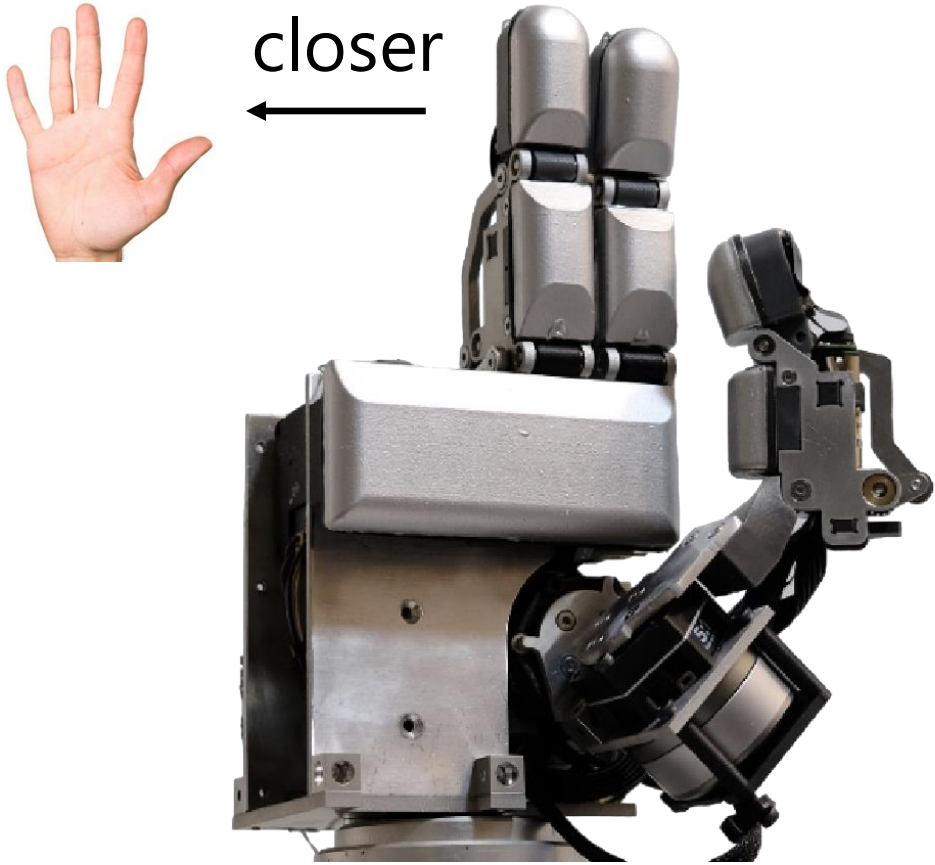


Make tactile sensing closer to human

EyeSight Hand: Design of a Fully-Actuated Dexterous Robot Hand with Integrated Vision-Based Tactile Sensors and Compliant Actuation,

How to achieve?

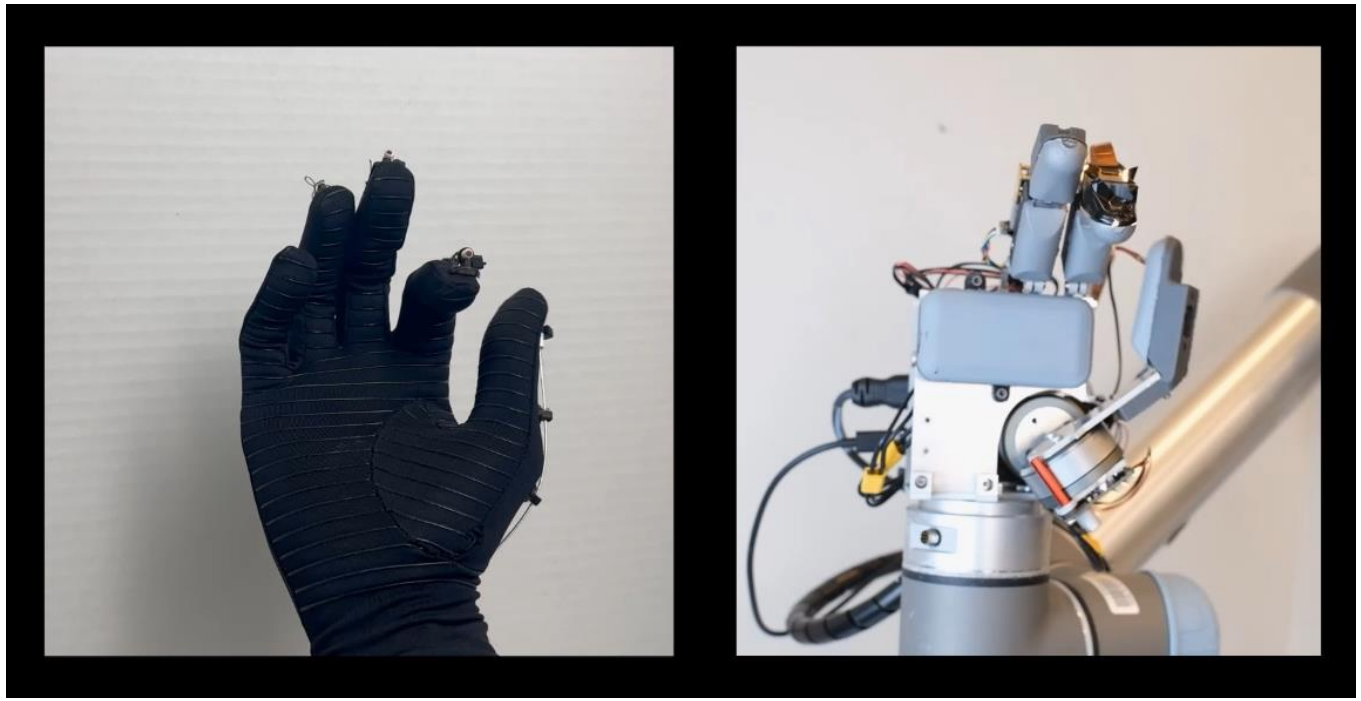


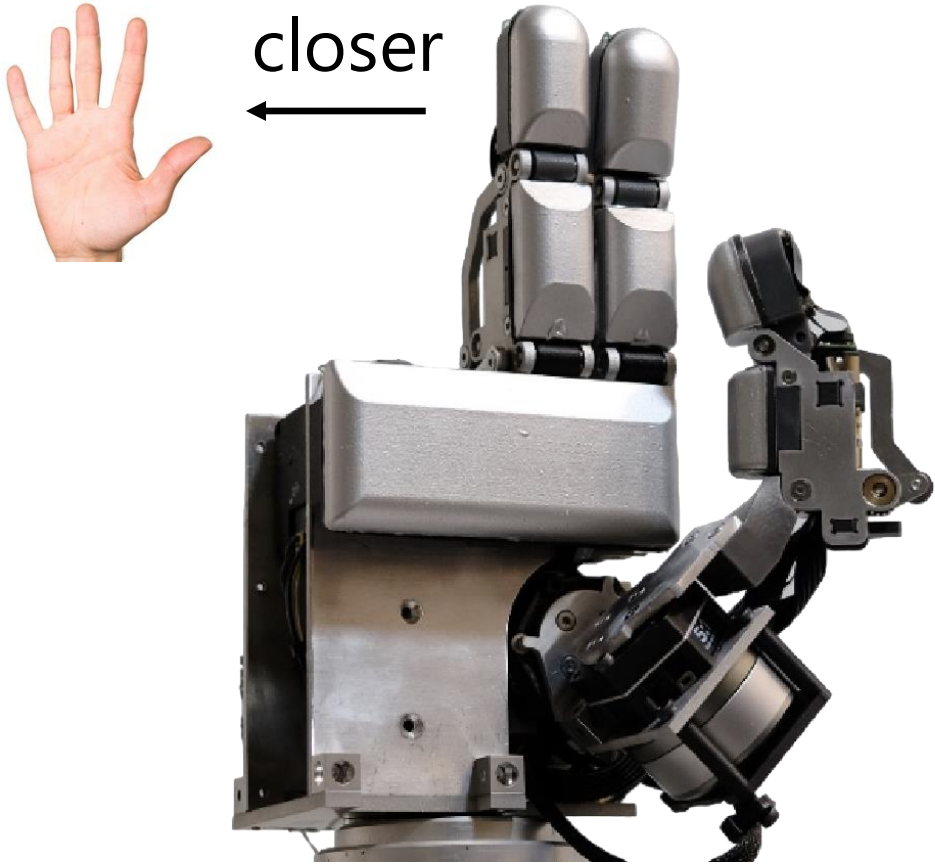


Make dynamic closer to human

EyeSight Hand: Design of a Fully-Actuated Dexterous Robot Hand with Integrated Vision-Based Tactile Sensors and Compliant Actuation,

How to achieve?



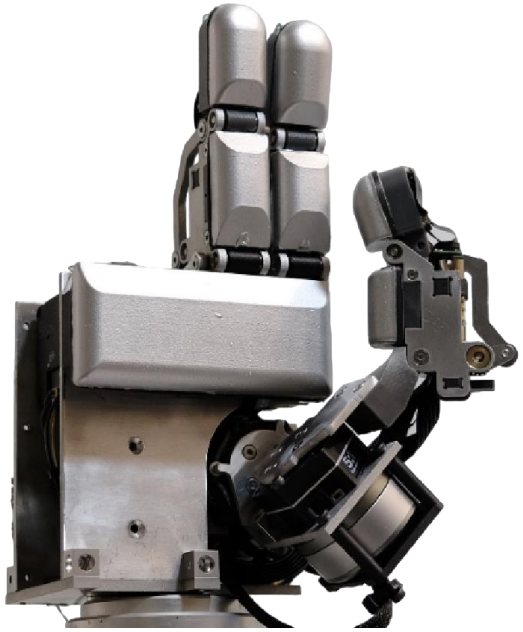


Make form factor closer to human

How to achieve?

Constraints

Constraints



Human hand

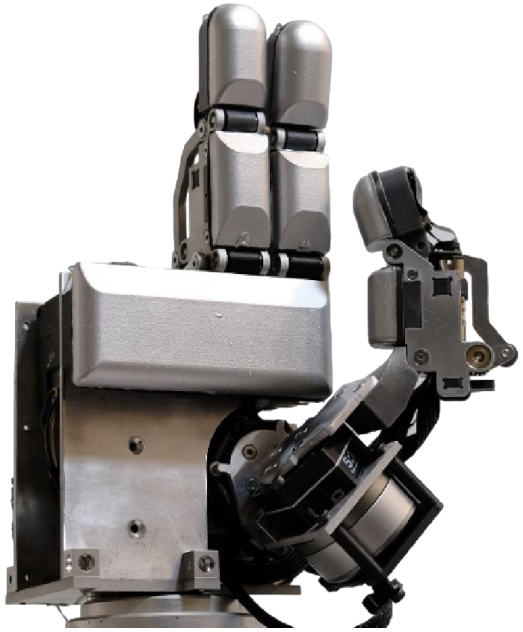
Interaction interface

Robotic hardware

How to achieve?

Bridge

Bridge

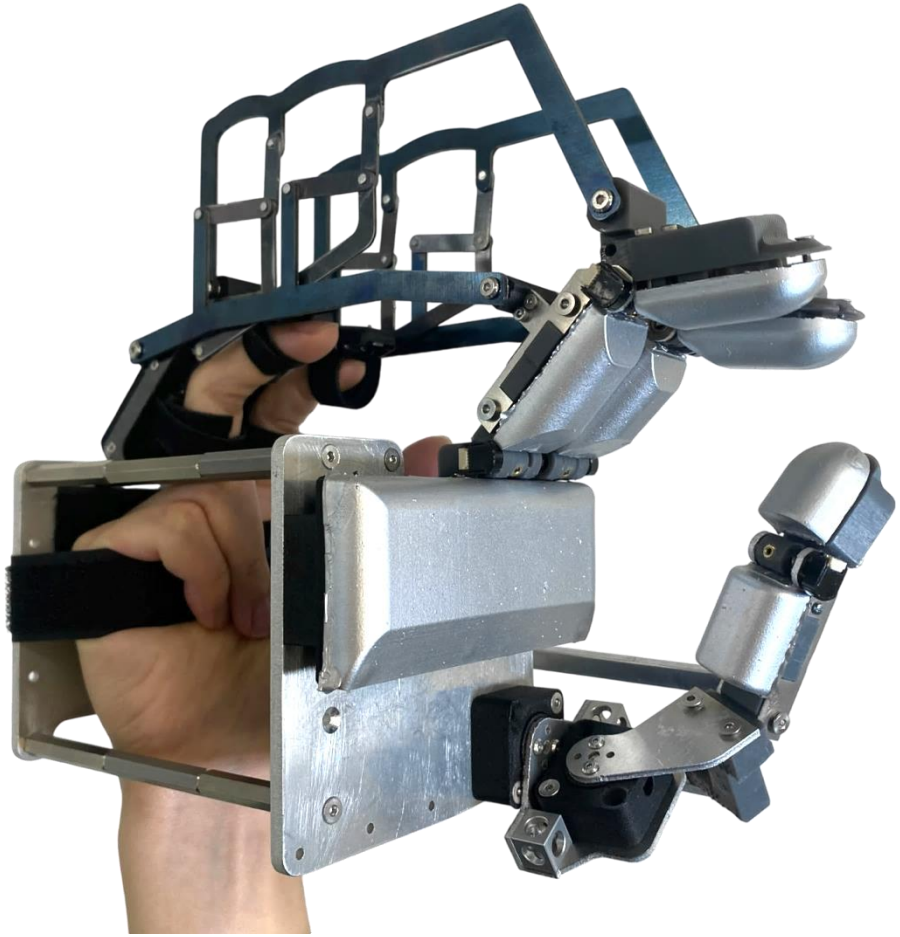


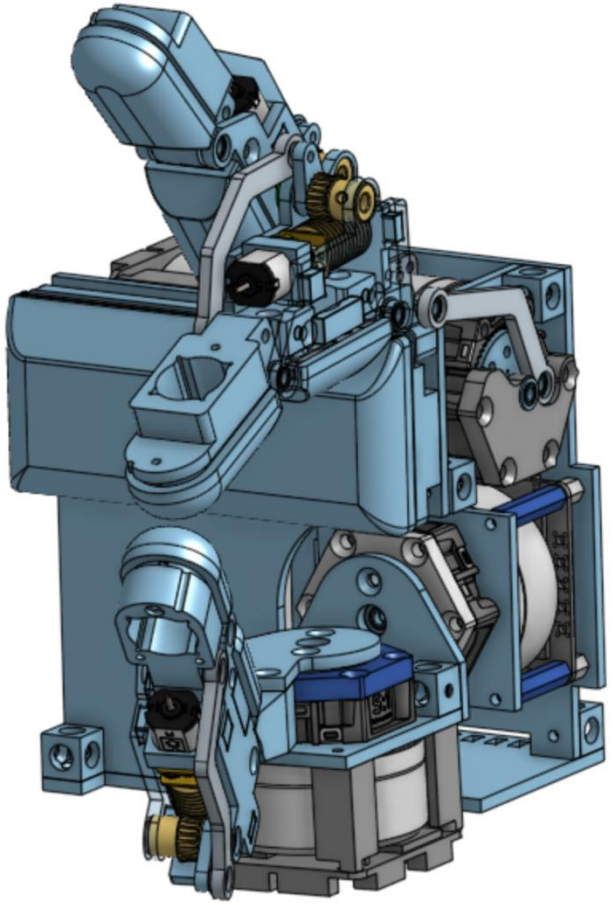
Human hand

Interaction interface

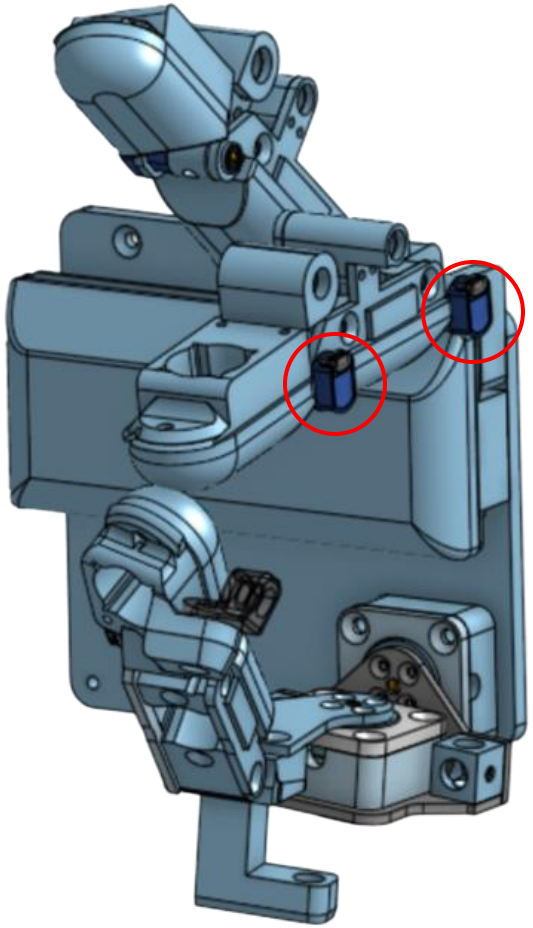
Robotic hardware

How to achieve?





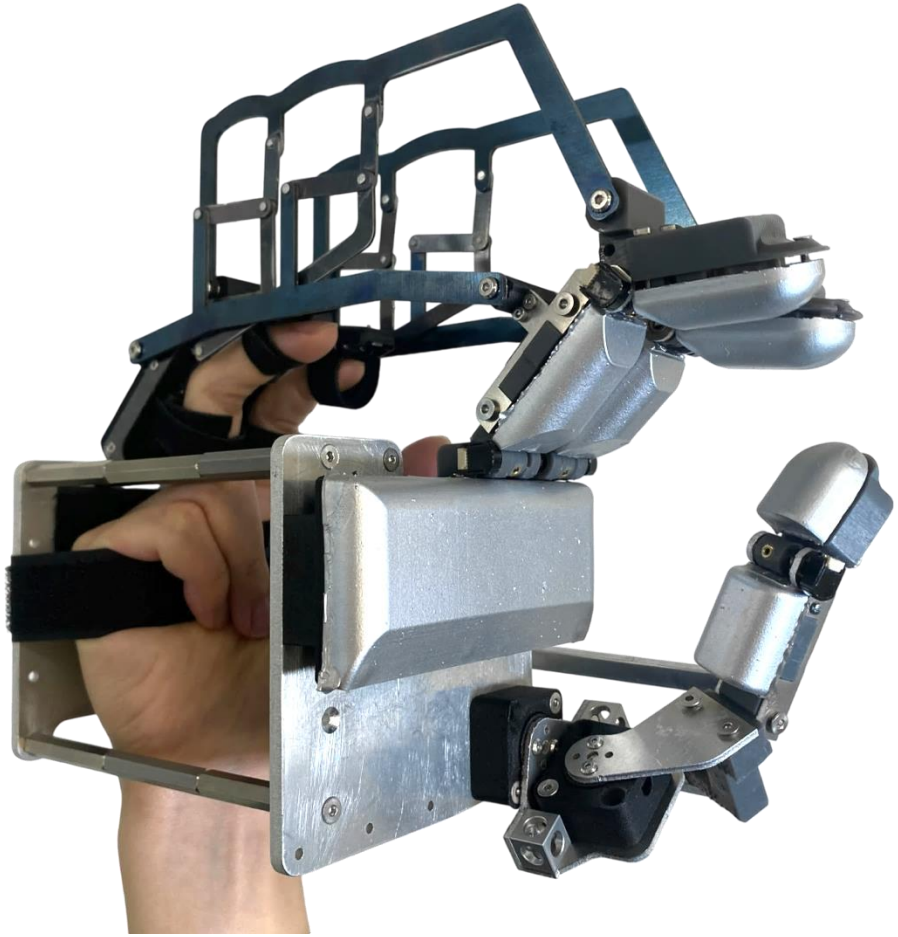
Actual hand

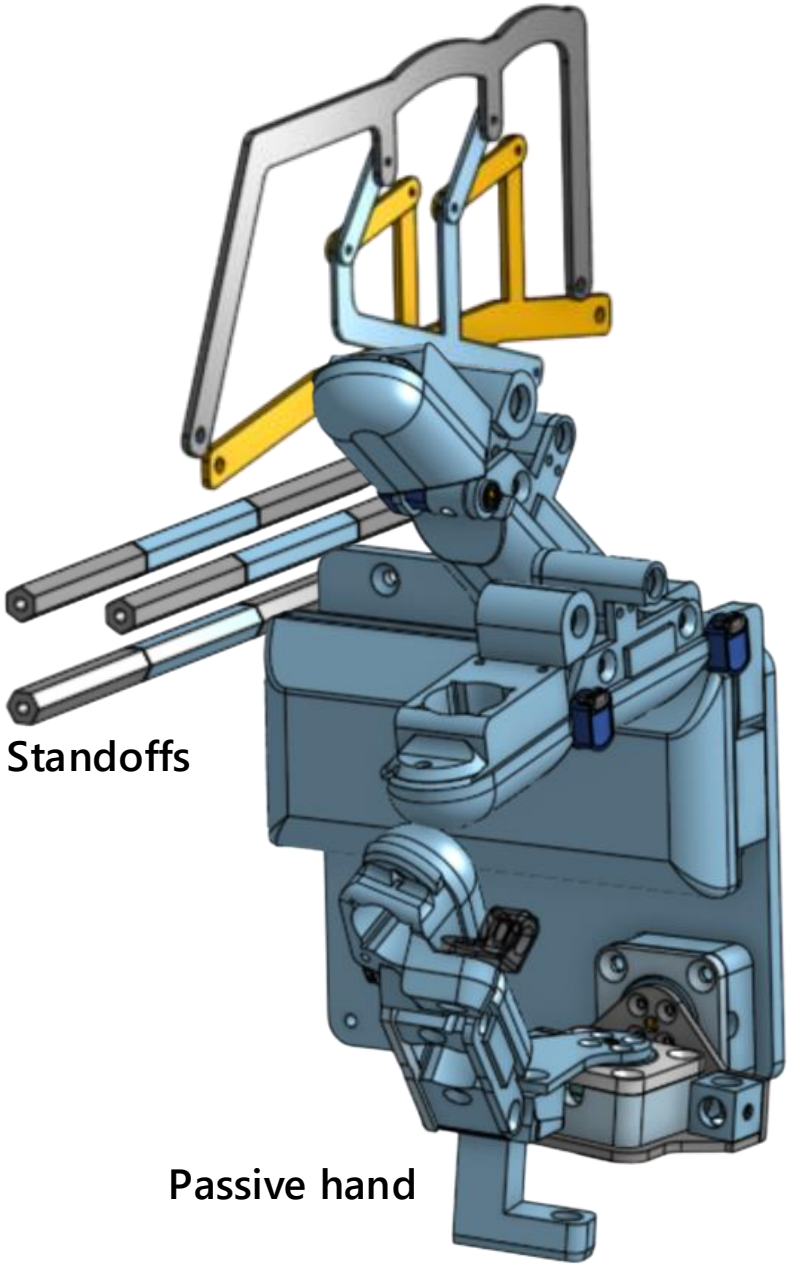


Passive hand

DEXO: Hand Exoskeleton System for Teaching Robot Dexterous Manipulation In-The-Wild, In submission

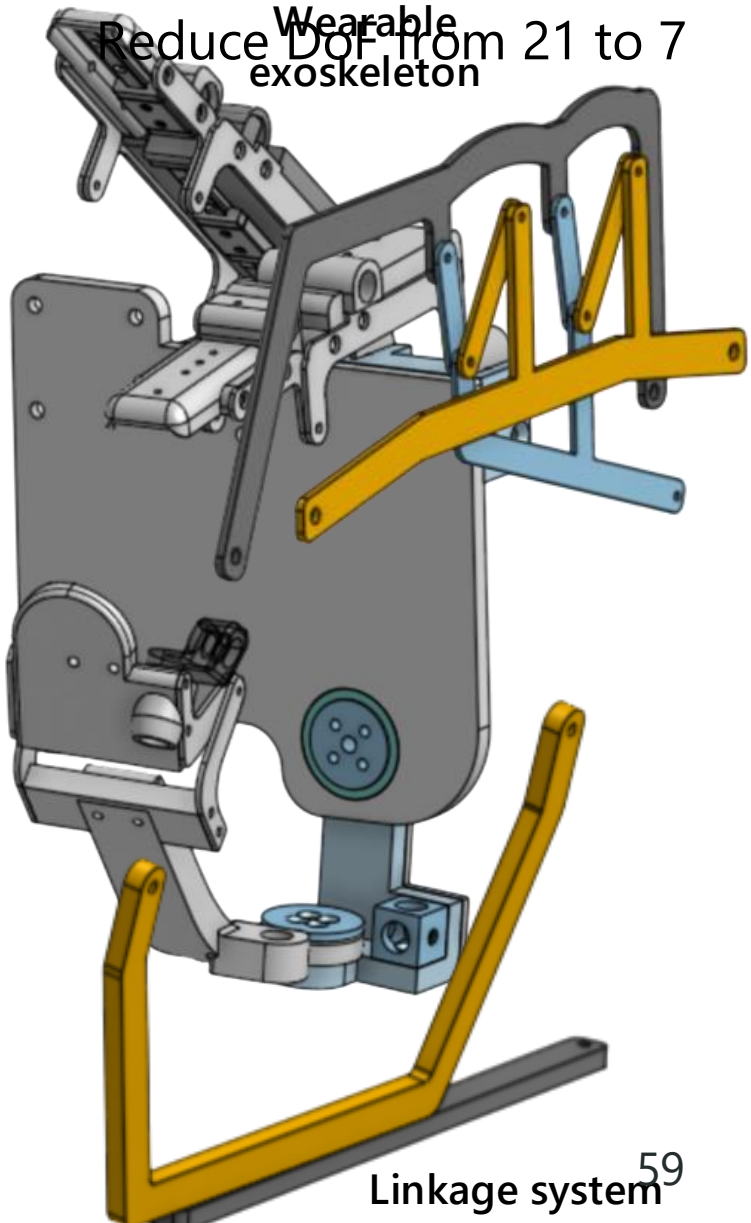
How to achieve?





Transmit force to human

Reduce DoF from 21 to 7



Why is it better?

- Observation
  - Tactile: same
  - Wrist cam: same
  - Head cam: transferable
- Action
  - Angle: same
  - Torque: computable

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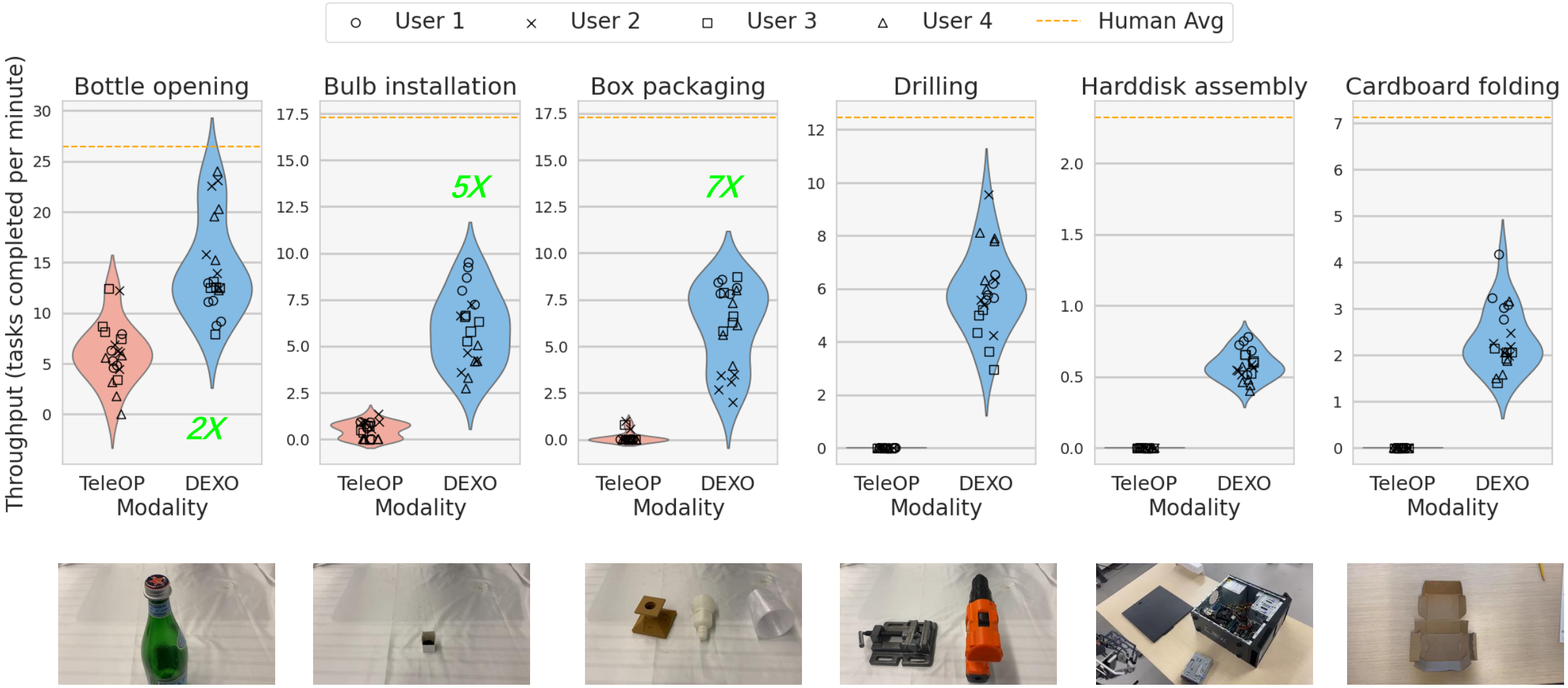
Why is it better?



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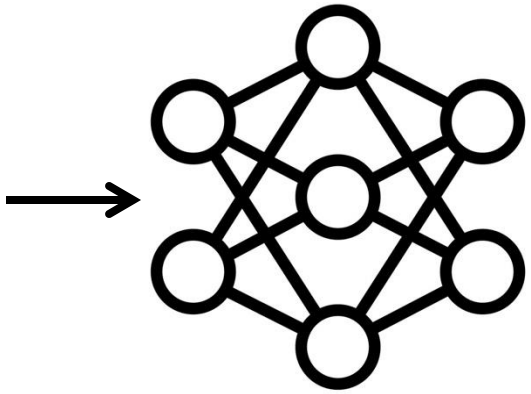
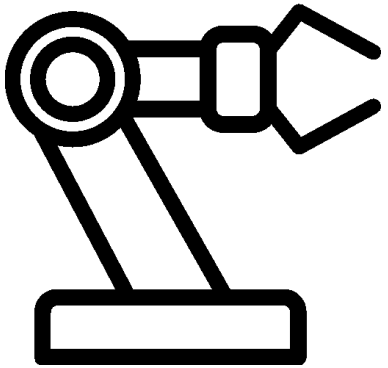
Policy learning

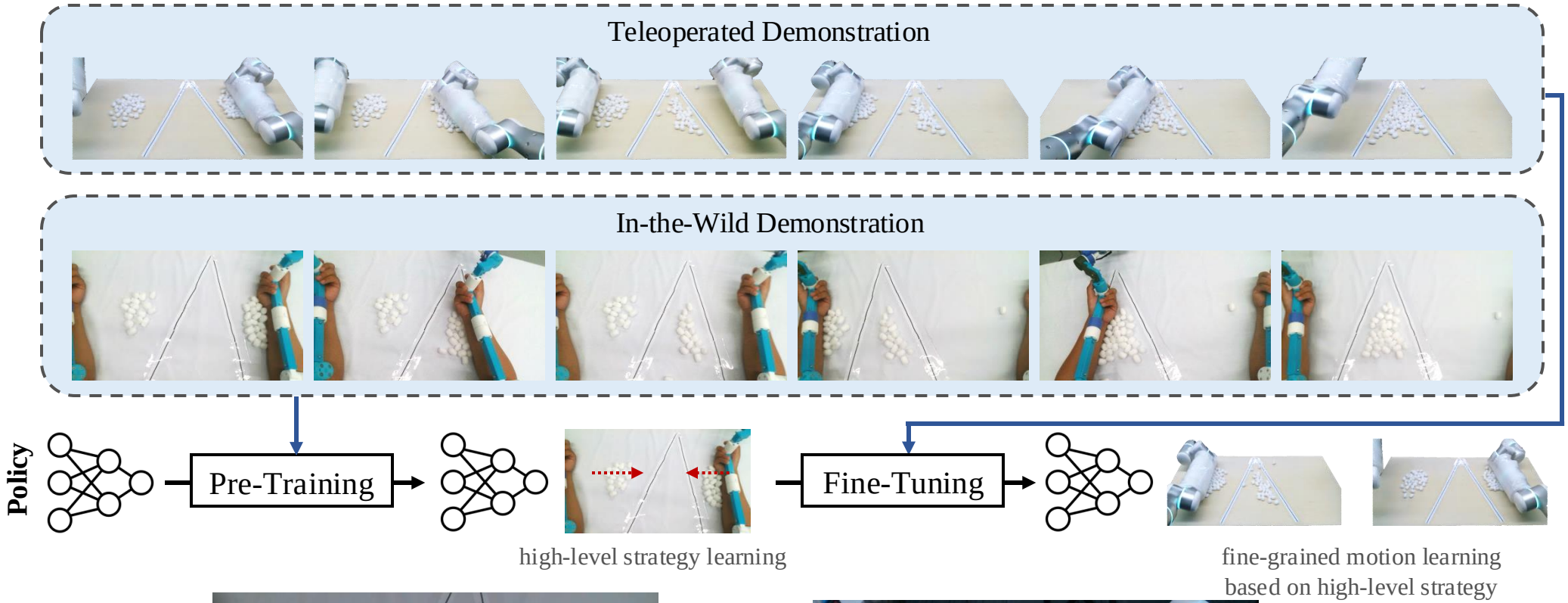
World / Robot States
from Sensors

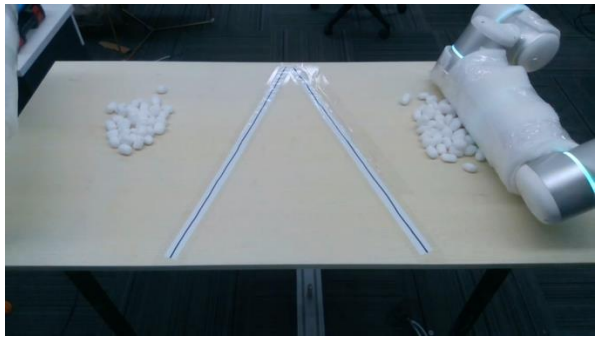


Robot Actions



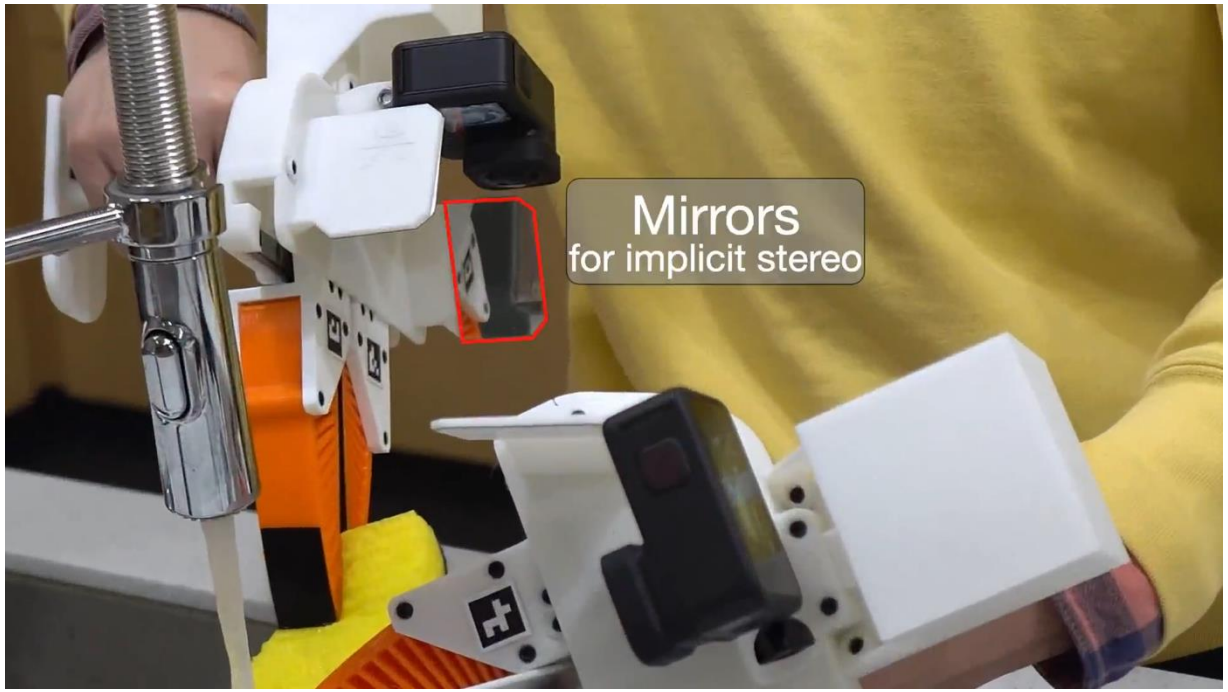
Policy learning





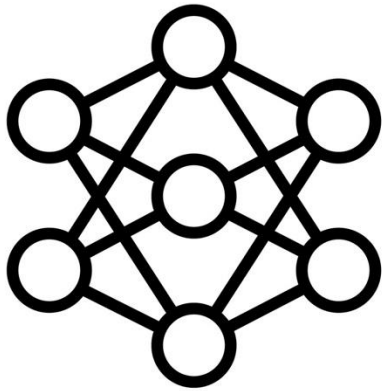
AirExo: Low-Cost Exoskeletons for Learning Whole-Arm Manipulation in the Wild

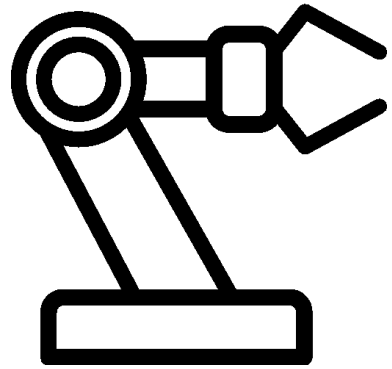
Policy learning



Same observation space

Recover action through SLAM

World / Robot States from Sensors →  → Robot Actions



Universal Manipulation Interface: In-The-Wild Robot Teaching Without In-The-Wild Robots

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Next Class: Hands-on Tutorial

Sneak Peak