Introduction to Human-Robot Interaction

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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

Reading Responses

- Many questions on learning (e.g., Reinforcement Learning) and the types of systems (e.g., second-order systems)
    - When do systems update their goals and

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



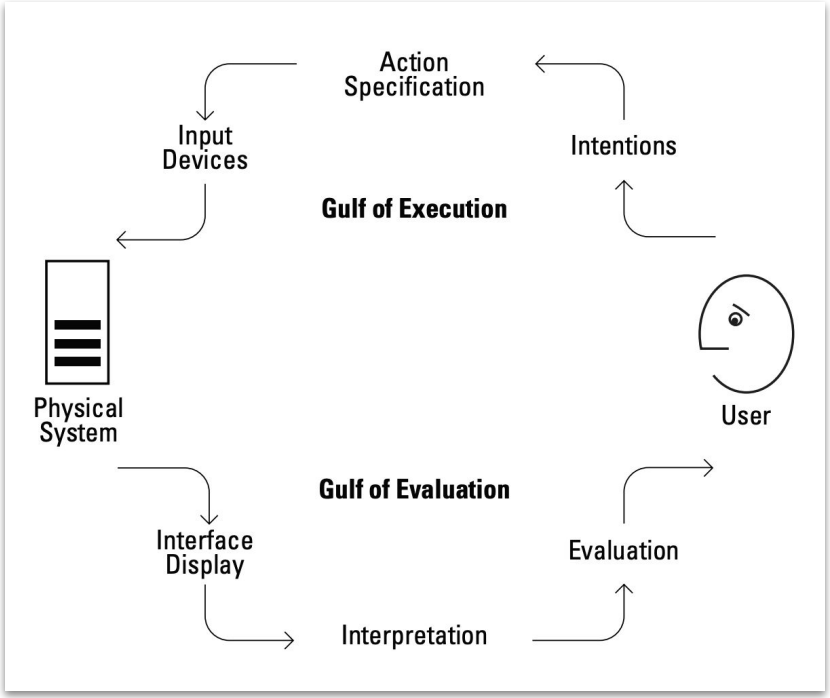

What makes HRI hard?

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…"



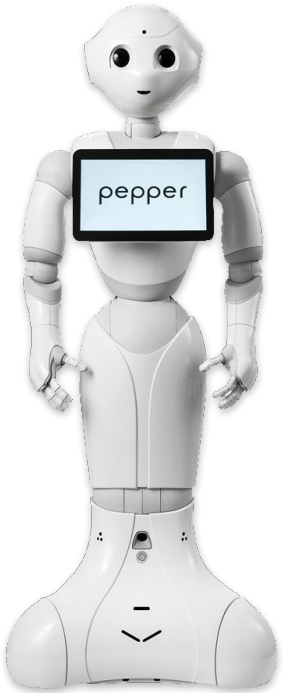
Dubberly et al. What is Interaction? Are There Different Types?. 2012.
Don Norman. The Design of Everyday Things. 2015.

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

Gulf of Execution

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

Gulf of Execution in HRI



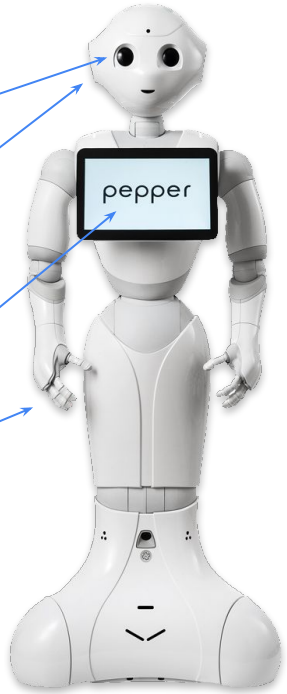
Gulf of Execution in HRI

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)?

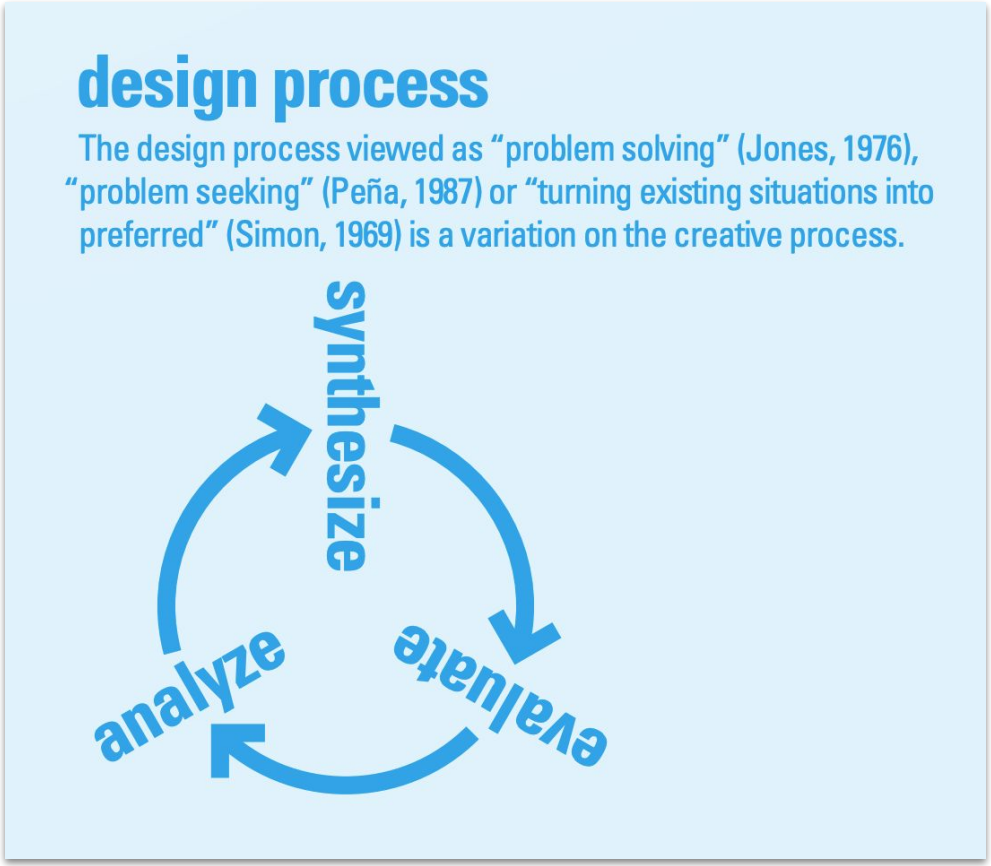
Roomba; user might want it to clean kitchen only. How to set the zone? App? voice?

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

HRI Methods

How do we do this?

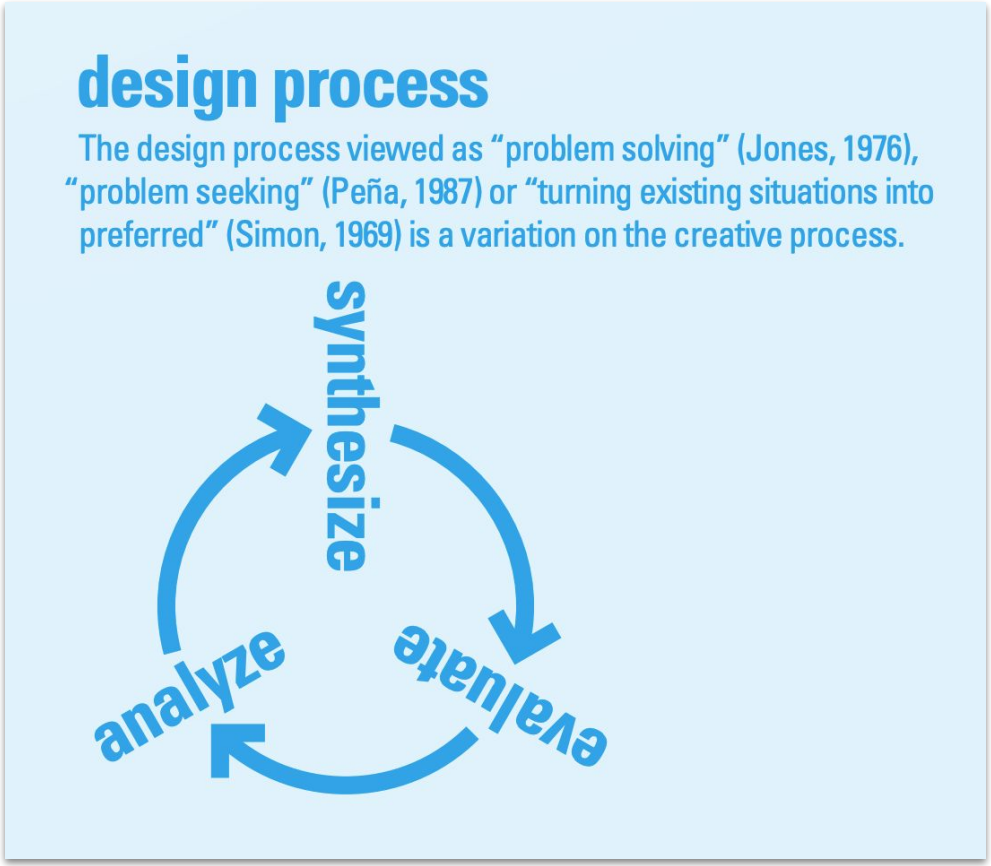
A typical HRI research pipeline includes a **“design process”**



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)

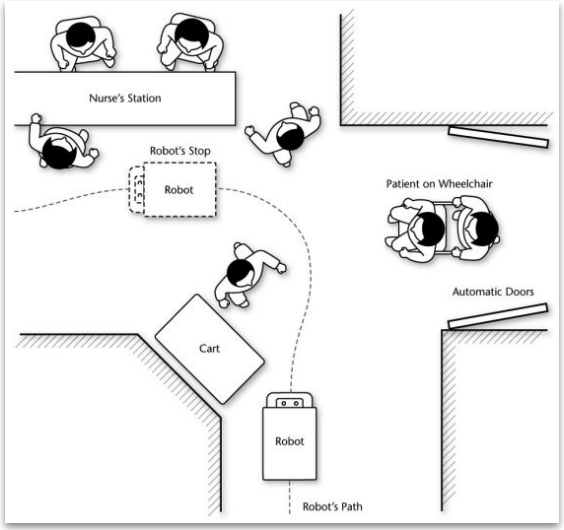


HRI Methods

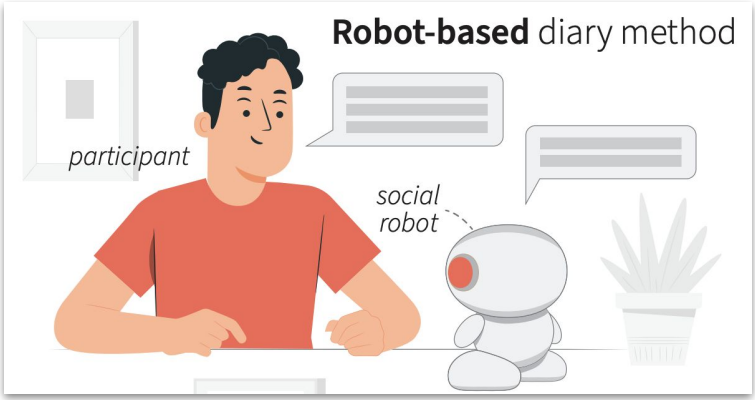
Analysis

➔ **Methods:**

- Ethnography
- Contextual inquiry
- Diary studies
- Task analysis



Mutlu et al., 2008

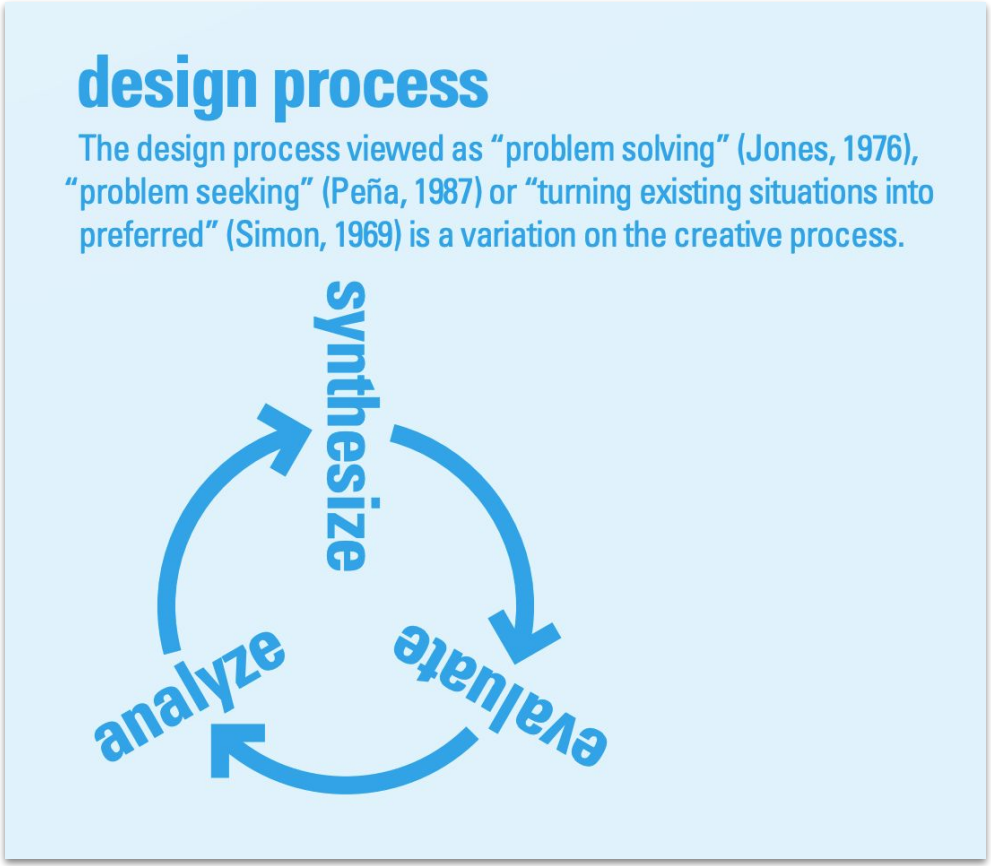


Xu et al., 2025

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



HRI Methods

Synthesis

➔ **Methods**:

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

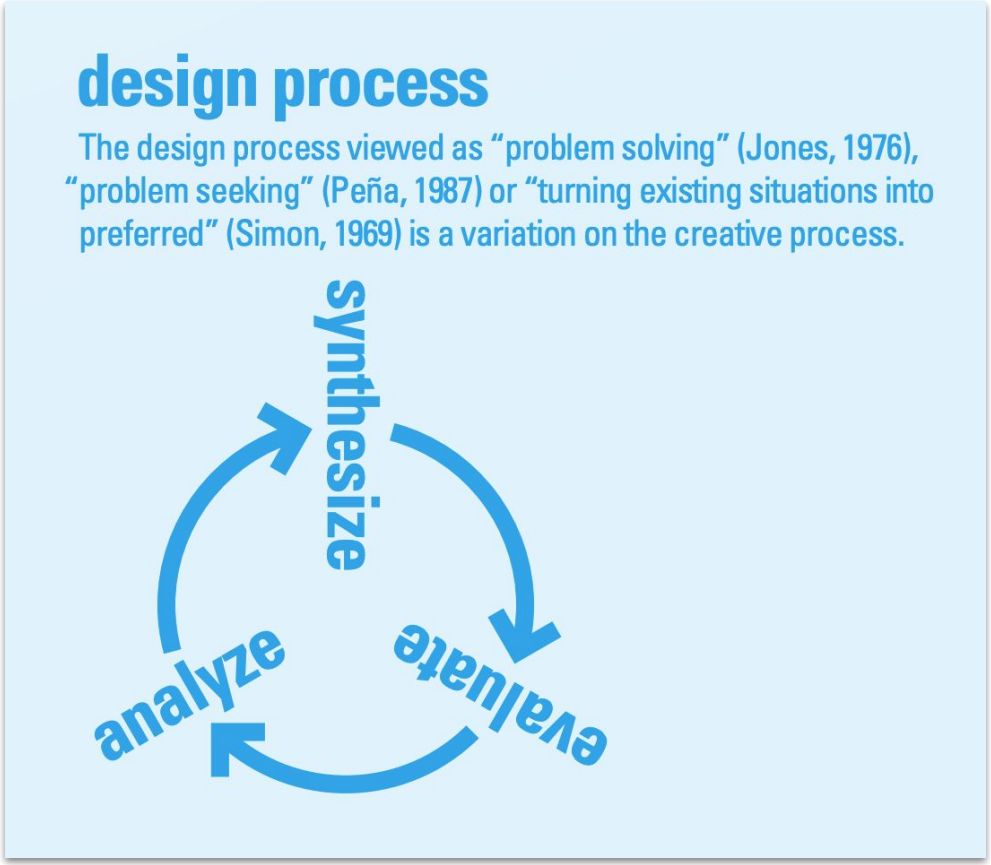
Lee et al., 2022

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

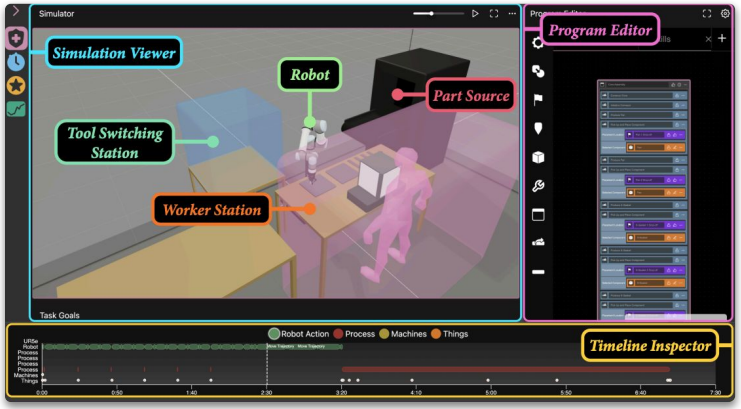


HRI Methods

Evaluation

➔ **Methods**:

- Usability testing
- User studies
- Field deployments



Sullivan et al., 2024

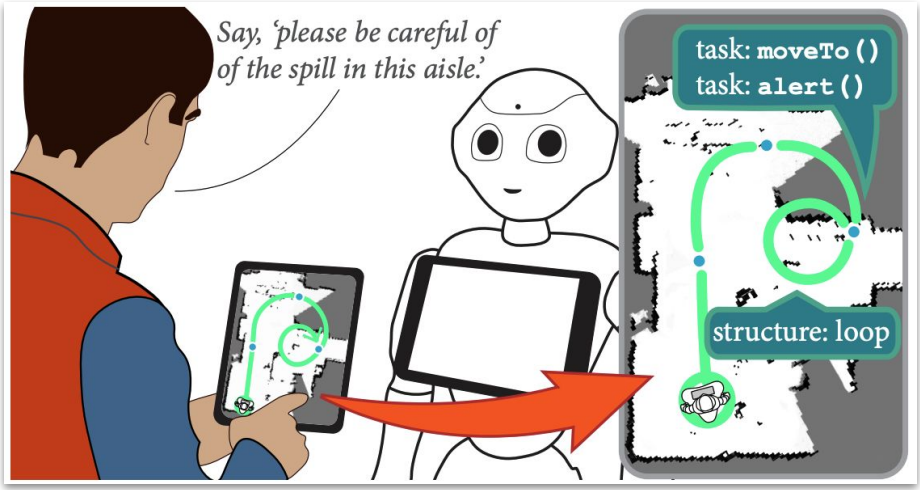
Hu et al., 2025

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 HRI Tackles Gulf of Execution Challenges

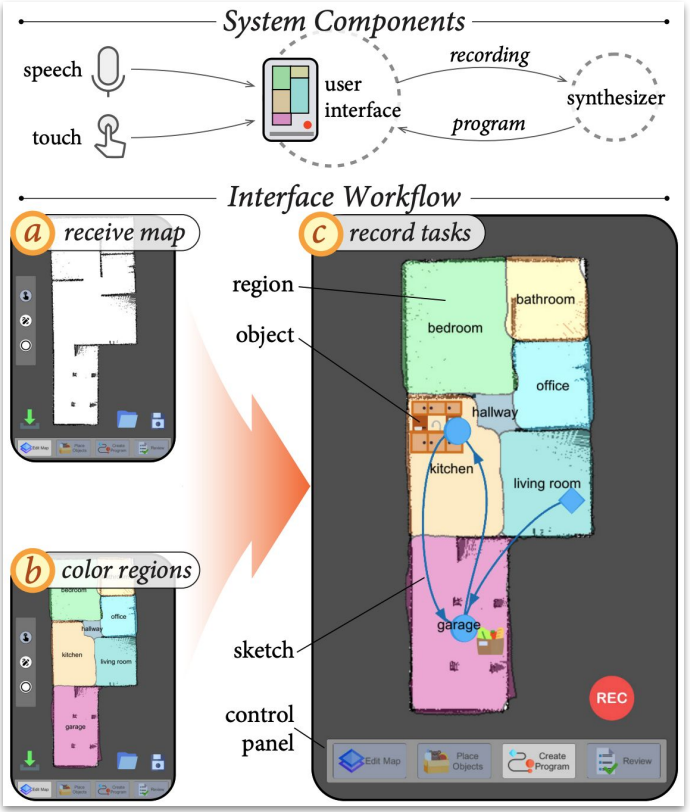
➔ **Motivation**: It can be very challenging for novice users to program service robots



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

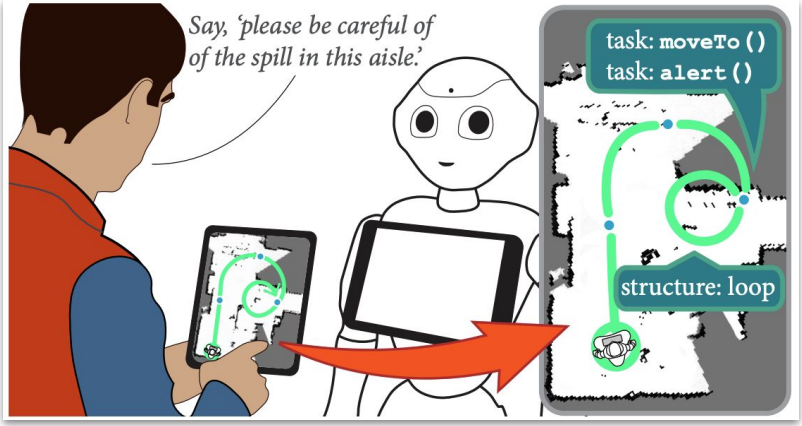
How HRI Tackles Gulf of Execution Challenges

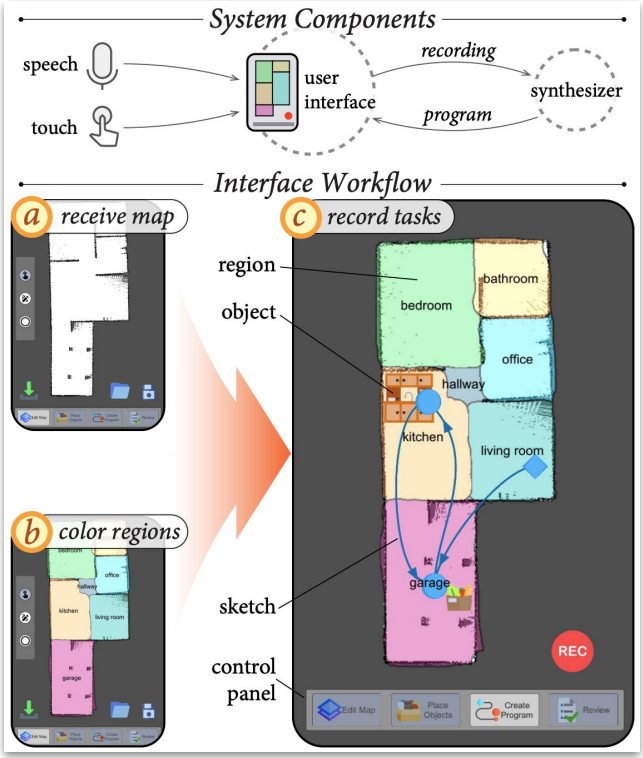
➔ **Goal**: Develop a convenient end user programming tool for novice users



How HRI Tackles Gulf of Execution Challenges

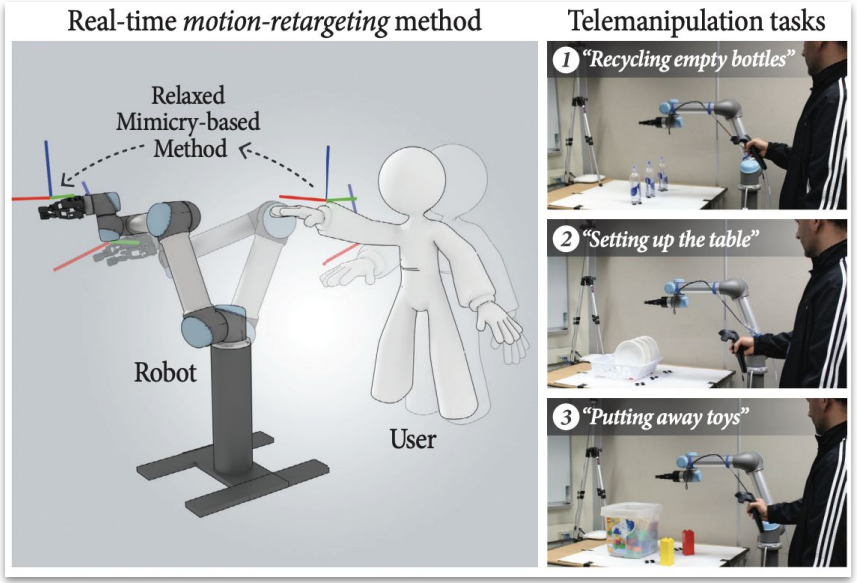
➔ **Addressing the Gulf of Execution**:
Allow users a convenient medium to input robot task requests





How HRI Tackles Gulf of Execution Challenges

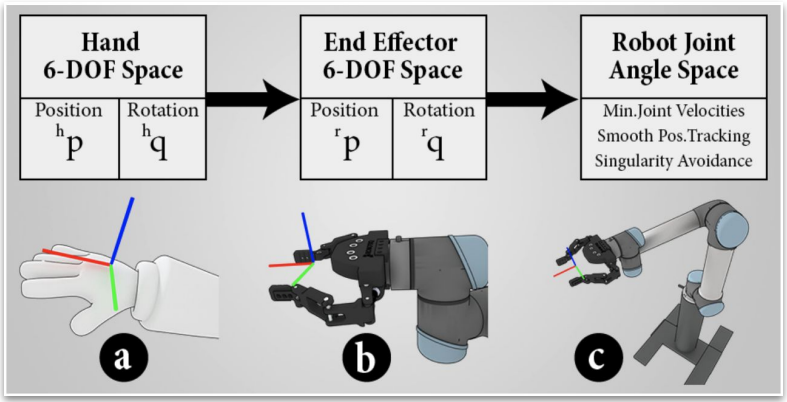
➔ **Motivation**: direct and effective control of a robot arm is hard, because robots have different kinematic and speed capabilities than a human arm

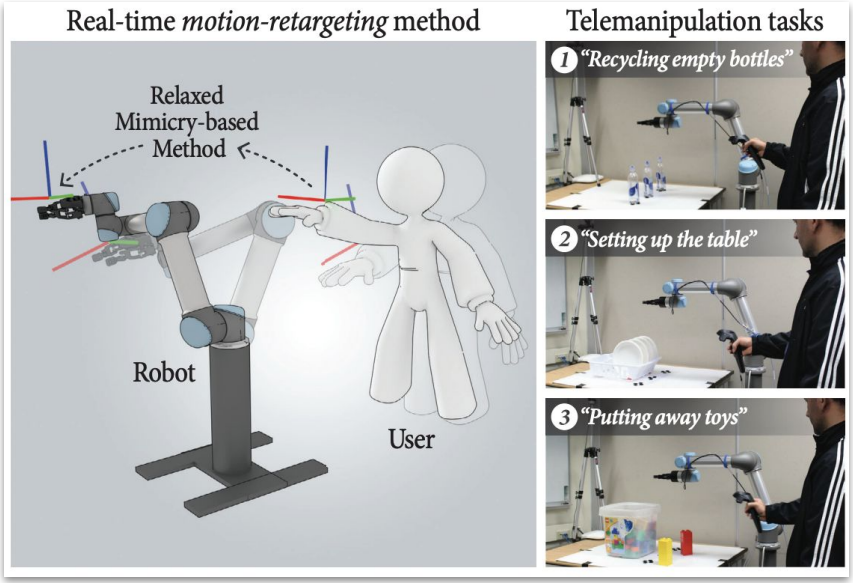


Rakita et al., "A motion retargeting method for effective mimicry-based teleoperation of robot arms." *HRI*. 2017.

How HRI Tackles Gulf of Execution Challenges

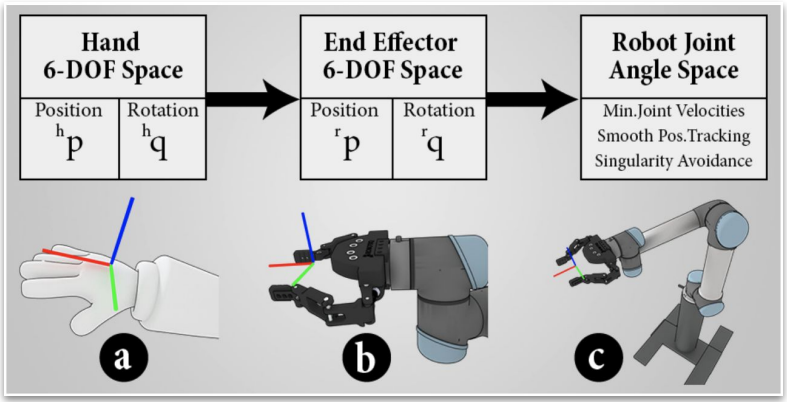
➔ **Goal**: Enable users to intuitively and effectively control the robot's arm through real-time mapping.

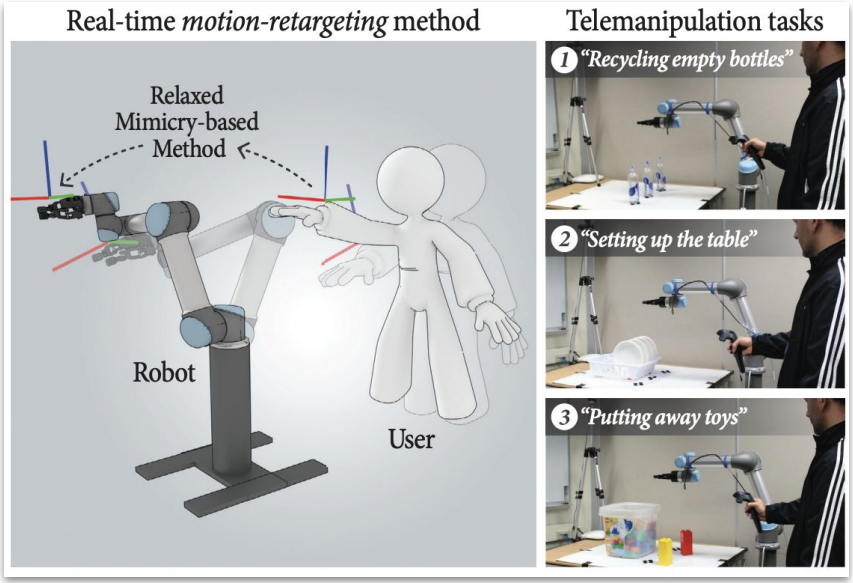




How HRI Tackles Gulf of Execution Challenges

➔ **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
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How HRI tackles execution challenges

~~Danny multimodal input~~

Emmanuel's interface – collab robot that has certain task skills, the

David Tabula

-Project overview

-Goal

-How it ties back to gulf of execution

How HRI tackles execution challenges

Research examples, now real-world examples

Starship robot

Examples that is not very good, example that is very good

Gulf of execution is much more challenging

Lid opens through the app – so it's really hard to know what you are supposed to be doing

Another robot that presses and opens

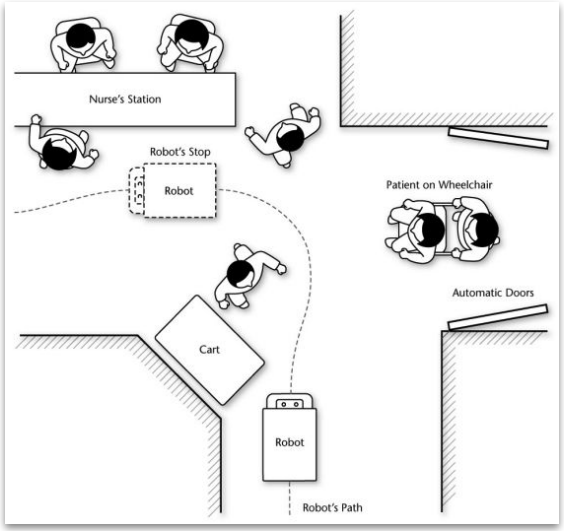
Tensor robot,

Tesla full self driving

HRI methods

Design

- Ethnography – Understand the context in which **robots can be used**
- Participatory Design – Develop prototype designs with participants based on **expected or intended use**



Mutlu et al., 2008

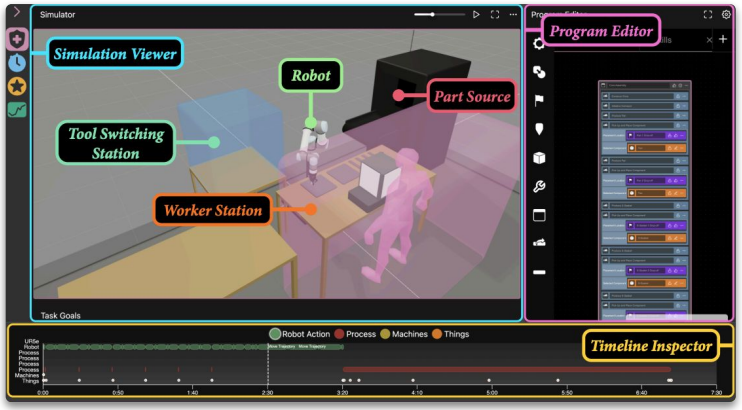
Lee et al., 2022

HRI methods

Develop

- Prototyping – Develop prototype designs for evaluation
- Simulation – Simulate system operation prior to deployment or evaluation

Koike et al., 2023



Sullivan et al., 2024

HRI methods

Deploy

- In-lab Study – Assess theories, designs, or systems in a **controlled lab environment**
- Field Study – Assess theories, designs, or systems **in the wild**

Porfirio et al., 2021

Hu et al., 2025

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What is HRI? Designing robots people can understand and trust

~~Gulf of evaluation~~

Recap of last class

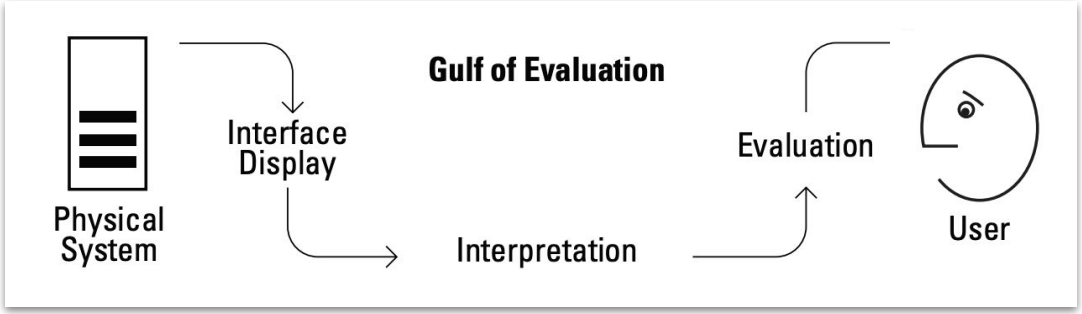
Why interpretation, evaluation of robot actions matter

Robots act in a physical space – we need to know what they are doing, why, and whether they succeeded in their task. Confusion can lead to distrust, errors, or safety issues

The gulf of evaluation

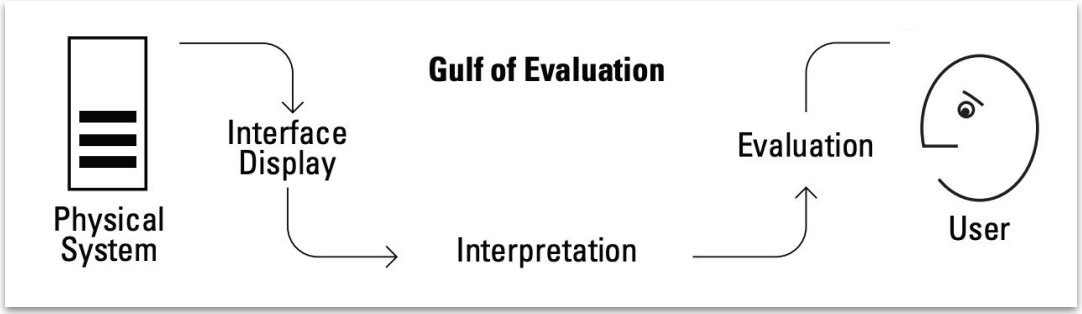
- The gap between what the robot is doing and what the user understand
- Visual diagram

Gulf of Evaluation



*"The Gulf of Evaluation reflects the **amount of effort** that the person must make to **interpret the physical state** of the device and to determine how well the **expectations and intentions have been met**."* Norman (2015)

Gulf of Evaluation: Review



"What are the major design elements that help bridge the Gulf of Evaluation? ***Feedback and a good conceptual model****."* Normal (2015)

Examples of evaluation breakdowns

- Silent failure
- Unexpected behavior
- Mismatched expectations (robot succeeds, but user thinks it failed)

HRI’s goal for evaluation

- Make robot behavior legible and predictable
- Provide feedback
- Show system state or failure reasons

HRI research methods for evaluation

- Studies on trust, user mental models, explainability,
- user-centered design for feedback

Example work that we did

- Explanation and transparency (rex…)
- Behavior (amy soft robot)

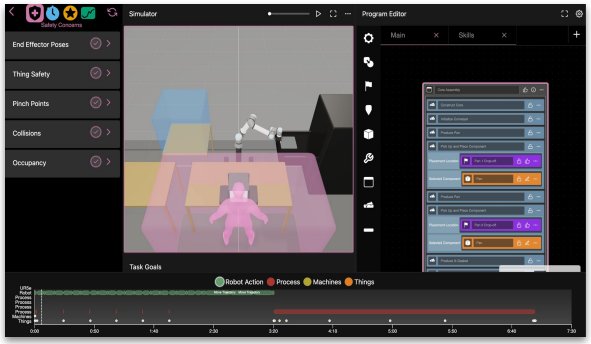
Activity? - add half way through

Summary of HRI

existing

People and Robots Laboratory

PLACEHOLDER



Citations

Norman 2015 - The Design of Everyday Things

The Glossary of Human Computer Interaction

Bilge Ethnography Paper

Pepper Documentation