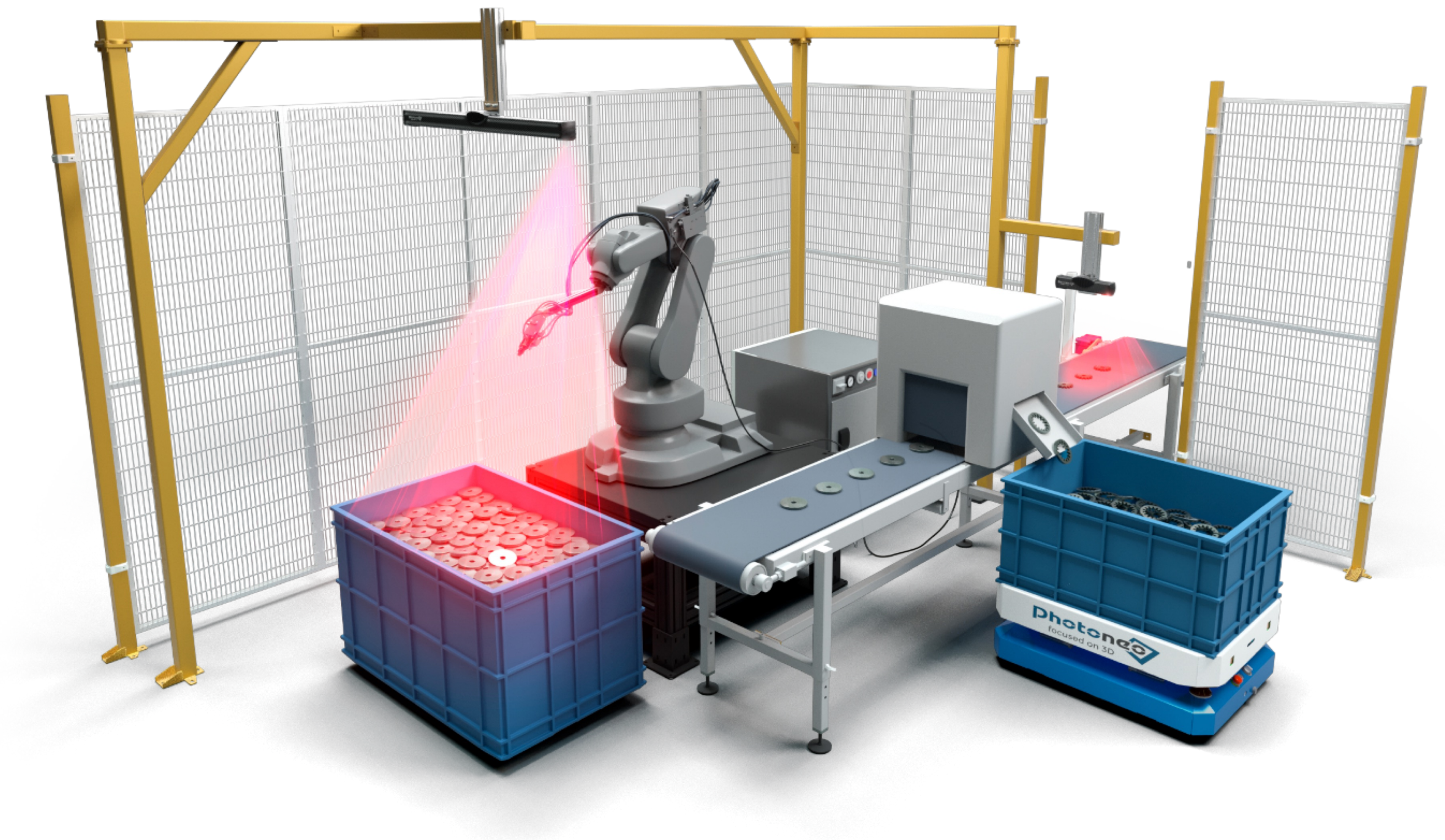
Welcome to ME336

Collaborative Robot Learning



Lecture 01
Course Introduction

Song Chaoyang
Southern University of Science and Technology

Introduce you to the field of Collaborative Robot Learning

definition, why it is important, and why it is challenging

Today's Objectives

Collaborative Robot Learning

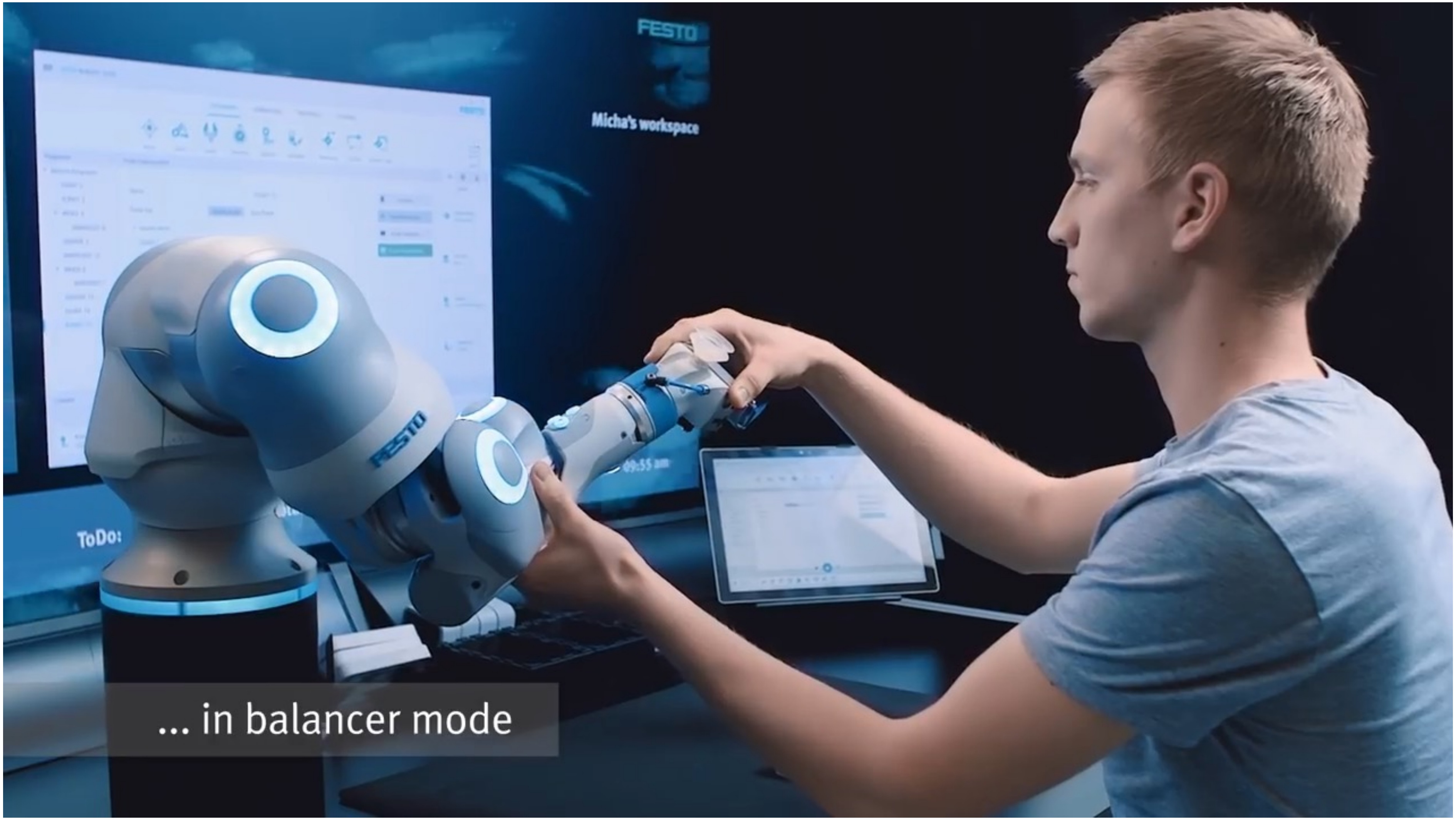
A *working* definition

- Cobots, or collaborative robots, are robots intended for direct human robot interaction within a shared space, or where humans and robots are in close proximity.
- Cobot applications contrast with traditional industrial robot applications in which robots are isolated from human contact.

Source: Wiki …

A Futuristic Concept

How would you feel, if you were the one in this video?



Source: FESTO

A More Realistic Concept …

What about now?

Source: Universal Robots

A Cobot in Assembly Action: *more than a concept*

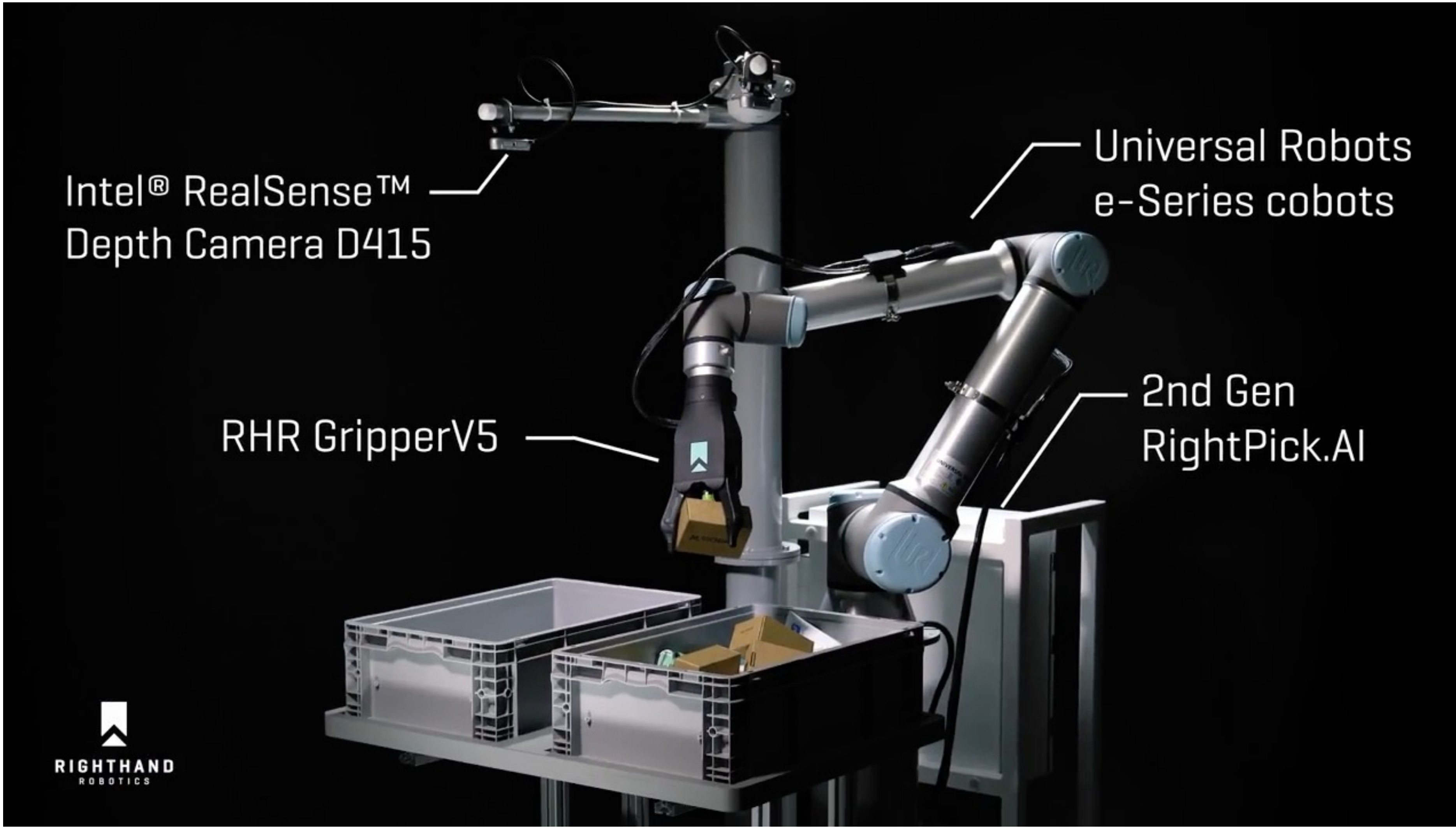
Source: Universal Robots

Common Applications of Cobot in Automation

Highly repetitive tasks that require different levels of dexterity

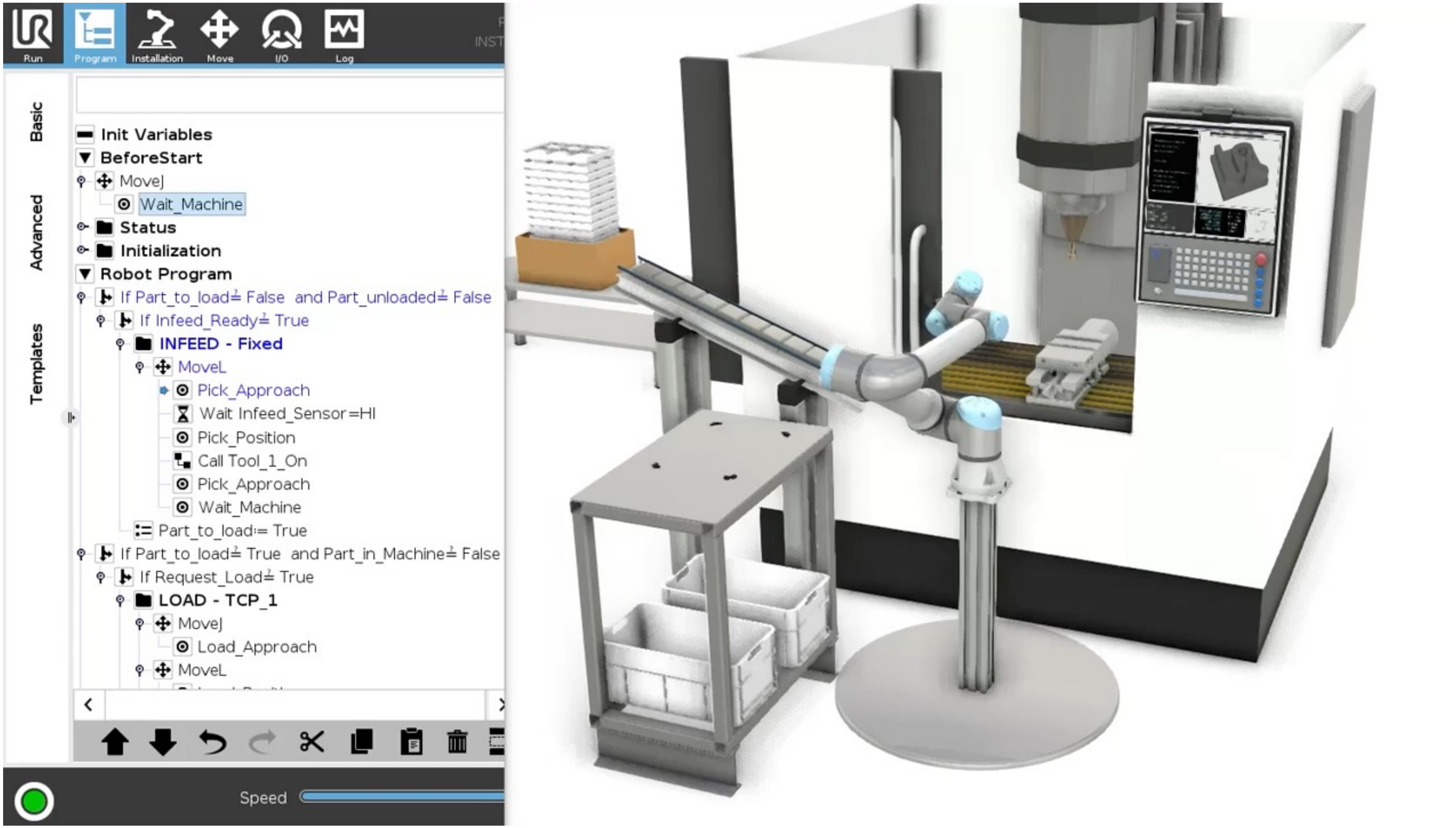
- Object Relocation
  - Handling object from one location to another
  - Pick & Place | Machine Tending | Packing and Palletizing
- Material Releasing
  - Releasing material from the robot to the target location
  - Gluing | Dispensing | Welding | Screwdriving
- Material Removal
  - Removing material from the target object using the robot
  - Polishing | Grinding | Deburring
- Information Gathering
  - Collecting information using sensors attached to the robot
  - Quality Inspection

Object Relocation: Pick & Place



Source: RightHand Robotics

Object Relocation: Machine Tending



Source: Universal Robots

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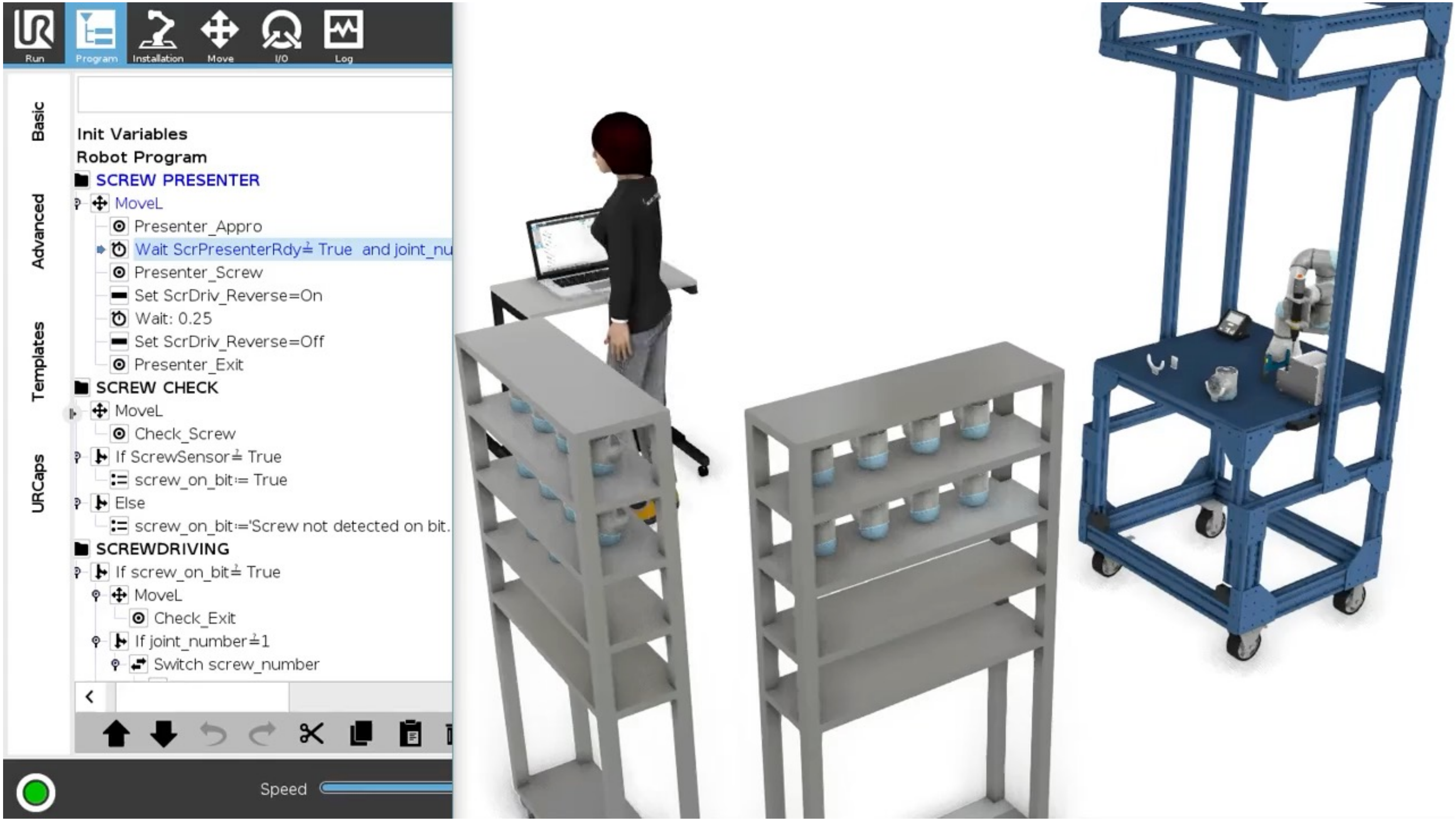
Material Releasing: Screwdriving



Source: Universal Robots

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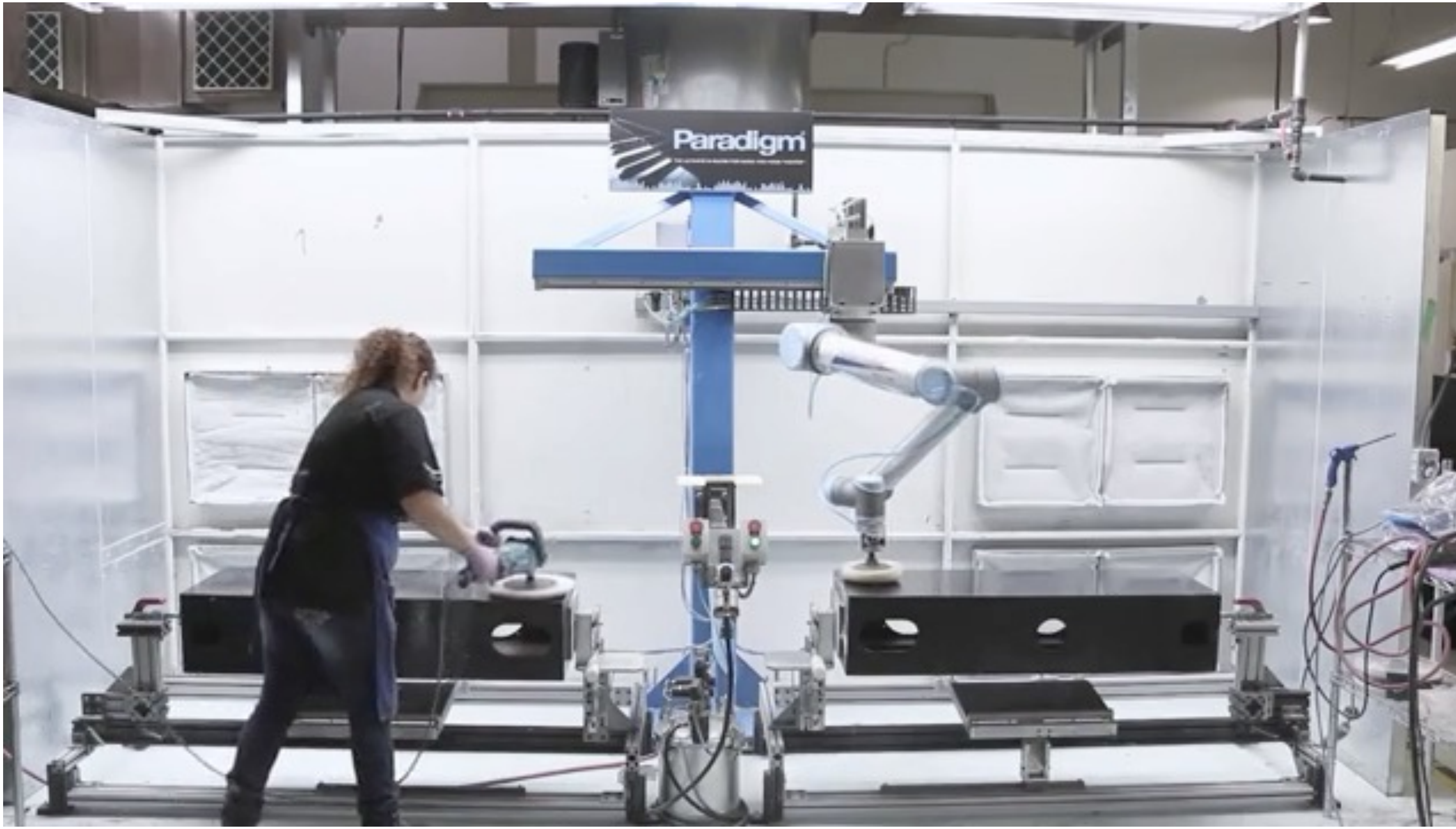
Material Removal: Polishing



Source: Universal Robots

Common Applications of Cobot in Automation

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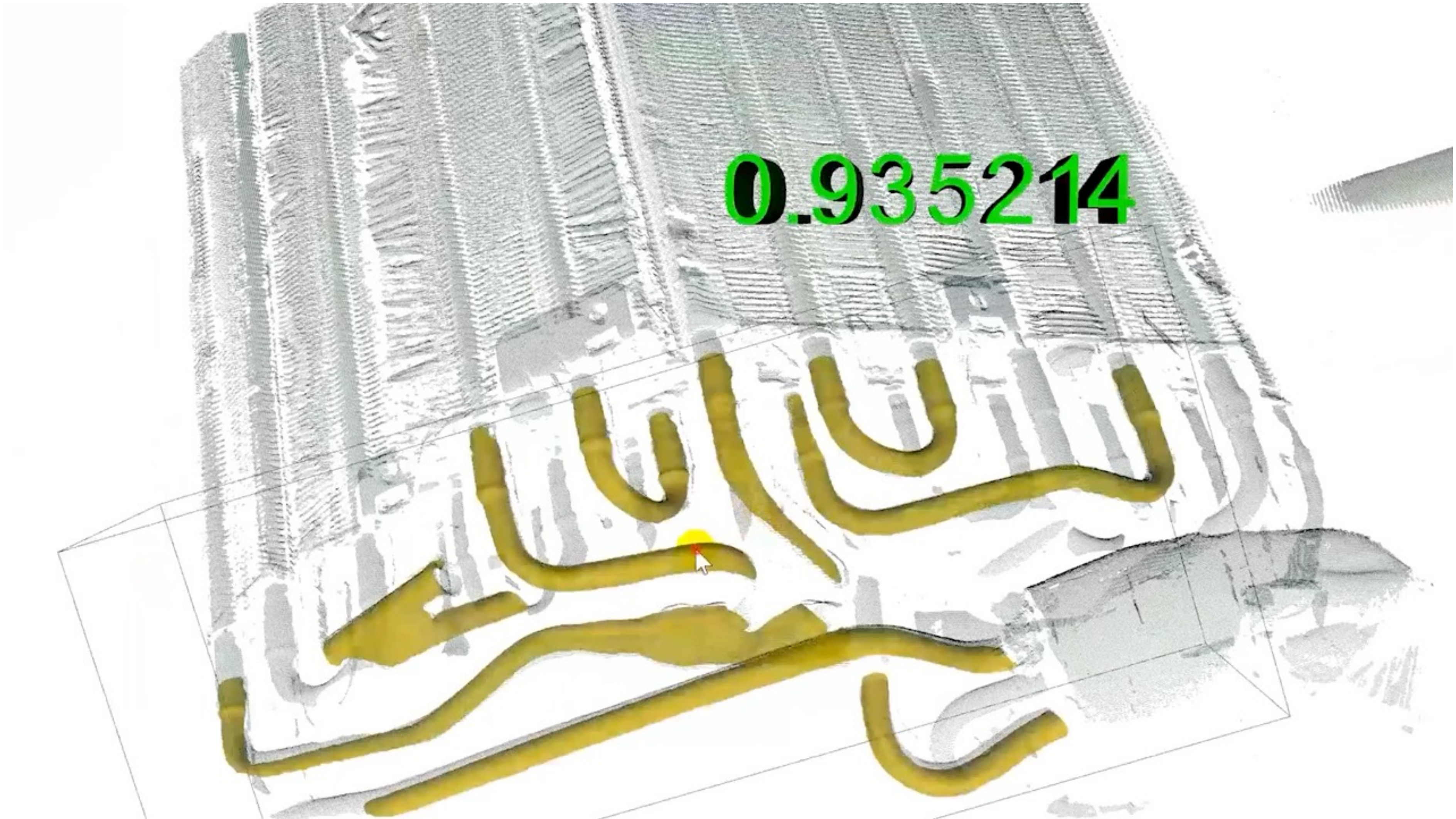
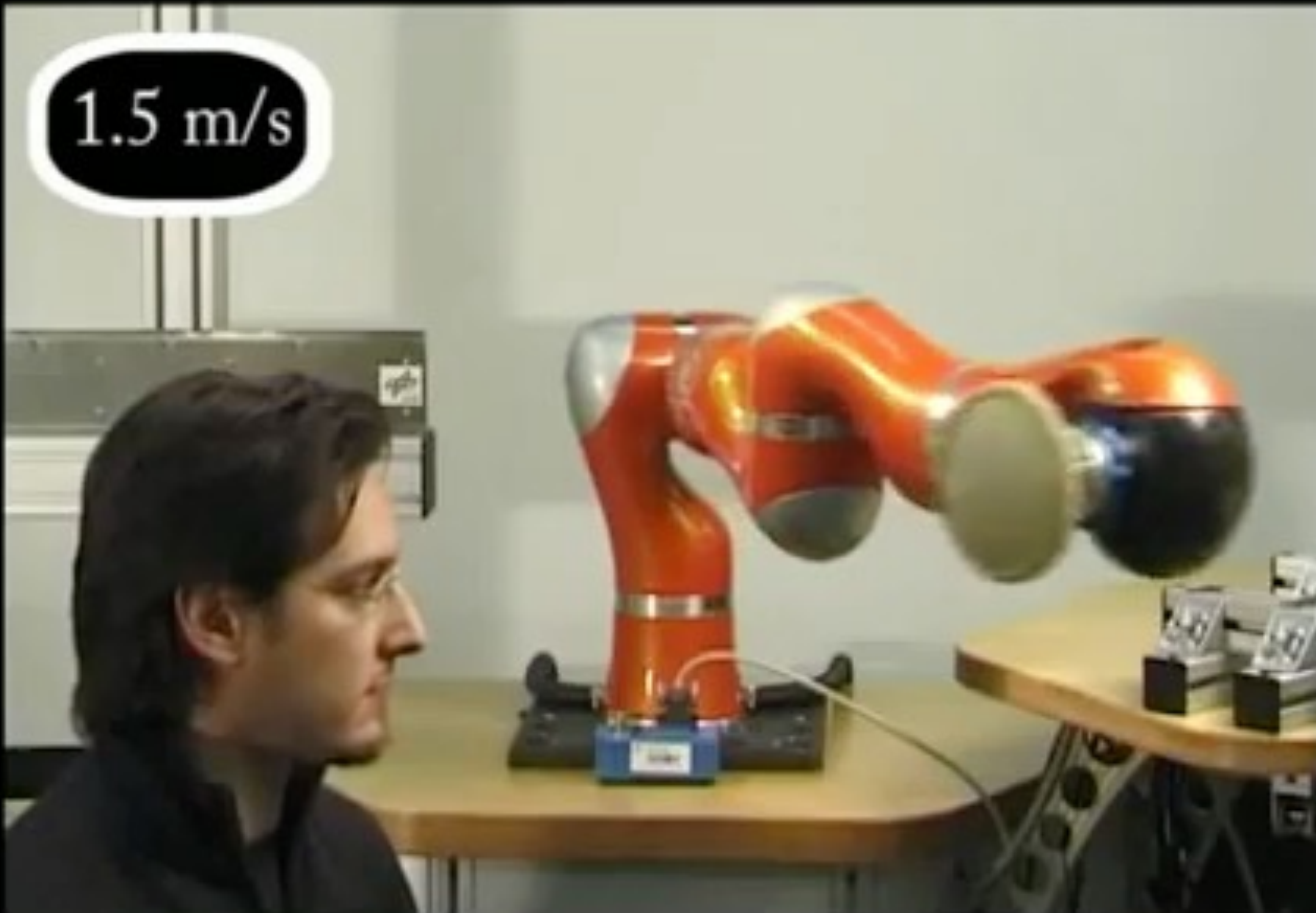
Material Removal: Information Gathering



Source: Photoneo

How to define Collaboration with Robots?

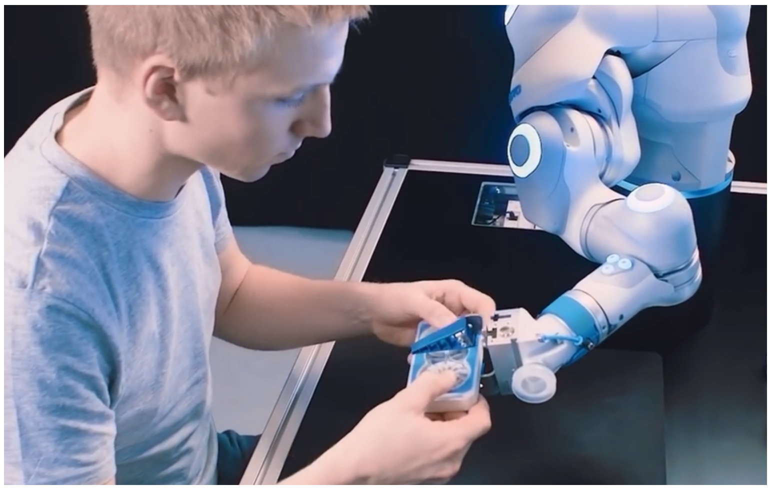
Collaborative Robot Technical Specification ISO/TS 15066

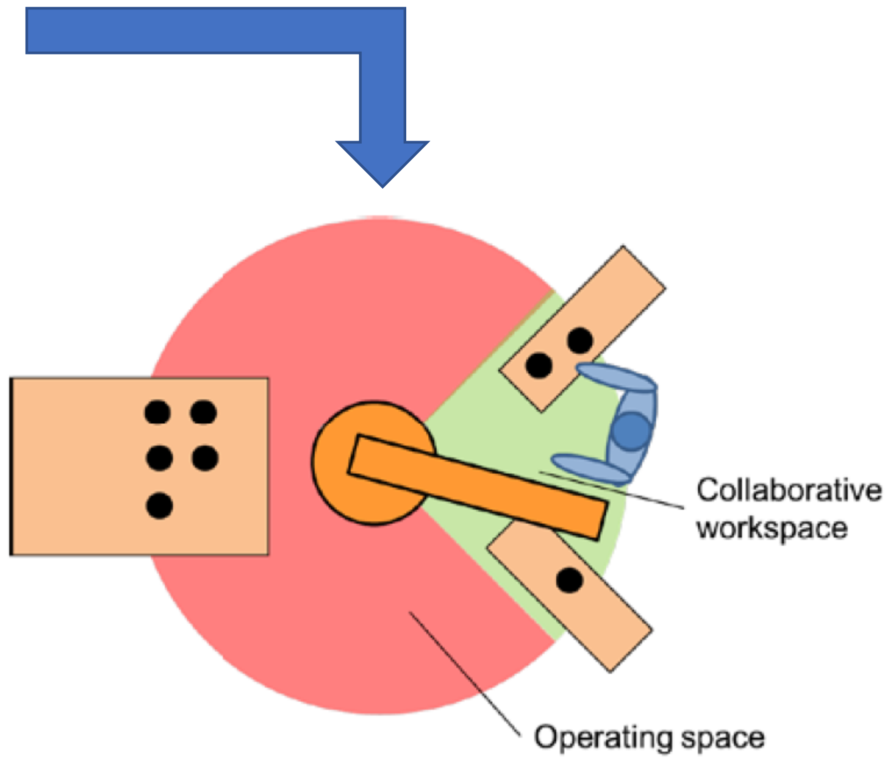


Source: DLR

Define Collaboration with Robots

A robot that CAN (capable) for use in a collaborative operation

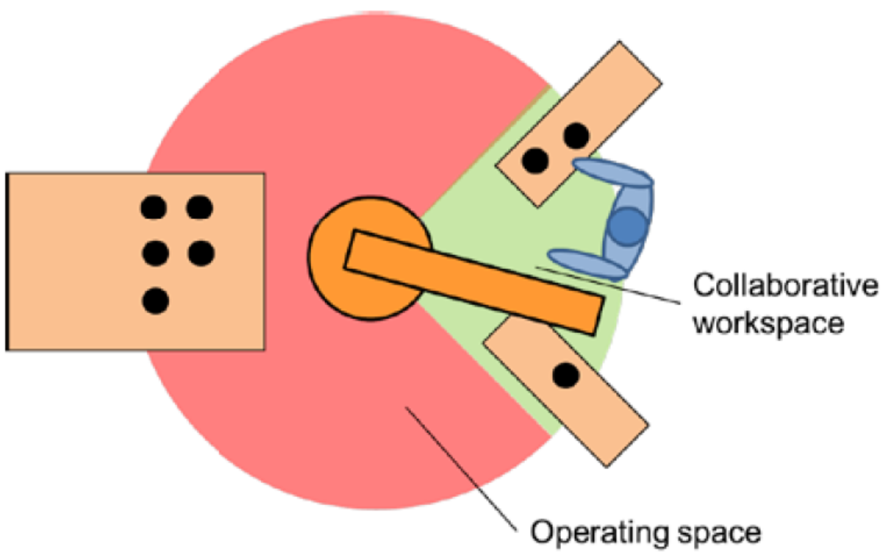




Define Collaboration with Robots

A robot that CAN (capable) for use in a collaborative operation

- Purposely designed robot systems work in direct cooperation with a human within a defined workspace



Define Collaboration with Robots

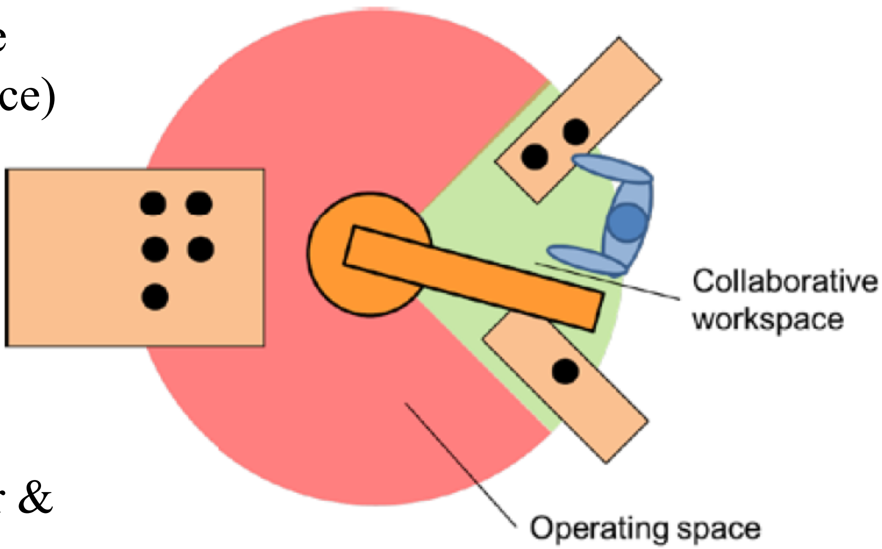
A robot that CAN (capable) for use in a collaborative operation

- Purposely designed robot systems work in direct cooperation with a human within a defined workspace

[Collaborative Workspace] space within the operating space where the robot system (including the workpiece) and a human can perform tasks concurrently during production operation.

[Robot] Robot arm & robot control

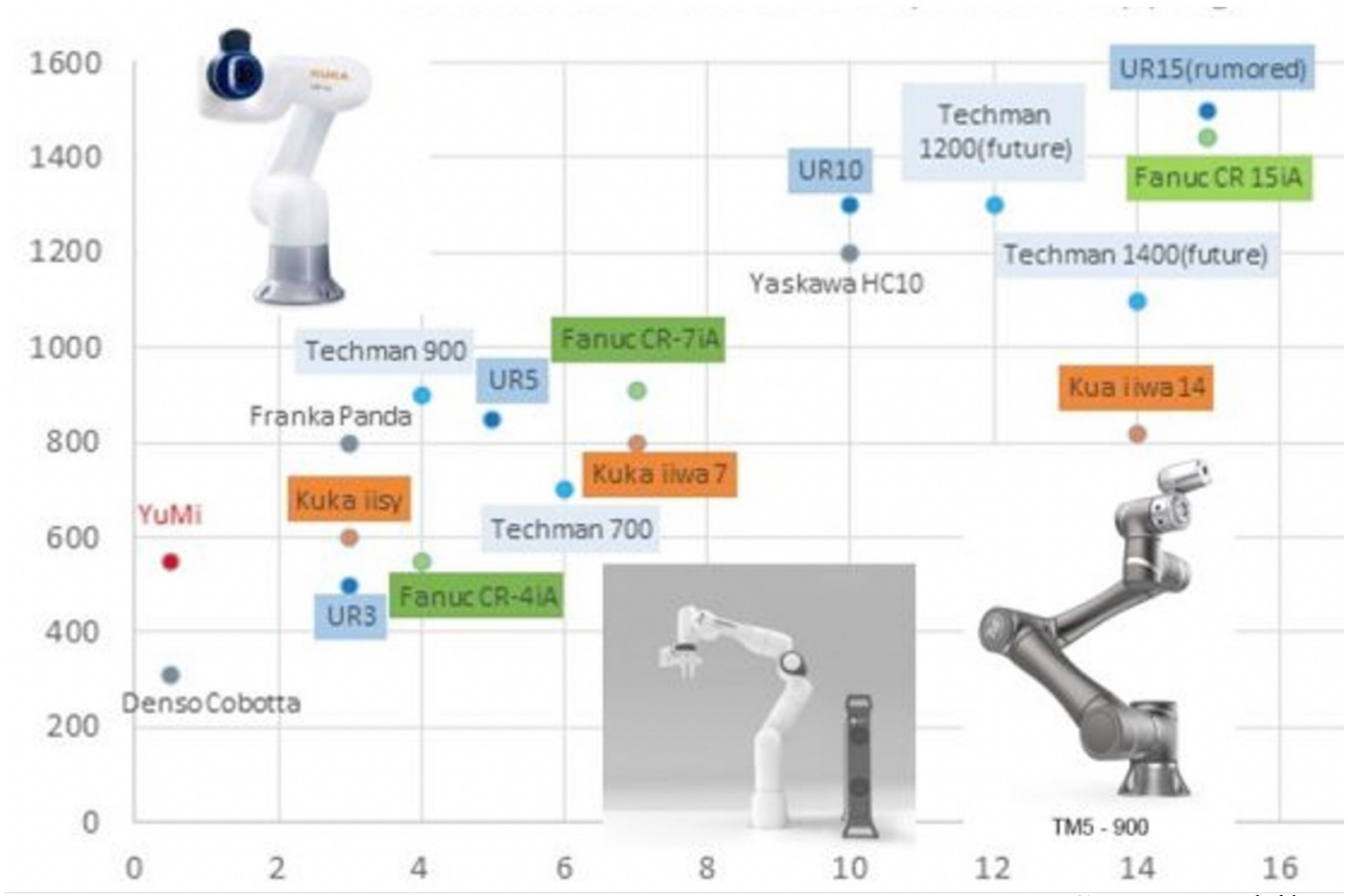
[Robot System] Robot, end-effector & workpiece



Collaborative Reach vs. Output Payload

The Design Need for Robotic Collaboration

Reach (mm)



Payload (kg)

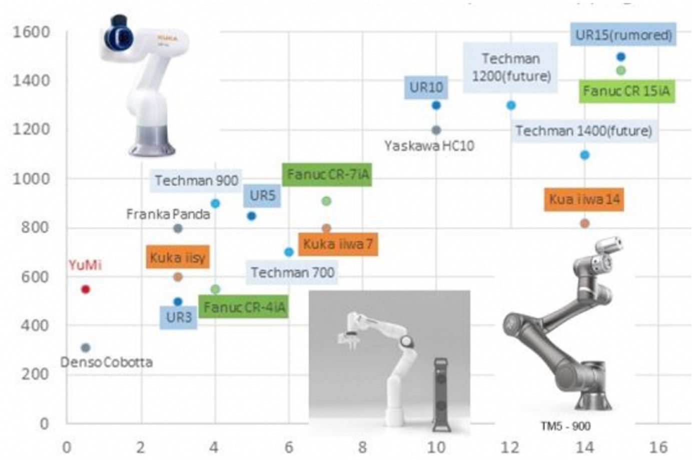
Source: Zhihu

Collaborative Reach vs. Output Payload

The Design Need for Robotic Collaboration

- Small payload
  - Force limiting for safe interaction
- Small footprint
  - Less disruption to the existing automation line
- Highly repetitive
  - Labor replacement for added value
- Ease of integration
  - Flexible implementation for the changing demand
- Cost-Effectiveness
  - Lower cost in purchase, use, and maintenance

Reach (mm)



Payload (kg)

Challenge to Adoption

Viewpoint from the real world

Customers indicating top challenge and top 5 challenges

Percent

Source: McKinsey Global Robotics Survey 2018

All players identified the cost of robots as one of the primary challenges to adoption

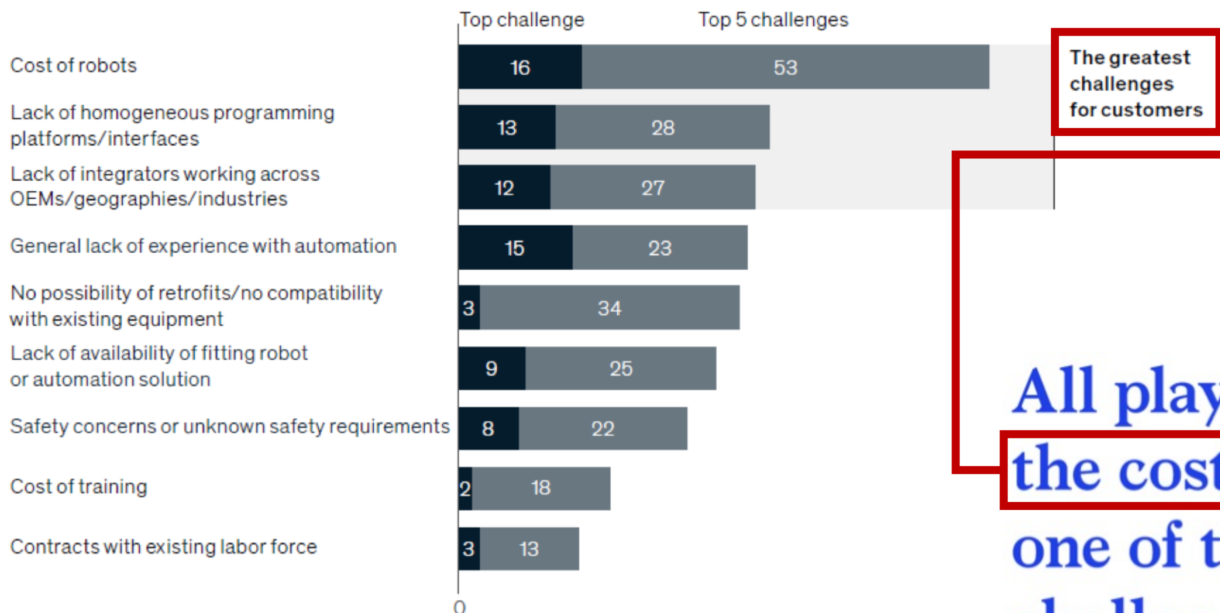
Challenge to Adoption

Viewpoint from the real world

The cost of which is higher?
- human or
- robot?

Customers indicating top challenge and top 5 challenges

Percent



Source: McKinsey Global Robotics Survey 2018

All players identified the cost of robots as one of the primary challenges to adoption

A research field at the intersection of machine learning and robotics that studies techniques allowing a robot to acquire novel skills or adapt to its environment through learning algorithms.

Collaborative **Robot Learning**

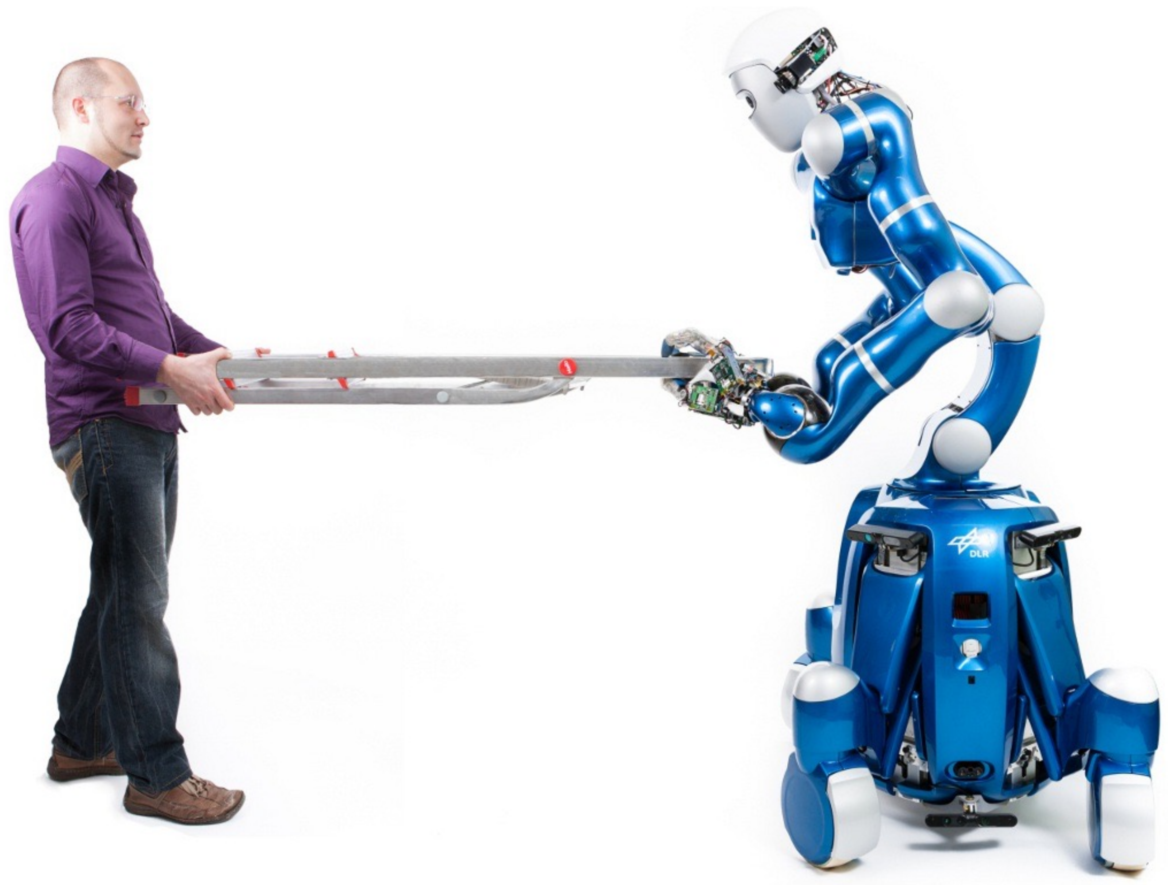
Source: Wiki …

So … What if Robots can Learn?

I, Robot?

Possible Ways of Collaboration

Passing a Ladder?



Source: DLR

Robot-Assisted Surgery

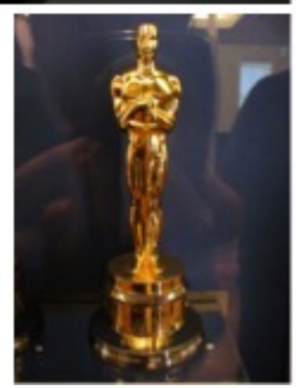
Put your life on the table?

Radiation Therapy

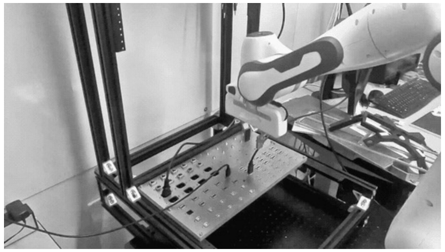
Robotic inspection?

Film Production

Make another movie?

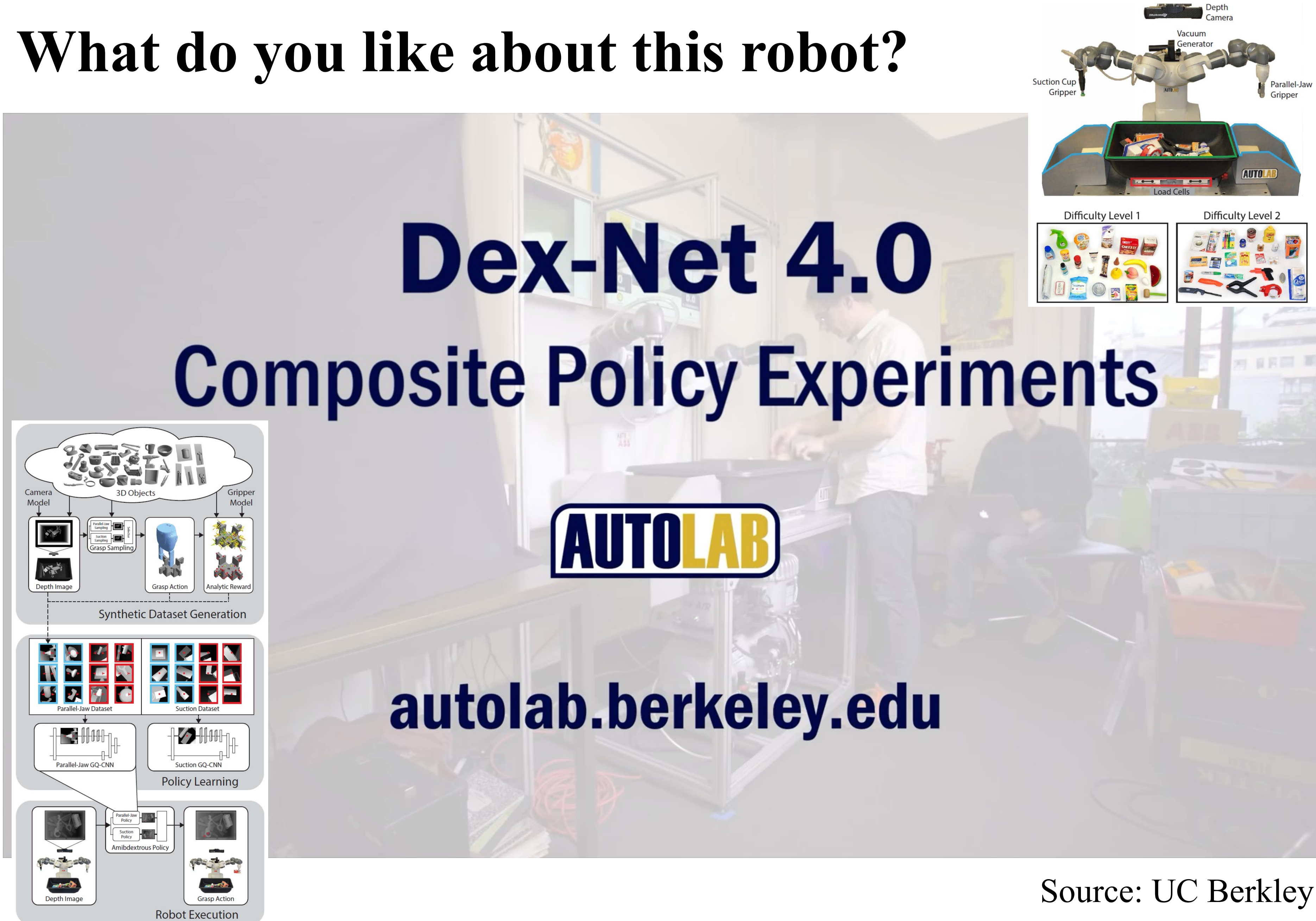


Source: Bot'n'Dolly



Now, again,
How would you feel,
if you were to work with these robots?

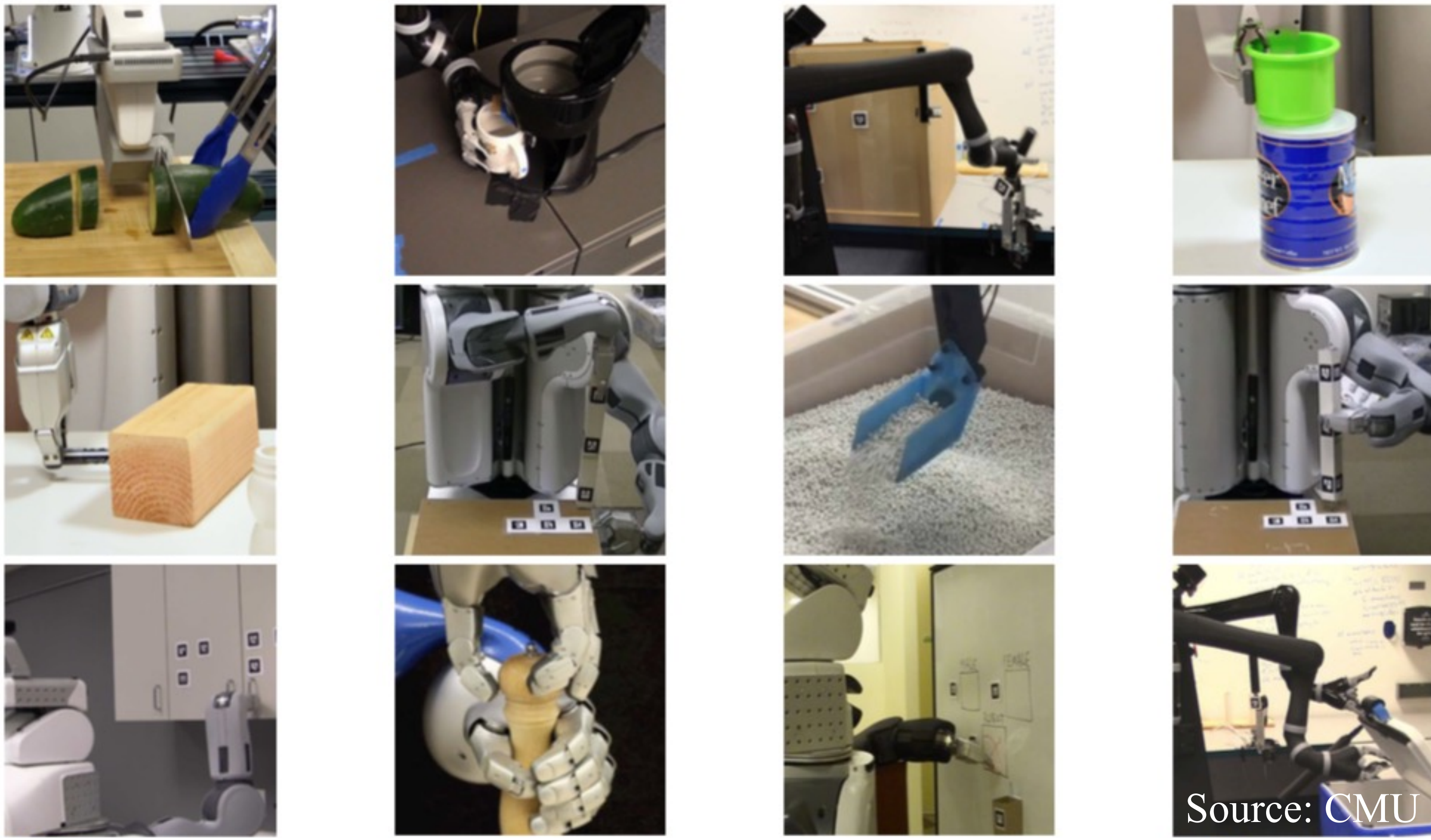
What do you like about this robot?



Source: UC Berkley

Robot Manipulation

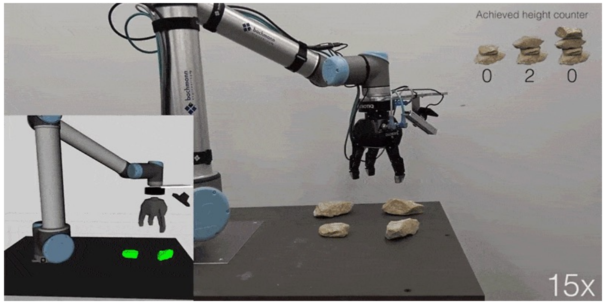
How a robot should learn to manipulate the world around it



Source: CMU

Common Concepts in Learning for Manipulation

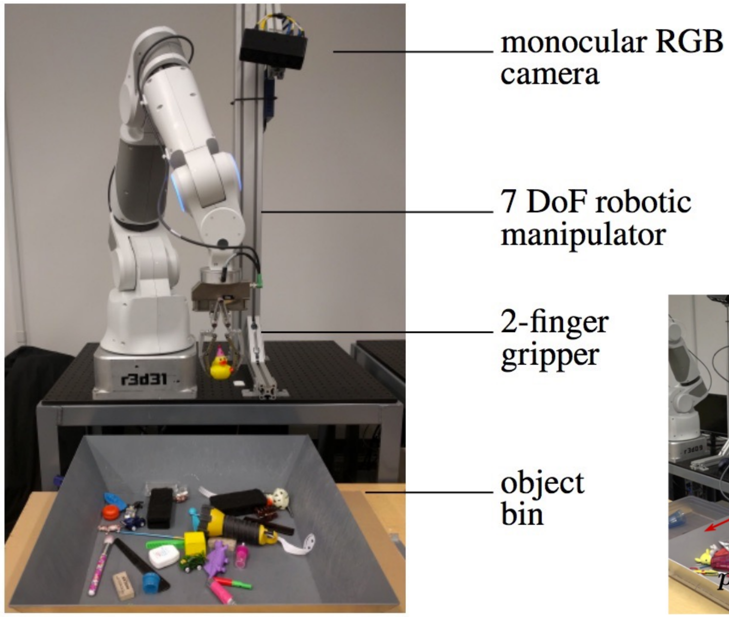
Internal structure of a manipulation task



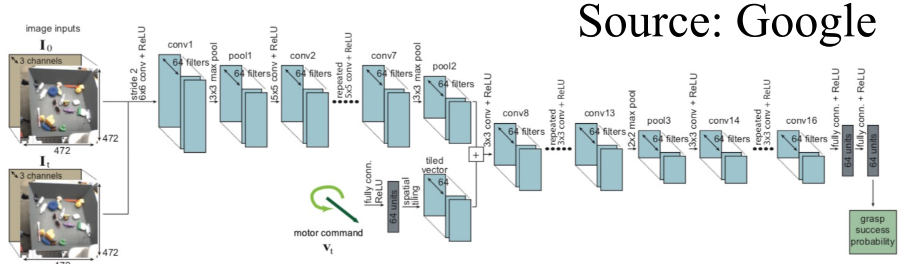
- **Manipulations as Physical Systems**
  - *Laws of physics and the structure they impose provide strong prior knowledge*
  - *Exploit such concepts using learning algorithms and making learning skill tractable*
- **Underactuation**
  - *The DOFs of the physical environment can be easily larger than those of the robotic system*
- **Nonholonomic Constraints**
  - *a system whose state depends on the path taken in order to achieve it. (Controllable DOFs ≠ Total DOFs caused by non-integrable constraints)*
- **Modes in Manipulations**
  - *Breaking or making of contacts, i.e. collision with obstacles*
  - *A modular structure for convenient implementation, but will make the manipulation tasks inherently discontinuous*
  - *The robot must reach a suitable mode before it can perform a desired manipulation*

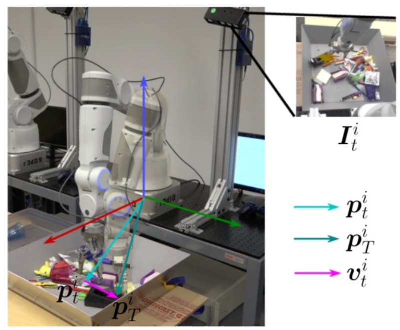
Interactive Perception and Verification

Paving the pathway for supervised learning



Source: Google





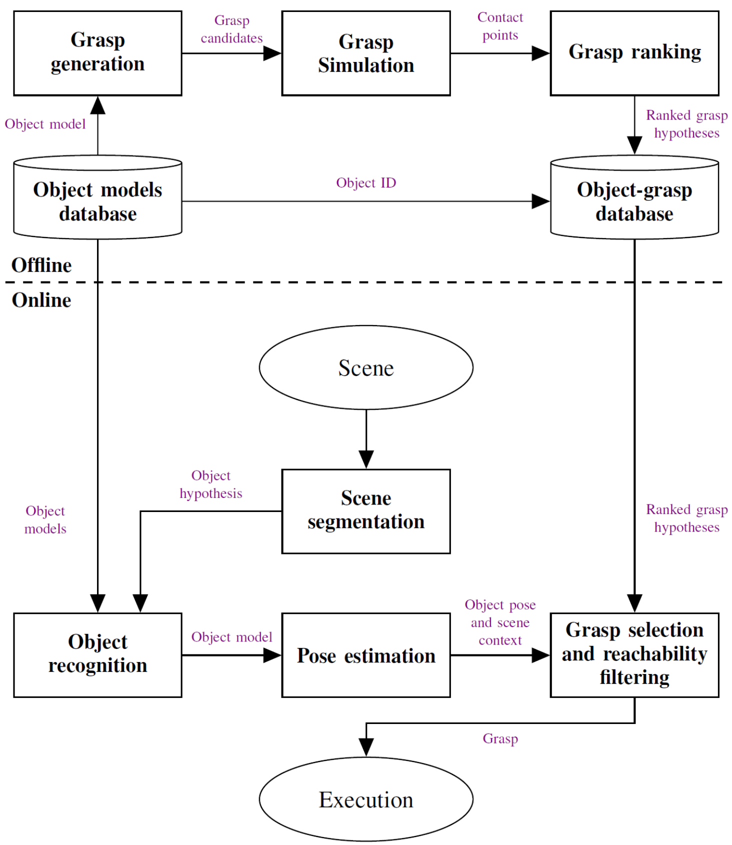
Algorithm 1 Servoing mechanism $f(\boldsymbol{I}_t)$

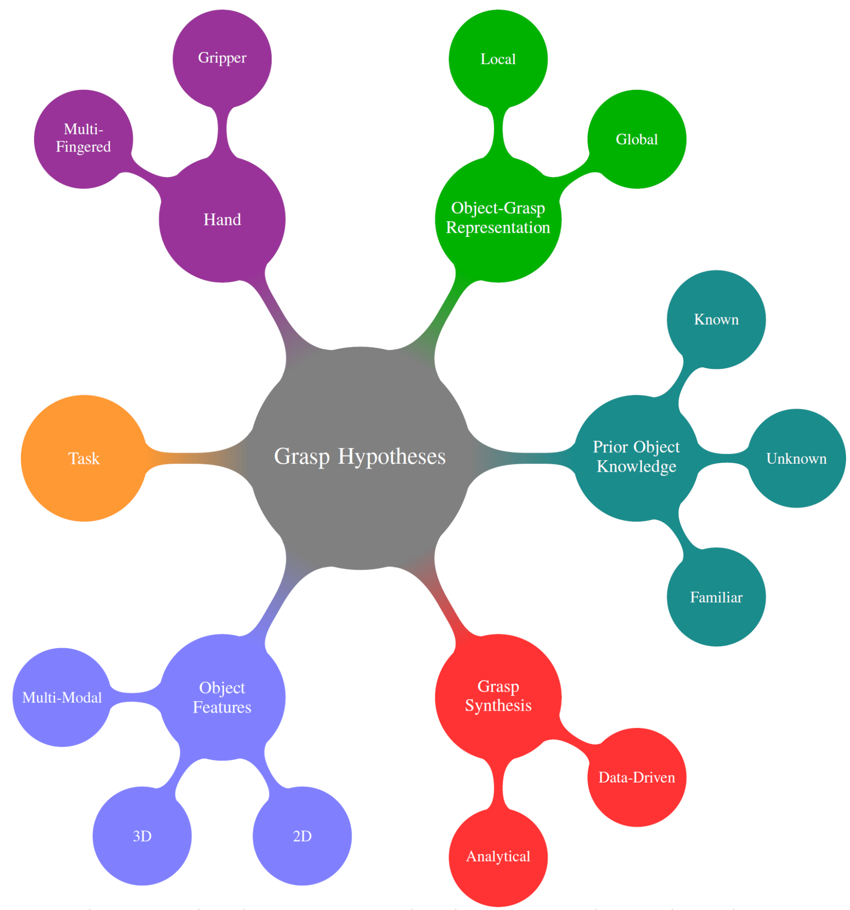
Given current image $\boldsymbol{I}_t$ and network g.
Infer $\boldsymbol{v}_t^\star$ using g and CEM.
Evaluate $p = g(\boldsymbol{I}_t, \emptyset)/g(\boldsymbol{I}_t, \boldsymbol{v}_t^\star)$.
if $p = 0.9$ **then**
  Output $\emptyset$, close gripper.
else if $p \leq 0.5$ **then**
  Modify $\boldsymbol{v}_t^\star$ to raise gripper height and execute $\boldsymbol{v}_t^\star$.
else
  Execute $\boldsymbol{v}_t^\star$.
end if

- **Interactive Perception** *enables the robot to perceive latent object properties by observing the outcomes of different manipulation actions*
- **Verification** *is usually done through interactive perception to get the ground truth value for supervised learning with passive perception*
- **Active Learning** *is the process of actively selecting samples to label to maximize learning performance, often used together with interactive perception*

Structured Decomposition of Vision-based Picking

Hierarchical Task Decompositions and Skill Reusability





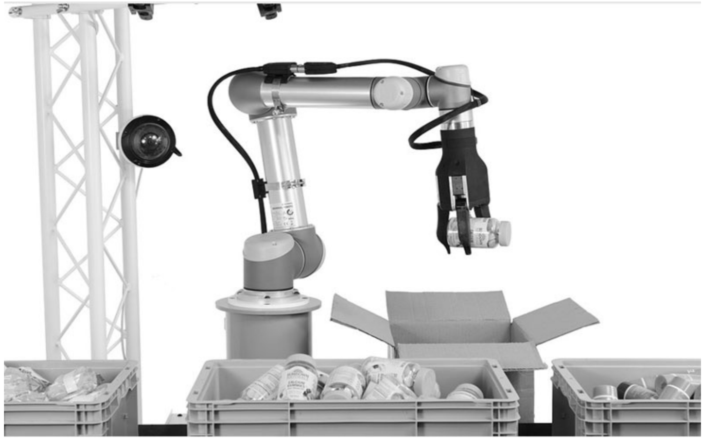
Data-Driven Grasp Synthesis - A Survey, Jeannette Bohg, Antonio Morales, Tamim Asfour, Danica Kragic (https://arxiv.org/pdf/1309.2660.pdf)

System Integration of Object-centered Robotic Manipulation

Object-Centric Generalization

Abstract representations

- *Find a representation under which we can consider a family of objects to be equivalent or identical, even though they vary substantially at the pixel or feature level.*



Generalization via objects

- *across different objects,*
- *between similar (or identical) objects in different task instances*

Usually enough to generalize across task instances

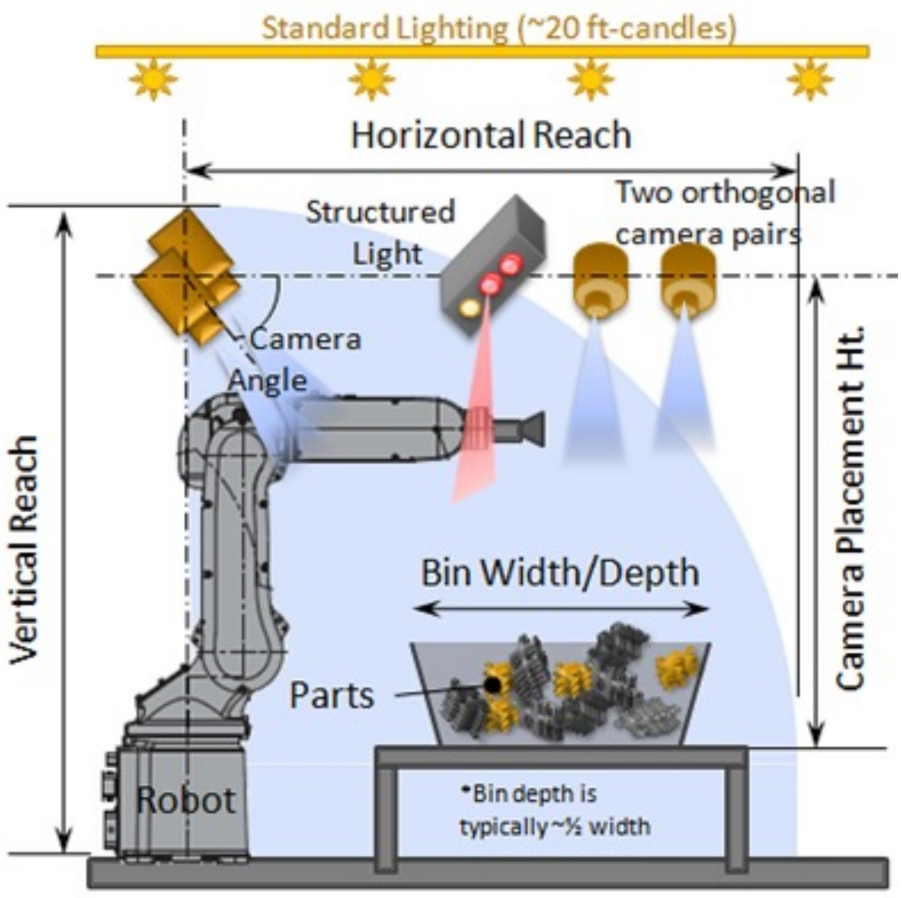
- *Generalizing across different objects will require both motor skills and object models that adapt to variations in object shape, properties, and appearance.*

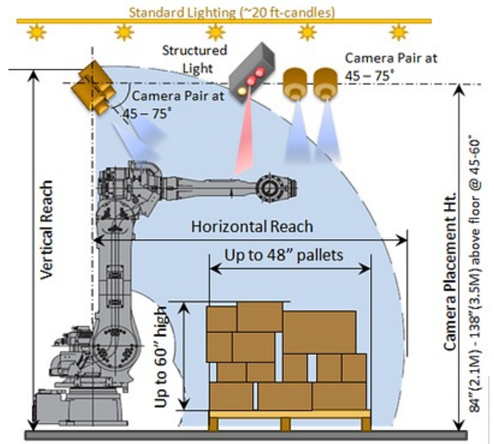
Rigid-Soft Interactive Learning

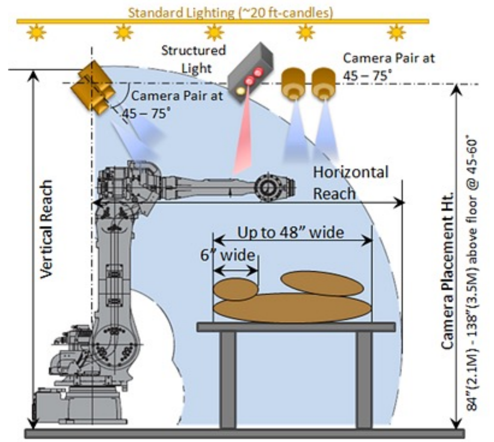
- *In some cases, this can be done implicitly, e.g., with a compliant gripper that automatically adapts its shape to that of an object during grasping.*

Discovering
Novel Concepts and Structures

A structured hierarchy for learning structural skills







Success Examples in Robot Learning

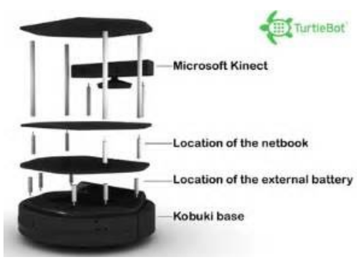
A Peek into the History

Autonomous Vehicles | Autonomous Drones | Arm-Type Robots

Research Challenge (Science 1st)

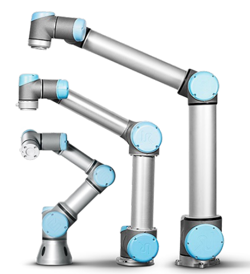
Industry Need

Consumer Electronics (Cost 1st)



?

Service Integration (App 1st)



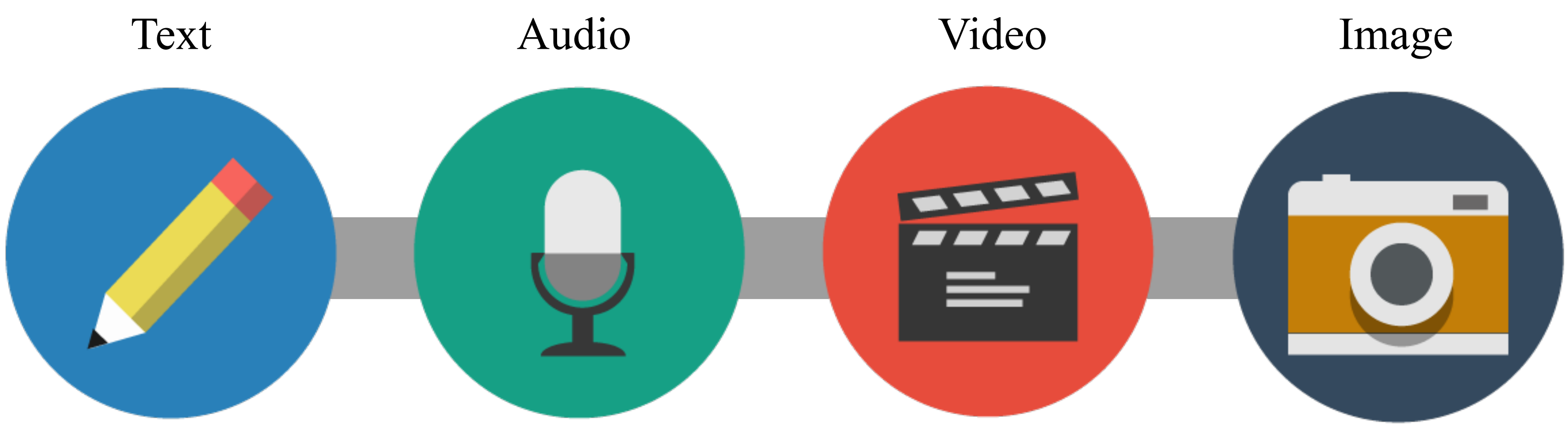
Service Penetration

What are the Challenges?

Translating Success in Machine Learning for Robotics

- Computing Unit ☑
- Advanced Algorithms ☑
- Big Data ☑

For Machine Learning



Source: https://techblogwriter.co.uk/wp-content/uploads/2016/01/text-video-audio-and-images..png

What are the Challenges?

Translating Success in Machine Learning for Robotics

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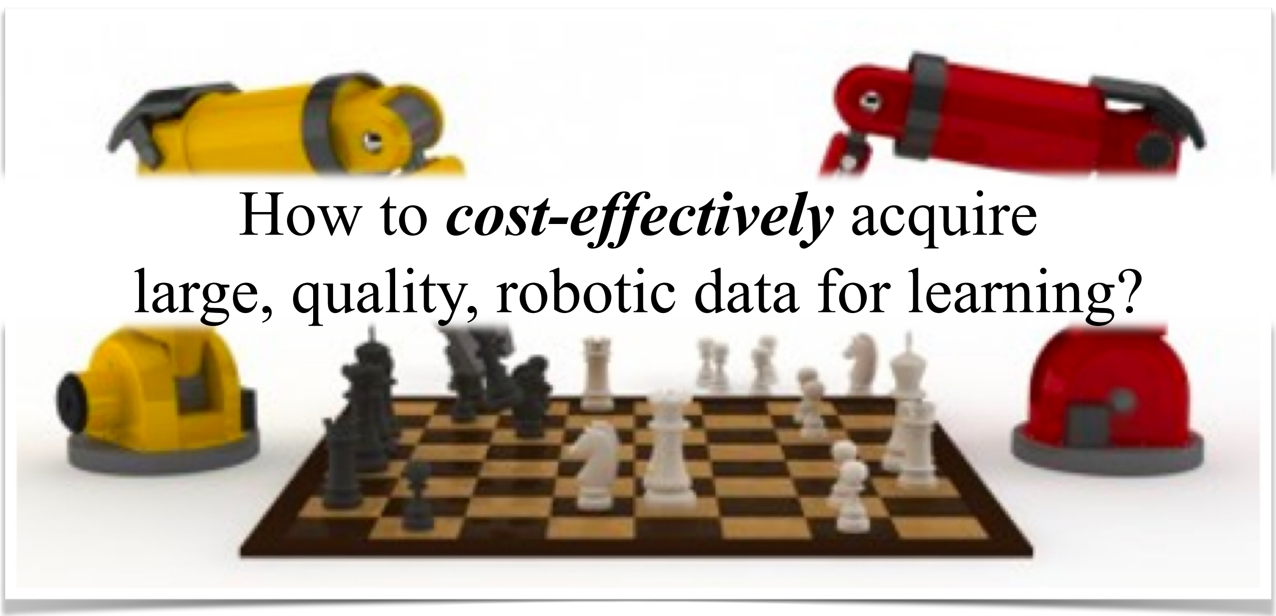
- Advanced Algorithms ?
- Big Data ⊗

For Robots to learn?



How to ***cost-effectively*** acquire
large, quality, robotic data for learning?

A Structural, Object-Centric Decomposition of the Unstructured, Physical Interactions into Shareable & Reproducible Machine Intelligence through Design + Learning

Collaborative Robot Learning

Input

A Structural, Object-Centric Decomposition of the Unstructured, Physical Interactions into Shareable & Reproducible Machine Intelligence through Design + Learning

Collaborative Robot Learning

A Structural,
Object-Centric Decomposition of
the Unstructured,
Physical Interactions into

Output

Shareable & Reproducible
Machine Intelligence
through Design + Learning

Collaborative Robot Learning

A Structural,
Object-Centric Decomposition of
the Unstructured,
Physical Interactions into
Shareable & Reproducible *Knowledge*
Machine Intelligence
through Design + Learning

Collaborative Robot Learning

A Structural,
Object-Centric Decomposition of
the Unstructured,
Physical Interactions into
Shareable & Reproducible
Machine Intelligence

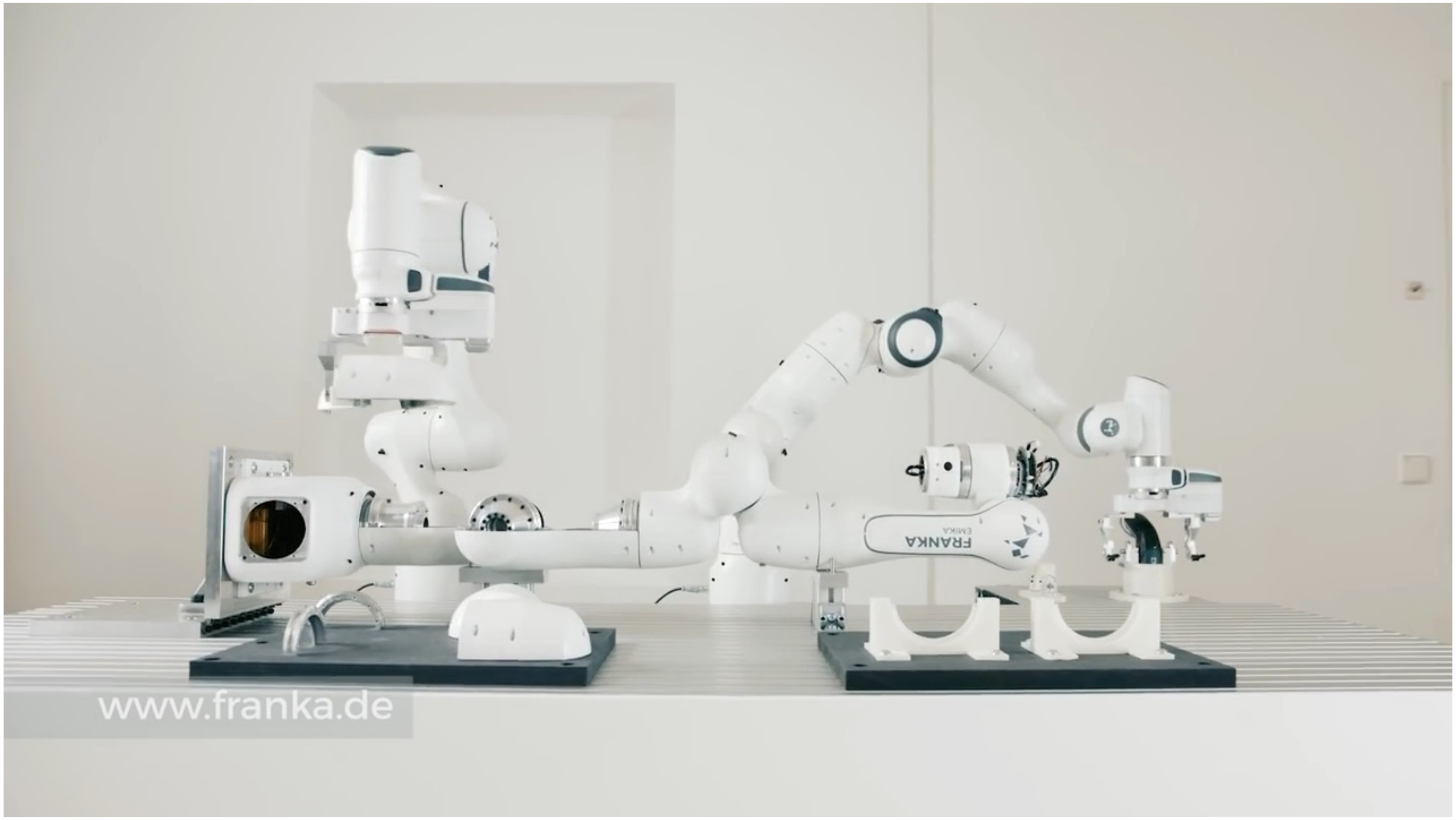
through Design + Learning *Method*

Collaborative Robot Learning

Machine Intelligence *to be* Designed & Learned

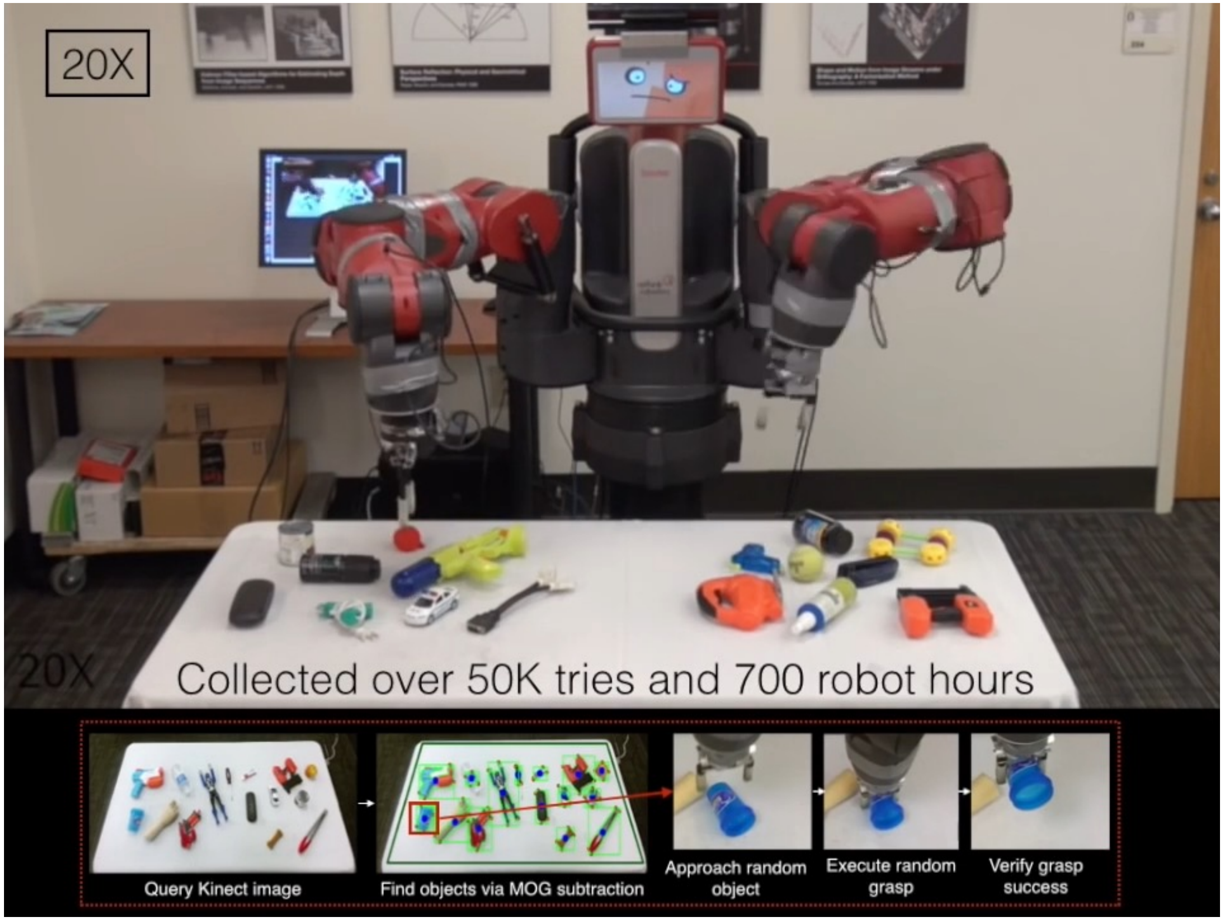
Mechanical Systems

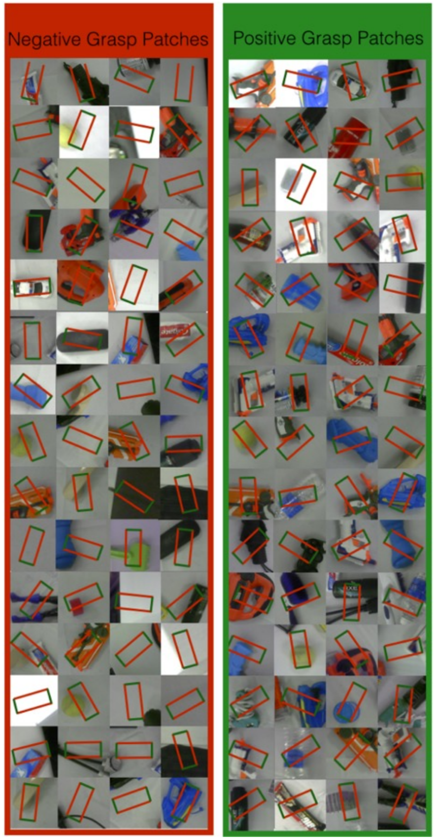
Learning Algorithms



Supersizing self-supervision:

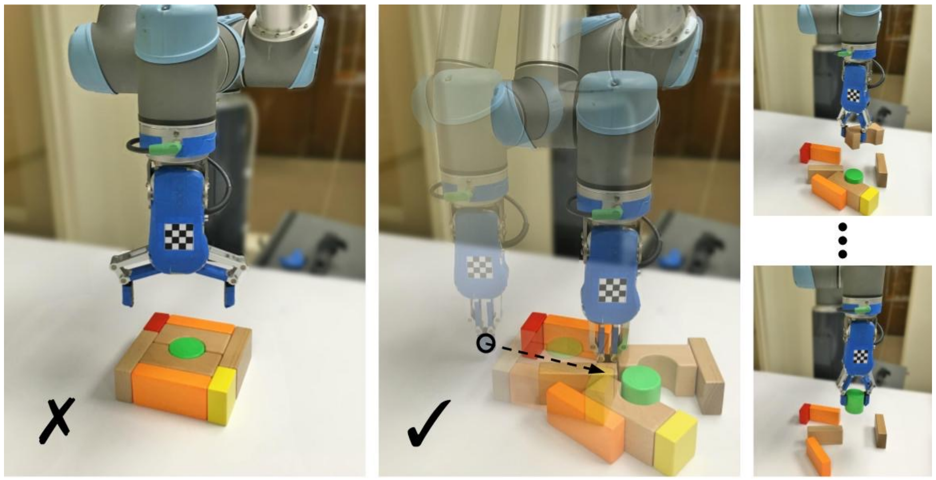
Learning to grasp from 50k tries and 700 robot hours

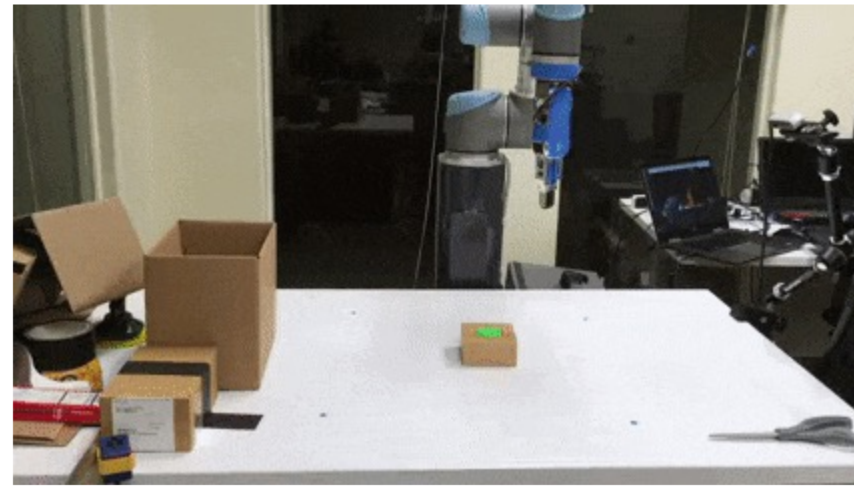


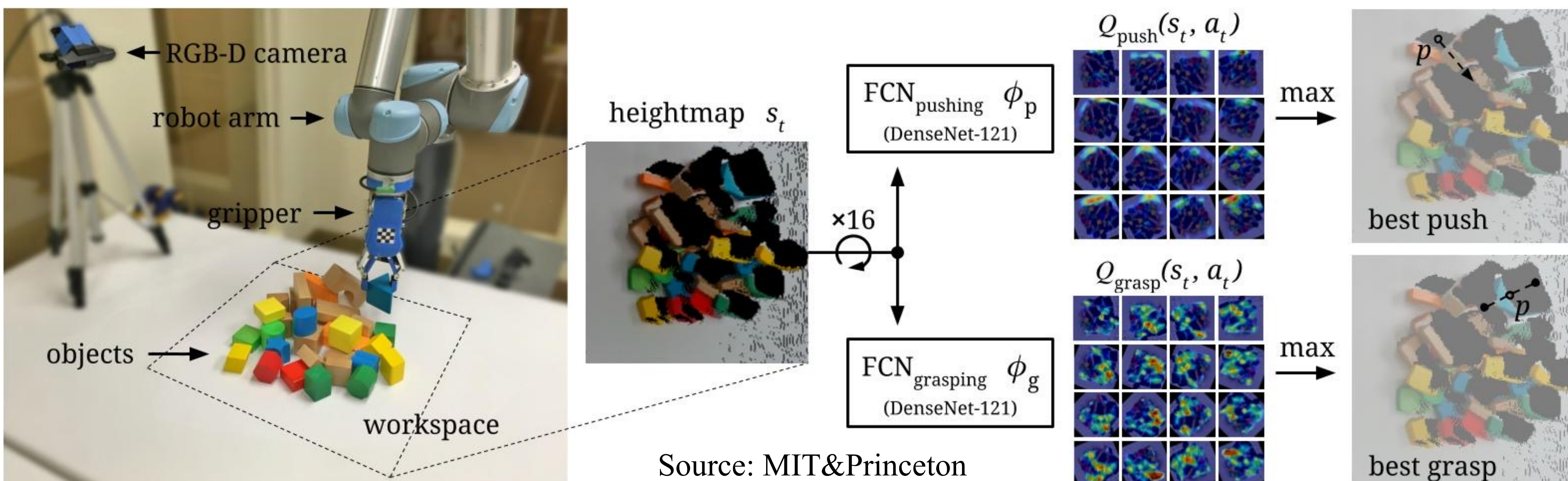


Source: CMU

Learning Synergies between Pushing and Grasping with Self-supervised Deep Reinforcement Learning

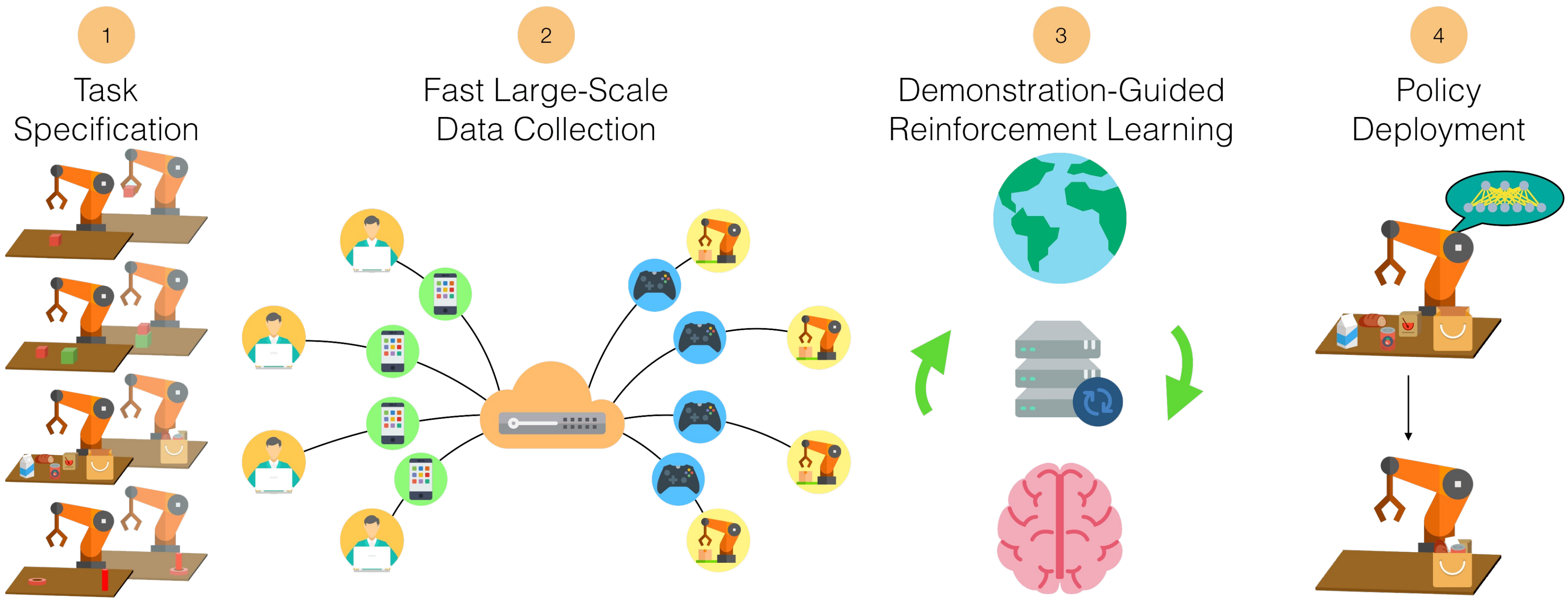


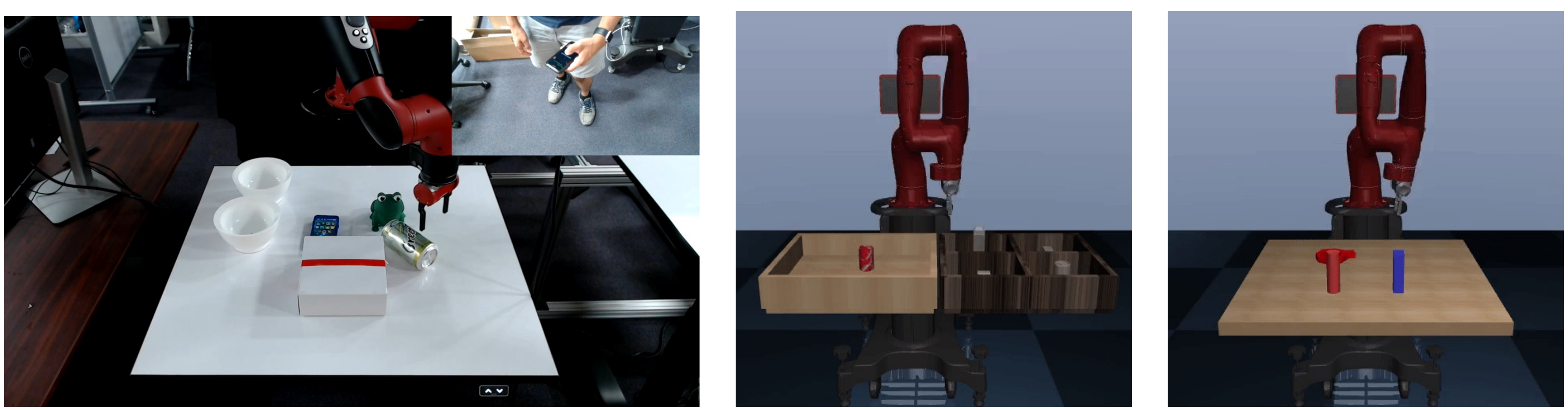




Source: MIT&Princeton

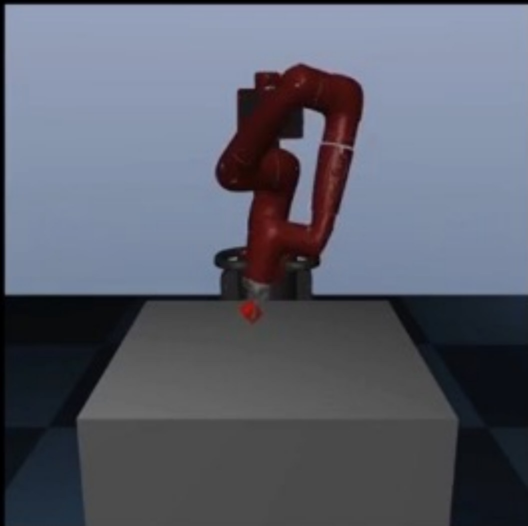
RoboTurk: A Crowdsourcing Platform For Robotic Skill Learning Through Imitation



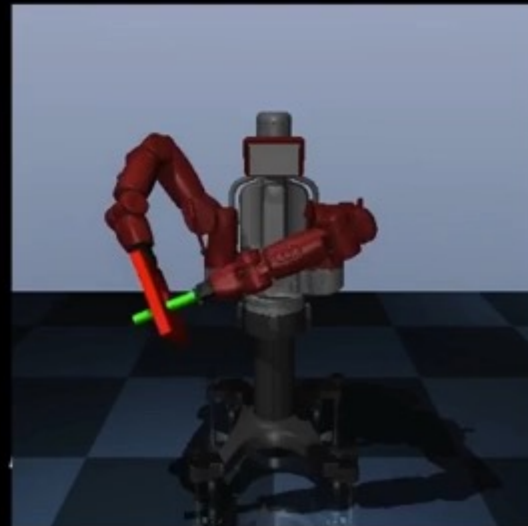


Source: Stanford

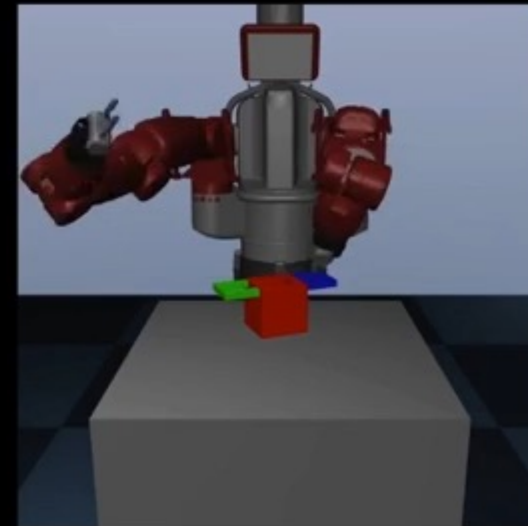
Surreal Robotics Suite Tasks: Surreal-PPO Agents



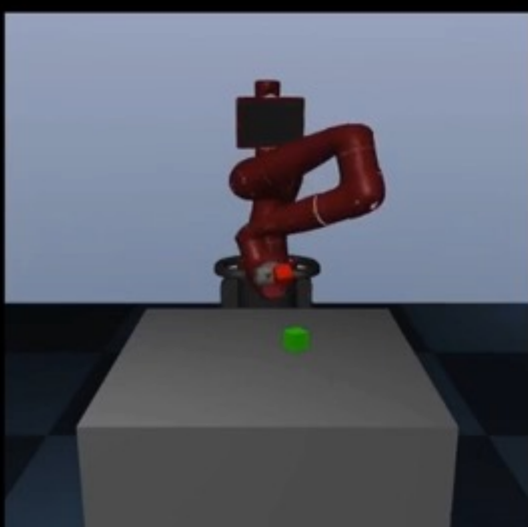
Block Lifting



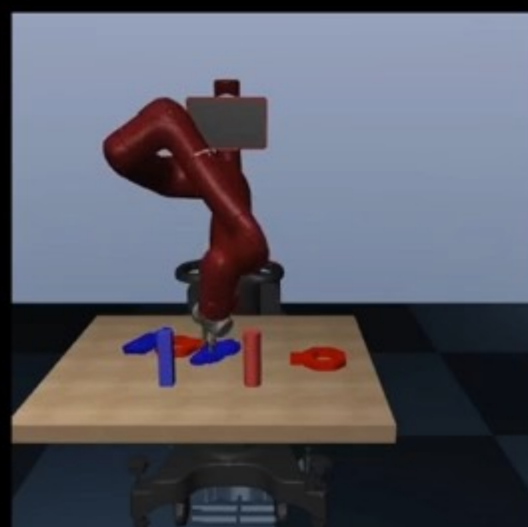
Bimanual Peg-in-Hole



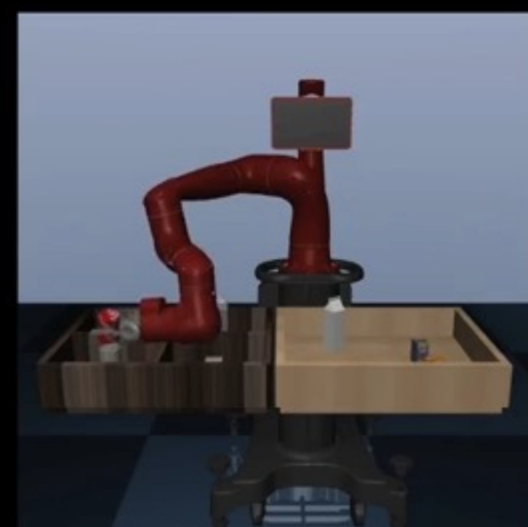
Bimanual Lifting



Block Stacking

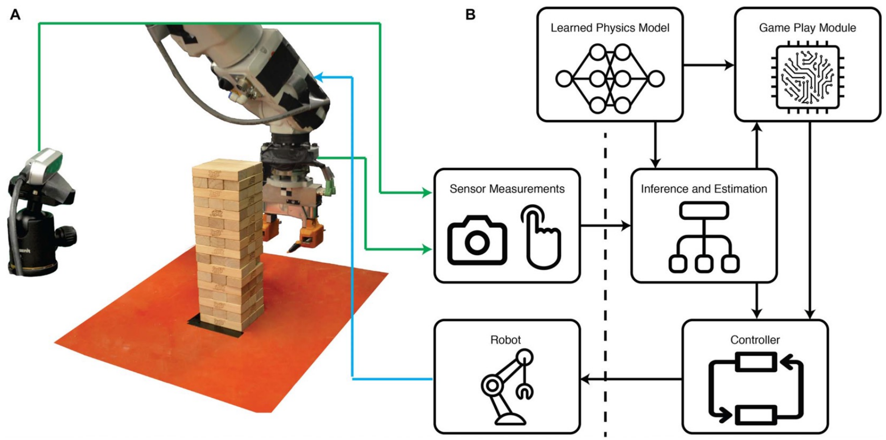


Nut-and-Peg Assembly



Bin Picking

See, Feel, Act: Hierarchical learning for complex manipulation skills with multisensory fusion



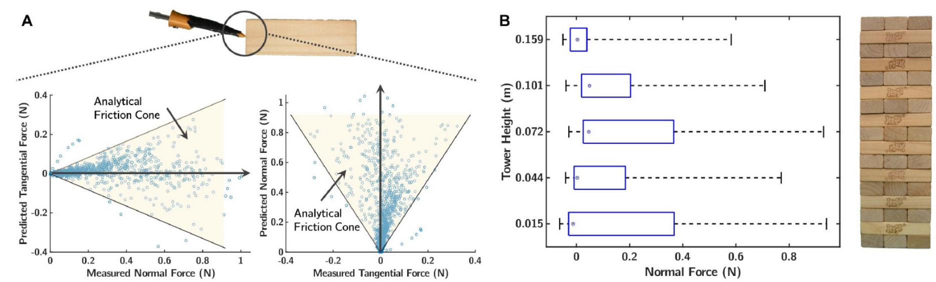
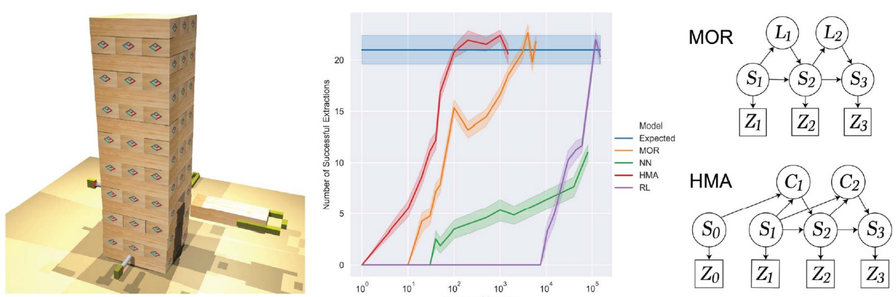
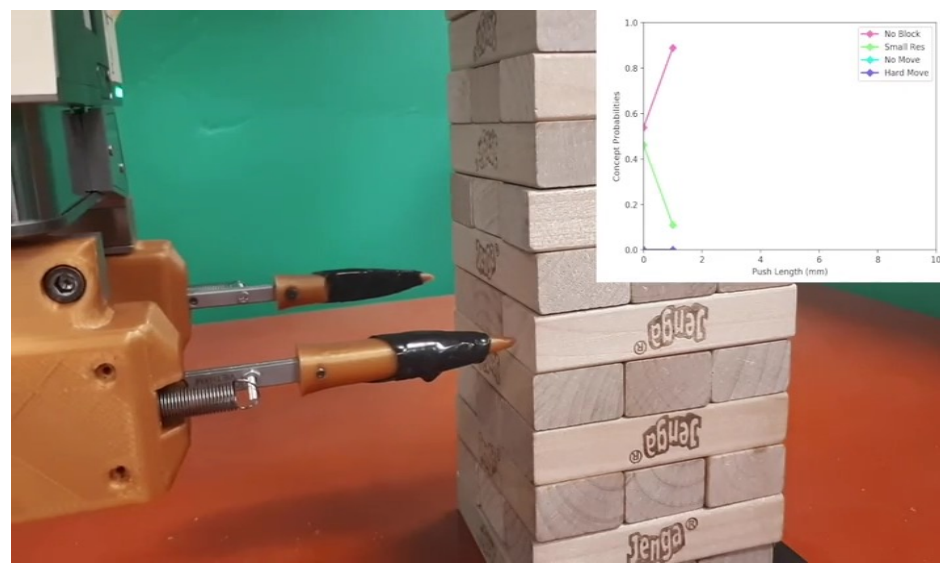


Fig. 4. Learned intuitive physics. (**A**) Overlay of the analytical friction cone and predicted forces given the current measurements. The friction coefficient between the finger material (PLA) and wood is between 0.35 and 0.5; here, we use 0.42 as an approximation. (**B**) Normal force applied to the tower as a function of the height of the tower. Each box plot depicts the minimum, maximum, median, and standard deviation of the force measures.



A B C

Fig. 2. Jenga setup in simulation and the baseline comparisons. (**A**) The simulation setup is designed to emulate the real-world implementation. (**B**) Learning curve of the different approaches with confidence intervals evaluated over 10 attempts. Solid lines denote the median performances; shadings denote one standard deviation. (**C**) Visual depiction of the structure of the MOR and the proposed approach (HMA).



Source: MIT

Thank you ~

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