Causal Robot Communication Inspired by Observational Learning Insights


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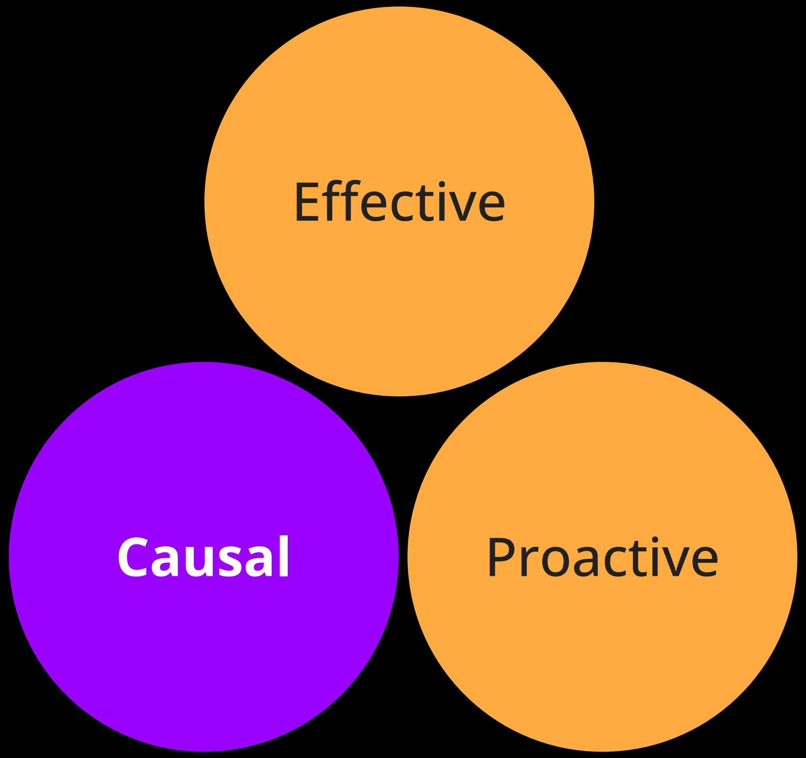
MIRRORLab
Mines Interactive Robotics Research

Motivation

For robots to **be trusted and gain acceptance**, they need to

- **Communicate effectively**
  - about intended actions
- **Proactively explain**
  - their intended behaviors and
  - the rationale for those behaviors
- **Determine which actions are causal** (Our focus)
  - So those action can be included in explanations
  - Causal: directly gives rise to the desired outcome



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How do we determine causal actions from a robot's underlying action sequence?

1. The **relevance** of observational learning
2. **Insights**
   - Social Cognitive Learning Theory (SCLT)
   - Causal markers
3. **How we applied these insights**

Behavior Learning & Imitation Learning

Behavior learning: *"the acquisition of attitudes, values and styles of thinking and behaving through observation of the examples provided by others (i.e., models)"*

Humans are observers!

Within behavior learning, **imitation learning is particularly relevant.**

- It studies how children and adults learn to imitate action sequences of others

Roboticists study the structure and its use!

Causal action reasoning during action sequences studied extensively!

Does imitation learning sound similar?

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Imitation Learning in Robotics

Leveraged in the learning by demonstration community

- **Robot: the learner**, learning from human demonstrations

Here, we argue they can be applied to **causal robot communication**

- **Human: the learner**, observing the robot while it is communicating

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Imitation Learning

Two types of behavior patterns:

1. Rational Learners

- Learn to ***extract and produce the most causal actions*** needed to achieve some outcome
- Not copying exactly the same sequence demonstrated by others

2. Over-imitation

Copy ***not only necessary and causal behaviors*** but ***also unnecessary and non-causal behaviors***, because they believe those behaviors are **normative**

Yet, HRI studies show children and adults are **less socially motivated to imitate robots' normative behaviors**

(Sommer et al., 2020; Maeda et al., 2021)

So rational paradigm is more applicable

Related Work: Causality in Robotics

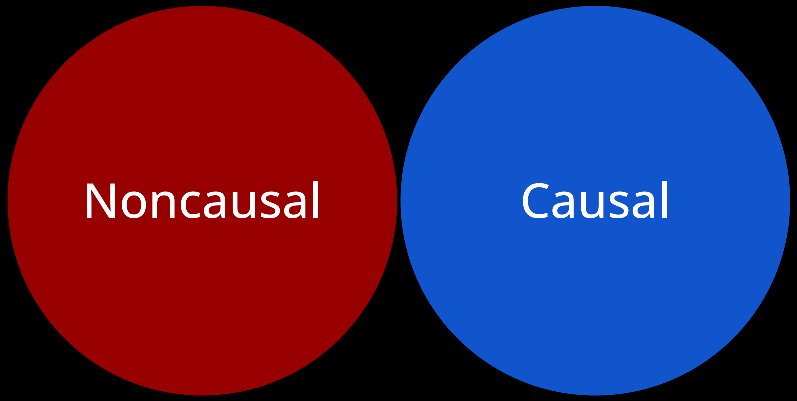
Non-psychology inspired approaches: **key states & actions**

- entropy-based
- formulated as optimization problems

The highly relevant observational learning is relatively underexplored

Research show **humans differentiate between causal and noncausal actions in their imitations**

Similarly, robots must also differentiate. Otherwise, it will be too verbose or not effective.



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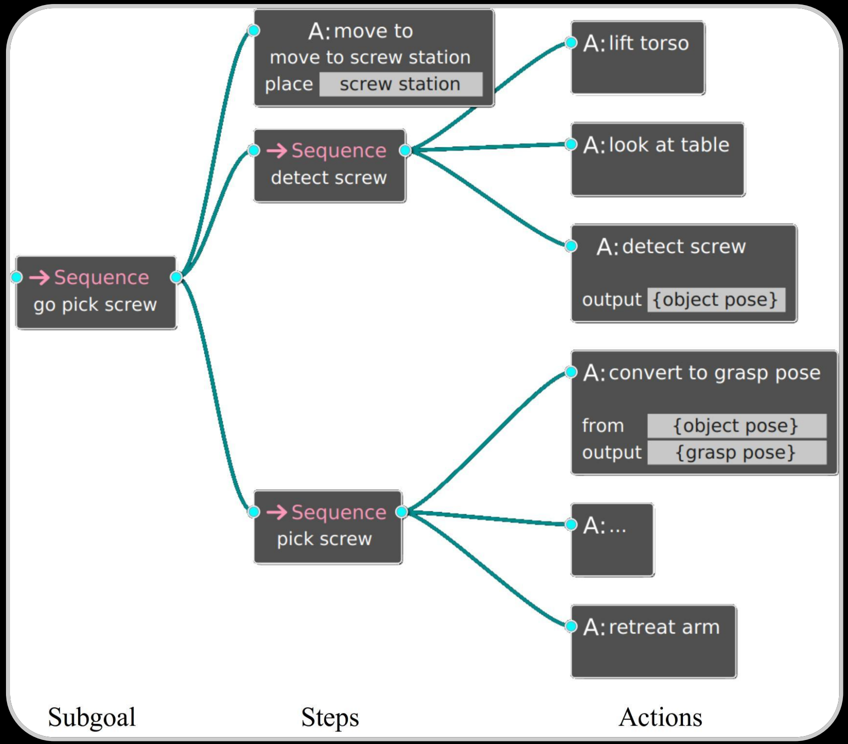
Related Work: Action Sequences in Robotics

Also known as: ***Robot Task Representation***

In our work, we encoded robot behavior with **behavior tree:**

- An expressive **action sequence method** for hierarchical task specification and execution
- Popular in AI, gained traction in robotics



A simplified behavior tree

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1. Behavior learning
2. Imitation learning in and outside of robotics
3. Causality and action sequences in robotics

What are the observational learning insights?

How to apply them to robot communication?

Insights From Observational Learning

Social Cognitive Learning Theory (SCLT)

- A key, validated theory from observational learning
- It seeks to **explain how humans observe & learn action sequences**

When a robot attempts to communicate the intent underlying its action sequence,

the robot can be viewed as "a model" and **the human as "an observer"**.

↑ *The theory is highly relevant!*

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Social Cognitive Learning Theory & Implications

Four subprocesses & its implications for robot model & human observer

1. **Attention**: Observers must attend to and perceive the modeling episode to profit from guidance (Yussen 1974)
   a. Robots should address people before communicating
   b. Attention is key to robots' success at initiating communication
2. **Retention**: Observers must discriminate and symbolically represent the modeled behavior to make it easy to recall (Bandura and Barab 1971)
   a. Robots must provide an easily memorable summary of its internal states
      i. to facilitate accurate symbolic representation of those states in the mind of their interlocutors
   b. organize and select high-level behaviors first rather than directly externalizing its arbitrary internal states

Social Cognitive Learning Theory & Implications

1. Attention
2. Retention
3. **Motor skills**: Observers need key motor skills to translate knowledge into physical movements
   a. **Probabilistic methods might be troublesome**
      i. They produce non-human-like and non-deterministic robotic movements
      ii. Those may not lead to quality physical responses
4. **Motivation**: Observers must be motivated to minimize departure of learned actions from demonstrations
   a. Ideally, while communicating with a particular outcome, a robot must motivate humans and remain aware of theirs motivations in order to re-motivate them as needed

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More Insights From Observational Learning

We have discussed humans observing (robot) models

How could models/demonstrators best model their behavior?

Research shows we as infants **only copy causal action sequences**
- i.e., we will ignore adjacent, non-causal, unnecessary actions

Research shows **imitators use intentionality to infer causal actions**
- Intentional actions with markers like "there" and "here" are assumed to be purposive to understand causality

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Applying The Insights

[Under review] Zhao Han and Holly A. Yanco. **Communicating Missing Causal Information to Explain a Robot's Past Behavior**. *ACM Transactions on Human-Robot Interaction (THRI).*

Research question: how a robot could communicate missing causal information

Motivation: Robots need to explain its **previous** actions in an **environment that has changed** due to its actions

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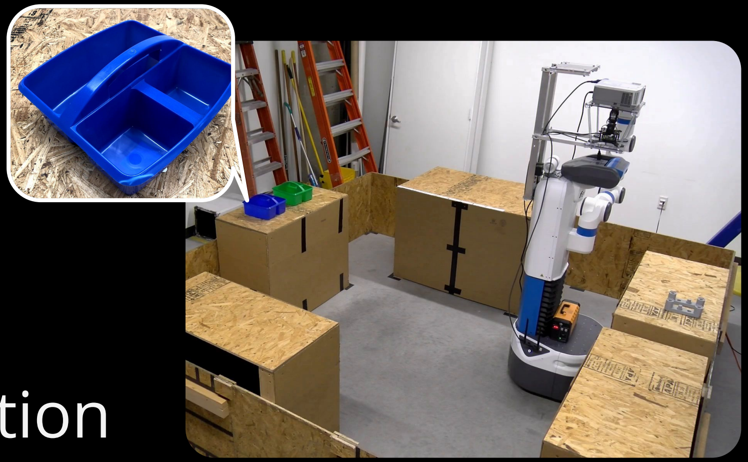
Applying Insights: Explaining a Robot's Past Behavior

Tasks: Participants needs to infer



1. where the robot grasped a misrecognized object
2. where a ground obstacle led to a detour
3. where an object was placed into a wrong caddy section

In these scenarios, the robot cannot communicate the causes directly as it is not aware of perception failures (1&3) nor it is in a simplified world (2).

Conditions: **verbal** and/or **projection** indicators with or without a **replay** of a robot's past physical actions

We programmed the robot selectively communicated **causal actions that would lead to environment changes immediately after the actions**.

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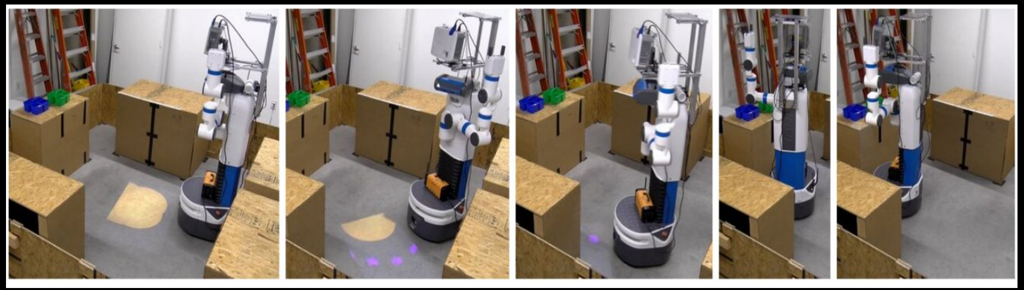

"Ok. I didn't **go** straight to the caddy table because there was something on the floor in front of me on my left."

"Ok. I **picked** up a gearbox bottom from here."

"Ok. I **placed** the gearbox bottom into the near right section of the caddy."

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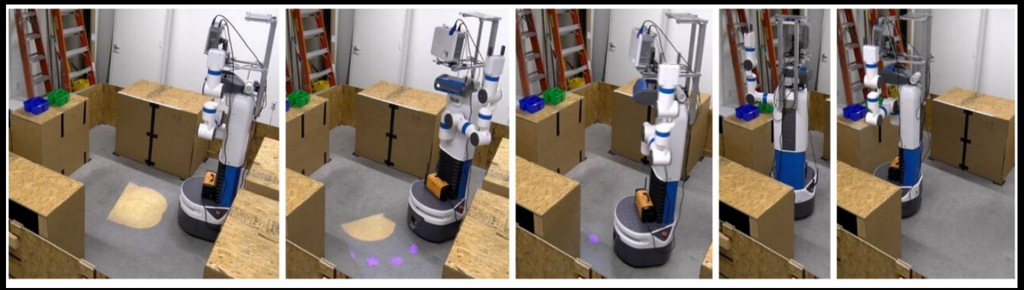

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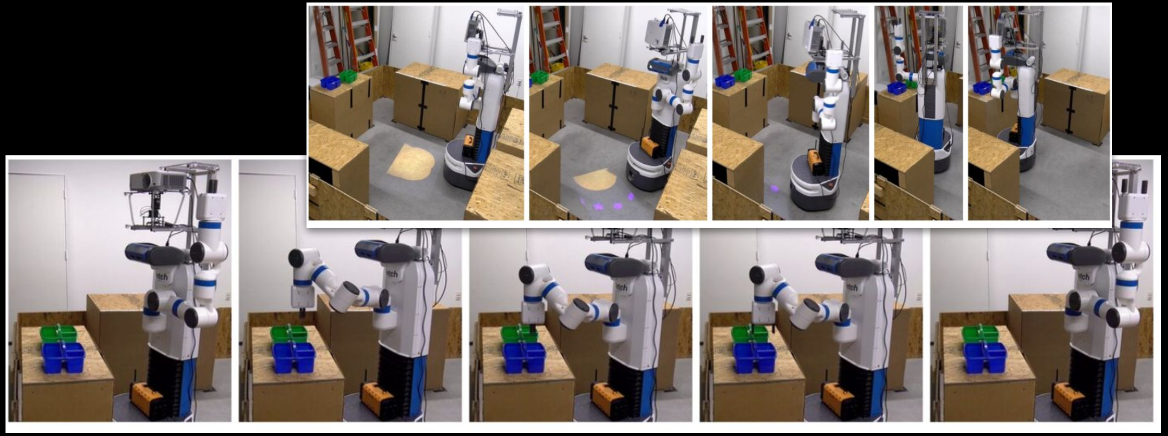
Insights Applied from Social Cognitive Learning Theory



1. "Ok" was used to draw **attention**
2. Robot speech was selected to convey key, memorable episodes, to improve **retention** of the robot's actions and communications in humans' memory. (high-level behaviors regarding nearby objects, not uninterpretable internal state information)
3. Speech was timed to avoid talking during non-human-like arm movements that would be hard to **reproduce** even imaginarily.

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Dependent Variables and Results

Participants were asked

- **whether they inferred** each missing causal information,
- **the confidence** in their inferences, and
- **how fast** they were.

Best: Combining replay with verbal and projection indicators

Verbal indicators alone worked the best for placement inferences
Mixed reality markers alone were the best for navigation inferences

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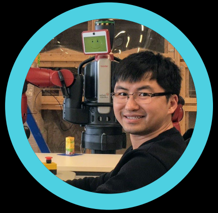

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Main Takeaways

1. **Observational learning is highly relevant** to **causal robot communication**: *robot models, human observers*.
2. We drew **insights from Social Cognitive Learning Theory**: attention, retention, motor skills, and motivation.
3. We discussed **implications** and applied them to **enable a robot to explain its past behavior by communicating missing past causal information**.
4. **Participants** were **able to infer them with confidence**.