CoBoTaT

Lecture 8: The effects of leader-follower dynamics on physical collaboration in human-robot dyads

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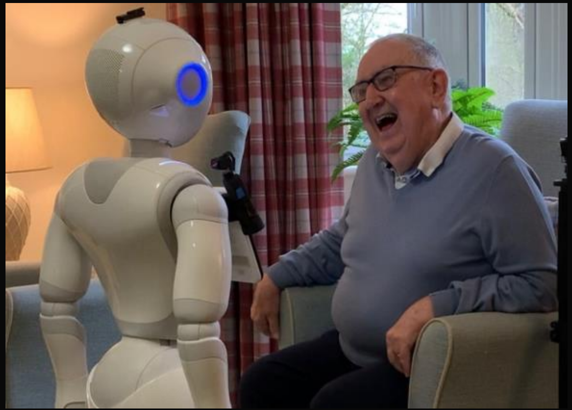
Examples of human-robot interaction





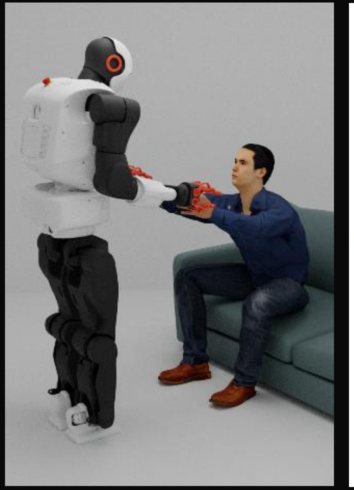



- Traditional industrial manipulators
- Robot assisted rehabilitation
- Collaborative robot for manufacturing
- Robotic exoskeleton
- Robots for construction
- Elder companionship

Research questions and challenges

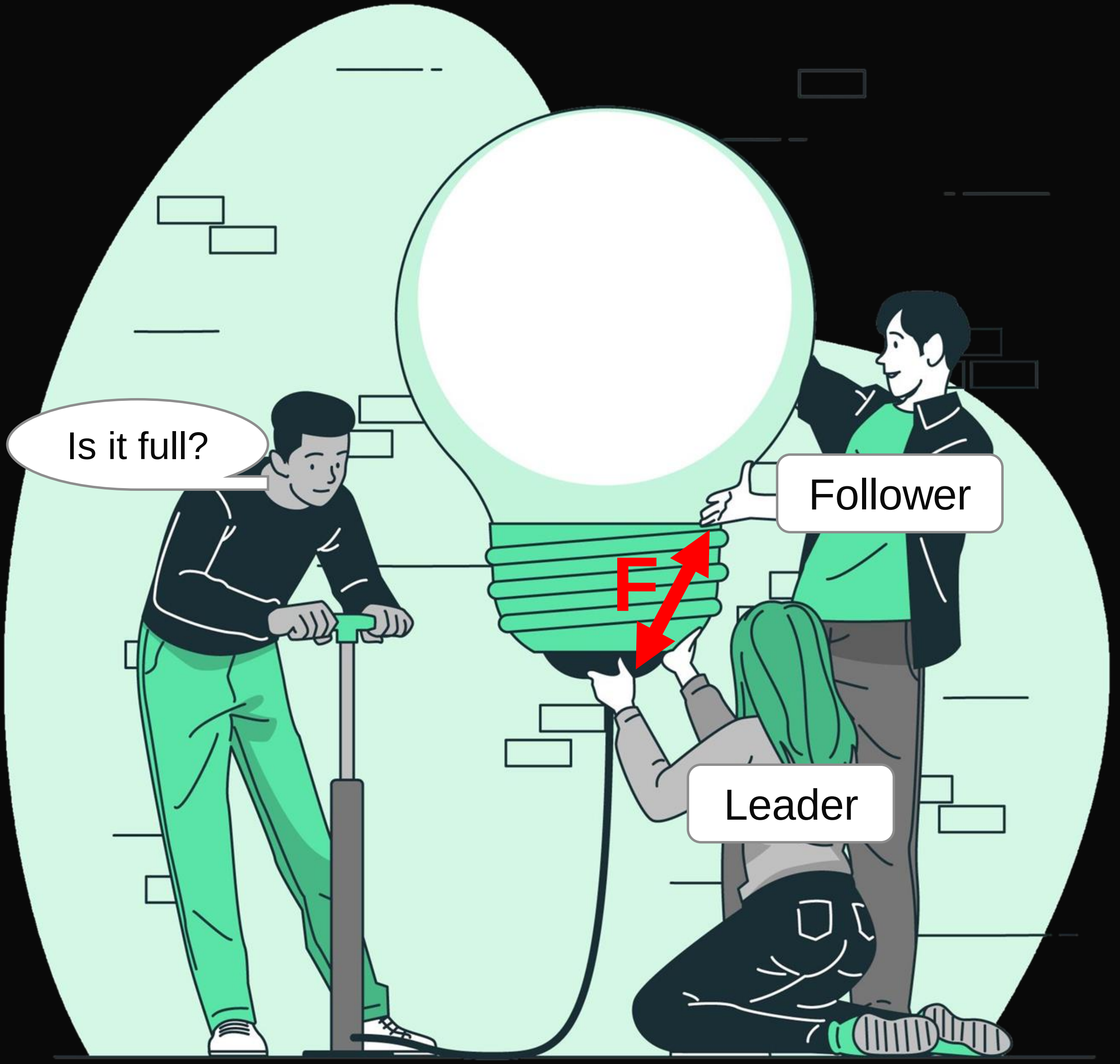
Outline

- How can roles (leader-follower) be defined in pHRI?
- What is the optimal level of co-adaptation?
- How can robots learn more like humans?
- How can robots learn more from humans?
- What kind of machine learning can be used in pHRI?



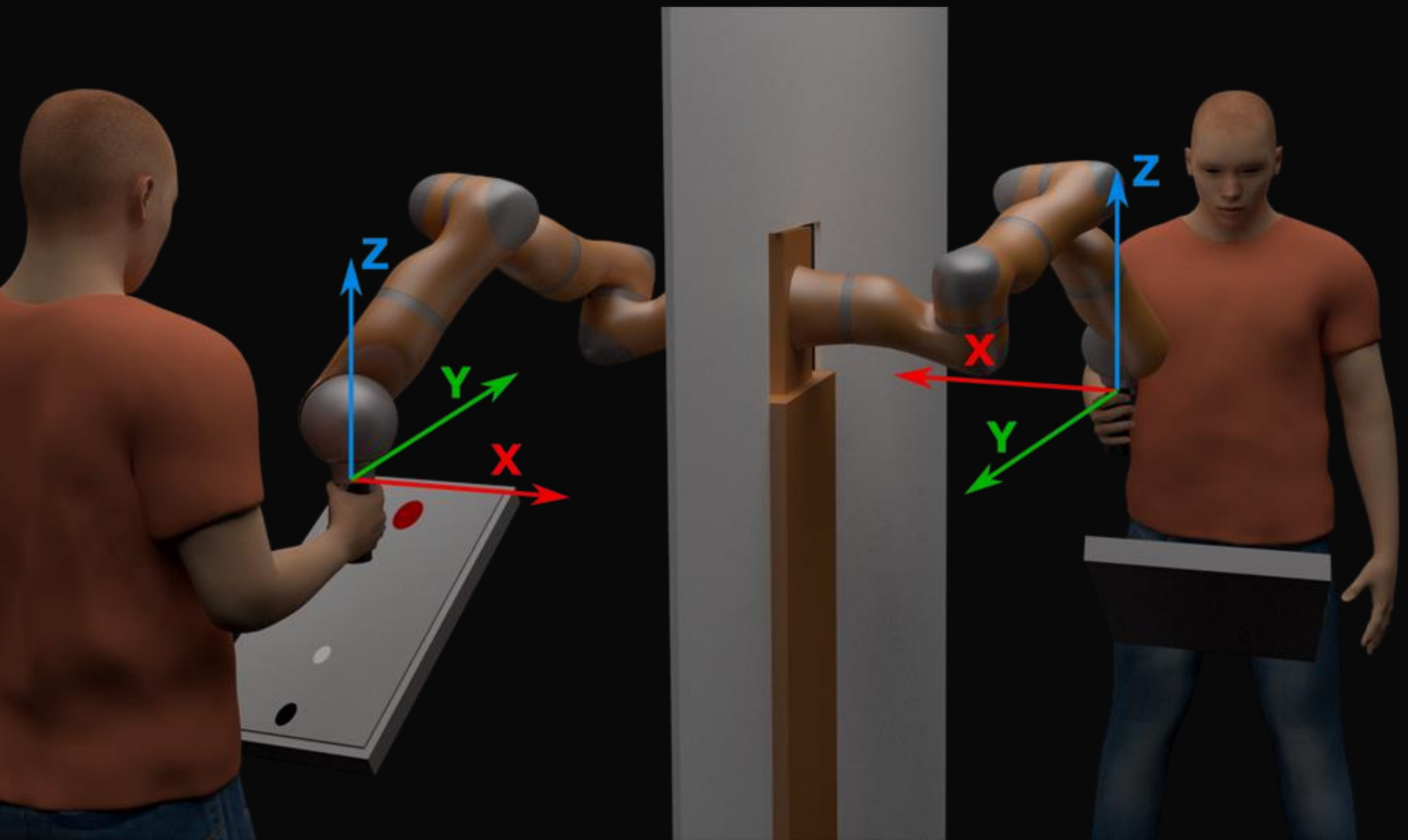
Collaboration between people

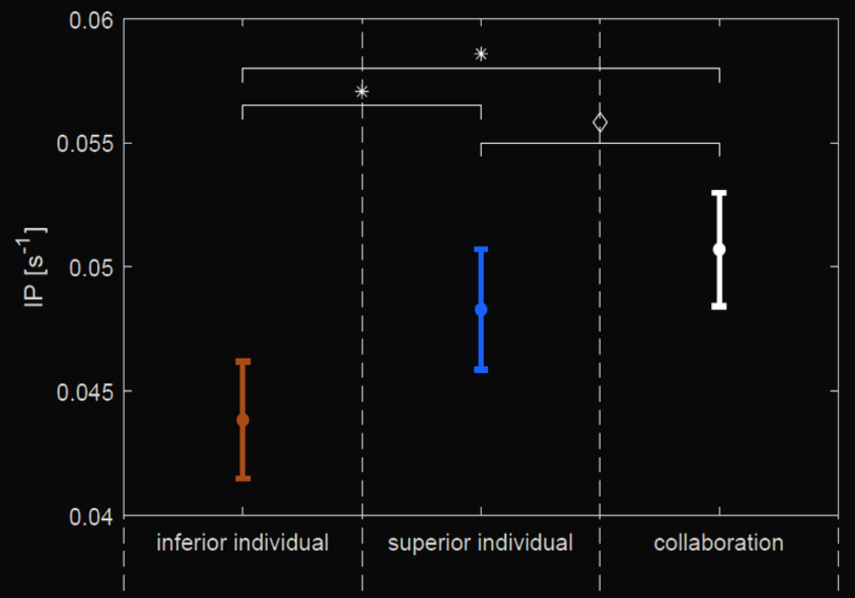
- Daily activity
- Coordination through communication
  - Verbal
  - Non-verbal
- Role allocation
  - important research area for HRC
  - mostly insufficiently researched

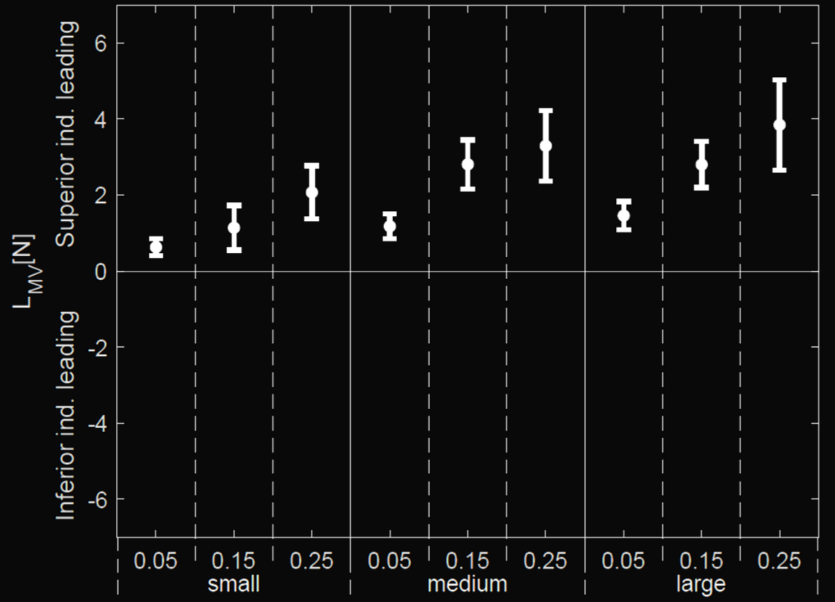


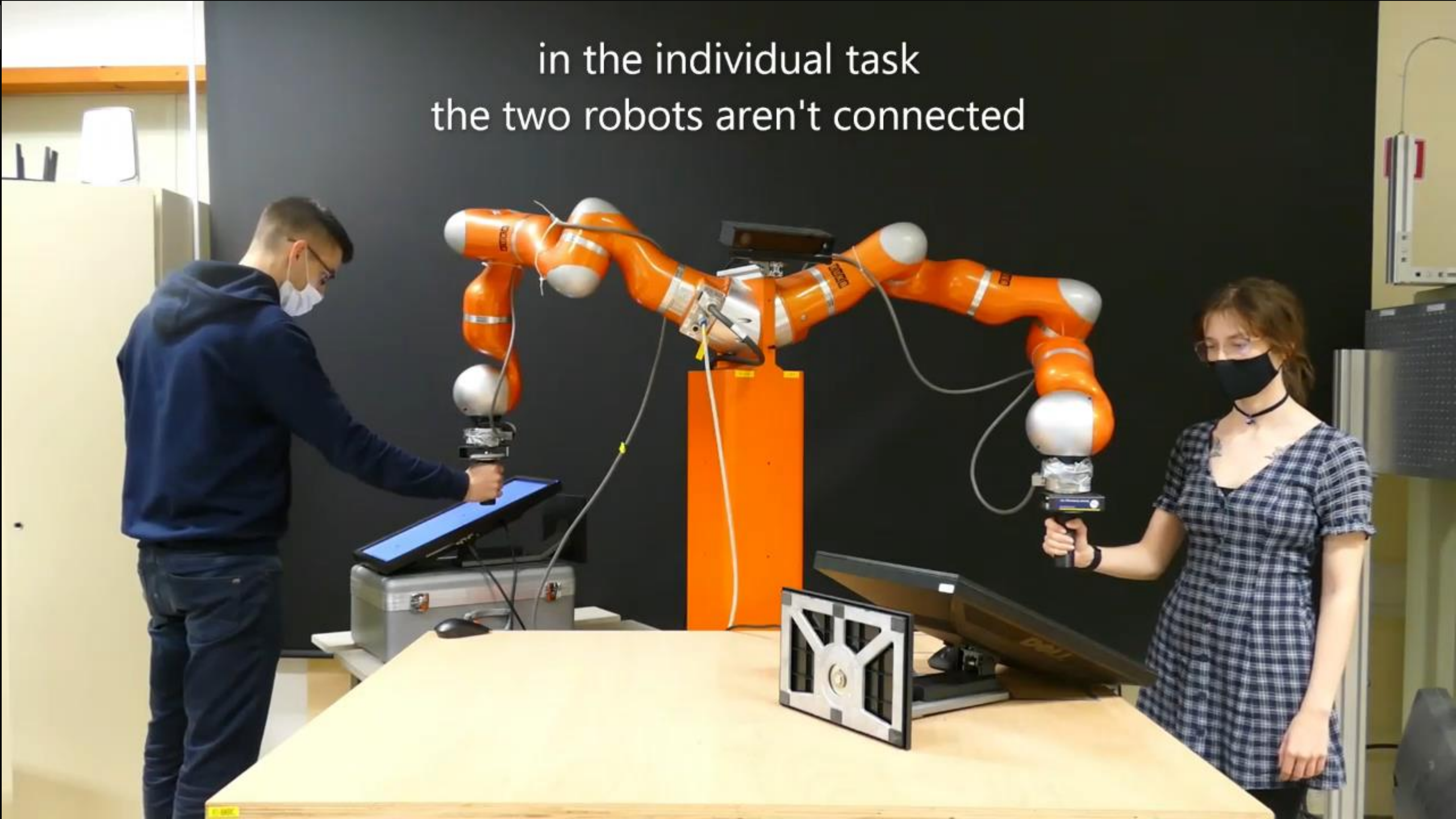
Study on leader-follower dynamics

- Increased performance in collaboration
  - Slower individual significant improvement
  - Faster individual no significant improvement or deterioration
- **Hypothesis**: leader has the greatest influence in task without start and aiming








in the individual task
the two robots aren't connected

Human-robot control evaluation

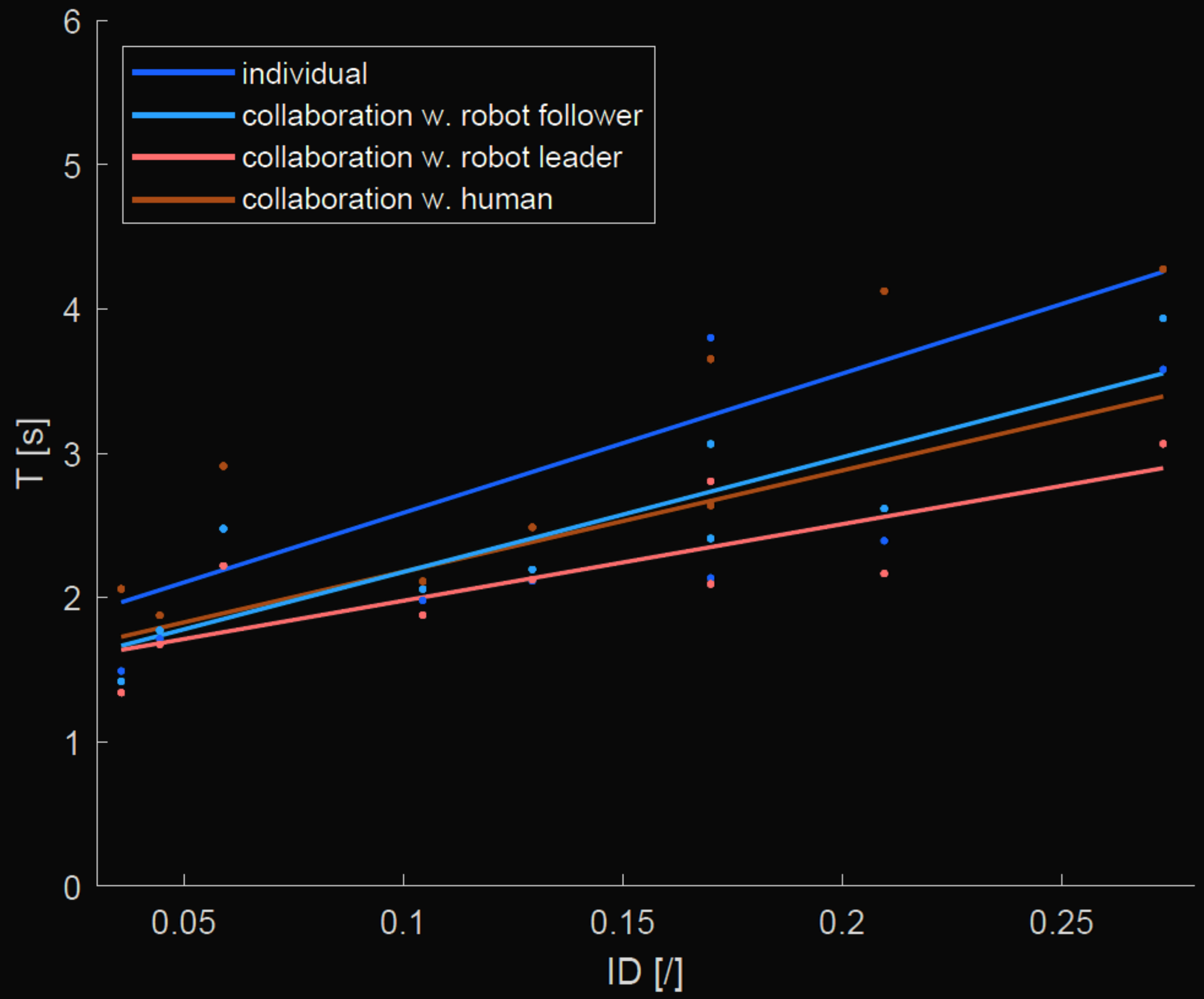
- Objective evaluation:
  - Fitts' law model
    - Time to complete the task depending on the complexity of the target
    - Lower time = better performance

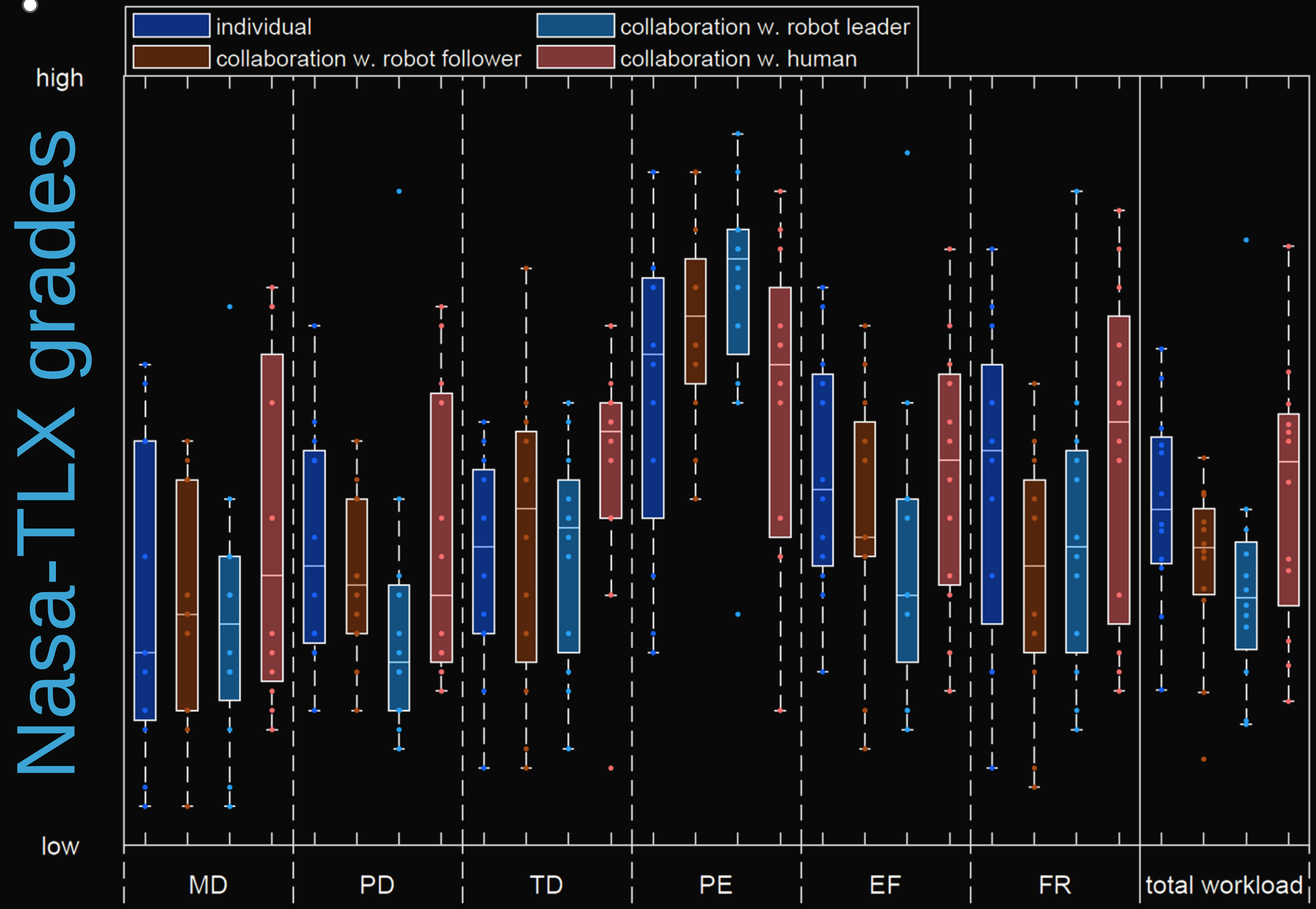
- Subjective evaluation:
  - Nasa-TLX (Task Load Index)

- Turing test
  - "If you chose one of the experiments that you found easiest?"
  - "For each experiment, choose whether you performed the task yourself, with a human, or with a robot."

Human-robot Fitts' law performance evaluation

- Performing the task in collaboration improves efficiency
- Best performance when human collaborates with a robot that is leading





- Best result when human collaborate with a robot that is leading
- The most dispersed assessments when two humans are collaborating

Turing test

1. If you chose one of the experiments that you found easiest?
   - Individual → 2/12
   - Human-robot collaboration (robot is follower) → 1/12
   - Human-robot collaboration (robot is leader) → 7/12
   - Human-human collaboration → 2/12

2. For each experiment, choose whether you performed the task yourself, with a human, or with a robot.
   - Individual → 9/12
   - Human-robot collaboration (robot is follower) → 4/12
     - (wrong: 5 Individual, 1 with human)
   - Human-robot collaboration (robot is leader) → 8/12
     - (wrong: 3 with human, 2 individual)
   - Human-human collaboration → 9/12

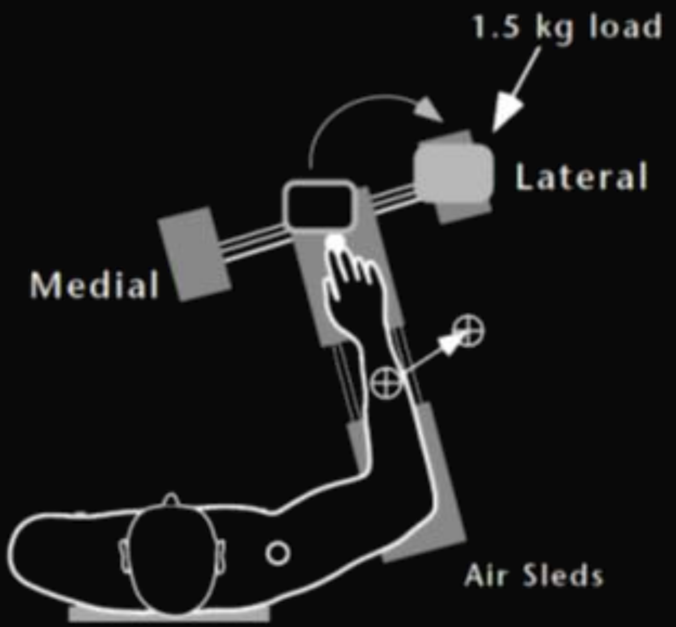
How do we bridge the gap?

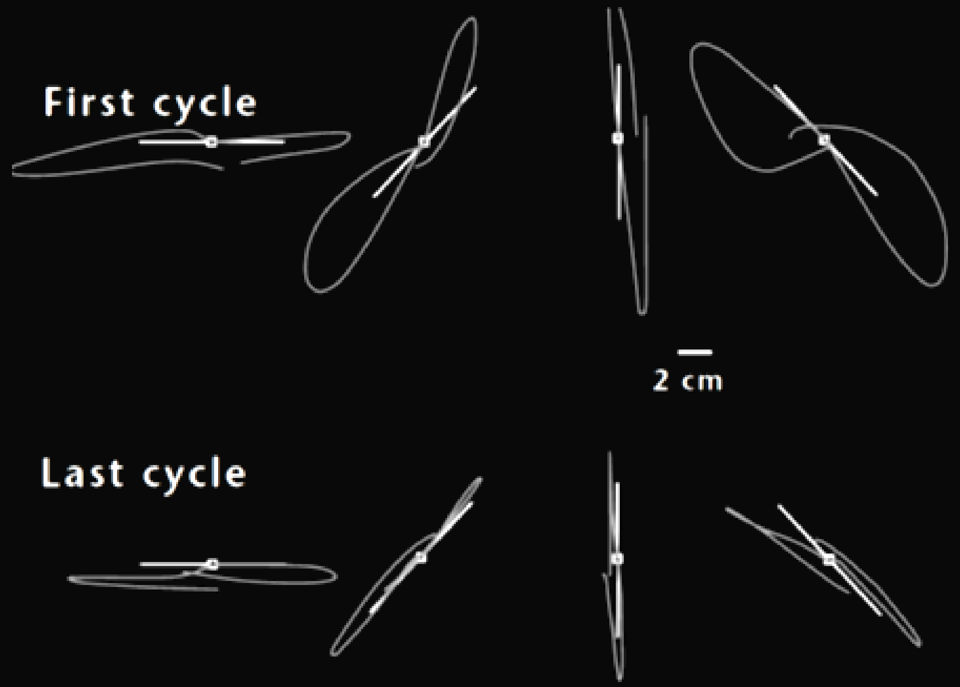
Robots should learn more like humans

- Learning internal dynamic models
- Learning task specific dynamics

Humans

- Krakauer, et al. (1999), Nature Neuroscience:
  - … hand kinematics are learned from errors in extent and direction in an extrinsic coordinate system, whereas dynamics are learned from proprioceptive errors in an intrinsic coordinate system…



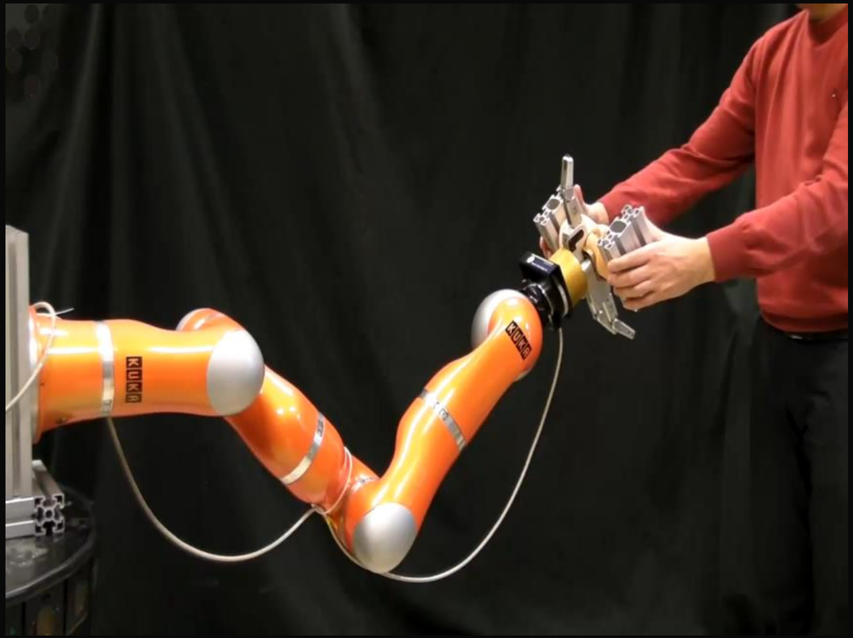


Compliant Movement Primitives (CMP)

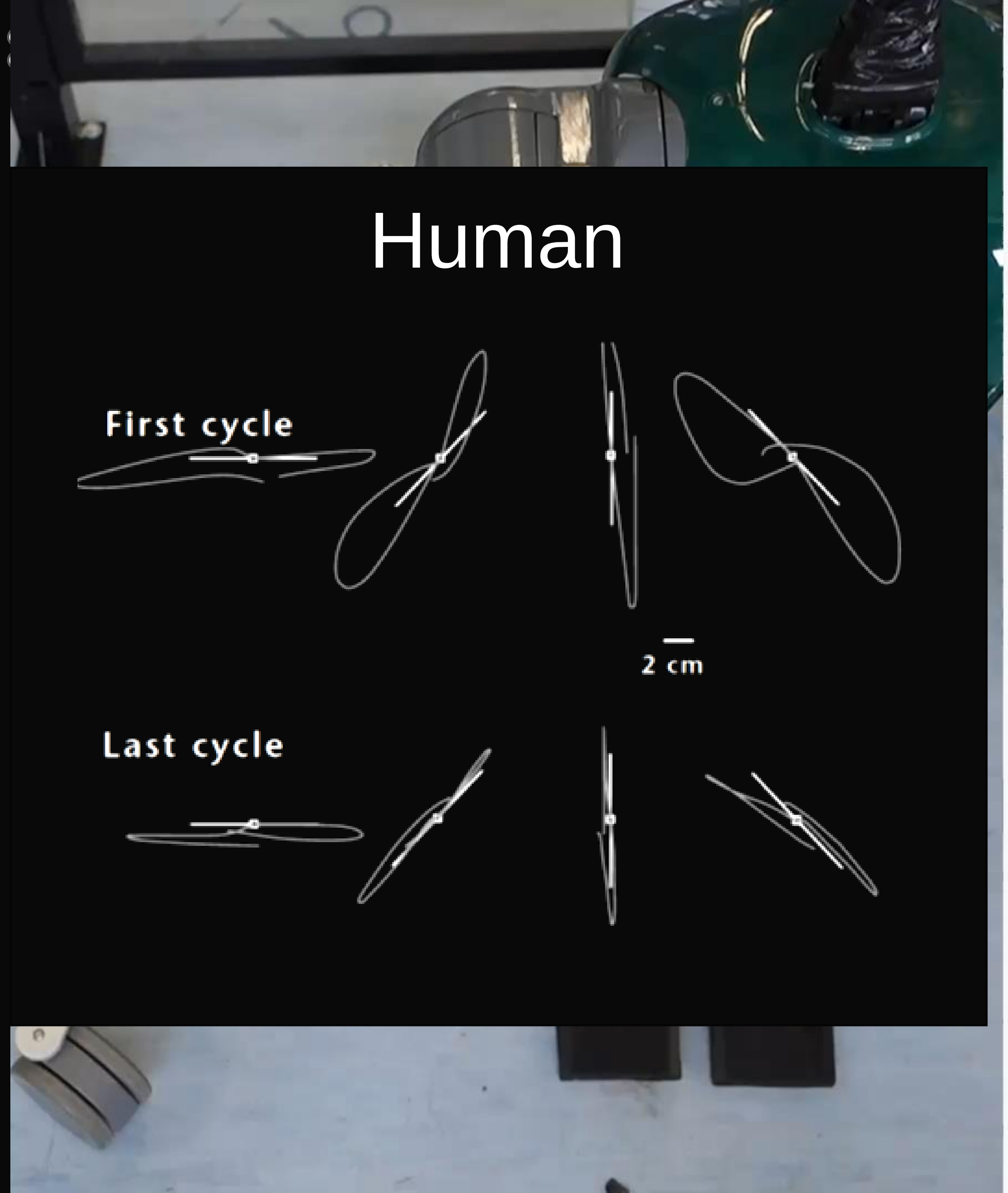
- CMP defines a task as a pair of signals: $h(t) = [q_d(t), \tau_f(t)]$
- Multi step process

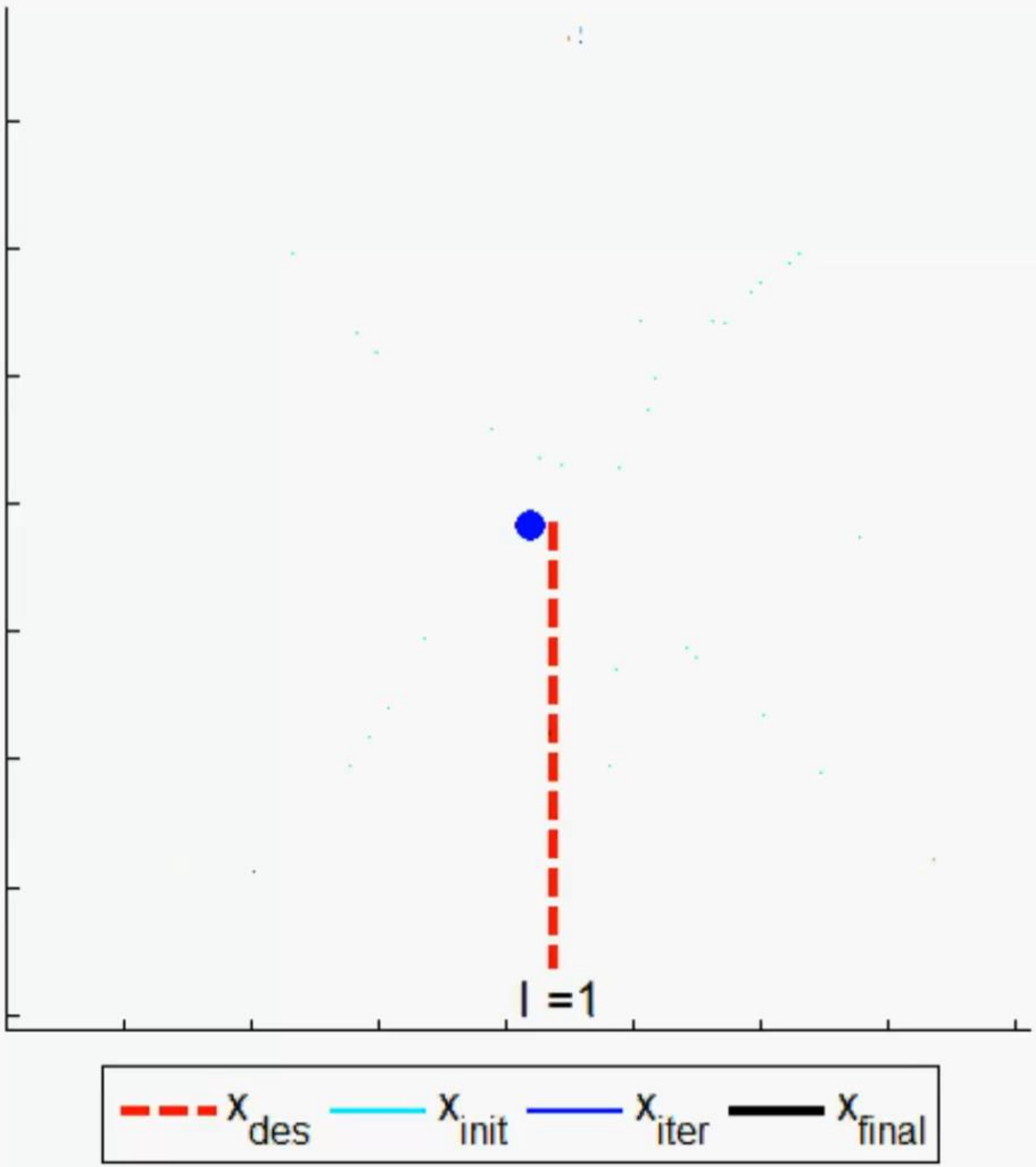
1. Motion trajectory $q_d(t)$ is learned by human demonstration

2. Iterative leaning of torque primitives $\tau_f(t)$ is updated based on kinematics



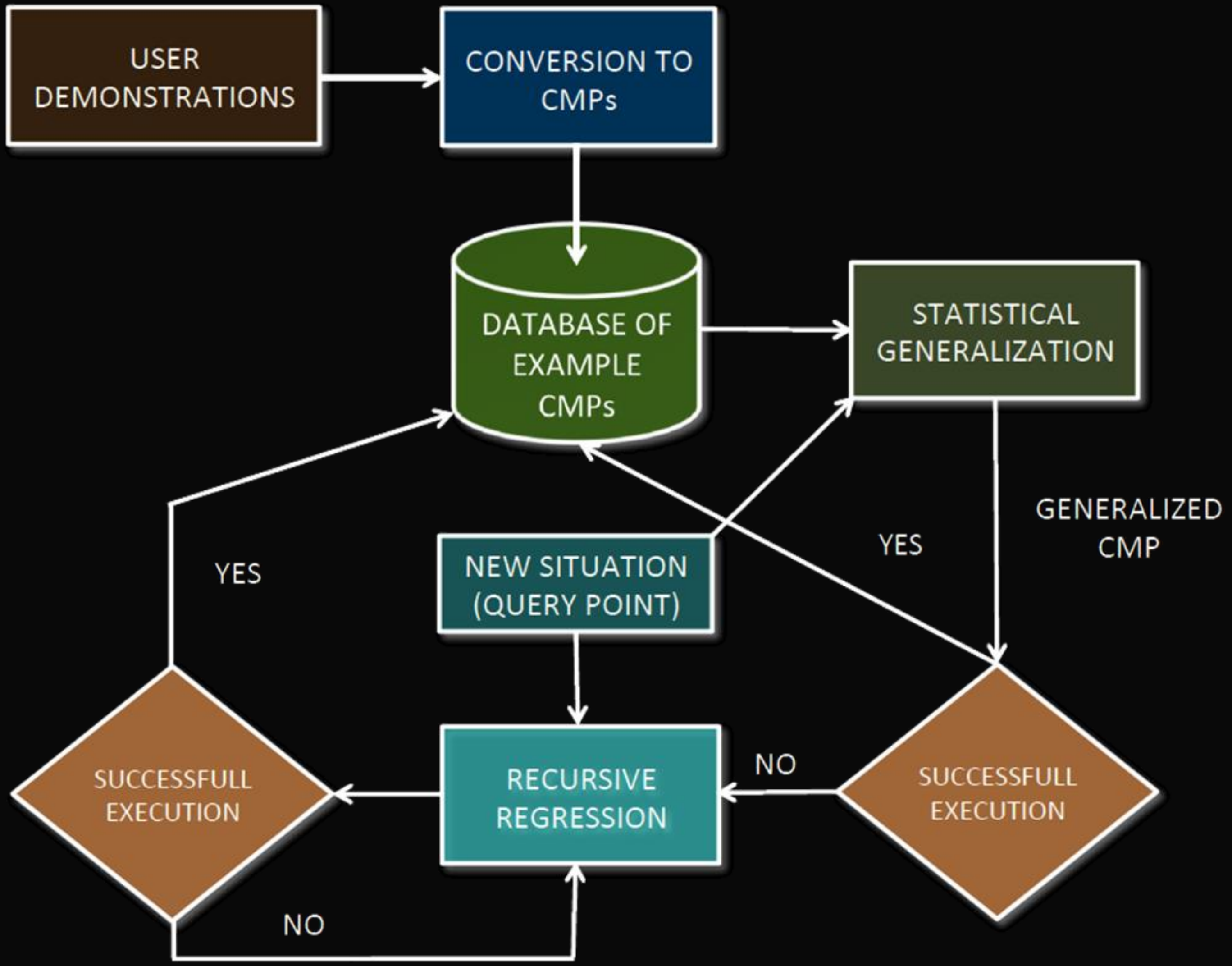
3. Movement and torque primitives are learned, stored and executed


Human
First cycle
2 cm
Last cycle

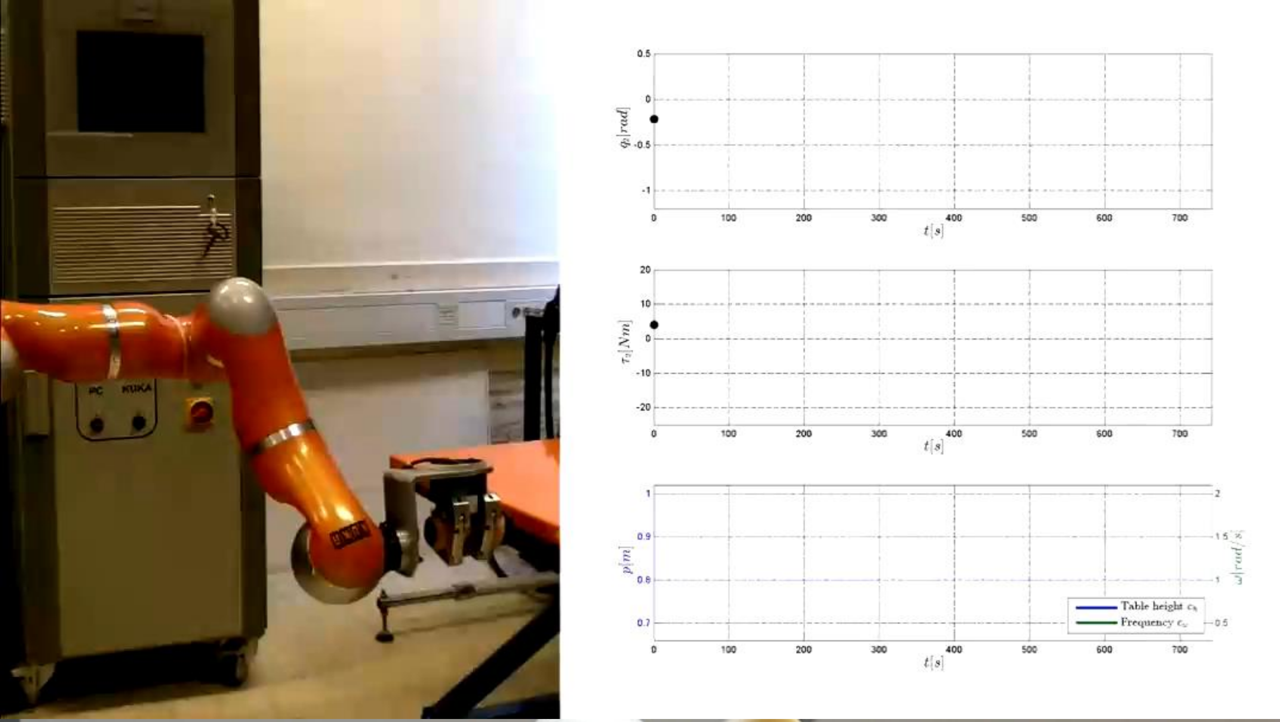

I =1
x des
x init
x iter
x final

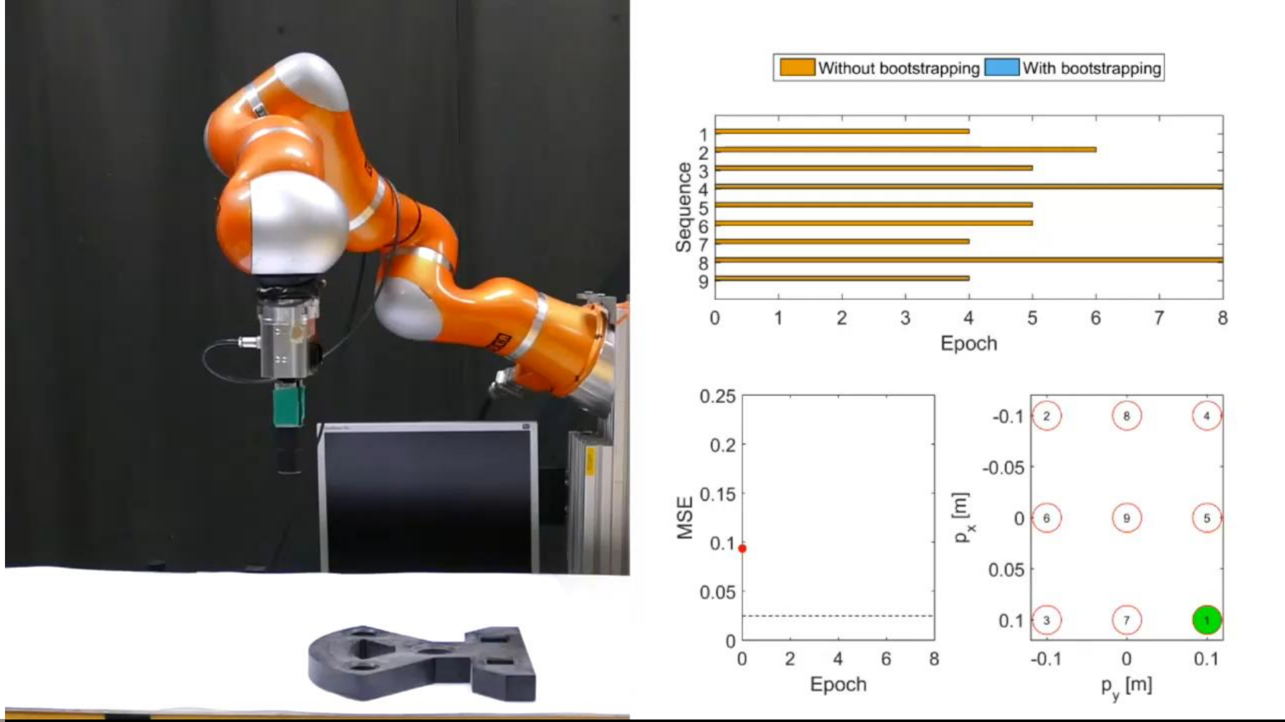
Generating database of CMPs

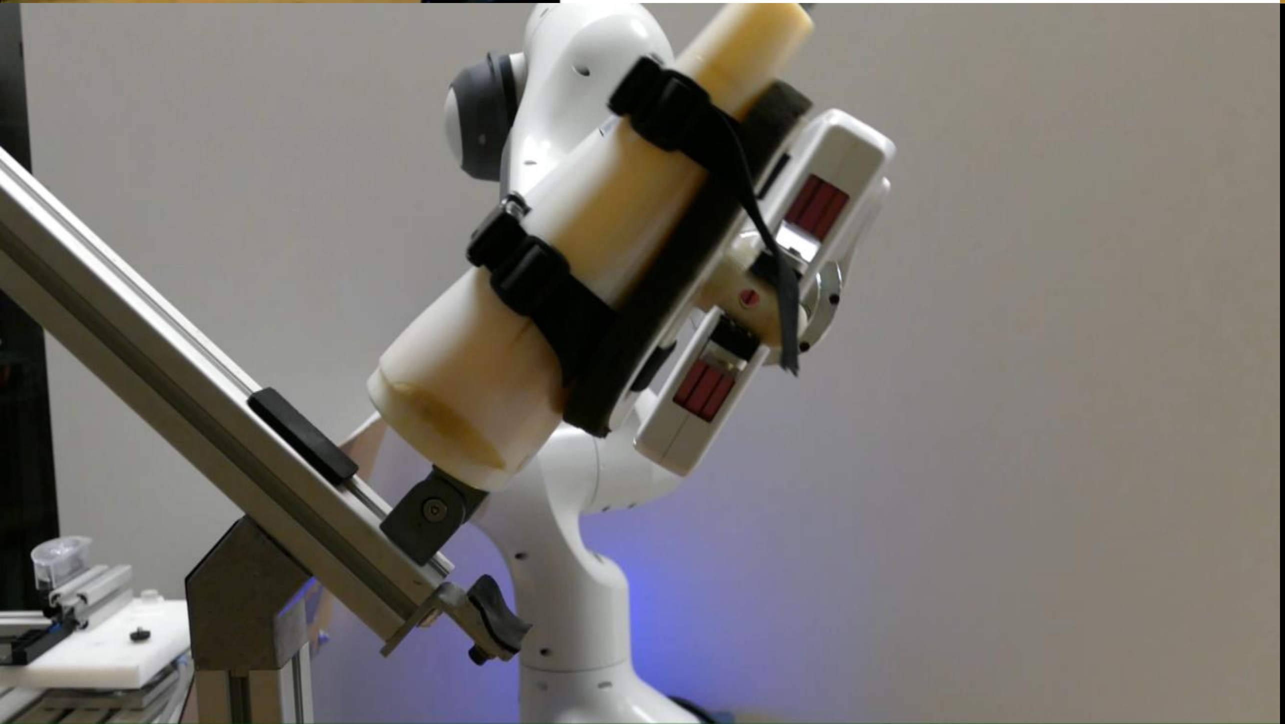
- CMPs have to be learned for every variation of the task.
- Different error metric can be used for determining if new CMPs should be added to the database.
- Learning can be, avoided or significantly accelerated by using statistical generalization.



- **T. Petric**, A. Gams, L. Colasanto, A. J. Ijspeert, and A. Ude, "Accelerated Sensorimotor Learning of Compliant Movement Primitives" *IEEE Transactions on Robotics*, 2018







Part 2:

Generalization of Discrete CMPs

Robots should learn more from humans

Human in the loop learning

Progress of SotA

Learning task relevant information, e.g. impedance

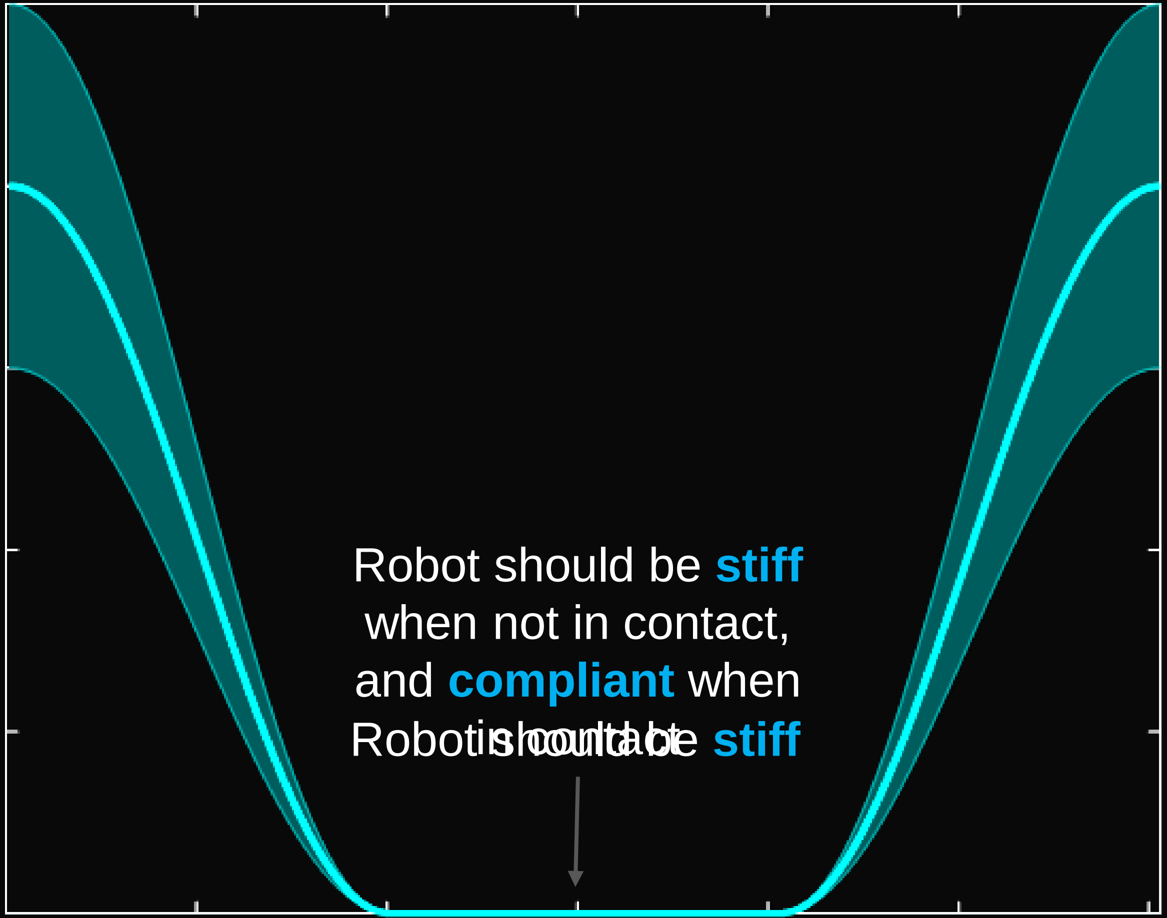
Learning by demonstration

Complexity of skill

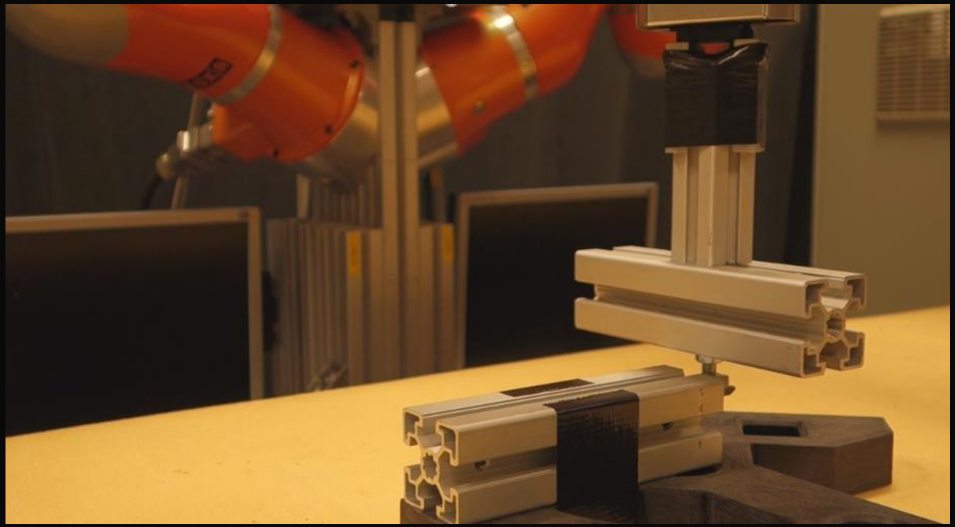
Acquisition of skill

How to transfer compliance?

- Path and standard deviation

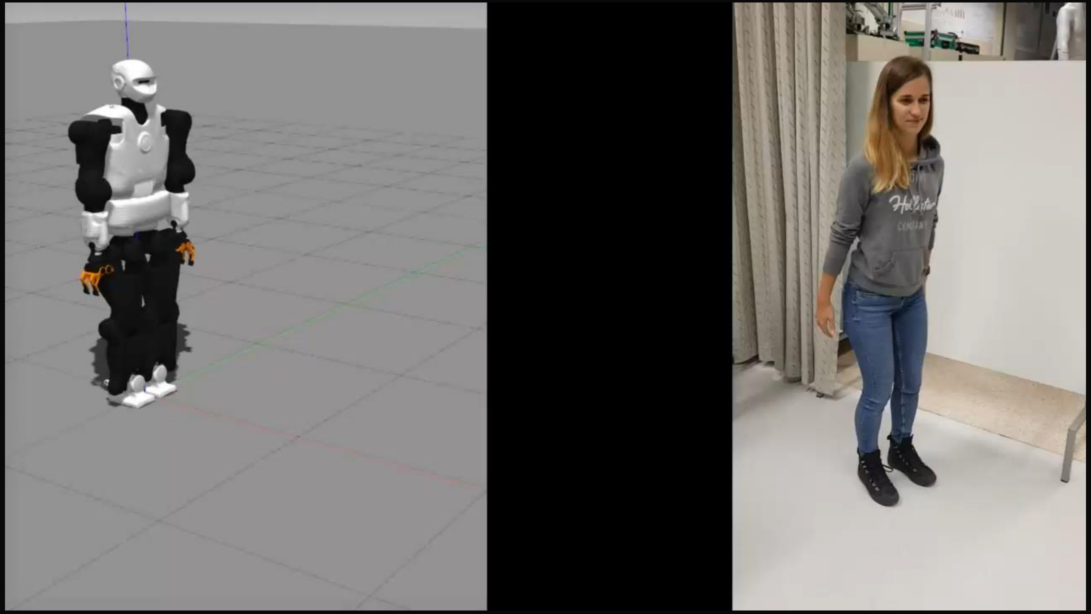


- When not in contact SD can be associated with robot compliance
- When the robot is in contact with environment we must use different strategy

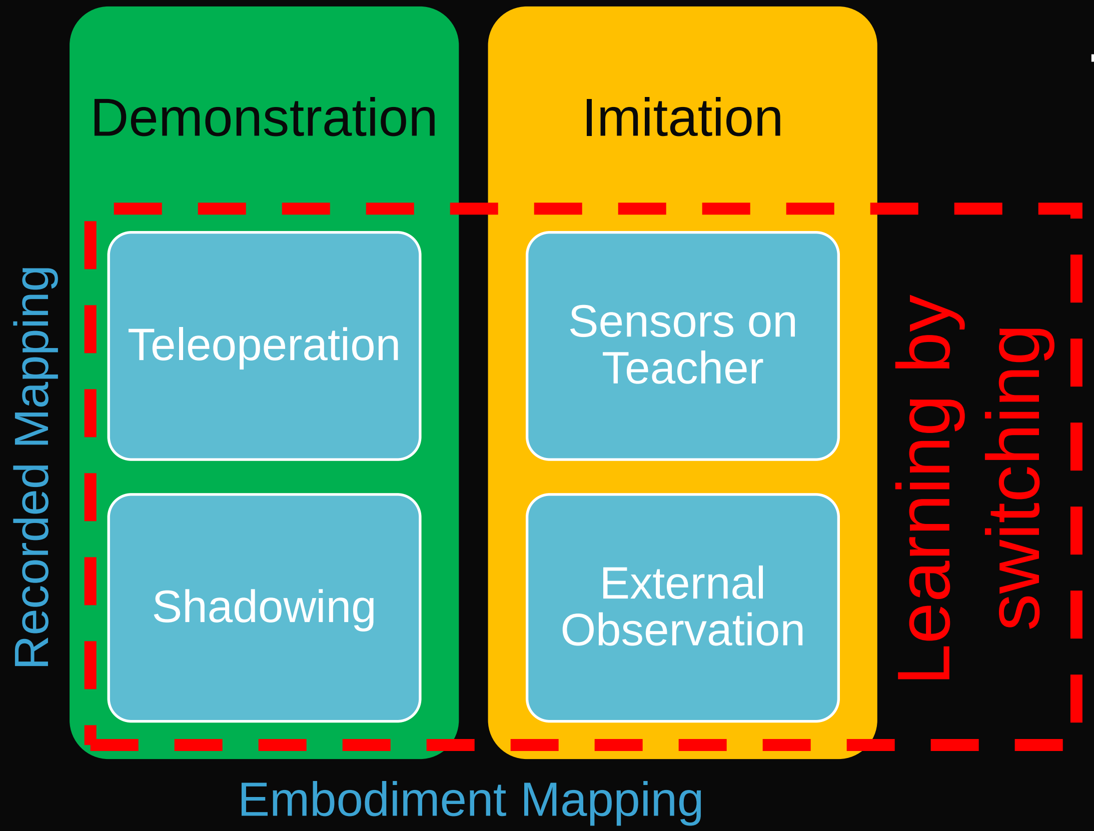


Dataset correspondence

- Because of differences in the teacher's sensors and actuators (human eyes, human joints) and the robot's sensors and actuators, a direct transfer of information from teacher to student is often difficult
- This issue, called **correspondence**, and can be broken down into two categories:
  - Record mapping: correspondence between teacher's actions and recorded data
  - Embodiment mapping: correspondence between recorded data and learner's execution



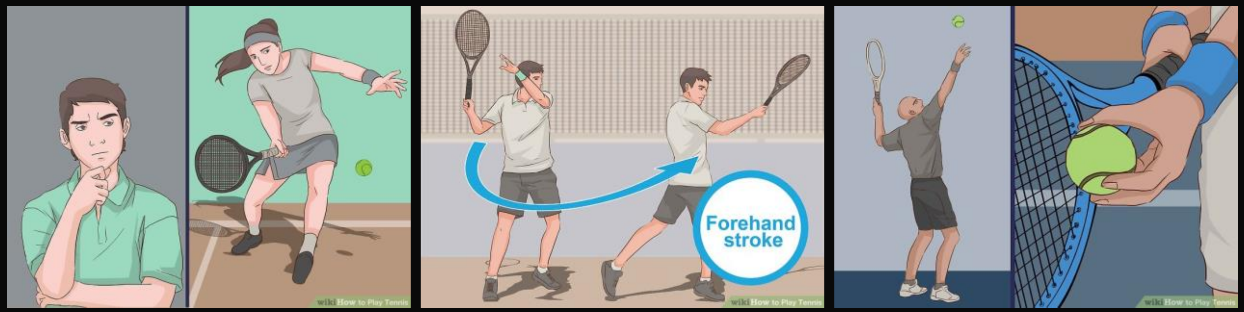
Acquired dataset with the recorded and the embodied mapping…



…enables:

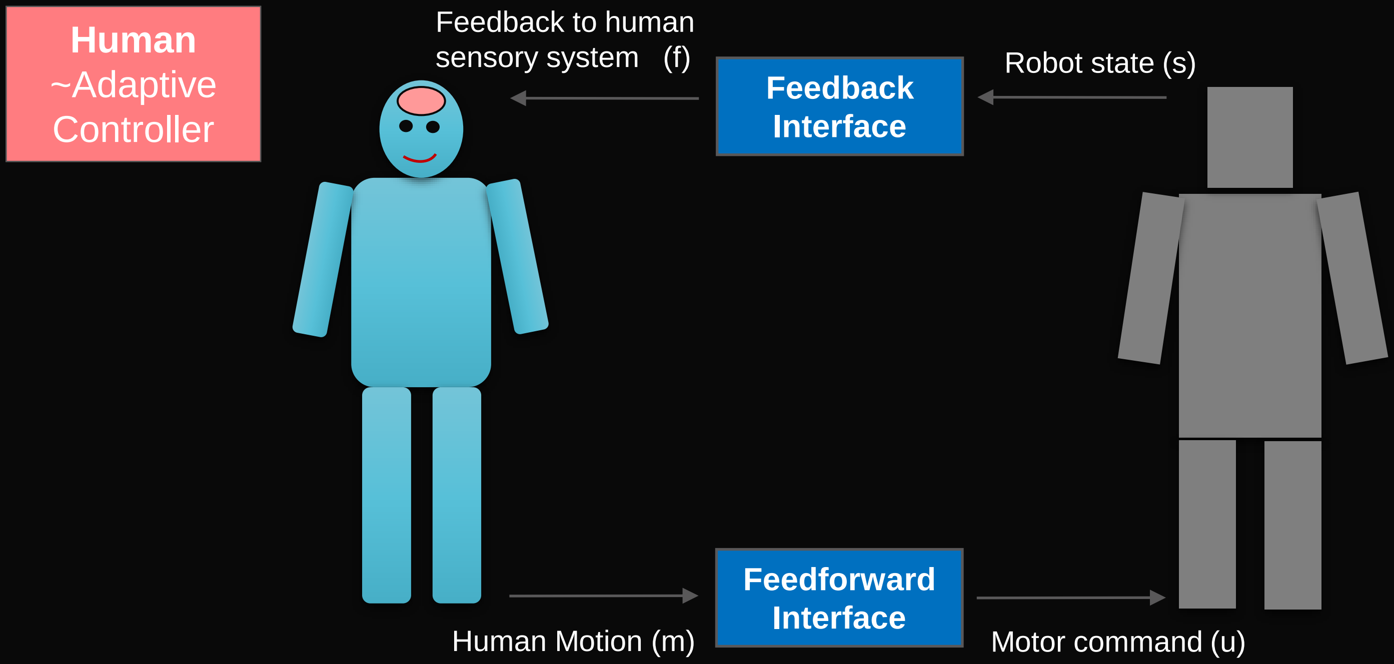
- Learning and control strategies for reactive behaviors
- Learning and control strategies for anticipative behaviors
- Subspace learning for physical collaboration

- Tennis example:

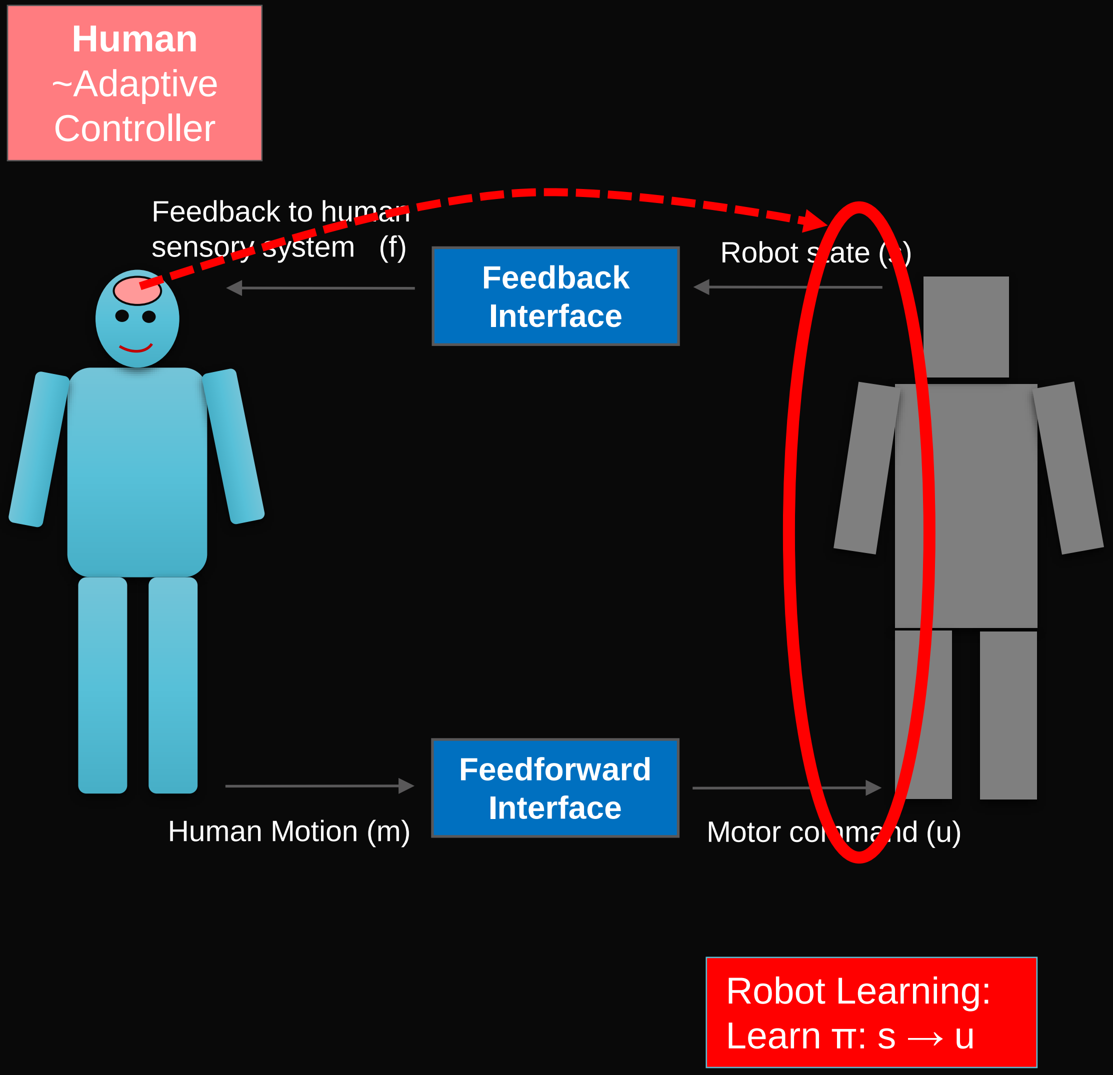


The paradigm

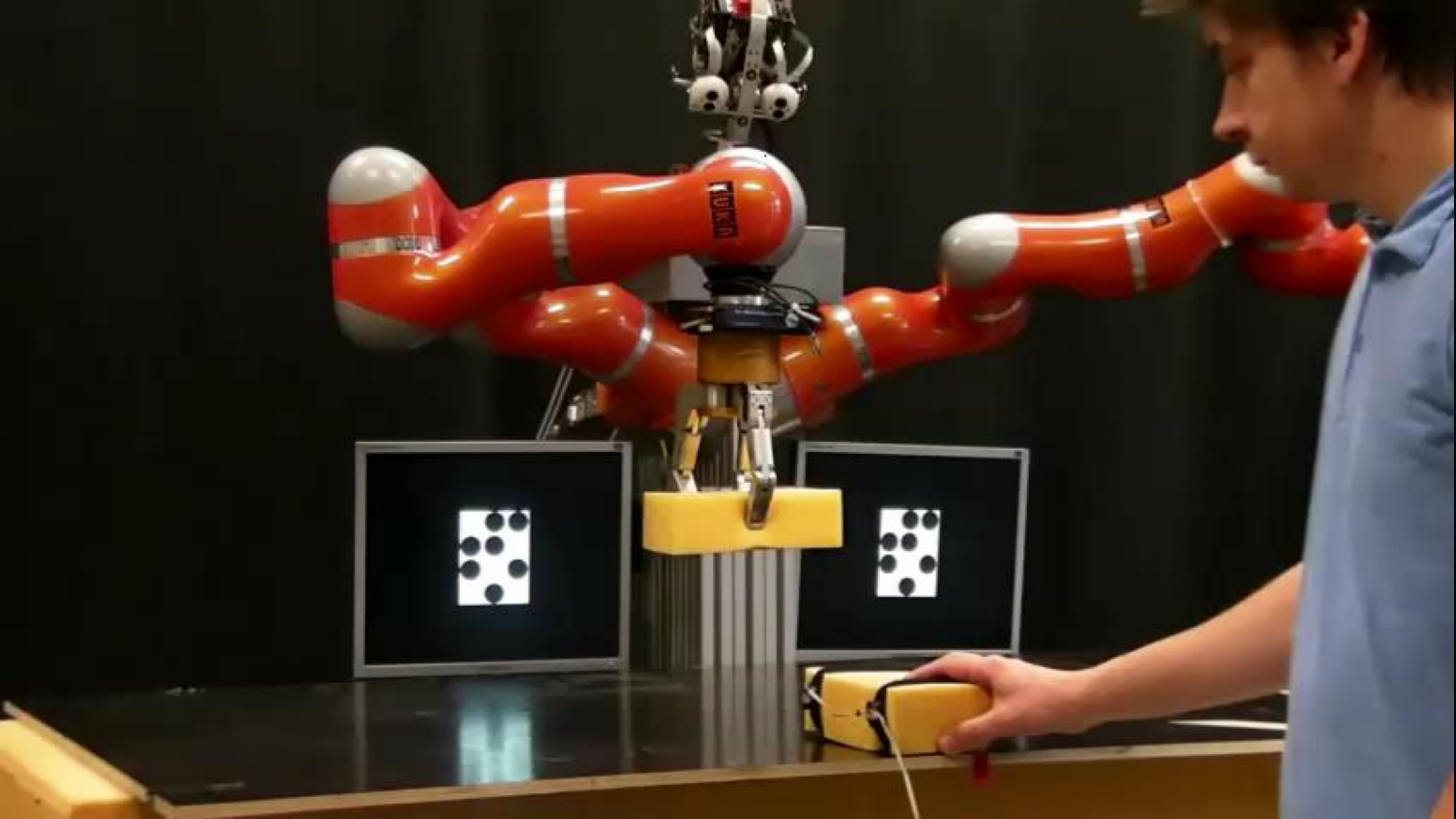
- Use human **sensorimotor learning** ability to obtain robot behaviors
  - Include the human in the control loop
  - May ask human to do extensive training
  - Utilize the human brain as the adaptive controller



Skill synthesis for autonomy

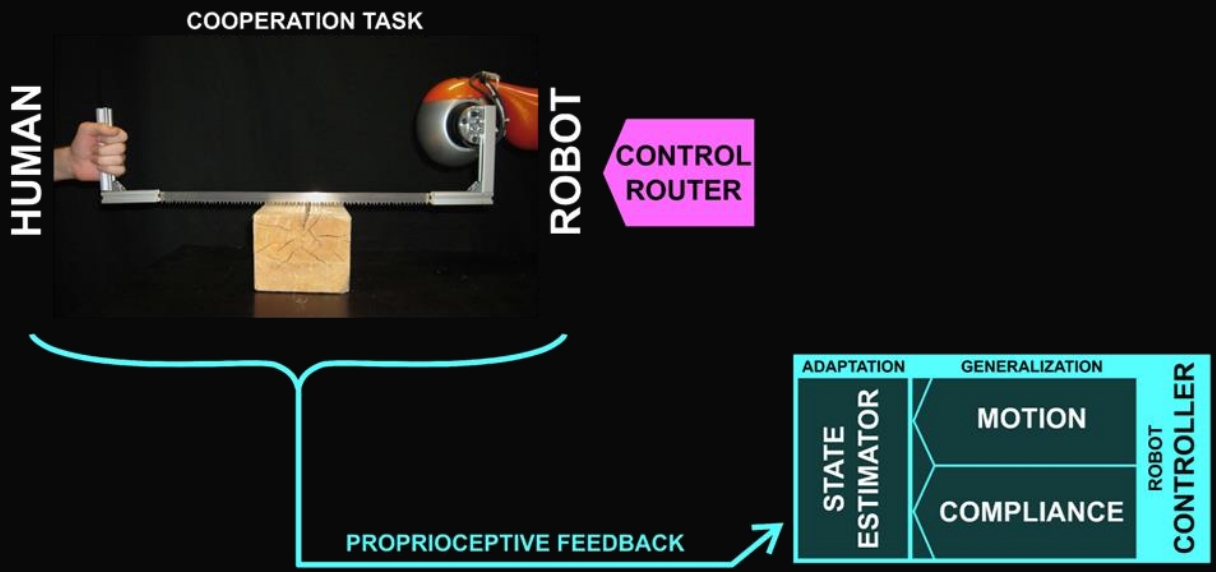


- Why should this paradigm work?
  - The ability of the brain to learn novel control tasks by forming **internal models**. The robot can be considered as a tool (e.g. as driving a car, playing an instrument, using chopsticks)
  - The flexibility of the **body schema**; extensive human training modifies the body schema so that the robot can be naturally controlled

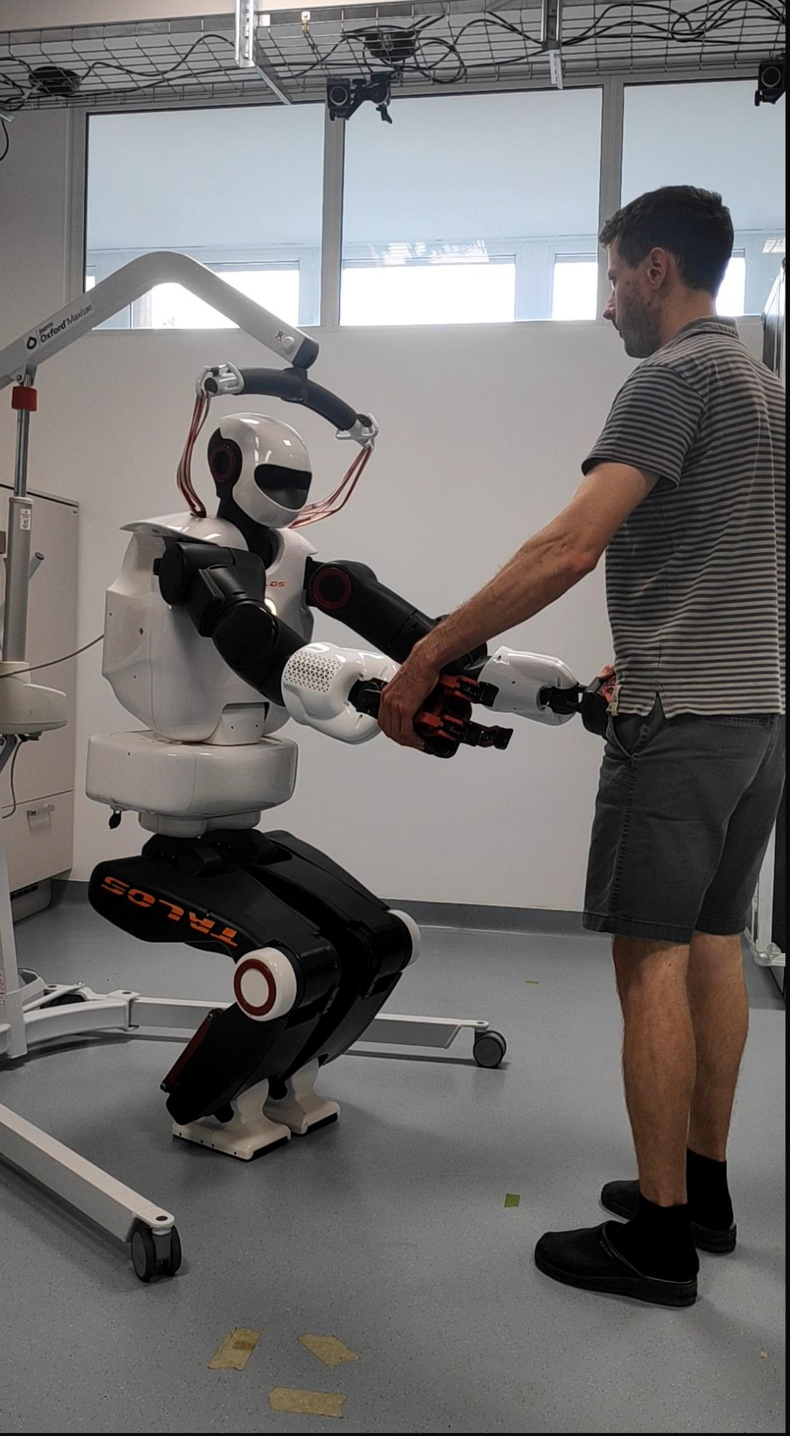


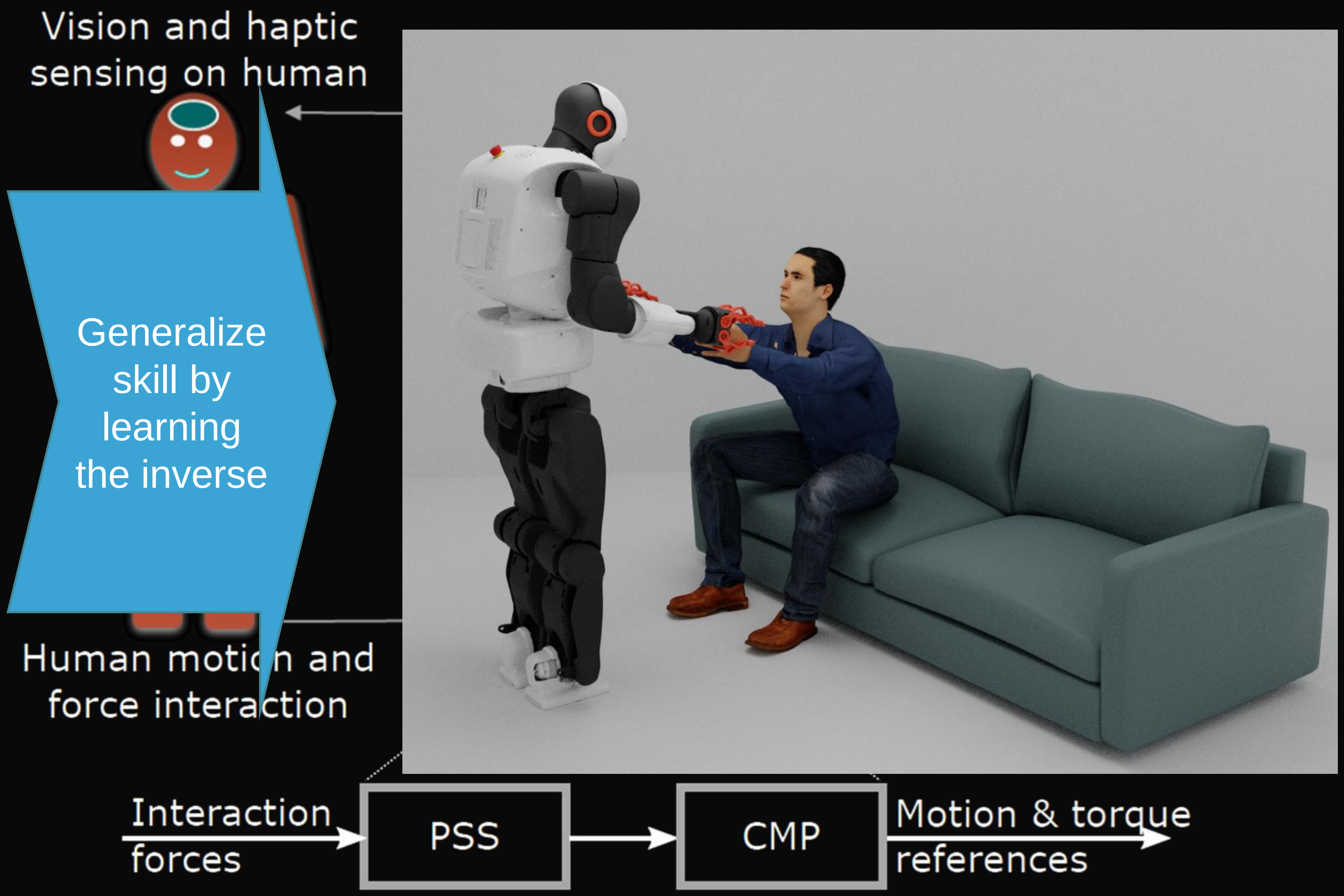
Cooperative dynamic manipulation

- Teach the robot to perform the manipulation tasks in collaboration with a human partner
- Online learning and adaptations
- Gradually transfer control responsibility from the human teacher to the autonomous robot controller



Stand-up example





Robot control for enhanced collaboration

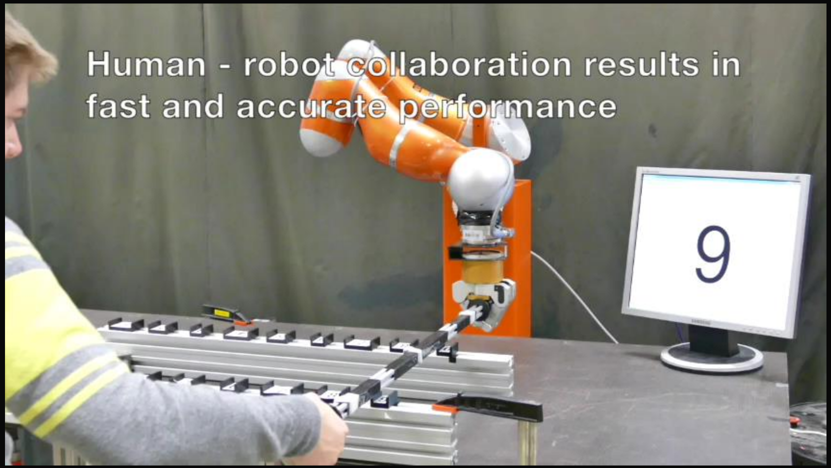
- Robots and humans collaborate in such a way as to enhance and emphasize the qualities of each other

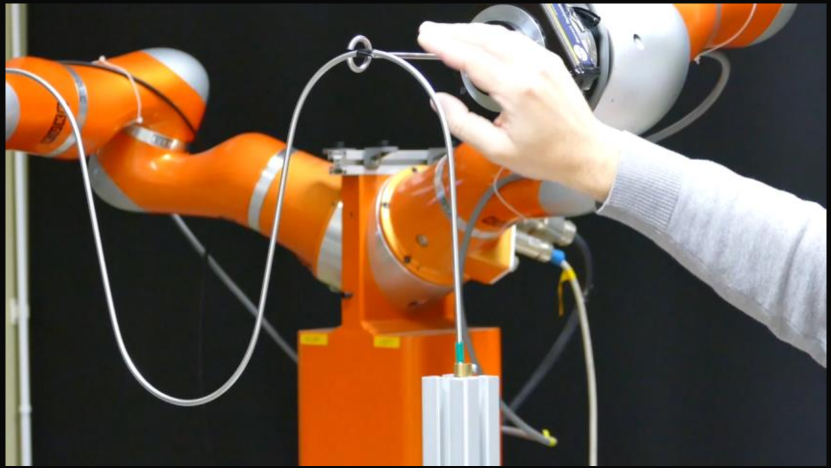
Robots gain:

- Workload
- Proprioception
- Cognition

Humans will:

- Improve speed-accuracy trade-off (Fitts' law)
- Extend the efficient workspace (Manipulability)
- Reduce the variability of motion (Virtual guides)





- **T. Petrič**, M. Cevzar, and J. Babič. "Utilizing speed-accuracy trade-off models for human-robot coadaptation during cooperative groove fitting task." *IEEE Humanoids 2017*
- **T. Petrič**, C.S. Simpson, A. Ude and A. J. Ijspeert, "Hammering Does Not Fit Fitts' Law." *Frontiers in computational neuroscience,* 2017
- **T. Petrič**, L. Peternel, J. Morimoto and J. Babič "Assistive Arm-Exoskeleton Control Based on Human Muscular Manipulability." Front. Neurorobot. 2019
- L. Žlajpah, and **T. Petrič**. "Unified Virtual Guides Framework for Path Tracking Tasks." *Robotica*, 2019

TAKE HOME MESSAGE

Neuromechanical modeling is a powerful tool that can be successfully used as the underlying basis for control of collaborative robots.