Robot Programming by Demonstration with **Crowdsourced Action Fixes**




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UNIVERSITY OF WASHINGTON

Human Computation & Crowdsourcing 2014, Pittsburgh, PA

VISION

general-purpose robots that can be **programmed by their end-users**, in the context of use

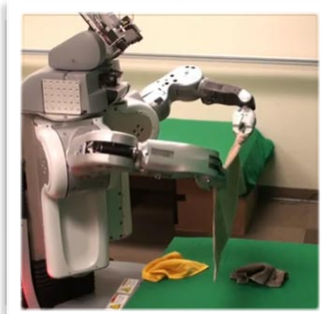
WHY?

unbounded use cases







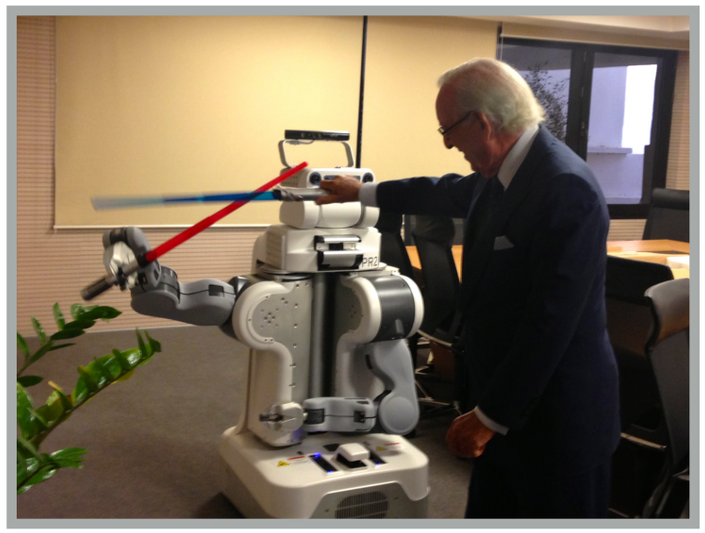


...

WHY?

unique preferences and needs

H. Evans
mute, quadriplegic



O. Benjelloun
BMCE bank chairman

WHY?

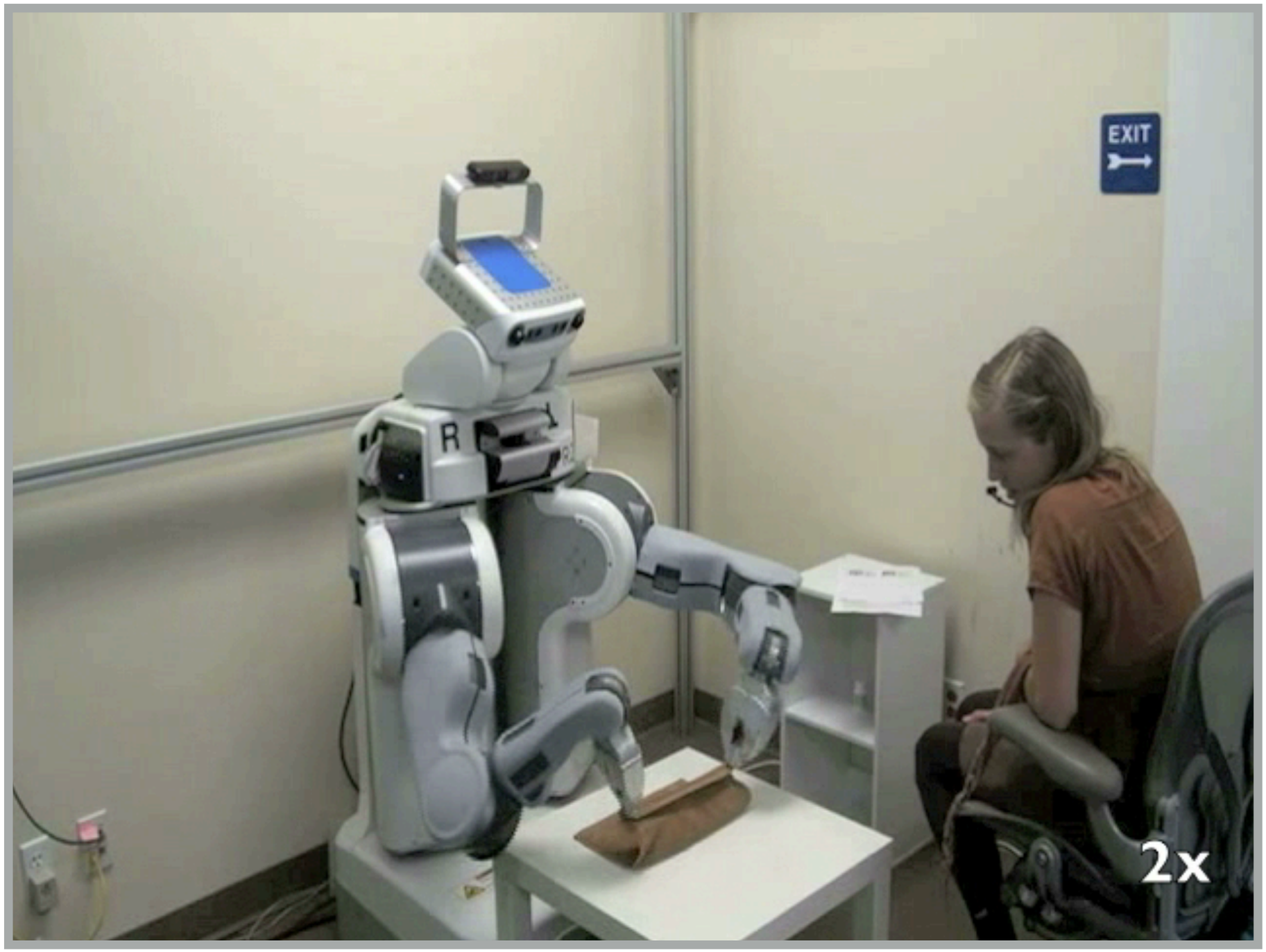
simpler engineering challenge

robot that can do
everything
everywhere

-VS-

robot that can do
a few things
in one context

PROGRAMMING BY DEMONSTRATION



Cakmak & Takayama, HRI 2014

ACTION REPRESENTATION

$$\mathcal{A}_n = \{(\theta^f, f, g)_k : k = 1..K\}$$

End-effector pose (6-DOF) in the reference frame of landmark f

gripper state

index of the reference frame of landmark

$$L = \{\ell_0, \ldots, \ell_N\}$$

Origin

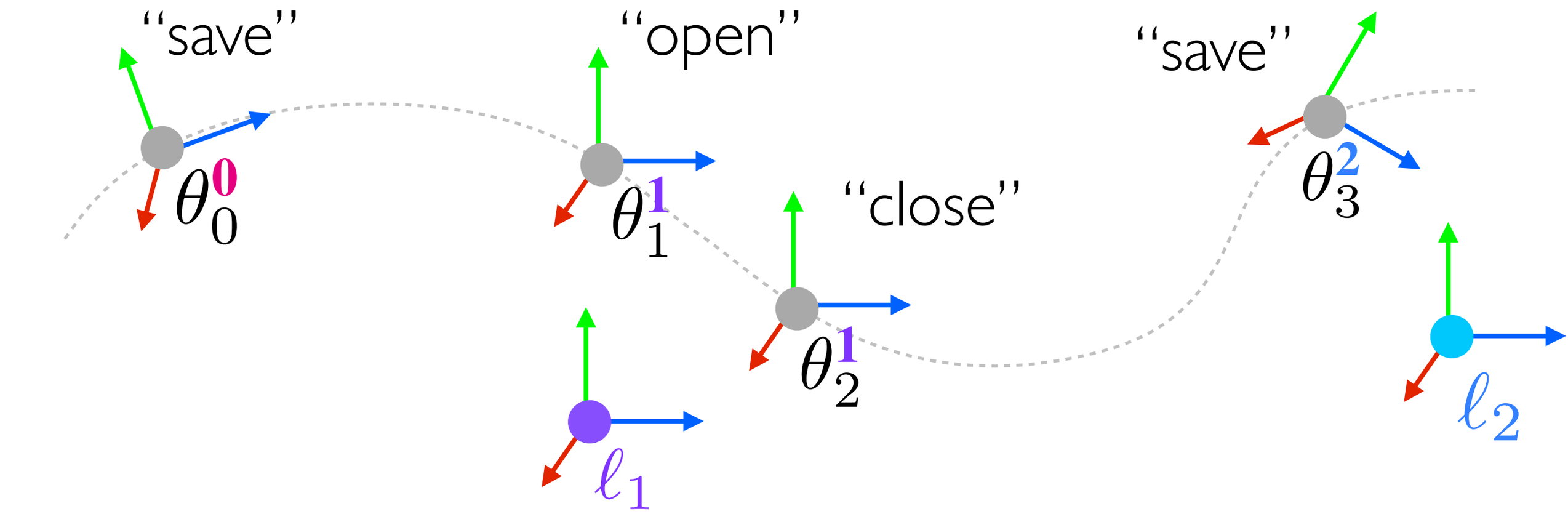
$$\ell_i = (\phi, \tau, v^\tau)$$

Landmark pose relative to robot origin

landmark type

descriptor

ACTION REPRESENTATION



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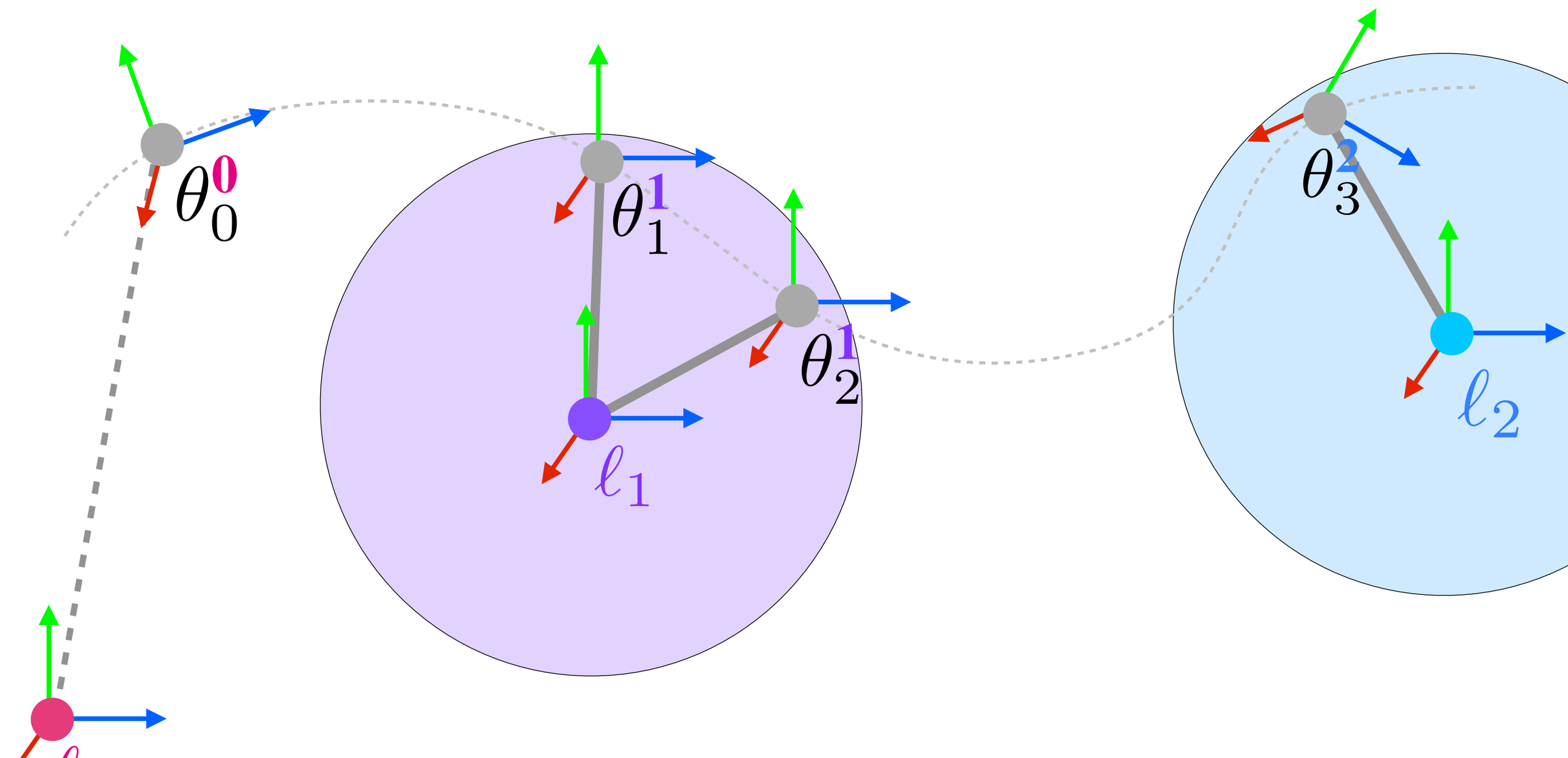
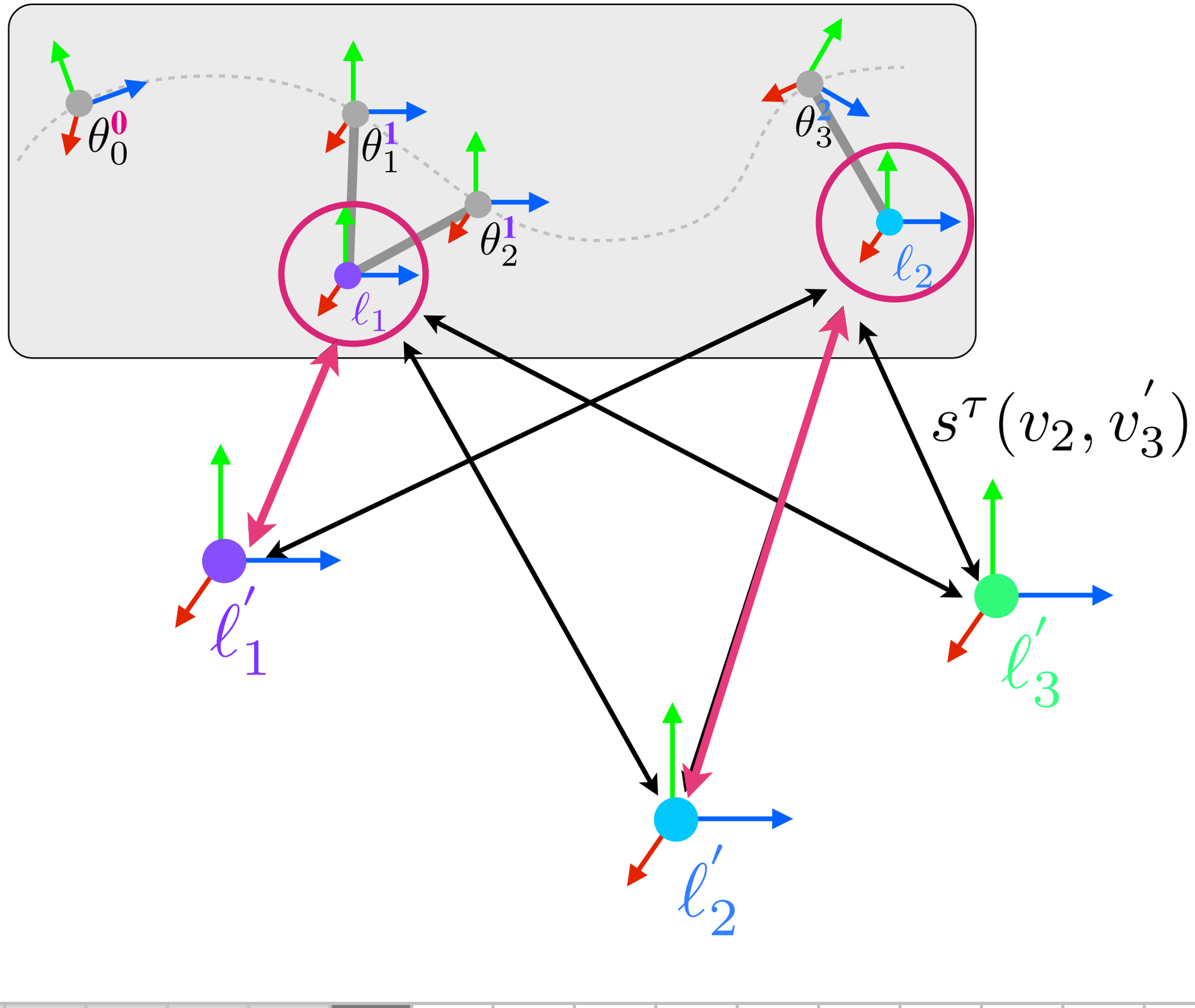


ACTION EXECUTION



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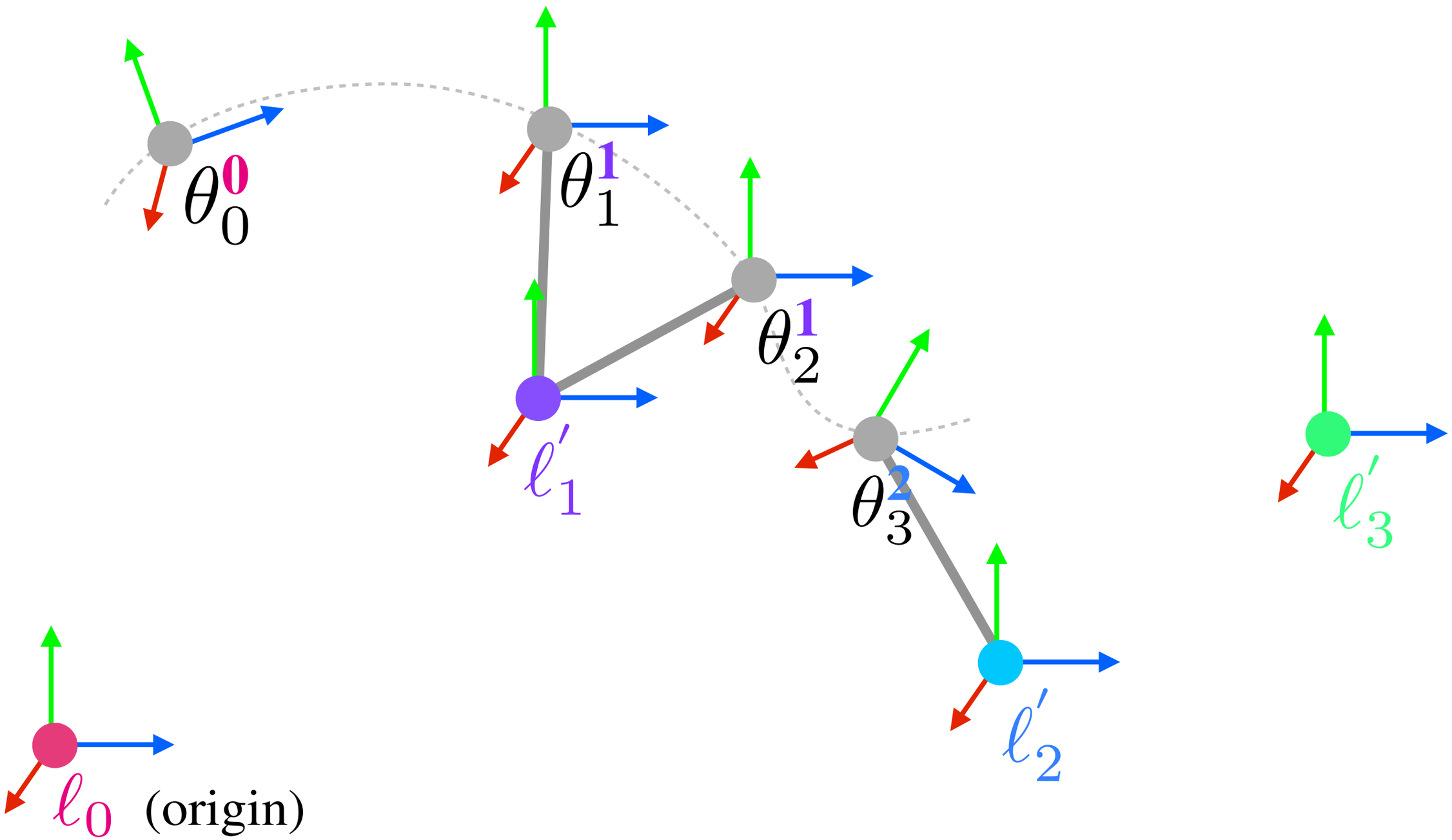
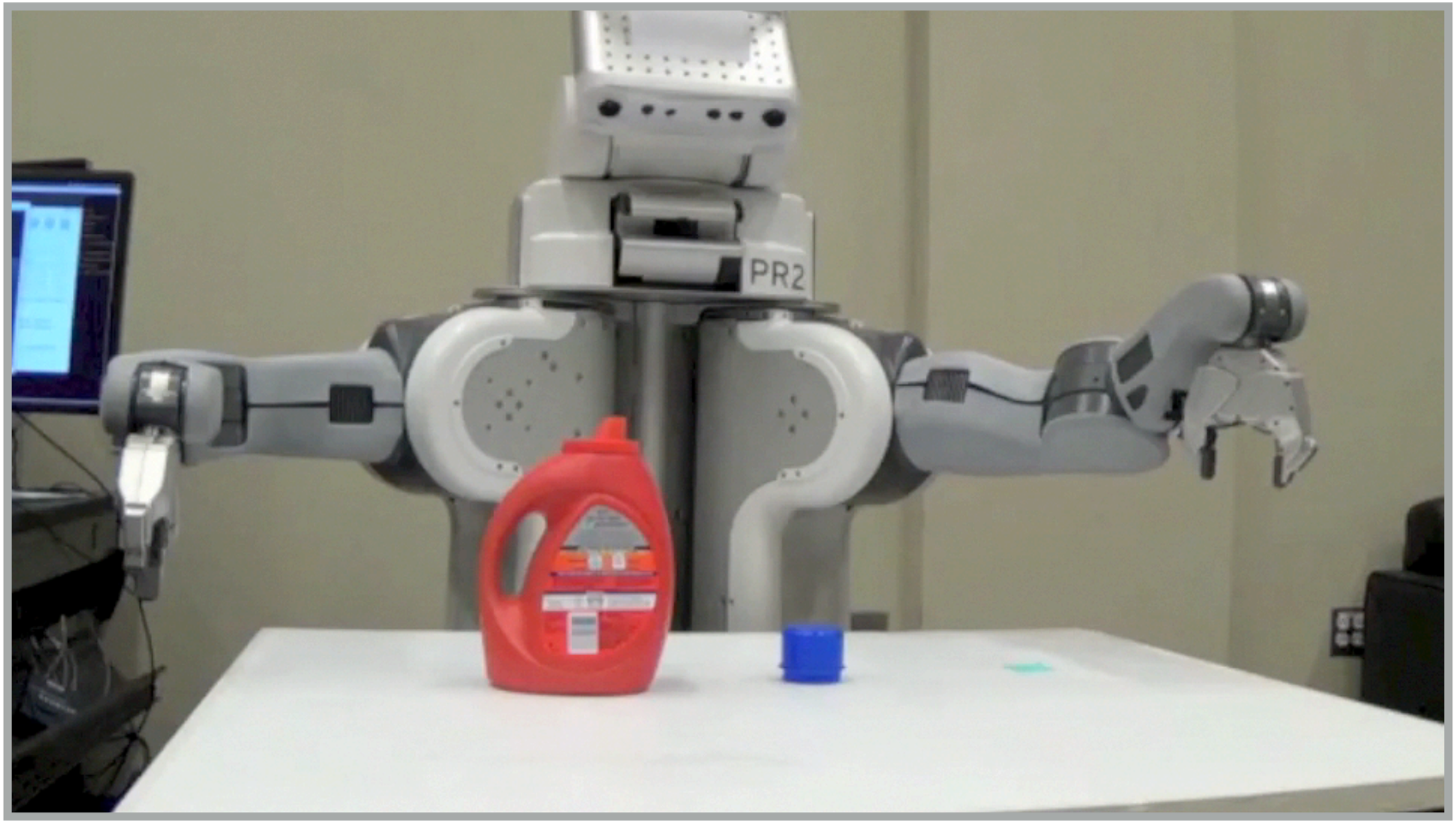


SIMPLE TASK

MORE DIVERSE TASKS



PROBLEM: GENERALIZATION

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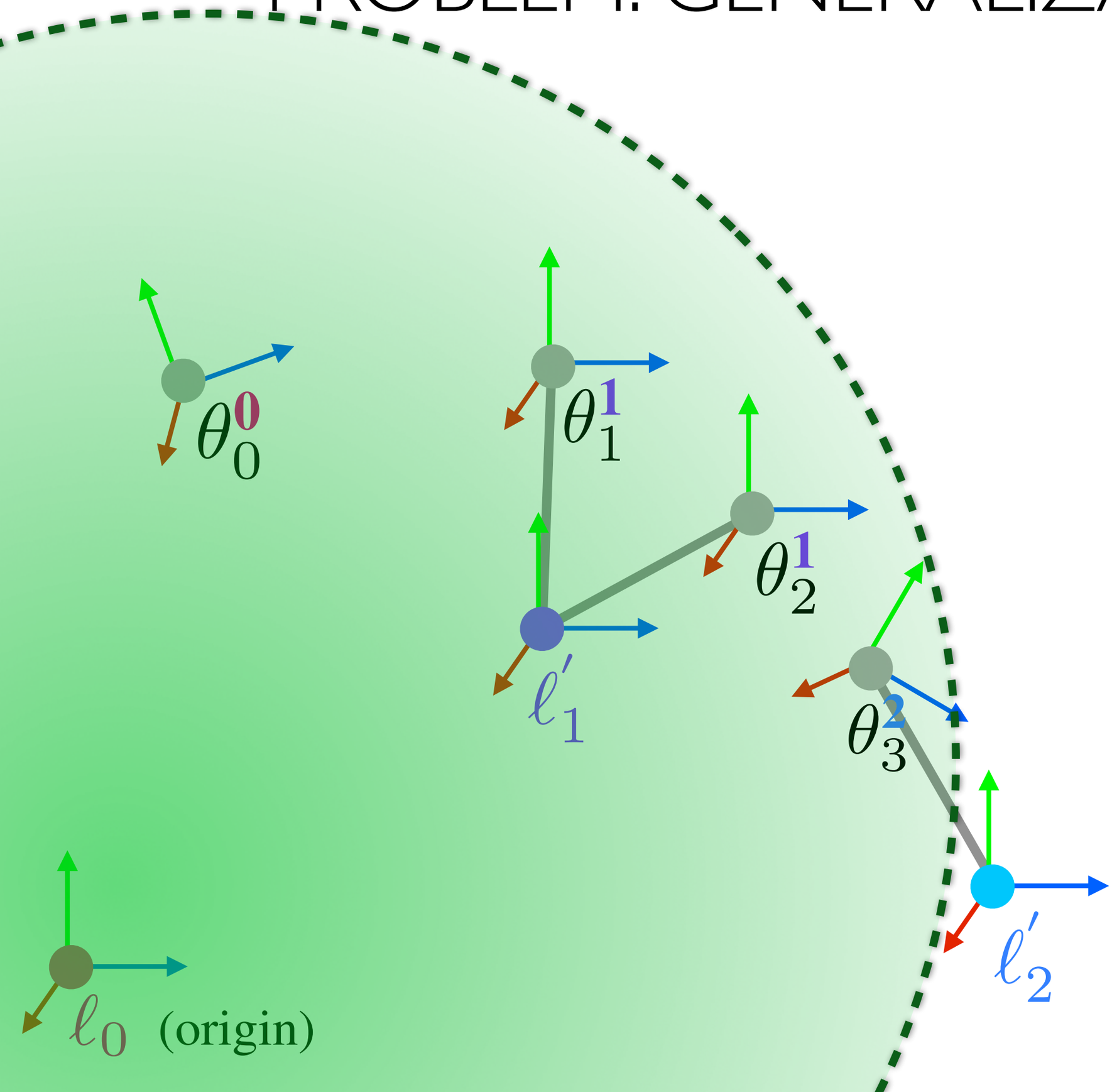

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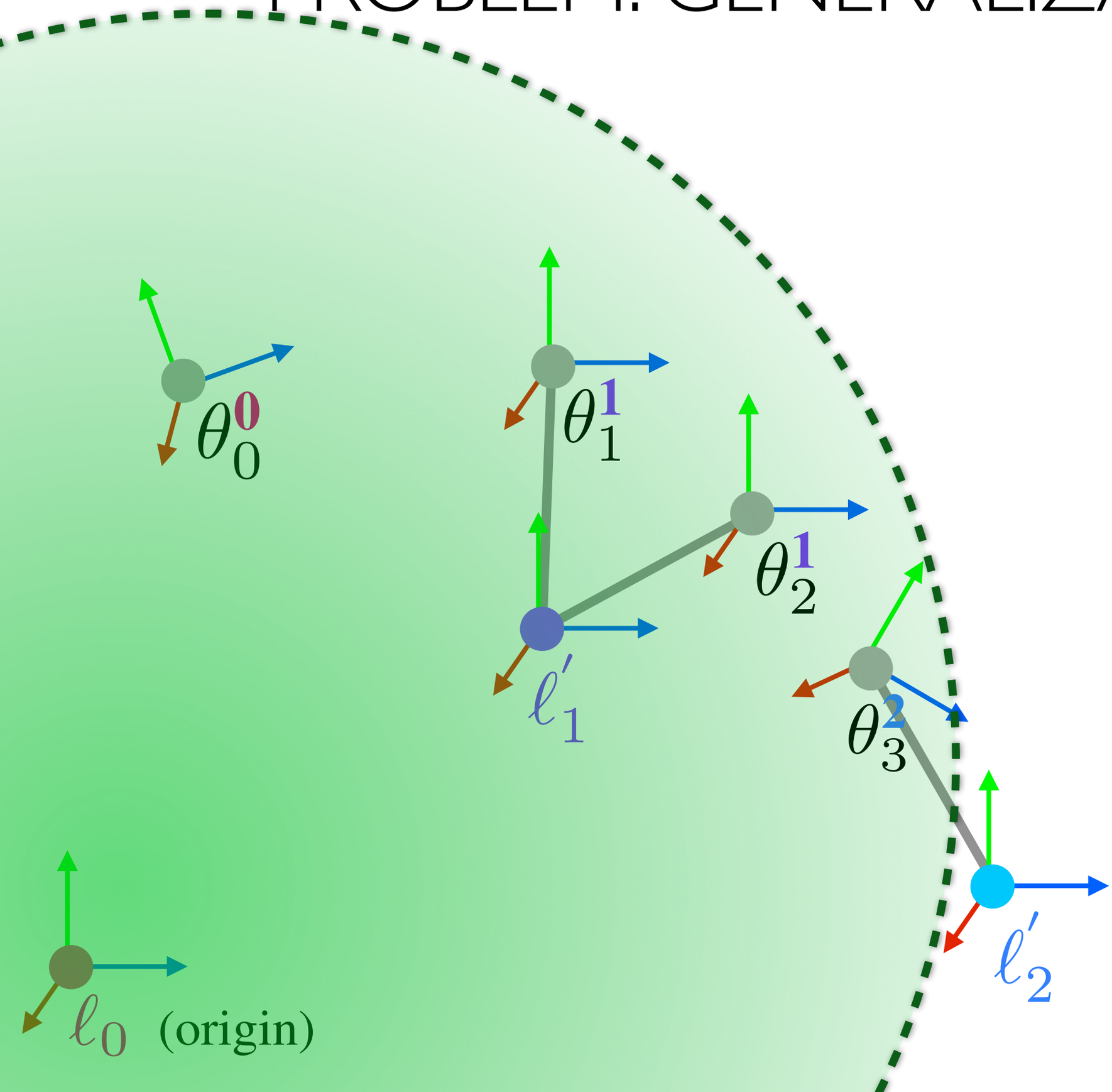

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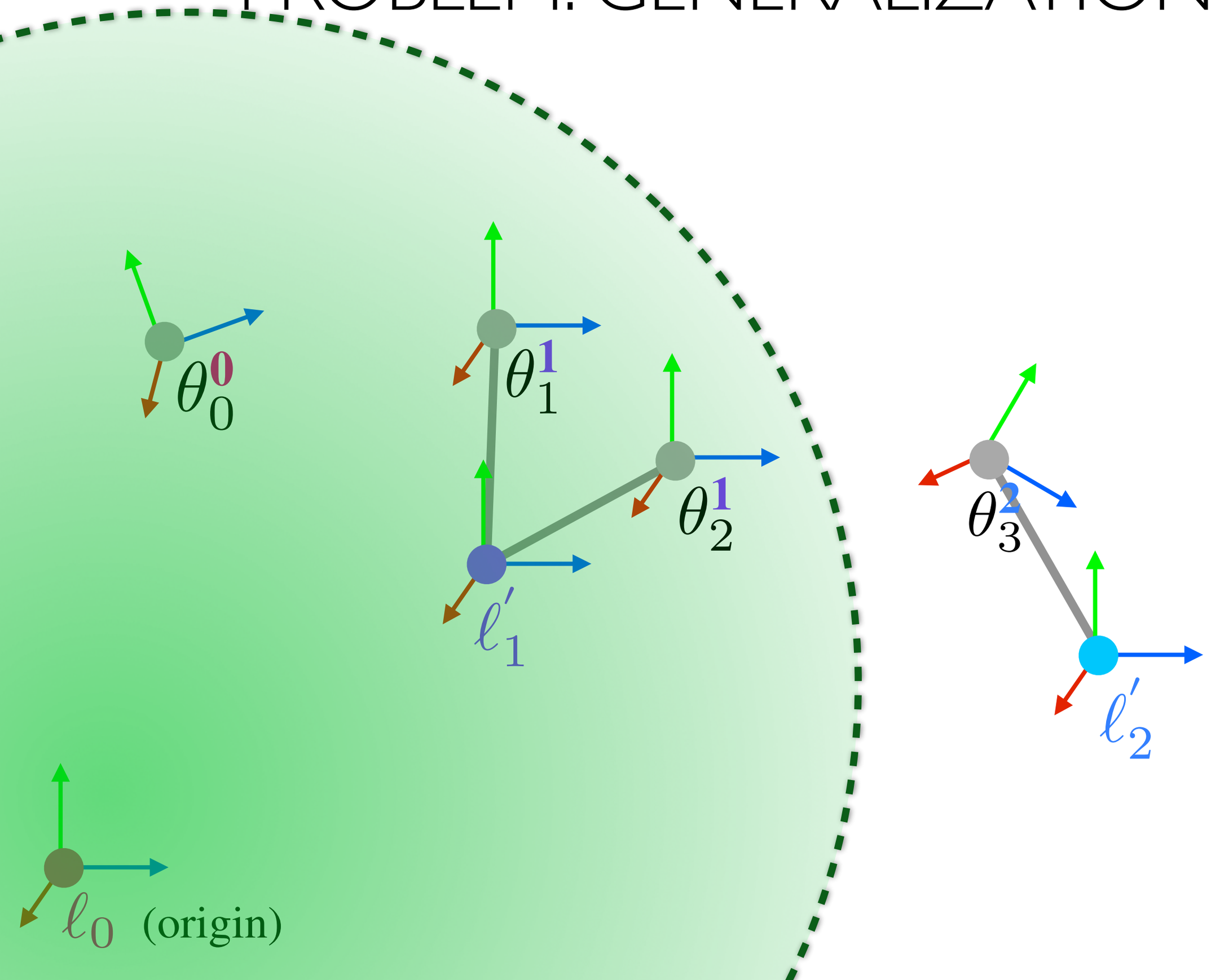

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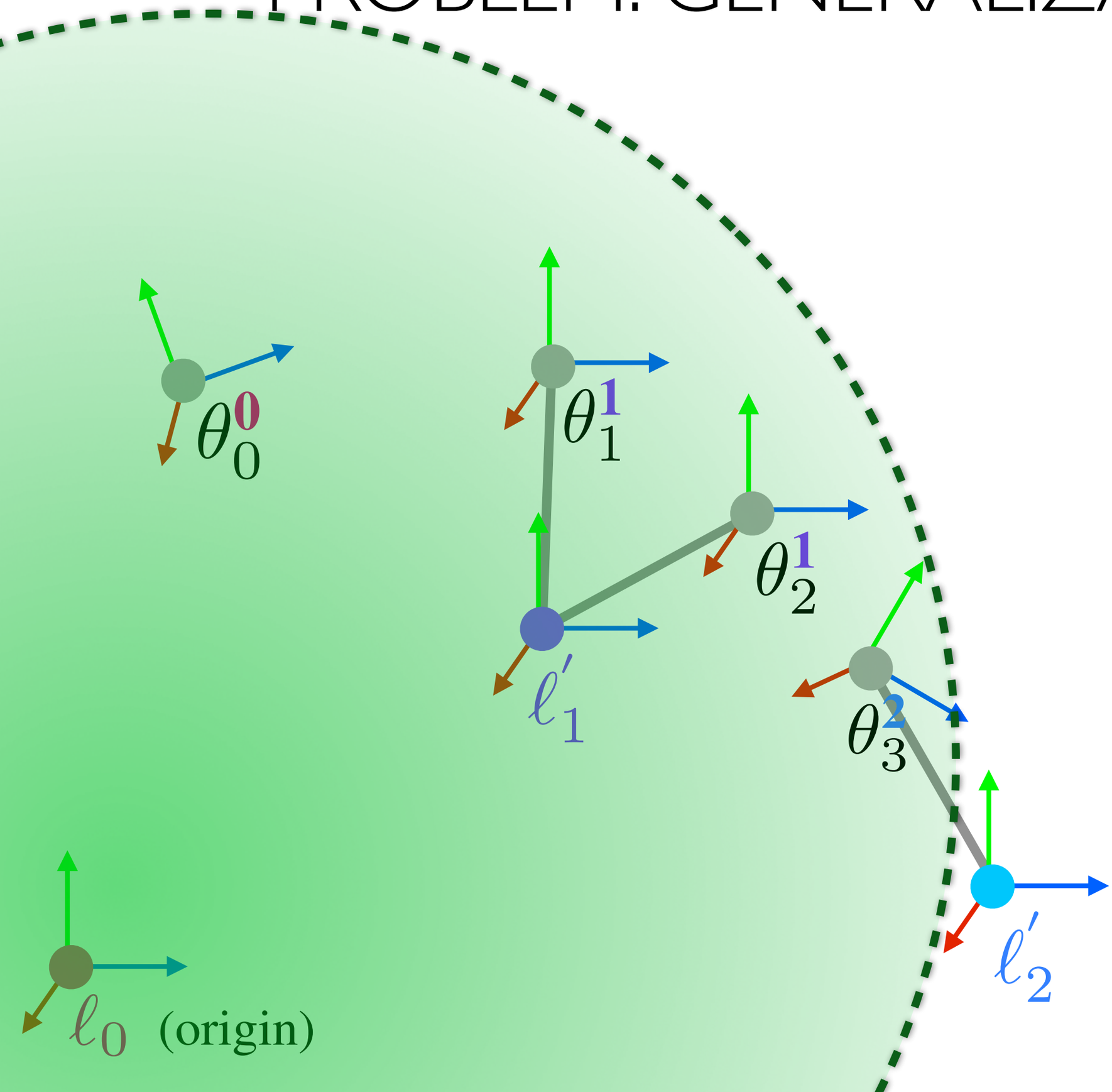

OBJECTIVES

- **Improve range of actions**
- Impose no additional requirements on users

APPROACH

1. Start with a single demonstration
2. Instance-based active learning
3. Crowdsource additional demonstrations

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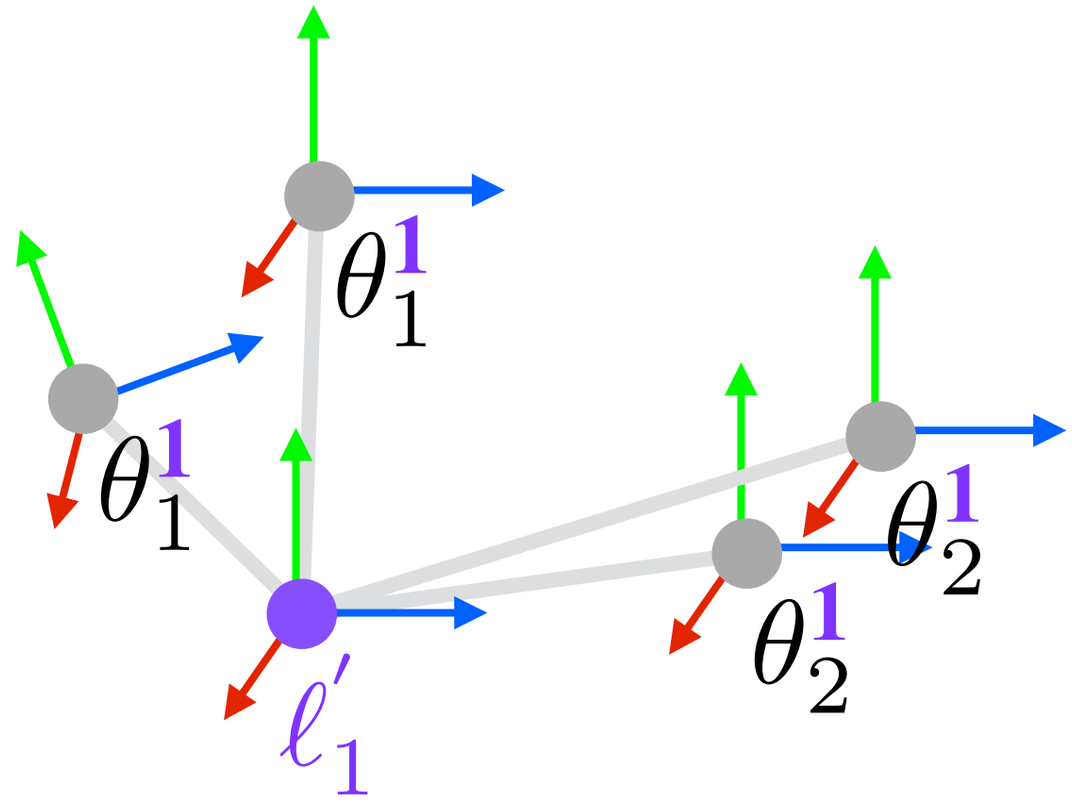
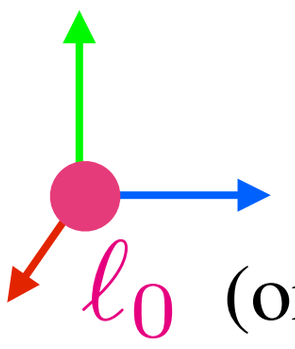
ADDITIONAL DEMONSTRATIONS





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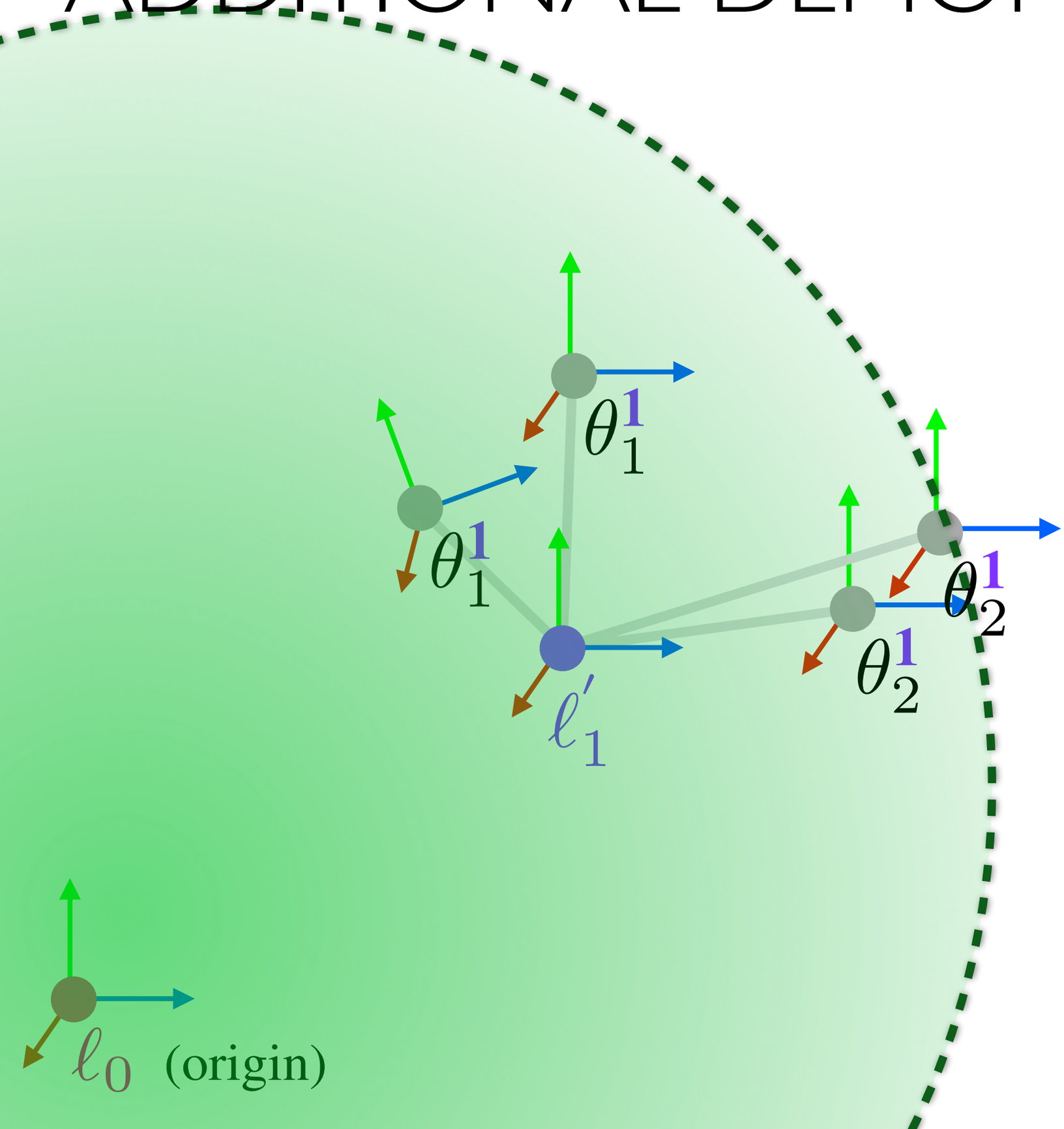


IMPLEMENTATION

1. Collect single demonstration of three actions

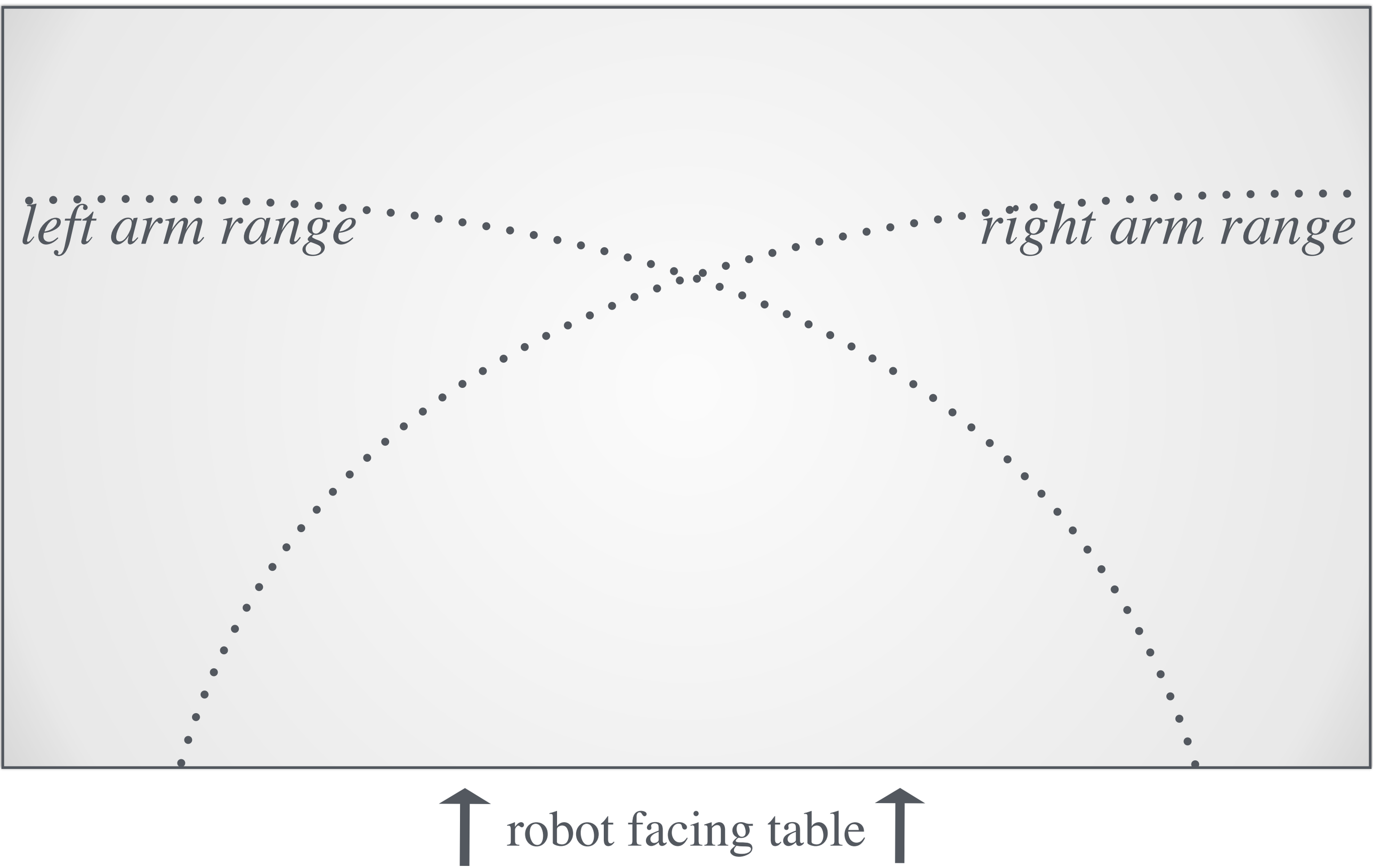
THREE ACTIONS

IMPLEMENTATION

1. Collect single demonstration of three actions

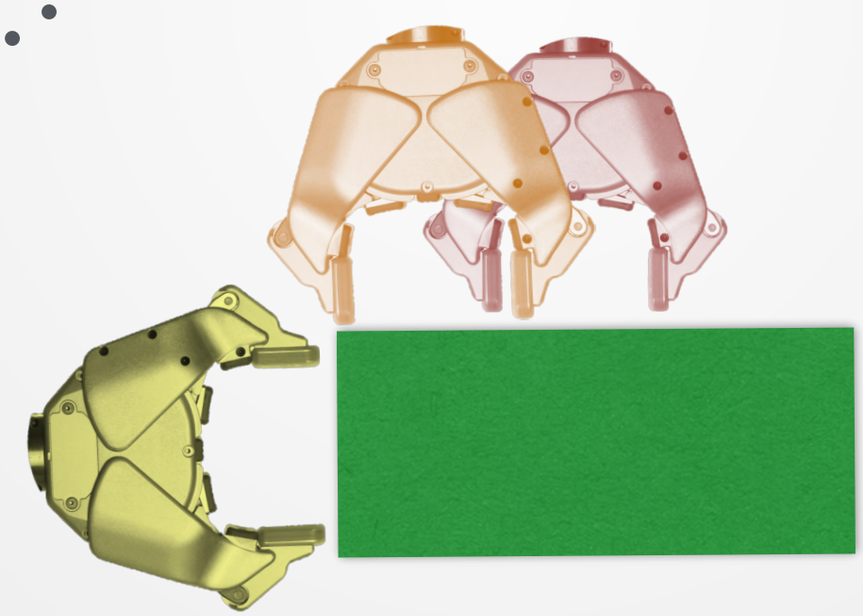
IMPLEMENTATION

1. Collect single demonstration of three actions
2. Filtered random sampling for active learning


left arm range
right arm range
robot facing table

left arm range

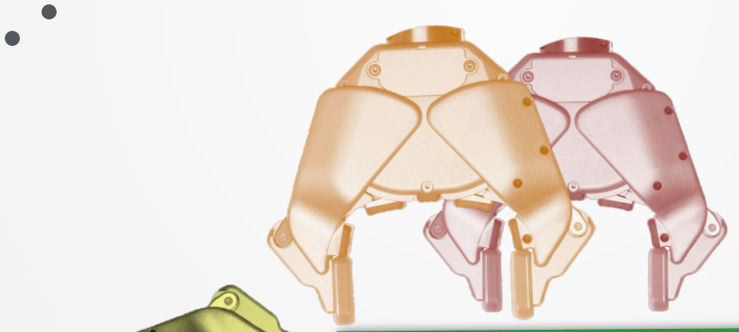
right arm range



robot facing table

left arm range

right arm range



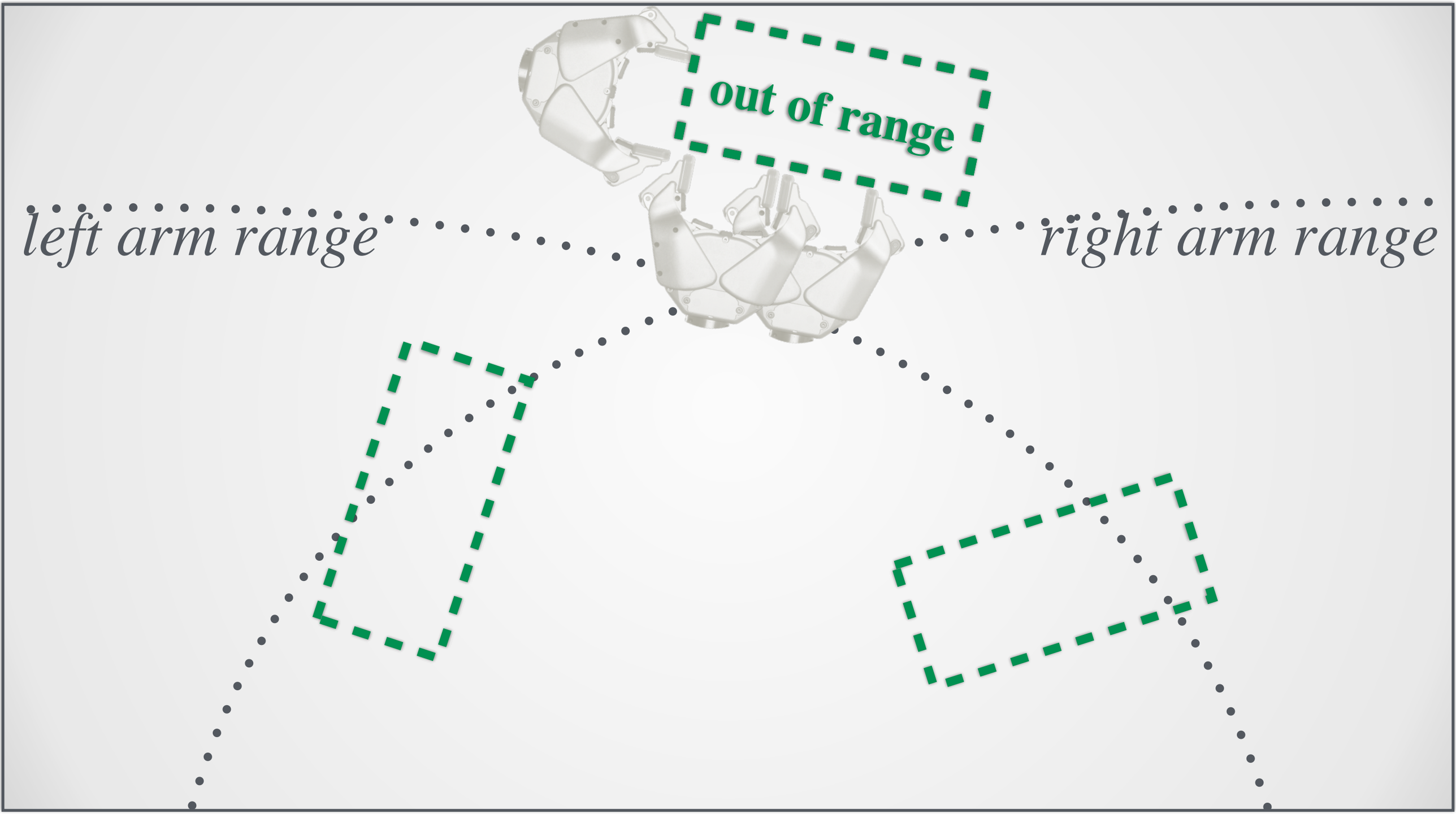
0 unreachable

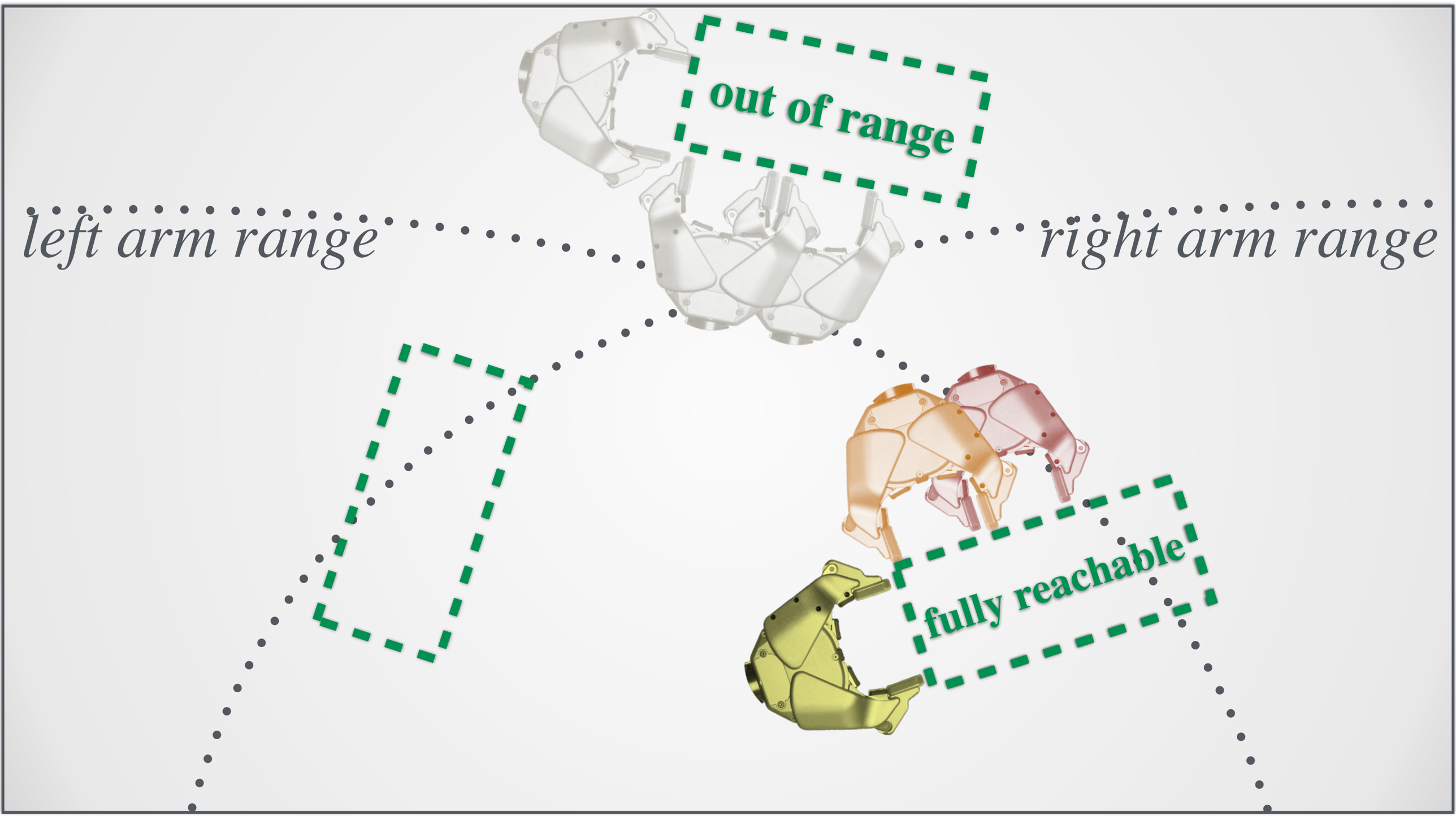
robot facing table

left arm range

right arm range

robot facing table


out of range
left arm range
right arm range
robot facing table


out of range
left arm range
right arm range
fully reachable
robot facing table

out of range

left arm range

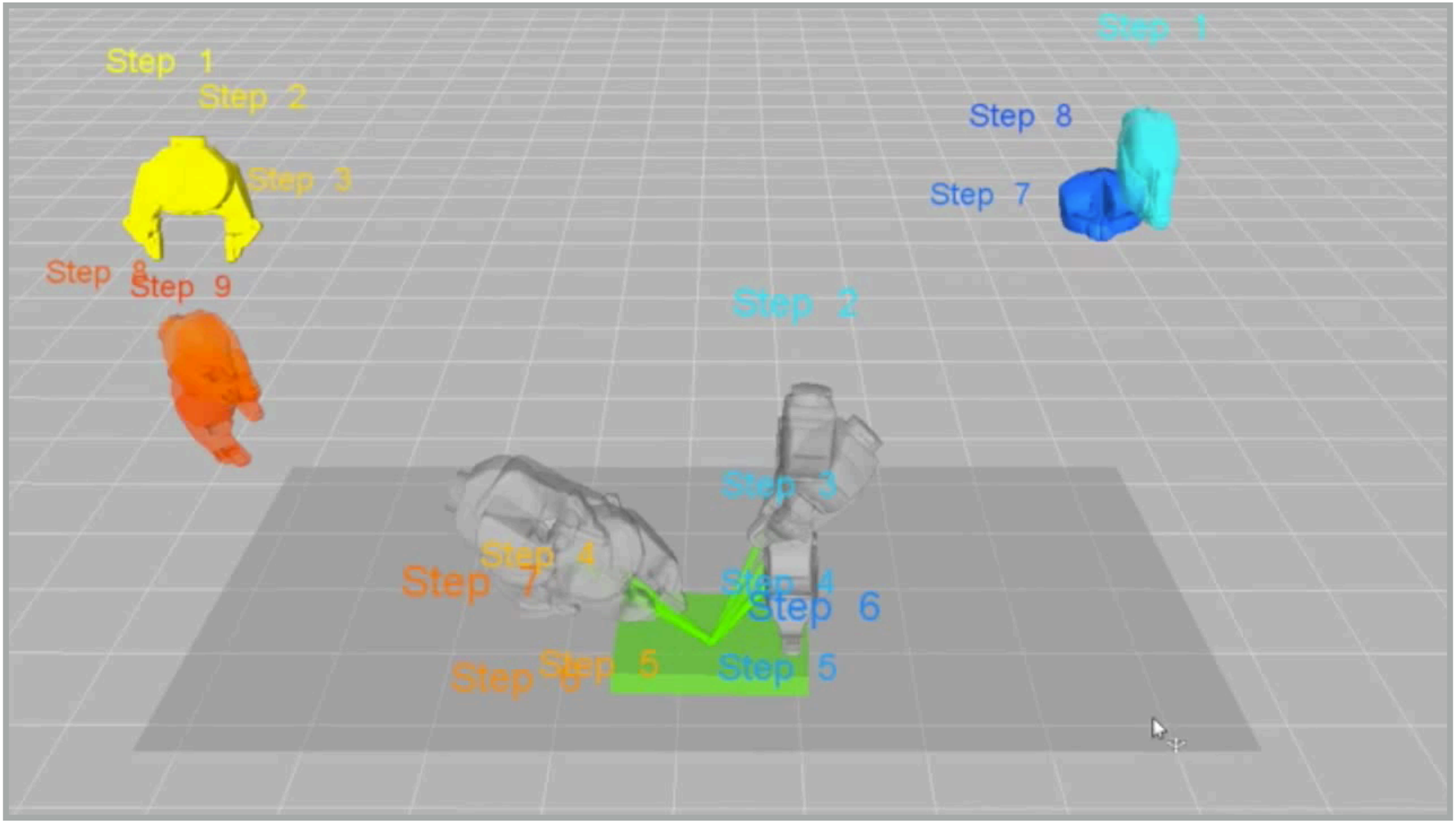
right arm range

2 unreachable

fully reachable

robot facing table

FILTERED RANDOM SAMPLING



IMPLEMENTATION

1. Collect single demonstration of three actions
2. Filtered random sampling for active learning

IMPLEMENTATION

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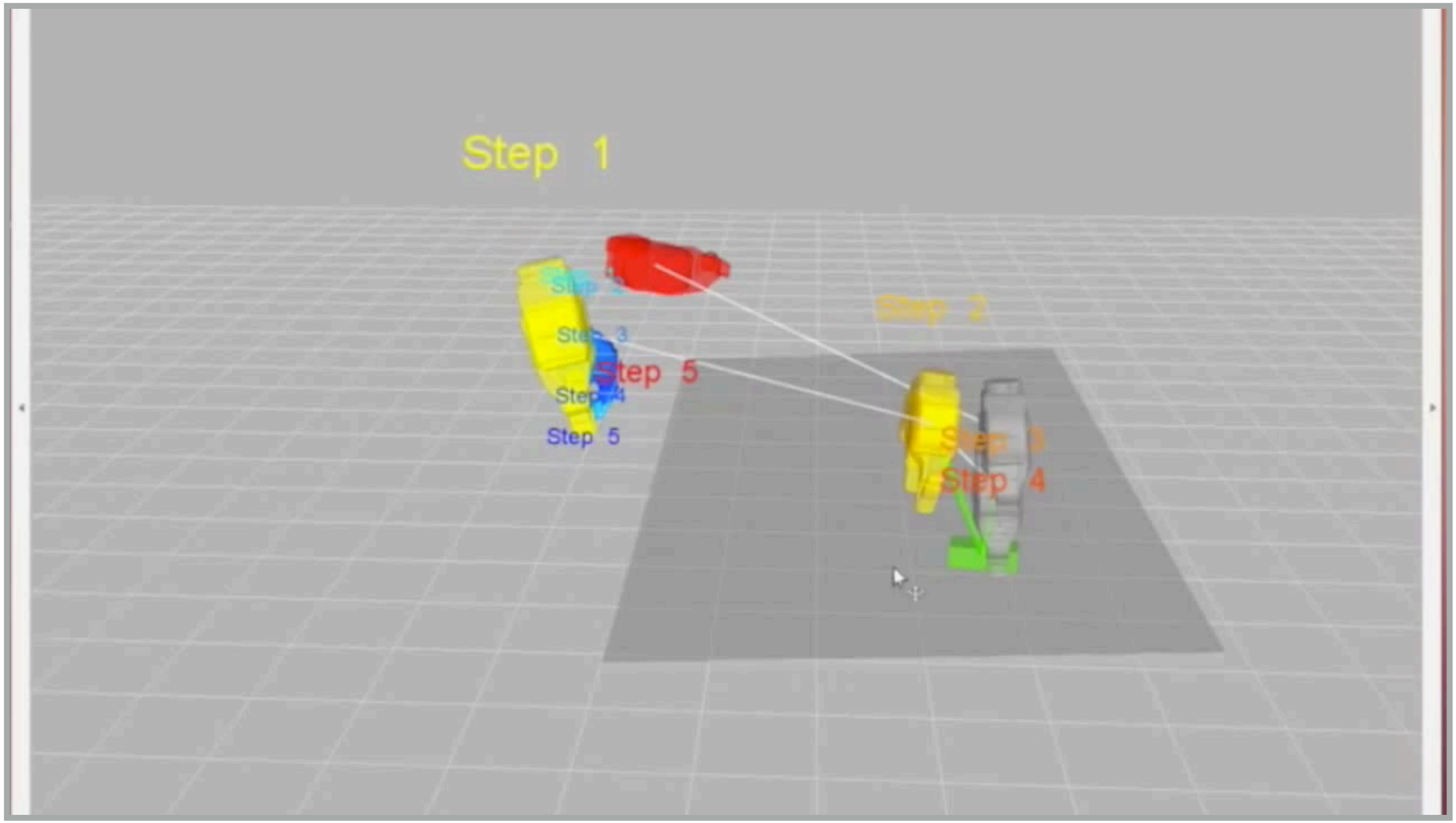
3. **Collect and process data**

   - **GUI**

GUI

If time, make slide about color coding of grippers.

GUI



IMPLEMENTATION

1. Collect single demonstration of three actions

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IMPLEMENTATION

1. Collect single demonstration of three actions

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3. **Collect and process data**

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   - **Score functions**

SCORE FUNCTIONS

1. Crowd confidence

$$s_o(\mathcal{D}_i) = conf(\mathcal{D}_i)$$

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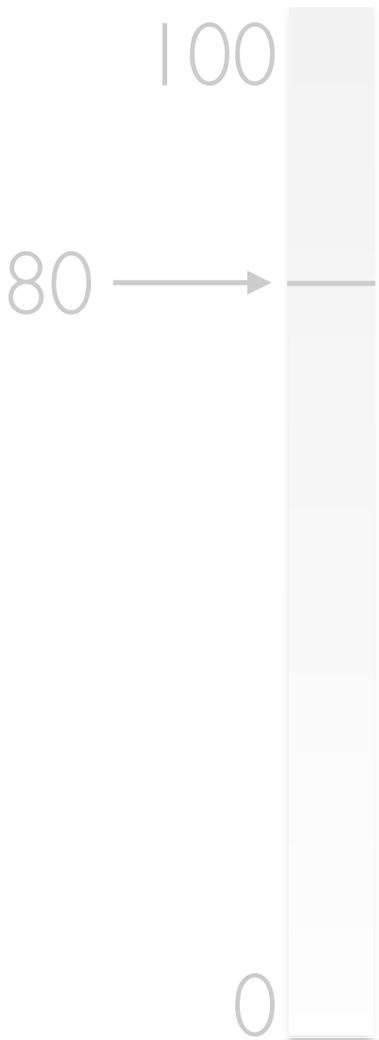
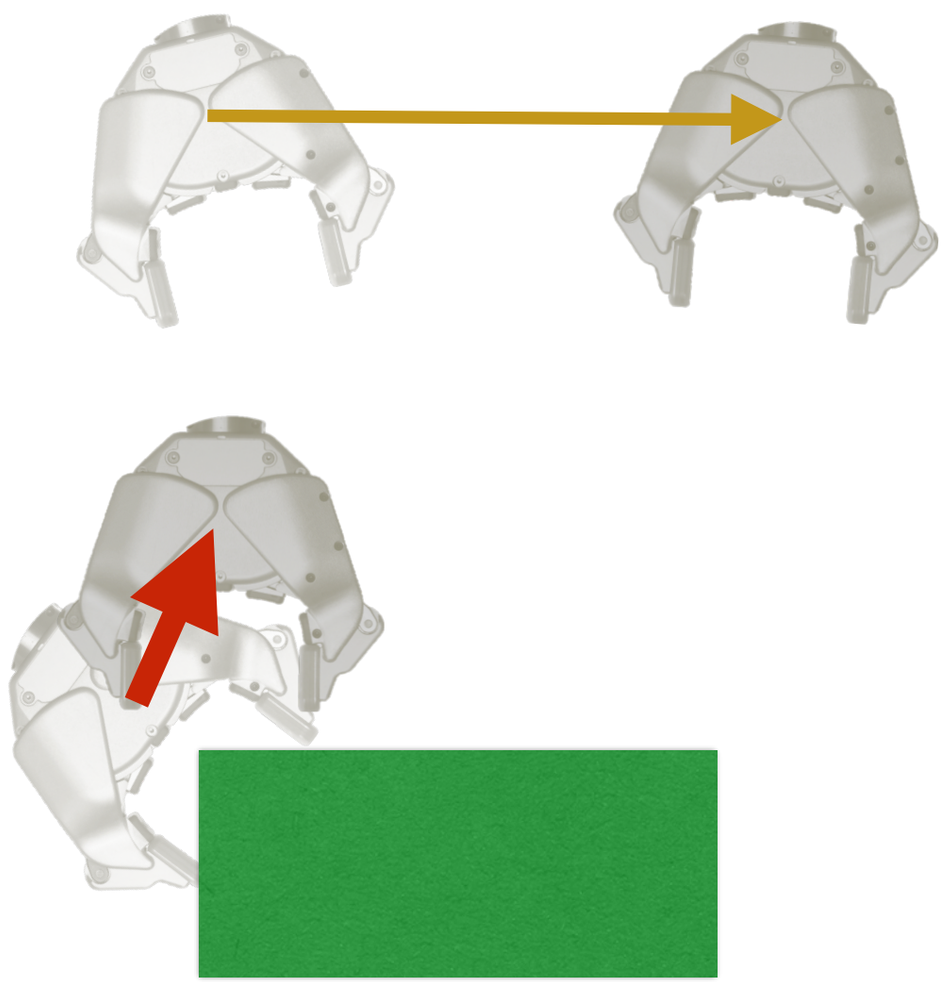


2. Seed distance

$$s_d(\mathcal{D}_i) = 1/\{\sum_{j=1}^{N_j} \frac{|\theta_{0,j}^f - \theta_{i,j}^f|}{|\theta_{0,j}^f|}\}$$



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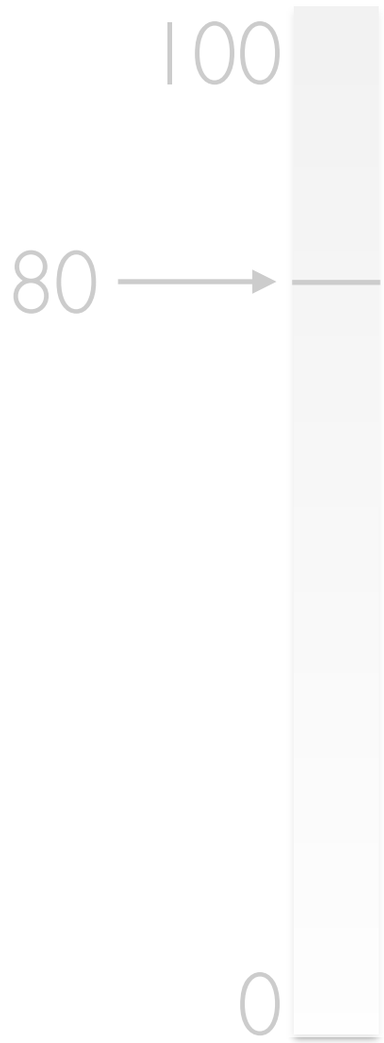

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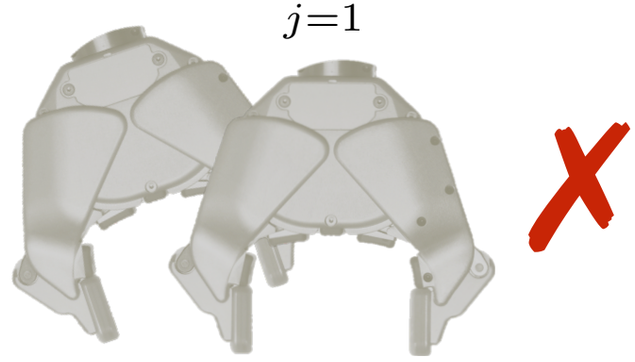
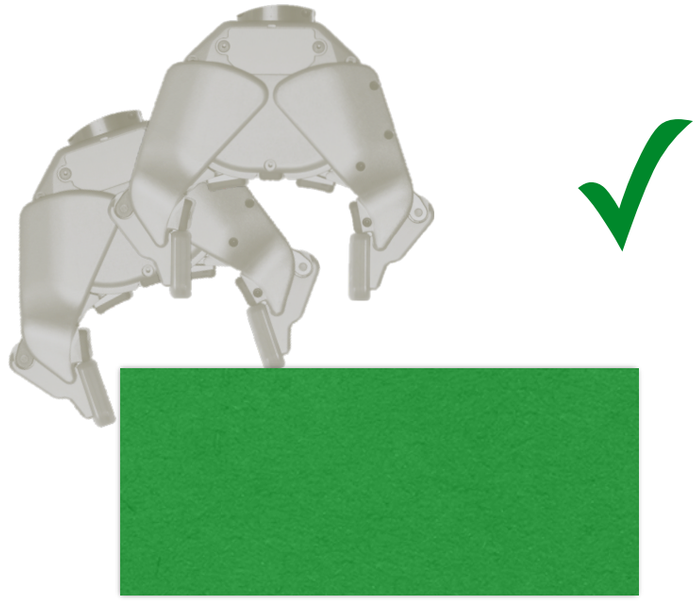
3. Compactness

$$s_c(\mathcal{D}_i) = 1/\{\sum_{j=1}^{K} |\theta_{i,j}^f|, f \neq \ell_0\}$$

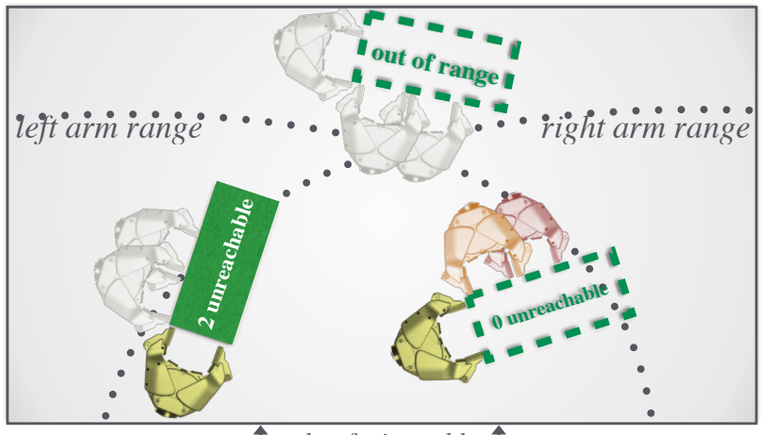


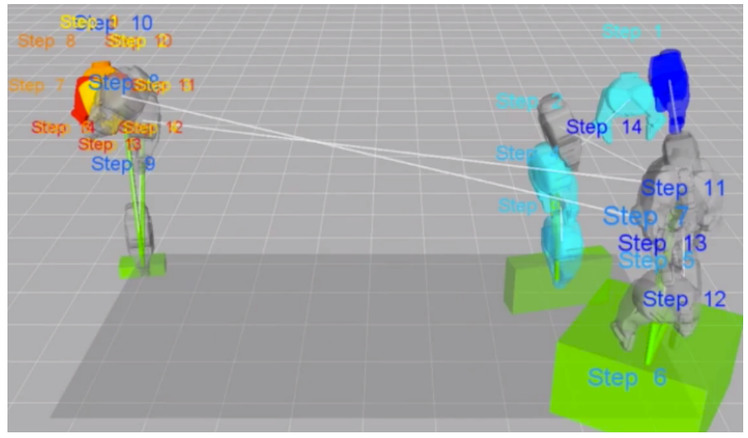


APPROACH

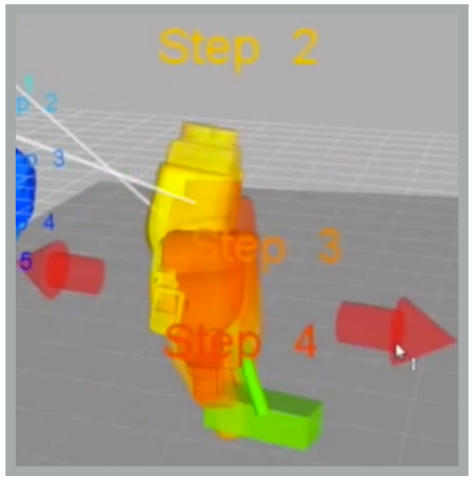
1. Actions

2. Active learning





3. Crowd data



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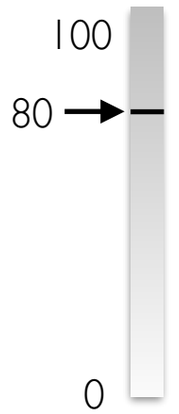

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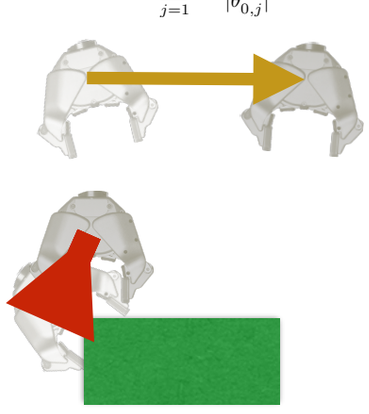

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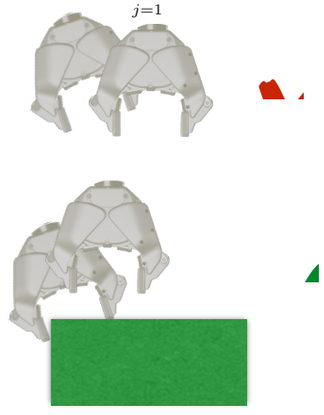

EVALUATION

Part 1

- Thank you for participating in our study.
- This is Rosie the Robot.
- The goal of our research is to enable everyday people to program new actions on general purpose robots like this one, so that it doesn't need to be preprogrammed for every possible action users might need.
- An intuitive way to program the robot is to just demonstrate the desired action.
- So in our previous research we have had people come in and program new actions by physically moving the robot's arms and using simple commands.
- This is called programming by demonstration.
- The way that it works is: the person saves a sequence of hand poses and then the robot moves its arms to go through those poses.
- Some poses are attached to objects so that the action will work even when the objects move around.
- Here is a video that explains this system.
- *Have them watch the PbD intro video (you might want to narrate as you go):* *https://www.youtube.com/watch?v=Eo7r0ex3JT0*

Part 2

- As you saw in the video, sometimes Rosie is not able to perform the actions that it was programmed to do correctly.
- This can happen when the objects are moved around.
- But as shown in the video you can **edit the programmed action** through the user interface to make it feasible in that scenario.
- That's exactly what we'll ask you to do today.
- Rosie has already learned three different actions but it automatically found some scenarios in which it is unable to perform each action.
- So you will go in and fix the action to work in those scenarios.
- We have a newer version of this interface

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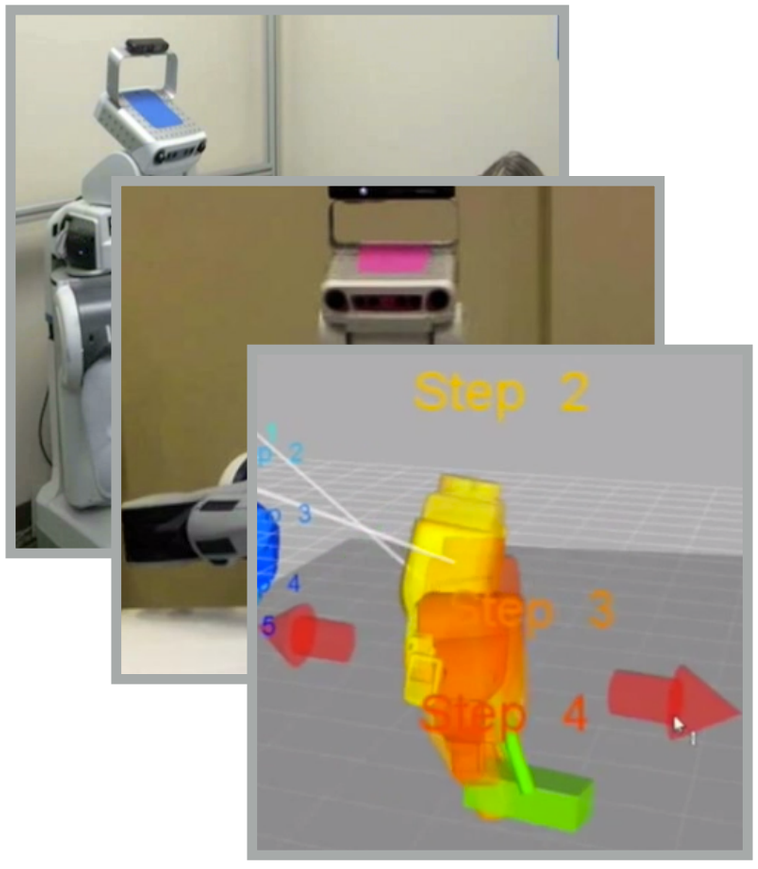

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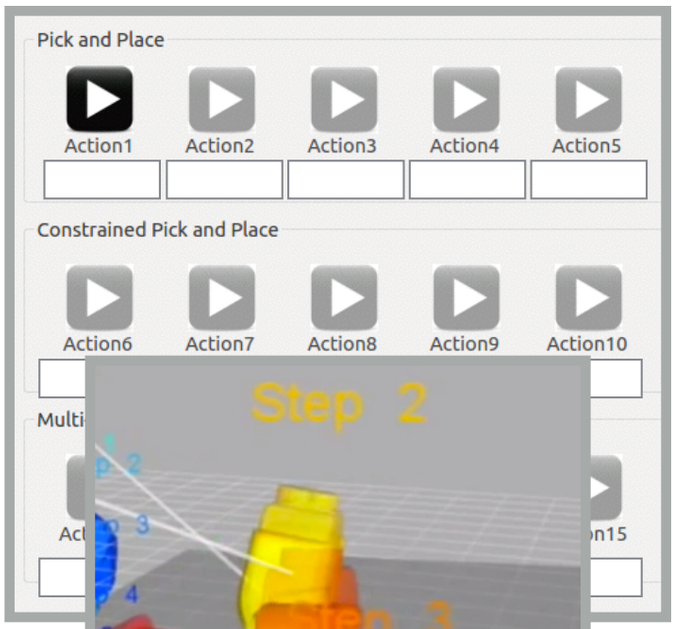
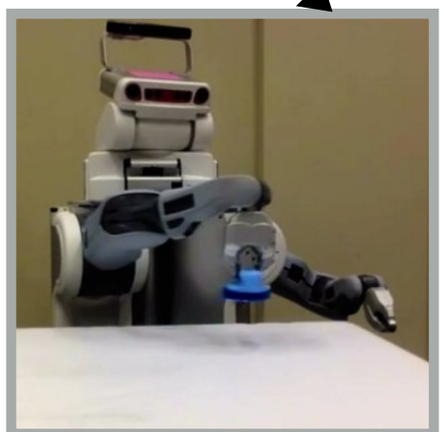
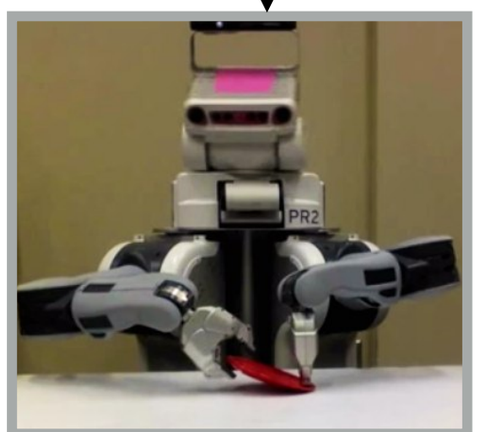
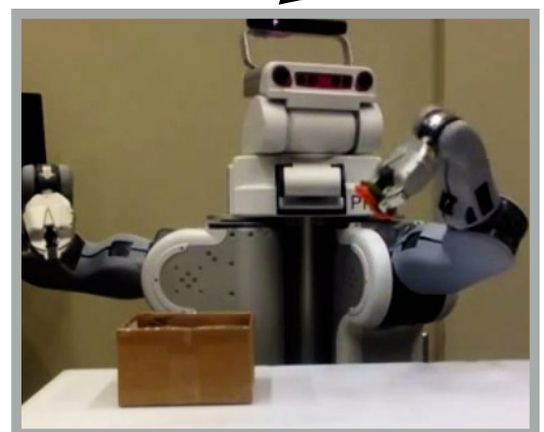
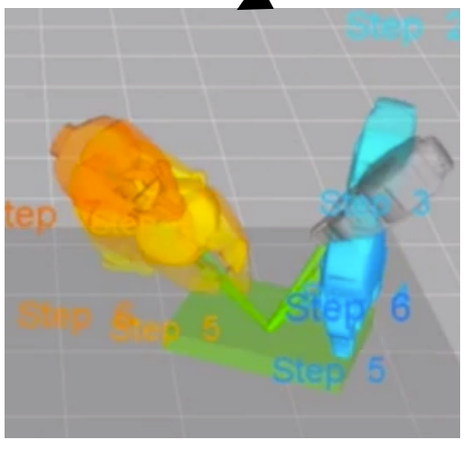


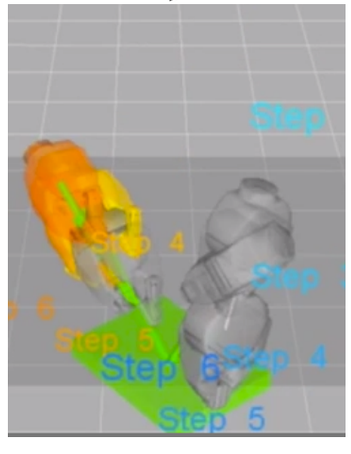
WORKER

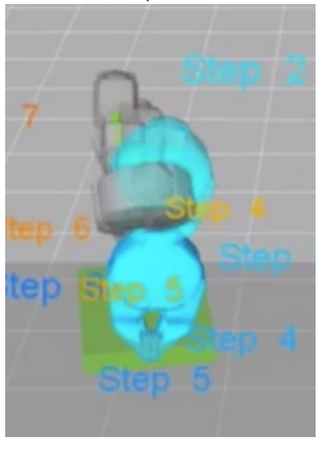


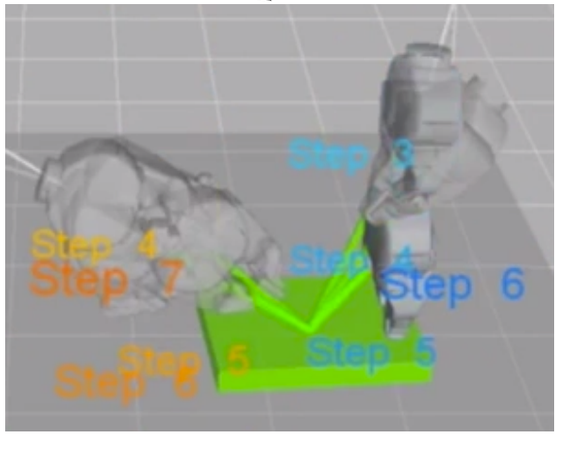


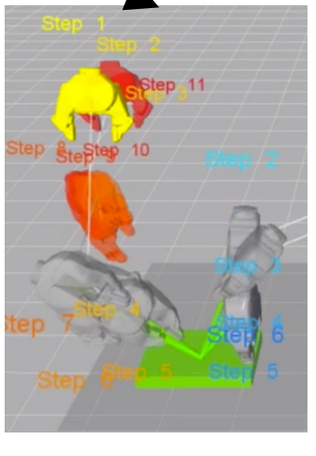




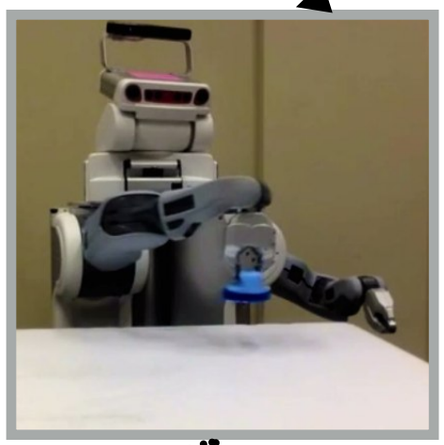


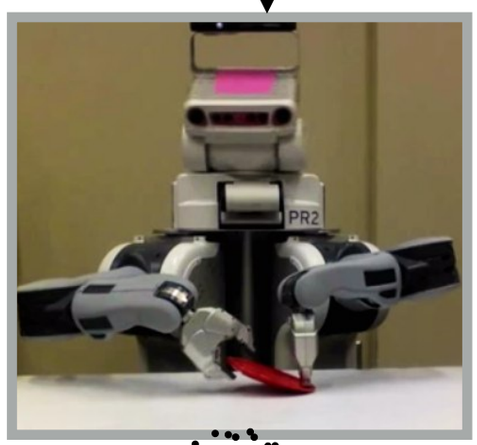


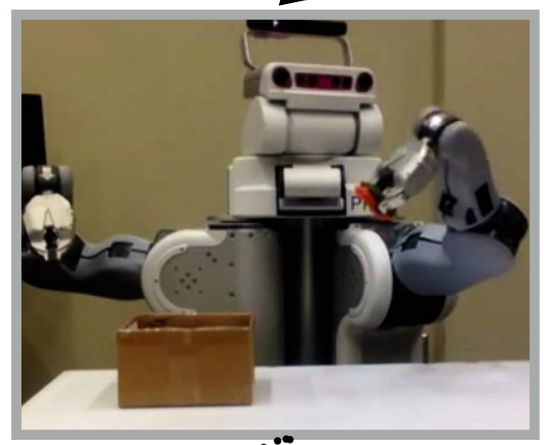


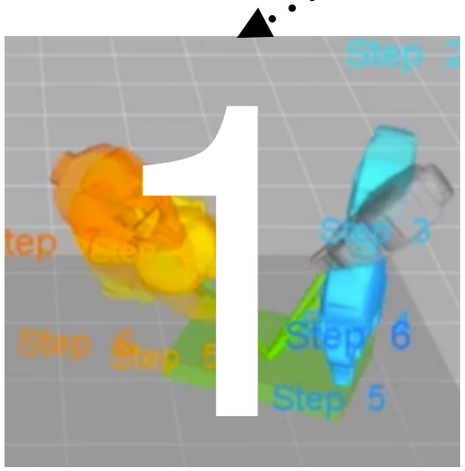


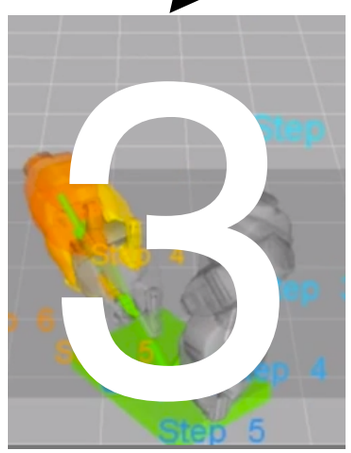
WORKER

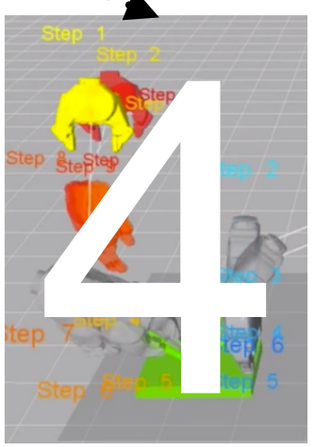






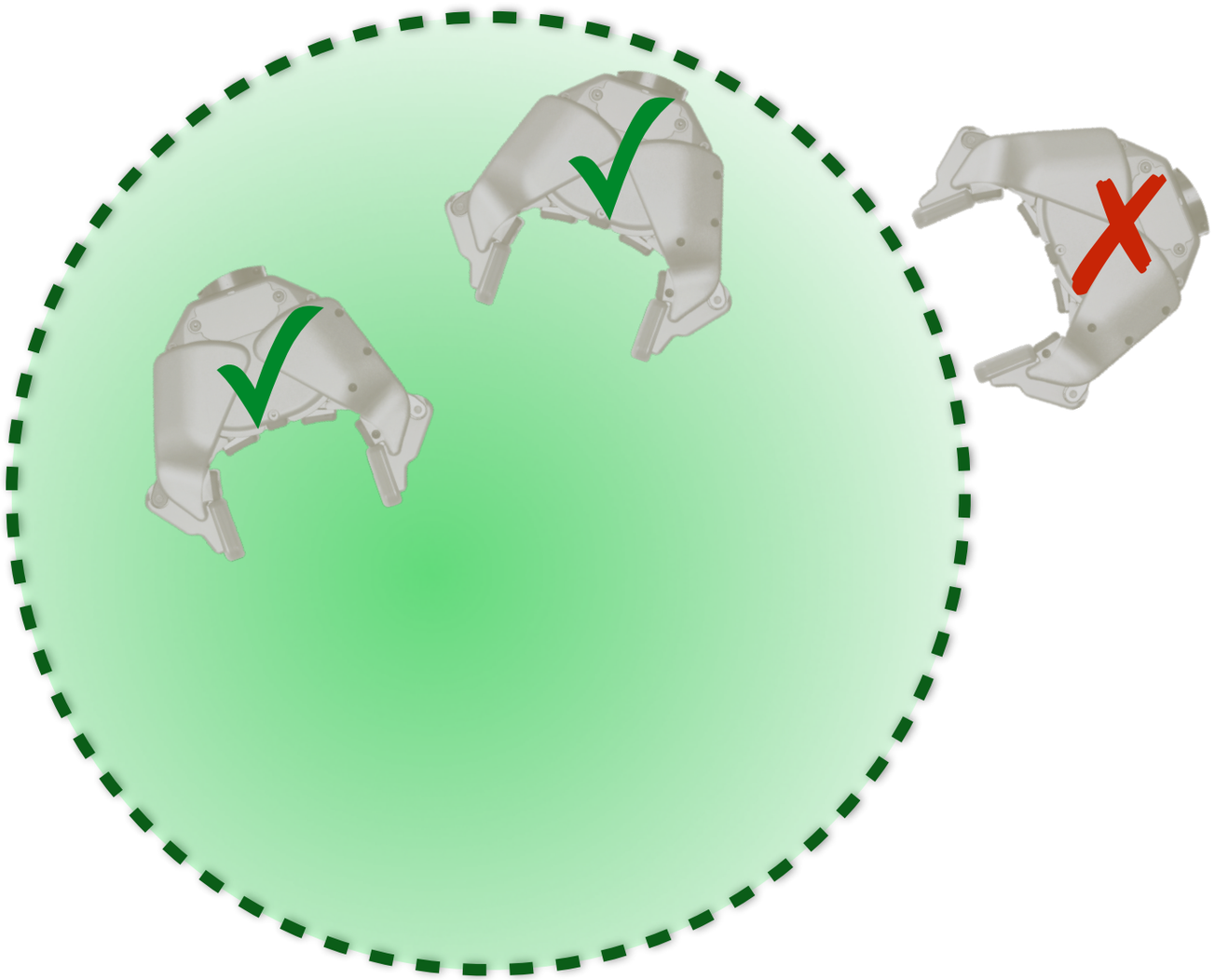




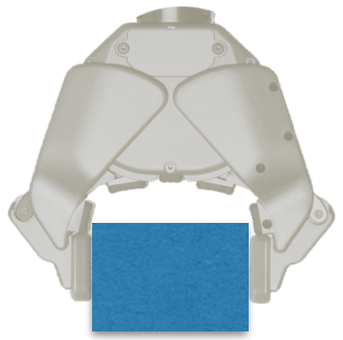


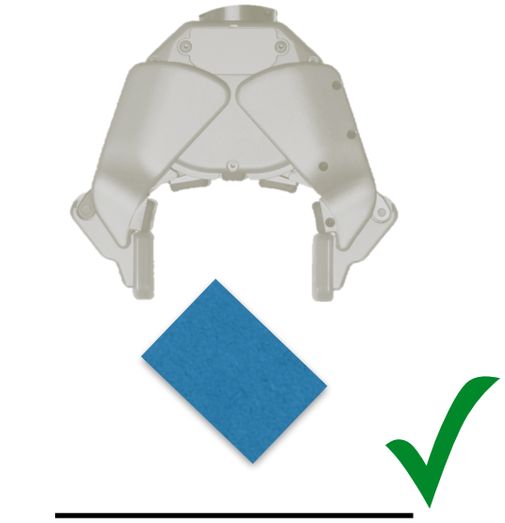
METRICS

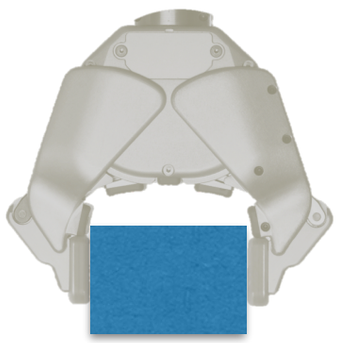
Reachability
(100 scenarios / action)

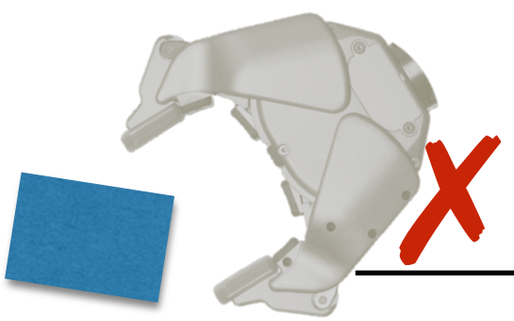


Success
(10 scenarios / action)





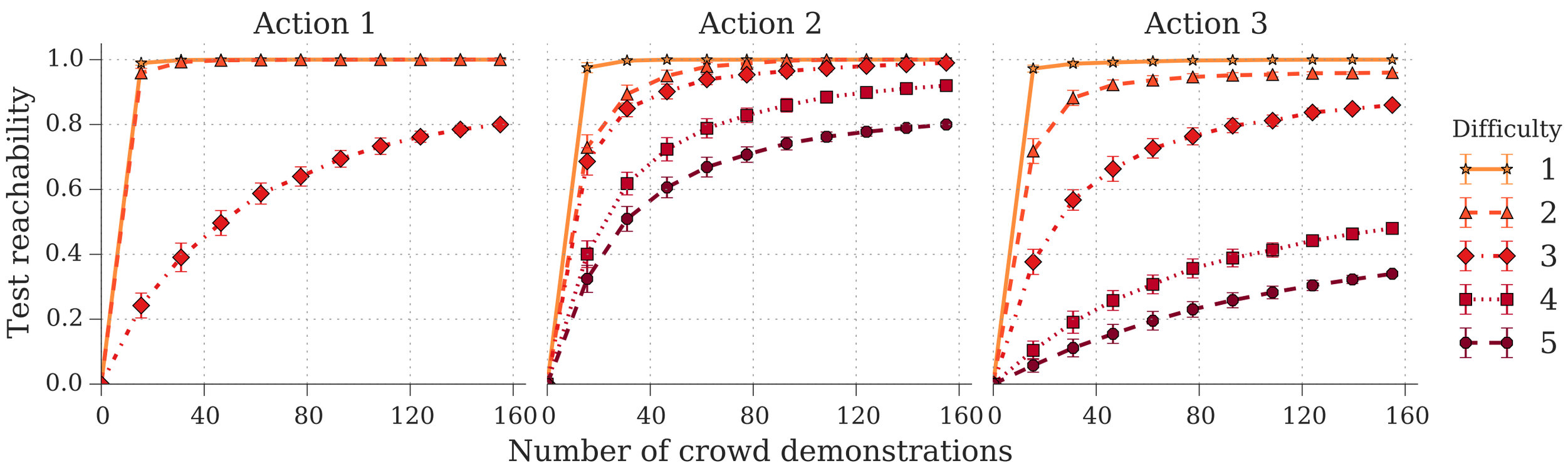


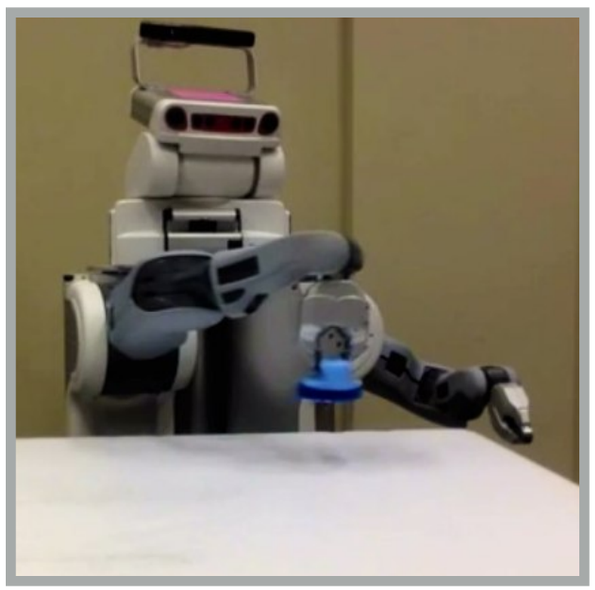


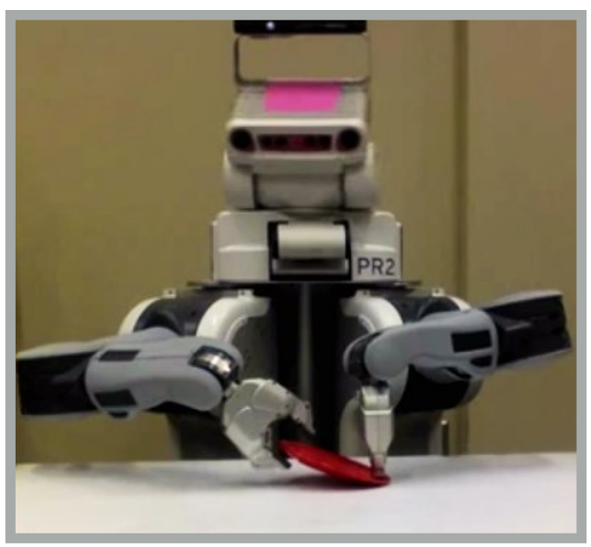
EVALUATION

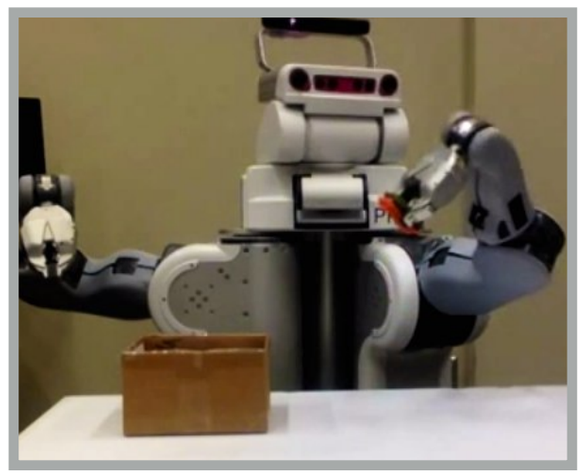
- Directions, videos, ~45 minutes of work
- 31 people x 15 demonstrations each
  = 465 demonstrations in total
- Metrics
  - reachability (100 scenarios / action)
  - success (10 scenarios / action)

FINDINGS: REACHABILITY

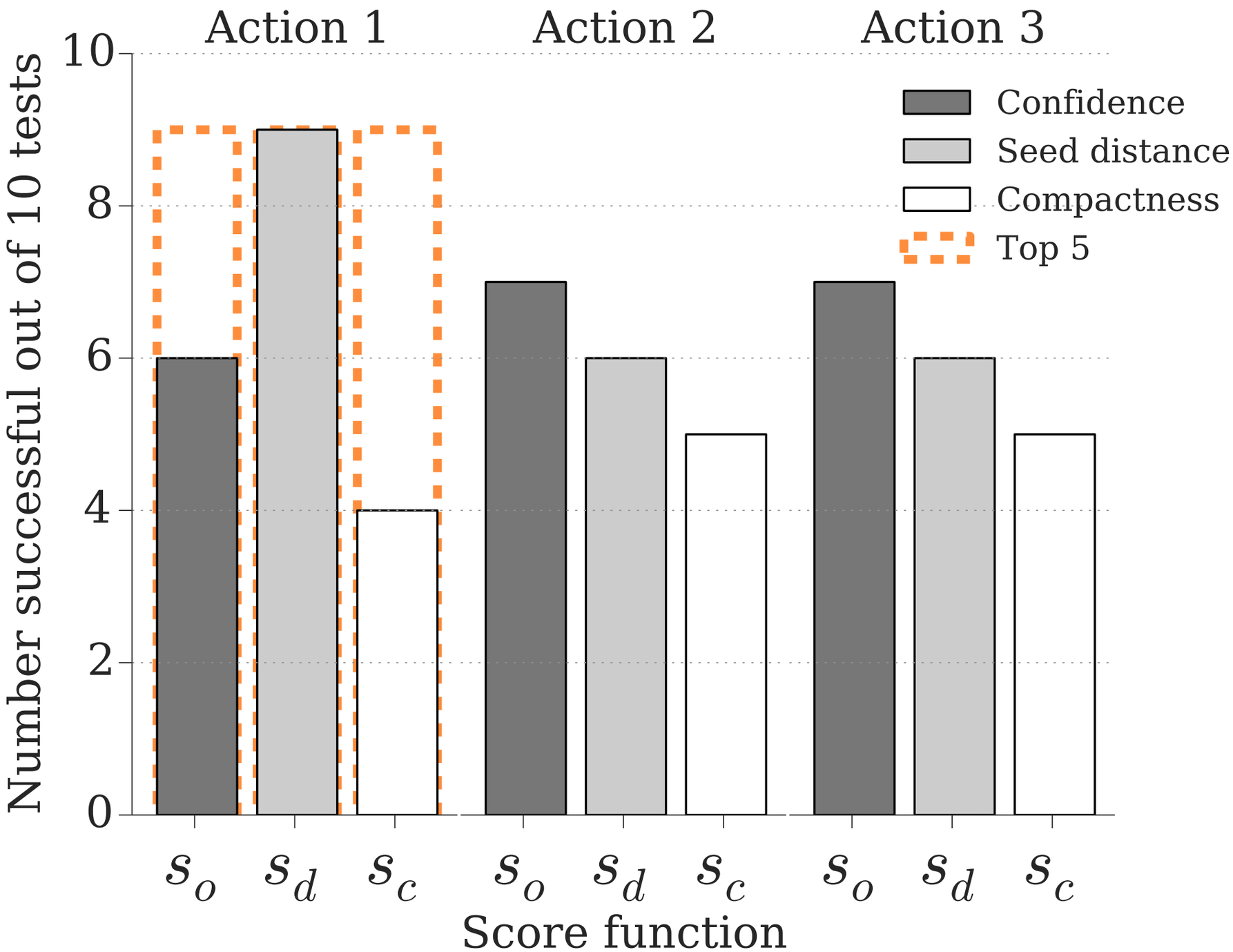




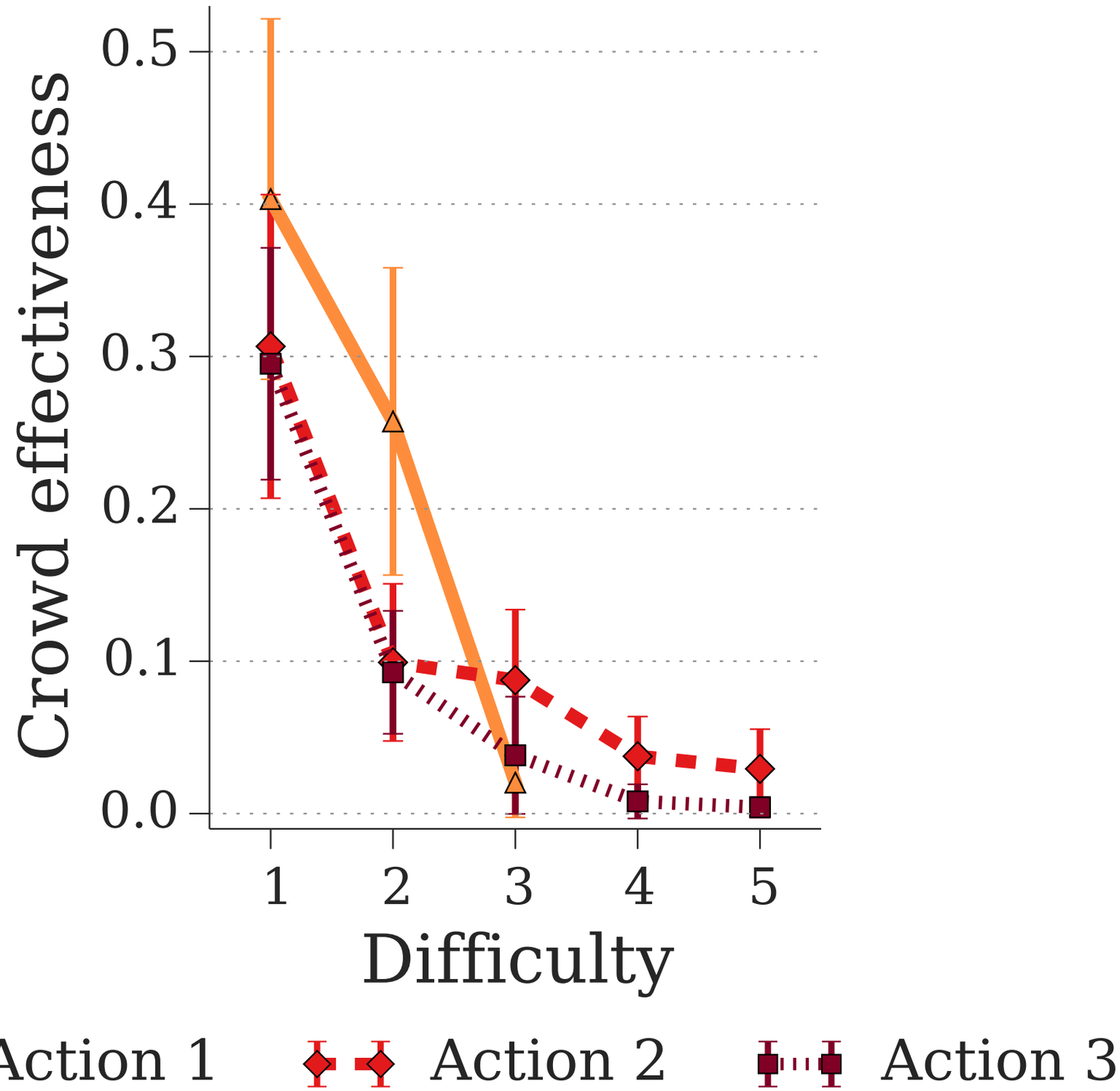




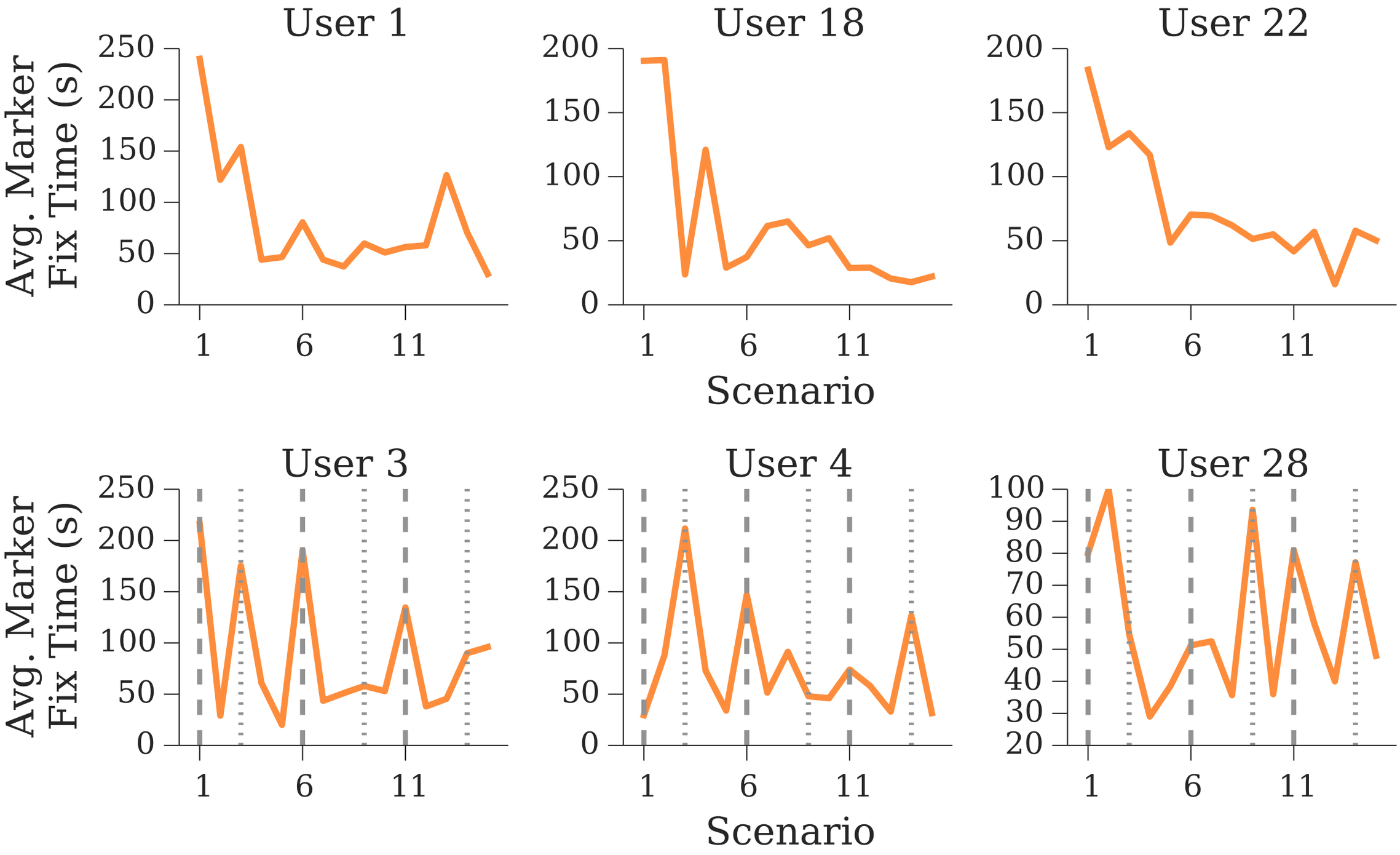
FINDINGS: SUCCESS



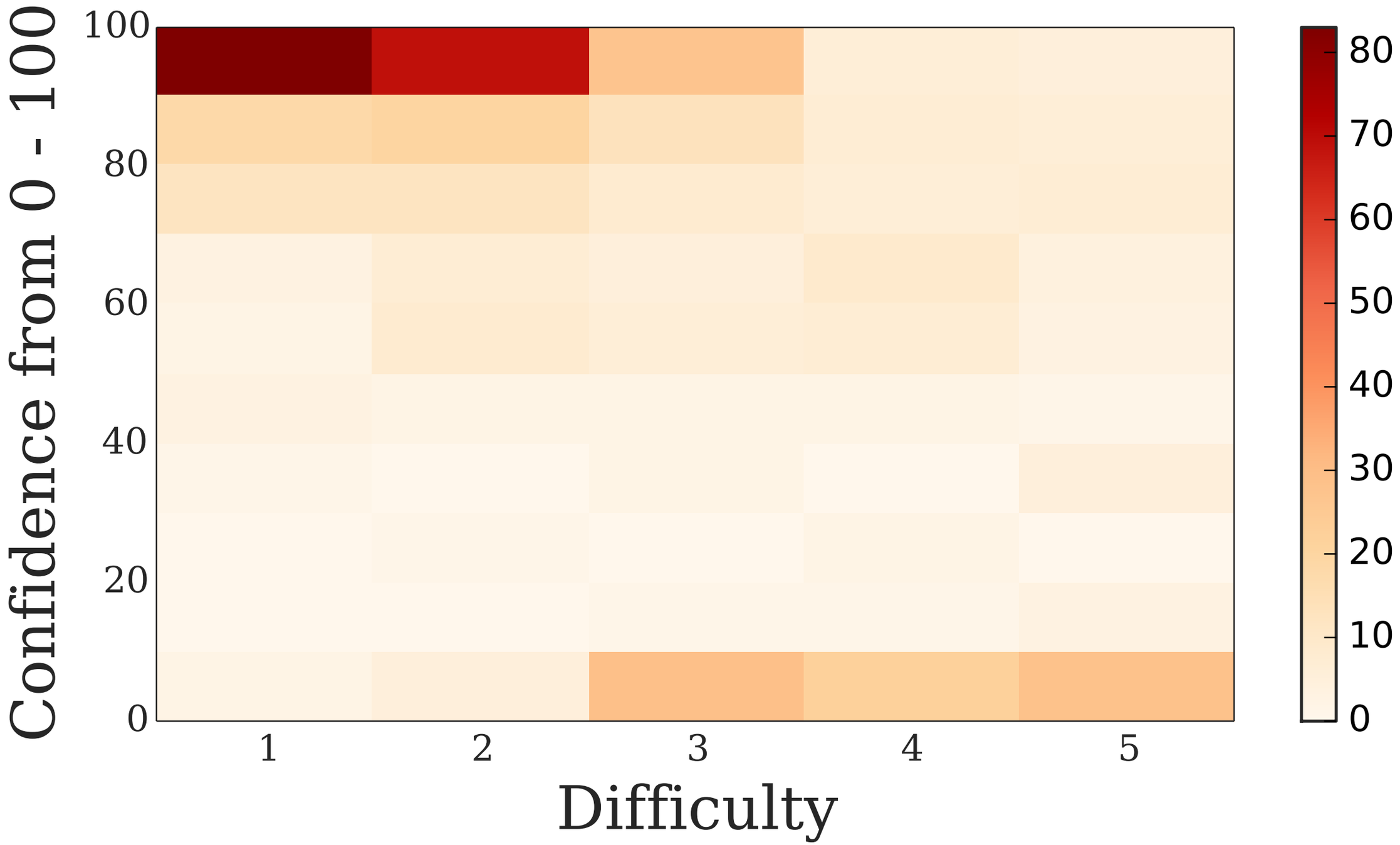
FINDINGS CROWD EFFECTIVENESS



FINDINGS: CROWD LEARNING



FINDINGS: CROWD SCORING



FINDINGS

- Reachability improves with more data
- **Achieved >= 70% on success metric**
- Choice of score function is difficult, important
- Crowd learns
- Need coarser-grained crowd rating system

LIMITATIONS

- No automatic success testing
- Difficult UI
- Crowd data collected in batch mode
- Not real crowdsourcing

SUMMARY

- Goal: **Improve generalizability** of actions in robot programming by demonstration
- Instance-based active learning
- Crowdsourced ~450 demonstrations
- Improved task reachability and success

Thank you

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Rajesh P. N. Rao	rao

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