MODULE 1: INTRODUCTION TO HUMAN FACTORS IN SOCIAL ROBOTS

Institute of System Science, NUS

Dr Nan Zhou Myo LEE

- Senior Lecturer in Software Systems Practice
- PhD and Bachelor of Mechanical Engineering with Robotics Specialization from NTU
- More than 14 years of sensorization, software simulation, intelligent system, digital solution development and integration using industrial IoT and automation technologies in both public and private sectors
- Worked at Data Storage Institute (DSI) (A*STAR) and Advanced Remanufacturing & Technology Centre (ARTC) (A*STAR)
- myokyawsett@gmail.com

Course Outline

- Day 1 — Module 1: Introduction to Human Factors in Social Robots

  Module 2: Robot Operating System
- Day 2 — Module 3: Planning under Uncertainty with Markov Decision Process

  Module 4: Human Factors in Autonomous Driving
- Day 3 — Module 5: Controlled Experiment Design

  Module 6: Heterogeneous Human Robot Interactive Systems
- Day 4 — Module 7: Human-Robot Interaction: Design and Build Workshop

  Final Presentation and Written Assessment

Objectives

- To acquire the knowledge of designing human-centred interactive systems with robots

Topics

- Introduction
- Remote vs Proximate Interactions
- Human & Robot Errors
- Mental models
- Usability
- Design Process for Human Robots Interaction

Human Robot Interaction

https://youtu.be/SOtPCX7Bs4o?si=-mto1Vu9IcVHfE0z&t=112

Human Robot Interaction

https://youtu.be/j4DkfKALnag?si=oPIEJTQ3__Iq7ZSP&t=141

IHMC Nadia

https://www.youtube.com/watch?v=R1JfVN76kAI

DeepRobotics Robot Dog

https://www.youtube.com/watch?v=4lryrrR4zpU

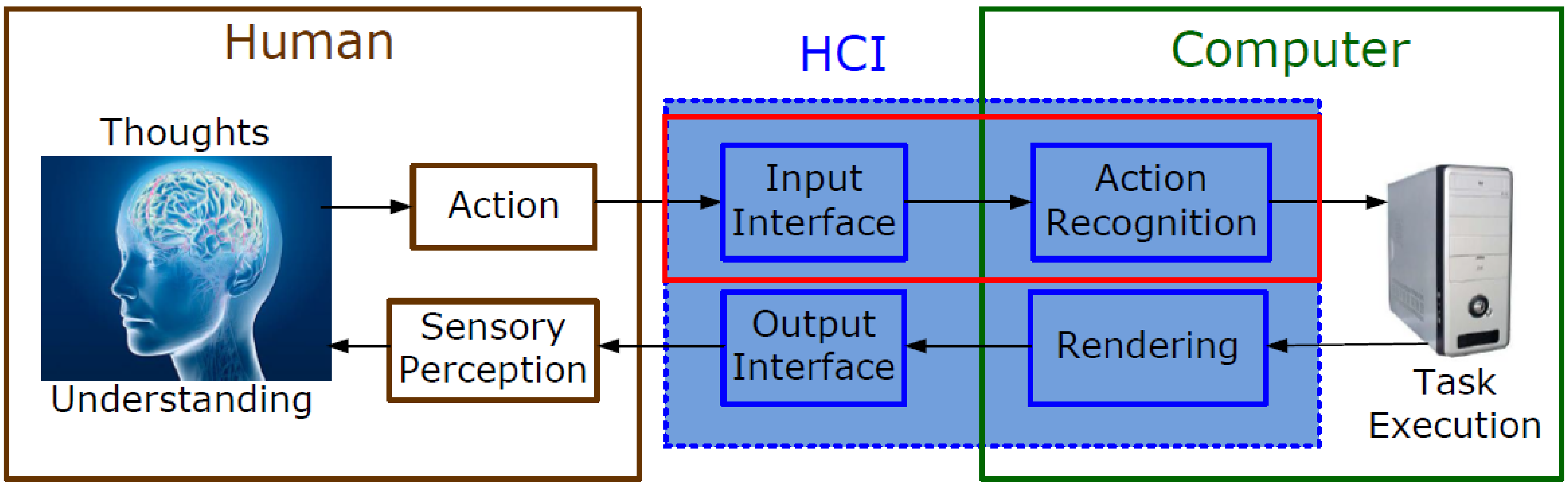
Introduction

- Human-Robot Interaction (HRI) is a field of study dedicated to **understanding, designing, and evaluating robotic systems for use by or with humans**
- HRI may take several forms, but are **largely influenced by whether the human and the robot are in close proximity or not**
- Two general categories:
  - Remote interactions
  - Proximate interactions

What categories are they in?

Human-Computer Interface (HCI)

- HCI is the medium that links man and robot
- HCI design and planning is critical for smooth operability and computing

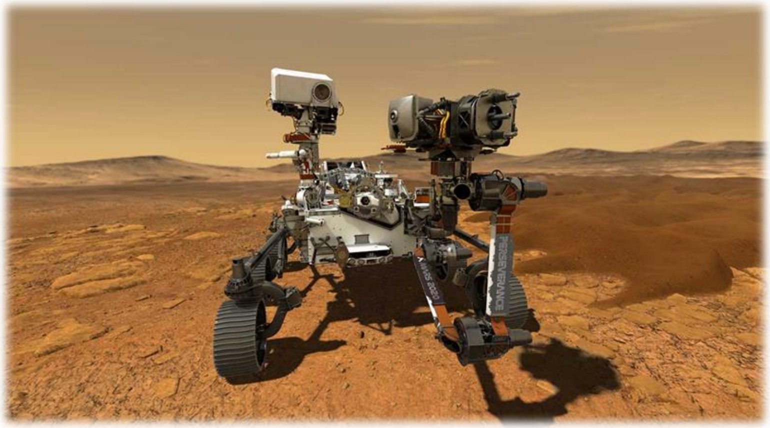


Source: Human-Computer Interfaces and Wearable Computing. Jeffrey Funk. MT5009 - Analyzing Hi-Technology Opportunities.

Input interfaces and their respective recognition are the main focus of this course.

Remote interaction

- Remote interaction with **mobile robot**→ **Teleoperation** or supervisory control



https://mars.nasa.gov/mars2020/

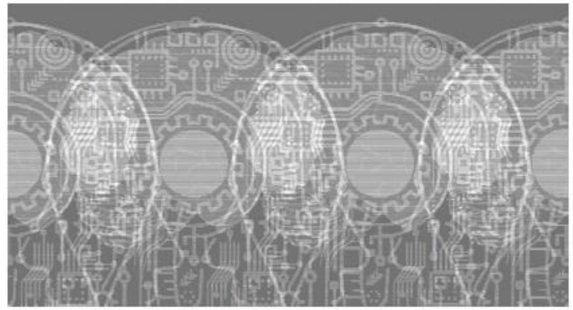
- Remote interaction with **physical manipulator** → **Telemanipulation**

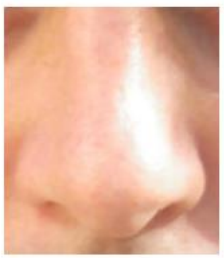
https://www.flushinghospital.org/newsletter/facts-about-robotic-surgery/

Proximate interactions

- **Proximate interaction with mobile robots:**
  - E.g. Robot assistant, receptionist
  - May include physical or social interactions
  - Physical → Collision avoidance
  - Social → Communications or collaborations
- **Social interaction types:**
  - Social, emotive and/or cognitive
  - More in proximate rather than remote

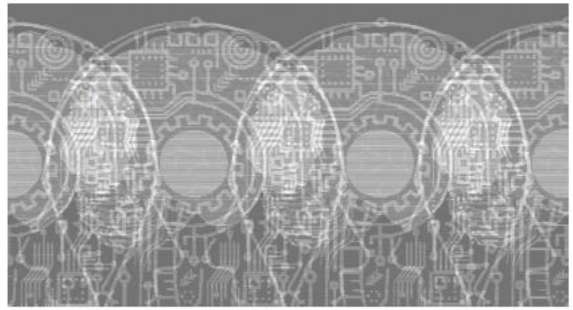
Interaction

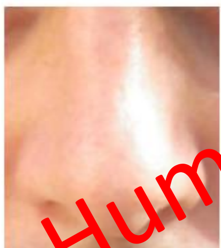




TASK

Interaction





Human Errors

TASK

HUMAN ERRORS

- Trivial OR serious?
- Why?
  - Mental model: we build our own theories to understand the causal behavior of the systems.
  - Characteristics of mental model
    - Partial
    - Unstable and subject to change
    - Internally inconsistent
    - Unscientific, superstition > evidence
    - Incorrect interpretation of the evidence
- **Human errors occur if mental model differs from reality (e.g. emotions, distractions)**
- HRI system designers needs to pay attention to
  - importance of a correct mental model
  - dangers of ignoring conventions

HUMAN ERRORS

https://www.youtube.com/watch?v=vxqBS2-4puw&t=5s

HUMAN ERRORS (CONT)

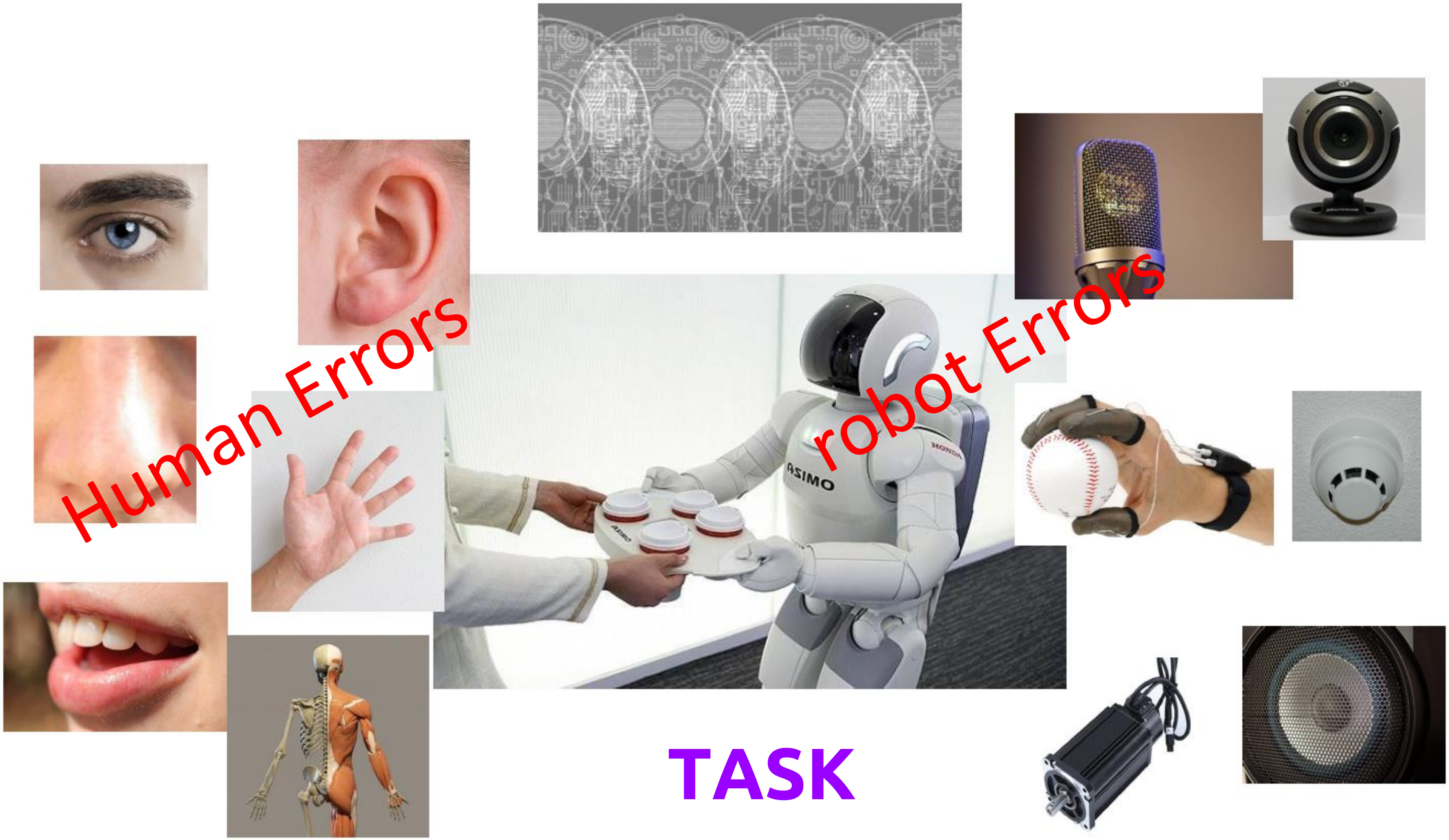
Waymo's Self-Driving Car Crash in Arizona Revives Tough Questions

Whether or not the autonomous Pacifica minivan was at fault, it's bad news for a young industry trying to prove it can makes roads safer for everyone.

- A self-driving Waymo minivan, operated by a human driver, was involved in a crash in Chandler, Arizona.
- A Honda sedan ran a red light, swerved to avoid another vehicle, and collided with the Waymo minivan, which was within the speed limit and following traffic laws.
- Waymo's preliminary data and video evidence suggest that their vehicle was not at fault.
- The crash involving a Waymo self-driving vehicle in Arizona, although not the fault of the autonomous car, has brought back difficult questions about the readiness and safety of autonomous driving technology.

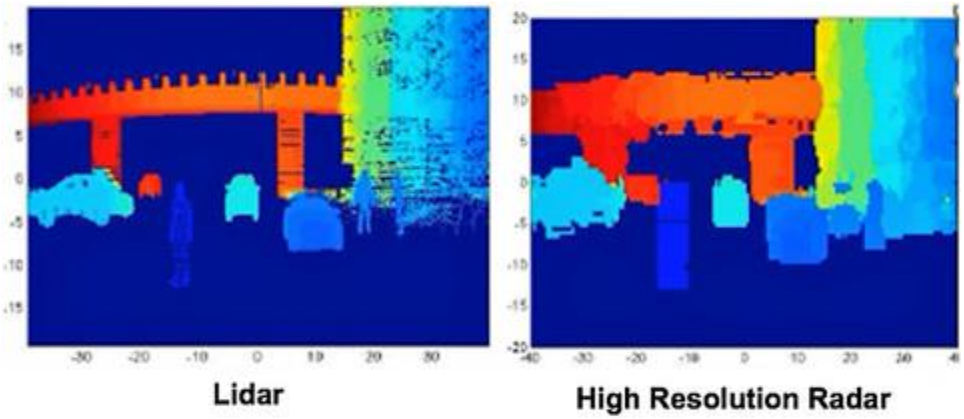
https://www.wired.com/story/waymo-crash-self-driving-google-arizona/

Interaction



ROBOT ERRORS

Imperfect sensing

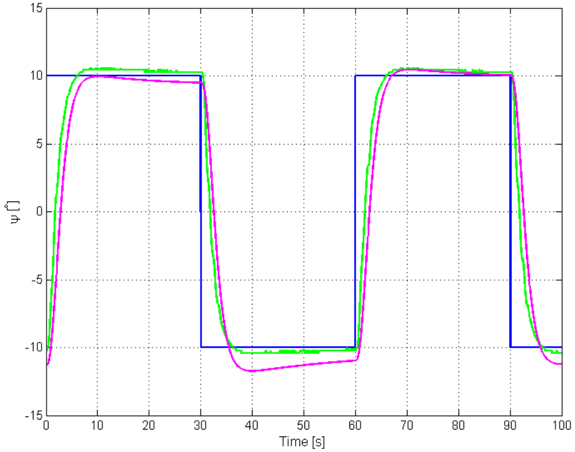


https://www.fierceelectronics.com/components/lidar-vs-radar

Imperfect decision

https://www.fastcompany.com/40568609/humans-were-to-blame-in-google-self-driving-car-crash-police-say

Imperfect control



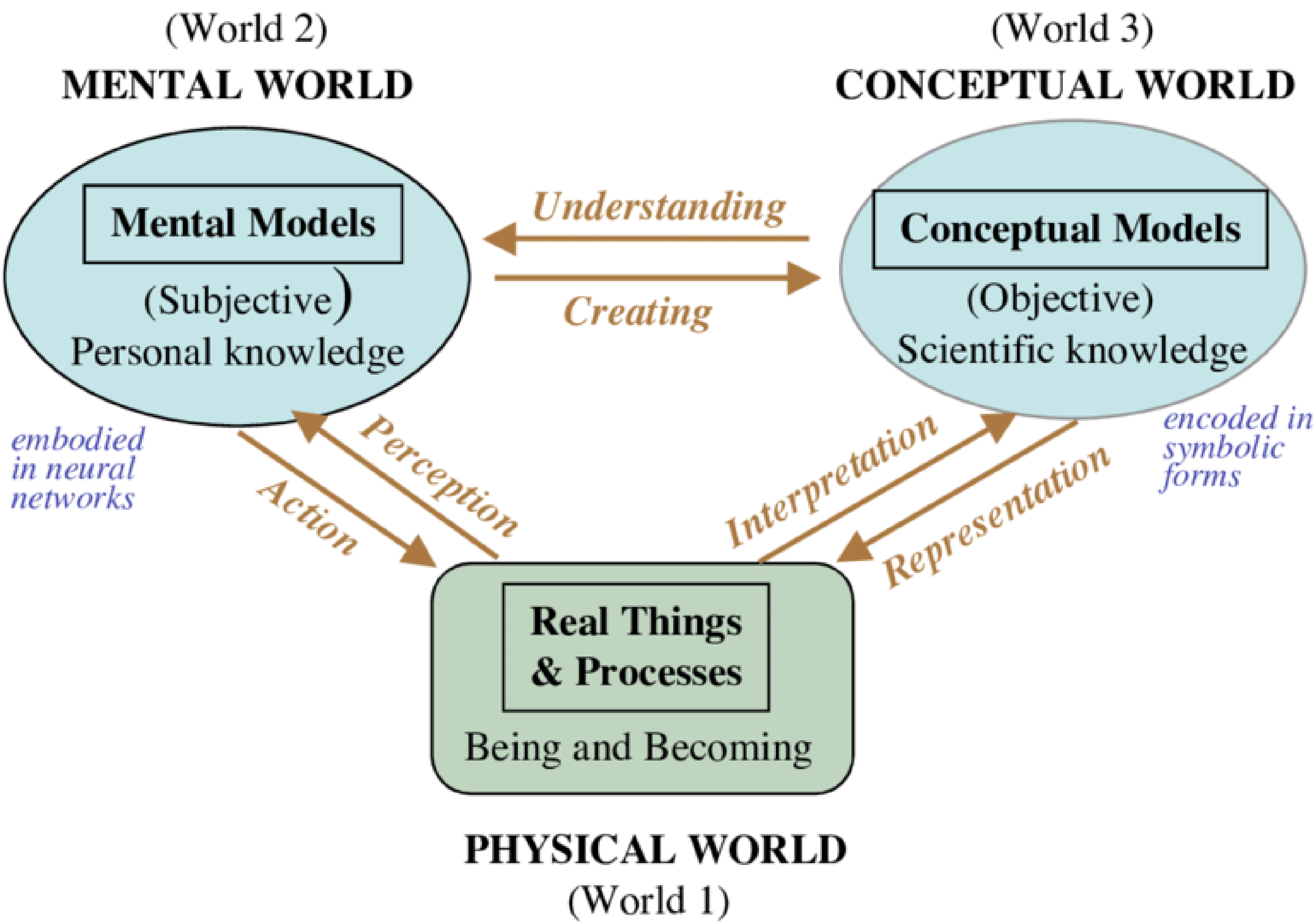
https://www.researchgate.net/publication/261058015_Modelling_of_nonlinear_helicopter_model_and_loopshaping_based_controller_synthesis/figures?lo=1&utm_source=google&utm_medium=organic

ROBOT ERRORS

- **Imperfect Sensing:**
  Misclassification
- **Imperfect Decision:**
  Erratic Behaviour
- A Tesla's Autopilot system mistakenly identifying a horse-drawn carriage
- It recognized the carriage as a truck, a car, a human, a human walking behind a car, and a human walking behind a truck
- At one point, the system even depicted the "truck" spinning around as if it were heading for a collision with the Tesla, which could potentially lead to inappropriate or unsafe actions by the AV

https://www.youtube.com/shorts/tpOg87AQvbo

Mental Models



https://www.researchgate.net/publication/253847244_Notes_for_a_Modeling_Theory_of_Science_Cognition_and_Instruction/figures?lo=1&utm_source=google&utm_medium=organic

USABILITY

Usability is a critical factor that determines how **effectively and comfortably humans can interact with robots:**

- **Useful** - accomplish the task;
  - The robot must be capable of performing the tasks it was designed for, effectively meeting the user's needs.
- **Usable** - do it easily and naturally, without danger of error, etc;
  - The robot should be easy to use, safe, and intuitive, allowing users to interact with it without frustration or difficulty.
- **Used** - make people want to use it, be attractive, engaging, fun, etc.
  - The robot should be engaging, attractive, and enjoyable to use, encouraging users to interact with it regularly and creating a positive overall user experience.

USABILITY - ISO Standard 9241

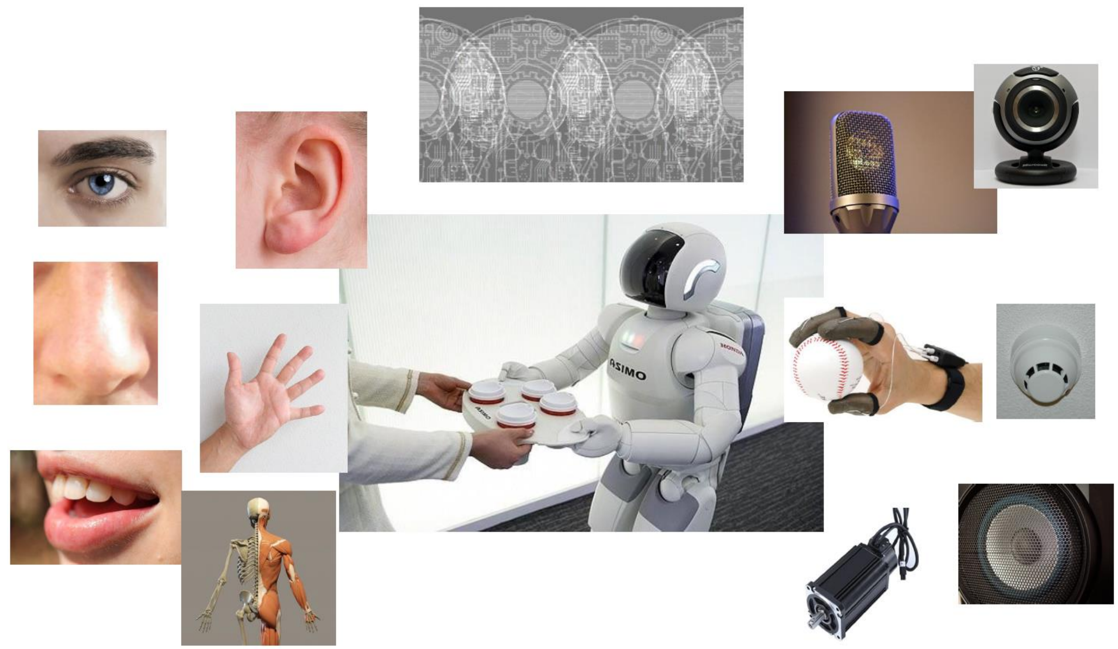
- Usability: the effectiveness, efficiency and satisfaction with which specified user achieve specific goals in particular environments.
- Effectiveness: The accuracy and completeness with which specified users can achieve specific goals in particular environments.
- Efficiency: The resources expanded to achieve the accuracy and complete the goal(s).
- Satisfaction: The comfort and acceptability of the work system to its users and affected parties

A Historical Overview of HCI/HRI

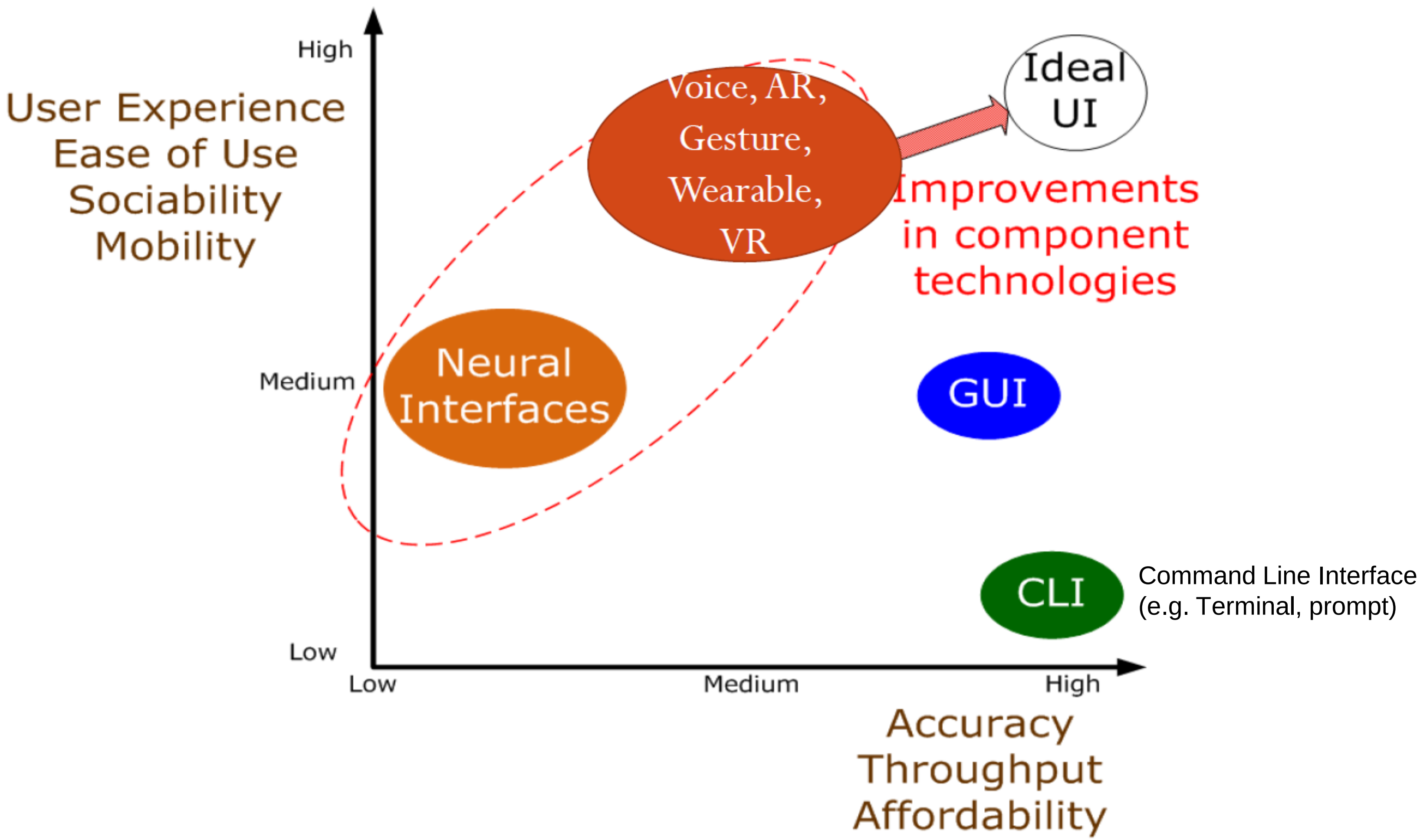
- How can an interactive system be developed to ensure its usability?
- How can the usability of an interactive system be demonstrated or measured?
- Design Paradigms
  - Paradigms are practical examples believed to enhance usability of interactive systems.
- HCI Patterns
  - Patterns are an approach to capturing and reusing the knowledge of what made a system / paradigm successful – to apply again in new situations.

Multi-modality

- Simultaneous use of multiple communication channels for both input and output. E.g.
  - Visual
  - Auditory
  - Tactile
  - Smell
  - Taste
  - Kinesthetic (body language)

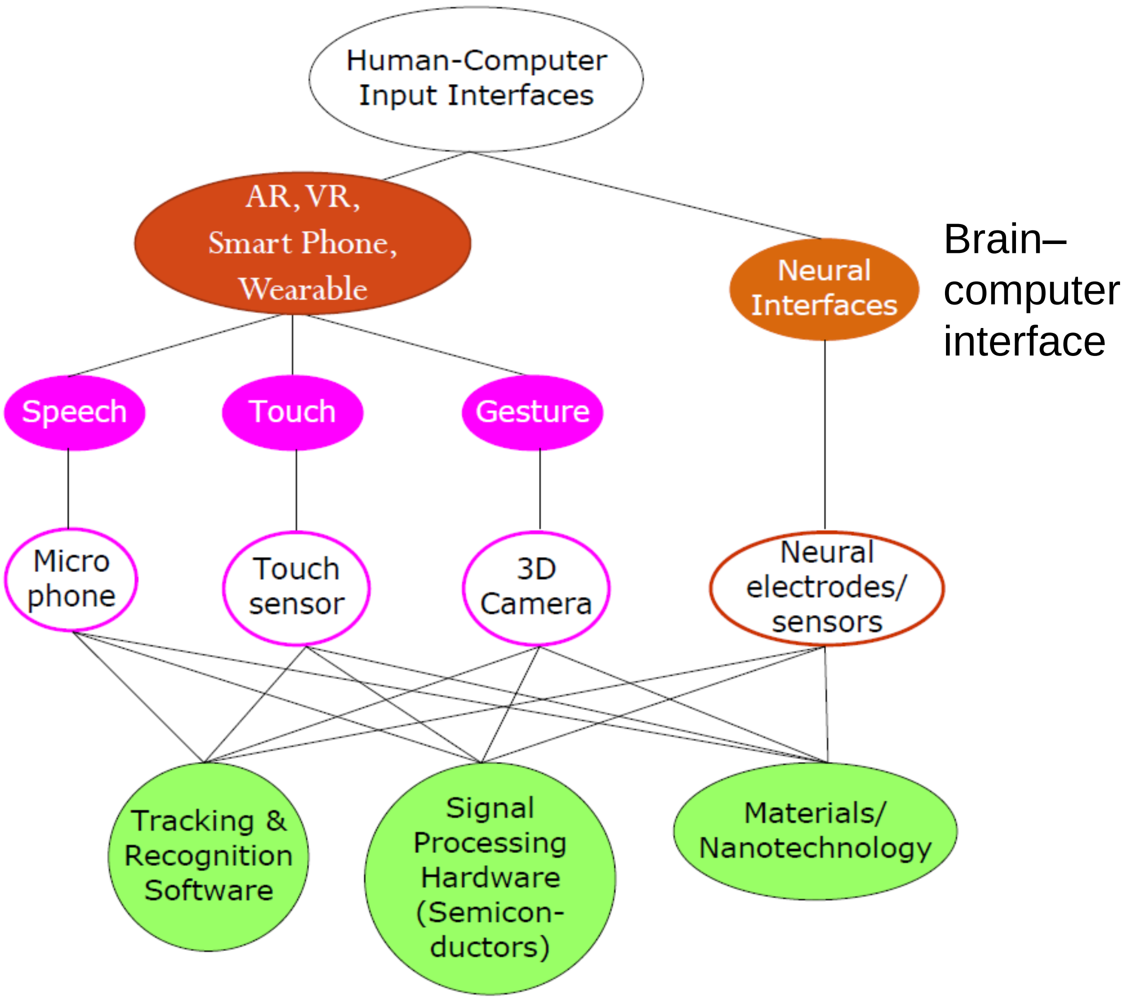


Comparison of Input Interfaces



Source: Human-Computer Interfaces and Wearable Computing. Jeffrey Funk. MT5009 - Analyzing Hi-Technology Opportunities.

Key Components of Input Interfaces



Source: Human-Computer Interfaces and Wearable Computing. Jeffrey Funk.
MT5009 - Analyzing Hi-Technology Opportunities.

Our NUS-ISS Stroke Rehab System

- Funded by SG Enable (>$500 K)
- Uses 3D cameras and speech for interaction

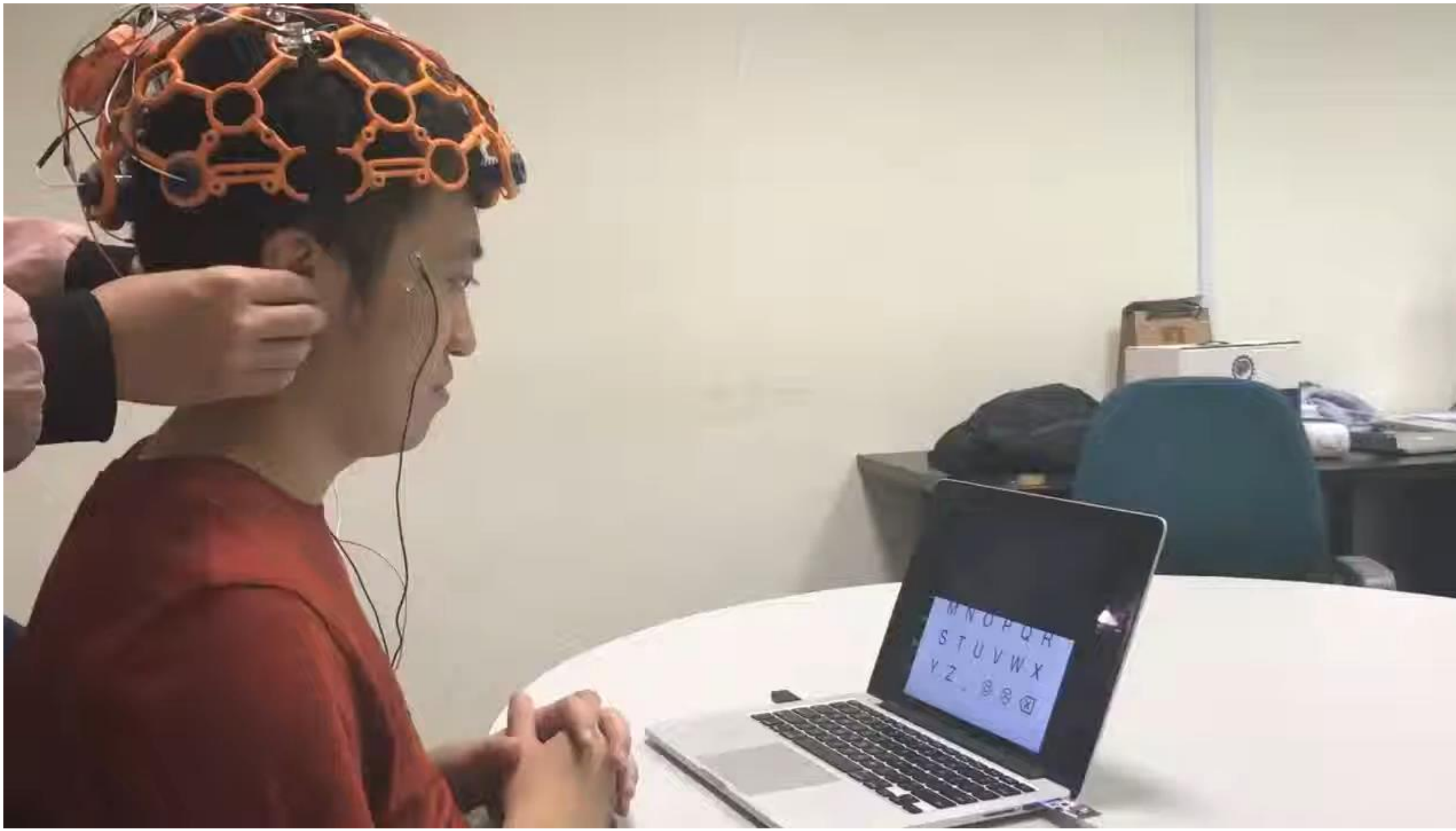
https://www.youtube.com/watch?v=ogI6IRPEXFU

Neural Interface: Brain Computer Synchronization

- Tools and Hardware: Brain scanning device
- Critical factors are Accuracy, Throughput and Affordability
- Currently limited accuracy – plasticity of brain
- Costs a deterrent factor
- **Mind-Controlled Drones Example (Video on the Right)**

https://www.youtube.com/shorts/QmNzUkDNoDc

Our NUS-ISS EEG System for LIS Patients



https://www.youtube.com/watch?v=e0-nev_pEQs

Effects of Design in HRI

Design can affect 5 attributes of HRI:

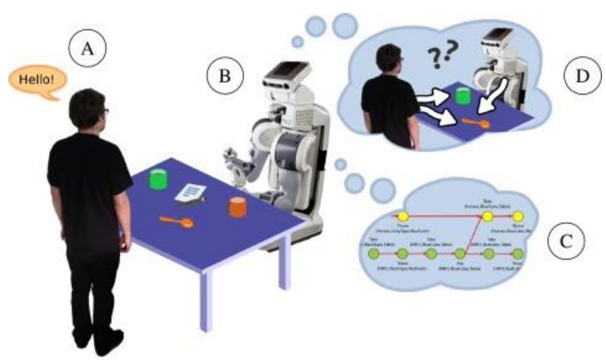
1. Level and behavior of autonomy
   - The design impacts how much control the robot has vs the human, influencing the dynamics of shared decision-making and trust in HRI.
2. Nature of information exchange
   - The design determines the effectiveness of communication channels between humans and robots, affecting understanding, responsiveness, and seamless interaction.
3. Structure of the teams
   - The design defines the roles and integration of humans and robots in a team, shaping collaboration, workload distribution, and interaction patterns.
4. Adaptation, learning and training of people and the robot
   - The design affects how both humans and robots can learn from each other and adjust their behaviors, enhancing mutual understanding and interaction quality.
5. Shape of the task
   - The design influences how tasks are defined and allocated between humans and robots, shaping the interaction flow and the complexity of joint task execution.

1. Autonomy

- Autonomy is not an end in itself in HRI, but a mean to supporting productive interaction
- Continuum of autonomy:
  - Computer offers no assistance; human does it all
  - Computer offers a complete set of action alternatives
  - Computer narrows the selection down to a few choices
  - Computer suggests a single action
  - Computer executes that action if human approves
  - Computer allows the human limited time to veto before automatic execution
  - Computer executes automatically then necessarily informs the human
  - Computer informs human after automatic execution only if human asks
  - Computer informs human after automatic execution only if it decides to
  - Computer decides everything and acts autonomously, ignoring the human

2. Information Exchange

- Efficient interactions are characterized by productive exchanges between human and robot
- Measures of the efficiency:
  - Time required for intent and/or instructions to be communicated
  - Cognitive or mental workload of an interaction
  - Amount of situation awareness produced by the interaction
  - Amount of shared understanding or common ground



3. Structure of Teams

- How many remote robots a single human can manage?
- Dependent on:
  - Level of autonomy of the robot (teleoperation and remote control requires vastly more direct attention from the human)
  - The task (which defines the load)
  - The available modes of communication (e.g. voice commands, visual/haptic feedback; these may hinder multi-robots management)
- Need for design of intelligent control interface between humans and multiple robots

4. Adaptation, Learning, and Training

1. Minimizing Operator Training

- Design **interfaces and control systems** that are intuitive and user-friendly to reduce the time and effort required for operators to learn how to effectively manage and interact with robots.

2. Efforts to Train Humans

- Comprehensive **training programs** that focus on enhancing operators' understanding of robot capabilities, limitations, and interaction protocols to ensure safe and effective human-robot collaboration.

3. Training Designers

- Educate robot and system designers on **human factors, usability principles, and the specific needs of end-users** to create more effective, user-centered robot interfaces and interaction models.

4. Training Robots

- Implement adaptive algorithms and learning techniques that enable robots to **learn from human interactions and experiences**, improving their performance, autonomy, and ability to collaborate with humans over time.

5. Task-Shaping

- Introducing technology fundamentally changes the way that humans do the task
- Task-shaping emphasizes the importance of considering how the task should be done and will be done when new technology is introduced

Examples of explicit task-shaping include:

- Specially designing space or underwater equipment and tools so that handles and connectors can be manipulated by a robotic arm
- “Pre-cleaning” a room so that a robot vacuum can accomplish its task most efficiently

5 Solution Themes of HRI

1. **Dynamic Autonomy, Mixed-Initiative Interaction, and Dialog**
   - Interactions that accommodate complexity; need for robots to dynamically adjust their level of autonomy based on the complexity of tasks and the current context of interaction
2. **Telepresence and Information Fusion in Remote Interaction**
   - Use information to provide humans an operational presence with robot
3. **Cognitive Modelling**
   - Robot to adjust information exchange according to human's cognitive state (e.g. voice, visual, mixture of both)
   - Generate robot's behaviour with models that are interpretable by humans (e.g. natural body languages, gestures)
4. **Team Organizations and Dynamics**
   - Cooperation between humans and robots in teams
5. **Interactive Learning**
   - Human and robots can learn from one another via actions and/or feedback to incrementally improve ability, autonomy and interaction; enables robots to improve their skills, autonomy, and interaction strategies over time, and enables humans to learn how to better communicate and collaborate with robots

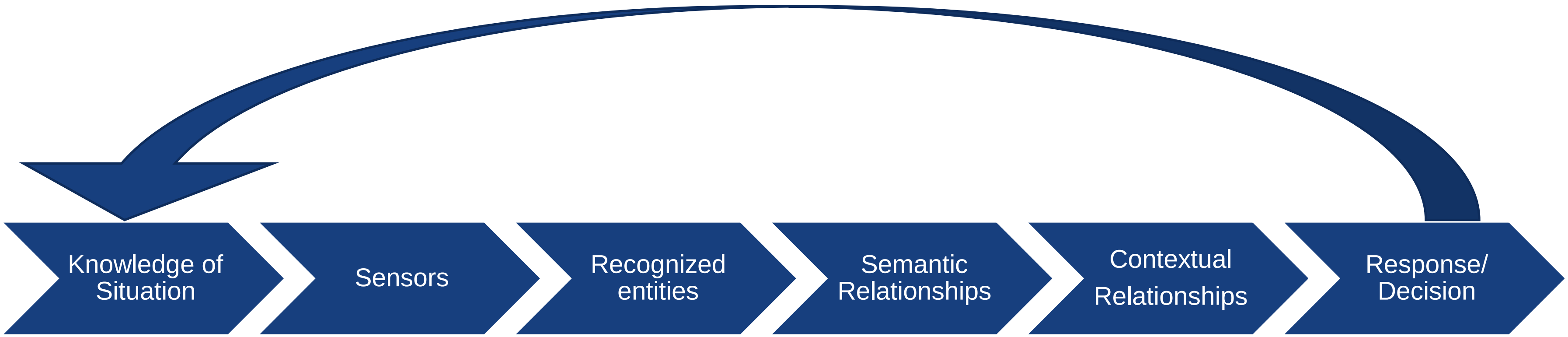
HRI Design Consideration

1. **Who is the design for?**
   - Understanding the target users is crucial; consider their needs and preferences
2. **Why do they want it?**
   - Purpose and goals of the HRI system
3. **What are the materials required?**
   - Necessary hardware and software components required for the system development
4. **What is the cost?**
   - Includes development, deployment and maintenance costs
5. **What are the safety/ethical issues?**
   - Ensures that the HRI system is reliable, secure, and respects user privacy and rights

Human Factors Design Principles

Type of Human Factor Engineering (HFE)	Examples of Principles	Examples of Design
Physical HFE - concerned with human anatomical, anthropometric, physiological and biomechanical characteristics as they relate to physical activity	• Minimize time required for perception, decision, and manipulation • Reduce or mitigate need for physical intervention • Optimize opportunities for physical movement	• ML to learn user preference • Auto-suggest based on initial few inputs • Voice or gesture inputs • Auto-highlight important information • Hardware repair/repositioning • Replacement of traditional keyboard and mouse with touchpad input devices to compensate limited workspace
Cognitive HFE - concerned with mental processes, such as perception, memory, reasoning, and motor response, as they affect interactions among humans and other elements of a system	• Consistency of interface design • Match technology and user's mental model • Minimize cognitive load • Allow for error detection and recovery • Provide feedback to users	• Active feedback on user's action based on sensors • Gamification elements to reduce boredom • ML to learn preference or gestures • NLP • Information overlay or AI guide • Adjustment of alarm parameter to reduce false alarms
Organizational HFE - concerned with the optimization of sociotechnical systems, including their organizational structures, policies, and processes - attainment of a fully harmonized work system that ensures employee job satisfaction and commitment - Include employee's communication, participation and cooperation with the system	• Provide opportunities to users to learn and develop new skills (*Meaningfulness of tasks*) • Allow user control over work systems • Support user access to social support • Involve user in system design	• Feedback from users to improve systems • Settings to configure layout/functions • Live help-desk operator (the user is human after all!) • Increase user awareness and understanding of the system; Virtual or augmented reality technologies can be utilized to enhance this

Design Process for Human-Robot Interaction



- Knowledge of Situation: Broad theme of what do you want the system to understand and do in the situation (based on various scenarios and contexts)
- Sensors: Types of hardware sensors to be used
- Recognized entities: 1st layer of feature groupings to yield specific recognized entities
- Semantic Relationships: 2nd layer of recognized entities groupings to yield specific semantic relationships
- Contextual Relationships: 3rd layer of Semantic Relationship groupings to yield specific contextual relationships
- Decision/Actuation

Applied Example

Robotic nurse, Tommy, in Italian hospital that cares for Covid-19 patients under quarantine

https://www.pri.org/stories/2020-04-08/tommy-robot-nurse-helps-italian-doctors-care-covid-19-patients

Case Study Example:

HRI Design Considerations for Covid-19 Robot

- **Who is the design for?**
  - Covid-19 patients and hospital staff
- **Why do they want it?**
  - To reduce interaction between staff and patients and to automate as much of the monitoring and caregiving as possible
- **What are the materials required?**
  - Mobile robot with on-board sensors (for monitoring vitals like blood pressure and oxygen saturation), a tablet for communication, a microphone, speakers, and a camera for video communication
- **What is the cost?**
  - Approx 100,000 Euros per unit
- **What are the safety/ethical issues?**
  - Wrong diagnostics, over-reliance on automation, patient acceptance and psychological impact, data privacy

Case Study Example:
HFE Design for Covid-19 Robot

Type of HFE	Design
Physical HFE	• Voice and gesture inputs and outputs for easier interaction between robots and patients • Distance sensors required to do SLAM and to avoid collision • IMU, heart rate, SpO2, infrared thermometer sensors to monitor patients' activities and vitals
Cognitive HFE	• Very simple instructions provided to patients • Alarm parameter changed to IoT-based as on-site alarms can disturb patients' rest (too noisy or too bright) • Active feedback on user's actions based on sensors (due to e.g. patients not resting enough or not drinking enough water or eating too much heaty food)
Organizational HFE	• Feedback from users to improve robot services (can come in touch screen with 3 emoticons to choose from, similar to feedback systems for some toilets) • Live help-desk operator available to address patients' concerns (e.g. suspected wrong medicine given by robot) • Increase user awareness and understanding of the system (e.g. via emails/apps, or providing a leaflet with summarized info on the service robot)

Case Study Example:
HRI Design Process for Covid-19 Robot

Knowledge of Situation	**Sensors**
Level of Activity and Vitals in Patients	4 Inertia Measurement Units Heart Rate Sensor SpO2 sensor Infrared Thermometer

Case Study Example: Covid-19 Robot

Sensors	Recognized Entities
3 Axis IMU Sensor	• Fast Repetitive Motion of Legs • Slow Repetitive Motion of Legs • Slow Non-Repetitive Motion of Legs • Static
3 Axis IMU Sensor	• Fast Repetitive Motion of Hands • Slow Repetitive Motion of Hands • Slow Non-Repetitive Motion of Hands • Static
Heart Rate	• Above Resting • At Resting
SpO2 data	• Above Resting • At Resting
Temperature	• High temperature • Low temperature

Case Study Example: Covid-19 Robot

Recognized Entities

- Fast Repetitive Motion of Legs
- Slow Repetitive Motion of Legs
- Slow Non-Repetitive Motion of Legs
- Static

- Fast Repetitive Motion of Hands
- Slow Repetitive Motion of Hands
- Slow Non-Repetitive Motion of Hands
- Static

- Above Resting
- At Resting

- Above Resting
- At Resting

- High temperature
- Low temperature

Semantic Relationships

- Vigorous Activity
- Static Exercises (Pushups/situps)
- Sleeping
- Walking
- Not moving with poor vitals

Case Study Example: Covid-19 Robot

Semantic Relationships

- Vigorous Activity
- Static Exercises (Pushups/situps)
- Sleeping
- Walking
- Not moving with poor vitals

Contextual

- Patient is over exerting
- Patient is healthy
- Patient is too sedentary
- Patient is in distress

Case Study Example: Covid-19 Robot

Contextual	Decision/Response
Patient is over exerting	Broadcast advice to patient to reduce activity
Patient is healthy	No action
Patient is too sedentary	Broadcast advice to patient to be more active
Patient is in distress	Perform emergency intervention

Application Project

- **Think of a robotic system application** in your company or future business **that requires HRI design**
- Apply **a detailed design consideration and HRI design process** for your application
- **To be presented and submitted on the 4th day**
- **10 minutes presentation** (around 10 slides) and 5 minutes Q&A per person
- Have more graphics/charts/figures than wordy
- PowerPoint-based (use provided template: "HRSE M1 Presentation template")

Module 1
Quiz Exercise

End of Module 1

