MTRN 3060: ROBOTICS and AUTOMATIONS
Week 10

MACQUARIE University
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Workshop: Human-Robot interaction
Lecture Jacobians: Velocities and Static forces

Challenges in Human System integration

One of the main reasons behind system failure is when human is considered as a problem of interface.

Instead the human needs to be integral to the design, conception and development system up front

The Littoral Combat Ship: An Example

Goal	Reduce the number of sailors required to operate the ship by introducing intelligent automation and robotics
Initial Design	Built to be operated by 45 sailors
New Design Outcome	Required 60 highly skilled sailors with a higher pay grade, so the ship failed to meet the goal

Source: Shattuck, G.L. (n.d.). *Transitioning to autonomy: A human systems integration perspective* [PowerPoint slides]. National Aeronautics and Space Administration.http://human-factors.arc.nasa.gov/workshop/autonomy/download/presentations/Shaddock%20.pdf

The Littoral Combat Ship: An Example

Negative Outcome

Manpower

- System undermanned by 50%
- Required sailors at higher skill level and pay grade
- High workload and fatigue led to high turnover

Expense

- High cost of retrofitting
- 60 sailors at a higher pay grade instead of 45

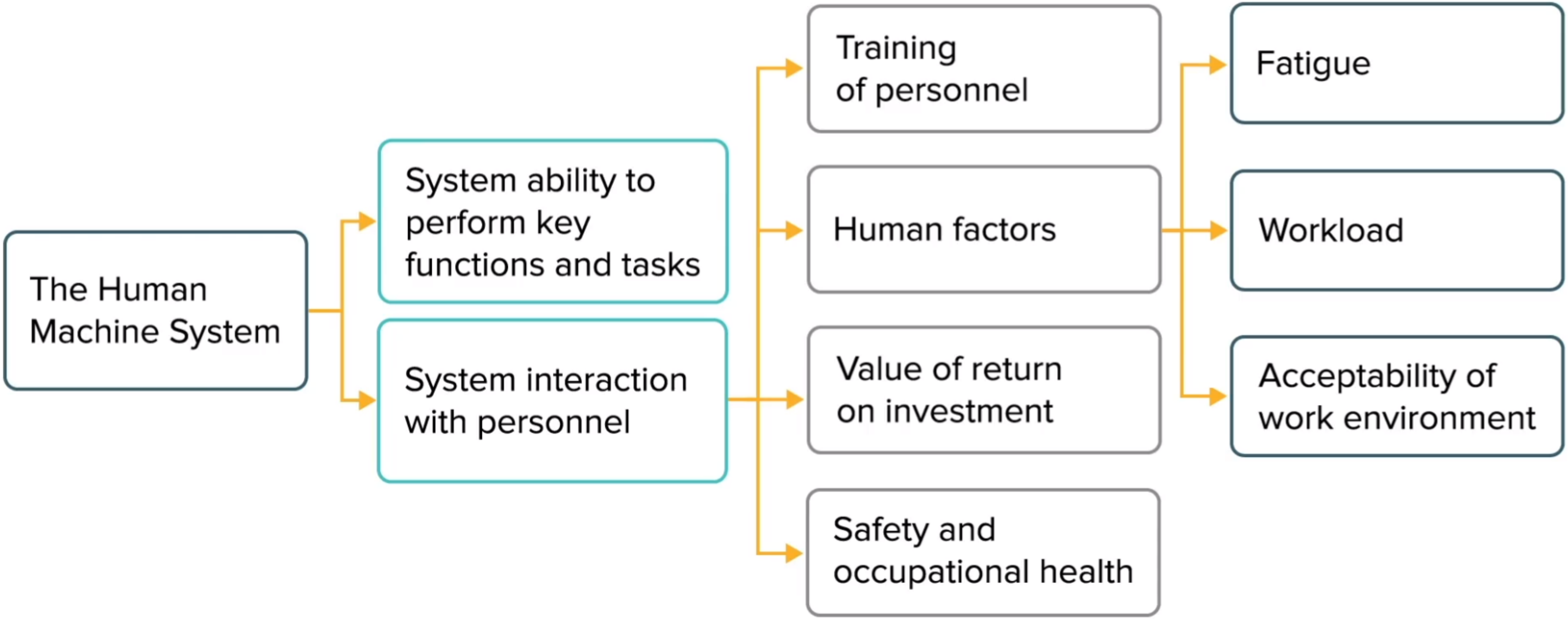
Training

- Separate training pipelines for the two different types of ships
- Negative transfer from training to operate one type of ship to training for other types of ship

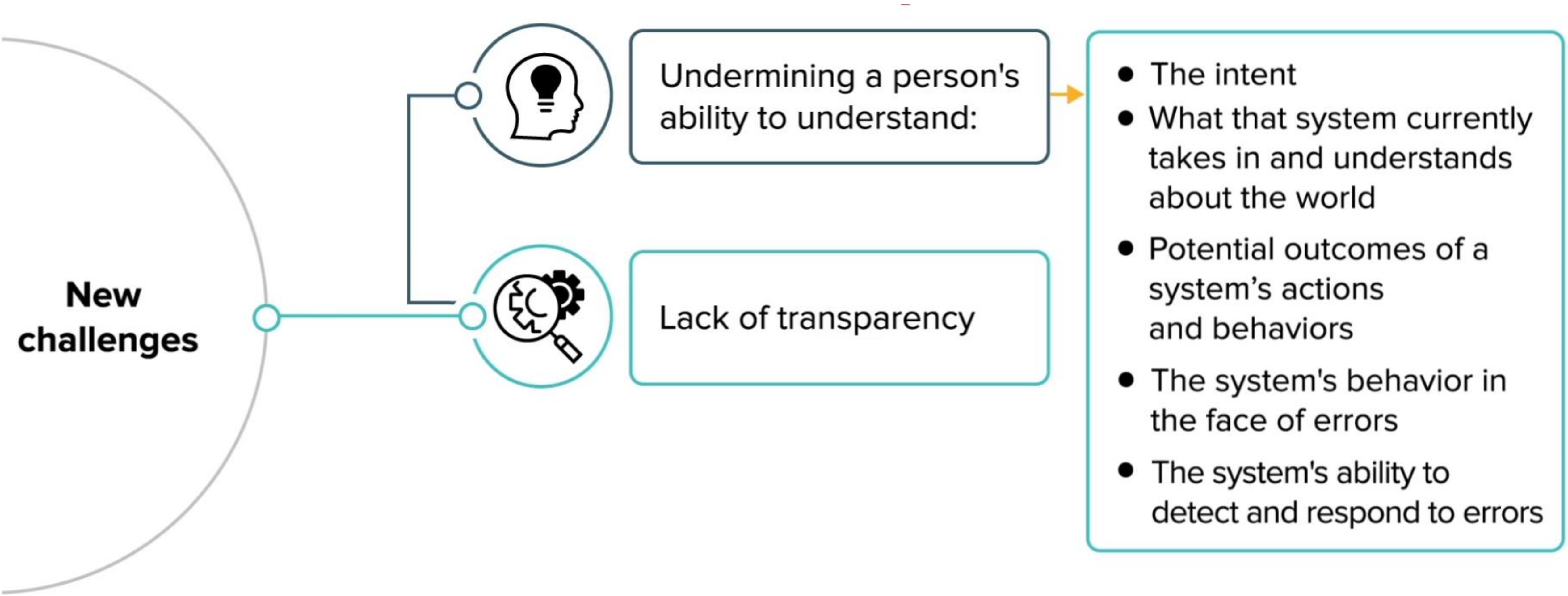
The Human Systems Integration Process

- Acknowledges that the human is a critical component of any complex system, from its conception, design, and implementation to its operation
- Requires an interdisciplinary approach
- Cannot be undertaken by technologists that go deep on developing the robotic and automated capability
- Requires understanding the trade-offs of the introduction of technology across the whole life cycle, and the different aspects of the operation
- Has the overall goal of optimizing or improving the total system performance

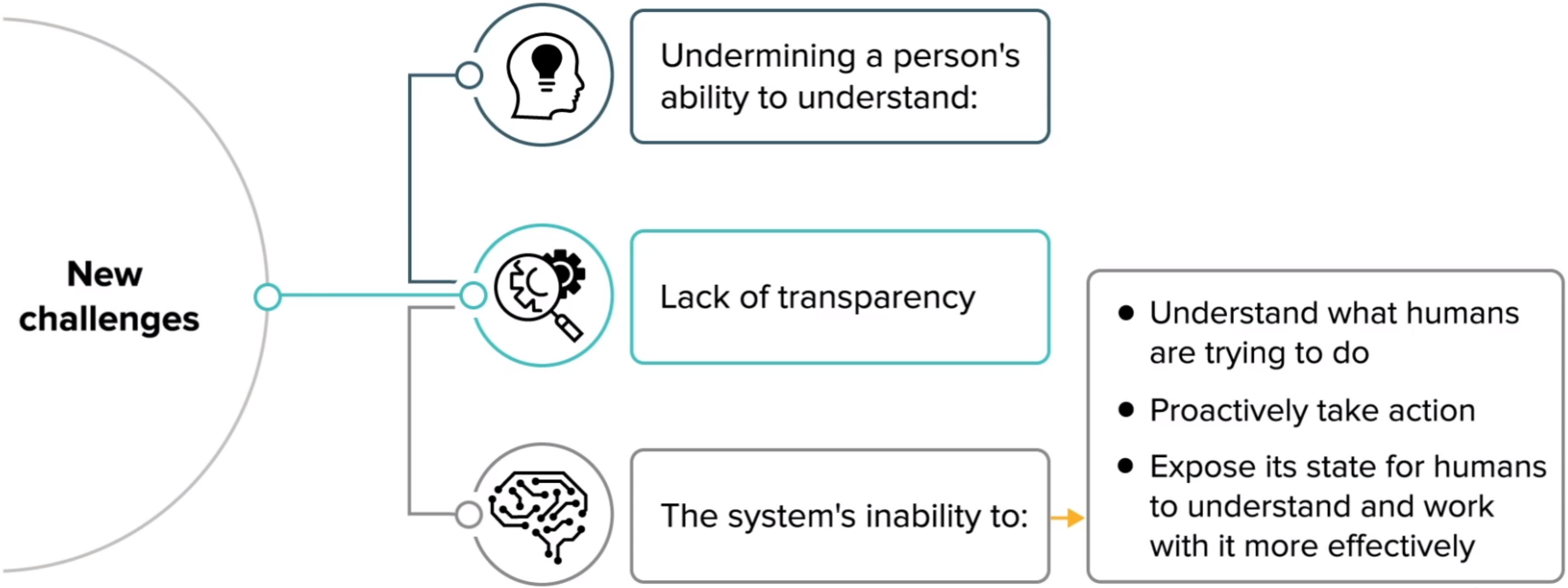
How to concave of Human-Machine interface



New challenges Due to the Introduction of Advanced Capabilities



New challenges Due to the Introduction of Advanced Capabilities



Categories of Human-Robot Interaction (HRI)

- Remote Control of Robot
- Supervisory Control of Robots
- Human as a passenger
- Robot for social interaction

Categories of Human-Robot Interaction (HRI)

Category 1: Remote control of a robot

- Human cognitive capabilities
- Human perception capabilities
- Joystick control or verbal commands

Categories of Human-Robot Interaction (HRI)

Category 1: Remote control of a robot

The origins of remotely controlled robots date back when robots were used to manipulate nuclear materials in which:

- The material is dangerous in close proximity for a person

Remote control operators of UAVs may pilot vehicles from a distance in a controlled environment in almost the same way they would pilot the vehicle as if they were in the cockpit

Categories of Human-Robot Interaction

Category 2: Supervisory control of robots

Not tasking the robot at the lowest level, but supervising the robot or a fleet of robots

Supervisory control of a robot

Supervisory control of a robot refers to a higher-level control system that oversees and manages the operation of one or more robots. This type of control is typically used in situations where robots perform complex tasks that require coordination, decision-making, and adaptability. The supervisory control system provides a more abstract and strategic level of control, allowing humans or other computer systems to guide the robot's actions and make high-level decisions. Key aspects of supervisory control of robots include:

1. **Task Planning:** The supervisory control system can define and plan tasks for the robot. This involves specifying what the robot needs to do, the sequence of actions, and any constraints or priorities.

2. **Monitoring:** It monitors the robot's state and progress to ensure that it is executing tasks correctly. If deviations or issues are detected, the supervisory control system can initiate corrective actions.

3. **Adaptation:** Supervisory control allows for adaptive behavior. If the robot encounters unexpected obstacles or changes in the environment, the supervisory system can modify the robot's plan or provide new instructions to handle the situation.

4. **Human Interaction:** In many cases, humans can interact with the supervisory control system to provide high-level guidance, change objectives, or intervene if necessary.

5. **Coordination:** In multi-robot systems, supervisory control can coordinate the actions of multiple robots to ensure they work together efficiently and avoid conflicts.

Category 2: Supervisory control of robots

Supervising systems operated by other people

Challenges

Supervising systems operated by autonomy or machine intelligence

Categories of Human-Robot Interaction (HRI)

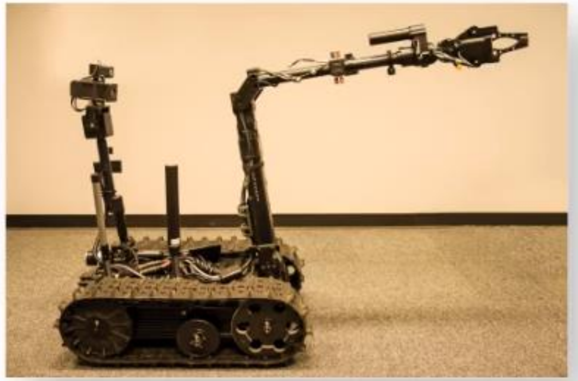
Category 3: Human as passenger or bystander

A passenger in an automated vehicle may have some supervisory function, but these would be very different than someone solely trained for supervising a complex fleet of robots.

Categories of Human-Robot Interaction (HRI)

Category 4: Robots for social interaction

It may be necessary or advantageous to include social capability on robots in:



Search and rescue

Assembly lines

Hospitals

Offices

Categories of Human-Robot Interaction (HRI)

Category 4: Robots for social interaction

This mainly includes ways in which we interact with robots where our goal is social interaction:

Entertainment

Teaching

Assistance

Define Human Robot Integration (HRI) Problem

The humans need to be put at the center.

Problem statement

To identify how the designer can understand and shape the interactions between one or more humans and one or more robots

Goal

To evaluate the capabilities of humans and robots, and design the technologies and training that produce the desirable interactions

In class discussion

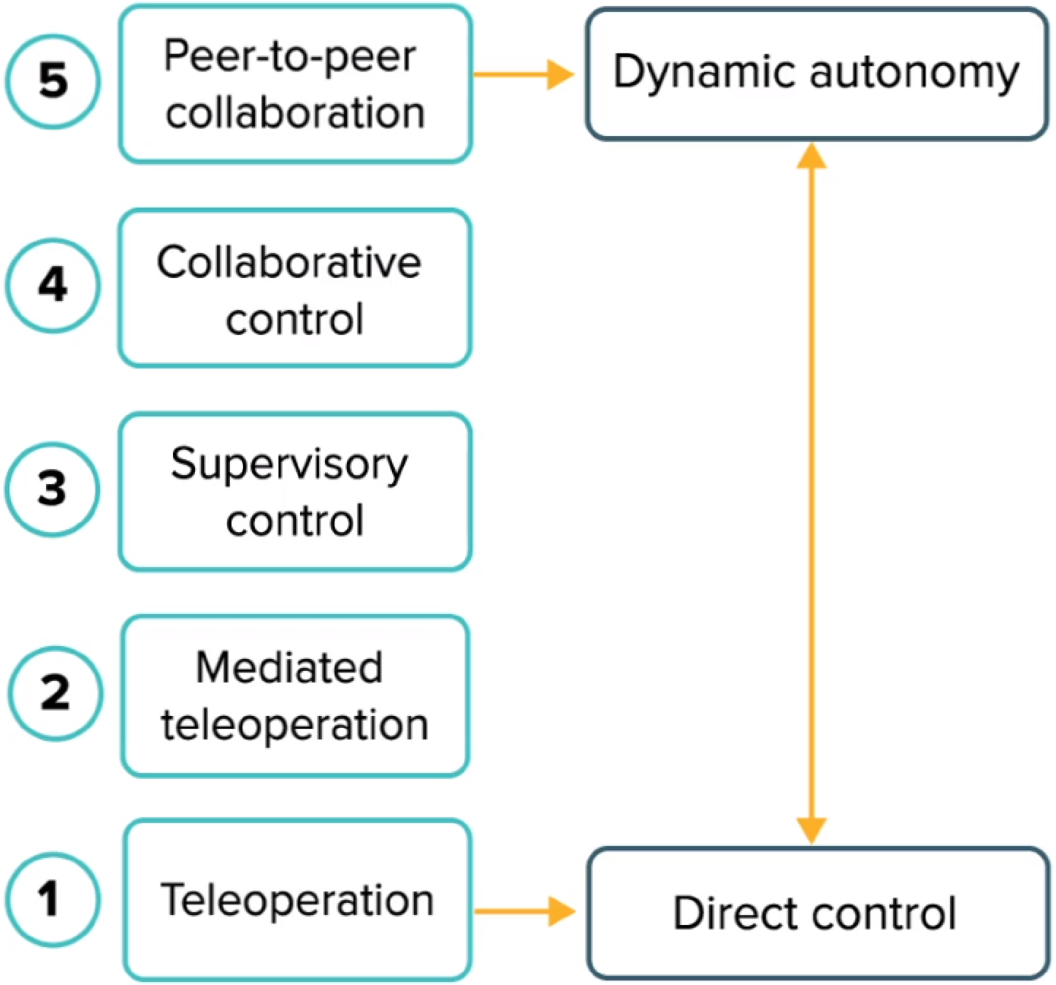
- Discuss three cases on why it is difficult to get the human-Robot interaction done right.
- In your response, discuss why/how it is difficult to develop a safe system that elevates the information which is transparent to the user in the right way and that can integrate into society in a way that to provide value.
- How would you change/modify the design of the human interface to getting all of this right.

Define Human Robot Integration (HRI) Problem

10	the computer makes all decisions and acts autonomously, ignoring the human
9	the computer decides whether to inform the human
8	the computer informs the human only if asked to do so, or
7	the computer executes automatically and necessarily informs the human, or
6	the computer provides a restricted time for the human to veto before automatic execution
5	the computer executes the alteranative if the human approves, or
4	suggests one alternative
3	narrows the set down to a few alteranatives, or
2	the computer offers a complete set of alternative decisions/actions, or
1	The computer offers no assistance: the human makes all decisions and take actions

Source: Sheridan, T., Verplank, W., & Brooks, T. (1978). *Human and computer control of undersea teleoperators* [Conference paper]. NASA. Ames Res. Center The 14th Ann. Conf. on Manual Control.

Levels of autonomy



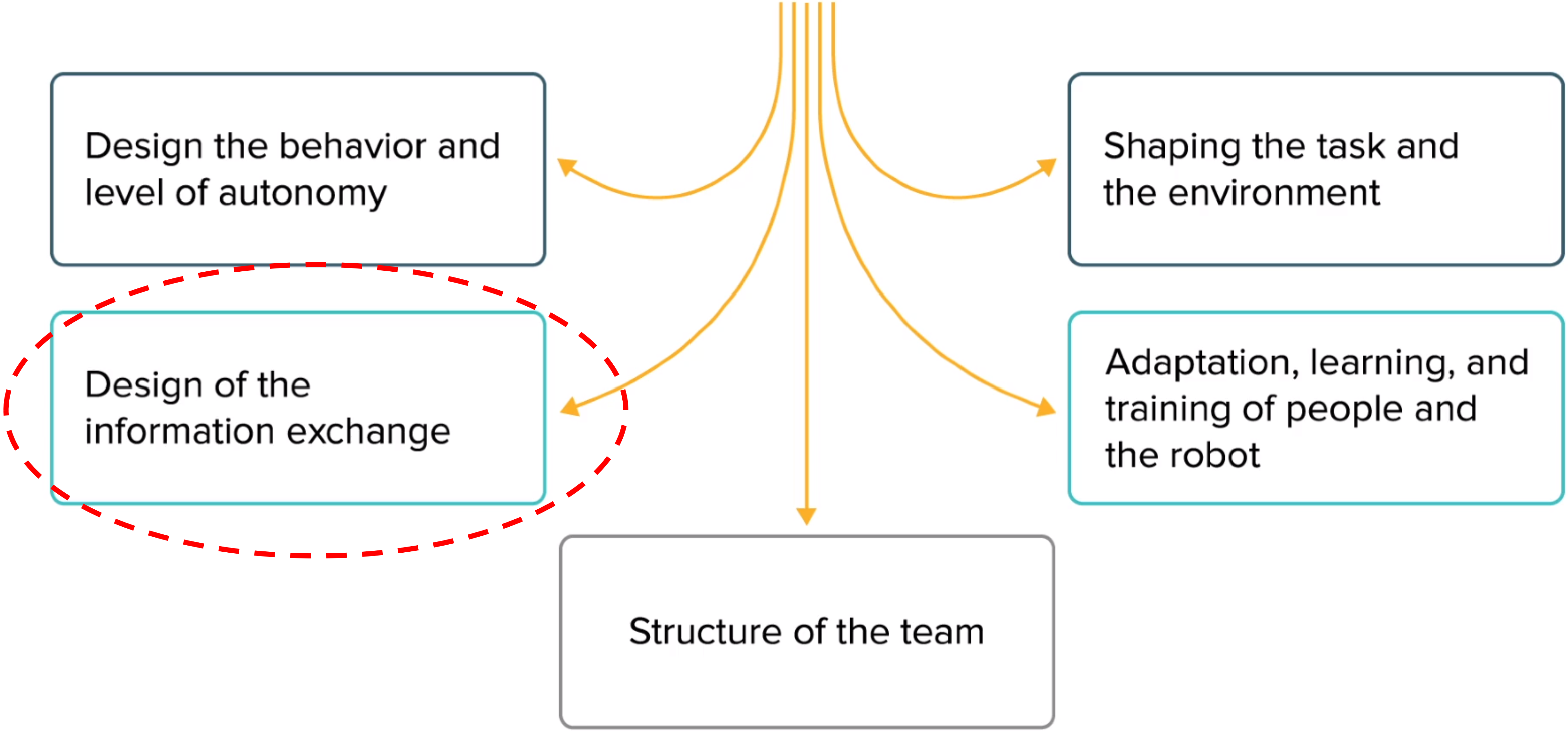
The measures of efficacy of an interaction between humans and robots include:

- The way in which the information exchange supports the human situational awareness of that system and of the progress through the task
- The extent to which the interfaces and information exchange can enable a common ground or understanding between the two

Shadow Teleoperation System - Robot hands with human dexterity

https://www.youtube.com/watch?v=J-3CcyF4Emw&ab_channel=ShadowRobot

Attributes affecting HRI



Information exchange between human and robot

Communications medium

Seeing	Hearing	Touching and tactile interaction
• Visual displays • Gestures	• Speech and natural language media • Nonspeech audio	• Physical interaction • Haptics

Attributes affecting HRI

Design the behavior and level of autonomy

Shaping the task and the environment

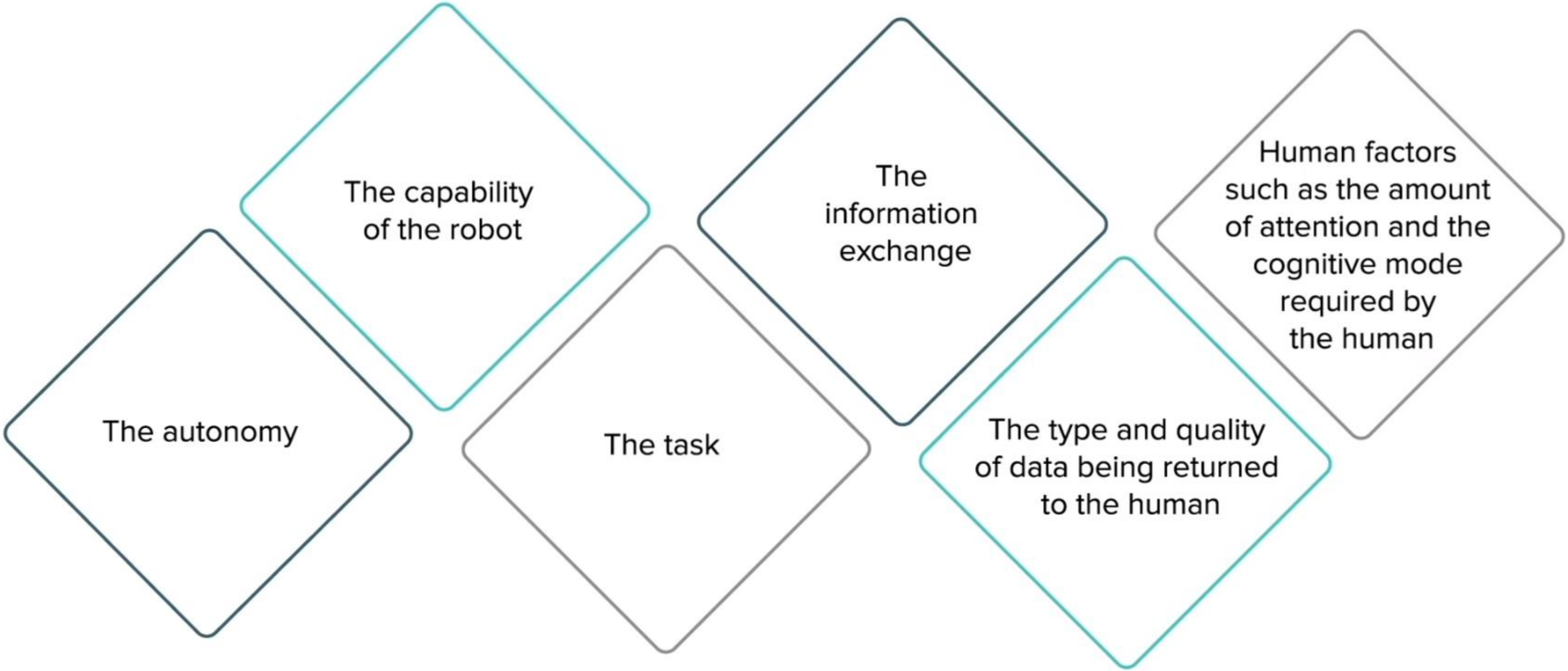
Design of the information exchange

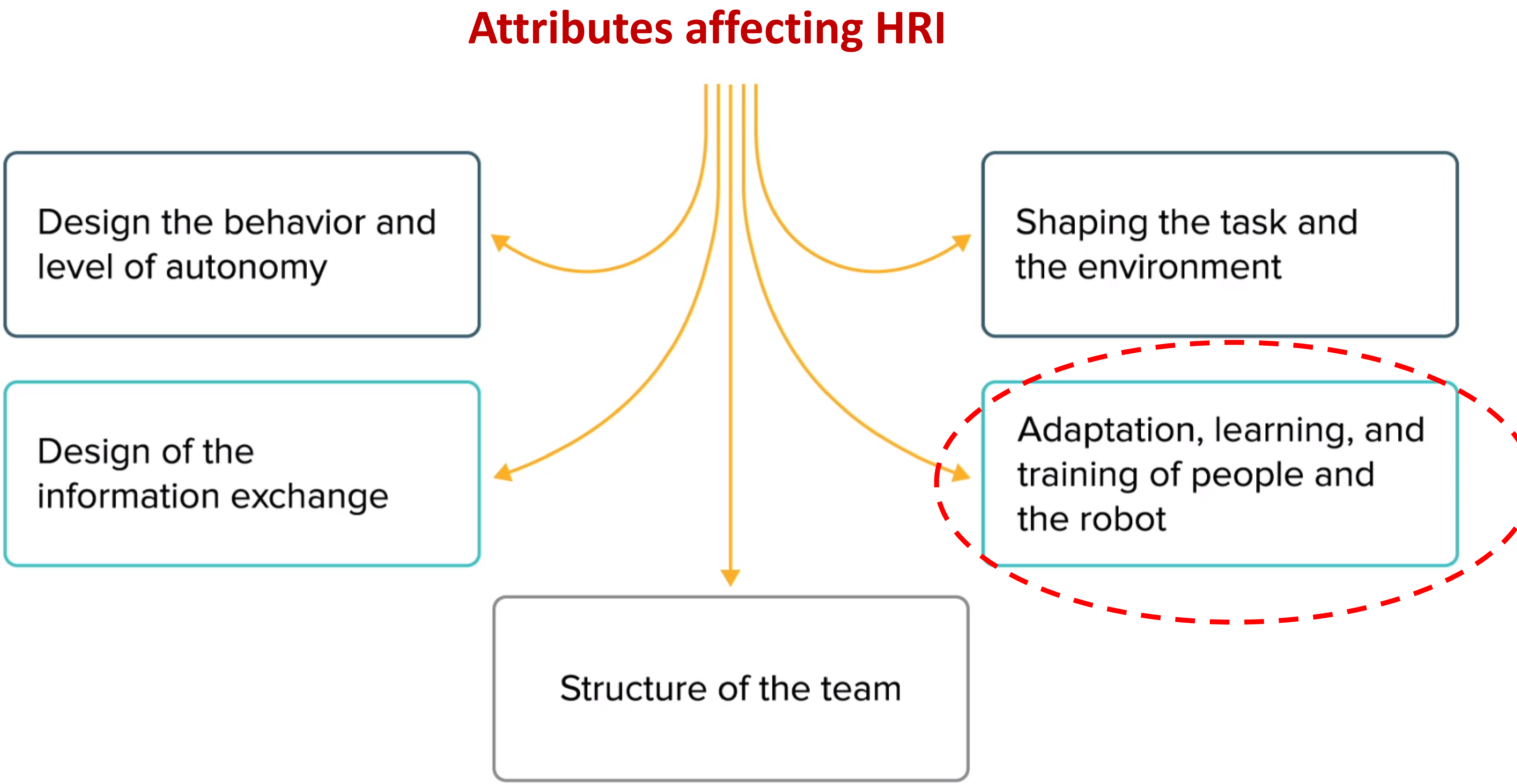
Adaptation, learning, and training of people and the robot

Structure of the team

Team Architecture

The way we architect the team, the authority, the responsibility, the roles, etc., depends on




Attributes affecting HRI
Design the behavior and level of autonomy
Shaping the task and the environment
Design of the information exchange
Adaptation, learning, and training of people and the robot
Structure of the team

Adaption, leering and training

Minimizing operator training

The training should:

- Be lightweight and quick
- Promote safe operation

Training humans to work with robots

Train a person to understand how to engage in a workflow that involves automation

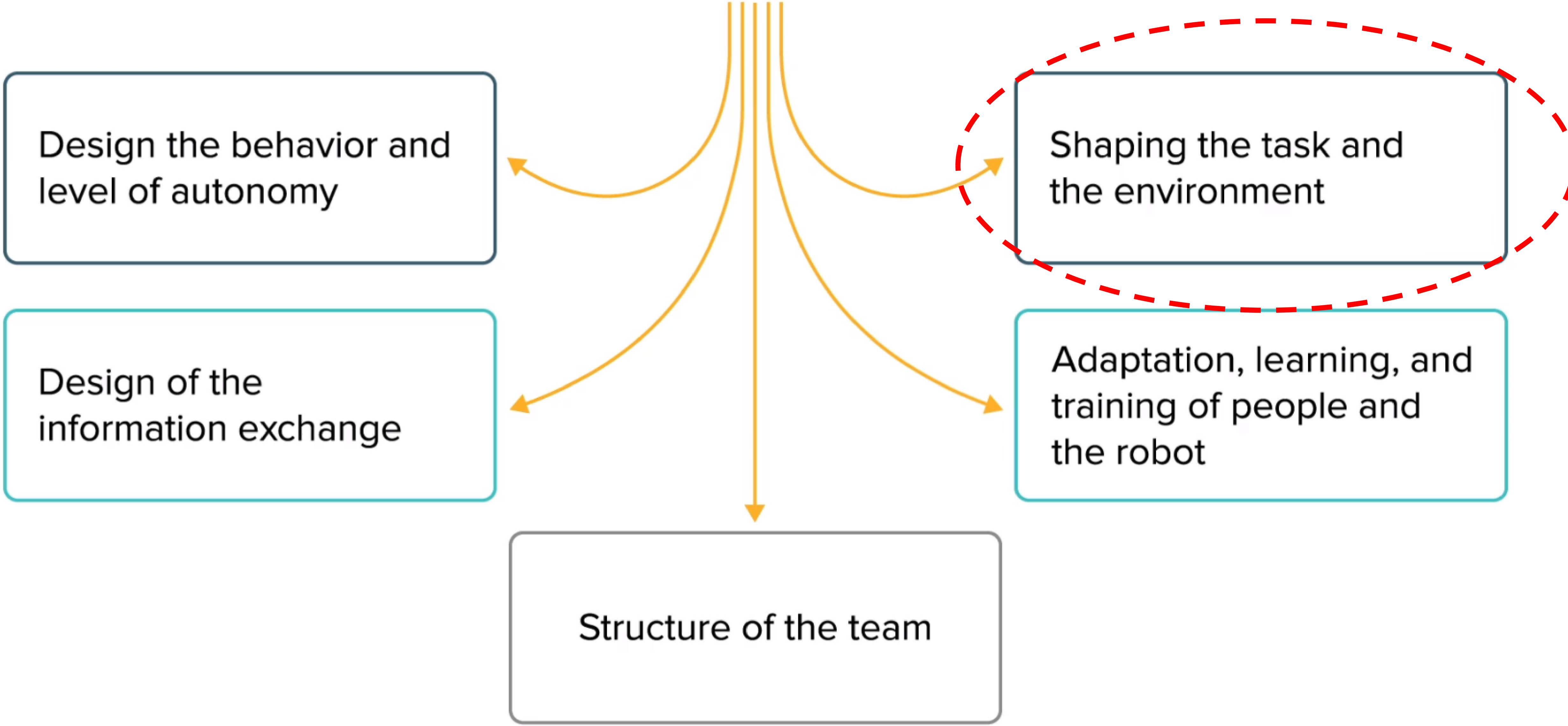
Training designers

The educational qualifications of the designers brought in to control and program the system

Adapting, learning, and training the robot when it is deployed in the environment

Designing the ways in which it improves over time and gains proficiency in its task

Attributes affecting HRI



Introducing technology fundamentally changes the way that humans do tasks that they might have previously done on their own

Task Shaping

- It emphasizes the importance of considering how the new task should be done when the technology is introduced
- It involves designing the technology and co-designing the task to be performed by the system

Environmental-shaping

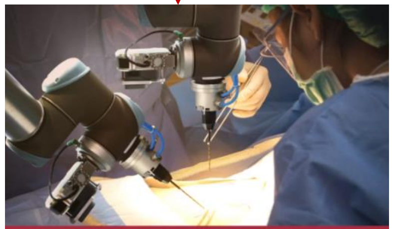
- Standard industrial robots need highly structured environments to perform repeatable actions
  - They need to know exactly where things are
  - They need to be set up in a structured way
- Employing more autonomy on the robots helps in introducing additional flexibility

Metrics for human-robot interaction (HRI):

- Metrics help us determine how, and to what extent, a system is compatible with people who interact with it throughout its design and life cycle
- The human-robot interaction community has not reached a strong consensus on standard metrics and benchmarks

Taskable agents	Remote-presence robots	Social or entertainment robots
Robots with one or more independent autonomous capabilities	Humans work through the robots in real time	Robots have independent autonomous generation of social competencies, but the behaviors are conditioned from human interaction

Self-driving cars



Surgical robots

Robot pets

Challenges in HRI Deployment

Roombas

Alexa & smart home devices

Sidewalk delivery robots

Security guard robots

Stop and Shop robots

How hard could designing effective human-robot interaction be if we have so many successful examples of robots currently deployed?

The robots don't make an imprint on our consciousness the way we would expect them to do.

Challenges in HRI Deployment

The systems' ability to integrate within our human world and collaborate with us, to augment and enhance our well-being and capability, is limited

Consider an example of a car crash case in Michigan:

- The person had to be taken out of the vehicle and transported via helicopter to a hospital
- The helicopter was waved away because a drone was circling the area to get footage of the accident
- The helicopter was delayed in landing, and the patient ultimately passed away

San Francisco Just Put the Brakes on Delivery Robots

Challenges

The robots created problems for the elderly and people with disabilities:

- The systems considered humans as any other obstacle in the environment
- The interaction was perceived to be unsafe

San Francisco Just Put the Brakes on Delivery Robots

Challenges → **Outcome**

- The delivery robots were removed from the most populated areas of the city
- The systems were relegated to an industrial sector without people

San Francisco Just Put the Brakes on Delivery Robots

Challenges

Outcome

Key takeaway

The ability to integrate these systems and help them understand and be capable around people is key to deploying them more broadly in environments where they can be helpful to us.

The human-robot interface and human-robot interaction are crucial for solving issues of everyday life

Study Conducted at Georgia Tech

The researchers put people in a building

They allowed people to interact with the robot to understand its capabilities

They simulated a fire and had the robot lead people out of the building

Every participant followed the robot in the emergency

Even when the robot led them to a dark room with no discernible exit, the majority of the people chose to follow it

In-class assignment-ilearn submission

The first step in this discussion is to search online for a published news article (or academic article) that involves *shared-space* human-robot interaction in a real-world or lab setting. In a written discussion, please briefly provide a summary of the article you chose and the human-robot system it describes. After providing your description, provide a written response that addresses each of the following categories and their corresponding questions. If any of these categories or questions are not addressed in your article, please provide your own explanation for how the issues might be successfully approached.

1) Shared-space collaboration

How do the robot and humans communicate with each other in order to be transparent about their states, plans, or beliefs?

2) Challenges of real-world HRI deployment

How does the robot ensure that people are safe around it and people feel safe around it?

3) Human-centered design

- What media does the robot use to communicate with the human?
- What does, or should, the robot do if the human does not understand its communication?

Singularity

“Singularity" refers to a specific configuration or position in which the robot arm loses one or more degrees of freedom, making it unable to move or control its end effector (the tool or device attached to the end of the arm) effectively. Singularities are significant points of concern in robotic arm design and control.

- **Momentary singularity:** is a term used in robotics to describe a brief and temporary situation where a robot arm or manipulator passes through a singular configuration during its motion but does not remain stuck in that configuration.

- **Permanent singularity:** refers to a situation where a robot arm or manipulator becomes mechanically locked or reaches a configuration where it cannot continue its motion without external intervention.

Singularity

Singularity happen when the Jacobian is not invertible

$$\underbrace{V}_{\text{Cartesian velocities}} = \underbrace{J}_{\text{Jacobian}}\ \underbrace{\dot{\theta}}_{\text{Joint velocities}}$$

$\dot{\theta} = J^{-1} \cdot V$ → Given V, we can find $\dot{\theta}$

If $Det(J) \neq 0$ → J is invertible

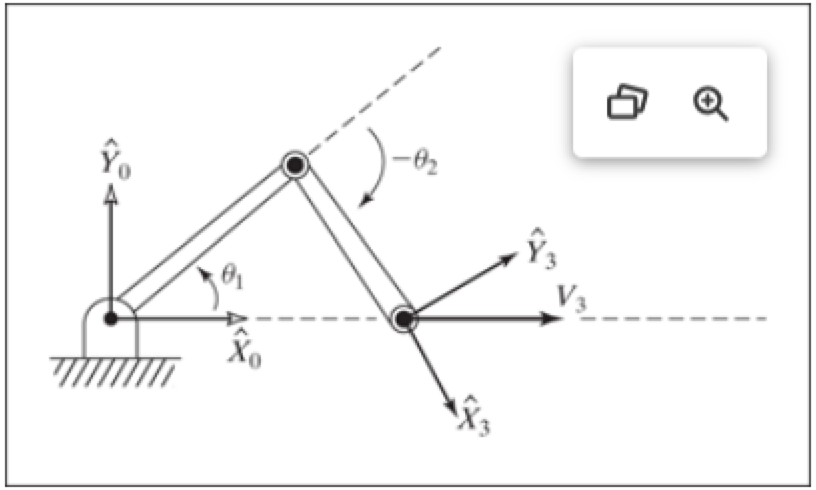
if $Det(J) \approx 0$ → J is invertible, but dangerous joint velocitis will occur

A momentary singularity refers to a specific configuration or state in which a robotic manipulator (such as a robot arm) experiences a momentary loss of control or behaves unpredictably due to the mathematical and mechanical characteristics of its joints. This occurs when the robot's joints align in a way that results in mathematical singularities.

A singularity is a point where the **Jacobian matrix** becomes singular, meaning it is not invertible. When this happens, the robot's control system cannot uniquely determine how to move the end-effector in response to certain joint motions. As a result, the robot may exhibit erratic behavior, and it can be challenging to control its movement precisely during this momentary singularity.

Typically, robot control algorithms and software are designed to avoid or navigate through singularities to ensure safe and stable operation. This may involve joint limit avoidance, joint velocity and acceleration constraints, or trajectory planning to prevent the robot from encountering and getting stuck in singular configurations. Identifying and handling singularities is an important aspect of robotics, especially in applications that require precise and controlled motion.

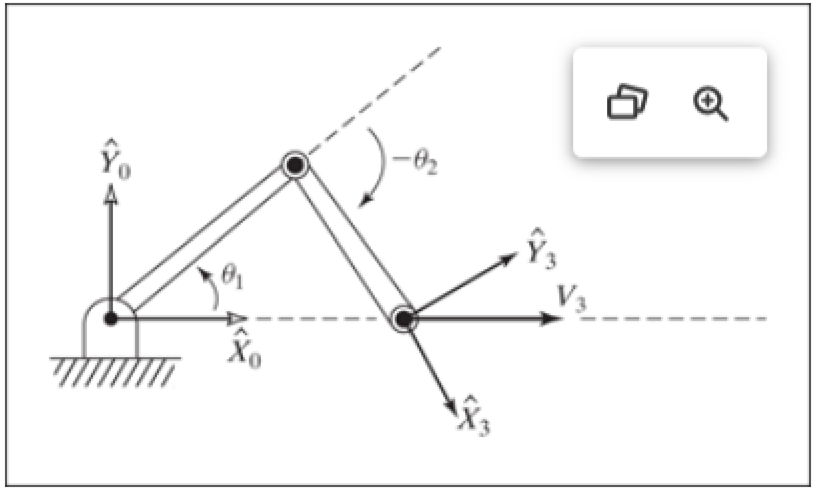
Example 1

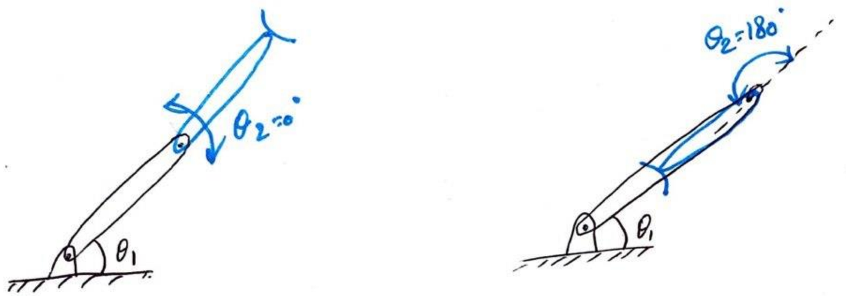


$$DET[J(\Theta)] = \begin{bmatrix} l_1 s_2 & 0 \\ l_1 c_2 + l_2 & l_2 \end{bmatrix} = l_1 l_2 s_2 = 0.$$

Clearly, a singularity of the mechanism exists when θ_2 is 0 or 180 degrees. Physically, when $\theta_2 = 0$, the arm is stretched straight out. In this configuration, motion of the end-effector is possible along only one Cartesian direction (the one perpendicular to the arm). Therefore, the mechanism has lost one degree of freedom. Likewise, when $\theta_2 = 180^\circ$, the arm is folded completely back on itself, and motion of the hand again is possible only in one Cartesian direction instead of two. We will class these singularities as workspace-boundary singularities, because they exist at the edge of the manipulator's workspace. Note that the Jacobian written with respect to frame {0}, or any other frame, would have yielded the same result.

Example 1





$$DET[J(\Theta)] = \begin{bmatrix} l_1 s_2 & 0 \\ l_1 c_2 + l_2 & l_2 \end{bmatrix} = l_1 l_2 s_2 = 0.$$

The inverse of the jacobian is

$$^3J^{-1} = \frac{1}{L_1 L_2 S_2} \begin{bmatrix} L_2 & 0 \\ -L_1 C_2 - L_2 & L_1 S_2 \end{bmatrix}$$

Since: $\dot{\Theta} = {}^3J^{-1} \cdot {}^3\nu \Rightarrow \begin{bmatrix} \dot{\theta}_1 \\ \dot{\theta}_2 \end{bmatrix} = \frac{1}{L_1 L_2 S_2} \begin{bmatrix} L_2 & 0 \\ -L_1 C_2 - L_2 & L_1 S_2 \end{bmatrix} \cdot {}^3\begin{bmatrix} \dot{x} \\ \dot{y} \end{bmatrix}_3$

Then: $\dot{\theta}_1 = \frac{\dot{x}}{L_1 S_2}$

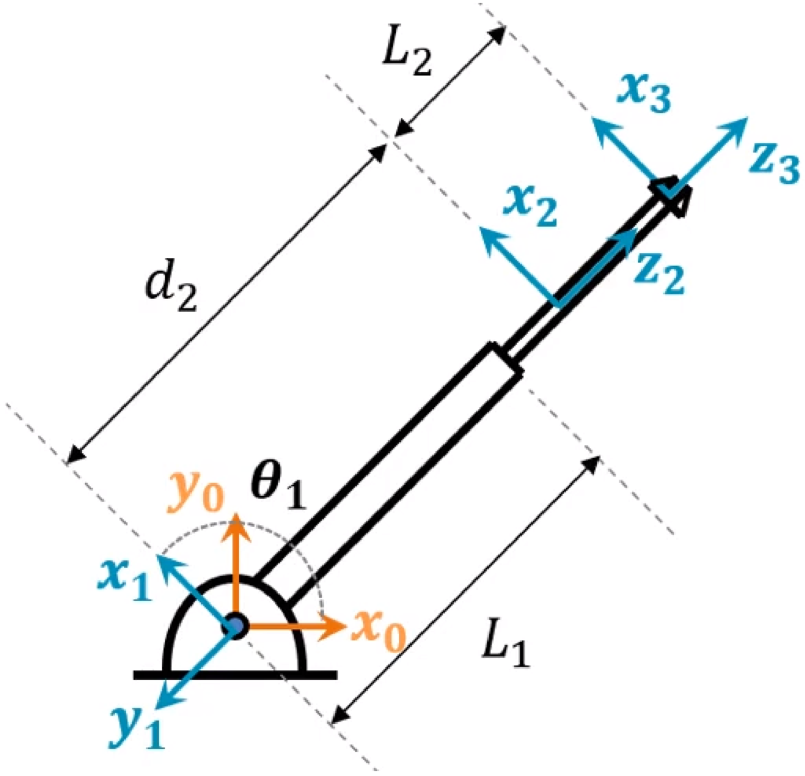
$$\dot{\theta}_2 = \frac{-(L_1 C_2 + L_2)\dot{x}}{L_1 L_2 S_2} + \frac{\dot{y}}{L_2}$$

Example 2

For a planar 2 DOF RP robotic arm

$$^{0}\begin{bmatrix}\dot{x}_3\\ \dot{y}_3\end{bmatrix} = \begin{bmatrix}c_1(d_2+L_2) & s_1\\ s_1(d_2+L_2) & -c_1\end{bmatrix}\begin{bmatrix}\dot{\theta}_1\\ \dot{d}_2\end{bmatrix}$$

Under which condition, would there be a singularity for this manipulator?



Example 2

$$^{0}\begin{bmatrix}\dot{x}_3\\ \dot{y}_3\end{bmatrix} = \begin{bmatrix}c_1(d_2+L_2) & s_1\\ s_1(d_2+L_2) & -c_1\end{bmatrix}\begin{bmatrix}\dot{\theta}_1\\ \dot{d}_2\end{bmatrix}$$

$$^{0}[\mathrm{J}_v]_{2\times 2} = \begin{bmatrix}c_1(d_2+L_2) & s_1\\ s_1(d_2+L_2) & -c_1\end{bmatrix}$$

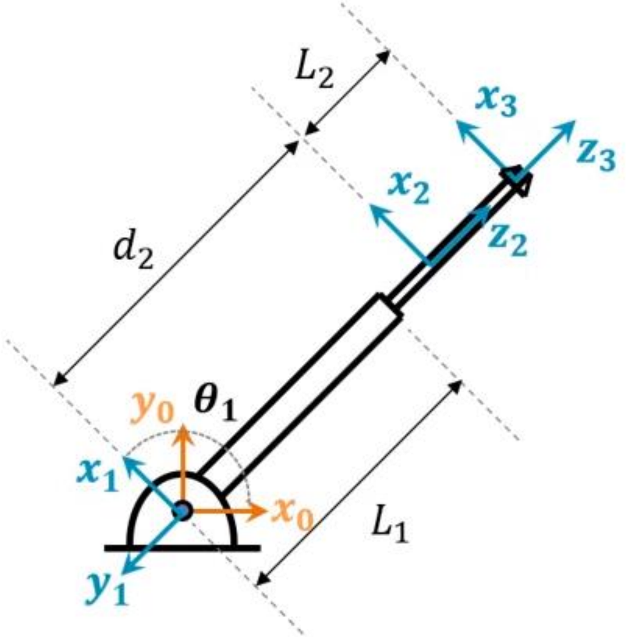
$$|\mathrm{J}_v| = c_1(d_2+L_2)(-c_1) - s_1 s_1(d_2+L_2)$$

$$|\mathrm{J}_v| = -(d_2+L_2)(c_1)^2 - (s_1)^2(d_2+L_2)$$

Set $|\mathrm{J}_v| = 0$

$$(d_2+L_2)\left((c_1)^2 + (s_1)^2\right) = 0$$

$$d_2 = -L_2$$



End of week 10