Current state of self-driving cars
and
new approaches coming from Cognitive Science

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Artificial Intelligence Trento Journal Club

- What are autonomous vehicles (AV)?
- How good are AV compared to human drivers?

S.A.E. AUTOMATION LEVELS

LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
No automation	The system assists the human	The system can steer and accelerate	The system controls the vehicle and monitors the environment	The system drives in autonomy under certain conditions	The system drives in autonomy in all conditions
The human drives the vehicle	The human controls the vehicle	The human monitors the system and the environment	The human supervises the system all the time	The human has to drive only when required	The human is not required

The human driver monitors the environment

The artificial system monitors the environment

AUTONOMOUS VEHICLES vs. HUMAN DRIVERS

- In the US, an average human driver causes:
  - a fatal accident every 100,000,000 miles,
  - a minor accident every 10,000,000 miles.

  (National Highway Traffic Safety Administration, *Fatality Analysis Reporting System*, 2017)

- Main causes of accidents are influence of alcohol or drugs, inattention, tiredness, and reckless or illegal maneuvers.

  (National Highway Traffic Safety Administration, *Critical Reasons for Crashes Investigated in the National Motor Vehicle Crash Causation Survey,* 2015)

- Waymo reports a disengagement every 30,000 miles.

  (California's Department of Motor Vehicles, Disengagement Report, 2021)

WHY ARE AUTONOMOUS VEHICLES NOT WORKING AS EXPECTED

CHALLENGING ENVIRONMENTS

- Understanding unstructured environments and other human road users

- Behaving correctly in unexpected situations

CHALLENGING ENVIRONMENTS

- Understanding unstructured environments and other human road users

- Behaving correctly in unexpected situations

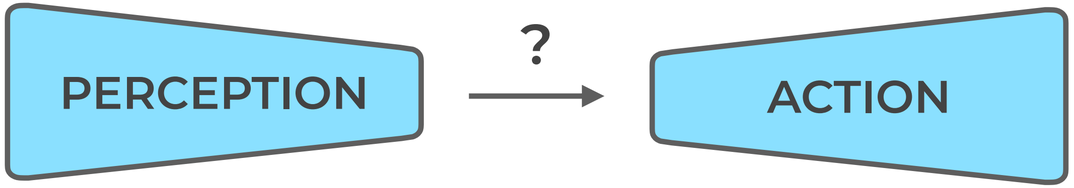
CLASSIC PARADIGM

- Convenient decomposition of the system's function
- Optimal when the system's states can be modeled beforehand
- No guarantees for situations not specified in advance
- Limited set of human-programmed symbols and related actions

CLASSIC PARADIGM

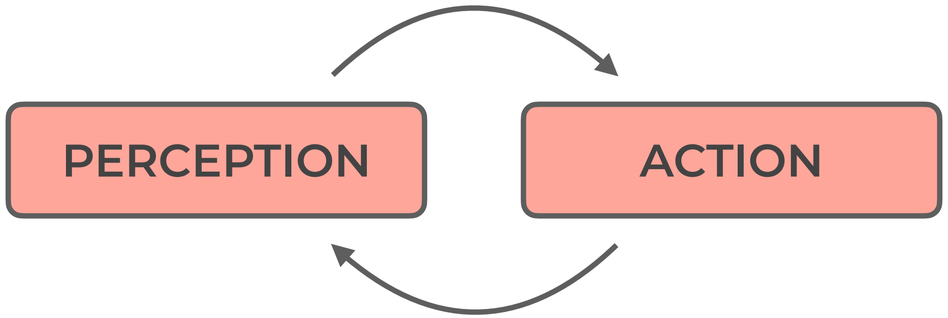
CLASSIC PARADIGM

END-TO-END PARADIGM



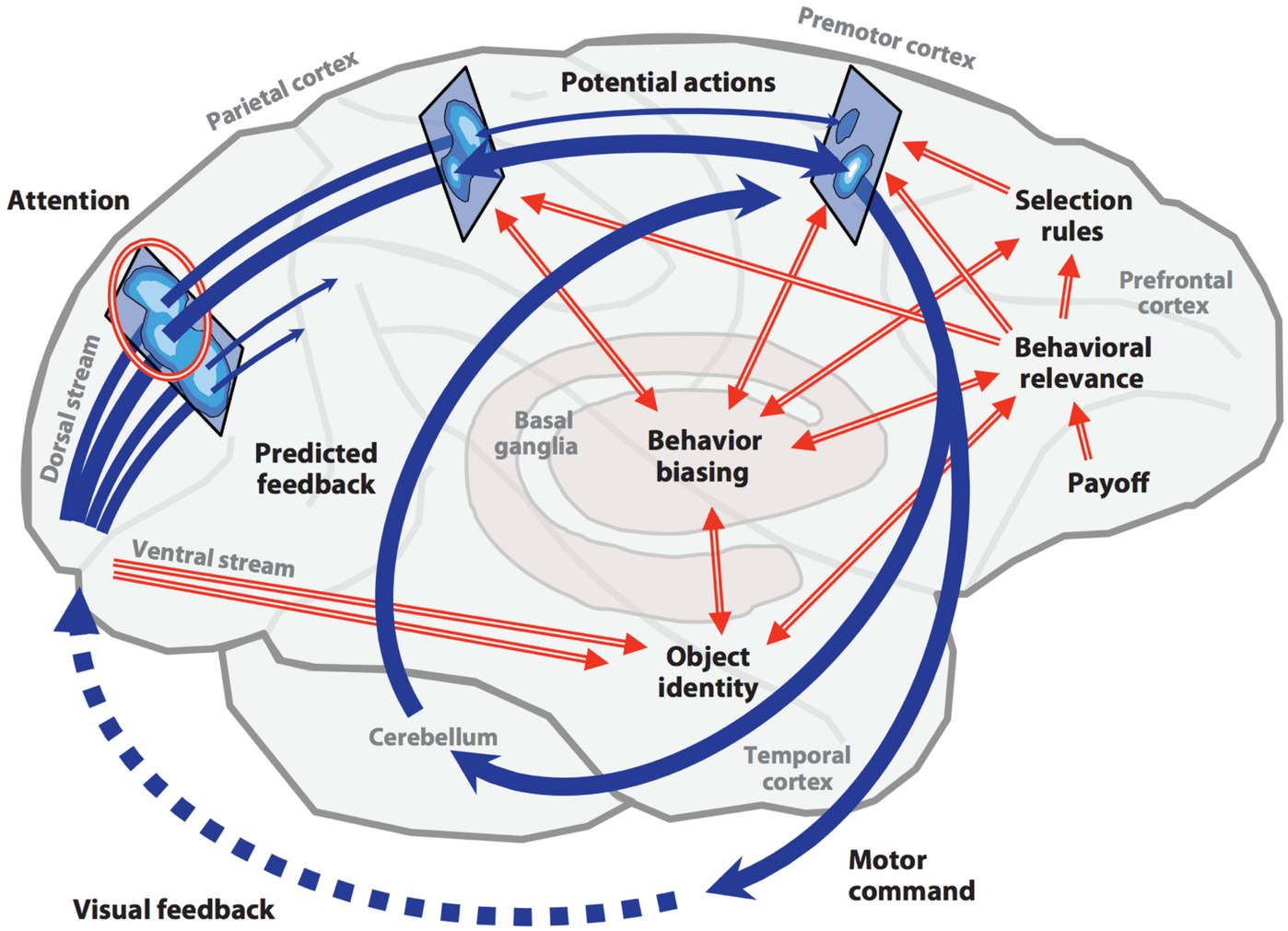
- No human-programmed internal representations
- Need for an impossibly vast dataset to learn to drive in all situations
- No explanations on action selection

COGNITIVE-INSPIRED PARADIGM



- Close to real cognitive mechanisms occurring when driving
- Mental simulations to learn new behaviors
- Action priming and action selection are explainable
- Difficult to replicate cognitive architectures on hardware

HUMAN COGNITION



OUR CONTRIBUTION

Mauro Da Lio
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Francesco Biral
Associate professor

Gastone Pietro Rosati Papini
RTD-B

Antonello Cherubini
RTD-A

Alice Plebe
Postdoc

Edoardo Pagot
Phd student

Mattia Piccinini
Phd student

Matteo Larcher
Phd student

Mattia Piazza
Phd student

OUR CONTRIBUTION

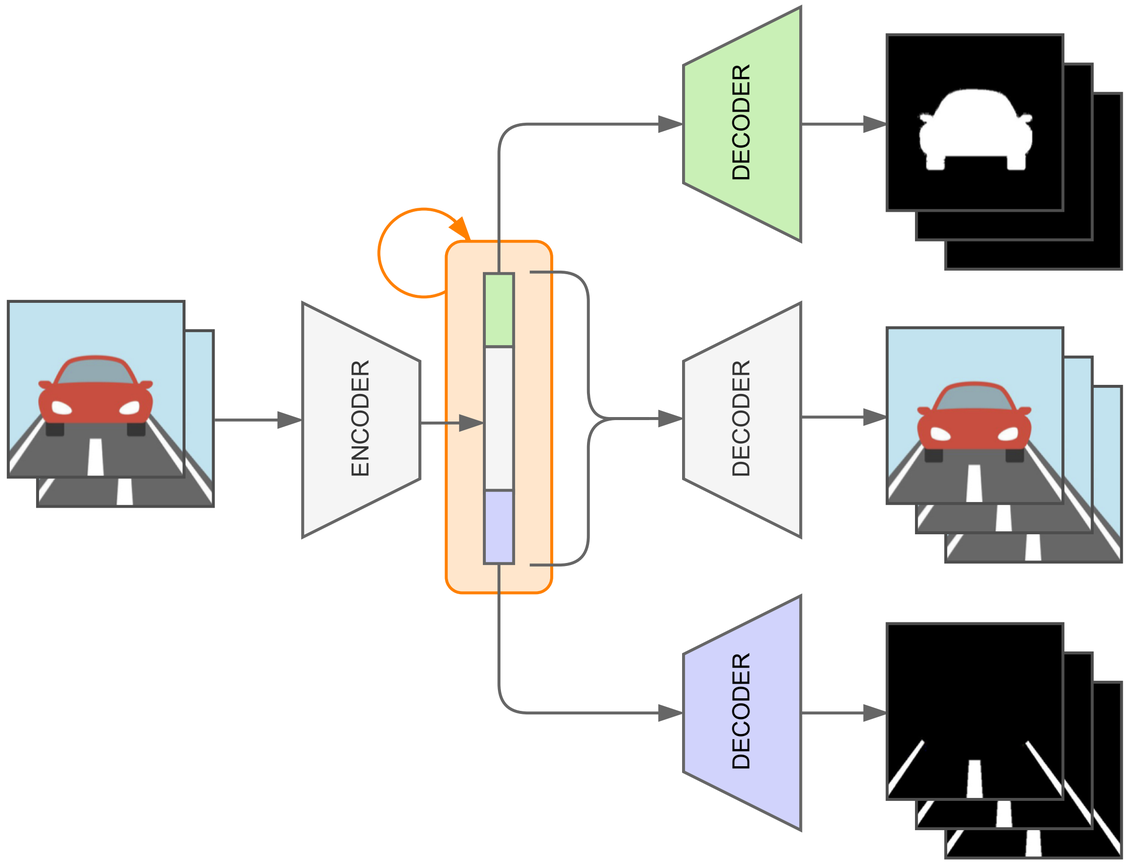
1. Explore proof-of-concepts for human-like perception
2. Implement emergent behavior in an autonomous agent
3. Experiments with a driving simulator

DREAMS4CARS

COGNITIVE-INSPIRED VISUAL PERCEPTION

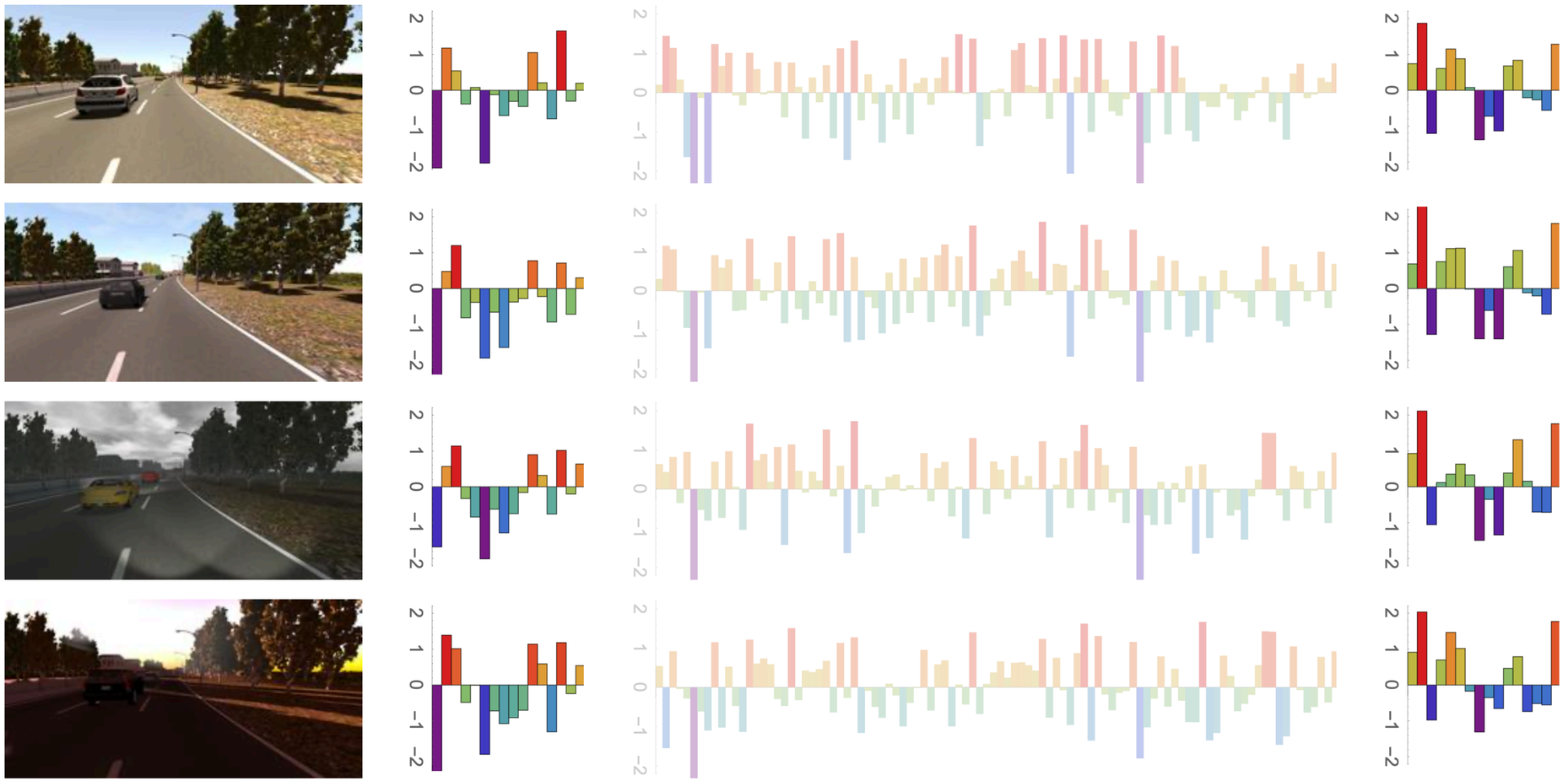
COGNITIVE-INSPIRED PERCEPTION

- Ventral / dorsal streams
- Conceptual / spatial learning
- Concepts with semantic organization and temporal coherence
- Mental imagery



A. Plebe and M. Da Lio, "On the road with 16 neurons: Towards interpretable and manipulable latent representations for visual predictions in driving scenarios", IEEE Access, 2020

COGNITIVE-INSPIRED PERCEPTION



INPUT VEHICLES OTHER VISUAL FEATURES LANES

COGNITIVE-INSPIRED PERCEPTION

- Ventral / dorsal streams
- Conceptual / spatial learning
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- Mental imagery

COGNITIVE-INSPIRED PERCEPTION

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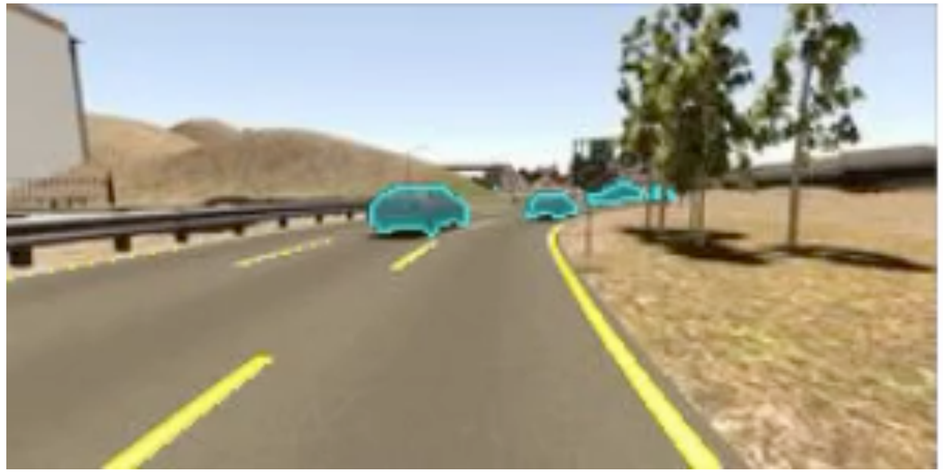

COGNITIVE-INSPIRED PERCEPTION

- Visual attention
- Saccadic eye movement
- Cortical magnification

ATTENTION

A. Plebe, J. F. Kooij, G. P. Rosati Papini, and M. Da Lio, "Occupancy grid mapping with cognitive plausibility for autonomous driving applications", IEEE/CVF International Conference on Computer Vision (ICCV), 2021

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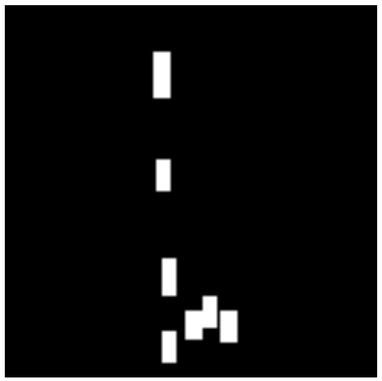

MAGNIFICATION

COGNITIVE-INSPIRED PERCEPTION

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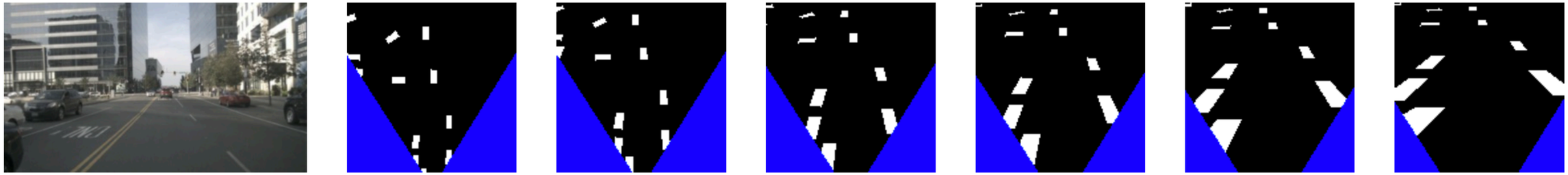
- Saccadic eye movement
- Cortical magnification

FACTOR OF MAGNIFICATION

$$w(Z) = \log(Z + \omega) - \log(\omega)$$



COGNITIVE-INSPIRED PERCEPTION

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COGNITIVE-INSPIRED PERCEPTION

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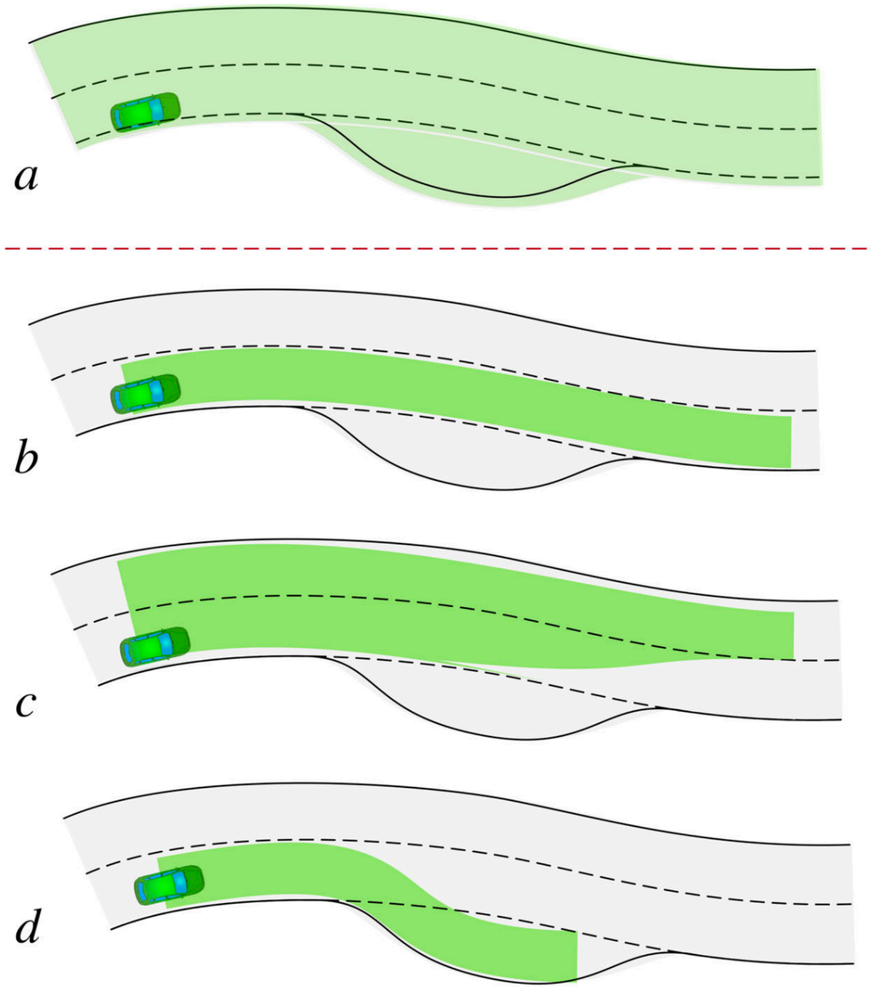
COGNITIVE-INSPIRED MOTOR CONTROL

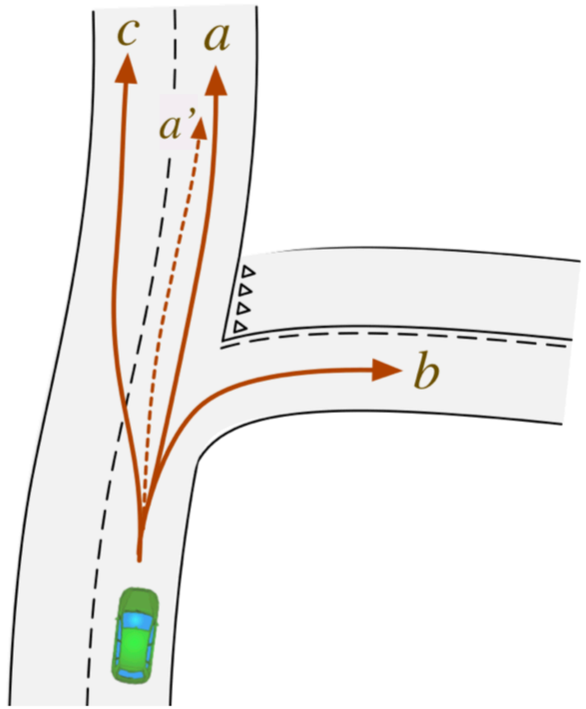
AFFORDANCE COMPETITION

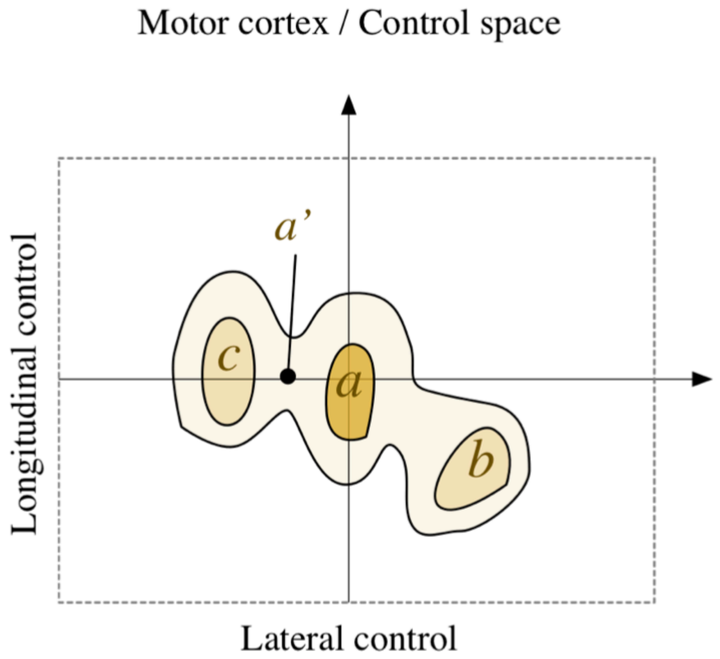
- Topographic organization of motor space
- Action priming and action selection
- Behavior steering via biasing of action selection



M. Da Lio, A. Cherubini, G. P. Rosati Papini, and A. Plebe, "Complex self-driving behaviors emerging from affordance competition in layered control architectures", Cognitive Systems Research, 2023

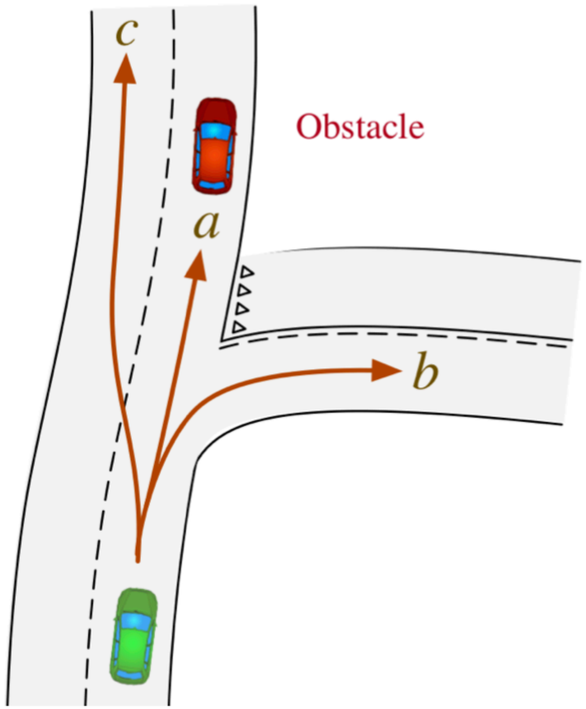
ARTIFICIAL MOTOR CORTEX

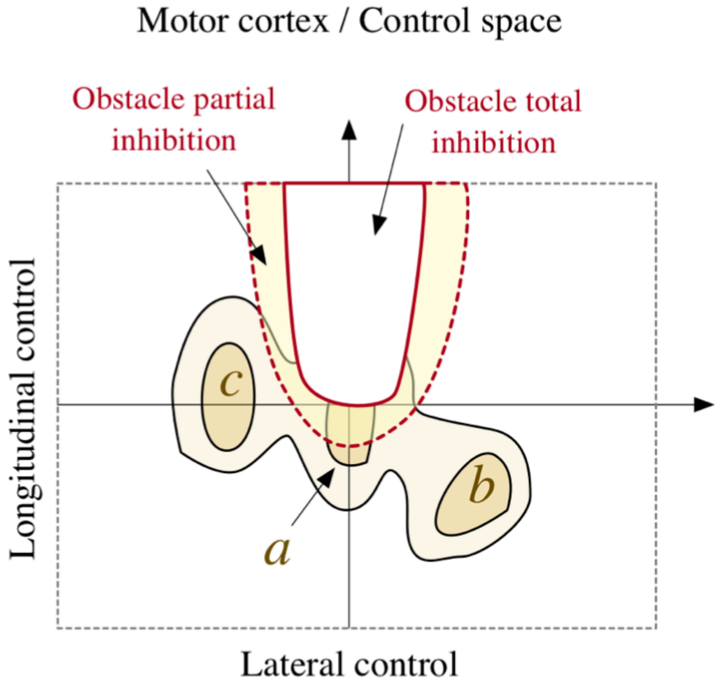




$$s_a(j_0, r_0) = \sup\{v(\gamma) \mid \gamma \in a\}$$

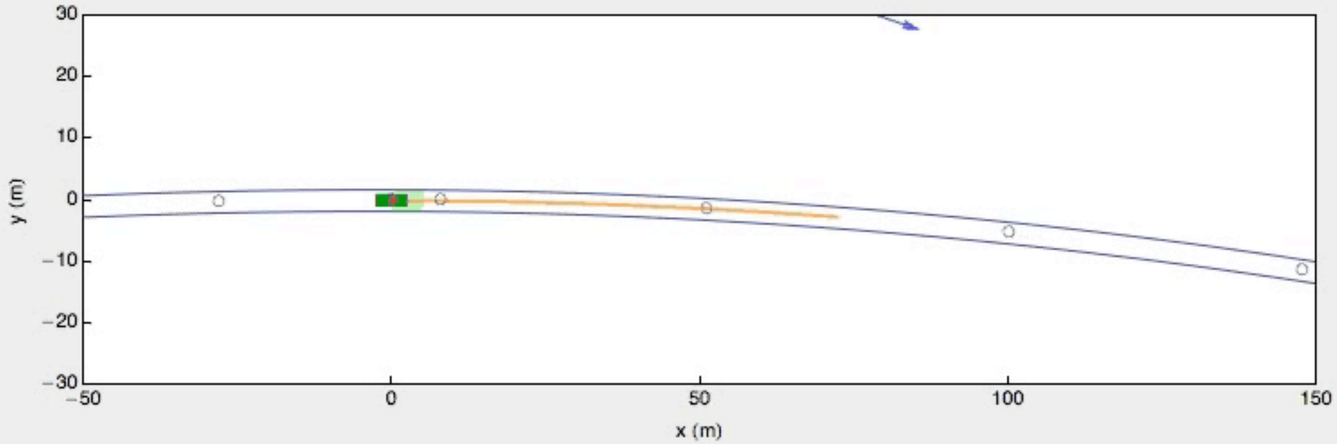
ARTIFICIAL MOTOR CORTEX





$$s(j_0, r_0) = \max\{ w_a \, s_a(j_0, r_0) \mid a \in \mathcal{A} \}$$

G. P. Rosati Papini, G. Valenti, A. Plebe; M. Da Lio, "MSPRT action selection model for bio-inspired autonomous driving", I-RIM 2020



Free Flow

Speed Limit

Curve

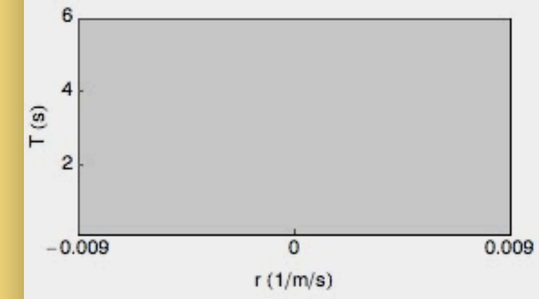
Car Follow

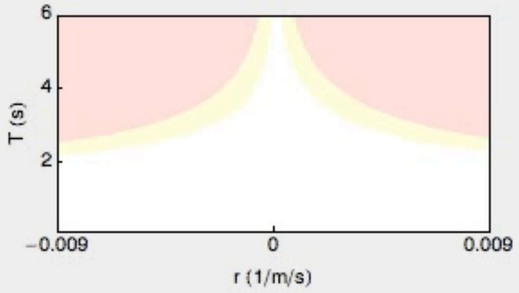
HIGHWAY MERGE

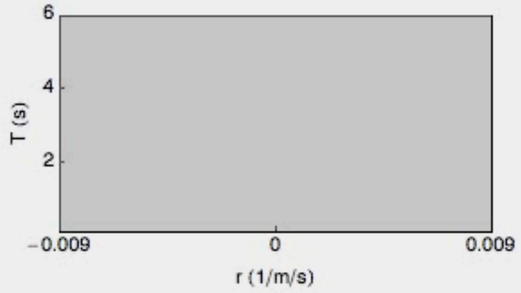
Change Left

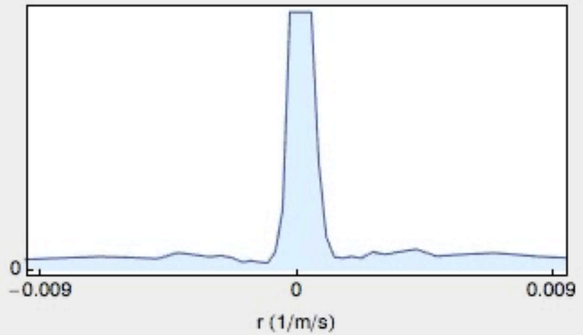
Lane Follow

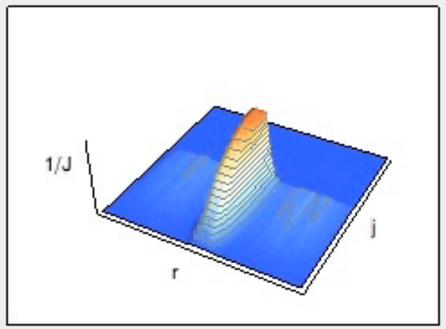
Change Right

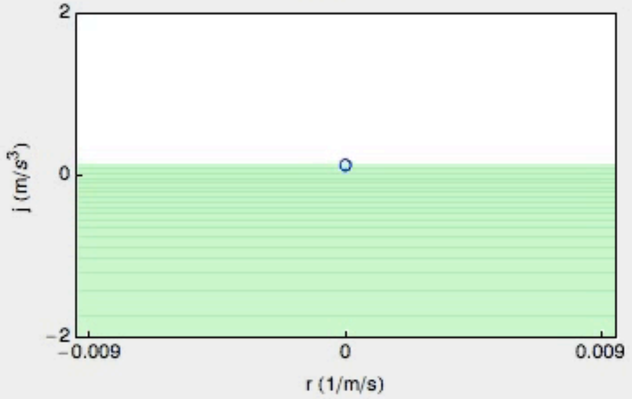


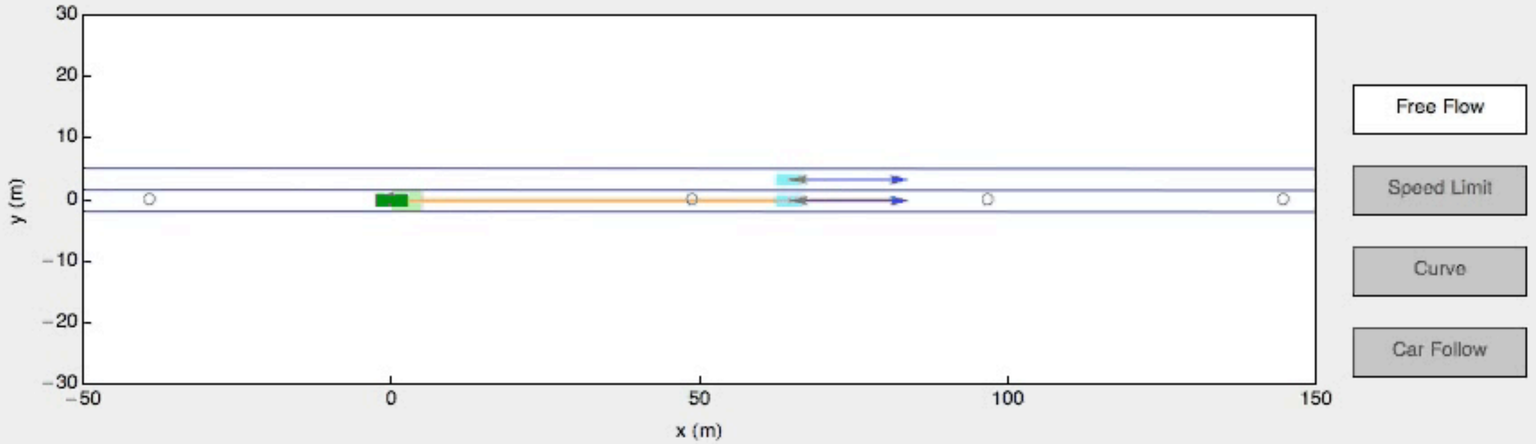












Free Flow

Speed Limit

Curve

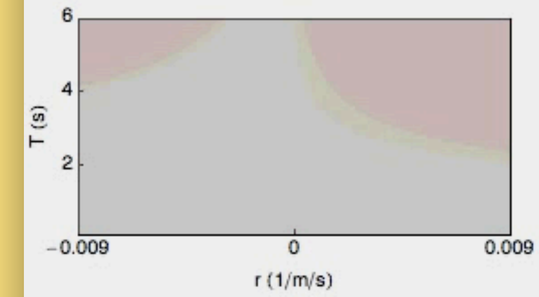
Car Follow

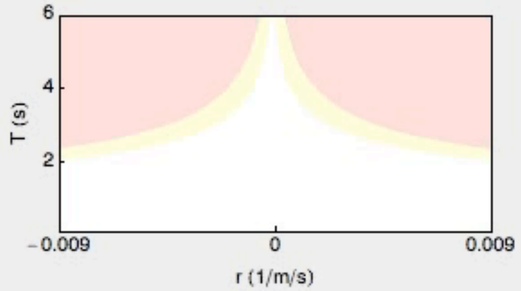
FOLLOW AND OVERTAKE

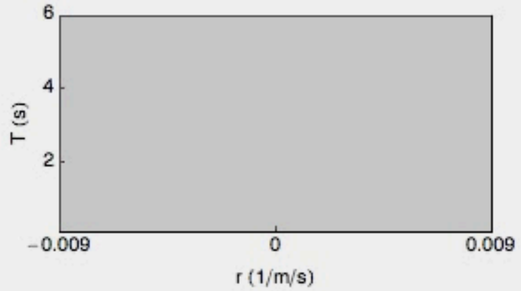
Change Left

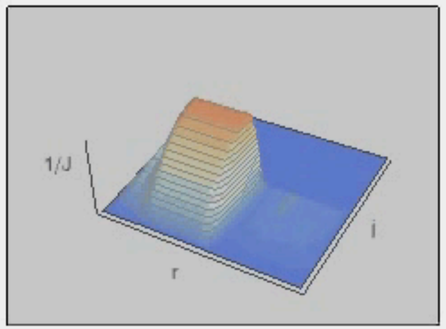
Lane Follow

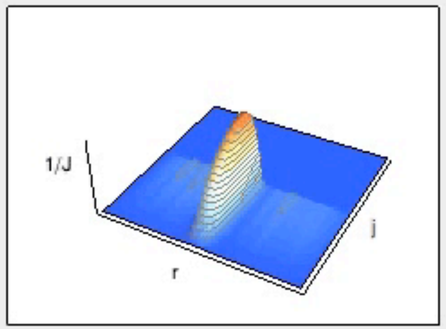
Change Right

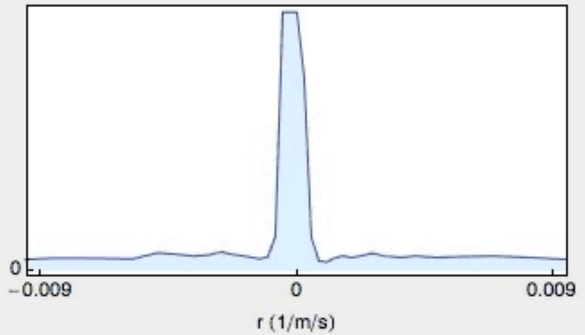


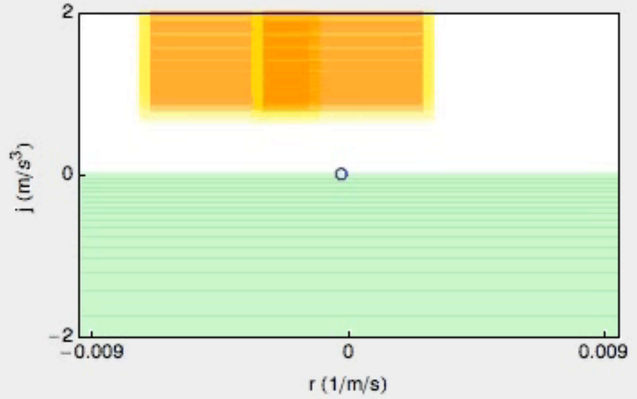


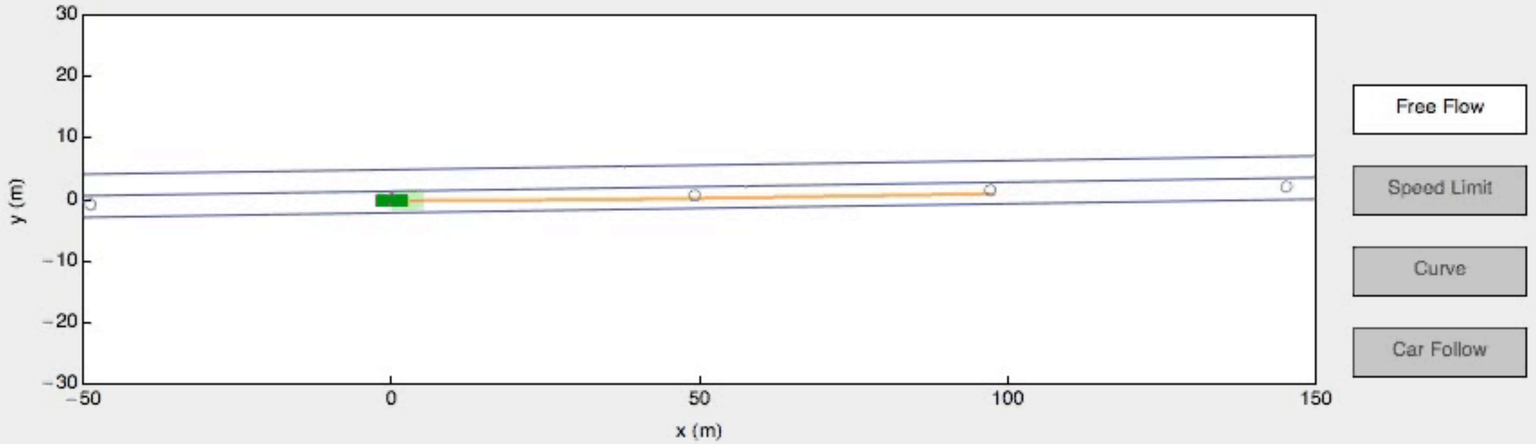












Free Flow

Speed Limit

Curve

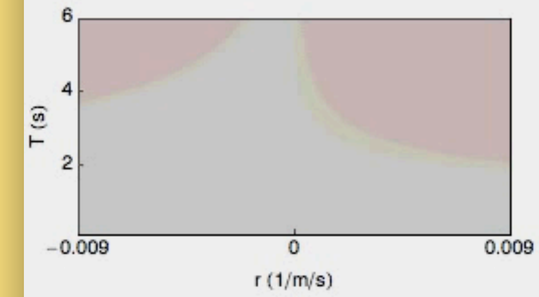
Car Follow

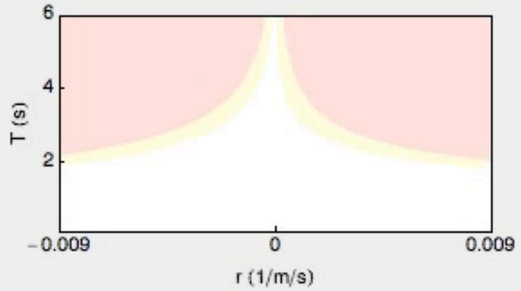
CUT-IN

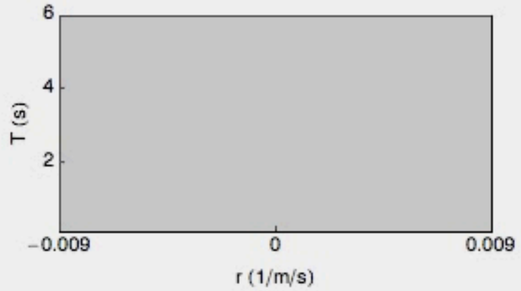
Change Left

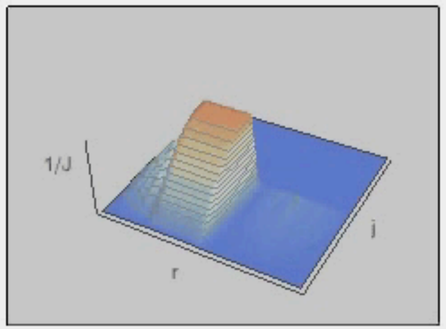
Lane Follow

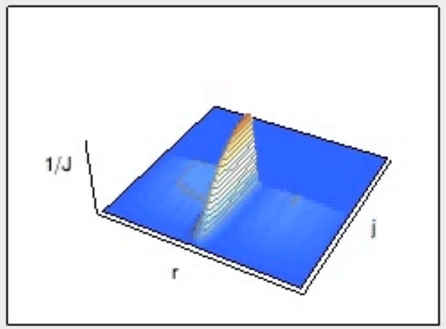
Change Right

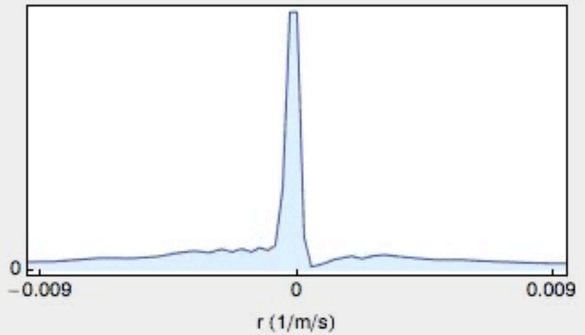


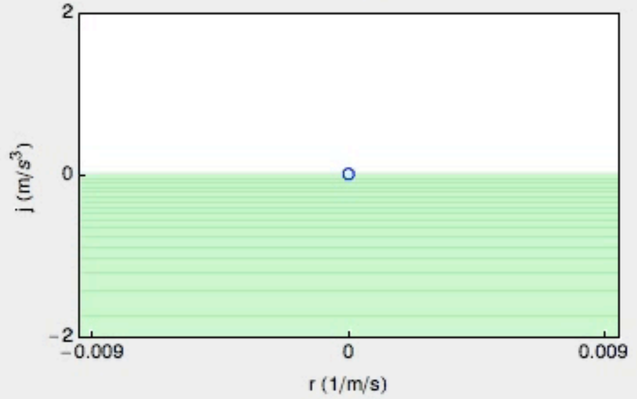


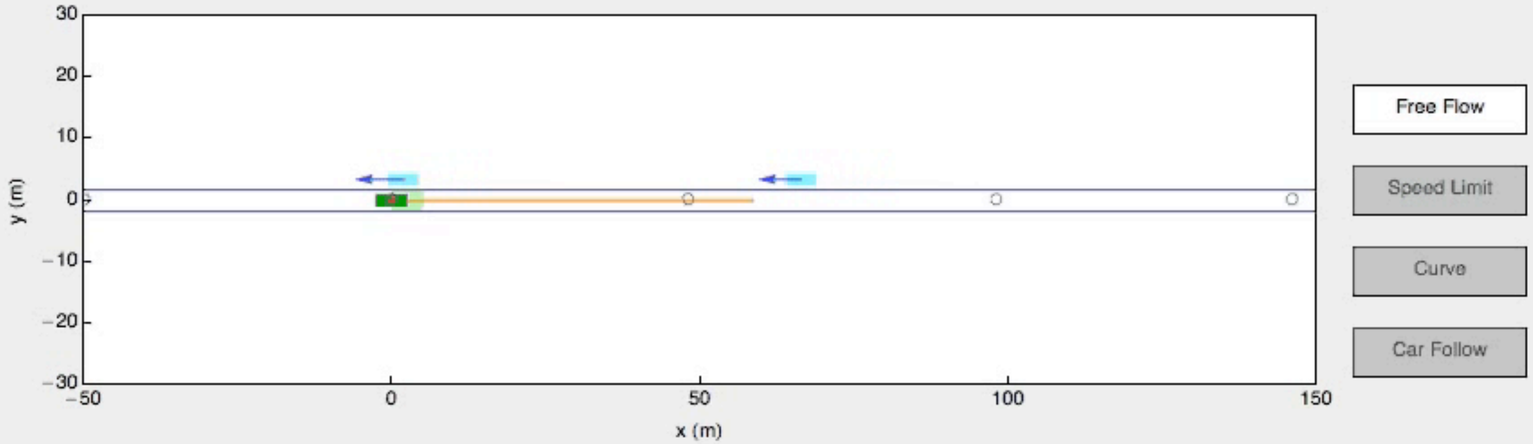










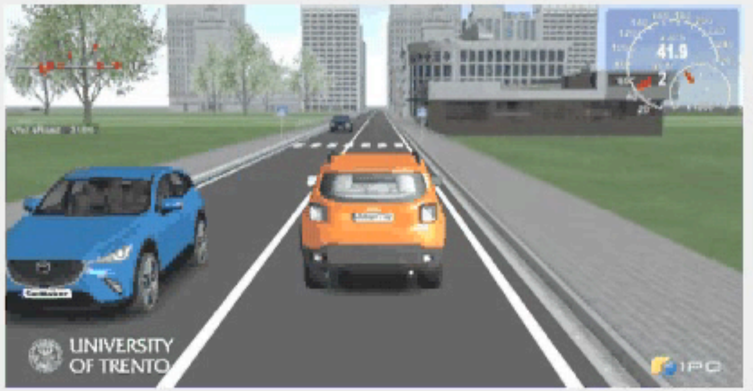


Free Flow

Speed Limit

Curve

Car Follow

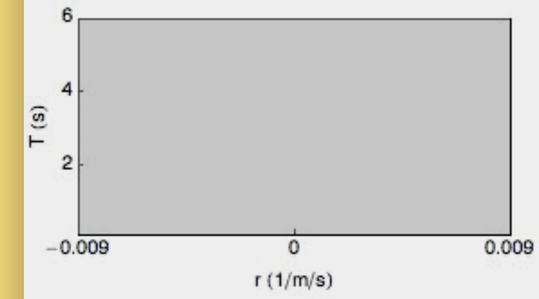


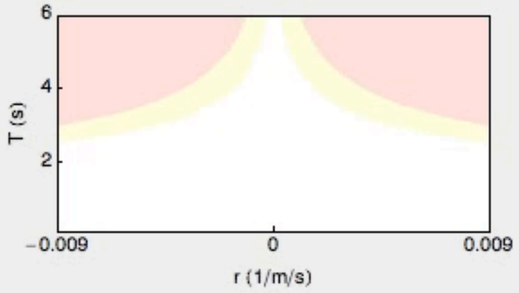
CROSSING TRAFFIC

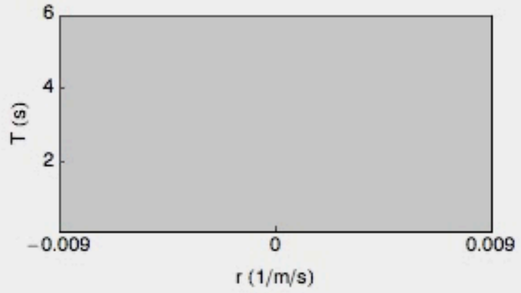
Change Left

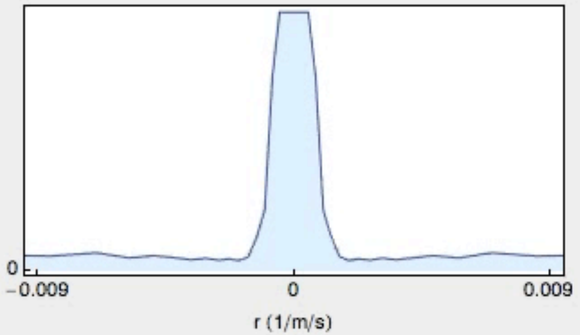
Lane Follow

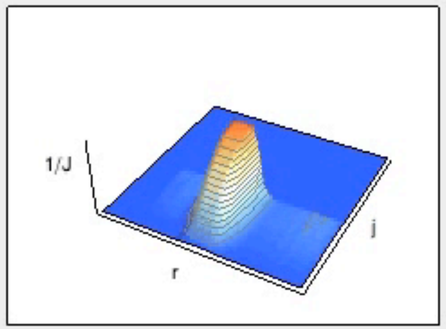
Change Right

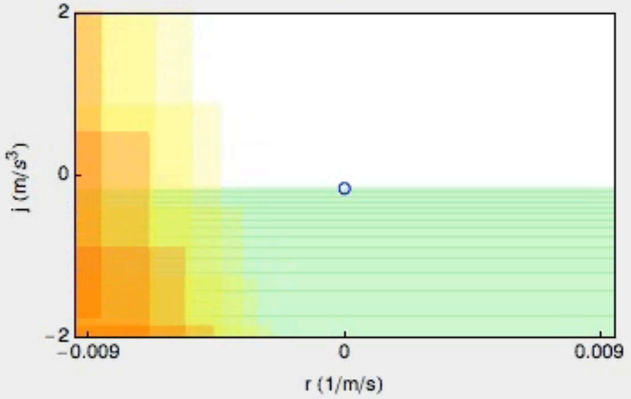


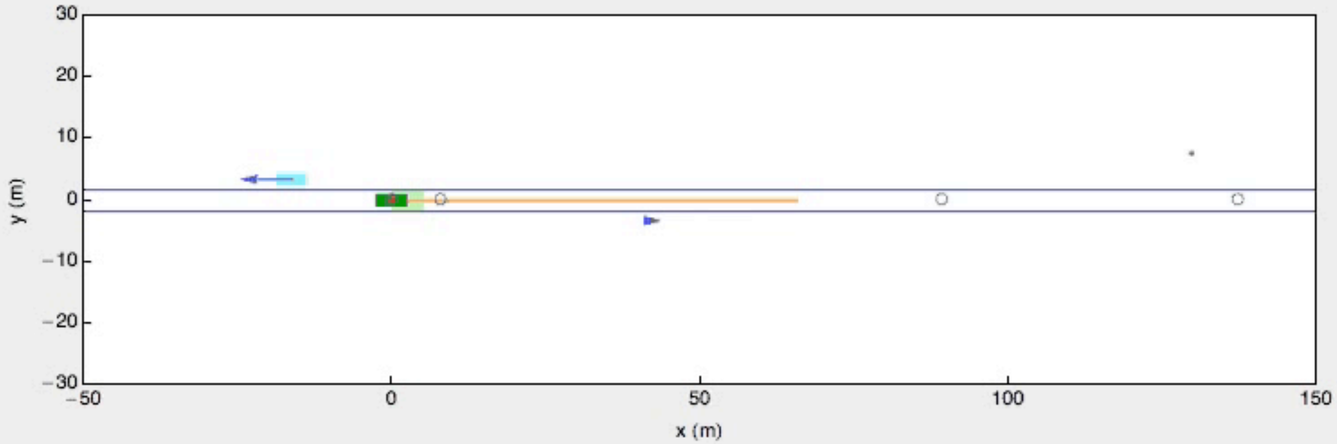












Free Flow

Speed Limit

Curve

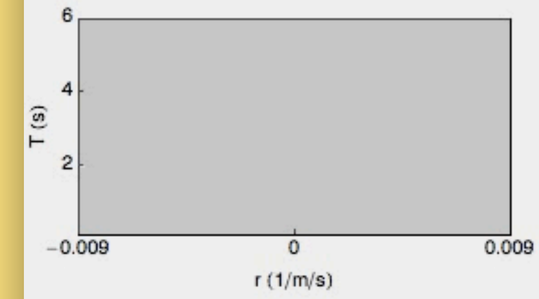
Car Follow

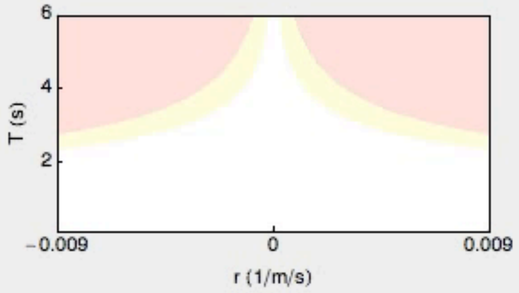
PEDESTRIAN CROSSING

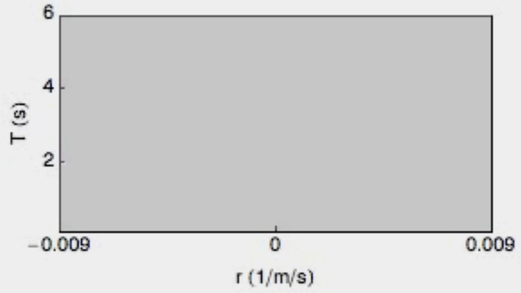
Change Left

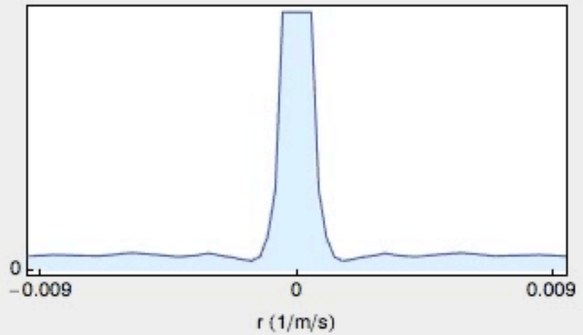
Lane Follow

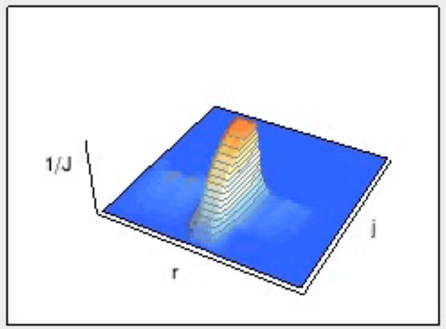
Change Right

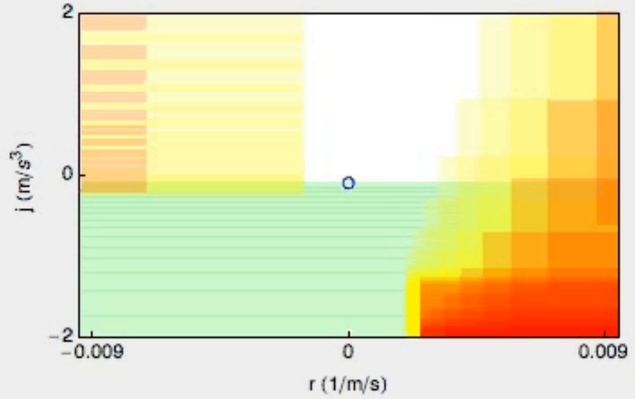












DRIVING SIMULATOR

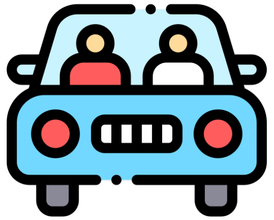
DRIVING SIMULATOR (BEFORE)

DRIVING SIMULATOR (NOW!)

DISTRIBUTED COGNITION

The horse-rider metaphor (H-metaphor) *(Flemisch et al., 2003)*

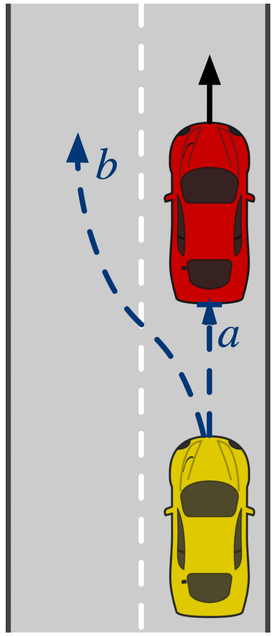
- The human communicates with the horse through the reins.
- The horse can understand the human's intentions.

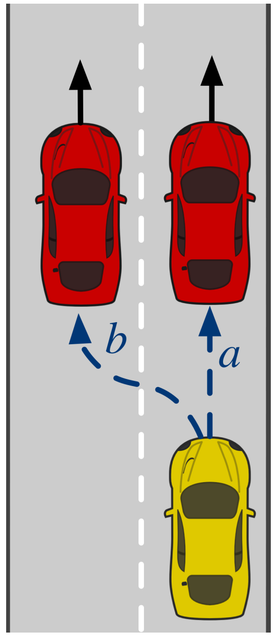


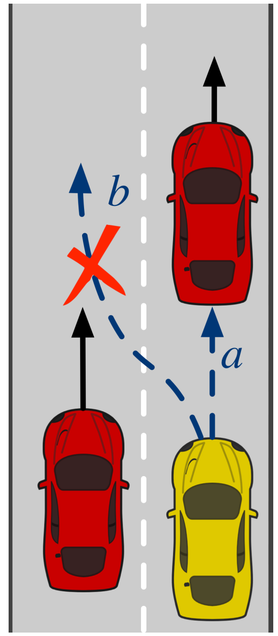
- The human can influence the agent's decision-making through pedals and steering wheel.
- The agent can dismiss the human's suggestion if dangerous or not significant.

A. Plebe, G. P. Rosati Papini, A. Cherubini, and M. Da Lio, "Distributed cognition for collaboration between human drivers and self-driving cars", Frontiers in Artificial Intelligence, 2022

DISTRIBUTED COGNITION

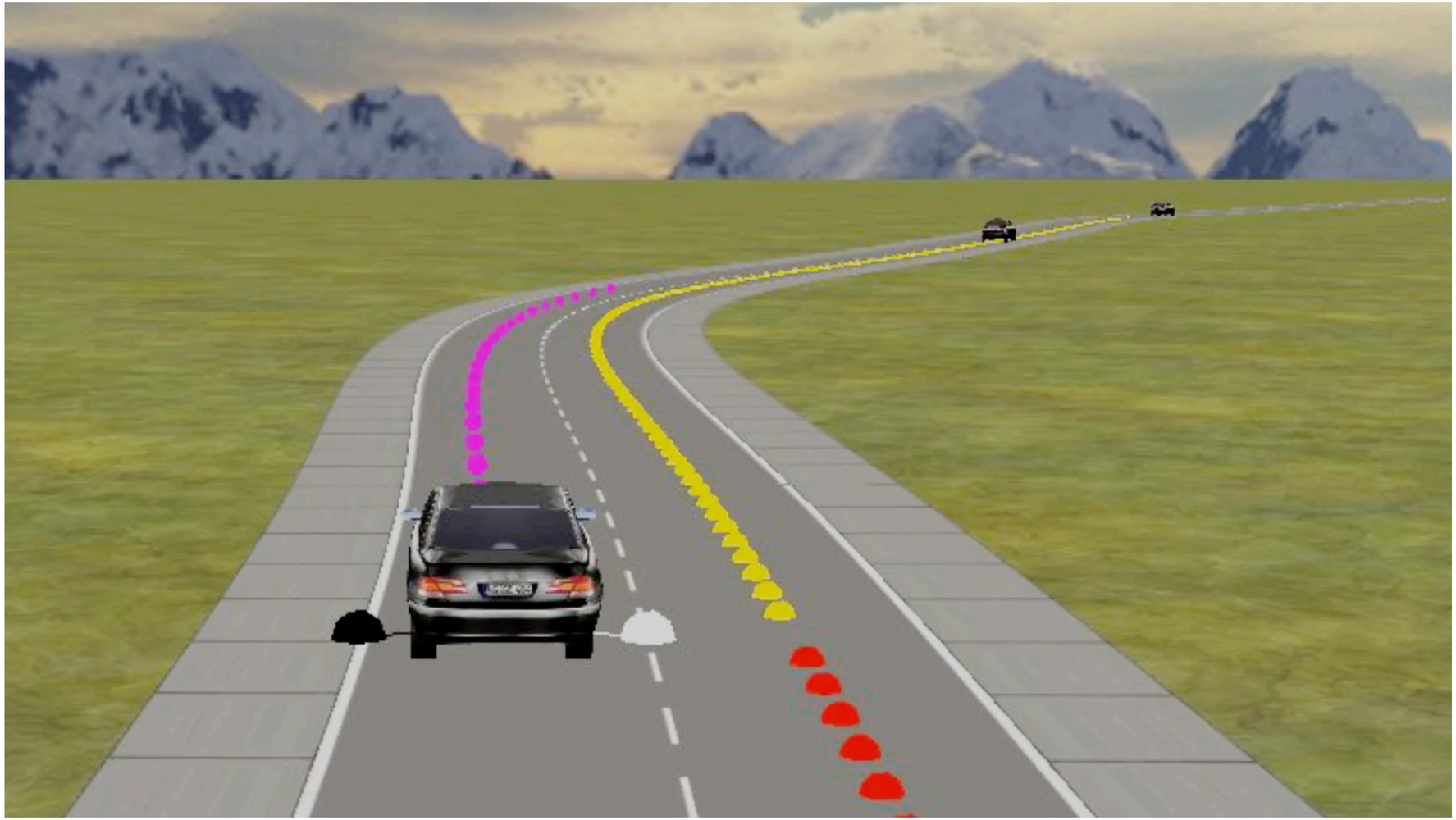






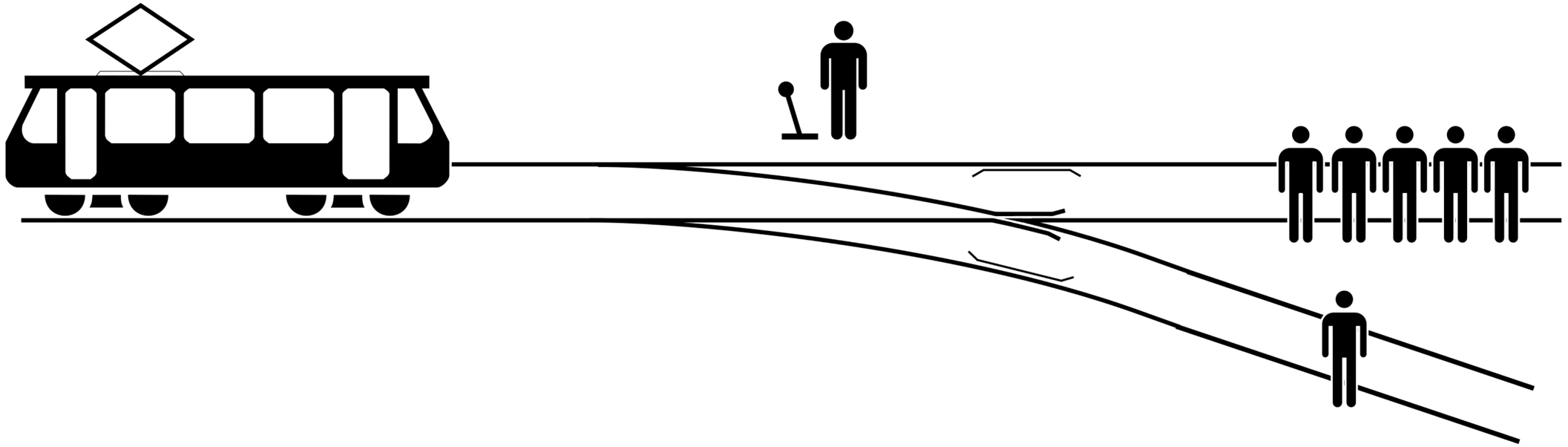
M. Da Lio, R. Donà, G. P. Rosati Papini, and A. Plebe, "The biasing of action selection produces emergent human-robot interactions in autonomous driving", IEEE Robotics and Automation Letters, 2022

DISTRIBUTED COGNITION



TROLLEY PROBLEM

(P. Foot, 1967)



SUMMARY

- Human drivers still outperform autonomous vehicles
  - sense-think-act vs. perception-action

- Inspiration from cognitive mechanisms:
  - dorsal/ventral streams, cortical magnification, attention;
  - motor cortex, action priming, biasing of action selection.

- Driving simulator:
  - data collection, distributed cognition, h-metaphor, trolley problem

THANK YOU!