MODULE 1: INTRODUCTION TO HUMAN FACTORS IN SOCIAL ROBOTS

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About Nicholas Ho

- nicholas.ho@nus.edu.sg
- Lecturer at NUS ISS; Courses covered include:
  - ➢ Robotic Systems
  - ➢ Autonomous Robots and Vehicles
  - ➢ Human-Robot System Engineering
- BEng and PhD degree from School of Mechanical Engineering, NUS
- Specialized in architecture, design & development
  - ➢ Artificial Intelligence
  - ➢ Augmented/Virtual Reality
  - ➢ Internet-of-Things (IoT) & Cyber-Physical System (CPS)

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

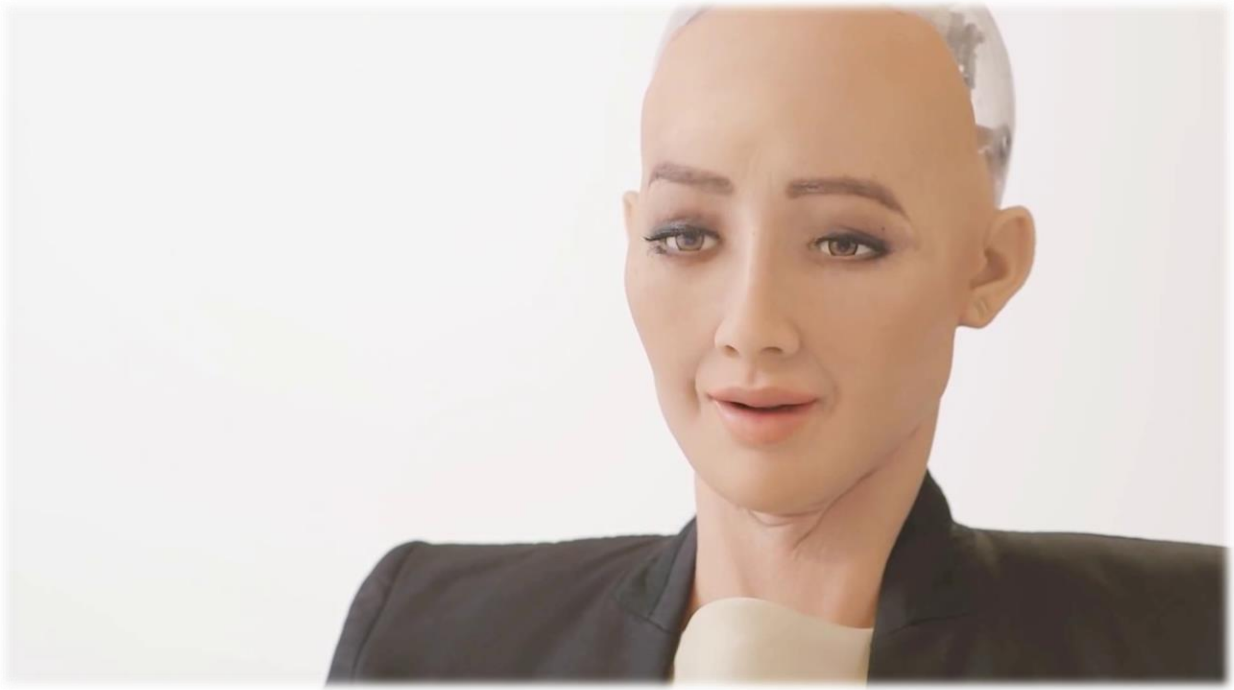
- Introduction
- Design rules
- Prototype
- Metaphors
- Simulation
- Mental models
- Design Process for Human Robots Interaction

Human Robot Interaction

https://www.youtube.com/watch?v=SOtPCX7Bs4o

Sophia

- First humanoid to be granted citizenship in Saudi Arabia



https://www.youtube.com/watch?v=Bg_tJvCA8zw&t=332s

Park Avenue Rochester Hotel Robot

- Bellboy, delivery and taking of orders….
- Right here in SG

https://www.youtube.com/watch?v=I15_EOkePhk

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

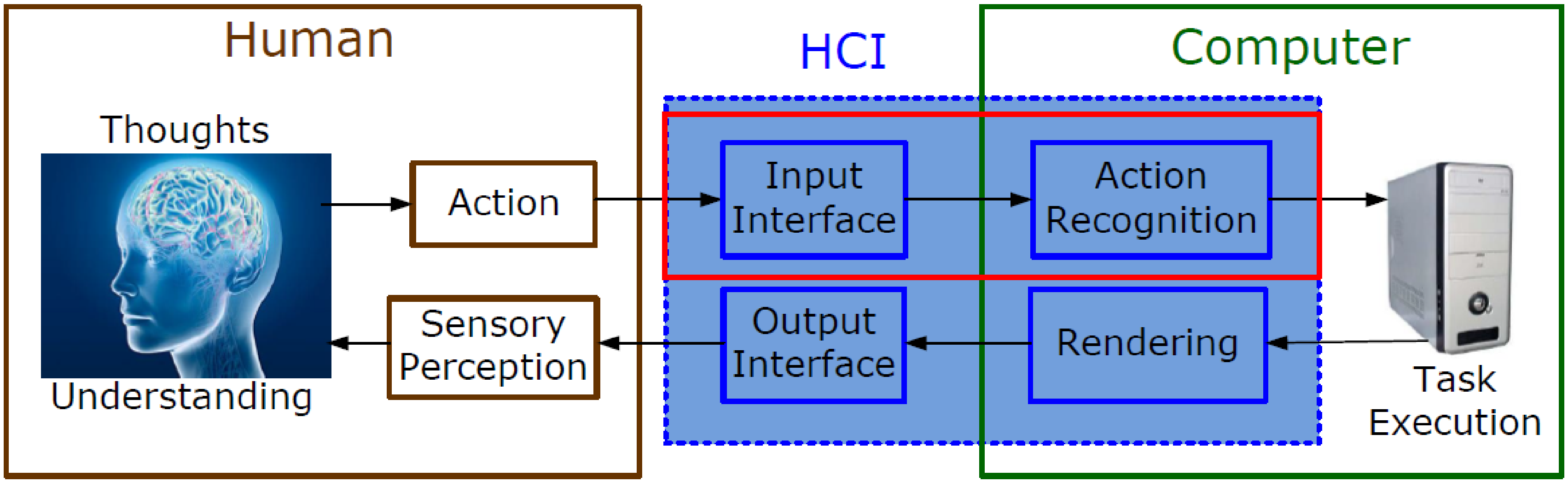
What categories are they in?






Human-Computer Interface (HCI)

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

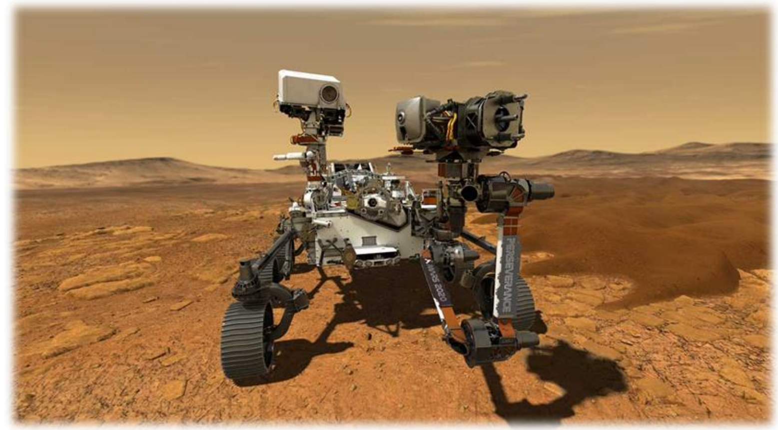


Source: Human-Computer Interfaces and Wearable Computing. Jeffrey Funk. MT5009 - Analyzing Hi-Technology Opportunities.

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/

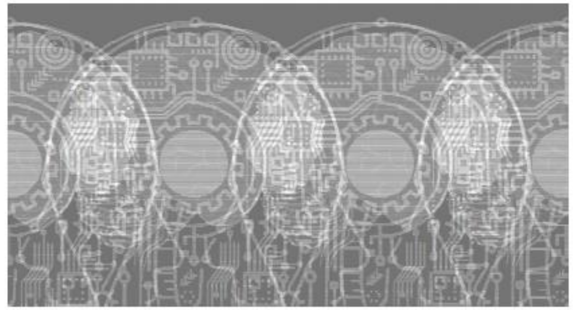
- Remote interaction with **physical manipulator** → **Telemanipulation**

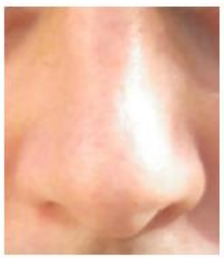
https://www.flushinghospital.org/newsletter/facts-about-robotic-surgery/

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

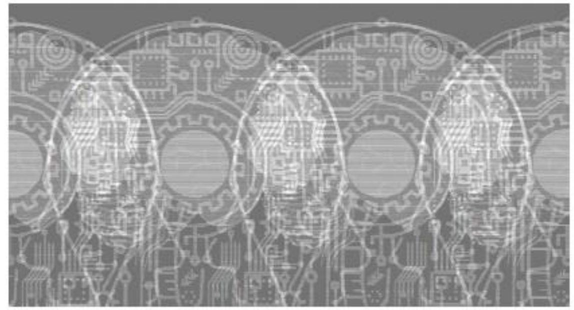
Interaction

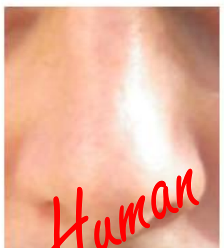




TASK

Interaction





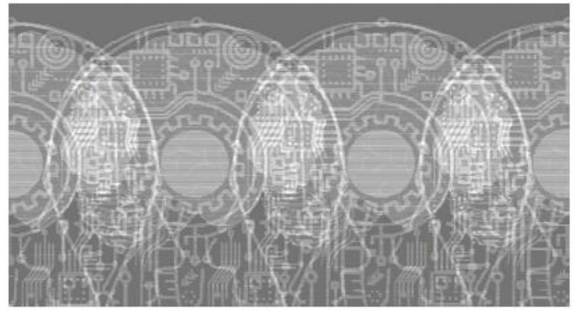
Human Errors

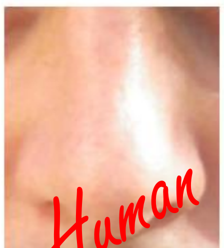
TASK

HUMAN ERRORS

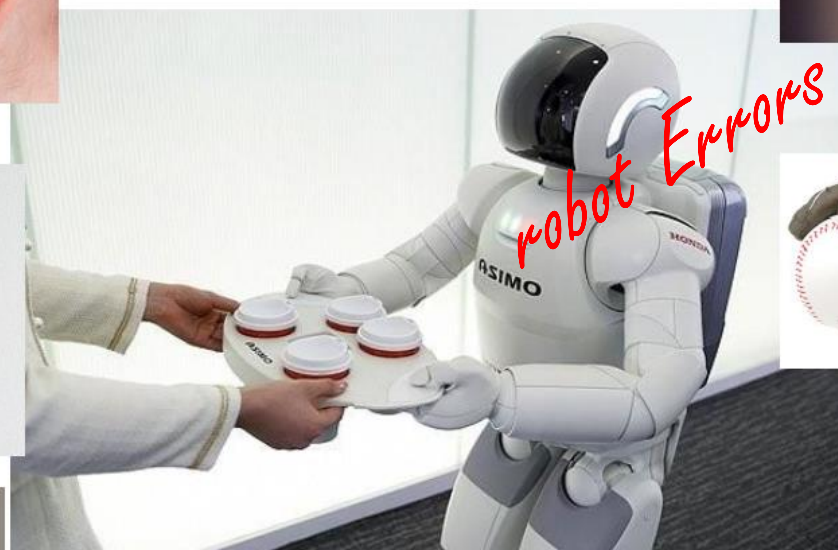
- Trivial OR serious?
- Why?
  - Mental model: we build our own theories to understand the causal behavior of the systems.
  - Characteristics of mental model
    - Partial
    - Unstable and subject to change
    - Internally inconsistent
    - Unscientific, superstition > evidence
    - Incorrect interpretation 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

Interaction





Human Errors

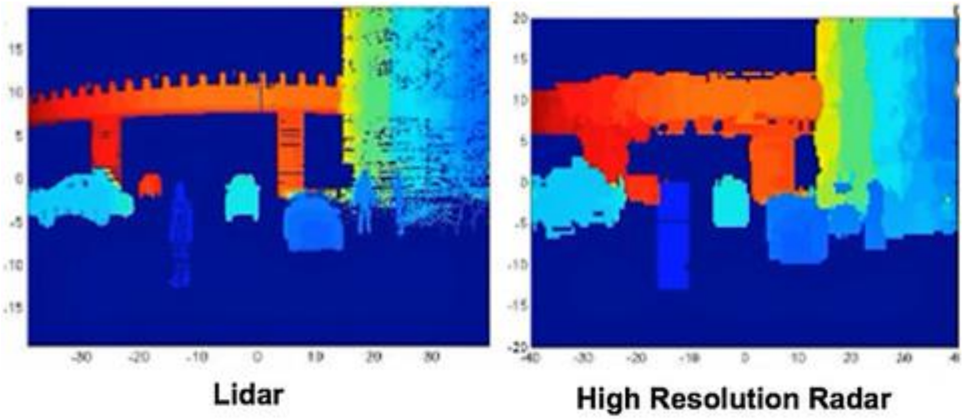


robot Errors

TASK

ROBOT ERRORS

Imperfect sensing

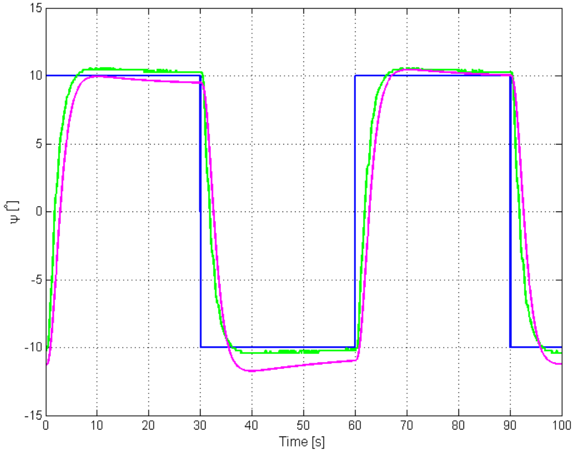


https://www.fierceelectronics.com/components/lidar-vs-radar

Imperfect decision

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

Imperfect control

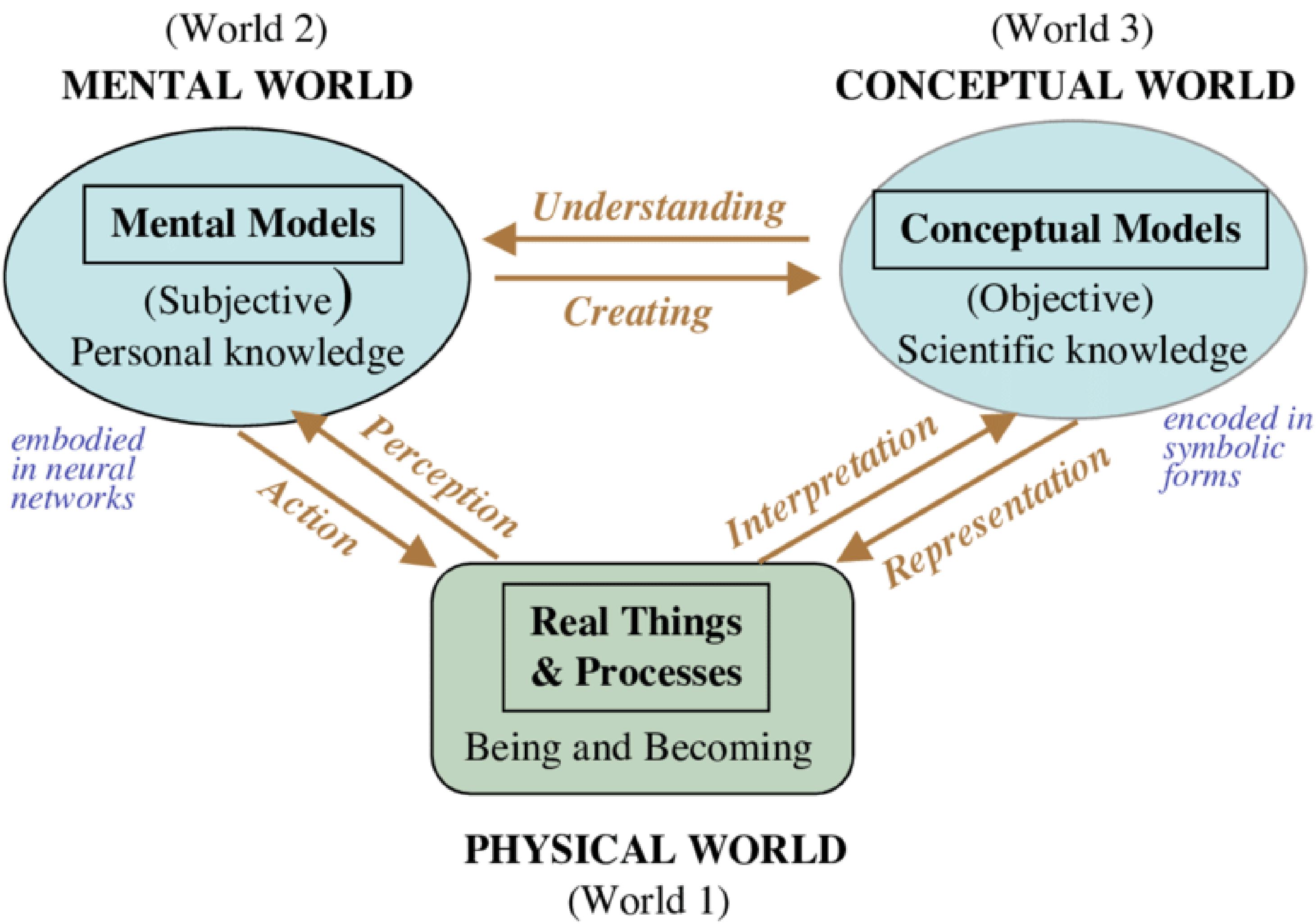


https://www.researchgate.net/publication/261058015_Modelling_of_nonlinear_helicopter_model_and_loopshaping_based_controller_synthesis/figures?lo=1&utm_source=google&utm_medium=organic

ROBOT ERRORS

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

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

- Useful - accomplish the task;
- Usable - do it easily and naturally, without danger of error, etc;
- Used - make people want to use it, be attractive, engaging, fun, etc.

USABILITY - ISO Standard 9241

ISO 29990:2010

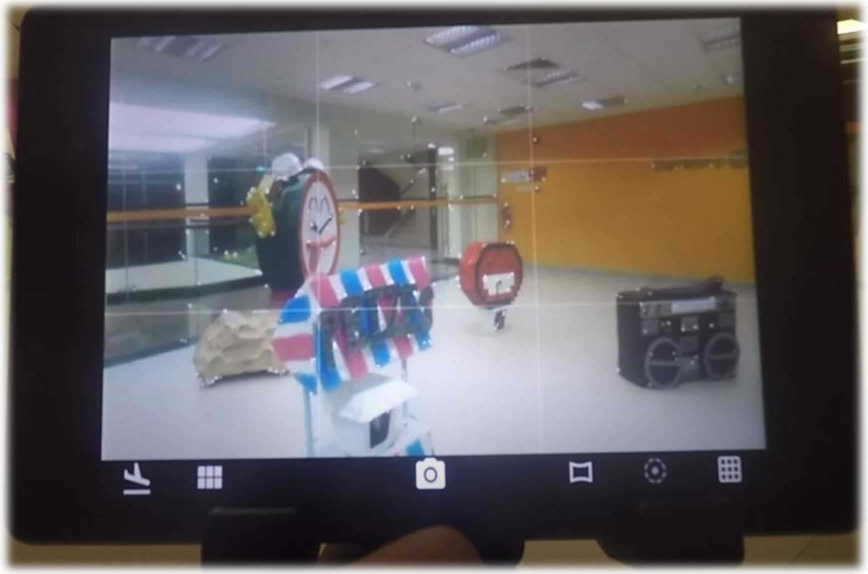
- Usability: the effectiveness, efficiency and satisfaction with which specified user achieve specific goals in particular environments.
- Effectiveness: The accuracy and completeness with which specified users can achieve specific goals in particular environments.
- Efficiency: The resources expanded 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.

Direct Manipulation (since 1980s)

- What You See Is What You Get (WYSIWTG)
  - Visibility of the objects of interest;
  - Incremental action at the interface with rapid feedback on all actions;
  - Reversibility of all actions, so that users are encouraged to explore without severe penalties;
  - Syntactic correctness of all actions, so that every user action is a legal operation;
  - Replacement of complex command languages with actions to manipulate directly the visible objects.



https://www.youtube.com/watch?v=Y2GsRP7khes

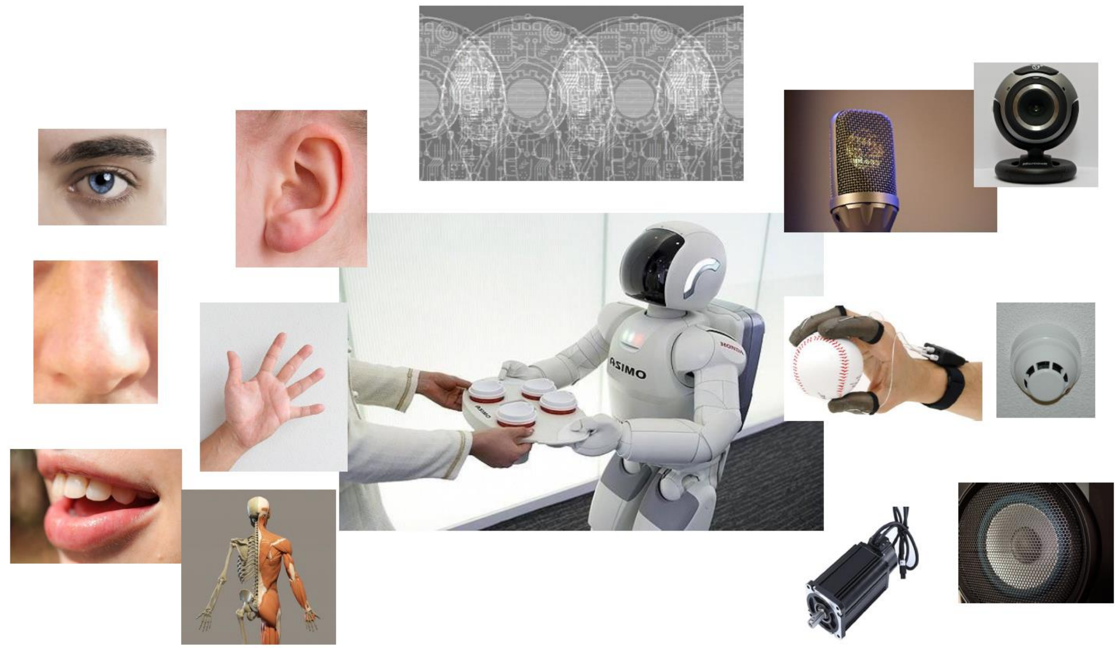
Language

https://www.youtube.com/watch?v=61SKrfITrB4

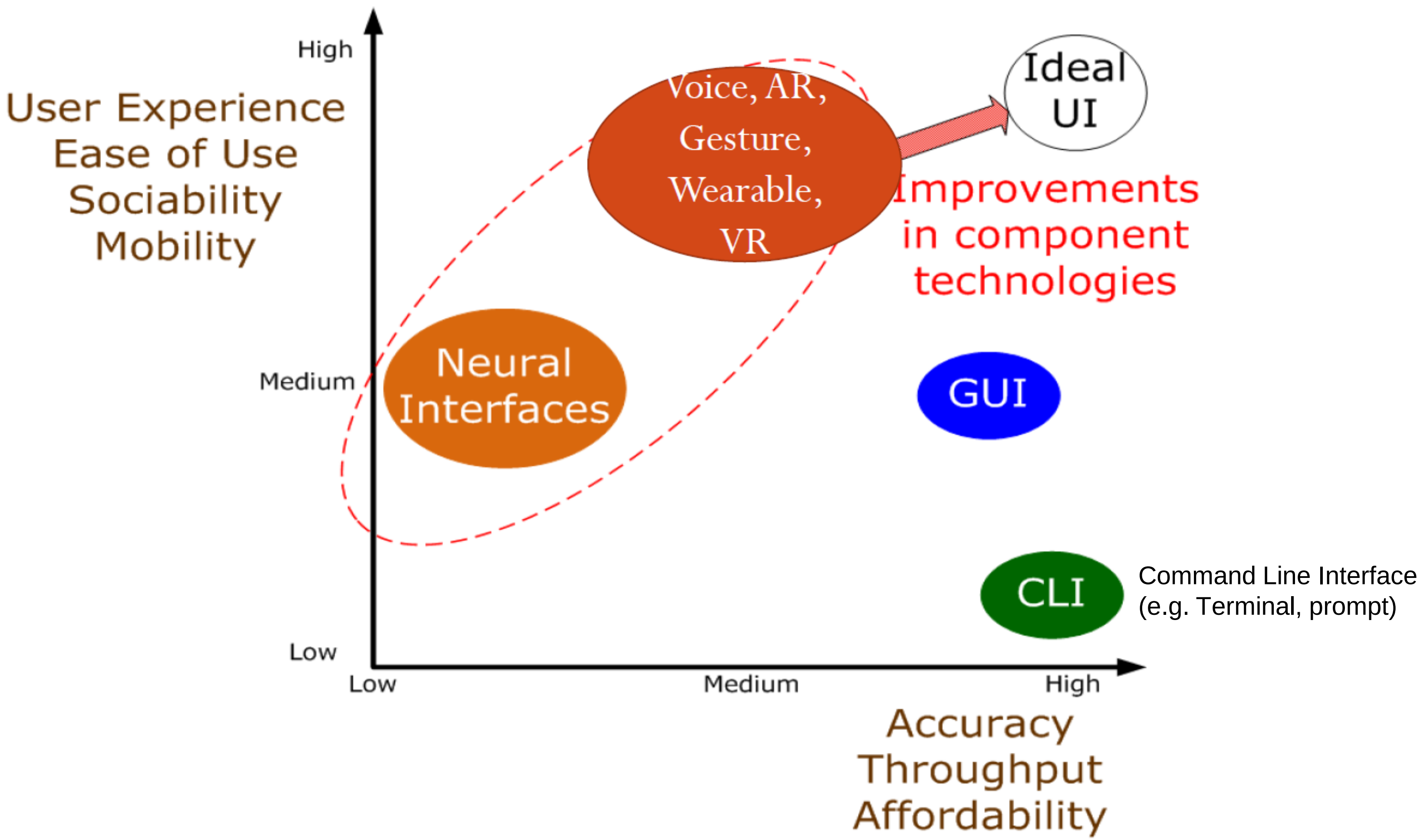
Multi-modality

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

    (body language)

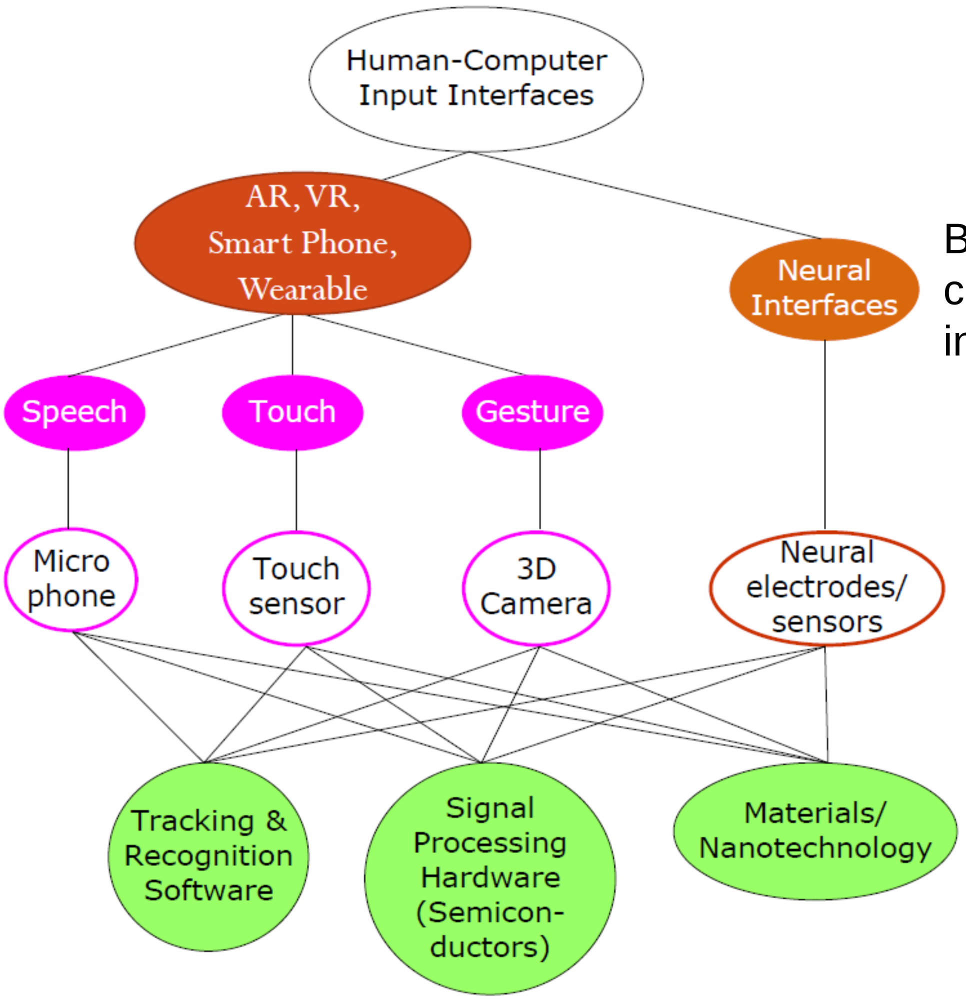


Comparison of Input Interfaces



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

Key Components of Input Interfaces



Brain–computer interface

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

Our NUS-ISS EEG System for LIS Patients

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

Effects of Design in HRI

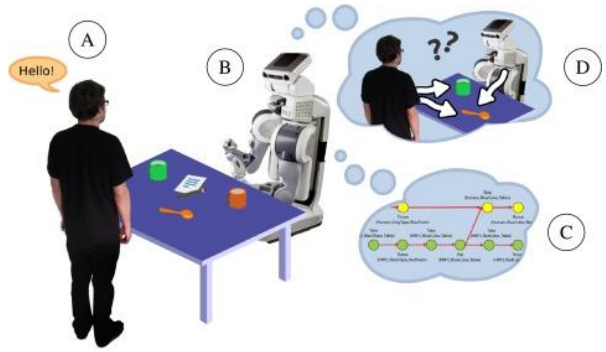
- Design can affect 5 attributes of HRI:
  - Level and behavior of autonomy
  - Nature of information exchange
  - Structure of the teams
  - Adaptation, learning and training of people and the robot
  - Shape of the task

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

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



Structure of Teams

- How many remote robots a single human can manage?
- Dependent on:
  - Level of autonomy of the robot (teleoperation requires vastly more direct attention from the human)
  - The task (which defines the load)
  - The available modes of communication
- Need for design of intelligent control interface between humans and multiple robots

Adaptation, Learning, and Training

- Minimizing Operator Training
- Efforts to Train Humans
- Training Designers
- Training Robots

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:

- 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
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)
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

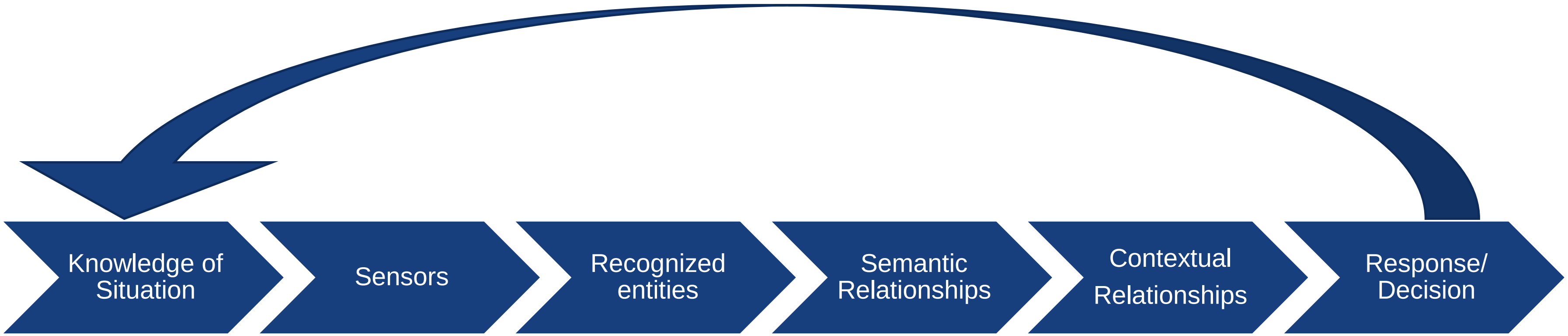
HRI Design Consideration

- Who is the design for?
- Why do they want it?
- What are the materials required?
- What is the cost?
- What are the safety/ethical issues?

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: 1^{st} layer of feature groupings to yield specific recognized entities
- Semantic Relationships: 2^{nd} layer of recognized entities groupings to yield specific semantic relationships
- Contextual Relationships: 3^{rd} 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 and medication
- What is the cost?
  - Approx 100,000 Euros a piece
- What are the safety/ethical issues?
  - Wrong diagnostics, wrong administration of medication

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