Human Robot Interaction (HRI)

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Outline

- HRI principles and challenges
- Design issues in HRI
- Natural language processing in robotics

What is HRI?

- Human robot interaction is commonly referred to as a new and emerging field, but the notion of human interaction with robots has been around as long as the notion of robots themselves.

"robotics is concerned with the creation of physical robots and the ways in which these robots manipulate the physical world, HRI is concerned with the ways in which robots interact with people in the social world."

"Human—Robot Interaction (HRI) is a field of study dedicated to understanding, designing, and evaluating robotic systems for use by or with humans " *(Goodrich and Schultz, 2007, p. 204).*

As a discipline interdisciplinary endeavor, HRI is related to human computer interaction (HCI), robotics, artificial intelligence, the philosophy of technology, and design.

What is HRI?

- HRI focuses on developing robots that can interact with people in various everyday environments.
- Dynamics and complexities of humans and the social environment.
- This also opens up design challenges, related to robotic appearance, behavior, and sensing capabilities to inspire and guide interaction.
- From a psychological perspective, HRI offers the unique opportunity to study human affect, cognition, and behavior when confronted with social agents other than humans.

What is HRI?

- When robots are not just a tool but, rather, collaborators, companions, guides, tutors, and all kinds of social interaction partners, HRI research considers many different relationships with the development of society, both in the present and in the future.

- HRI research includes issues related to the social and physical design of technologies, as well as societal and organizational implementation and cultural sense-making, in ways that are distinct from related disciplines.

HRI - there is no such thing as ‘Natural Interaction

- In HRI, 'good' interaction with a robot must reflect *natural* (human-human) interaction and communication.
- What is natural behaviour to begin with? Is a person behaving naturally in his own home, when playing with his children, talking to his parents, going to a job interview, meeting colleagues, giving a presentation at a conference?
- Challenge: people's face-to-face interactions are highly dynamic and multi-modal — involving a variety of gestures, language, body posture, facial expressions, eye gaze, in some contexts tactile interactions, etc.
- Leads to intensive research

HRC vs HCI

- Human-Robot Interaction (HRI) and Human-Computer Interaction (HCI) are related fields, but they differ in focus and complexity

- HRI:
  - Focuses on interaction between humans and robots.
  - Robots have a physical embodiment, which makes physical interaction and spatial considerations essential
  - Robots often operate autonomously or semi-autonomously and can exhibit behavior influenced by AI.
  - Interaction involves more complexity because it integrates physical, social, and emotional dimensions.

- HCI
  - Centers on interaction between humans and computers, usually involving interfaces like keyboards, mice, touchscreens, or voice assistants.
  - Typically lacks physical embodiment. Interactions are virtual, through graphical interfaces or auditory feedback.
  - Computers are usually tools that respond predictably to user input, with less emphasis on autonomous behavior.
  - Interaction is usually limited to cognitive tasks, such as navigating menus, typing, or clicking buttons.

Design in HRI

- An important way to develop common ground between robots and humans so that people can understand robot capabilities and limitations appropriately and adapt their interactions accordingly.

- If a robot looks like a human, it is expected to act like a human; if it has eyes, it should see; if it has arms, it should be able to pick up things and might be able to shake hands.

- The task of HRI design is not only to create a robotic platform but also to design and enable certain interactions between humans and robots in various social contexts.

Design in HRI

- What tasks or problems is the robot expected to solve or assist with?
- What are the user's expectations for the robot’s capabilities, limitations, and autonomy?
- What modalities (voice, touch, gestures, etc.) should the robot use to communicate with users?
- How intuitive is the robot’s interface and interaction process for the user?

Design in HRI

- How can the robot ensure safety during physical interaction with humans?
- What level of trust do users have in the robot’s decisions and actions?
- How can the robot demonstrate social behaviors (e.g., politeness, empathy) appropriate to its role?
- Does the robot need to recognize and respond to human emotions, and how effectively does it do so?

Design in HRI

- Core Design Issues in HRI
  - Usability: Simplified interfaces and intuitive interactions.
  - Safety: Preventing harm in physical and digital interactions.
  - Ethics: Respecting privacy, autonomy, and moral considerations.
  - Adaptability: Designing for diverse environments and user groups.
  - Feedback Mechanisms: Real-time communication for better understanding.

Design Paradigms for Social Robots

- The demand for social robots in fields like healthcare, education, and entertainment increases due to their emotional adaptation features.
- These robots leverage multimodal communication, incorporating speech, facial expressions, and gestures to enhance user engagement and emotional support.
- Design of a social robot is an interdisciplinary undertaking
- Social robot design paradigms, categorizing into
  - Cognitive architectures,
  - Role design models,
  - Linguistic models,
  - Communication flow,
  - Activity system models,
  - Integrated design models

Frieske et al. (2024). Survey of Design Paradigms for Social Robots

Design Paradigms for Social Robots

- Cognitive Architectures
  - Is a group of models that try to create a robot cognition framework based on neuroscience.
  - Provide a structured approach to developing intelligent systems by mimicking human cognitive processes.
  - Use standard model of the mind- Adaptive Control of Thought-Rational (ACT-R), SOAR, CLARION (Connectionist Learning with Adaptive Rule Induction ON-line)
- Role Design Model
  - Is the design paradigm that designs actions of both humans and robots in the interaction.
  - Robotic dialogue systems and categorized dialogue design along: interlocutor composition, dialogue structure, and discourse genres.

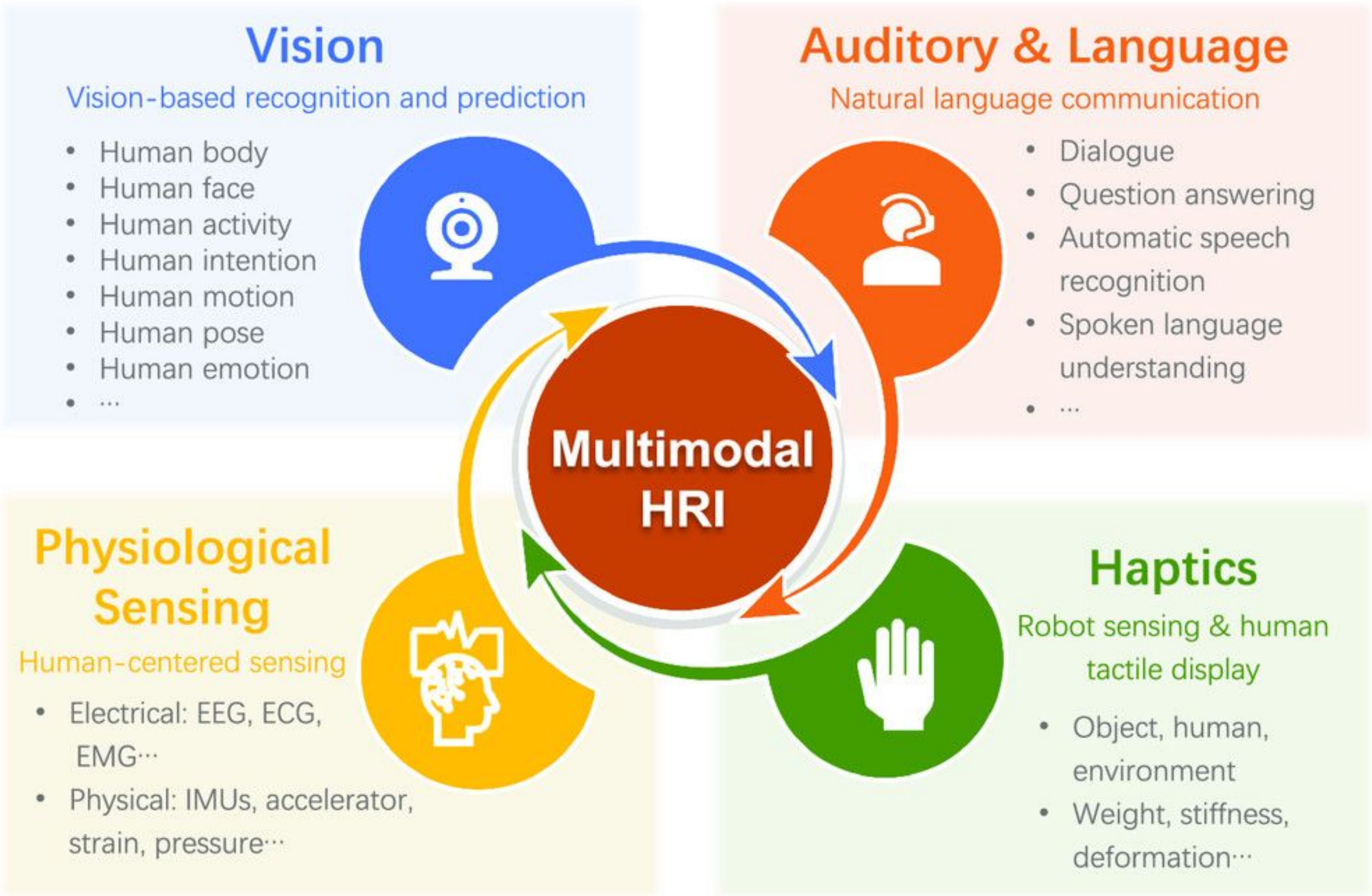
Design Paradigms for Social Robots

- Linguistic Model
  - Views speech as an action rather than just conveying information.
  - The Linguistic Model focuses on the pragmatic aspects of language use, such as speech acts, conversational implicatures, and context-dependent meaning.
    - Speech Acts: Speech acts theory categorizes utterances based on their function in communication, such as asserting, questioning, requesting, or commanding.
    - Conversational Implicatures: This concept refers to the implied meanings and intentions behind spoken language, which are often inferred from context and shared knowledge.
    - Context-Dependent Meaning: The meaning of an utterance can vary based on the situational context, requiring the system to interpret language dynamically and adaptively.

Design Paradigms for Social Robots

- Communication Flow
  - Provides a framework for managing the exchange of information in a dialogue, ensuring that interactions are coherent, contextually relevant, and goal-oriented.
    - Awareness and Perception: Both the human and the robot need to be aware of each other's communication attempts and perceive multimodal signals accurately.
    - Understanding and Interpretation: The system must be capable of interpreting the meaning of signals and utterances based on context, previous interactions, and multimodal cues.
    - Response and Reaction: The robot's responses should be timely, relevant, and appropriate to the ongoing dialogue, maintaining the flow and coherence of the interaction.

Augmented Robotics Dialog System for Enhancing Human–Robot Interaction



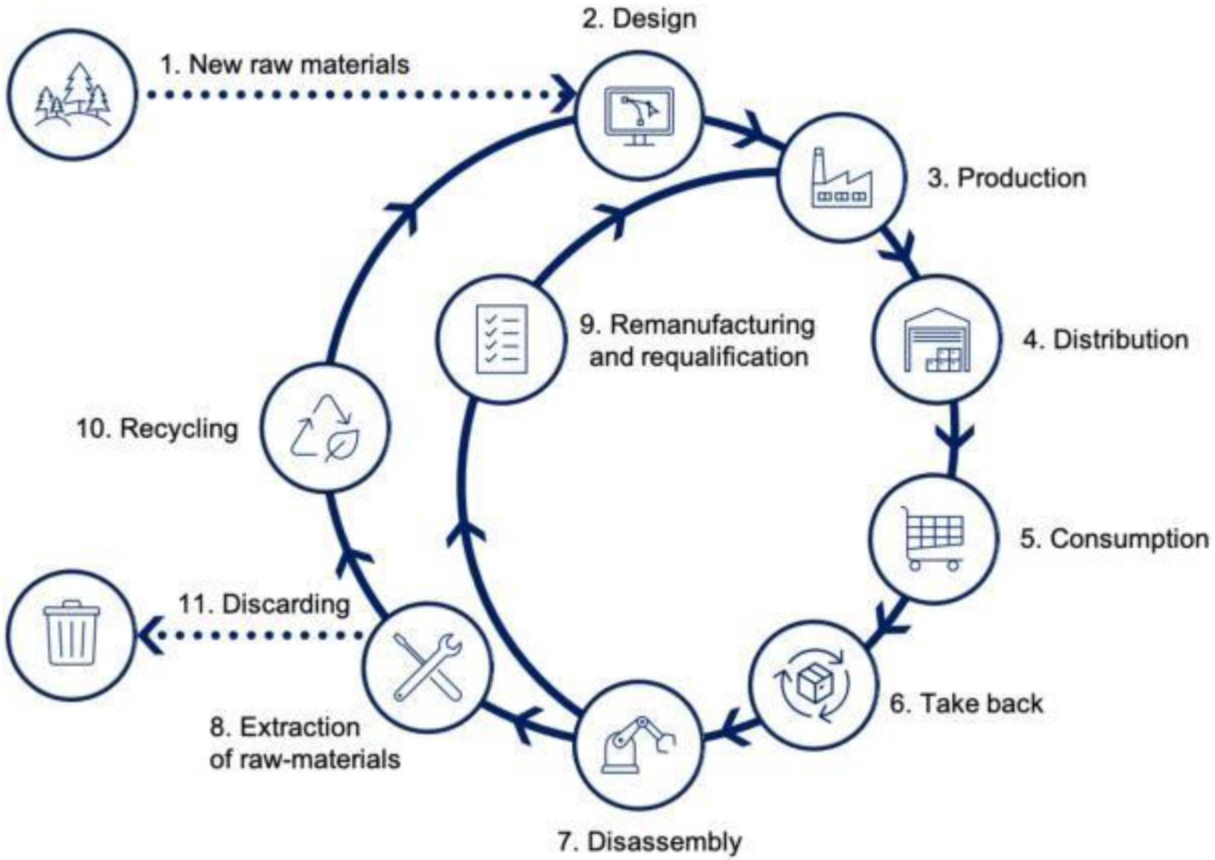
Four typical modalities of HRI.

Augmented Robotics Dialog System for Enhancing Human–Robot Interaction

- Augmented reality, augmented television and second screen are cutting edge technologies that provide end users extra and enhanced information related to certain events in real time
- This main idea was applied to human–robot interaction (HRI), to how users and robots interchange information.
- Augmented robotic dialog system (ARDS), which uses natural language understanding mechanisms to provide two features:
    - A non-grammar multimodal input (verbal and/or written) text; and
    - A contextualization of the information conveyed in the interaction.

Alonso-Martín et al. (). Augmented Robotics Dialog System for Enhancing Human–Robot Interaction

Human–Robot Collaboration in Industrial Environments



Challenges for de-/remanufacturing system:

- High variability in the conditions of post-use parts
- Poor information about return products
- Increasing product complexity
- Short life-cycle of products and high product variety
- Increasing quality requirements on recovered materials and component
- Pressure on costs and efficiency

Abstract visualization of the resource life cycle according to the circular economy business model. 01: New raw materials enter the production; 02: Design & manufacturing of sub-components; 03: Production of final product; 04: Distribution of the product to customers; 05: Consumption of the product; 06: Take back of the EOL product (EOLP); 07: Disassembly of the EOLP; 08: Extraction of raw materials; 09: Remanufacturing and requalification of extracted sub-components; 10: Recycling of raw materials; 11: Discarding non-recyclable raw materials.

Human–Robot Collaboration in Industrial Environments

- HRC in the field of disassembly
  - HRC in Disassembly (HRCD) is a timely topic that has become the focus of industry stakeholders and researchers during the last decade.
  - Due to its complexity, it requires several advancements both in HRC technologies and standardization policies in terms of takeback requirements, product interfaces and possible serviceability to become profitable and environmentally viable.

Hjorth and Chrysostomou (2022): Human–robot collaboration in industrial environments: A literature review on non-destructive disassembly

Human–robot collaboration in industrial environments

- Solutions:
  - A framework towards human–robot collaborative disassembly based on perception, cognition, decision, execution and evolution
    - Where technologies such as cyber–physical production systems (CPPS) and artificial intelligence (AI) are combined
    - Deep learning system enabling a fluent and natural interaction between a human operator and an industrial manipulator for an industrial human–robot cooperative disassembly scenario
      - CNN–LSTM network to predict the motion of the human operator purely on the inputs of a vision system without the need for wearable devices or tags.

HRI and AI Integration

- Significant advancements in artificial intelligence (AI) have revolutionized human-robot interaction (HRI), leading to more natural, intuitive, and adaptive interactions between humans and robots.
- Machine learning algorithms enable robots to adapt to user preferences and behaviors, creating personalized and intuitive interactions.
- Computer vision advancements empower robots with enhanced perception, enabling them to recognize and interpret human gestures, emotions, and facial expressions.
- Reinforcement learning has played a pivotal role in enabling robots to learn from human feedback and optimize their actions in real-time.
- Natural language processing (NLP) facilitates seamless communication between humans and robots, enabling voice commands and context-aware responses.

HRI and AI Integration

- Challenges
  - Concerns about data privacy and security: AI-driven systems often collect and analyze vast amounts of data from users to personalize interactions and improve performance. However, this raises concerns about privacy and data security

  - Safety and security: Ensuring the safety and security of AI-driven HRI systems is critical to prevent potential harm to humans and protect against malicious use of AI technologies.

  - Trust: Building trust between humans and robots is essential for successful HRI, as trust influences user acceptance, engagement, and cooperation with AI-driven systems

  - Bias and fairness: Bias and fairness issues in AI algorithms pose significant challenges to achieving equitable and non-discriminatory outcomes in HRI.

Natural language processing in robotics

- NLP is a branch of artificial intelligence.
- Focuses on enabling robots to understand, interpret, and respond to human language.
- Bridges the communication gap between humans and robots.

[Source: NLP in Robotics: Enhancing Human-Robot Interaction]

Natural language processing in robotics

- NLP transforms human-robot communication by enabling robots to understand, decipher, and produce human language.
- Advantages of Using NLP in HRI
  - Enhanced Interaction: more organic and intuitive interactions between robots and humans.
  - Improved Human-Robot Collaboration: Speech processing-using robots can comprehend spoken language and its meaning.
  - Greater Flexibility: Robots may process and understand various languages, dialects, and accents.
  - Enhanced efficiency: Robots that know human language can perform jobs more effectively without intricate programming instructions.
  - Personalization: Through language processing, robots can adapt their interactions to users' tastes and demands.

Natural language processing in robotics

- Key Components of NLP in Robotics
  - Speech Recognition - Converting spoken language into text.
  - Natural Language Understanding (NLU) - Interpreting the meaning of text.
  - Natural Language Generation (NLG) - Producing coherent text responses.
  - Machine Translation - Translating between languages.

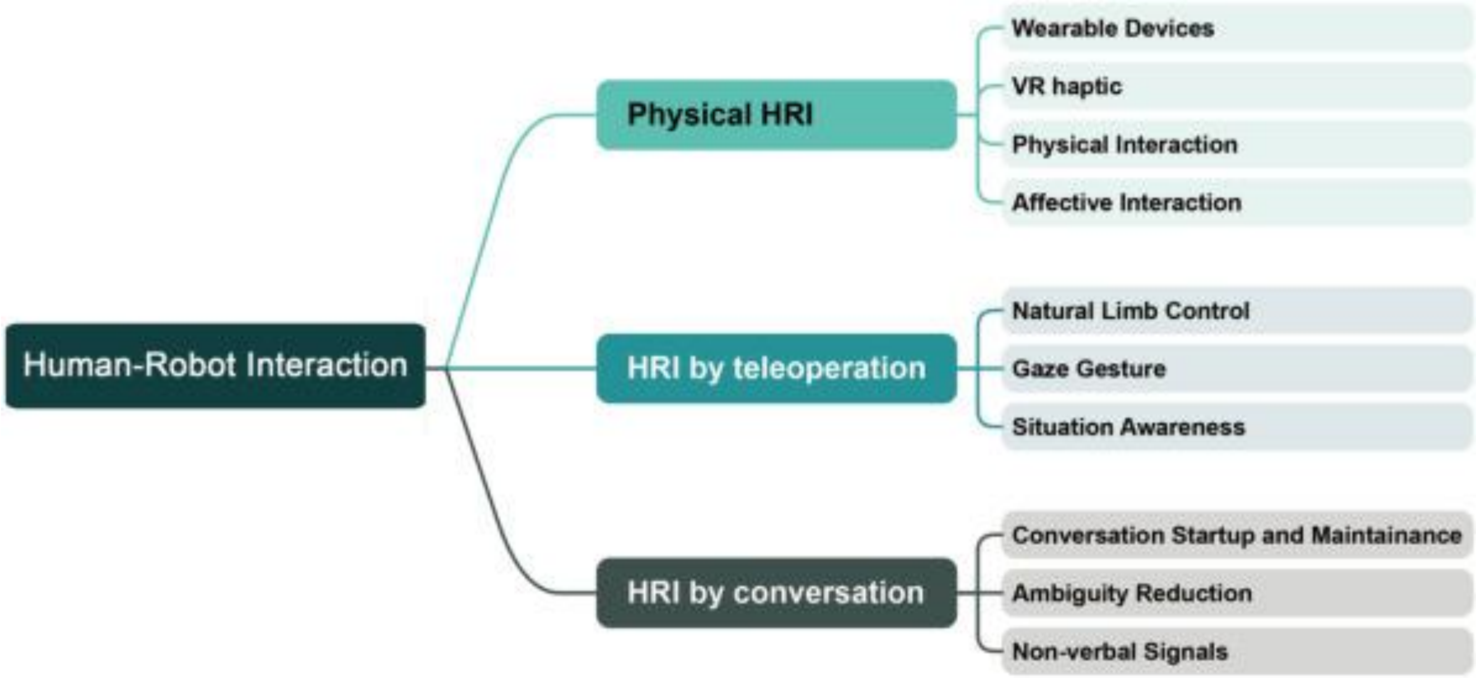
- Technological advances:
  - Use of Transformers (e.g., GPT, BERT) for improved understanding.
  - Integration of Reinforcement Learning for adaptive systems.
  - Multimodal Learning combining text, speech, and visual data.

Natural language processing in robotics

- Challenges in NLP for Robotics
  - Ambiguity in human language
  - Context understanding and adaptability
  - Processing speed for real-time responses
  - Multilingual and cultural differences

Large language models for HRI

- Fusion of large language models and robotic systems has introduced a transformative paradigm in HRI
- The emergence of LLMs has opened the potential to address long-standing challenges through their remarkable capacity for reasoning and generation



The intuitive list of the directions of work in HRI

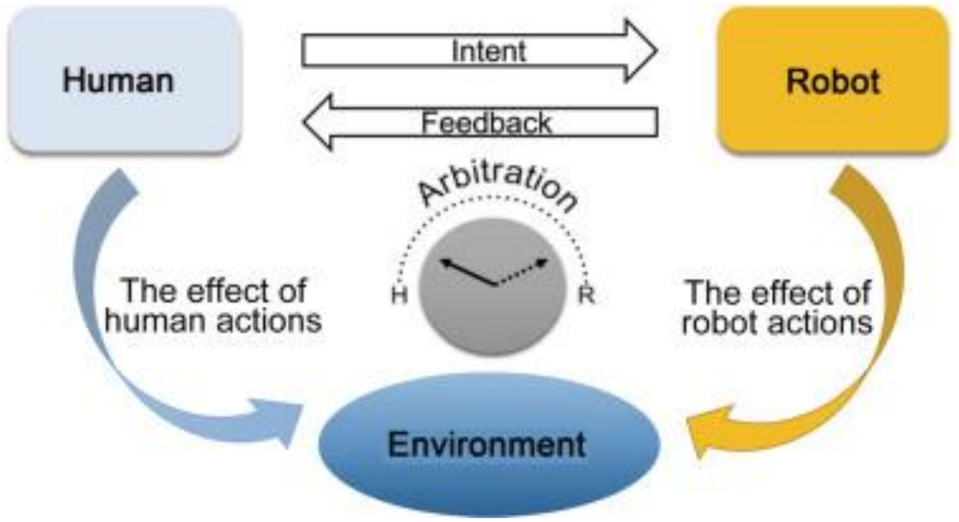
Zhang et al. (2023). Large language models for human–robot interaction: A review

Large language models for HRI

- Physical human–robot interaction
  - Interactions without a medium

  - The information exchange between human and robot is achieved by interactions with environment depending on which side the arbitration leans towards human or robots

  - Has great potential to be applied to other areas such as education and medical treatment.



Large language models for HRI

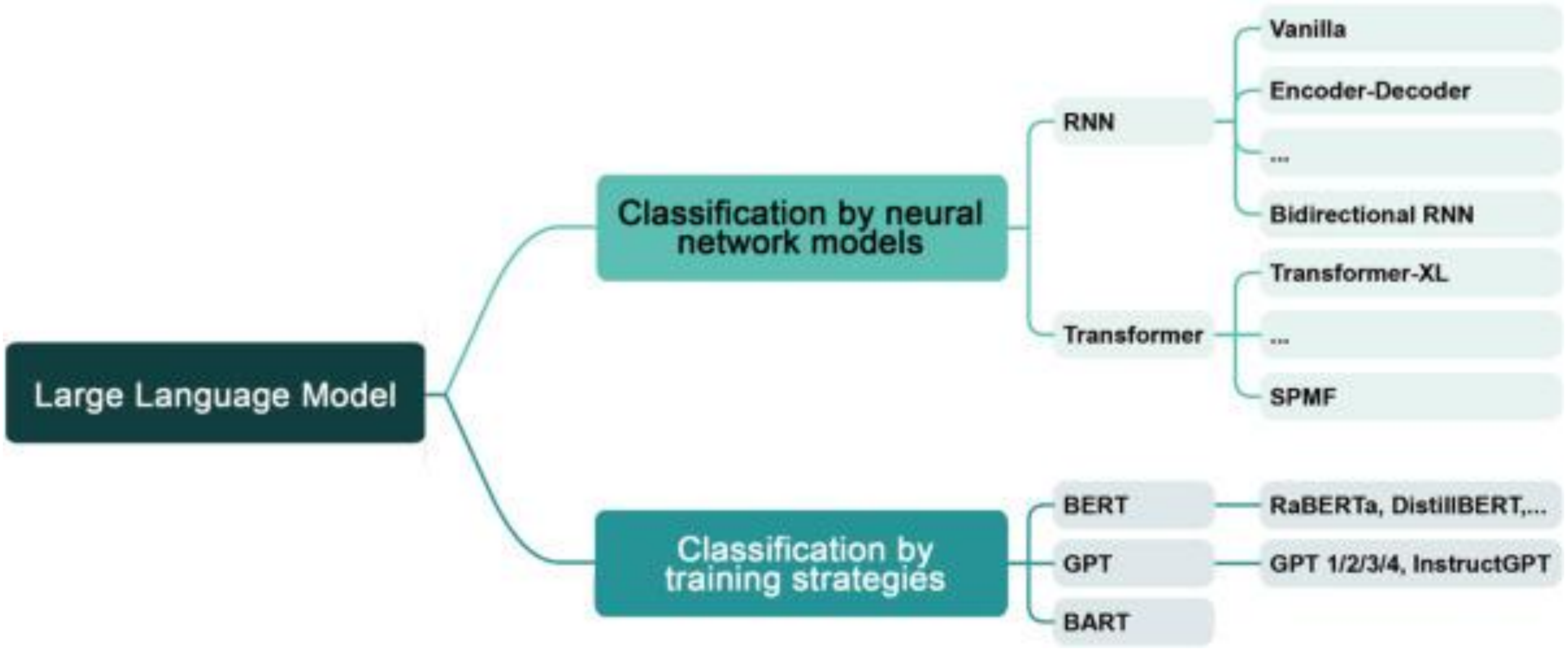
- HRI by Teleoperation
  - Takes advantage of the concept of controlling robots indirectly, usually by sending commands remotely through a console with functional buttons, which is beneficial as it allows robots to work in hazardous areas and tight spaces that are not accessible to humans.
    - A robot arm were designed that can teleoperate by movement of the human limb.
    - An integrated interface in ROS that allows the user to remotely control robots by hand motion and adjust the autonomy of the robot between different levels online.
  - The size of the two spaces can be vastly different, which significantly limits its practical application
    - Electromyography (EMG) signals in teleoperation to change the space drag and impedance, which solves the spatial constraints of natural limb control while maintaining the user’s posture.

Large language models for HRI

- HRI by conversation
  - Dialogue acts as a natural way of human communication, applying it to human–robot interaction is conducive to the integration of robots into human society.
    - A planning domain that allows robots to perform navigation tasks in a crowded environment in an acceptable manner, for which the robot can request permission when the path is blocked.
  - Problem arises when people do not interpret specifications in a concrete manner--can cause confusion for robots
  - In addition to the words spoken, humans also use nonverbal signals during communication, and the robot needs to comprehend their significance in order to react in a way that is satisfactory to humans.
    - Investigated the role of head nods in communication and showed that robot nodding in response to human words leads to more engaging conversations in HRI

Large language models for HRI

- List of the directions of work in LLMs



Applications of LLMs in HRI

- Potential of LLMs in different HRI cases:
  - Inquiry answering by multi-modal generation
    - large-scale statistical language modeling, deep neural networks combined with attention mechanisms
    - As modality and structure have been enhanced, language models are now able to generate responses in different forms to inquiries posed by users.

Applications of LLMs in HRI

- Social robots with commonsense
    - The integration of robots into human society has been a popular topic of research.
    - However, progress in this area has been hindered by the robots' lack of reasoning ability, which makes it difficult for them to gain commonsense, leading to potential hazard in some cases.
    - The introduction of LLMs greatly alleviated this challenge, providing robots with pretrained models that can generalize and act as vast repositories of knowledge to answer inquiries that require skills in different domains.

Applications of LLMs in HRI

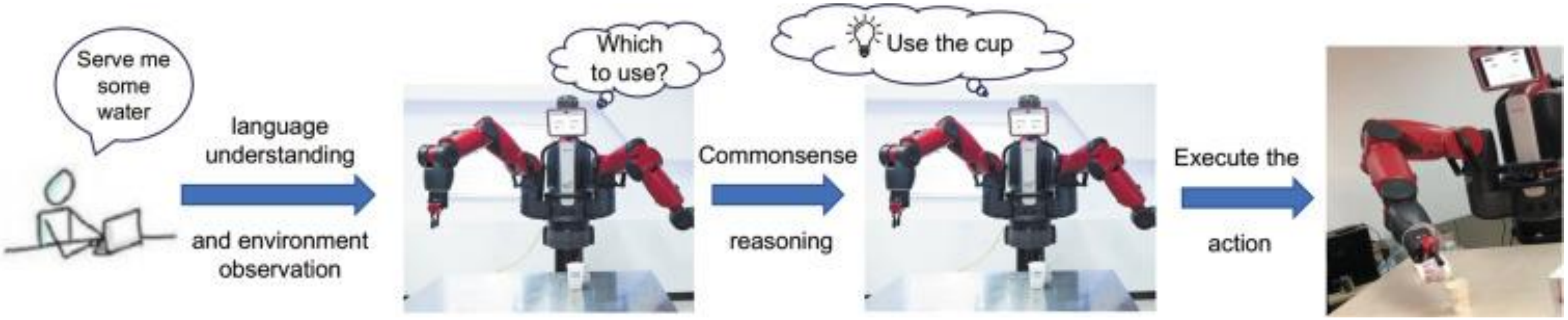
- Social robots with commonsense
  - Offering adolescents advice and information on topics such as sex, drugs, and alcohol.
  - A learning technique for children to acquire second language skills by an autonomous robot companion
  - A framework utilizing Augmented Reality (AR), Voicebots, and ChatGPT for foreign language learning.
  - By the impressive reasoning ability of large language models, chat robots are also able to generate coherent stories for children

(a) (b) (c)

Examples of social robots in (a) business reception (b) children education and (c) medical healthcare.

Applications of LLMs in HRI

- Instruction following and task completion
  - Recent studies have further explored its potential in physical robot applications… assisting people with daily routine tasks to automating assembly on the production line.
  - This field has been faced with a long-term difficulty: instructions provided by humans are usually vague and incomplete without thorough details.



Instruction following tasks by service robots. Given the command, large language models enable robot to reason with commonsense and look for possible tools in environment to accomplish the task.

The Future of HRI