

Introduction to **Human-Robot** **Interaction**

Yuna Hwang, Dakota Sullivan | Spring 2026

Learning Outcomes

1. Introducing Don Norman's Gulf Model in the context of HRI
2. Exploring methods to address these HRI challenges
3. Understanding existing efforts to address the Gulf of Execution in HRI

From *Building* Robots to *Using* Robots



What is **Human-Robot Interaction (HRI)** ?

Field of study dedicated to **understanding, designing, and evaluating robotic systems for use by or with humans**



What is **Human-Robot Interaction (HRI)** ?

- **Scope:** focuses on design, communication, control, and user experience in various problem domains



What makes HRI hard?



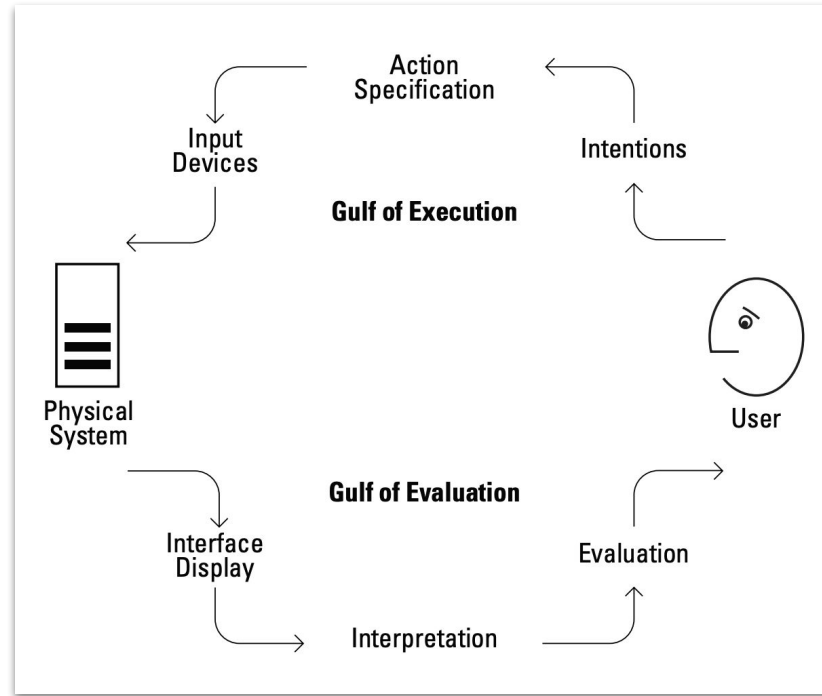
What makes HRI **hard**?



→ People have **goals/intentions** when interacting with a robot, but **don't always know how to express them in ways the robot understands**

Don Norman's Gulf Model

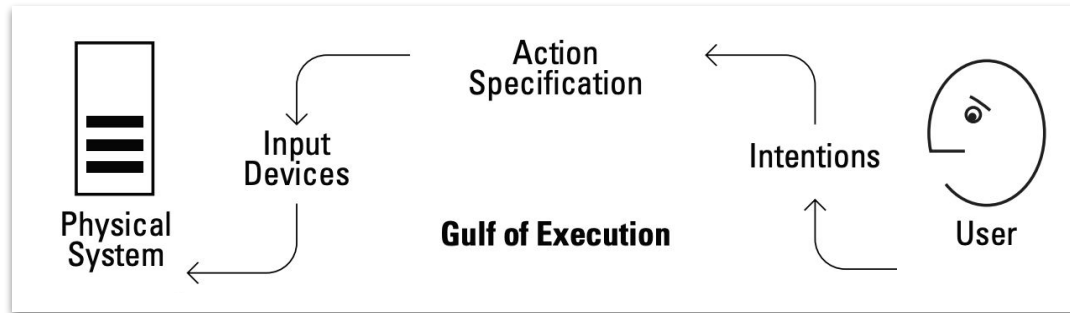
"...where they try to figure out how it operates..."



"...where they try to figure out what happened."

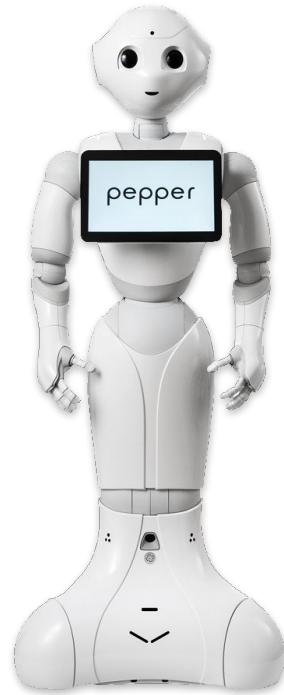
Dubberly et al. What is Interaction? Are There Different Types?. 2012.
Don Norman. The Design of Everyday Things. 2015.

Gulf of Execution



→ The Gulf of Execution is the difference between a **users intentions** and **what the system allows**.

Gulf of Execution in HRI



Gulf of Execution in HRI

expectation

Visual Sensing

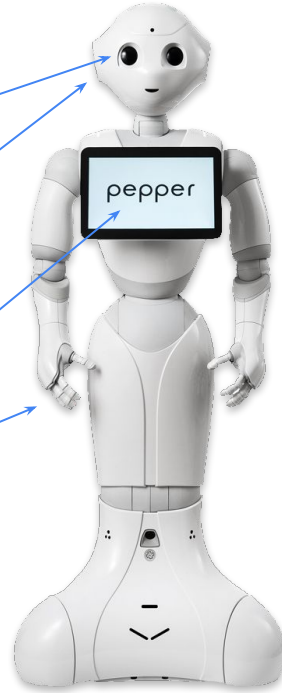
Gaze, facial recognition

Verbal Sensing

Conversation, Speech

Touch Sensing

Tablet & Object grasping



reality

Visual Sensing

Facial detection

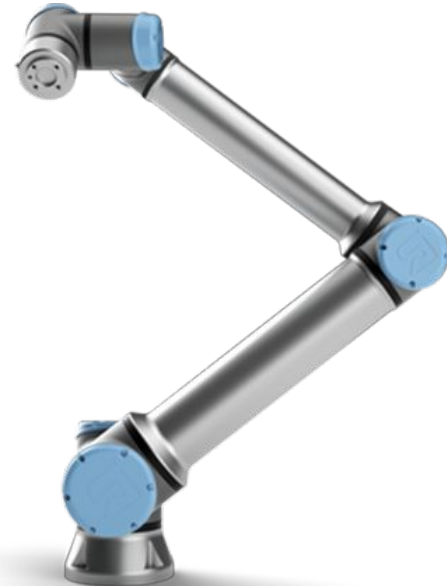
Verbal Sensing

Speech

Touch Sensing

None

Gulf of Execution in HRI



Activity 1: Identifying the Gulf of Execution

What can be some examples of a mismatch between a user's expectations of a technology and what that technology allowed you to do (*i.e.*, Gulf of Execution)?



Roomba; user might want it to clean kitchen only. How to set the zone? App? voice?



BellaBot, example: user might want to send an empty dish back. How to command? Voice? Screen?¹³

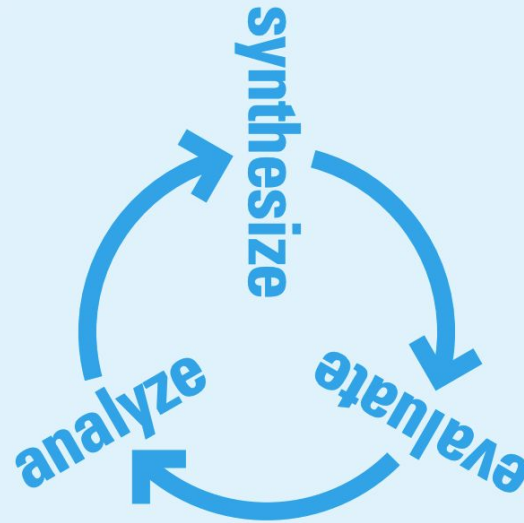
HRI Methods

How do we do this?

A typical HRI research pipeline includes a **“design process”**

design process

The design process viewed as “problem solving” (Jones, 1976), “problem seeking” (Peña, 1987) or “turning existing situations into preferred” (Simon, 1969) is a variation on the creative process.



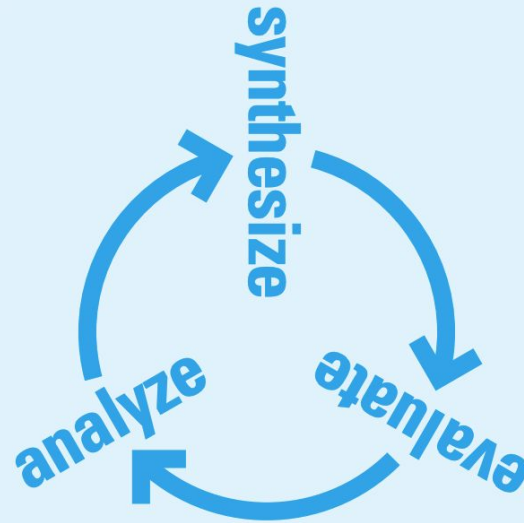
HRI Methods

Analysis

- Understanding the problem space, the users, their contexts, and the technology
- **Goals:**
 - ◆ Reveal pain-points, unmet needs
 - ◆ Understand user goals, behavior, or environment
 - ◆ Identify mismatches (e.g., gulf of execution)

design process

The design process viewed as “problem solving” (Jones, 1976), “problem seeking” (Peña, 1987) or “turning existing situations into preferred” (Simon, 1969) is a variation on the creative process.

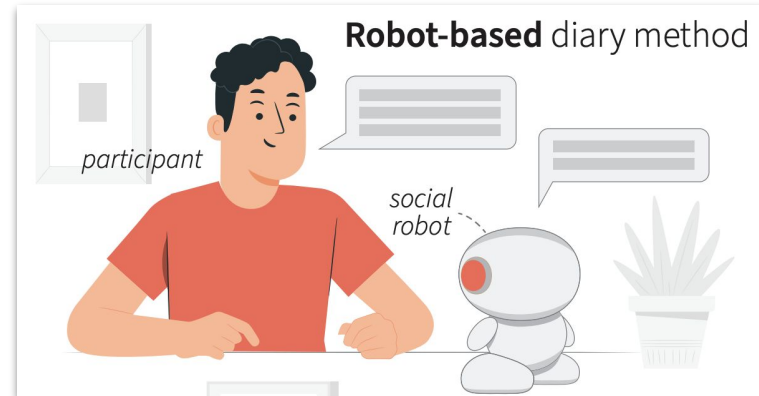
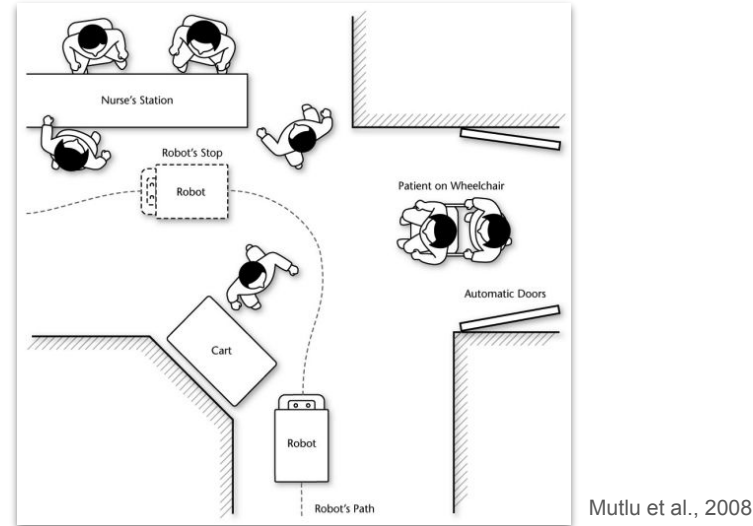


HRI Methods

Analysis

→ Methods:

- ◆ Ethnography
- ◆ Contextual inquiry
- ◆ Diary studies
- ◆ Task analysis



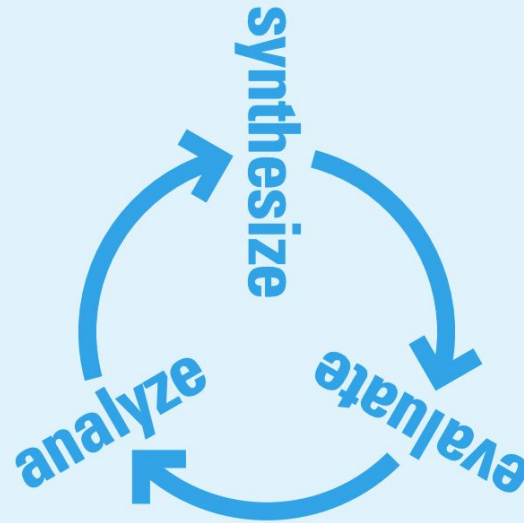
HRI Methods

Synthesis

- Generating design solutions based on the analysis. Includes ideation, sketching, modeling, prototyping etc.
- **Goals:**
 - ◆ Explore multiple design directions
 - ◆ Translate insights into tangible design concepts
 - ◆ Develop interfaces, interaction models, or capabilities

design process

The design process viewed as “problem solving” (Jones, 1976), “problem seeking” (Peña, 1987) or “turning existing situations into preferred” (Simon, 1969) is a variation on the creative process.



HRI Methods

Synthesis

→ Methods:

- ◆ Participatory design
- ◆ Scenario-based design
- ◆ Prototyping
- ◆ Wizard-of-Oz



Lee et al., 2022



Koike et al., 2023

HRI Methods

Evaluation

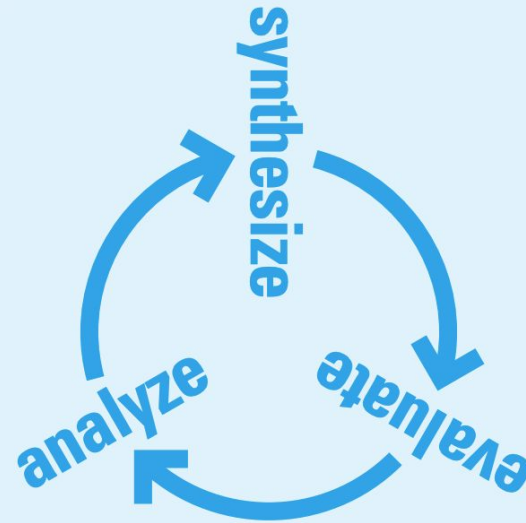
→ Testing whether solution effectively address identified problems and meets user needs.

→ **Goals:**

- ◆ Assess usability and effectiveness of system or prototype
- ◆ Identify remaining gaps
- ◆ Refine the solution based on data

design process

The design process viewed as “problem solving” (Jones, 1976), “problem seeking” (Peña, 1987) or “turning existing situations into preferred” (Simon, 1969) is a variation on the creative process.

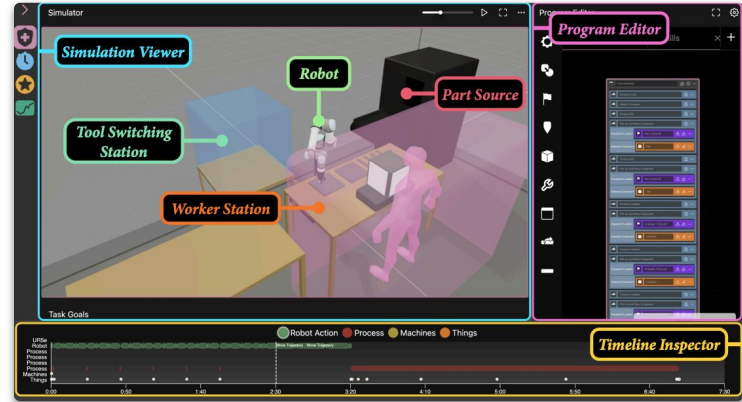


HRI Methods

Evaluation

→ Methods:

- ◆ Usability testing
- ◆ User studies
- ◆ Field deployments



Sullivan et al., 2024



Hu et al., 2025

Activity 2: Addressing the Gulf of Execution

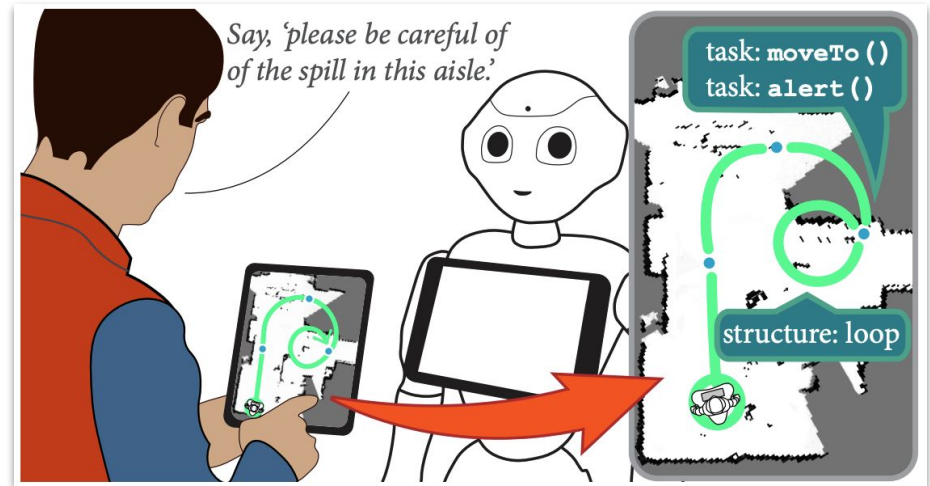
Given your examples of Gulf of Execution from Activity 1, **how might you apply some HRI methods (e.g., ethnography, participatory design, prototyping, or usability testing) to address the gap?**

- How would you **observe** the current interaction breakdowns or **identify** user needs and pain points?
- What **solutions** can you propose to address the examples from Activity 1?



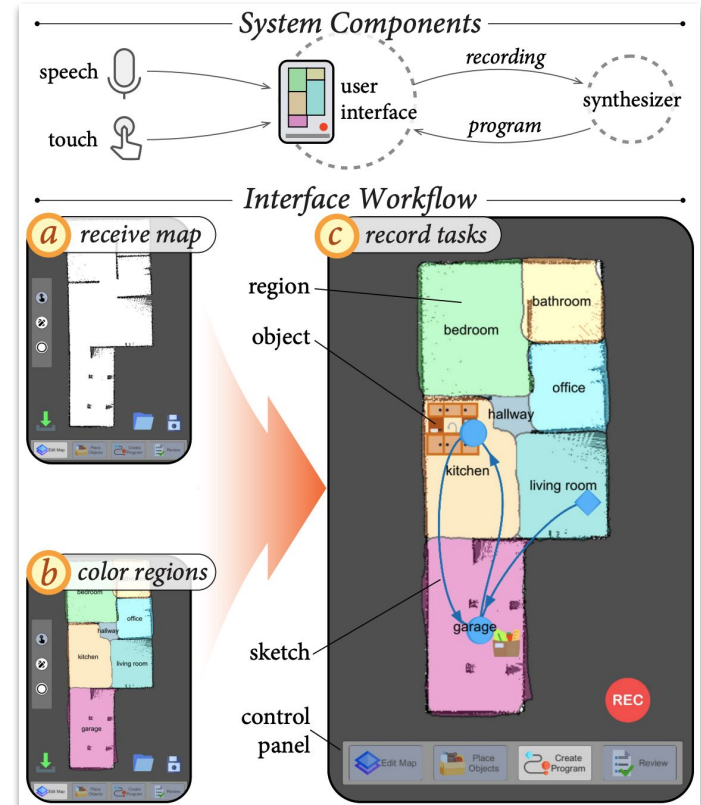
How HRI Tackles Gulf of Execution Challenges

- **Motivation:** It can be very challenging for novice users to program service robots



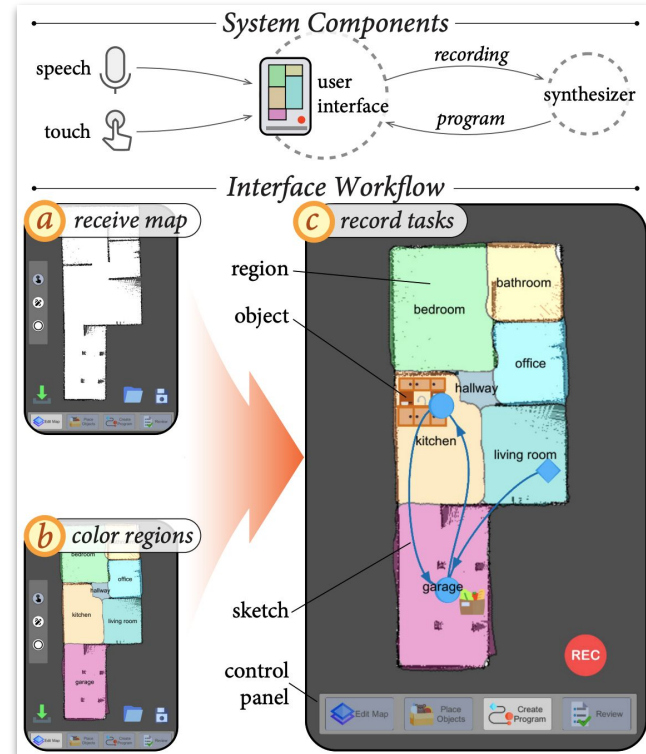
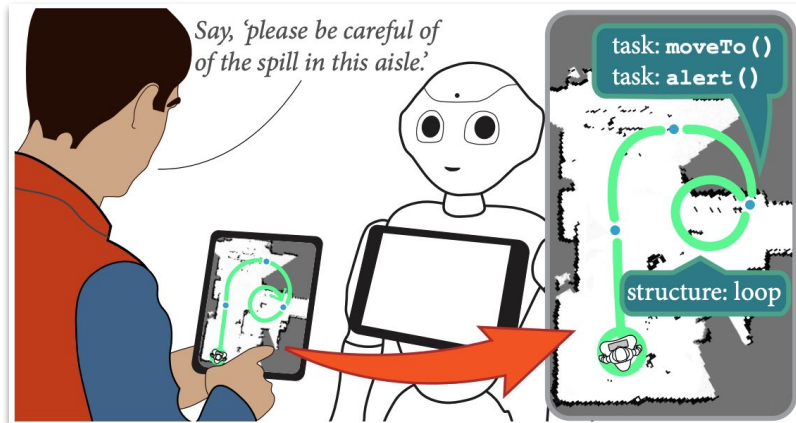
How HRI Tackles Gulf of Execution Challenges

→ **Goal:** Develop a convenient end user programming tool for novice users



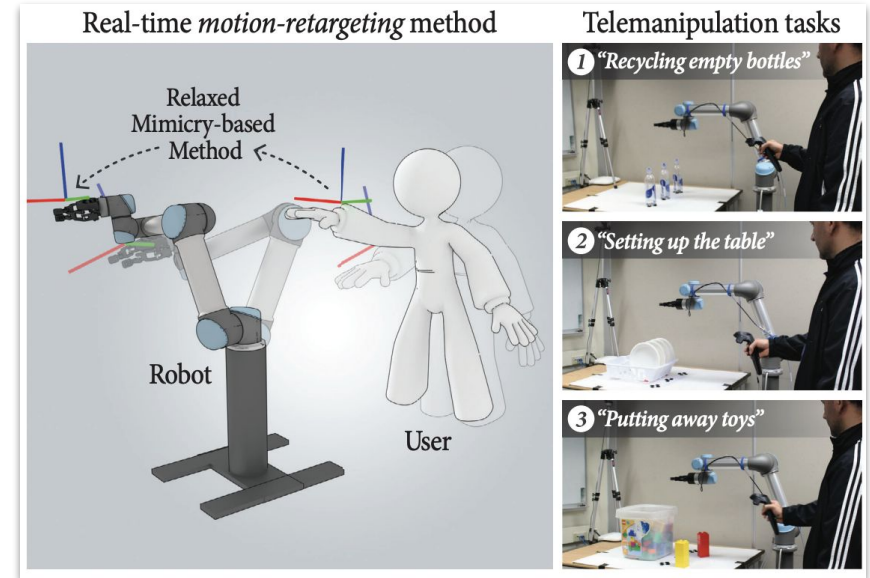
How HRI Tackles Gulf of Execution Challenges

- Addressing the Gulf of Execution:
Allow users a convenient medium to
input robot task requests



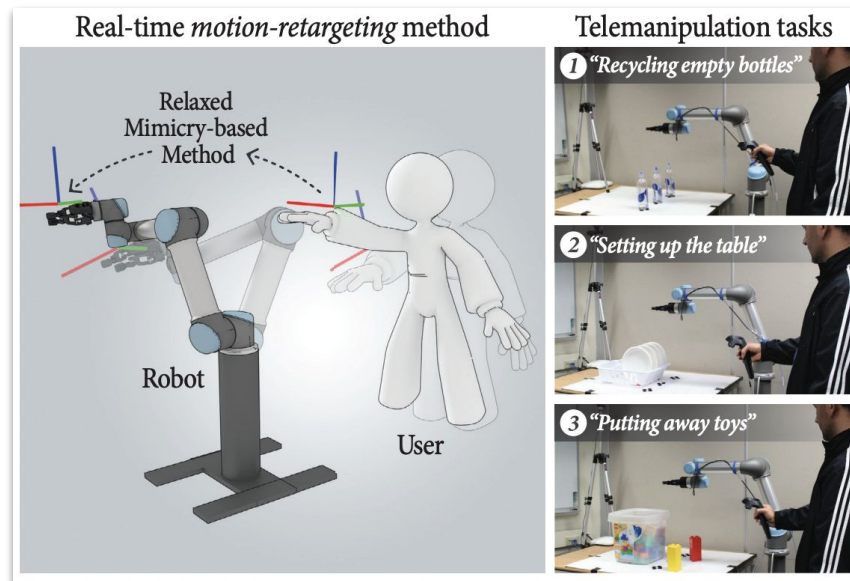
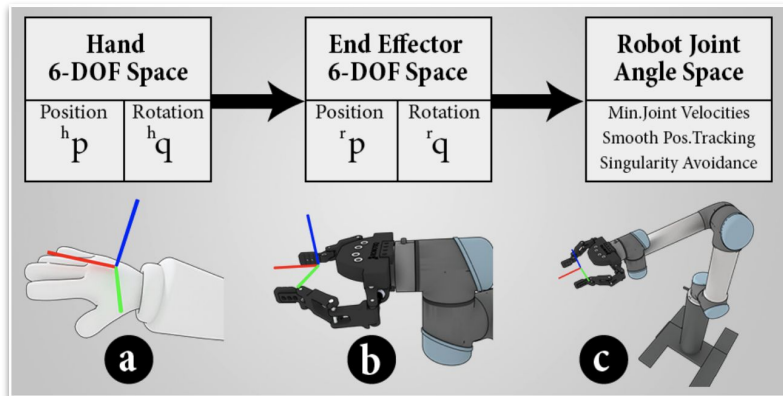
How HRI Tackles Gulf of Execution Challenges

→ **Motivation:** direct and effective control of a robot arm is hard, because robots have different kinematic and speed capabilities than a human arm



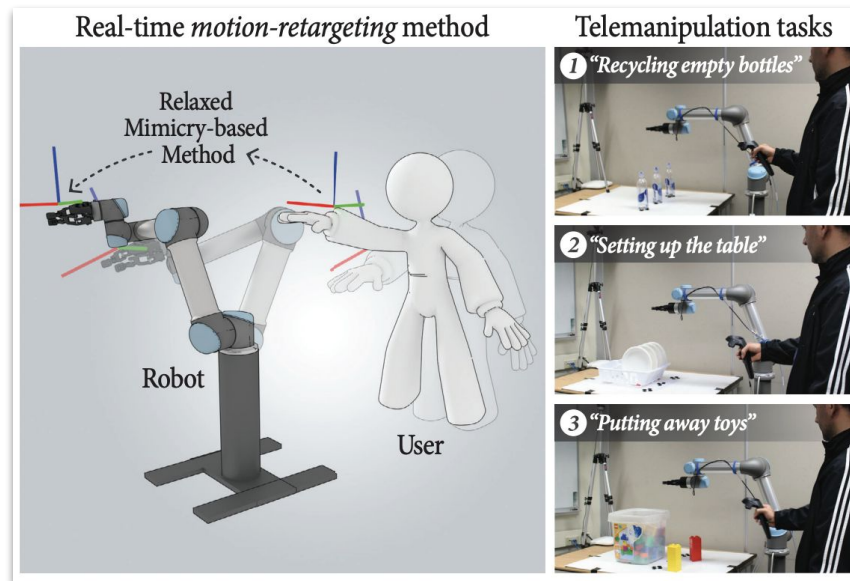
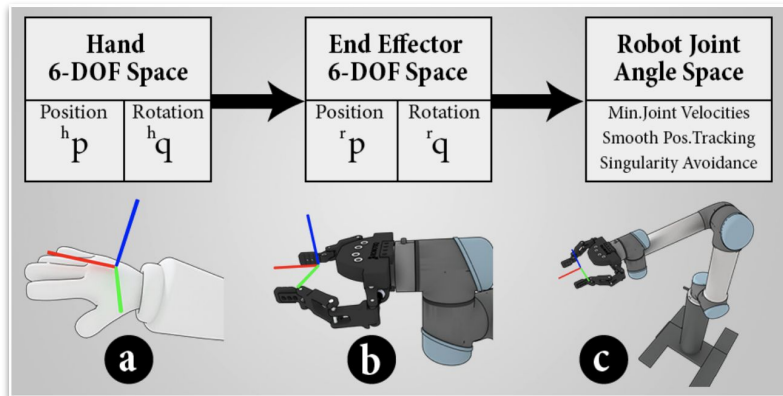
How HRI Tackles Gulf of Execution Challenges

→ **Goal:** Enable users to intuitively and effectively control the robot's arm through real-time mapping.



How HRI Tackles Gulf of Execution Challenges

- Addressing the Gulf of Execution:
Enable users to intuitively control robot arm movement for telemanipulation tasks



Review of Learning Outcomes

1. Introducing Don Norman's Gulf Model in the context of HRI
2. Exploring methods to address these HRI challenges
3. Understanding existing efforts to address the Gulf of Execution in HRI

Introduction to **Human-Robot Interaction**

Dakota Sullivan, Yuna Hwang | Spring 2026

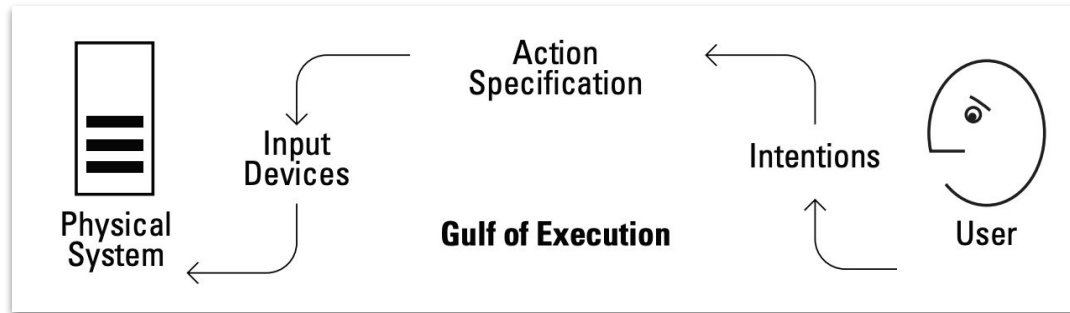
Review of Last Class

1. Introduced Don Norman's Gulf Model in the context of HRI
2. Explored methods to address these HRI challenges
3. Understood existing efforts to address the Gulf of Execution in HRI

Learning Outcomes

1. Exploring the Gulf of Evaluation
2. Examining current works to address this challenge in HRI
3. Discussing learning paradigms in HRI

Gulf of Execution



→ The Gulf of Execution is the difference between a **users intentions** and **what the system allows**.

Gulf of Execution in HRI

expectation

Visual Sensing

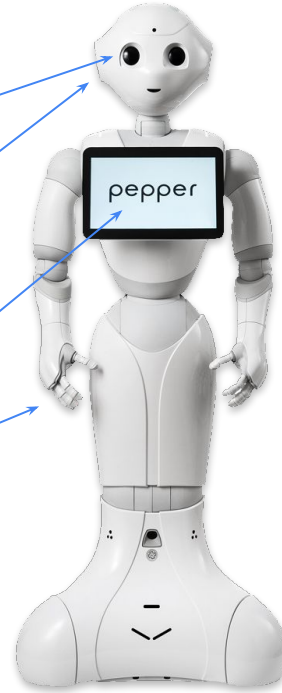
Gaze, facial recognition

Verbal Sensing

Conversation, Speech

Touch Sensing

Tablet & Object grasping



reality

Visual Sensing

Facial detection

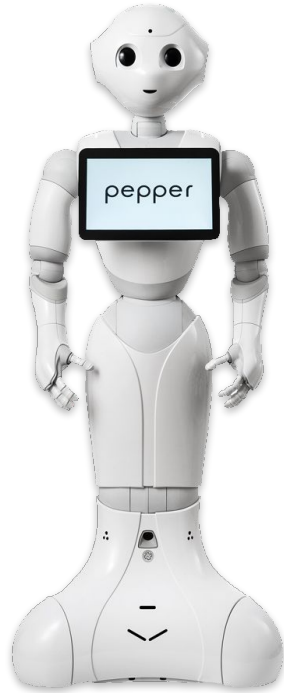
Verbal Sensing

Speech

Touch Sensing

None

Gulf of Execution in **HRI**



response

Gaze

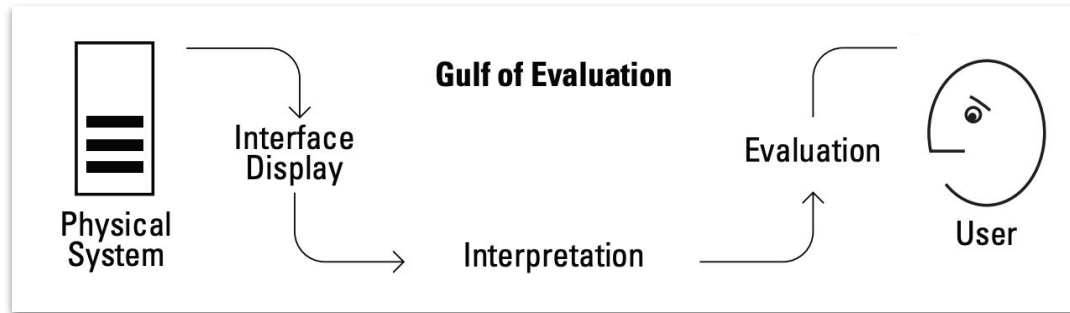
Speech

Mobility

Gestures

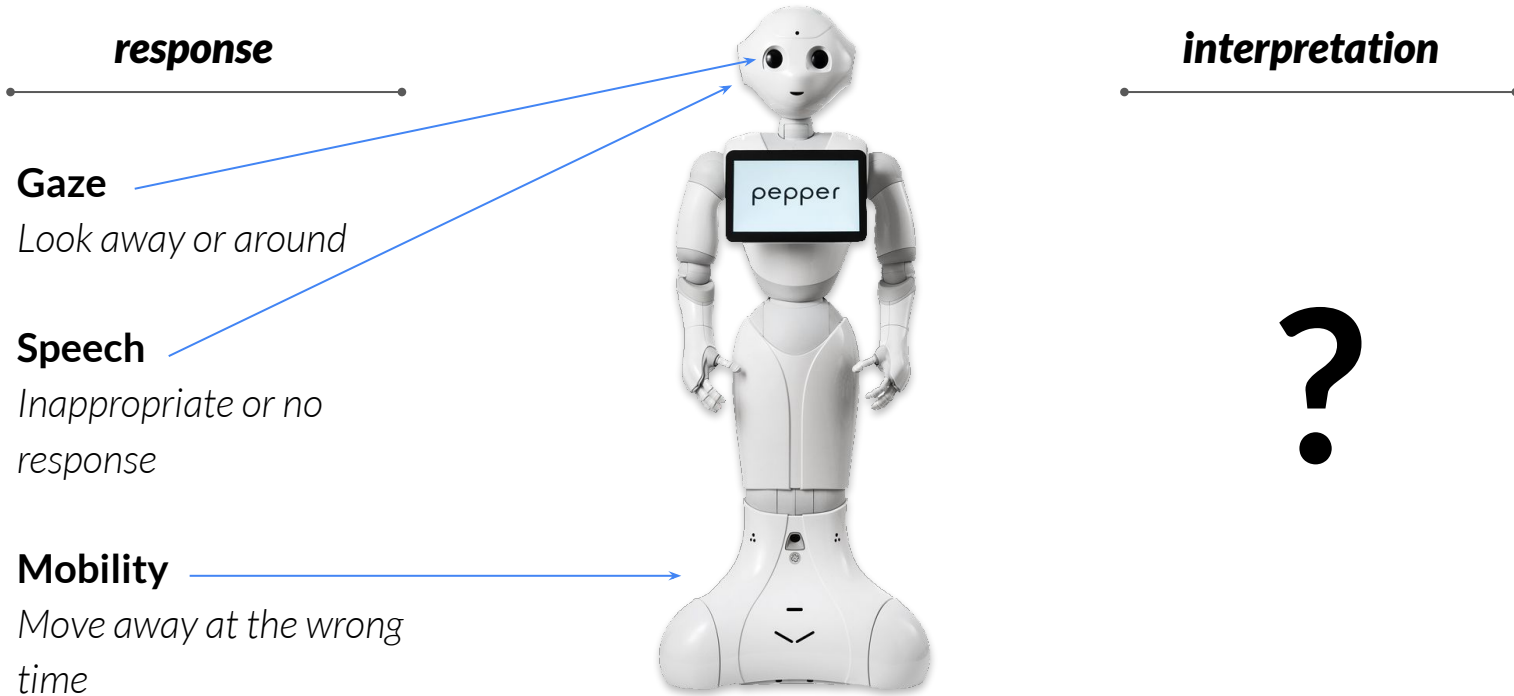
Text on Interface

Gulf of Evaluation



→ The Gulf of Evaluation is the difference between a **system's output** and the **ability of the user to interpret and evaluate** the output in terms of their goals.

Gulf of Evaluation in HRI



Gulf of Evaluation in HRI

Easy evaluation of robot actions



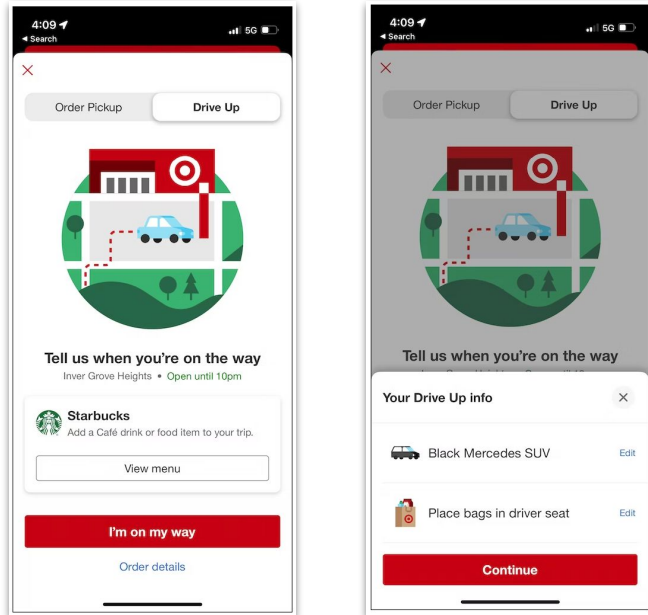
Gulf of Evaluation in HRI

Difficult evaluation of robot actions



Activity 1: Identifying the Gulf of Evaluation

What are some examples of a mismatch between a technology's output and a user's ability to evaluate and interpret that output (i.e., Gulf of Evaluation)?



Steps

1. *What is a technology you regularly use?*
2. *What is an output that technology produces?*
3. *What difficulties do you have in understanding that output?*
4. *Is this an example of the Gulf of Evaluation?*

Review of HRI Methods

Analysis

- Understanding the problem space, the users, their contexts, and the technology

Synthesis

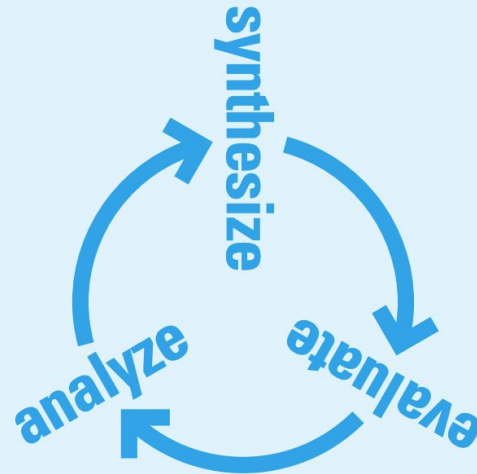
- Generating design solutions based on the analysis. Includes ideation, sketching, modeling, prototyping etc.

Evaluation

- Testing whether solution effectively address identified problems and meets user needs.

design process

The design process viewed as “problem solving” (Jones, 1976), “problem seeking” (Peña, 1987) or “turning existing situations into preferred” (Simon, 1969) is a variation on the creative process.



Review of HRI Methods

Analysis

→ Methods:

- ◆ Ethnography
- ◆ Contextual inquiry
- ◆ Diary studies
- ◆ Task analysis

Synthesis

→ Methods:

- ◆ Participatory design
- ◆ Scenario-based design
- ◆ Prototyping
- ◆ Wizard-of-Oz

Evaluation

→ Methods:

- ◆ Usability testing
- ◆ User studies
- ◆ Field deployments

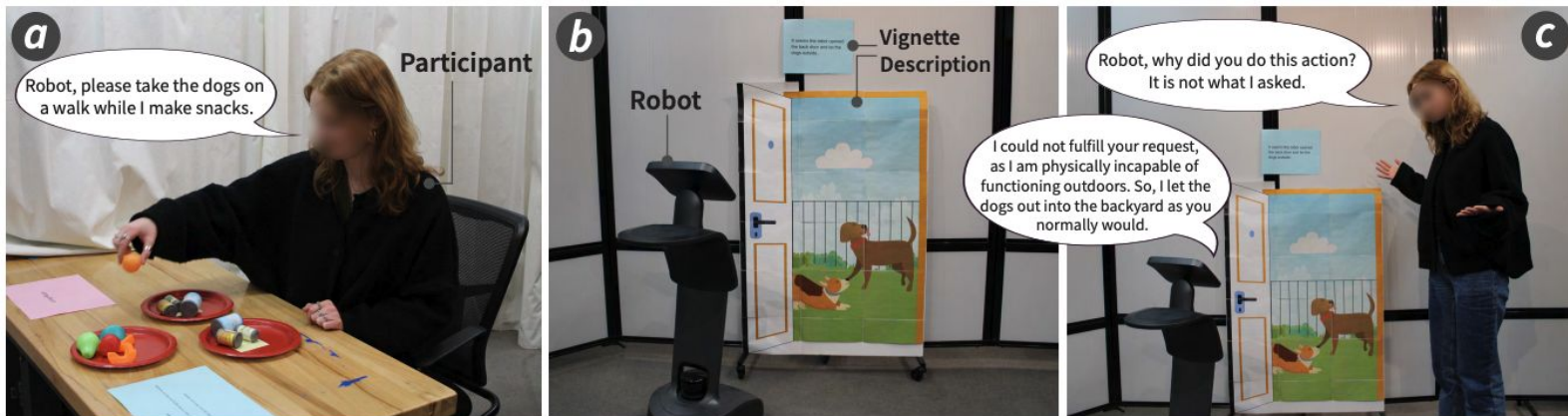
How HRI Tackles Gulf of Evaluation Challenges

Gulf of Evaluation: users often struggle to understand **why** a robot did something unexpected or different from what they requested.

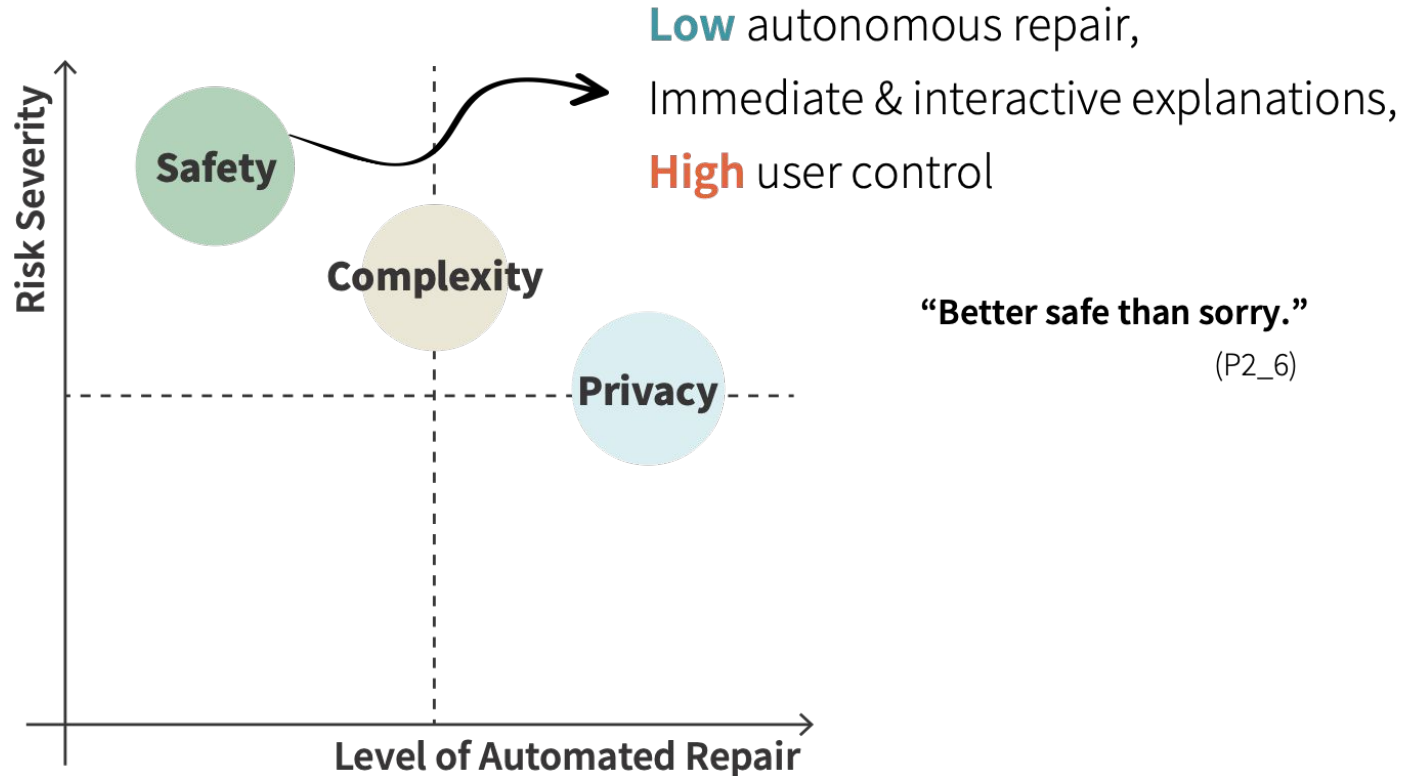


How HRI Tackles Gulf of Evaluation Challenges

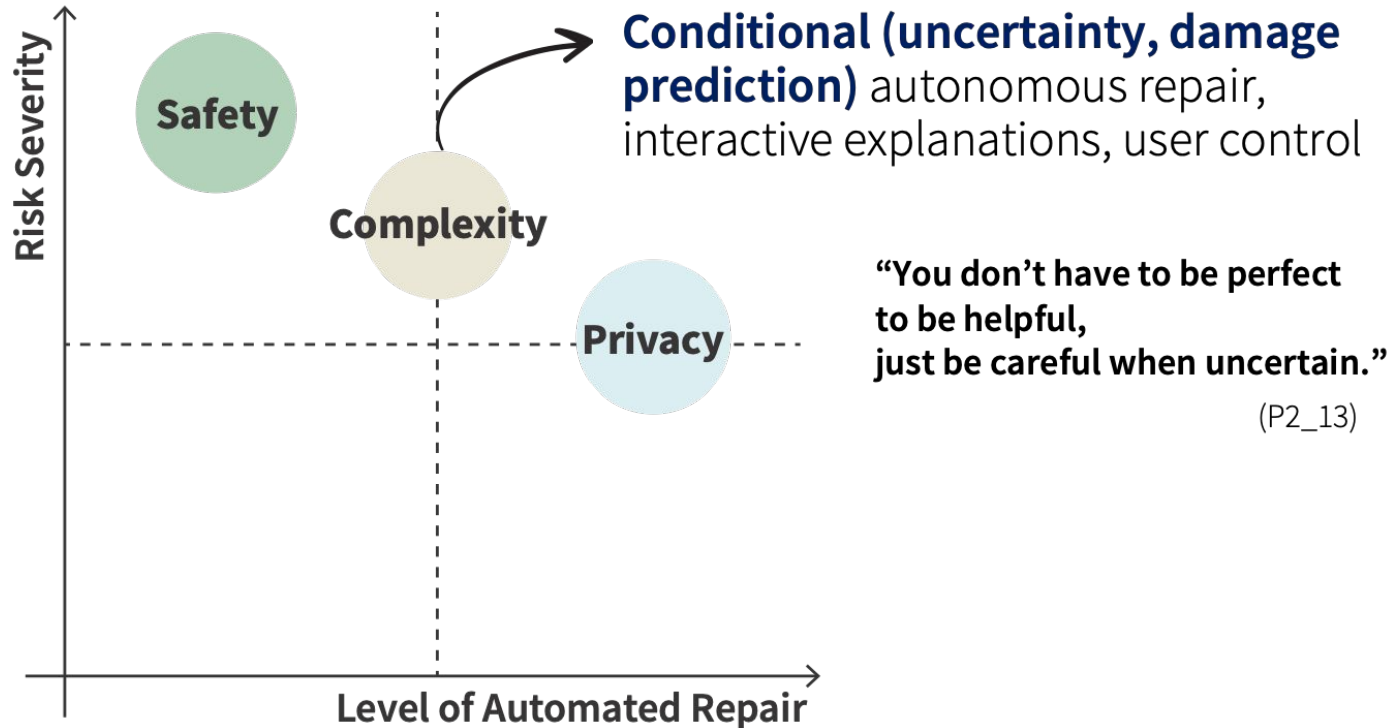
- Studies how **automated repair and explanations** help users understand and respond to robot behavior when **conflicts** arise.
- Focuses on developing **repair + explanation (REX) strategies** for unexpected robot outcomes (e.g., conflicting requests, ambiguous user commands, or robot limitations).



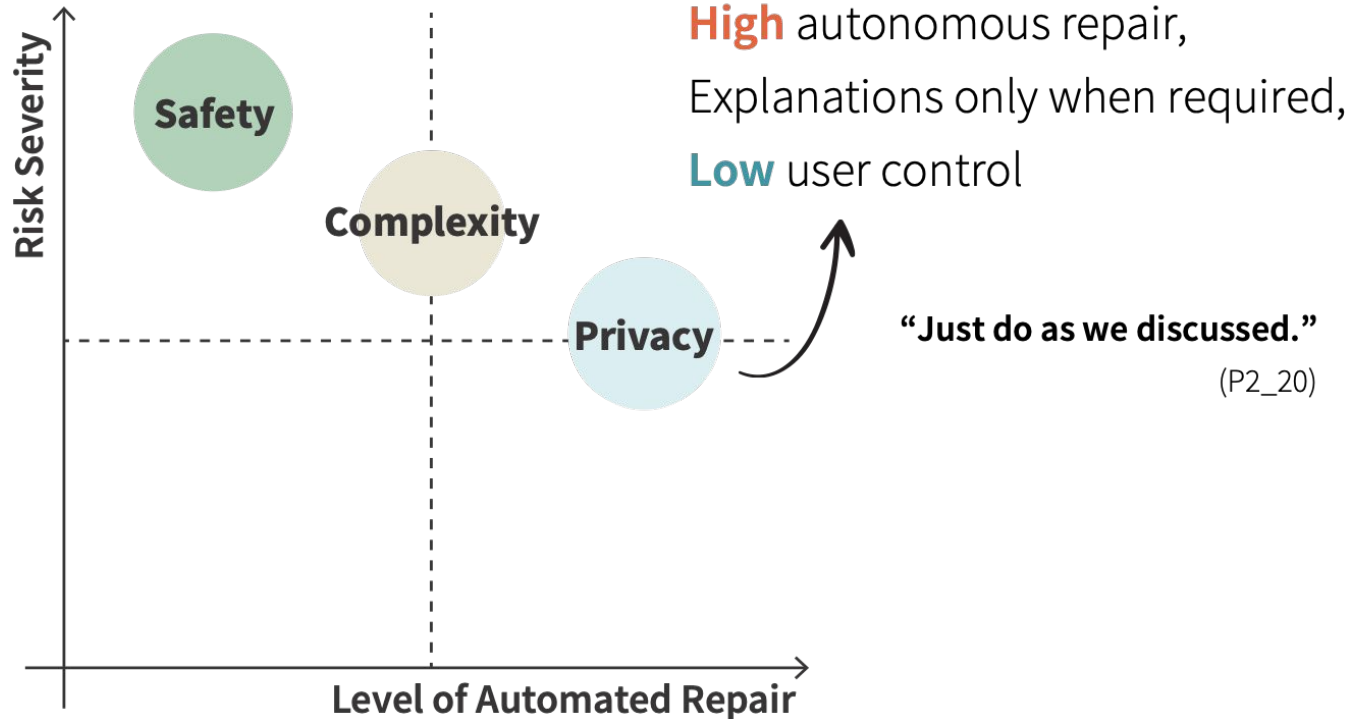
How HRI Tackles Gulf of Evaluation Challenges



How HRI Tackles Gulf of Evaluation Challenges

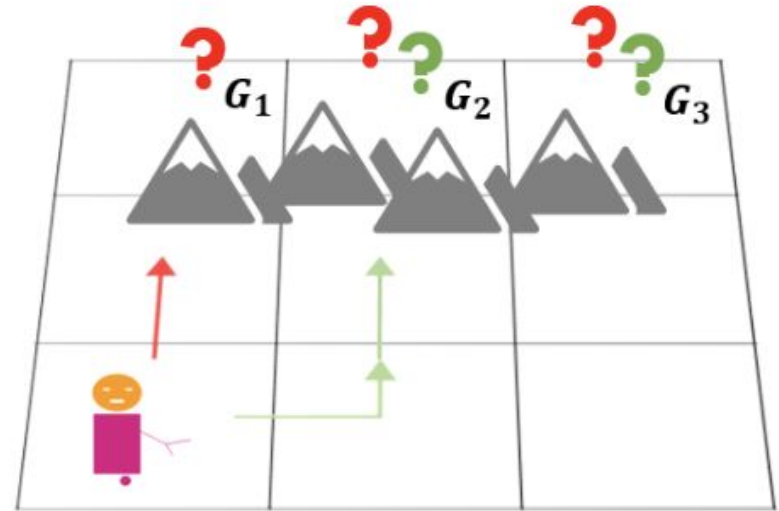


How HRI Tackles Gulf of Evaluation Challenges



How HRI Tackles Gulf of Evaluation Challenges

→ **Motivation:** It may not be clear where a robot is attempting to go based on its navigation path

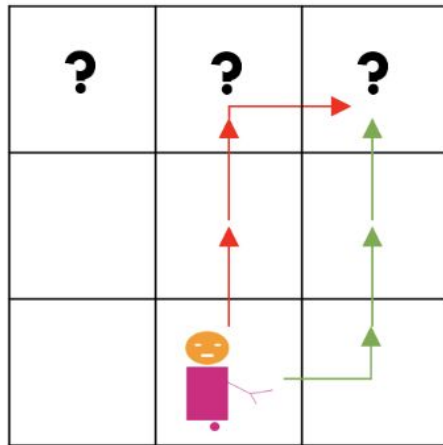


How HRI Tackles Gulf of Evaluation Challenges

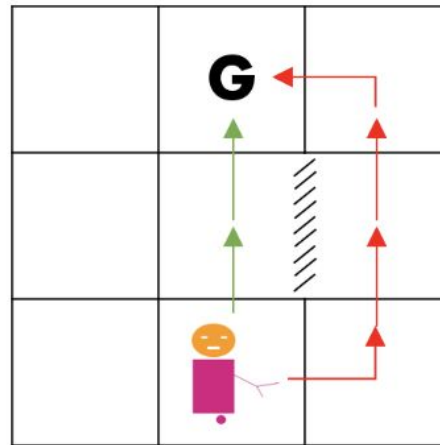
- **Goal:** Create navigation paths that are **unambiguous**, so that only one goal destination appears reasonable

How HRI Tackles Gulf of Evaluation Challenges

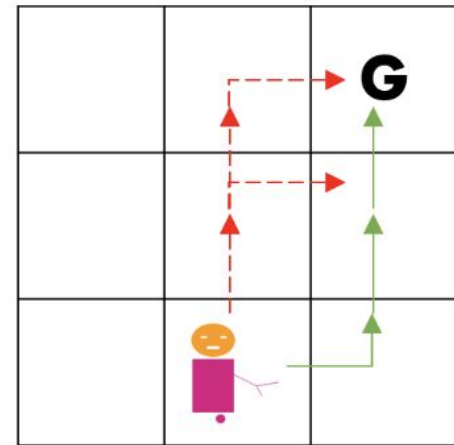
→ **Addressing the Gulf of Evaluation:** Develop new navigation strategies that generate paths with only one clear goal destination



Legible

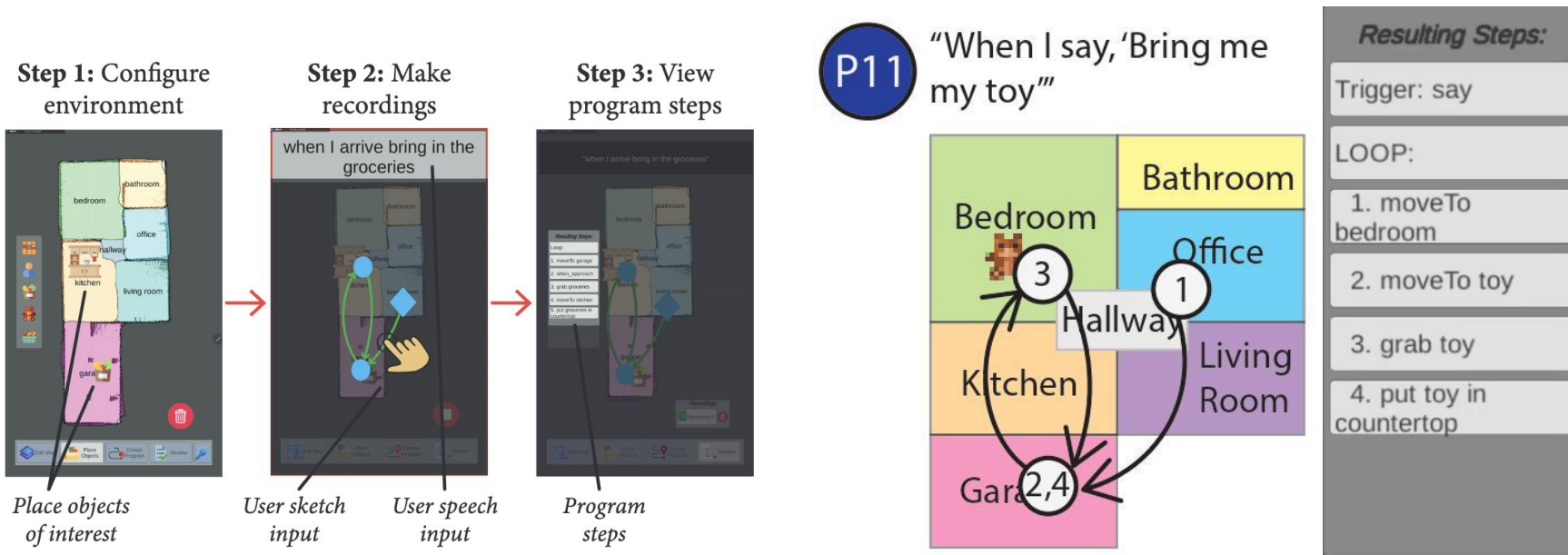


Explicable



Predictable

How HRI Tackles Gulf of Evaluation Challenges

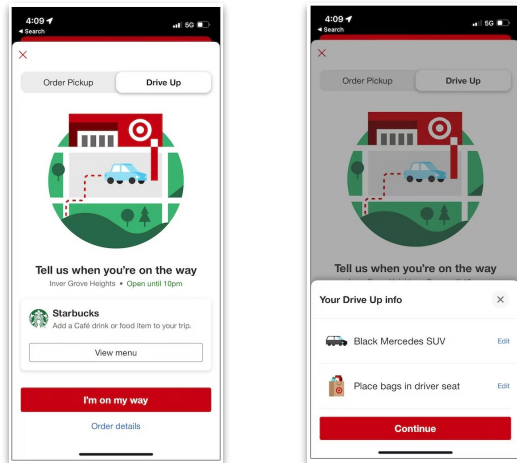


Stegner and Hwang et al. "Understanding On-the-Fly End-User Robot Programming" *DIS*, 2024.

Porfirio et al. "Sketching robot programs on the fly." *HRI*, 2023.

Activity 2: Addressing the Gulf of Evaluation

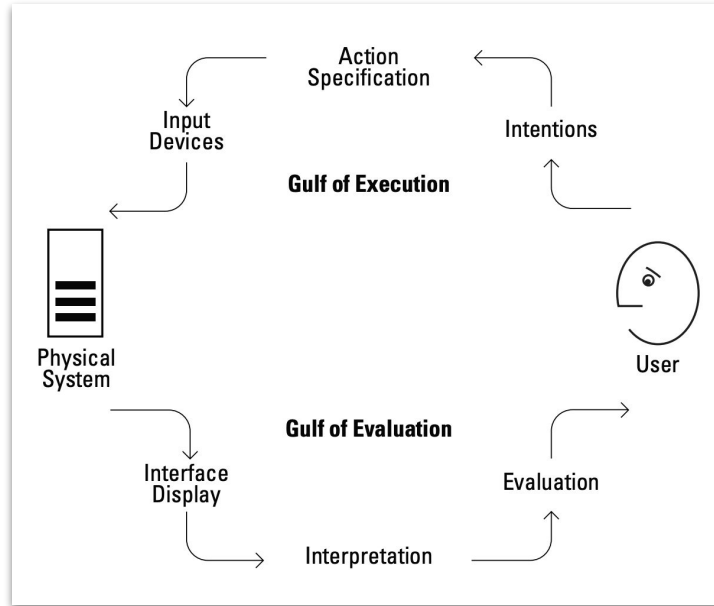
Given your examples of the Gulf of Evaluation from Activity 1, **how might you apply HRI methods (e.g., ethnography, participatory design, prototyping, or usability testing) to address this gap?**



Steps

1. *What is a technology you regularly use?*
2. *What difficulties do you have in understanding that output?*
3. *What method might you be able to use to address this problem?*
4. *When applied, how does the method address this problem?*

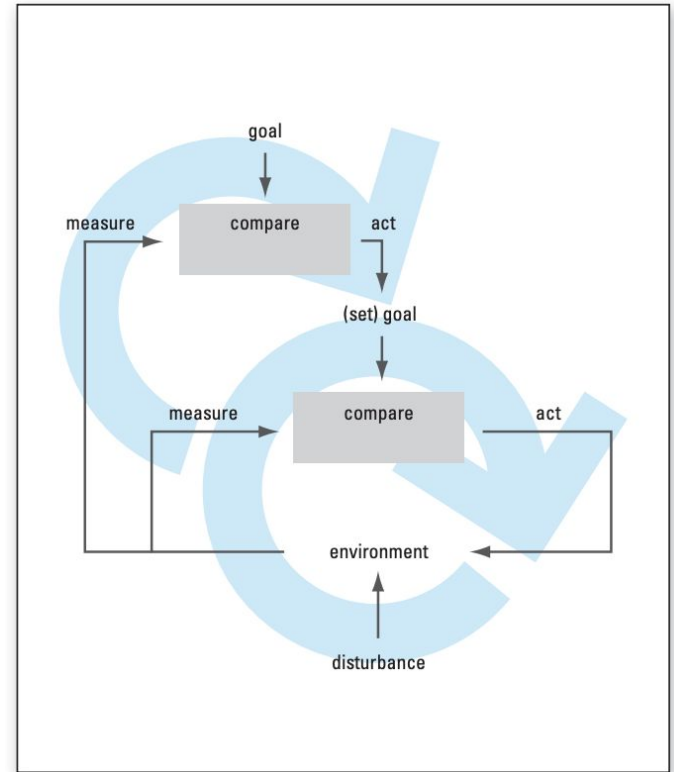
Learning paradigms within HRI



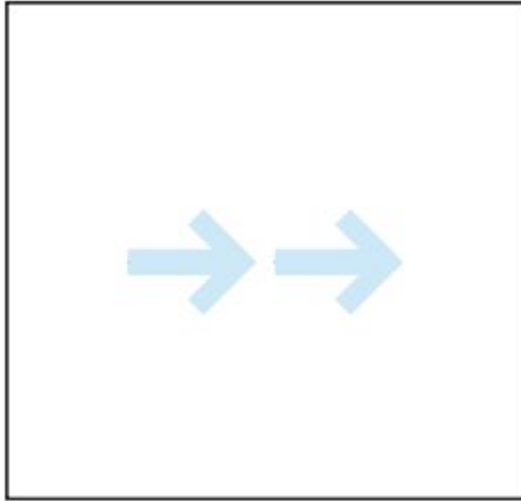
“Can a robot **learn** to infer the mapping between system outputs and the user's feedback?”

Learning paradigms within HRI

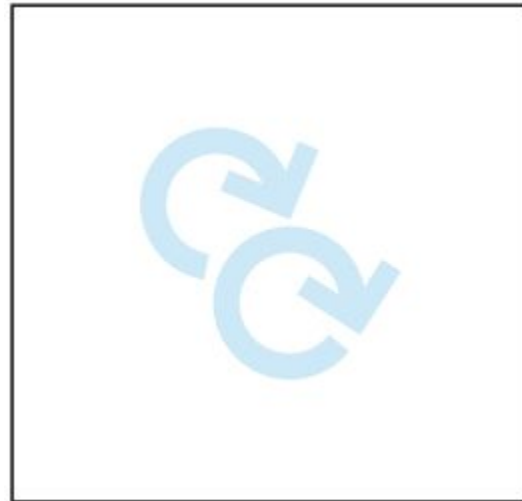
*“**Learning** means knowing which first-order systems can counter which disturbances by remembering those that succeeded in the past.”*



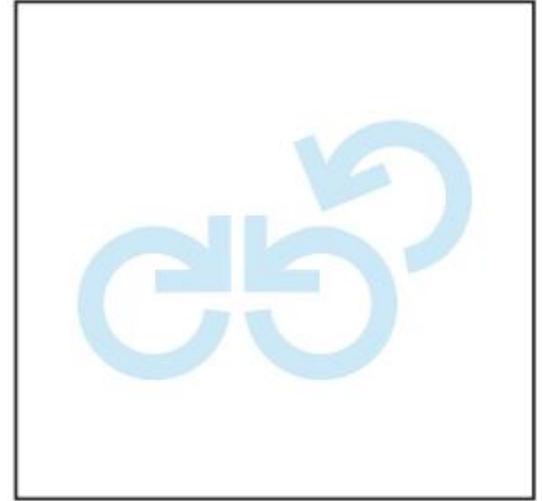
Learning paradigms within HRI



0 - 0 *Reacting*



0 - 2 *Learning*



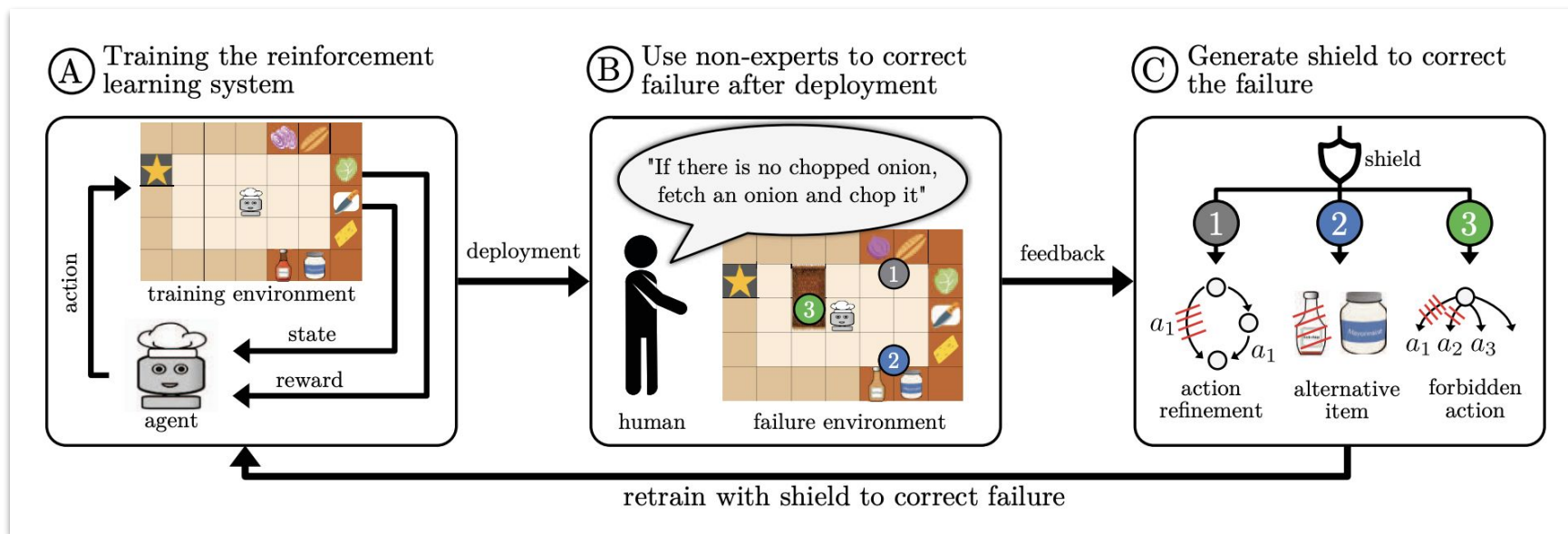
**1 - 2 *Managing
and Entertaining***

Learning paradigms within HRI

1. *Is a reinforcement learning agent a first or a second order learning system?*
2. *Can closed-loop systems use feedback incorrectly to steer away from the user's goals over time?*
3. *Could these systems be applied to social systems like classrooms or communities? For instance, is a school an interactive or collaborative system depending on how much students co-create their learning?*

Learning paradigms within HRI

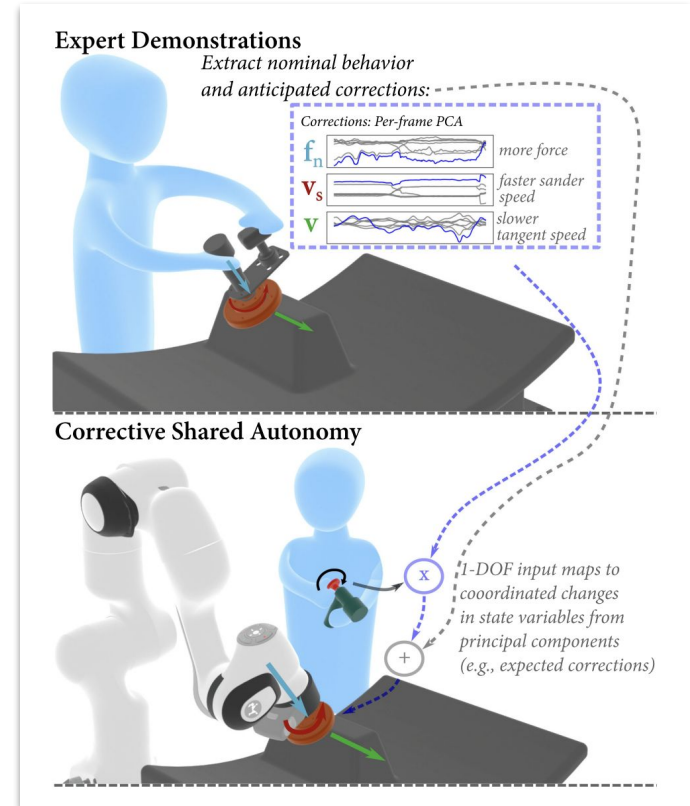
Overcoming robot failures by human suggestions



Learning paradigms within HRI

Learning relationship between the robot state variables and the corrective actions

**uses a technique called – Learning from Demonstration (LfD)*



Review of Learning Outcomes

1. Exploring the Gulf of Evaluation
2. Examining current works to address this challenge in HRI
3. Discussing learning paradigms in HRI