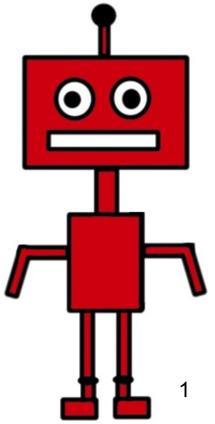
# Human-Robot Collaboration

Stefanie Tellex

BROWN



# Collaborators

Image of the members of the Human-Robot Collaboration removed due to copyright restrictions. Please see the video.

# Human-Robot Collaboration

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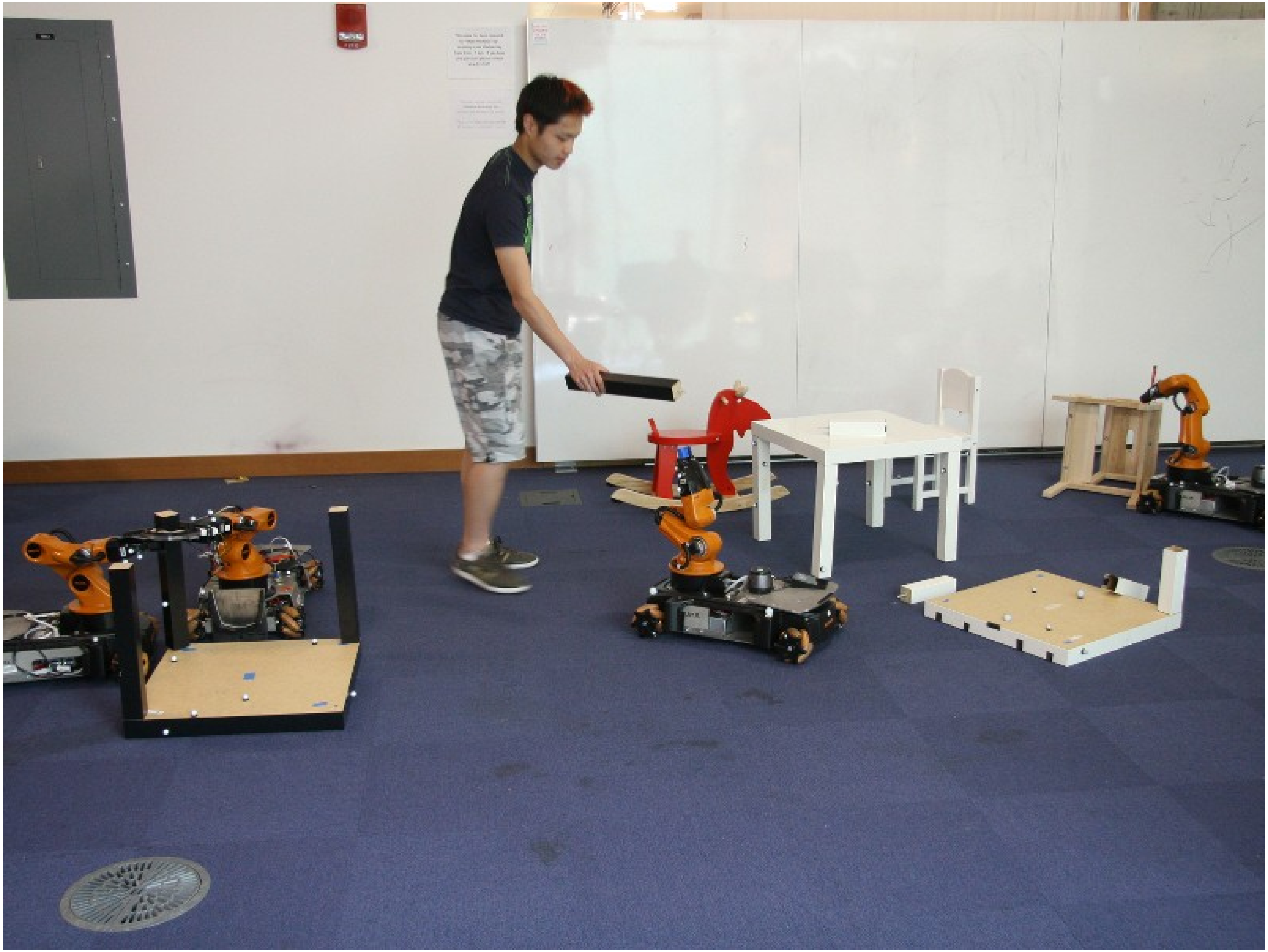

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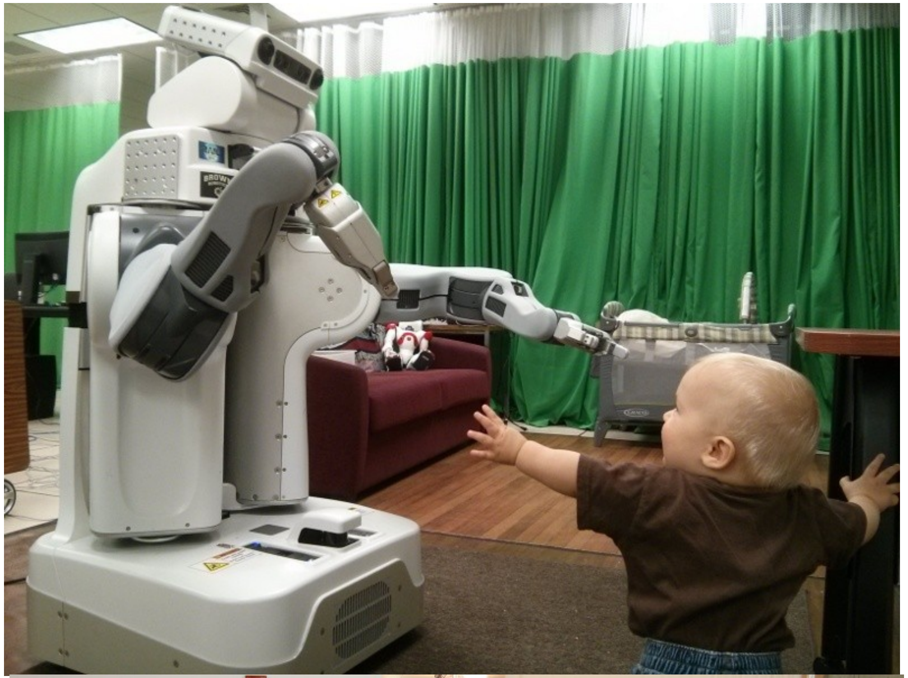
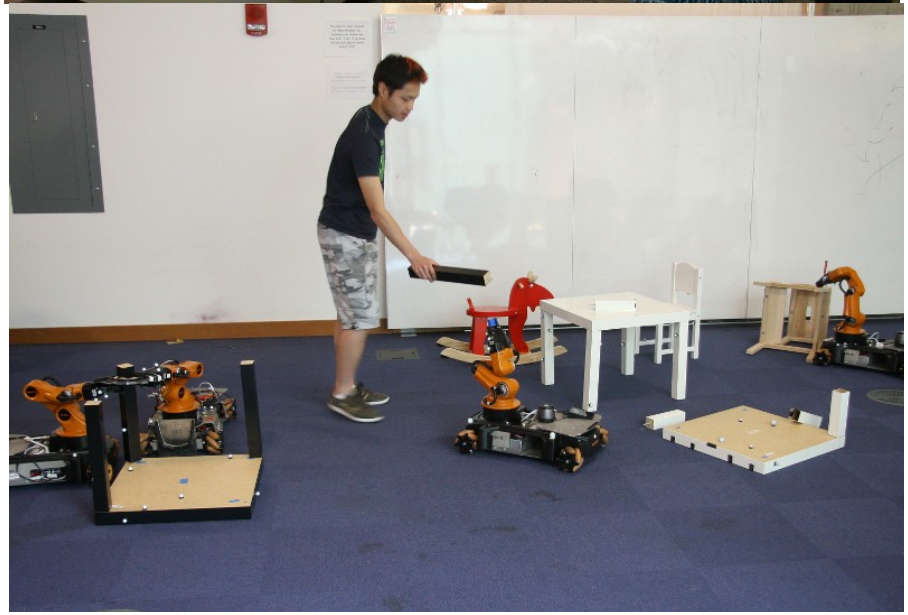
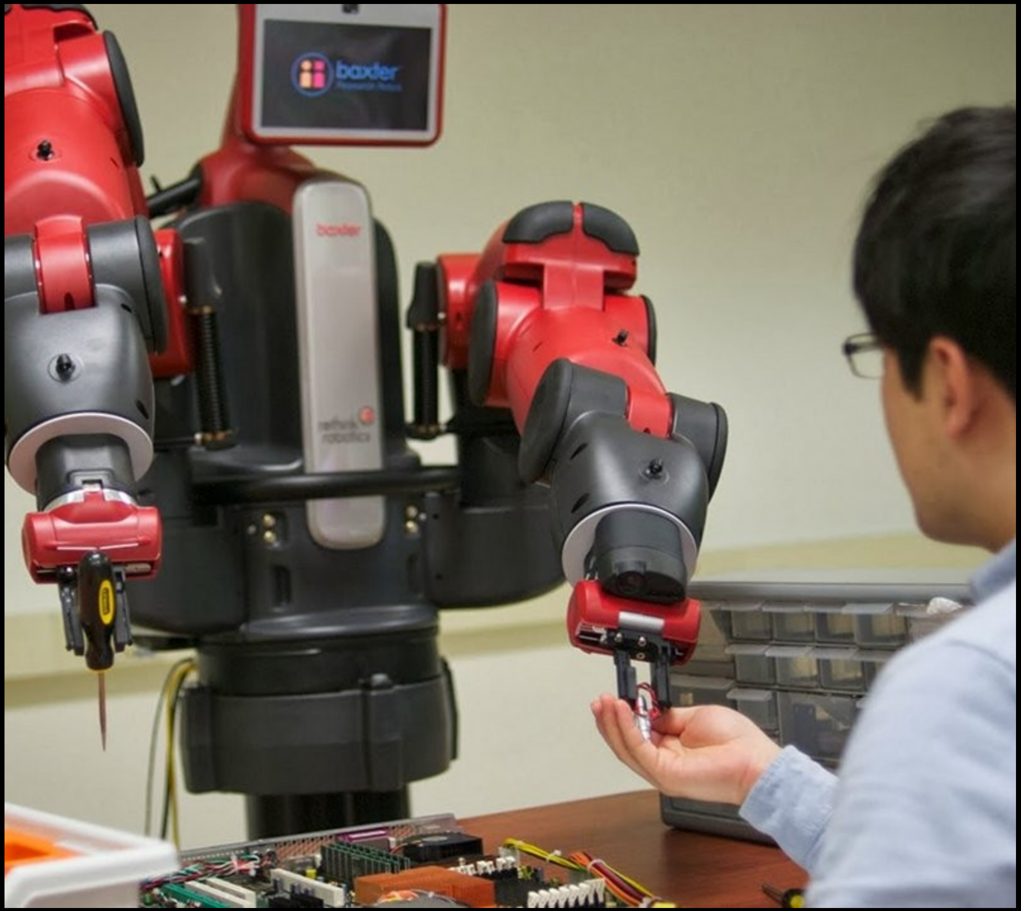




# Human-Robot Collaboration

- Robots that robustly perform actions in real-world environments.
- Robots that carry out complex sequences of actions.
- Robots that actively coordinate with people, establishing a social feedback loop.

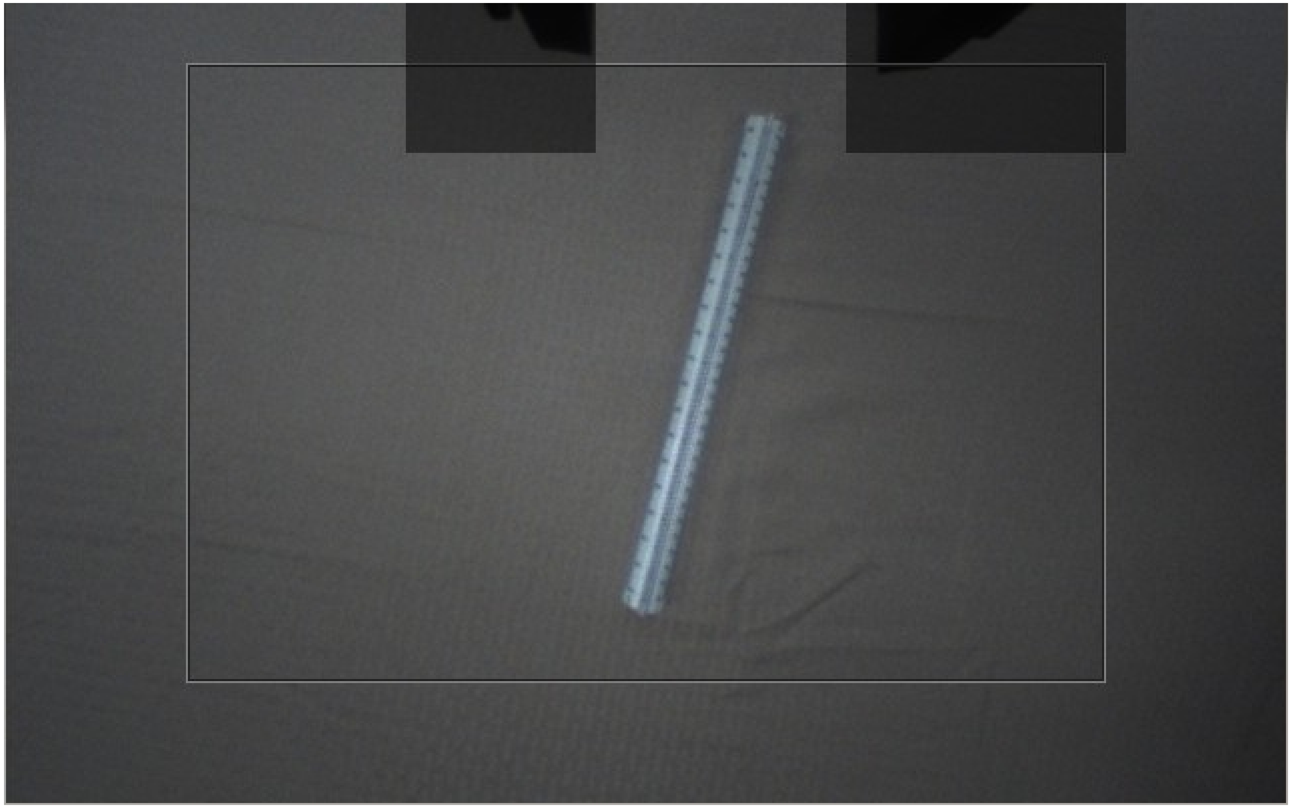
# Mapping Objects for Robust Pick and Place




# Mapping Objects for Robust Pick and Place

- What it is.

# Mapping Objects for Robust Pick and Place



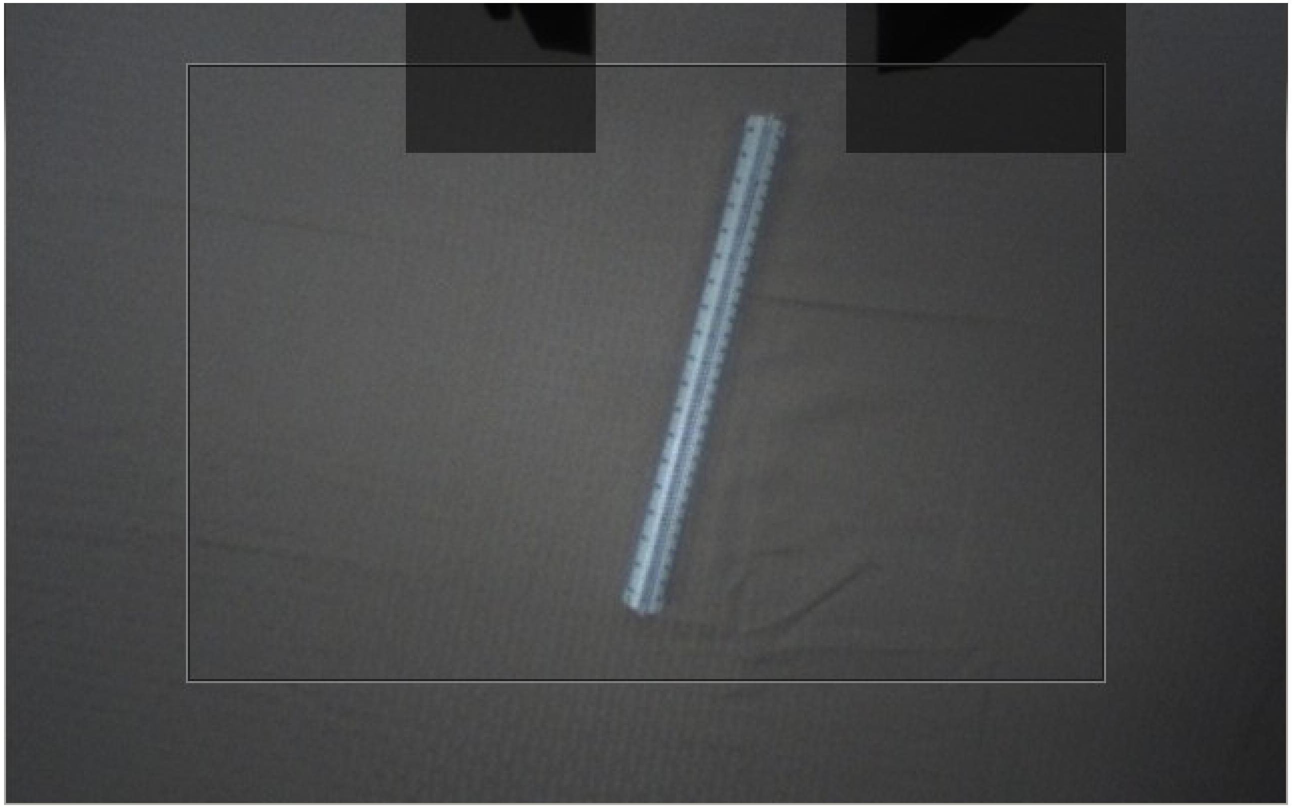
Courtesy of John Oberlin and Stefanie Tellex. Used with permission.

Ruler

# Mapping Objects for Robust Pick and Place

- What it is.
- Where it is.

# Mapping Objects for Robust Pick and Place





Ruler

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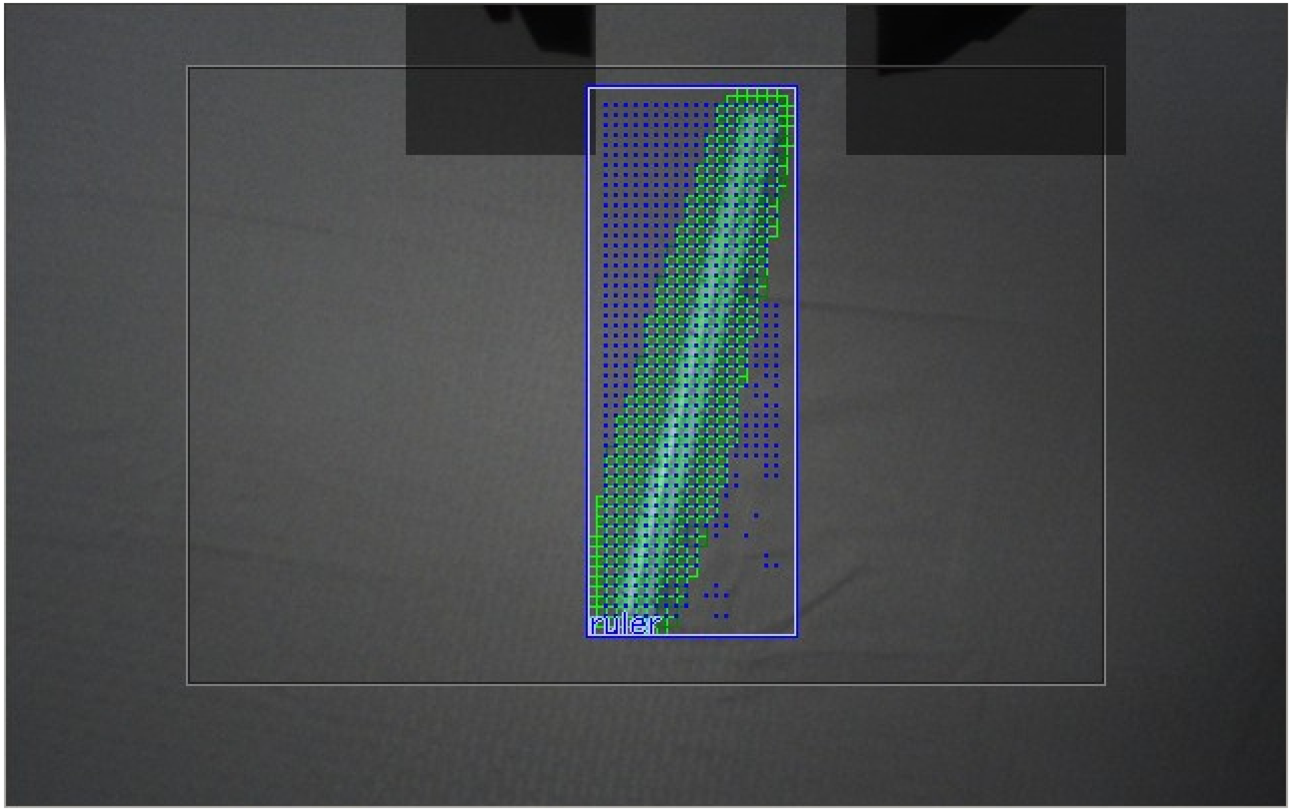


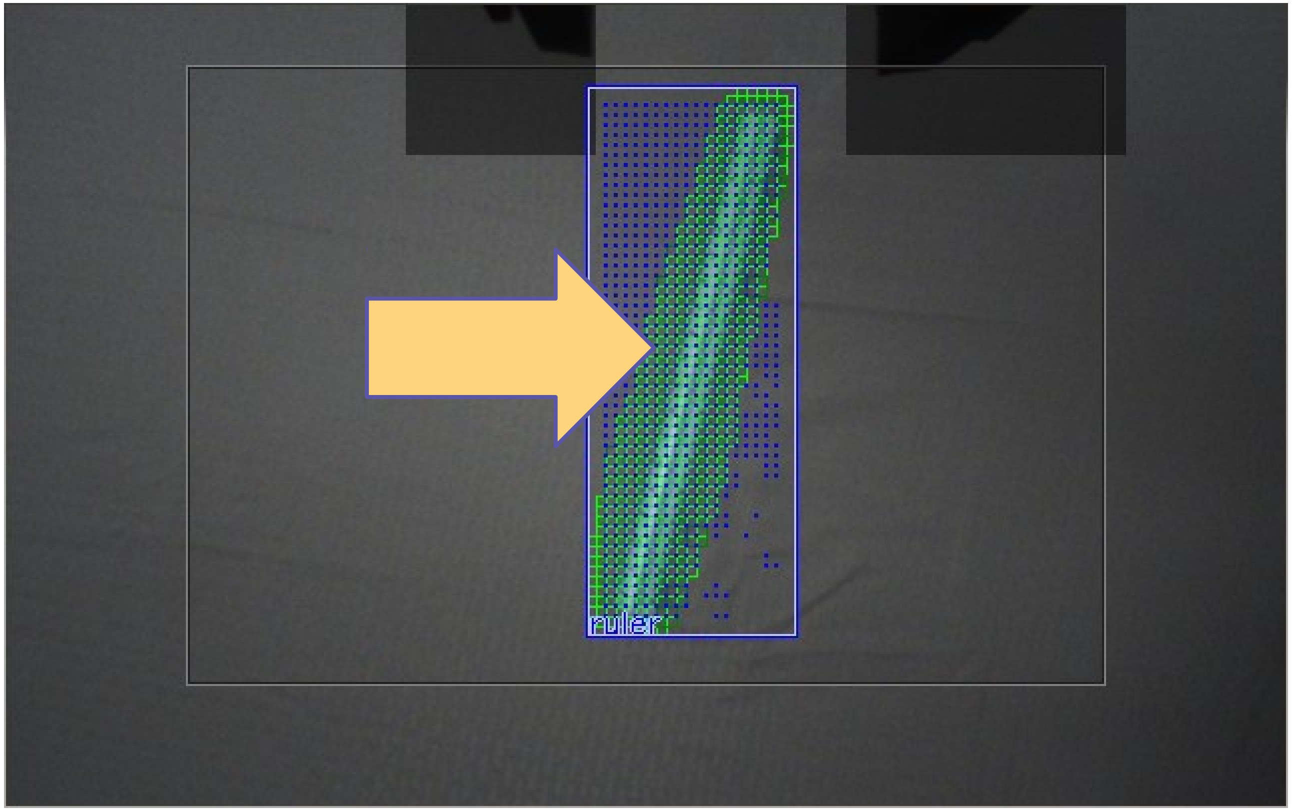



Ruler

# Mapping Objects for Robust Pick and Place

- What it is.
- Where it is.
- Where to put the gripper.

# Mapping Objects for Robust Pick and Place




Courtesy of John Oberlin and Stefanie Tellex. Used with permission.

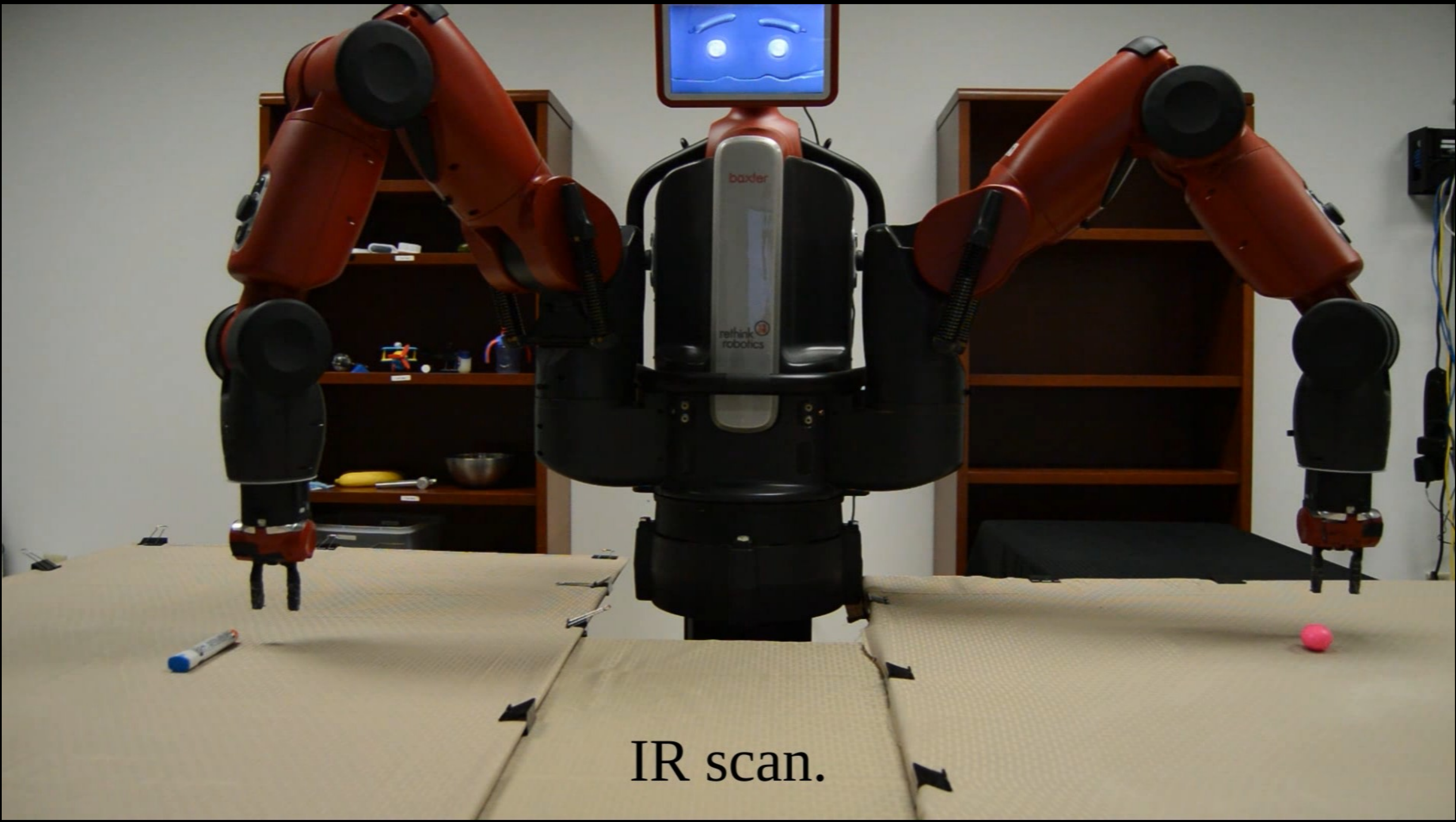
Ruler

# Conventional Approaches

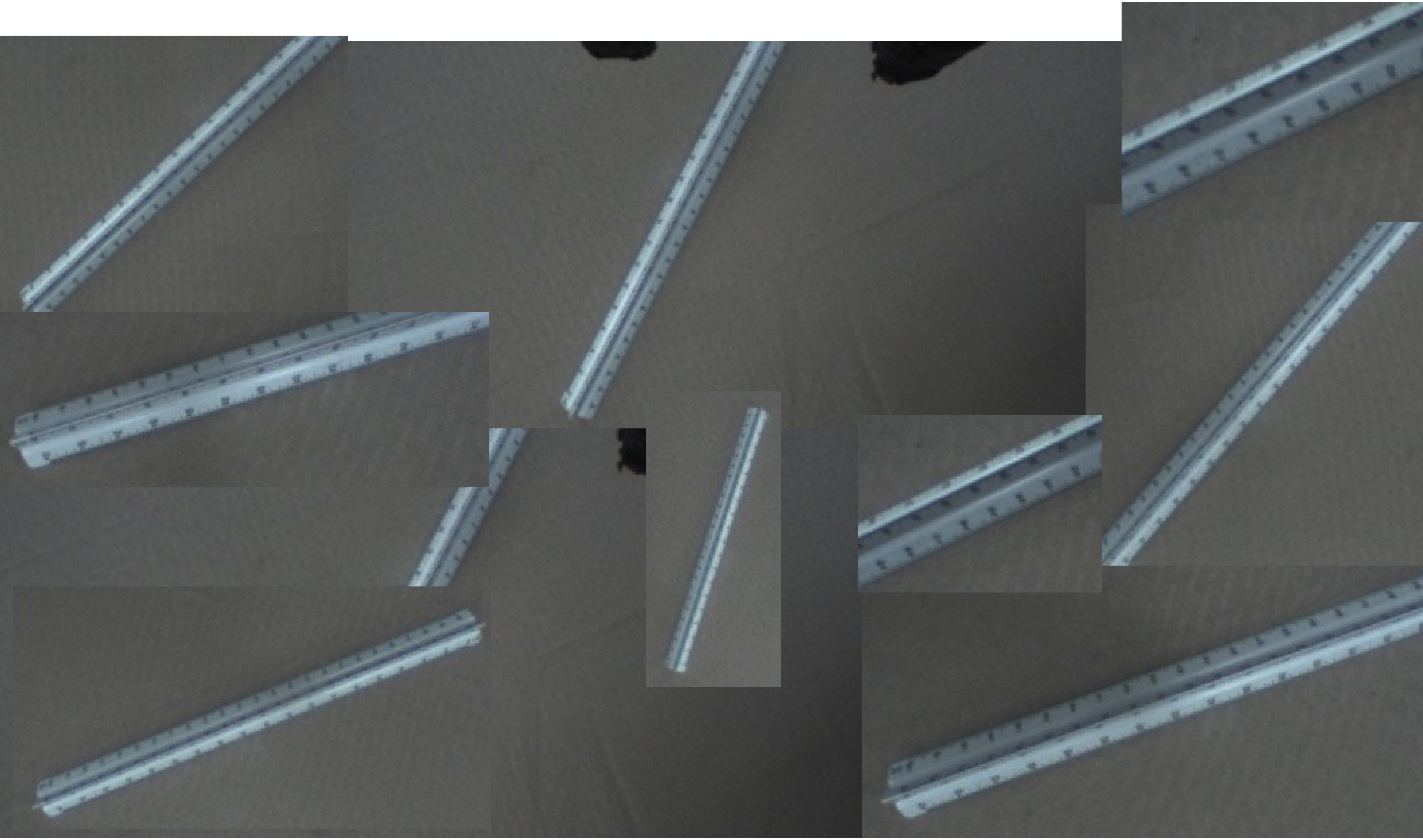
- Category-based grasping (Saxena et al. 2008)
  - Automatically infer object category and grasp points from sensor information.
  - Does not work well on novel objects.
- Instance-based grasping
  - Manually collect images and annotate grasps.
  - Highly accurate if you have enough data.

# Autonomously Collecting Data

The contribution of this work is an approach that enables a robot to autonomously collect the data that it needs to robustly manipulate objects.


baxter
rethink robotics
IR scan.

# RGB Images



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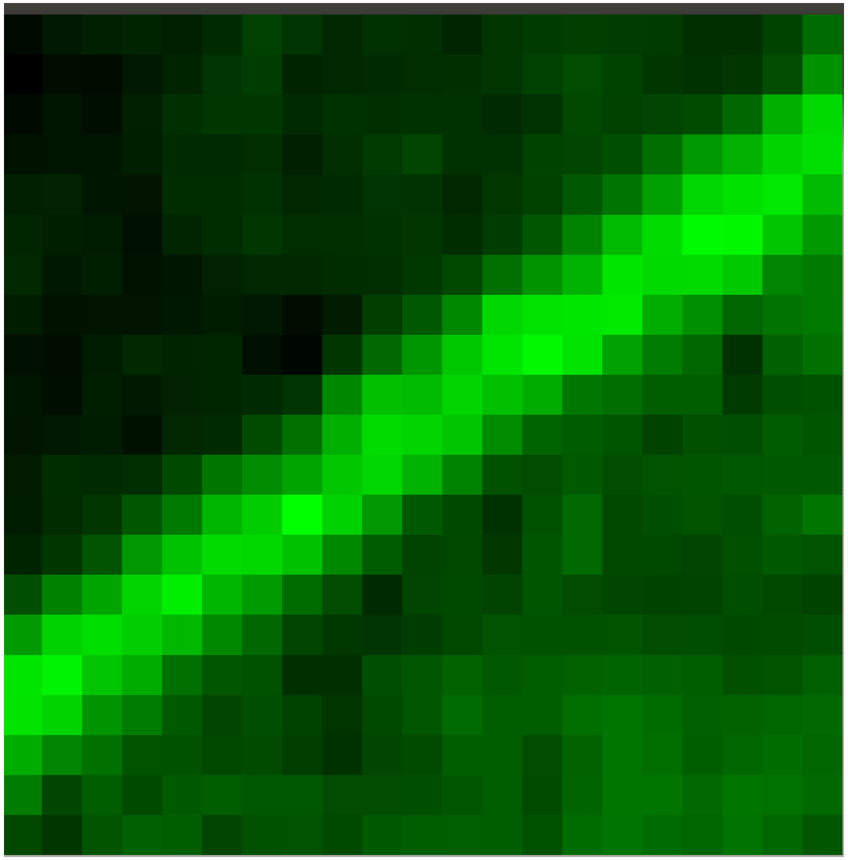
# Raster IR Scan



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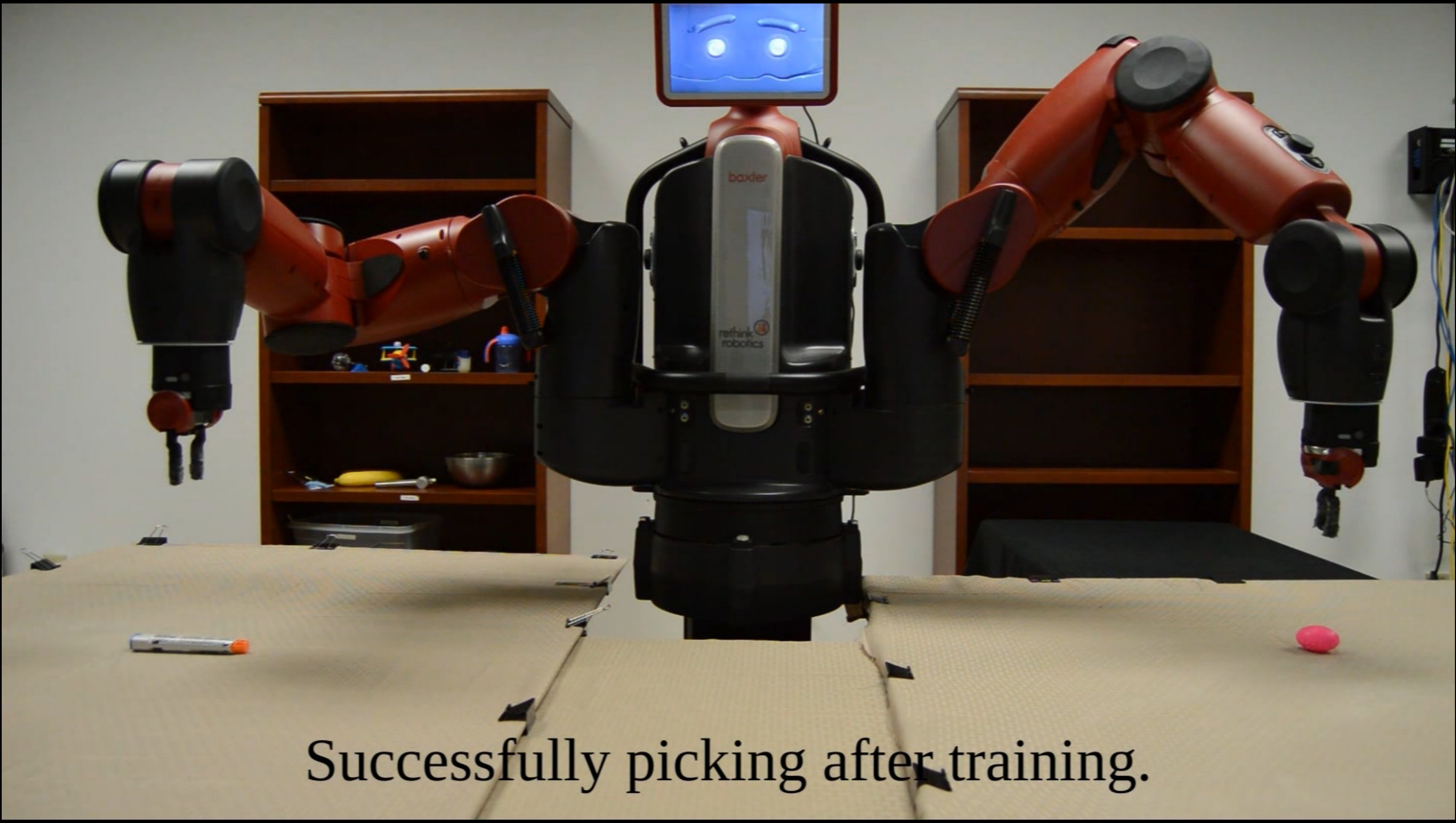
# Grasping After Acquiring Models



# Robust Pick and Place

# Before Training

# How can the robot learn to grasp challenging objects?

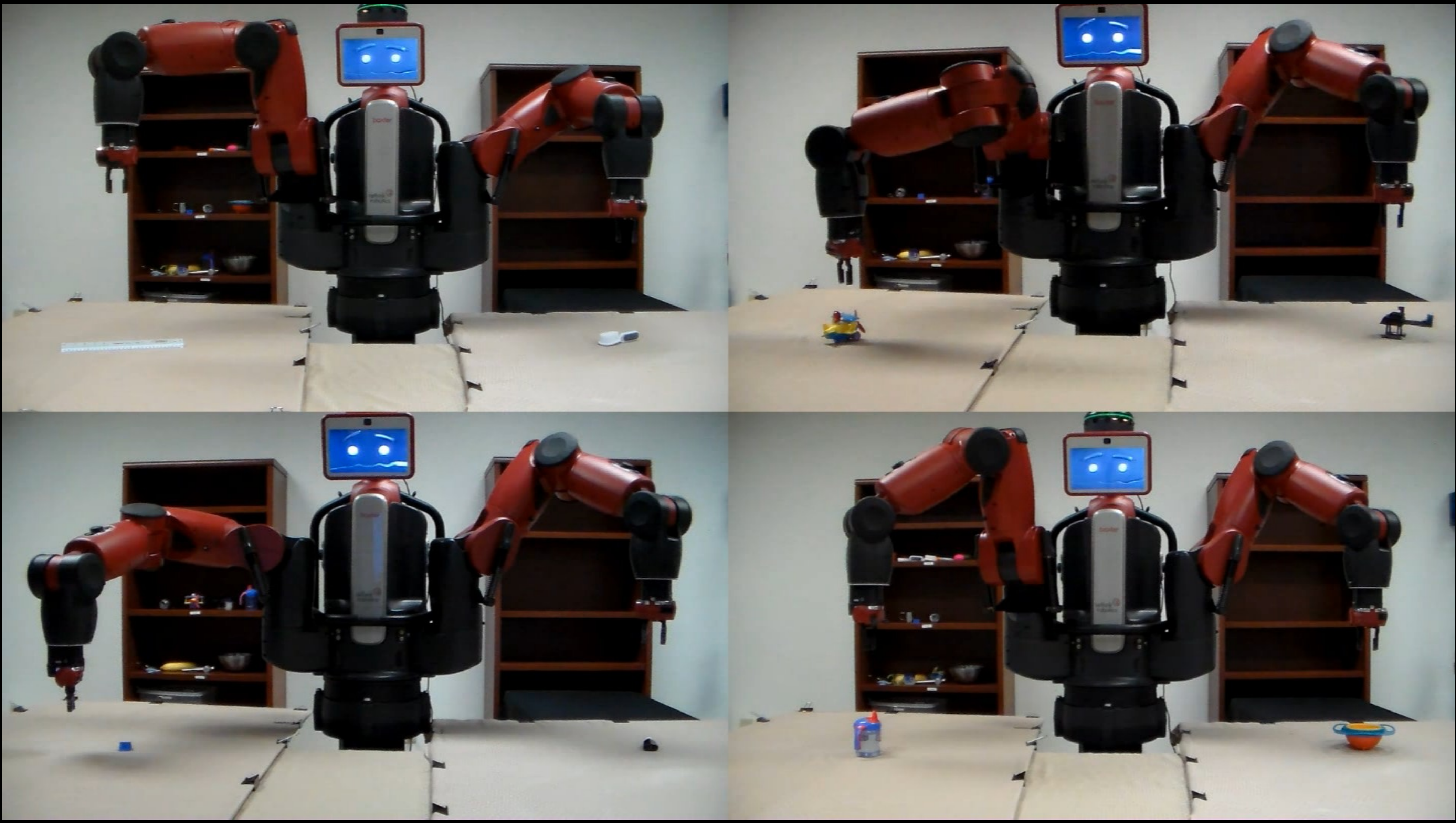
- Physical dynamics, such as the ruler twisting out of the gripper.
- Objects that are poorly visible in IR.

# N-armed Bandit

- Each grasp point and orientation is an arm with an unknown payout probability, $\mu$.
  - 1cmx1cm grid plus four orientations.
  - 1764 arms
- Best Arm Identification:
  - Given a budget of training trails, find the best arm as quickly as possible.

Oberlin and Tellex. (2015). ISRR.

# After Training

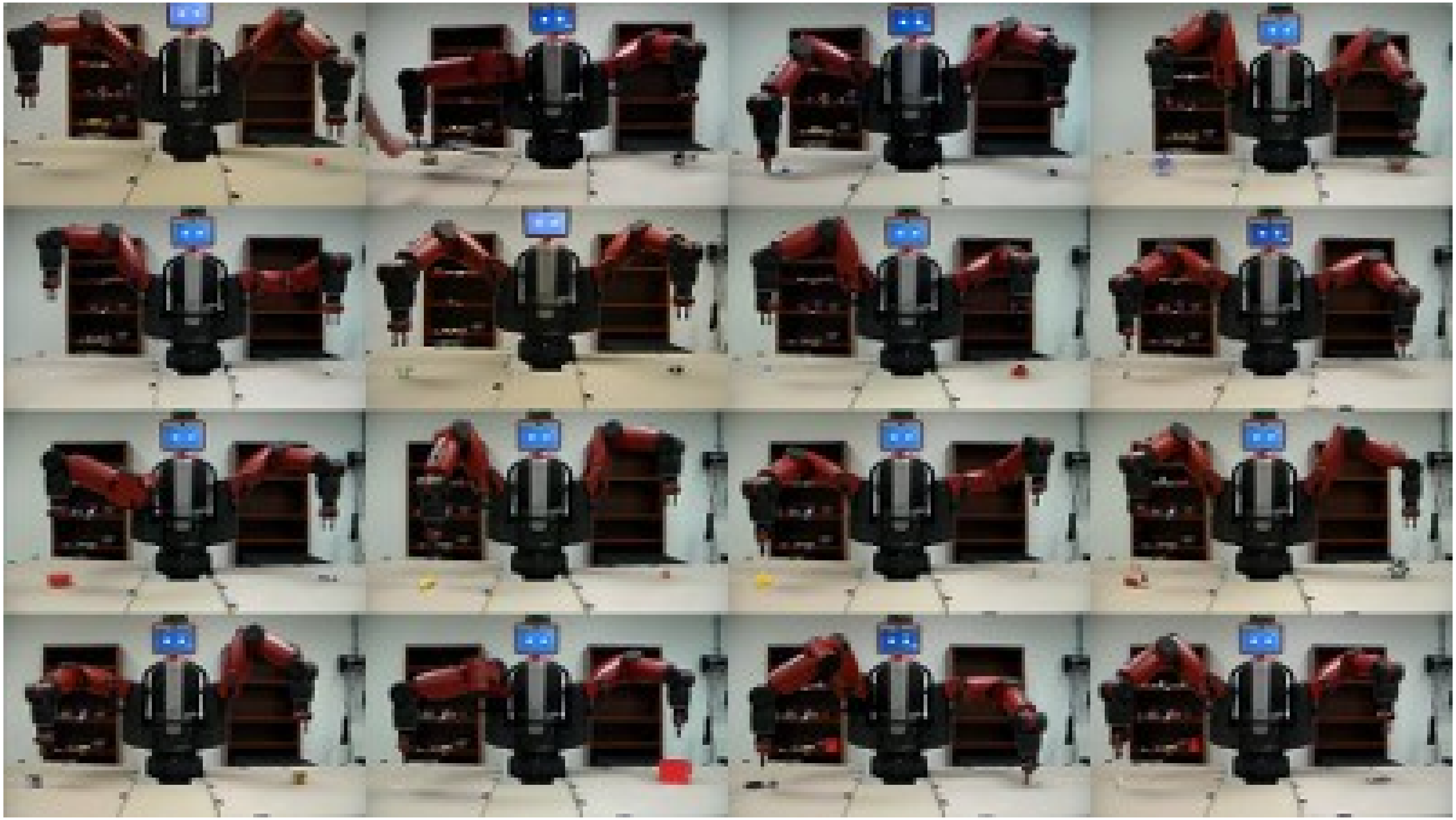


# Results

Before learning: 165 picks of 300 tries (50%)
After learning: 224 picks of 300 tries (75%)

# Baxter

~300 Research SDK Baxters sold
(compared to 50 PR2s)



Courtesy of Association for the Advancement of Artificial Intelligence. Used with permission.

# Million Object Challenge

MIT (Daniela Rus, Bianca Homberg)


Yale (Brian Scassellati, Brad Hayes)

Next: Rethink (tomorrow!), WPI, you?

Oberlin et al. (2015). Blue Sky Award at the RSS Shakey workshop

# Human-Robot Collaboration

- Robots that robustly perform actions in real-world environments.
- Robots that carry out complex sequences of actions.
- Robots that actively coordinate with people, establishing a social feedback loop.

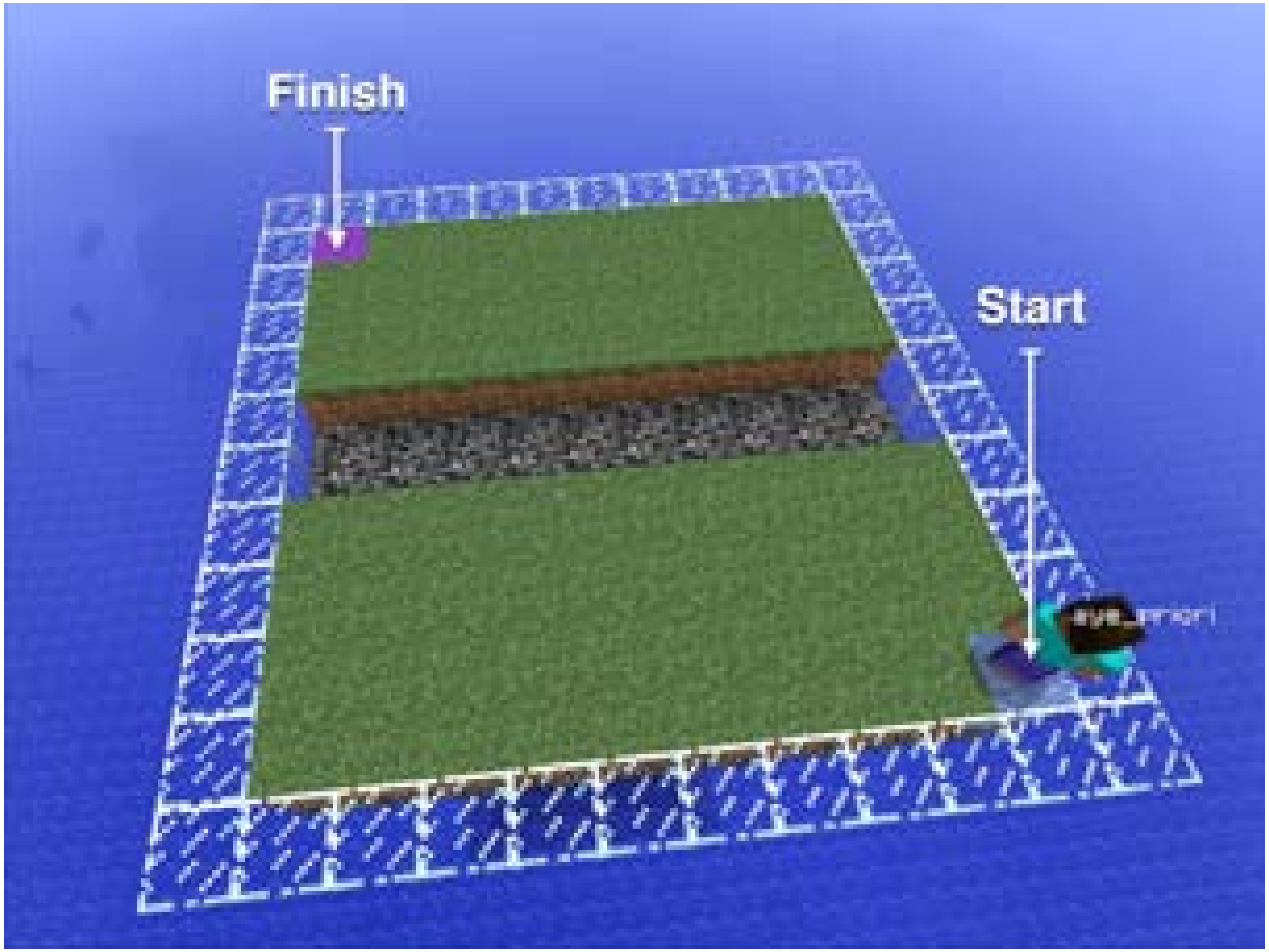

Put the pallet on the truck.
MIT
MIT
CSAIL
BAE SYSTEMS
TOYOTA
TOYOTA
MIT

# How to Pick Up a Dime with a Forklift



"Raise the forks 12 inches. Line up either fork in front of the dime. Tilt the forks forward 15 degrees. Pull the truck forward until one fork is directly over the dime. Completely lower the forks. Put the truck in reverse and gently travel backward a foot. The dime will flip up backwards onto the fork. Level the forks back to 90 degrees. Raise the dime with the forks 12 inches."

# Bridge Problems



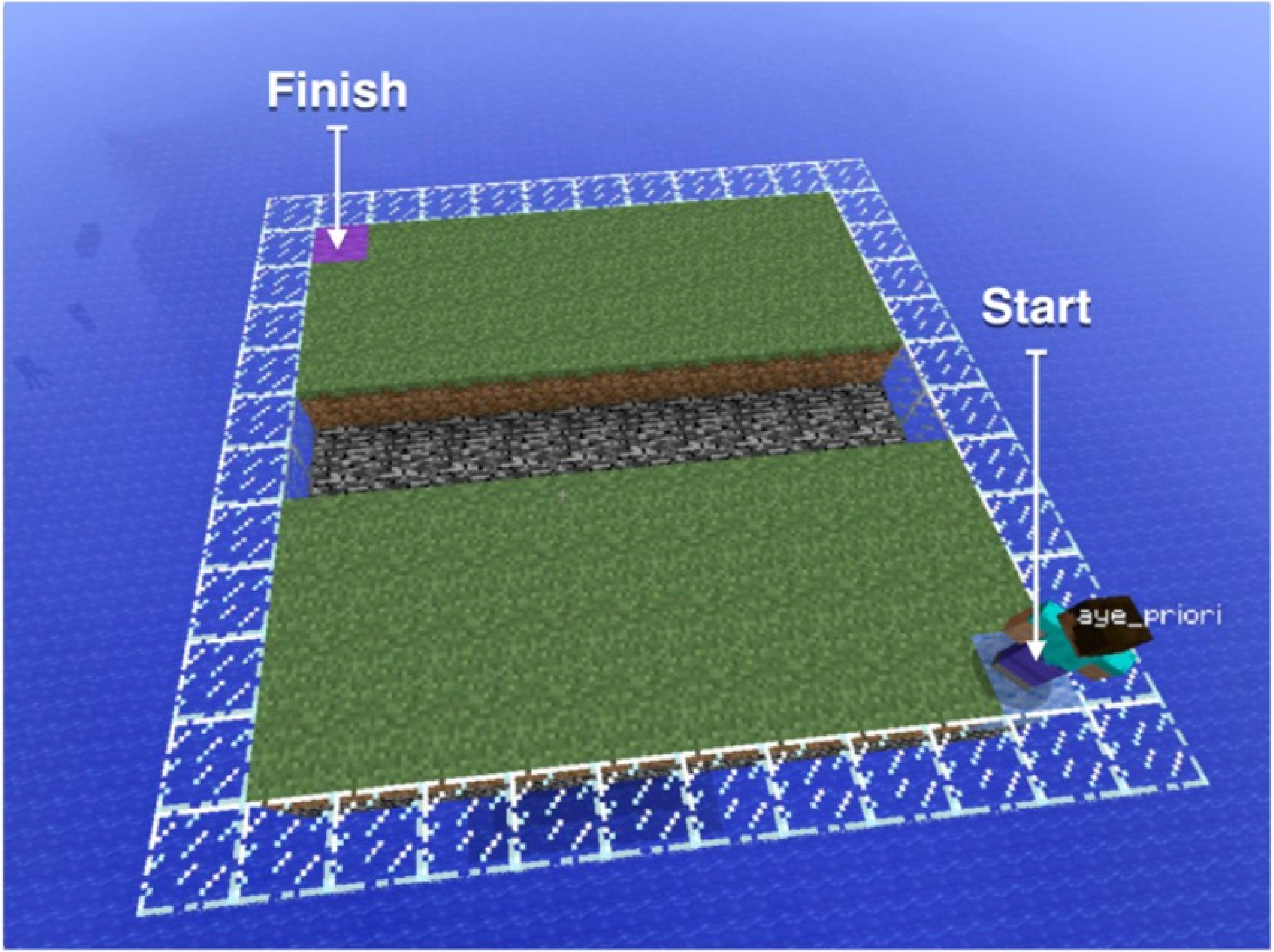



ACTIONS

- Move
- Place
- Destroy
- Use
- Jump
- Rotate
- Look
- Craft
- …

*≈ State Space Size: millions-billions*

# Bridge Problems



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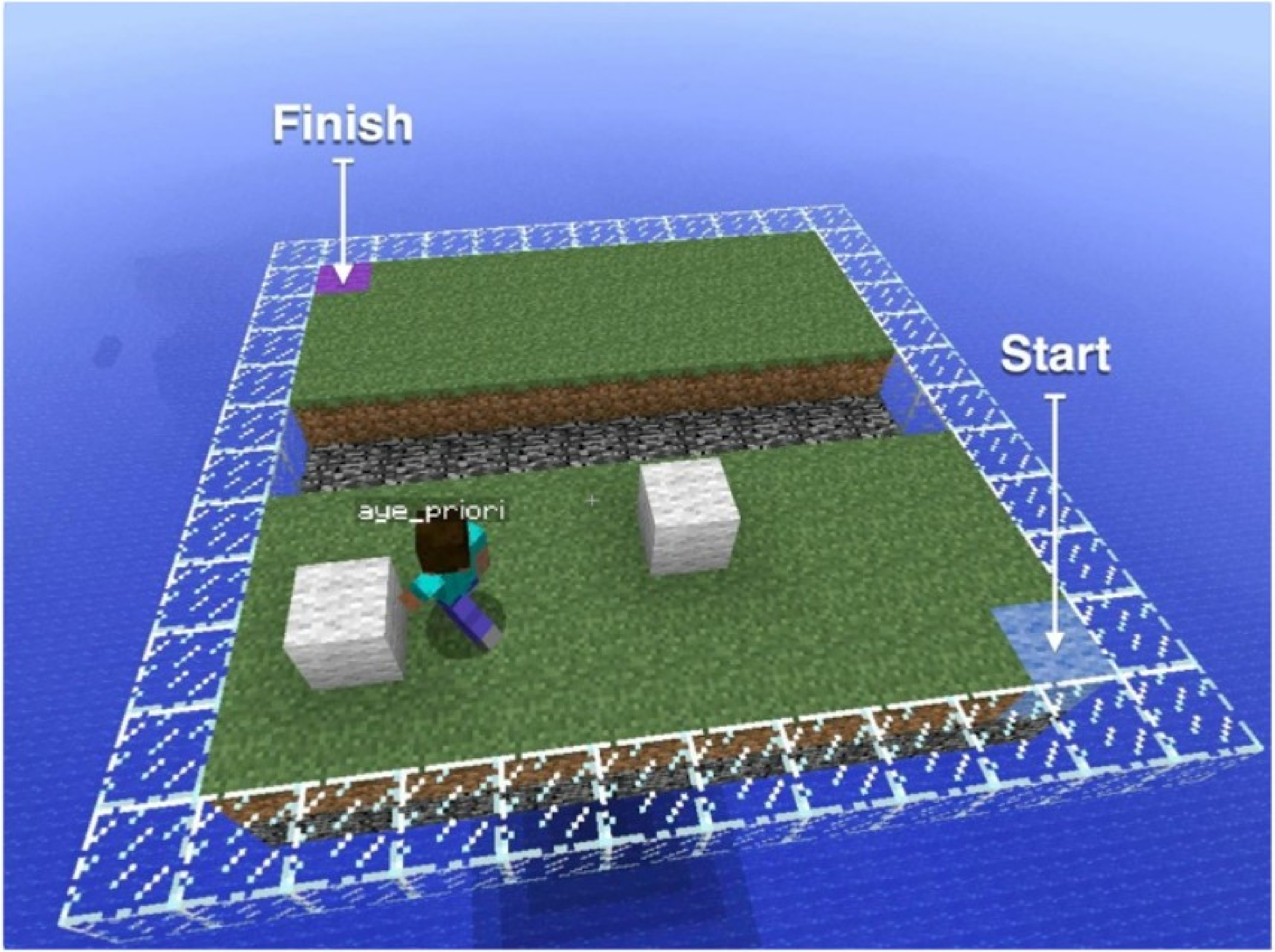
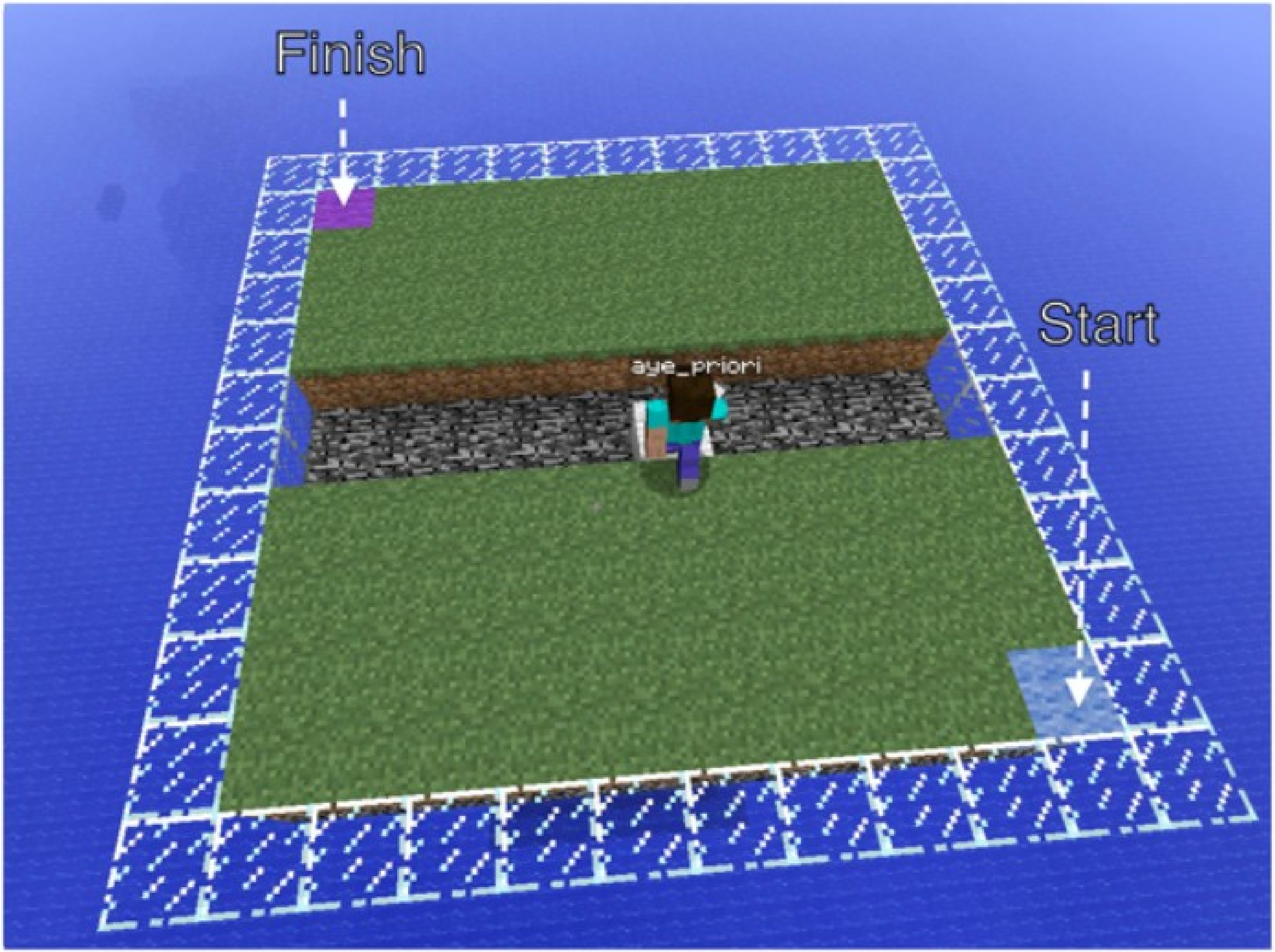
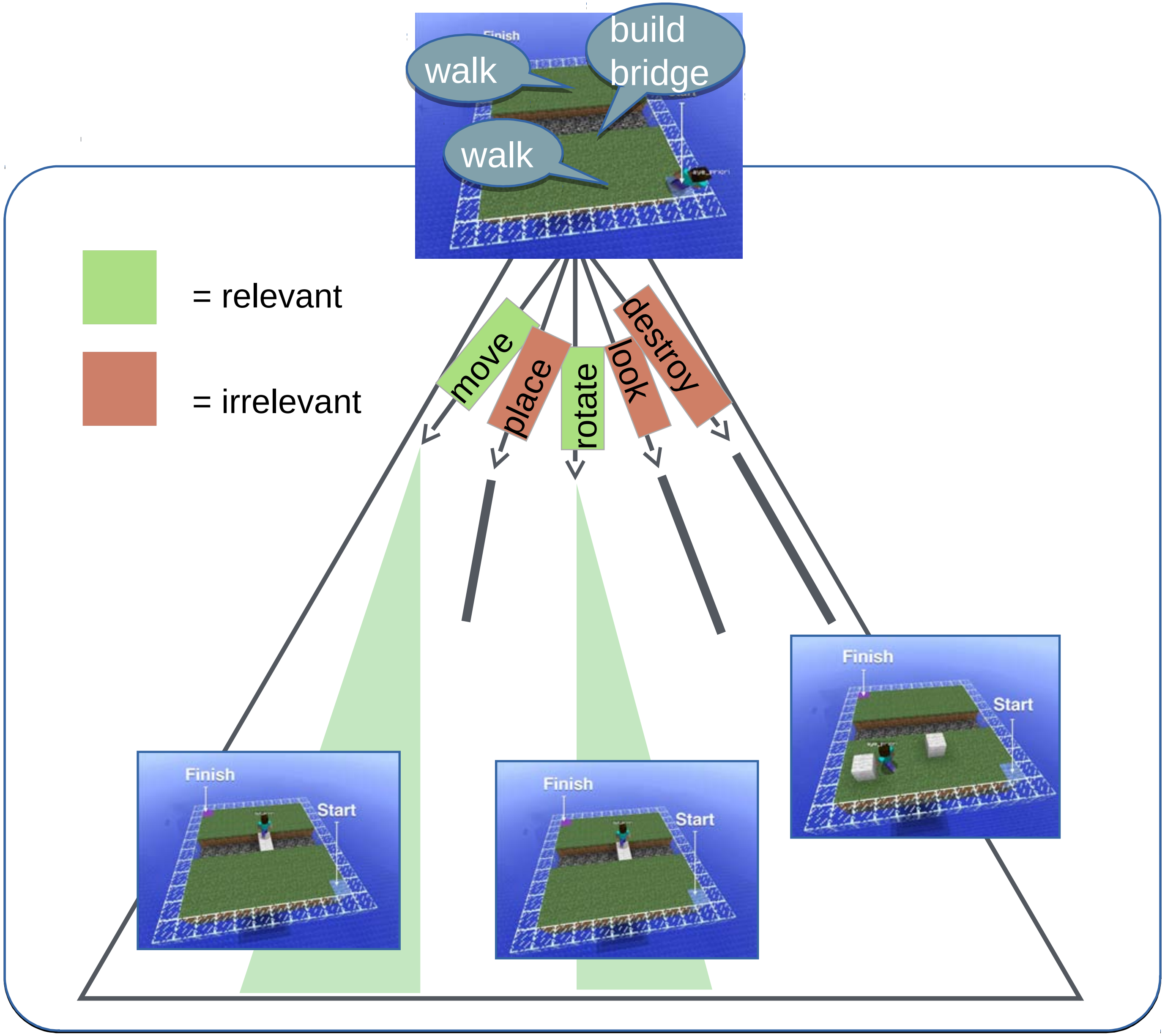


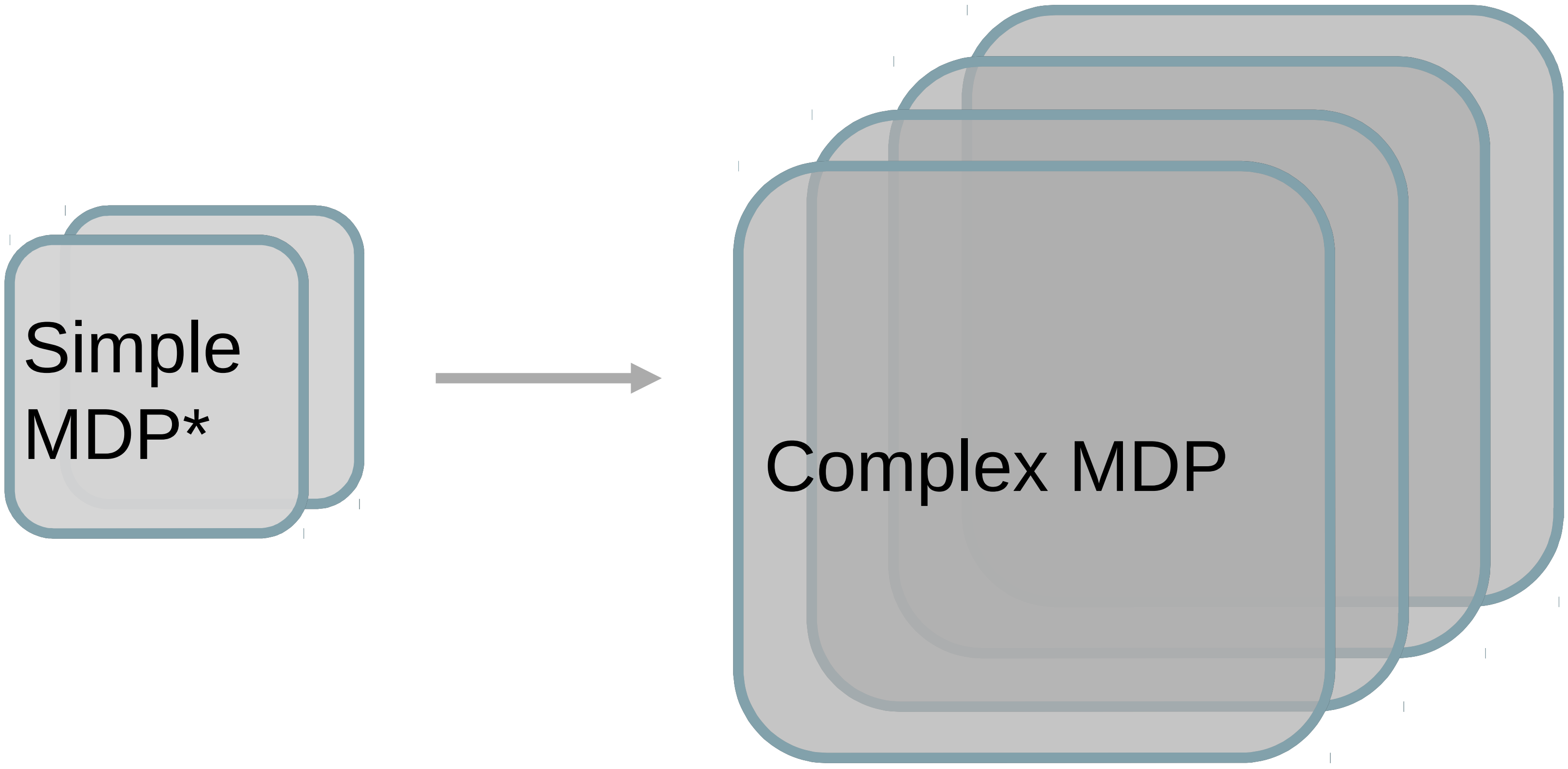
# Bridge Problems



# Goal-based Action Pruning



# Transferring Planning Knowledge




*: MDP = Markov Decision Process

# BurlapCraft

- Run RL algorithms in real Minecraft!
- Define small dungeons (grid problems, mazes, bridge problems).
- Or let the agent run wild in the “real world.”

https://github.com/h2r/burlapcraft

# Human-Robot Collaboration

- Robots that robustly perform actions in real-world environments.
- Robots that carry out complex sequences of actions.
- Robots that actively coordinate with people, establishing a social feedback loop.

# Symbol Grounding Problem

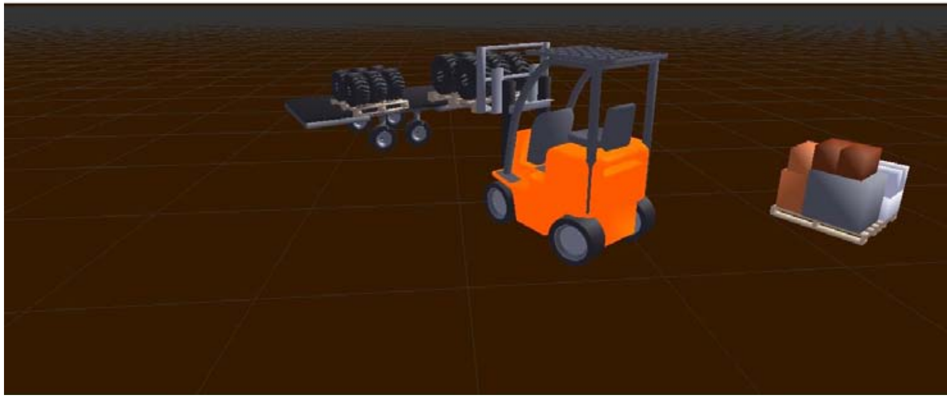
“The pallet of boxes on the left.”

another tyre pallet on the trolley.

Place the pallet of tires on the left side of the trailer.

lift the tire pallet to the truck

Arrange tire pallet to the truck.



Please lift the set of six tires up and set them on the trailer, to the right of the set of tires already on it.

Load the skid right next to the other skid of tires on the trailer.

Place a second pallet of tires on the trailer.

Place the pallet of tires that is on the forklift next to the pallet of tires that is already loaded on the trailer.

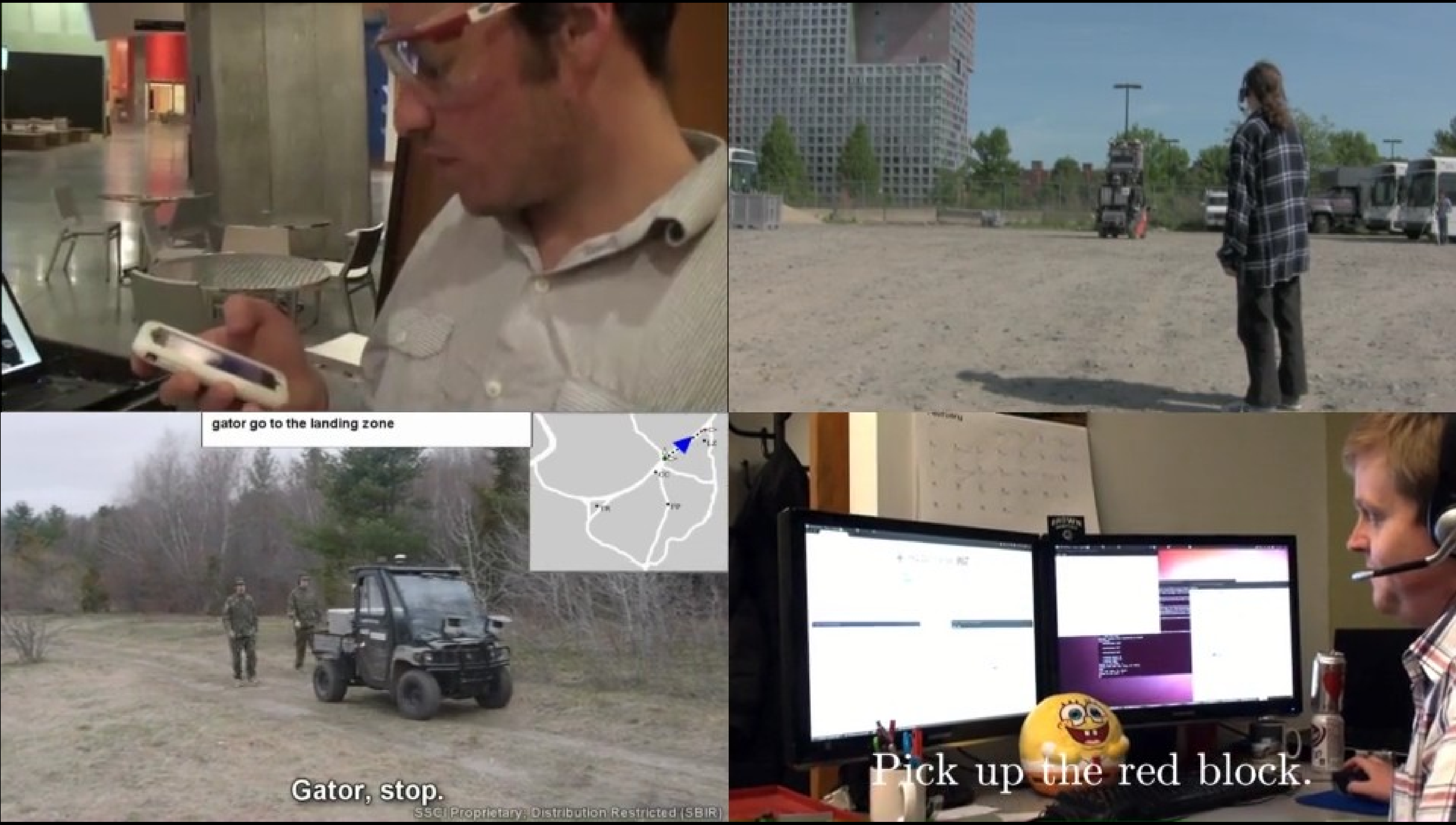
Lift tire pallet. Move to unoccupied location on truck. Lower tire pallet. Reverse to starting location. Lower forks. End.

Put the tire pallet on the trailer.

Lift the tire pallet in the air, then  proceed to deposit it to the right of the
tire pallet already on the table right in front of you.

Place the pallet of tires on the right side of the truck.

Lift the tire pallet and proceed forward to set it on the platform directly ahead, to the right of the tire pallet already there.




Tellex et al. AAAI 2011, Kollar, Tellex et al. HRI 2010, Huang, Tellex et al., IROS 2010, Tellex et al., JHRI 2013, Tellex et al., MLJ 2013




Move the pallet from the truck.

Remove the pallet from the back of the truck.

Offload the metal crate from the truck.

Pick up the silver container from the truck bed.

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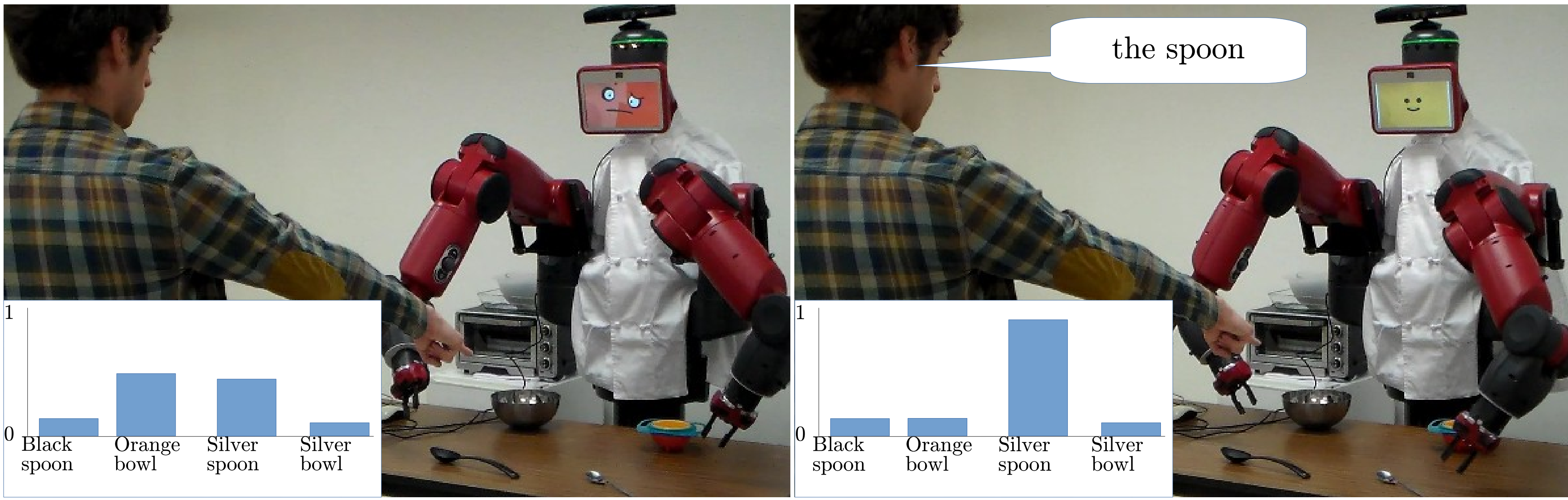
# Social Feedback

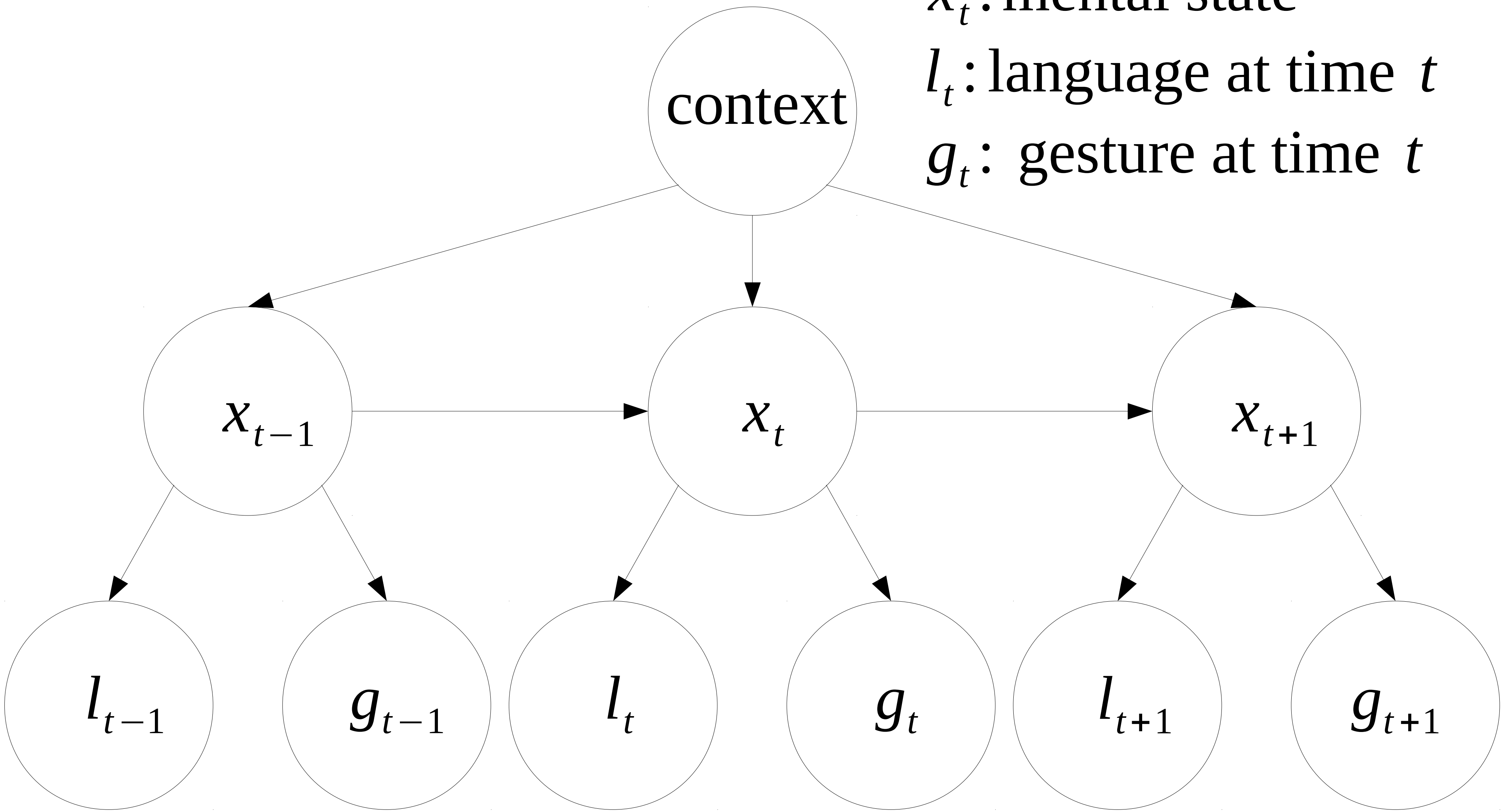
- Humans constantly coordinate with each other to establish common ground.
- In one study (Clark & Krych, 2004), one human instructs another to assemble objects:
  - 2x slower when they cannot see each other or see the workspace.
  - 8x more errors without feedback.

# Incremental, Real-Time Interpretation of Multimodal Communication

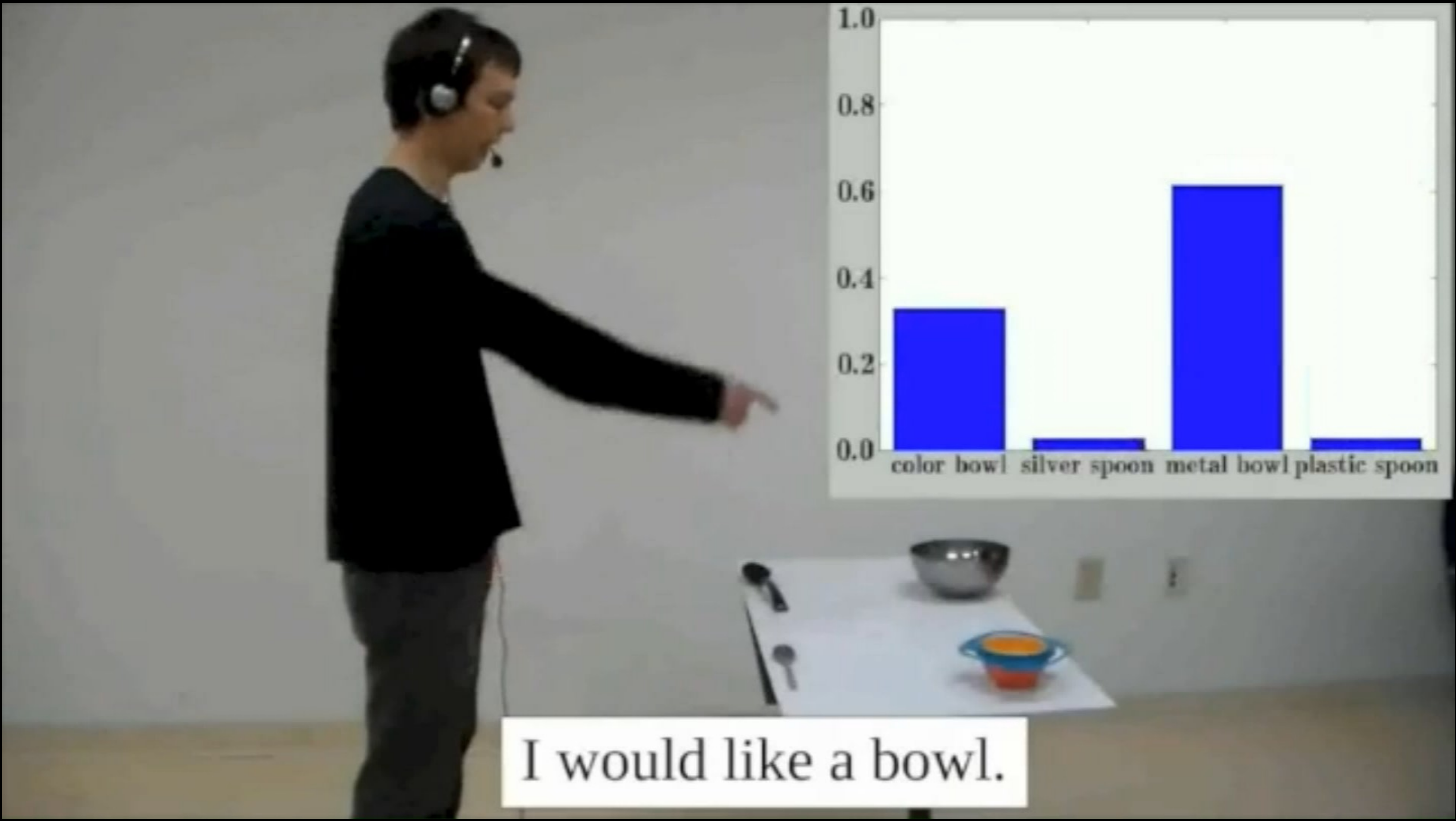


# Bayes Filter

$x_t$: mental state
$l_t$: language at time $t$
$g_t$: gesture at time $t$




1.0
0.8
0.6
0.4
0.2
0.0
color bowl
silver spoon
metal bowl
plastic spoon
Please hand me that.


1.0
0.8
0.6
0.4
0.2
0.0
color bowl
silver spoon
metal bowl
plastic spoon
I would like a bowl.


1.0
0.8
0.6
0.4
0.2
0.0
color bowl
silver spoon
metal bowl
plastic spoon
I would like a spoon.


1.0
0.8
0.6
0.4
0.2
0.0
color bowl
silver spoon
metal bowl
plastic spoon

# Results

| | % correct (end of interaction) |
|---|---|
| Random | 25% |
| Language only | 46% |
| Gesture only | 80% |
| Language and gesture | 91% |

# How can we make robots that collaborate with people?

- Robots that robustly perform actions in real-world environments.
- Robots that carry out complex sequences of actions.
- Robots that actively coordinate with people, establishing a social feedback loop.