MODULE 4: HUMAN FACTORS IN AUTONOMOUS DRIVING

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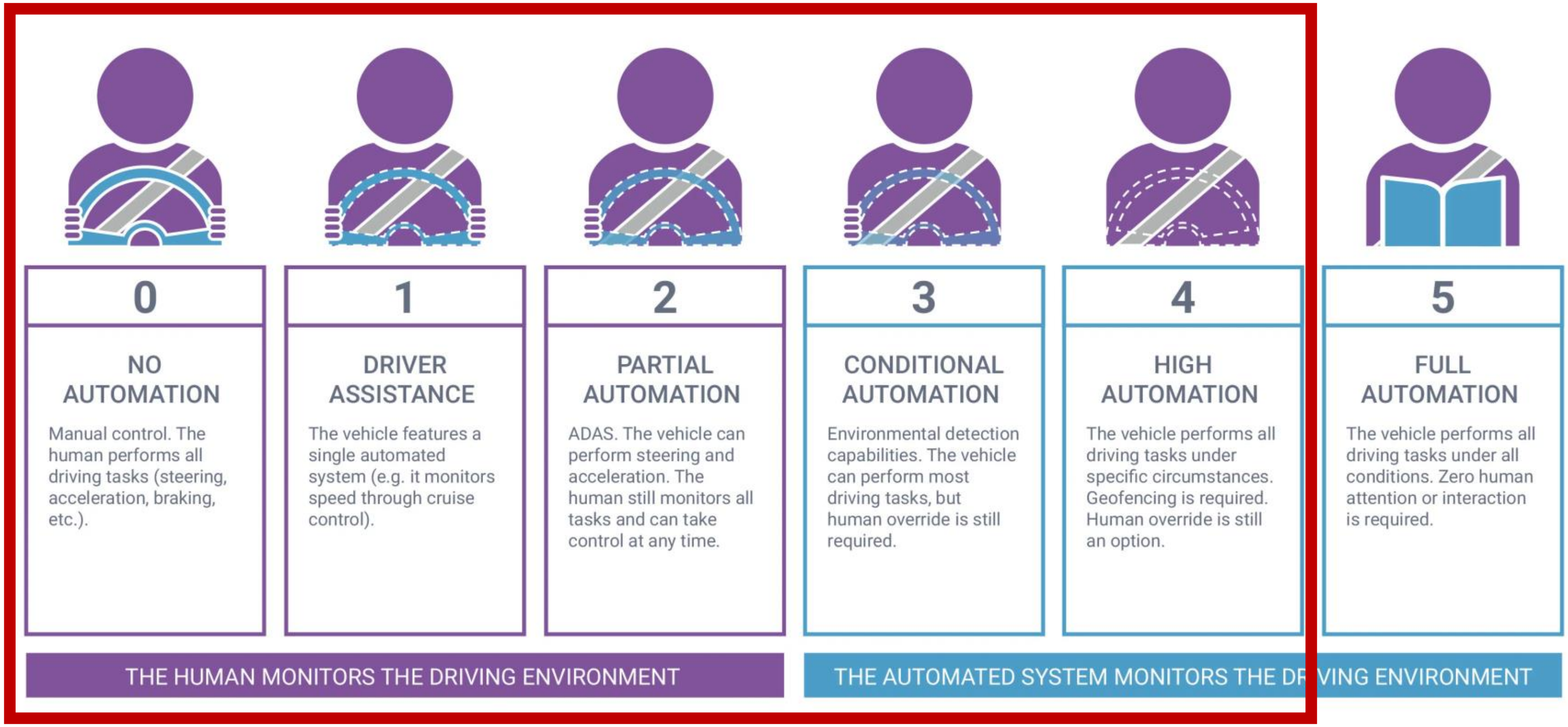
SAE International: Levels of Automation



Human Involvement in Driving???

SAE International: Levels of Automation

1 Driver Assistance	2 Partial Automation	3 Conditional Automation	4 High Automation	5 Full Automation
Example • City Emergency Braking	**Example** • Adaptive Cruise Control	**Example** • Highway Pilot	**Example** • City & Highway Pilot	**Example** • Robocar
Definition • Steering OR acceleration / deceleration • Human supervision	**Definition** • Steering AND acceleration / deceleration • Human supervision	**Definition** • All driving functions • Human intervention may be needed	**Definition** • All driving functions • Human can but don’t has to intervene	**Definition** • All driving functions • No human intervention possible

LEVEL 1: DRIVER ASSISTANCE

A SINGLE AUTOMATED SYSTEM

Acceleration Assistance: Adaptive Cruise Control

Source: https://www.youtube.com/watch?v=GInSPWZRFRM

Steering Assistance: Lane Keeping Assist

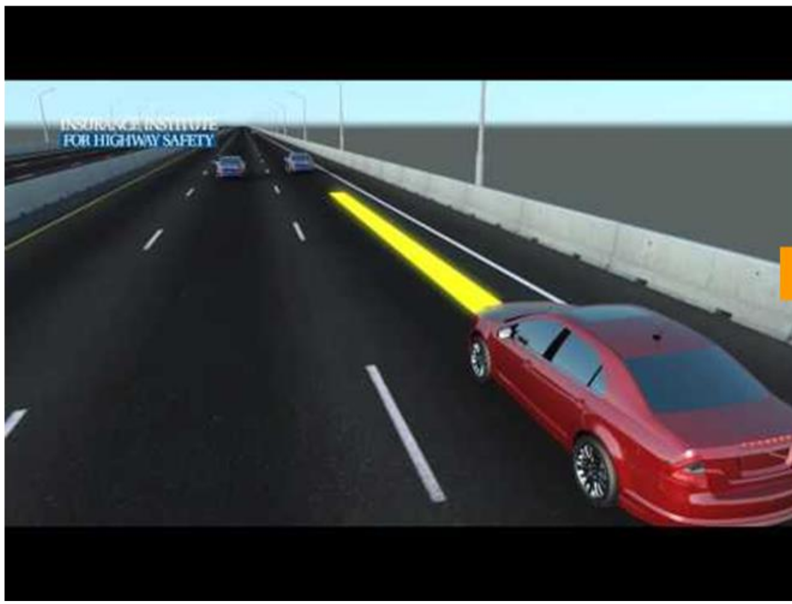
Source: https://www.youtube.com/watch?v=OQkdvi55woA

LEVEL 2: PARTIAL AUTOMATION

- STEERING + ACCELERATION
- HUMAN MONITORS ALL TASKS

Combination of Acceleration and Steering

Adaptive Cruise Control



Lane Keeping Assist

ZF’s L2+ AVs

Source: https://www.youtube.com/watch?v=EnqsH_Fu-6s

SAE Level 2 Fatal Accident

Source: https://www.youtube.com/watch?v=CgLE_ZLLaxw

Fatal accidents occurred due to drivers' complacency

LEVEL 3: CONDITIONAL AUTOMATION

- MOST DRIVING TASKS
- HUMAN MONITORS ALL TASK

Features of L3 AVs

- The vehicle temporarily takes over the driving task from the driver; the human driver does not have to monitor the system constantly, and **may pursue other activities within certain limits**
- When the systems reach their limits, the driver **must be able to intervene at any time** - after a warning period of **10 seconds**!
- Speed allowance is valid up to **60 km/h.** The human driver **may legally use the cell phone, watch movies, or participate in a video meeting**
- **Cannot sleep behind the steering wheel!**

Source: https://www.zf.com/mobile/en/technologies/automated_driving/stories/6_levels_of_automated_driving.html

Mercedes-Benz’s L3 AVs

Source: https://www.youtube.com/shorts/bMOxmOpimB8

SAE Level 3
Fatal Accident

Source: https://www.youtube.com/watch?v=ou8sqWr6mF0

Fatal accident example in 2018.

Again due to drivers' complacency.

Pedestrian fatality.

LEVEL 4: HIGH AUTOMATION

- ALL DRIVING TASKS UNDER SPECIFIC CIRCUMSTANCES
- GEOFENCING IS REQUIRED

LEVEL 5: FULL AUTOMATION

- ALL DRIVING TASKS UNDER ALL CONDITIONS

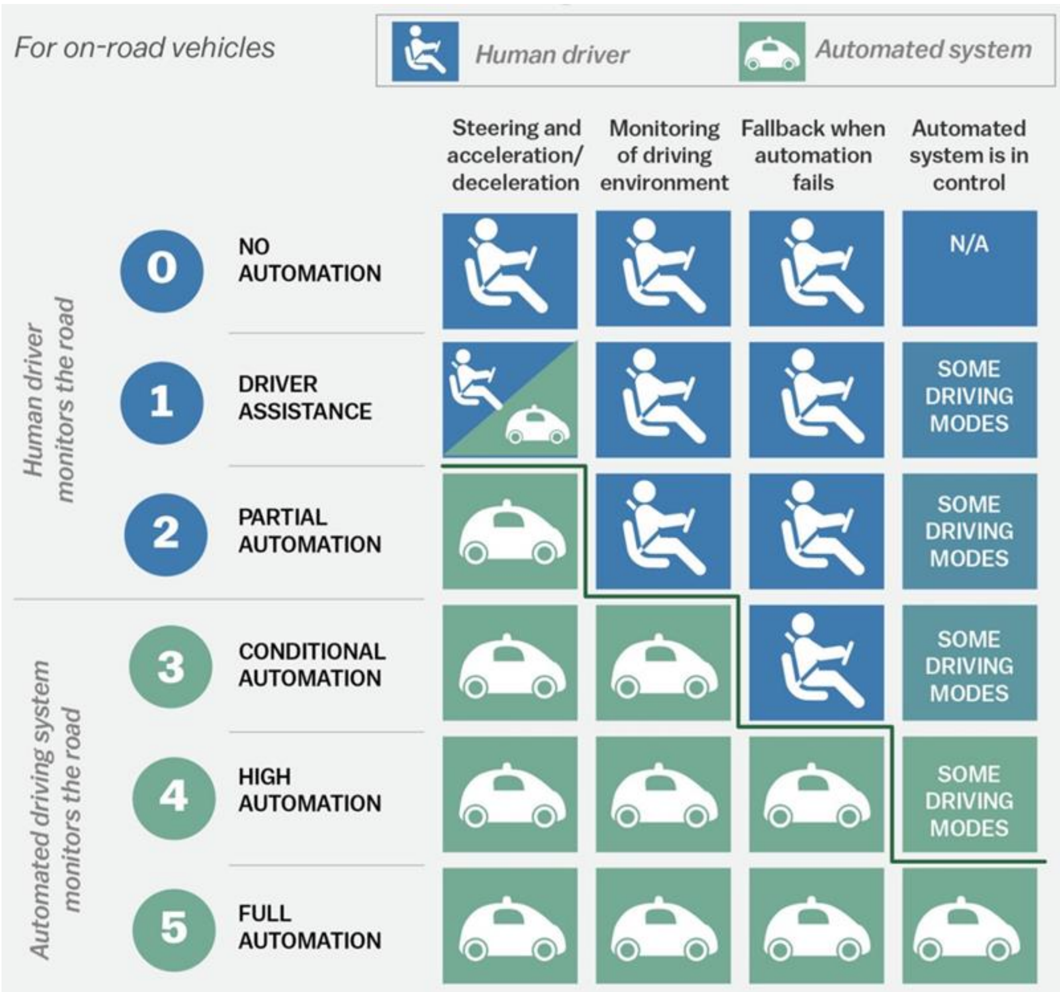
*A geofence is a virtual perimeter for a real-world geographic area; A predefined set of boundaries

Deliberate Human Disruptions to L4 AVs

Source: https://www.youtube.com/watch?v=8MfyIsPWhTk

And What If ……

SAE International: Levels of Automation



- It is a complex interaction between human drivers and SAE Levels 2 and 3 autonomous vehicles
- Any automated system that removes the human from the driving task, yet requires the human to monitor and supervise the system and regain control when necessary, could be unsafe

‘Ironies of automation’

- **Irony:** combination of circumstances, the result of which is the direct opposite of what might be expected

- *“The mere fact that you can automate does not mean that you should”*

- Humans may **misuse**, **disuse** and **abuse** automation technology
- Humans tend to be **poor supervisors** of automation

‘Ironies of automation’

Source: The Sorcerer's Apprentice (Fantasia)

Challenges

1. Driver inattention and distraction

- Automation induces a sense of security, which can falsely lead to complacency and distraction
- Human Driver may not be able to respond in time or with the necessary attention

Challenges

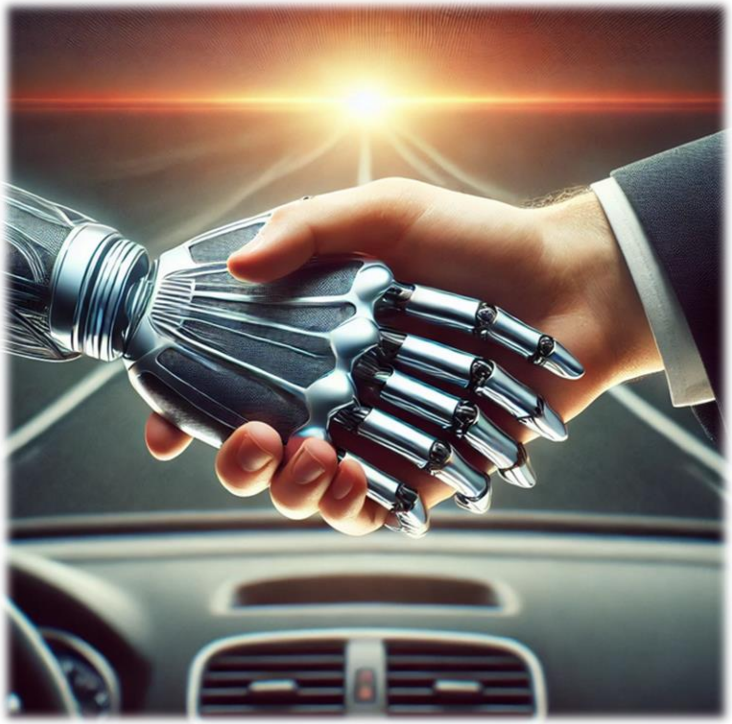
2. Situational awareness

- Drivers can easily lose awareness of their surroundings because they are no longer actively involved in driving decisions
- When prompted to take over, they may not have sufficient contextual information (e.g. current speed, proximity of obstacles) to make safe decisions

Challenges

3. Overreliance and trust

- Human drivers placing excessive trust in the system's ability to handle complex scenarios, assuming it will handle every situation flawlessly
- When the system encounters a scenario it cannot handle (e.g. unexpected roadworks or severe weather conditions), drivers may be slow to react due to their overconfidence in the AV's capabilities



Challenges

4. Skill degradation

- Because the driver is not constantly engaged in driving tasks, their manual driving skills can deteriorate over time
- Regular use of autonomous systems reduces a driver's muscle memory and ability to react instinctively in critical situations

Challenges

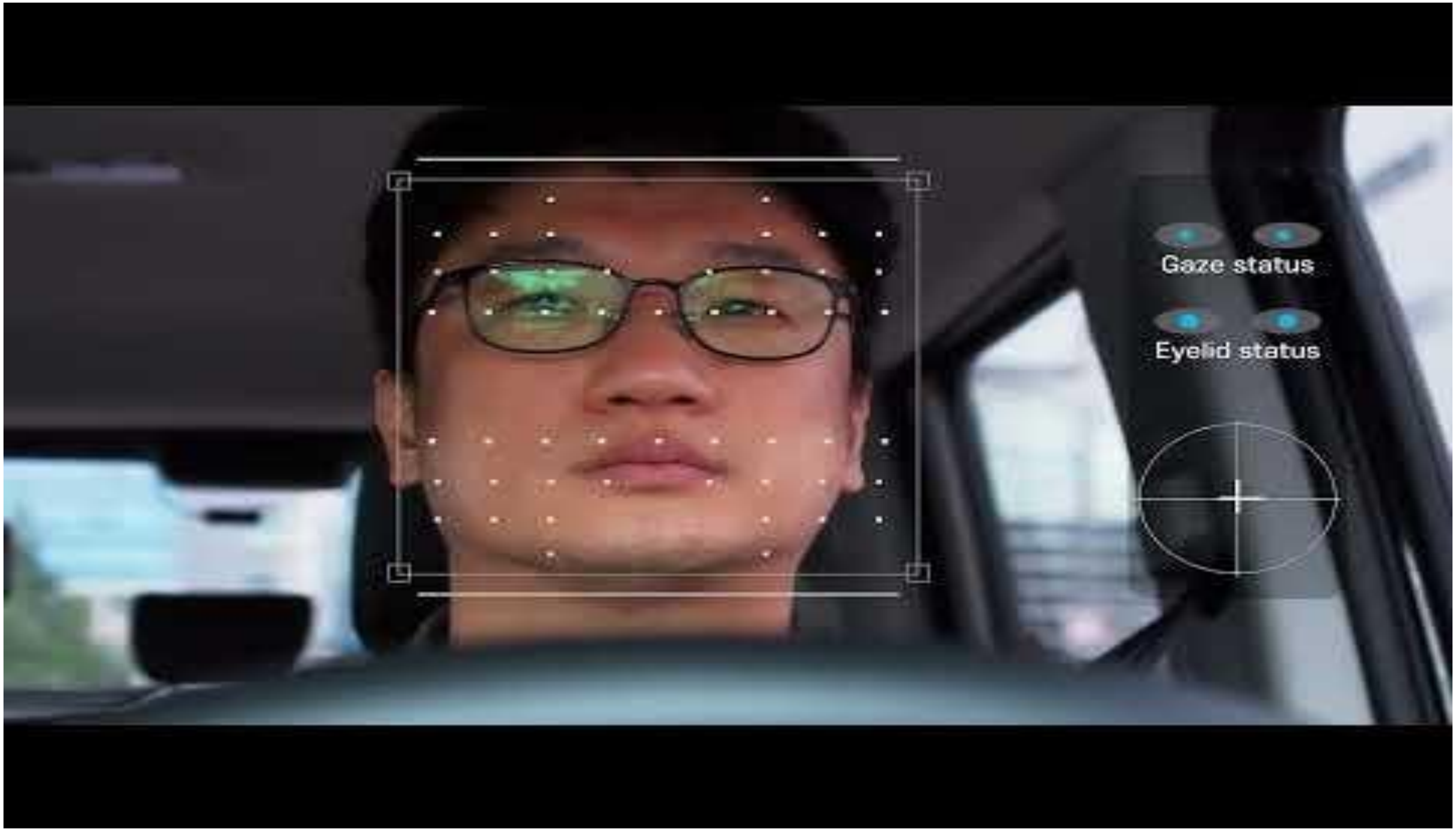
5. Motion sickness

- Human drivers may experience increased motion sickness as they disengage from driving and focus on other tasks
- Due to the mismatch between visual and audio inputs, as the car moves in ways that the passenger isn't directly controlling
- Increases inability to effectively take control when needed

Solutions???

1. **Re-engage the Driver:** Introduce periodic prompts or feedback to keep drivers attentive and ready to take control when needed
2. **Improve User Interfaces:** Design clear, real-time feedback systems that inform drivers about automation capabilities and when to intervene
3. **Monitor Drivers to Prevent Misuse:** Use AI technologies like eye-tracking to detect distraction and ensure drivers can take over as required
4. **Personalize Automation:** Tailor automation settings to individual driving habits for improved safety and user experience
5. **Foster Balanced Trust in AV Systems:** Provide education on system limitations and real-time feedback on system performance to prevent overreliance, ensuring drivers understand when intervention is necessary in complex or unexpected scenarios

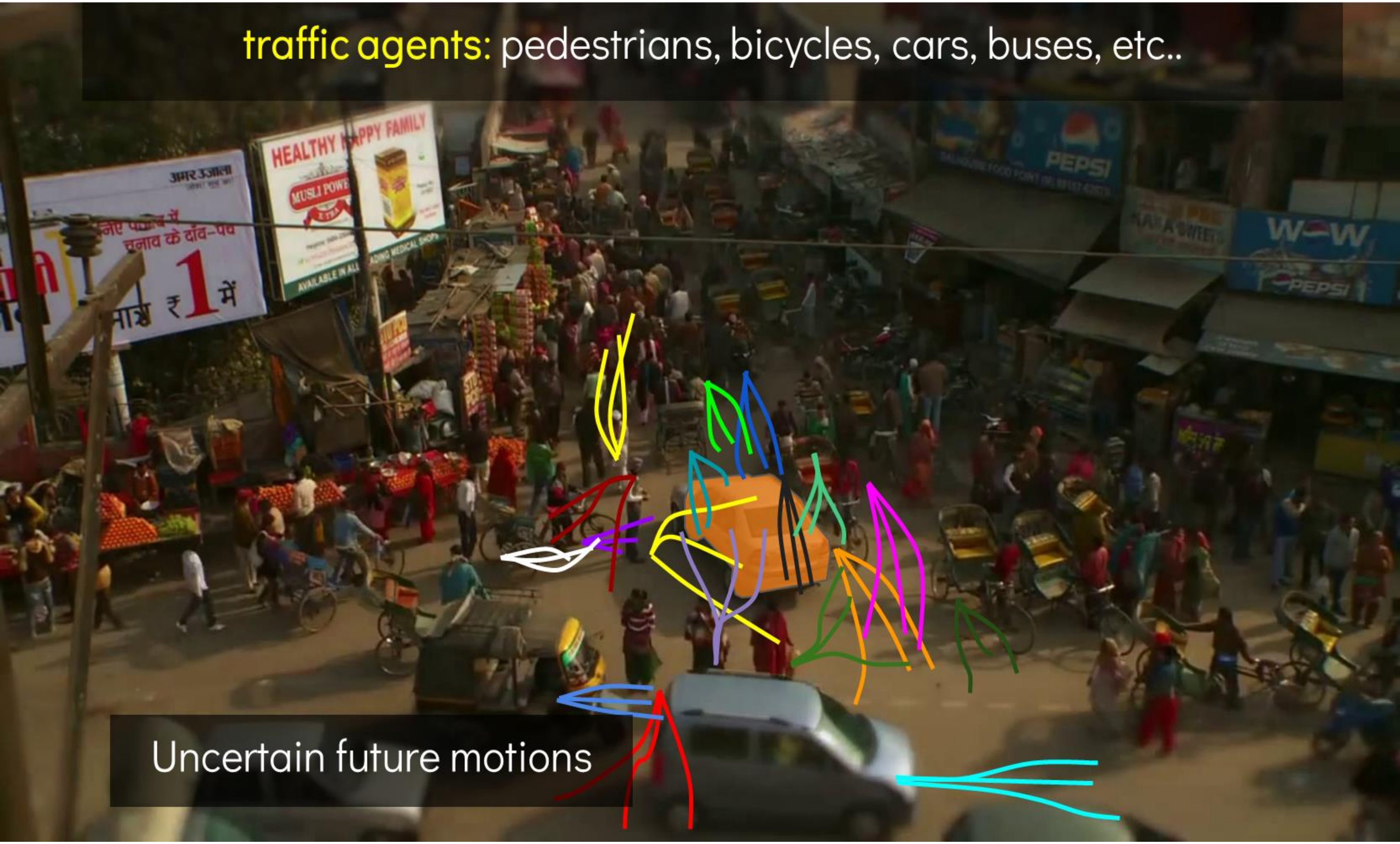
Monitoring & Re-engaging Human Drivers



Source: https://www.youtube.com/watch?v=x5UPeqXyPxA

HUMAN FACTORS IN LEVEL 5 AUTOMATION

What if ……


traffic agents: pedestrians, bicycles, cars, buses, etc..
Uncertain future motions
PEPSI

Problem Statement

predict:

future positions of N agents for t_{pred} steps

given:

- history positions
- types (pedestrian, bicycle, car, etc.)
- positions of obstacles

Challenges of predicting their motions

Diverse dynamics, geometry, behaviors
(heterogeneous)

Challenges of predicting their motions

Diverse dynamics, geometry, behaviors (heterogeneous)

Intensive interactions

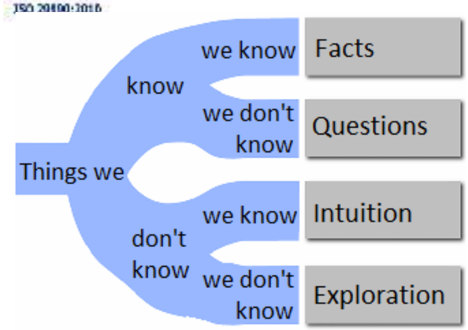
Challenges of predicting their motions

Diverse dynamics, geometry, behaviors (heterogeneous)

Intensive interactions

Complex road conditions

How real-world agents move?



intention

kinematics

Traffic agents try to reach their destinations under their kinematic constraints, and in the meantime, they share the responsibility for collision avoidance with each other, while having limited attention capabilities

responsibility

geometry

attention

We know these are unknown (uncertain)

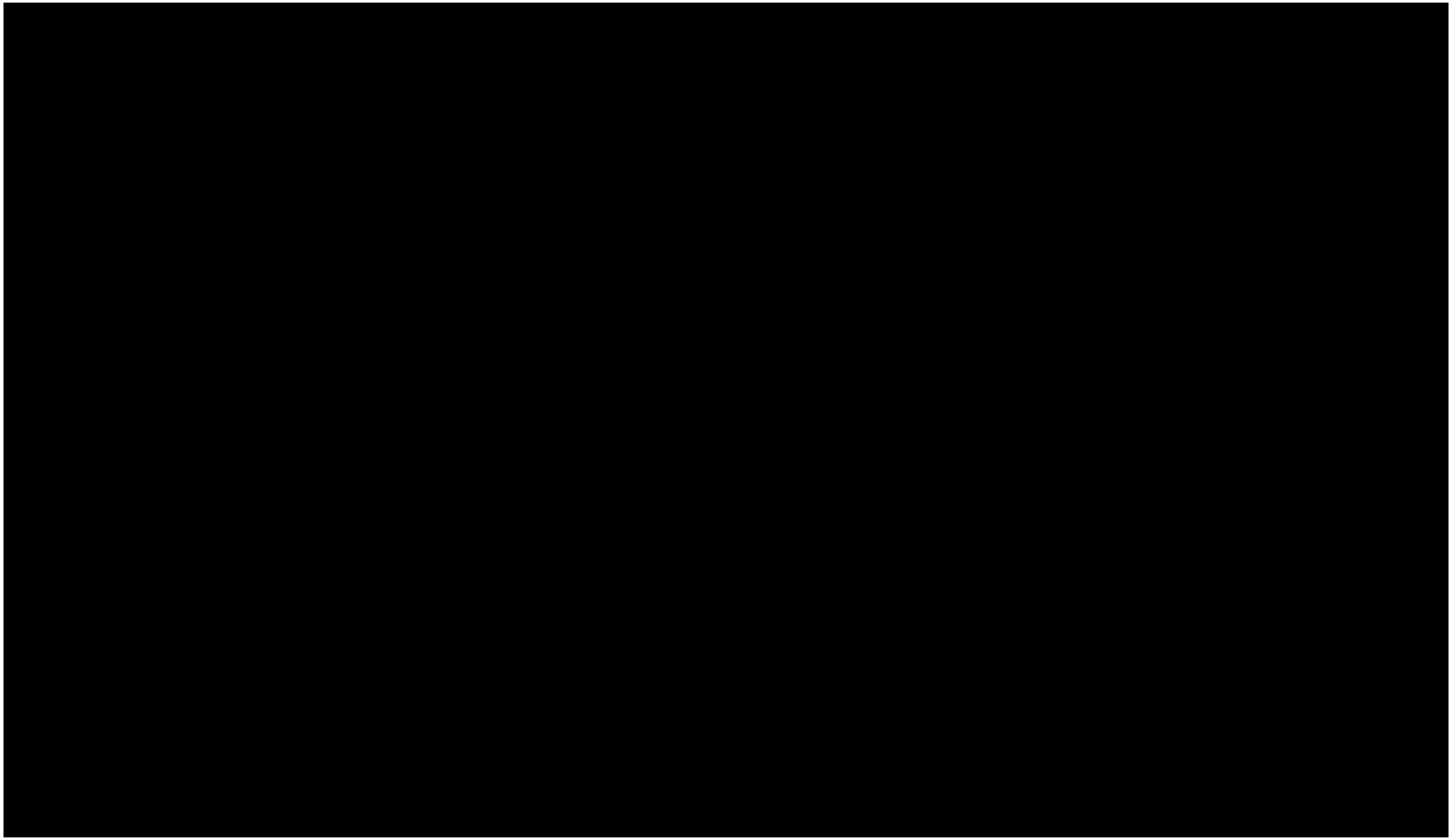
We know these are known (quite certain)

Driving is Active OR Reactive?!

To overtake, the car needs to:

- Understand the stopped car's intention of not moving
- Understand the road context information such as left/right lane exist and is of same direction

Active vs Reactive



Source: https://www.youtube.com/watch?v=SVPVTwxNRLc

More than just driving?

Remember one of the Autonomous & Vehicles workshops (i.e. Workshop 4, Group Project 5) that asked the following reflection question:

- What are the **advantages of utilizing manipulators in autonomous vehicles** or the like?

More than just driving?

Source: https://www.youtube.com/watch?v=ltzXGKKyLk

MODULE 3 & 4 WORKSHOP: WORKSHOP DAY 2

WORKSHOP: HANDS-ON CONSTRUCTION OF MDP/HRIMDP MODELS OF AUTONOMOUS DRIVING

Personal Healthcare Robot

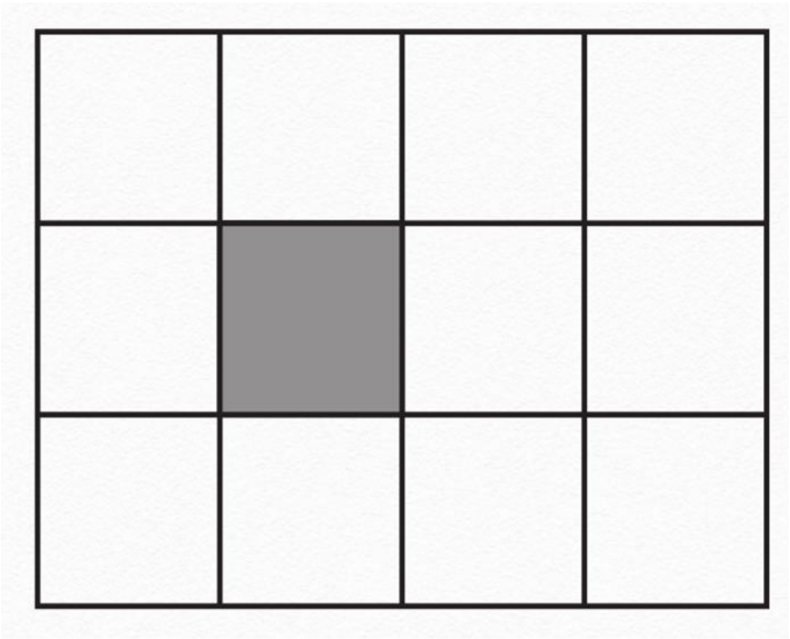
- Personal assistant robots gain their popularity, E.g., Google Home, Amazon Echo, Xiao Mi robot vacuum, ASUS Zenbo, etc
- They are perfect candidates to become the future personal healthcare givers that monitor the elderly users at the nursing home or in the hospital. In this workshop project, we formulate this interaction between the personal healthcare robot and the human user

Learning Objectives of Workshop Day 2

1. Basic programming that creates trajectories of human and robot movements within a virtual world
2. Basic programming that enables you to visualize these interactions between the human and robot (include movements and collision avoidance)
3. Implementation of a Human-Robot-Interaction-focused MDP method (named as HRIMDP) within a 5D gridworld
4. Understand the benefits of the HRIMDP method vs conventional MDP methods

Part A: Introduction to Grid World

Grid World



The perfect-sized environment to learn about Reinforcement Learning for the start

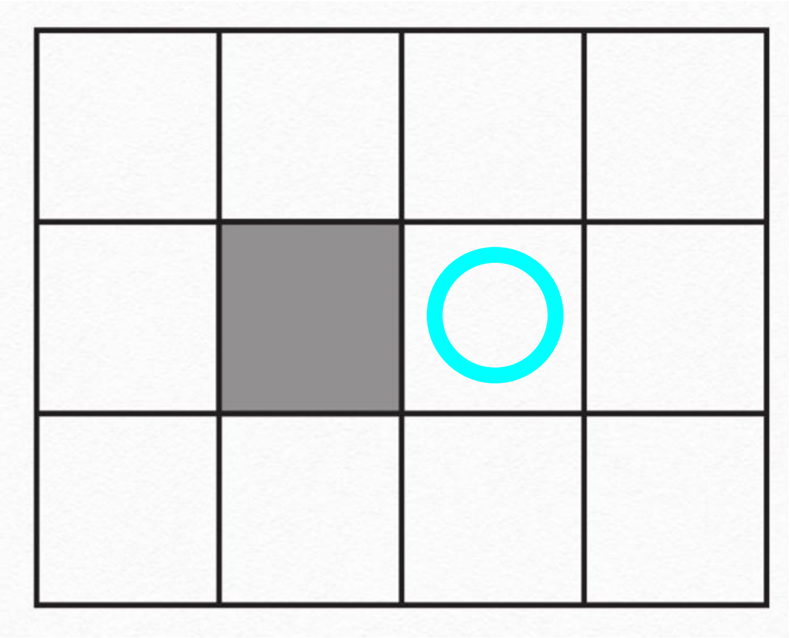
robot

human

world1.csv

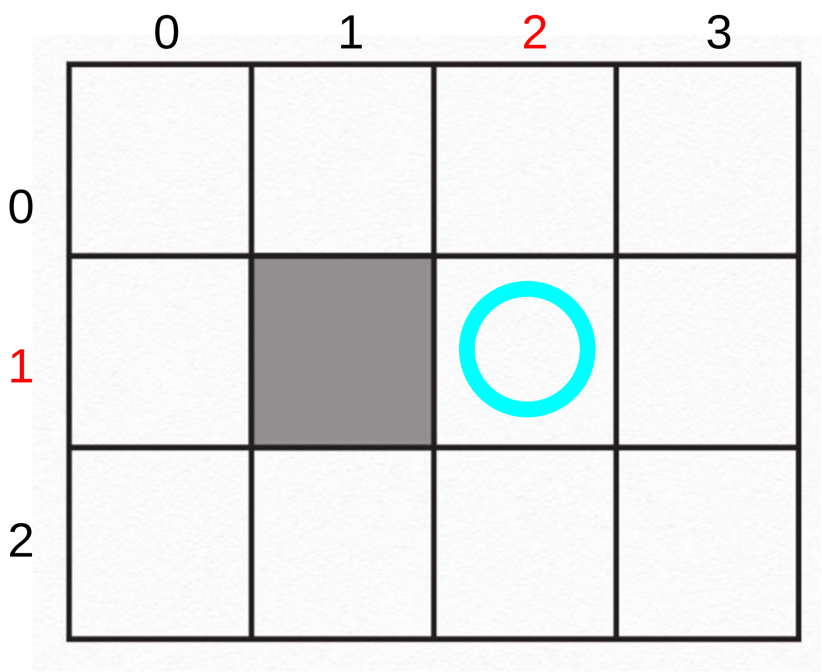
0,0,0,0
0,1,0,0
0,0,0,0

Robot Actions



- S: Stay put
- U: Go up
- D: Go down
- L: Go left (but in this case, stay put due to collision)
- R: Go right

Robot Execution



robot_a1.csv

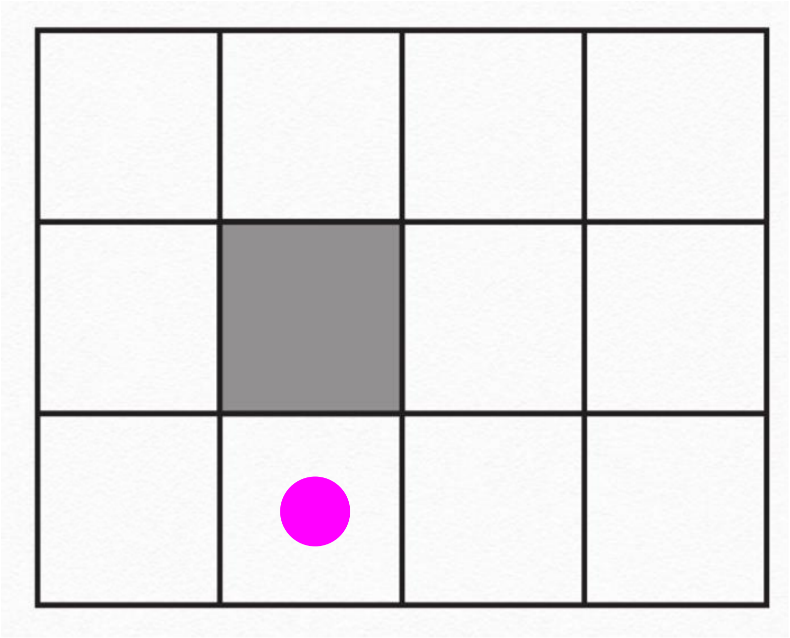
U,L,R,R,S,U,L,U,L

> python3 robot_execute.py	
world1.csv	Gridworld
robot_a1.csv	Robot actions
1 2	Robot initial state
robot_s1.csv	Robot trajectory

Executing the sequence of actions results in a robot trajectory:

[[1,2], [0,2], [0,1], [0,2], [0,3], [0,3], [0,3], [0,2], [0,2], [0,1]]

Human Actions



- S: Stay put
- U: Go up (but in this case, stay put due to collision)
- D: Go down (but in this case, stay put due to collision)
- L: Go left
- R: Go right
- T: Toggle request status

Human Request

-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	10	-1	-1	-1
-1	-1	10	10	10	-1	-1
-1	-1	-1	10	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1

1

-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-5	-1	-1	-1
-1	-1	-5	-10	-5	-1	-1
-1	-5	-10	-10	-10	-5	-1
-1	-1	-5	-10	-5	-1	-1
-1	-1	-1	-5	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1

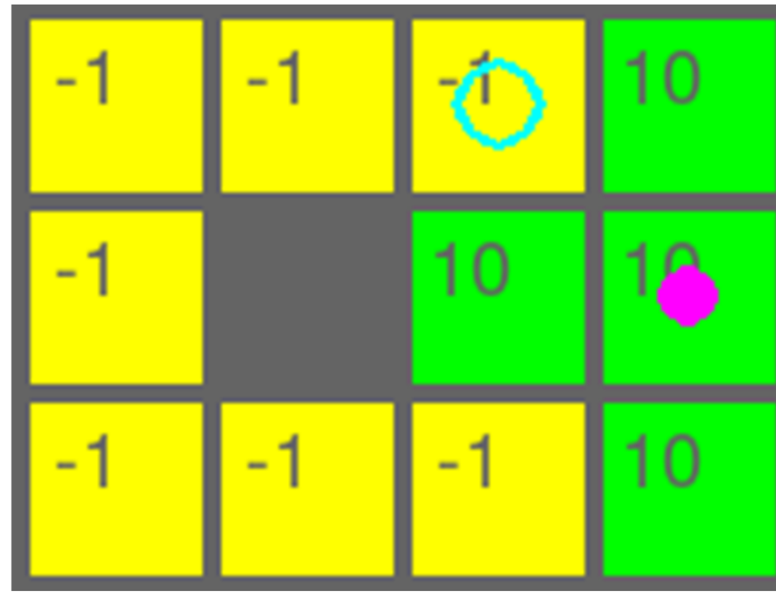
0

Why the rest of the cells is put at -1 reward instead of 0?

HRI Reward Structure

human_state [0]

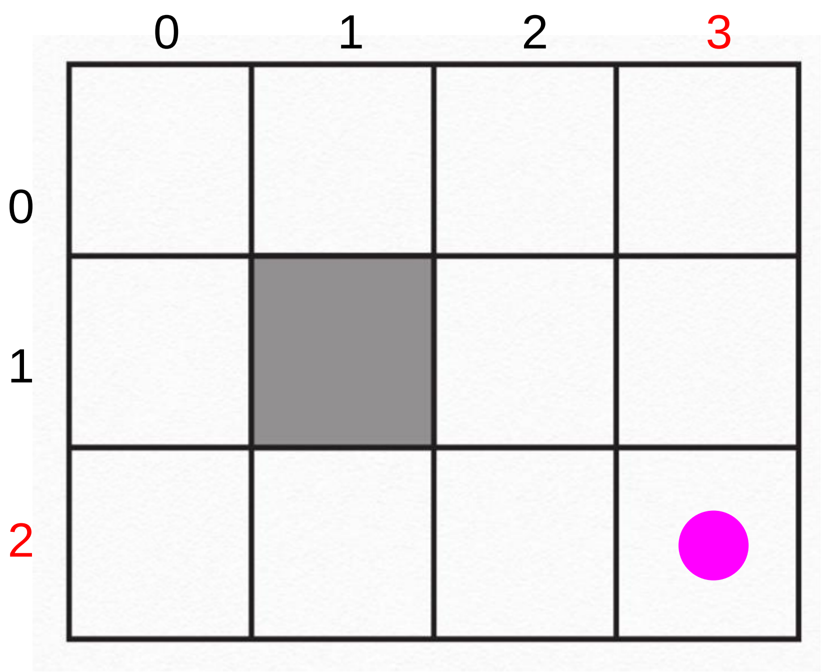
“Push” Robot away



human_state [1]

“Pull” Robot nearer

Human Execution



human_a1.csv

U,L,R,T,D,T,L

> python3 human_execute.py

world1.csv	Gridworld
human_a1.csv	Human actions
2 3 0	Human initial state
human_s1.csv	Human trajectory

Executing the sequence of actions results in a human trajectory:

[[2,3],0],[[1,3],0],[[1,2],0],[[1,3],0],
[[1,3],1],[[2,3],1],[[2,3],0],[[2,2],0]

Setup & Preparation

1. In terminal, change directory to the day2a folder

   First and last reminder!

2. Run the skeleton code with the following command. This step is to ensure all the dependencies and packages are properly installed. E.g. python3, pip3, pygame, etc

   python3 visualizer.py world1.csv human_s1.csv robot_s1.csv

3. Install all missing dependencies and packages

   Refer to "Setup and Preparation" README file

Complete Run (Try it out!)

1. Generate a valid trajectory of a human based on the init state and a sequence of actions

python3 human_execute.py world1.csv human_a1.csv 2 3 0 human_ss1.csv

2. Generate a valid trajectory of a robot based on the init state and a sequence of actions

python3 robot_execute.py world1.csv robot_a1.csv 0 1 robot_ss1.csv

3. Visualize

python3 visualizer.py world1.csv human_ss1.csv robot_ss1.csv

***Note that you need to install all dependencies beforehand (i.e. `python3, pip3, pygame`) beforehand**

Clarification

1. **The nature of the robot's movements will be dependent on the human's request status**
2. **Rewards are not collected and factored in yet**

Human is visualized as a dot, and the robot is visualized as a circle

-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	10	-1	-1	-1
-1	-1	10	10	10	-1	-1
-1	-1	-1	10	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1

[[x,y], 1]

-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-5	-1	-1	-1
-1	-1	-5	-10	-5	-1	-1
-1	-5	-10	-10	-10	-5	-1
-1	-1	-5	-10	-5	-1	-1
-1	-1	-1	-5	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1

[[x,y], 0]

DEMO

playback

simulate system dynamics

visualization

Part B: Introduction to HRIMDP

Comparison between GRIDMDP and HRIMDP

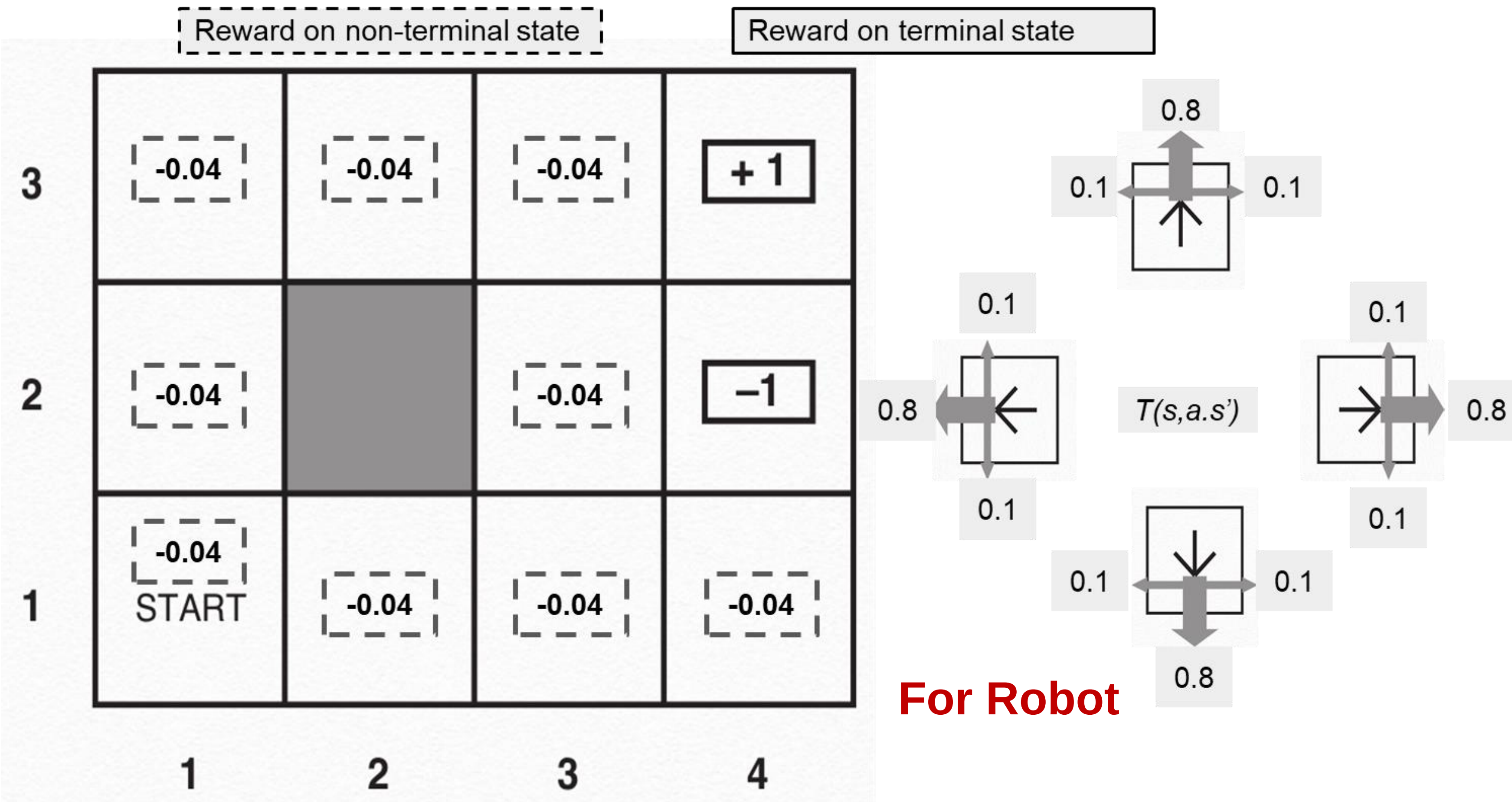
	GRIDMDP	HRIMDP
Has HUMAN	NO	YES
State Space	2D robot workspace $S_r = \{robot_x, robot_y\}$	5D joint state space $S_r \times S_h = \{(robot_x, robot_y, human_x, human_y, human_{request})\}$
Action Space	$A_r = \{'U', 'L', 'R', 'D'\}$	$A_r = \{'S', 'U', 'L', 'R', 'D'\}$
Transition	Uncertain execution	Certain execution But uncertain human state
Reward	Static 2D reward	Dynamic reward in 2D But static in 5D
Terminal States	Yes	No

Comparison between GRIDMDP and HRIMDP

		HRIMDP
Has HUMAN		YES
State Space		5D joint state space $S_r \times S_h = \{(robot_x, robot_y, human_x, human_y, human_{request})\}$
Action Space		$A_r = \{'S','U','L','R','D'\}$
Transition		Certain execution But uncertain human state
Reward		Dynamic reward in 2D But static in 5D
Terminal States		No

HRIMDP is designed to handle more complex, interactive environments where robots must not only navigate their own space but also **account for human behavior and requests**. This makes it **suitable for scenarios like collaborative tasks** in industrial settings or assistive robots **working with humans**

Reward & Transition Structures used for GRIDMDP



The **reward** function **R** and **transition** function **T** remain unchanged for this example unless stated.

Things to do

1. Verify installation, pytest is needed

python3 test_mdp.py

2. Try out solving MDP without terminal states

python3 test_mdp_without_terminal_states.py

3. Implement our HRIMDP with 5 dimensional gridworld
    a) Assign **reward[state]**
    b) Complete function **calculate_T**
    c) Implement function **human_execute_one_step**

4. Test implementation with

python3 test_hrimdp.py

Hints to complete test_hrimdp.py

1. Assign reward[state]

Need a set of codes to represent below reward structure

-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	10	-1	-1	-1
-1	-1	10	10	10	-1	-1
-1	-1	-1	10	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1

[[x,y], 1]

-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-5	-1	-1	-1
-1	-1	-5	-10	-5	-1	-1
-1	-5	-10	-10	-10	-5	-1
-1	-1	-5	-10	-5	-1	-1
-1	-1	-1	-5	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1

[[x,y], 0]

Hints to complete test_hrimdp.py

2. Complete function calculate_T

Assume Transition Matrix of Human Movements is:

<table>
<tr><td></td><td></td><td colspan="6">Next Status</td></tr>
<tr><td></td><td></td><td>S</td><td>U</td><td>D</td><td>L</td><td>R</td><td>T</td></tr>
<tr><td rowspan="6">Current Status</td><td>S</td><td rowspan="6">0.5</td><td rowspan="6">0.1</td><td rowspan="6">0.1</td><td rowspan="6">0.1</td><td rowspan="6">0.1</td><td rowspan="6">0.1</td></tr>
<tr><td>U</td></tr>
<tr><td>D</td></tr>
<tr><td>L</td></tr>
<tr><td>R</td></tr>
<tr><td>T</td></tr>
</table>

Hints to complete test_hrimdp.py

3. Complete function human_execute_one_step

- Refer to the function before this (i.e. robot_execute_one_step) for reference; both should be similar except for:
- You have to account for the following events:
  a) There is a toggle request from human, upon which, will change the toggle request status. This means if the current status is ‘False’, this action will change the next status to ‘True’; whereas if the current status is ‘True’, this action will change the next status to ‘False’
  b) There is NO toggle request, upon which, the toggle request status remains the same as the previous

DEMO

playback

simulate system dynamics

visualization

Instructions

This is a group project. Each group representative submits one zip file of all your codes/files (i.e. py) into Canvas at the end of the workshop

HRSE_Day2_Workshop.zip

- Download all files in the directory **/workshops/day2** for reference codes
- Refer to the README file for instructions

THANK YOU

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