Toward socially aware navigation : from pedestrian's behavior modeling to proactive navigation

Anne Spalanzani – Inria Chroma – WS PPNIV IROS 2022

Global objective

- **Autonomous vehicles integrated in spaces shared with** pedestrians**, bicycles, other vehicles**
- Develop a navigation system suitable for shared spaces with vulnerable road users

Main challenges

- Increase vehicle and pedestrian safety in congested environments
- Make autonomous vehicles friendly and actors in the global movement
- Understand and use social and urban rules for autonomous vehicles
- Produce accepted behaviors for passengers and pedestrians

Many scientific problems to solve

Detect, track and predict the trajectory of pedestrians

when they are numerous

in unknown environments

Navigate in highly dynamic, unpredictable and heavily populated environments

Little free space to plan

Constant replanning

safety

Understand pedestrians' intentions and willingness to cooperate

Crossing / Stopping

Passing

Obtaining socially acceptable behaviors

For the passenger in the car

For pedestrians around the vehicle

Predictable, readable behaviors

Focus on 3 problems

1. How to predict crowds' and pedestrians' behaviors ?

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2. How to navigate crowds ?
3. How to test experimentally our algorithms ?

Crowd simulation around AV

M. Prédhumeau, L. Mancheva, J. Dugdale, A. Spalanzani.

An Agent-Based Model to Predict Pedestrians Trajectories with an Autonomous Vehicle in Shared Spaces, AAMAS 2021 - 20th International Conference on Autonomous Agents and Multiagent Systems, International Foundation for Autonomous Agents and Multiagent Systems (IFAAMAS), May 2021. Best Student paper Award.

Pedestrian in open environments

PEDESTRIANS HAVE

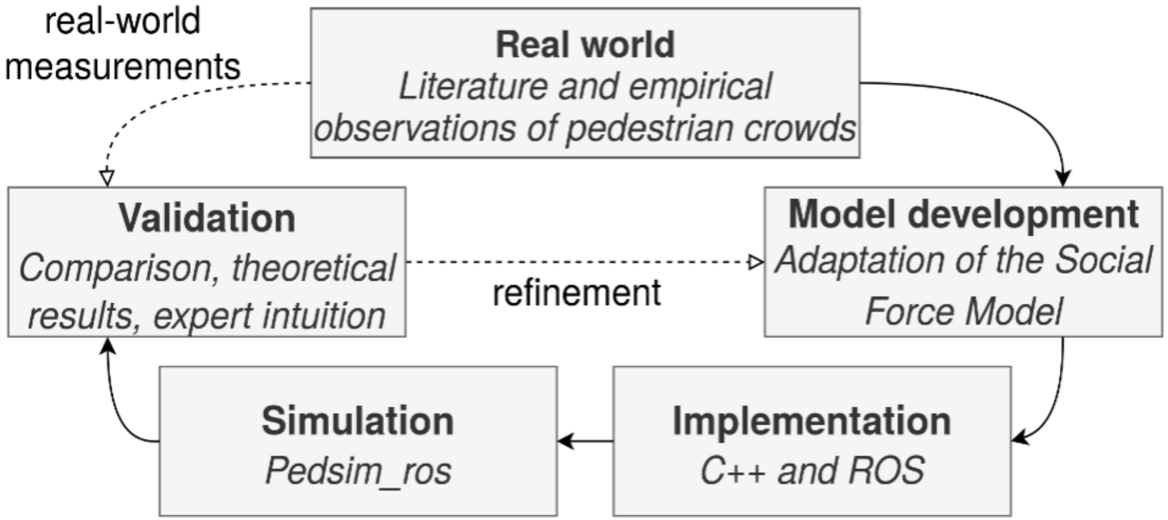
- A limited perception
- A limited attention
- A personal space whose shape depends on the situation
- A behavior (in terms of trajectories) that depends on the crowd's density

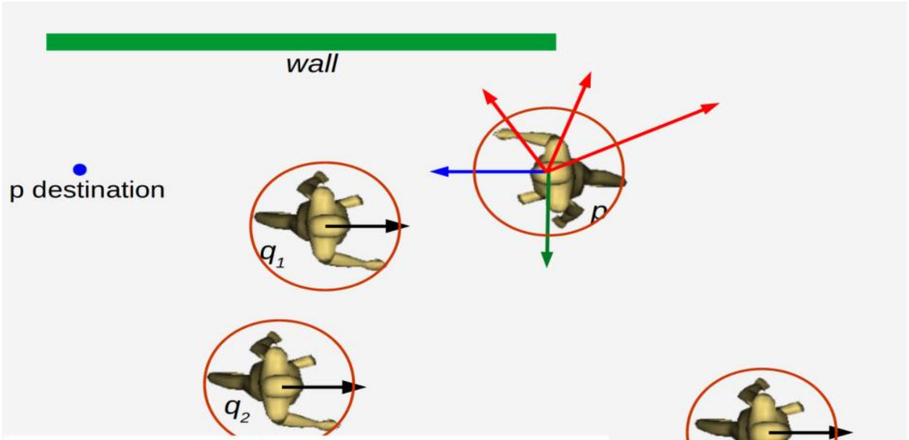
[1] Kitazawa, K. and Fujiyama, T. *Pedestrian Vision and Collision Avoidance Behavior.* In Pedestrian and Evacuation Dynamics 2008, p. 95–108. Springer Berlin Heidelberg, Berlin, Heidelberg, 2010.
[2] Hall, E. T. *The hidden dimension*. Anchor Books, New York, 1966.
[3] Hayduk, L. A. *The shape of personal space: An experimental investigation.* Canadian Journal of Behavioural Science/Revue canadienne des sciences du comportement, 13(1):87–93, 1981.
[4] Frohnwieser, A., Hopf, R., and Oberzaucher, E. *Human Walking Behavior - The Effect of Pedestrian Flow and Personal Space Invasions on Walking Speed and Direction.* Human Ethology Bulletin, pages 20–28, 2013.
[5] Liu, Y., Sun, C., and Bie, Y. *Modeling Unidirectional Pedestrian Movement: An Investigation of Diffusion Behavior in the Built Environment.* Mathematical Problems in Engineering, 2015:1–6, 2015.

Motivation to simulate crowds

- Model realistic behaviors of pedestrians
- Validate these behaviors with real data
- Predict pedestrian's trajectories around AV
- Taking into account : limited perception and attention, personal space, density, groups...
- Using social force models

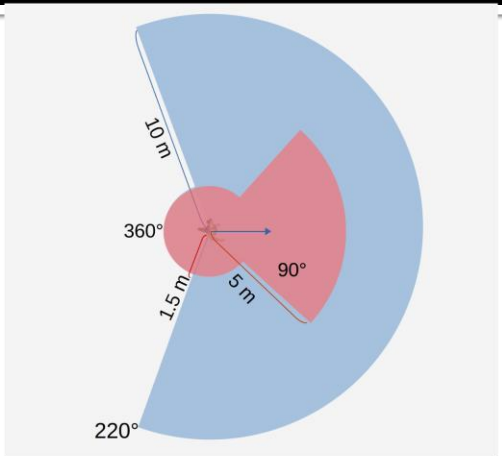
Methodology



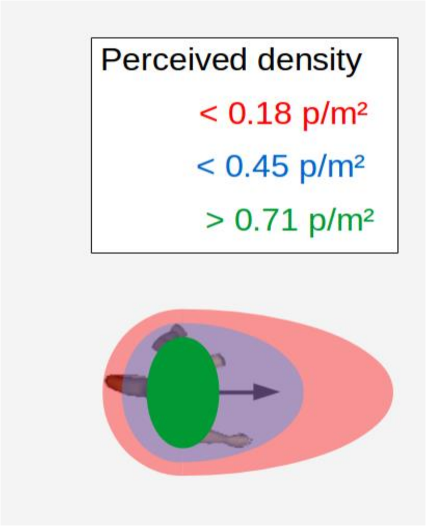


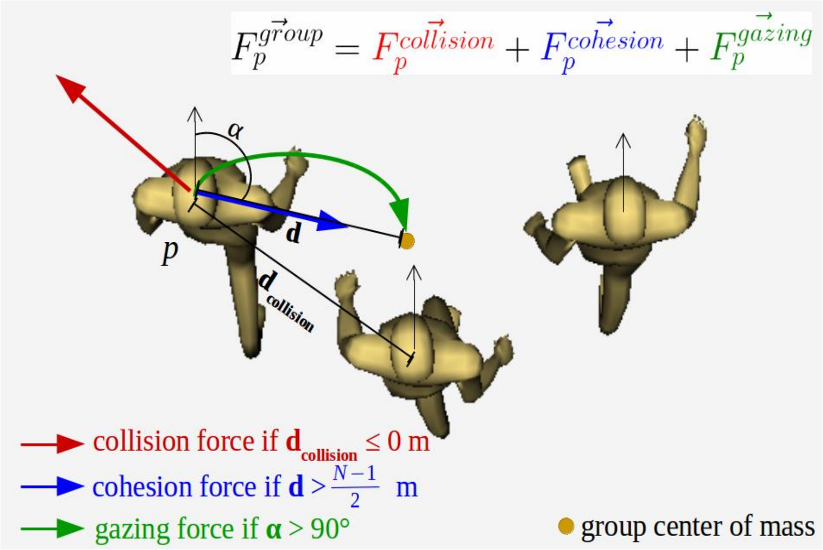
$$\vec{F}_p(t) = \vec{F}_p^{des}(t) + \sum_{q\neq p}^{N_{ped}} \vec{F}_{pq}^{soc}(t) + \sum_b \vec{F}_{pb}^{repuls}(t)$$

Pedestrian/pedestrian Interaction model

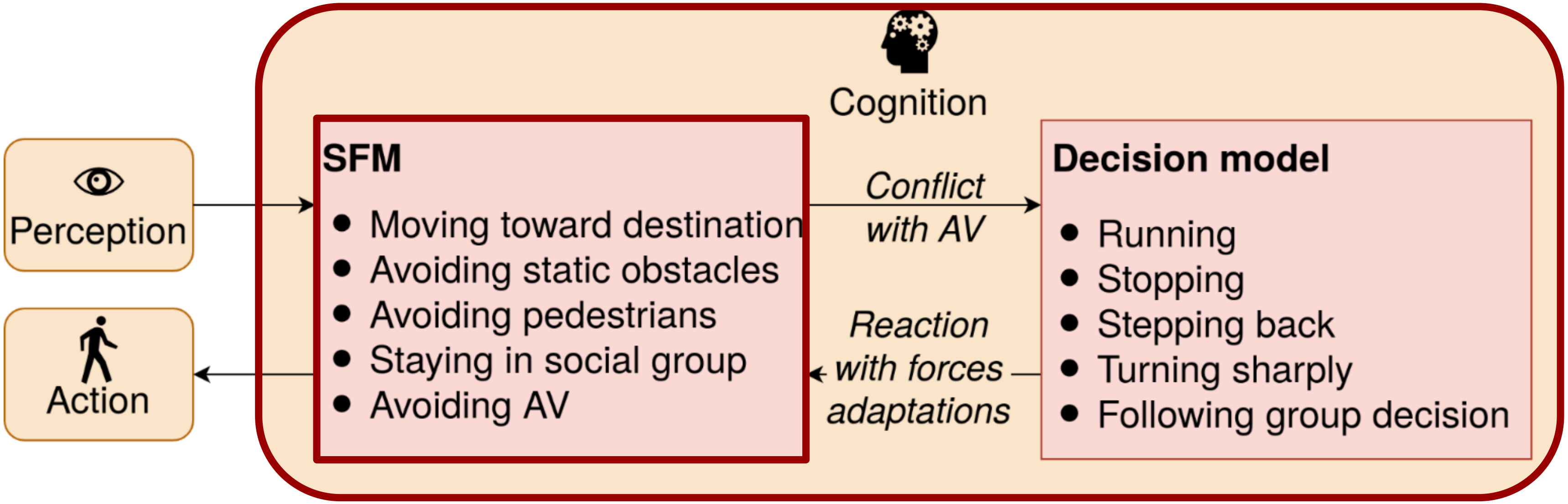


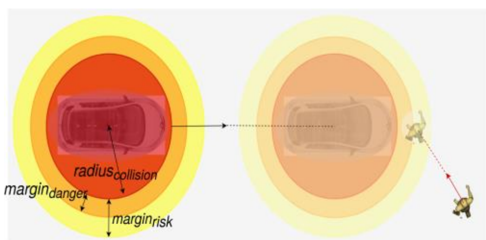
- Perception and attention model
- Adaptive personal space
- Groups modeling

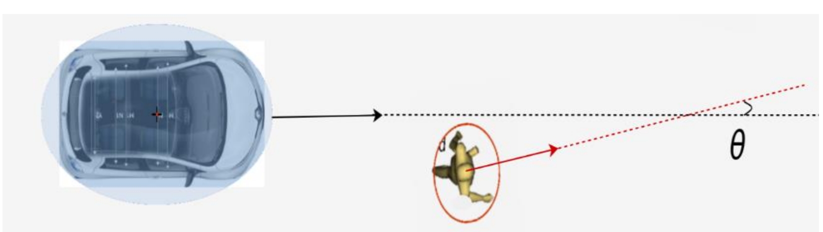


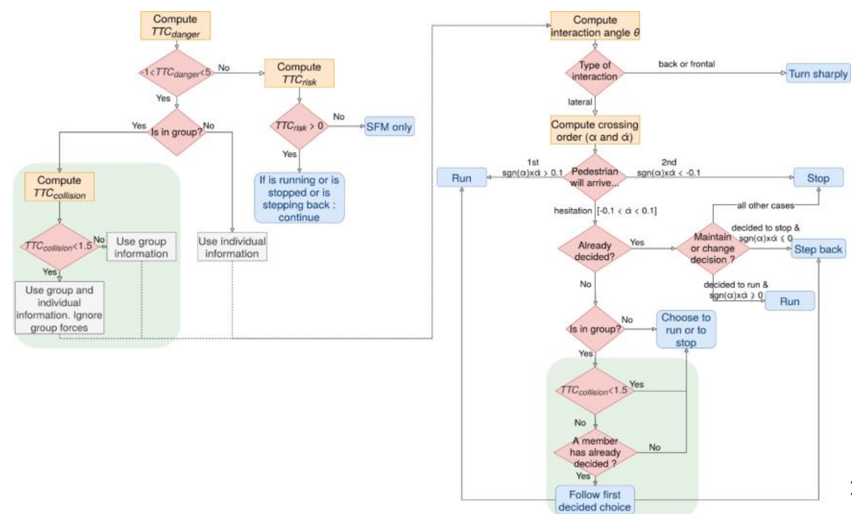


Pedestrian / AV Interaction model







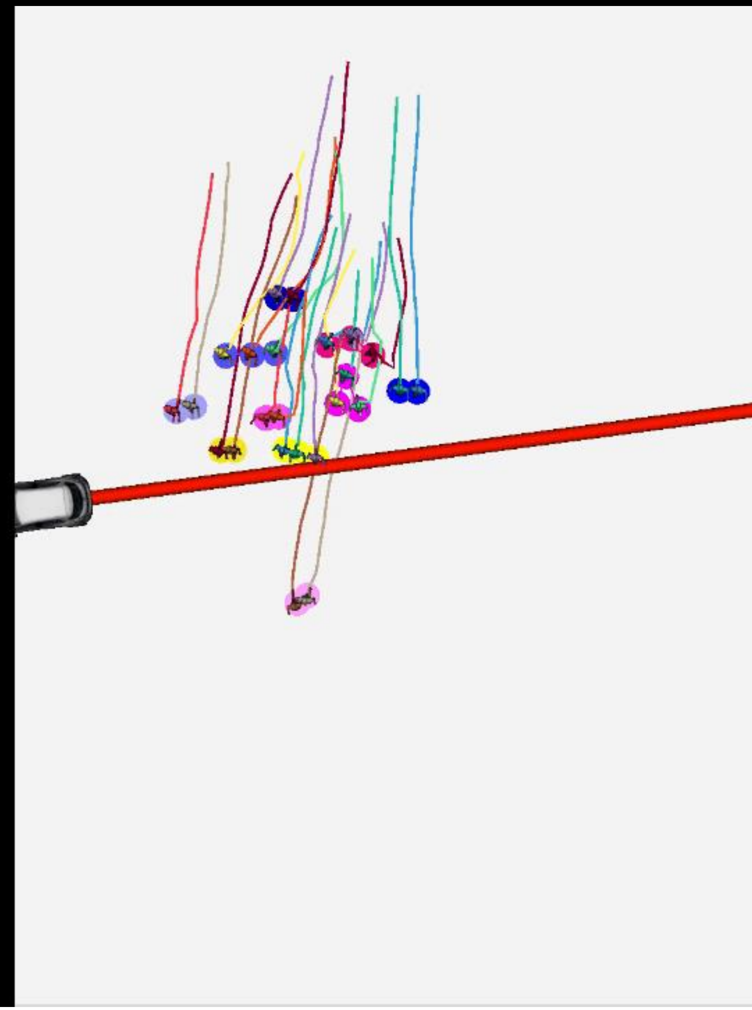


Pedestrian behaviors

In the proposed model, the members of the same group:

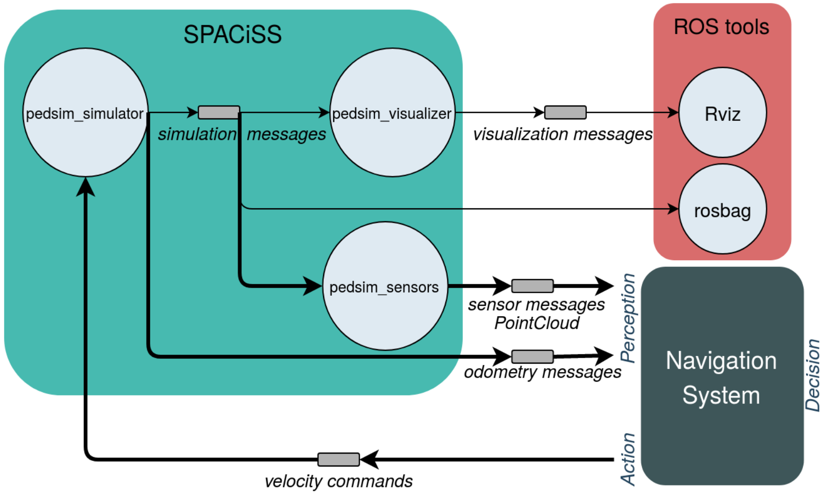
- stay together

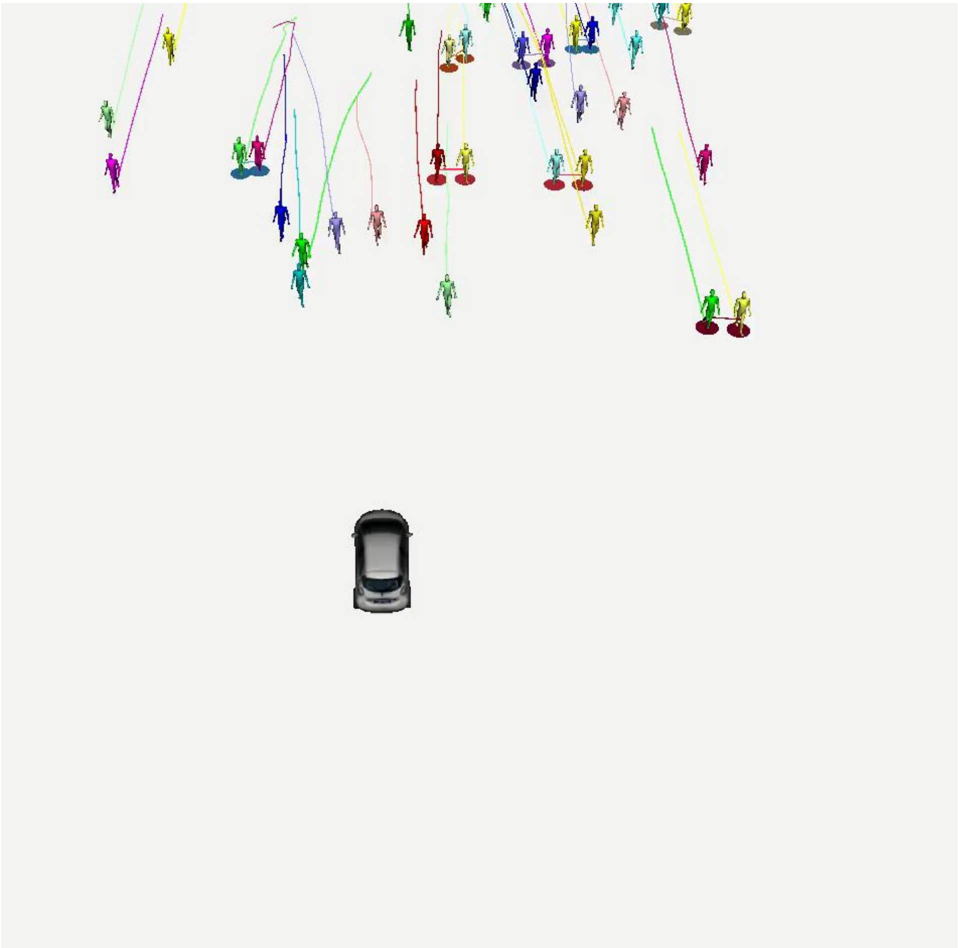
- do not collide with the autonomous vehicle



Real data taken from : Yang D., Li L., Redmill K., Özgüner Ü. Top-view Trajectories: A Pedestrian Dataset of Vehicle-Crowd Interaction from Controlled Experiments and Crowded Campus. In: 30th IEEE Intelligent Vehicles Symposium. Paris, France, 2019.

SPACiSS - Simulations





SPACiSS - Simulator for Pedestrians and an Autonomous Car in Shared Spaces

https://github.com/maprdhm/Spaciss

Focus on 3 problems

1. How to predict crowds' and pedestrians' behaviors ?
2. How to navigate crowds ?
3. How to test experimentally our algorithms ?

Proactive, cooperative and social navigation framework

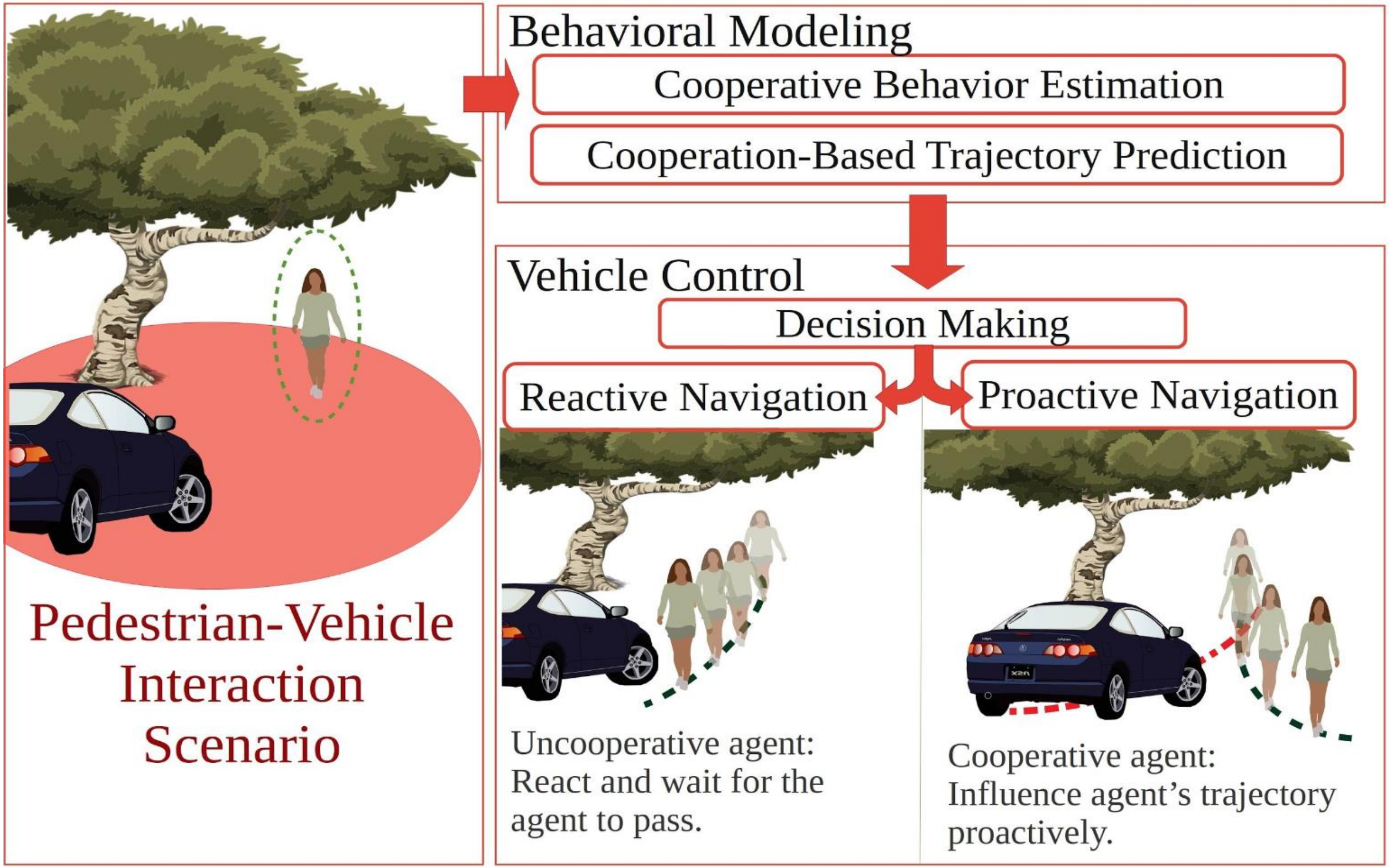
M. Kabtoul, A. Spalanzani, P. Martinet.

Proactive And Smooth Maneuvering For Navigation Around Pedestrians, International Conference on Robotics and Automation (ICRA), Philadelphia, United States, May 2022.

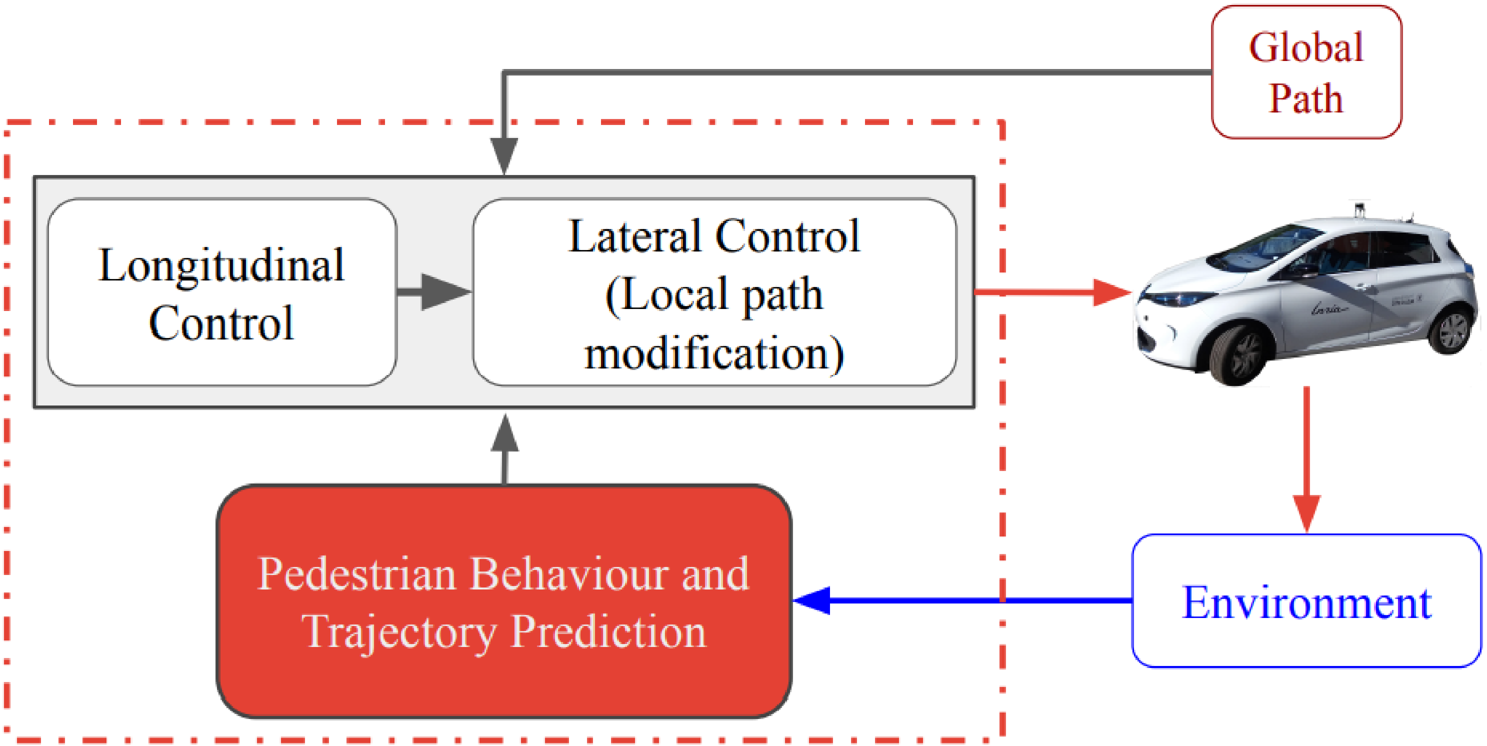
M. Kabtoul, A. Spalanzani, and P. Martinet.

Towards Proactive Navigation: A Pedestrian-Vehicle Cooperation Based Behavioral Model. In ICRA 2020 - International Conference on Robotics and Automation, Paris, France, May 2020.

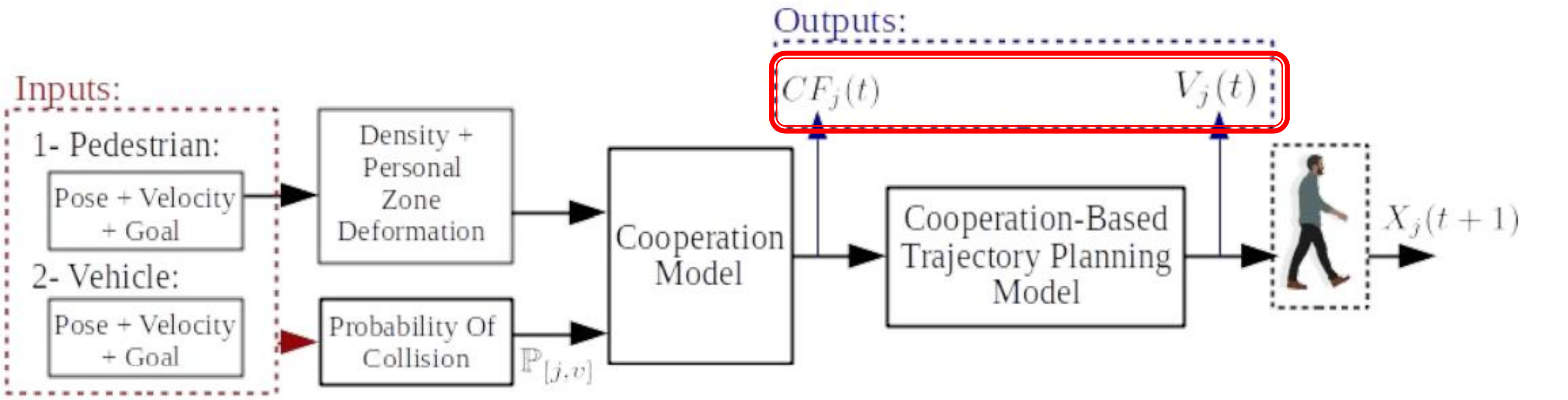
Framework

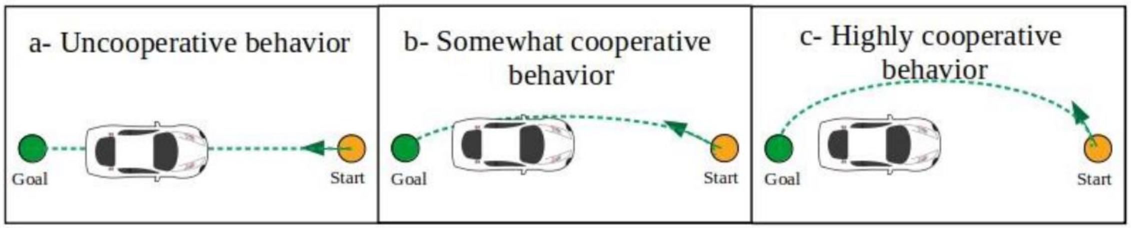

Behavioral Modeling
Cooperative Behavior Estimation
Cooperation-Based Trajectory Prediction
Vehicle Control
Decision Making
Reactive Navigation
Proactive Navigation
Pedestrian-Vehicle Interaction Scenario
Uncooperative agent: React and wait for the agent to pass.
Cooperative agent: Influence agent's trajectory proactively.

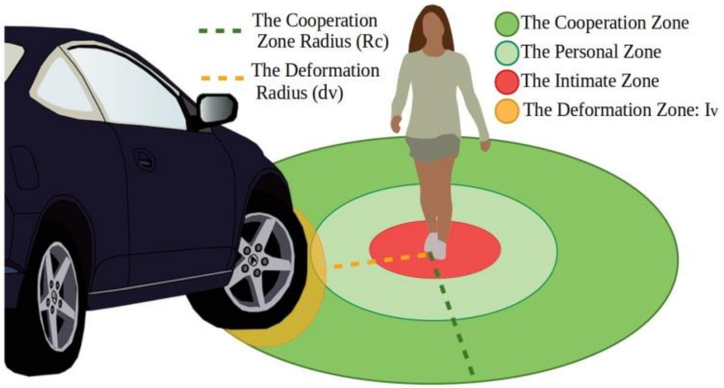
Proactive navigation



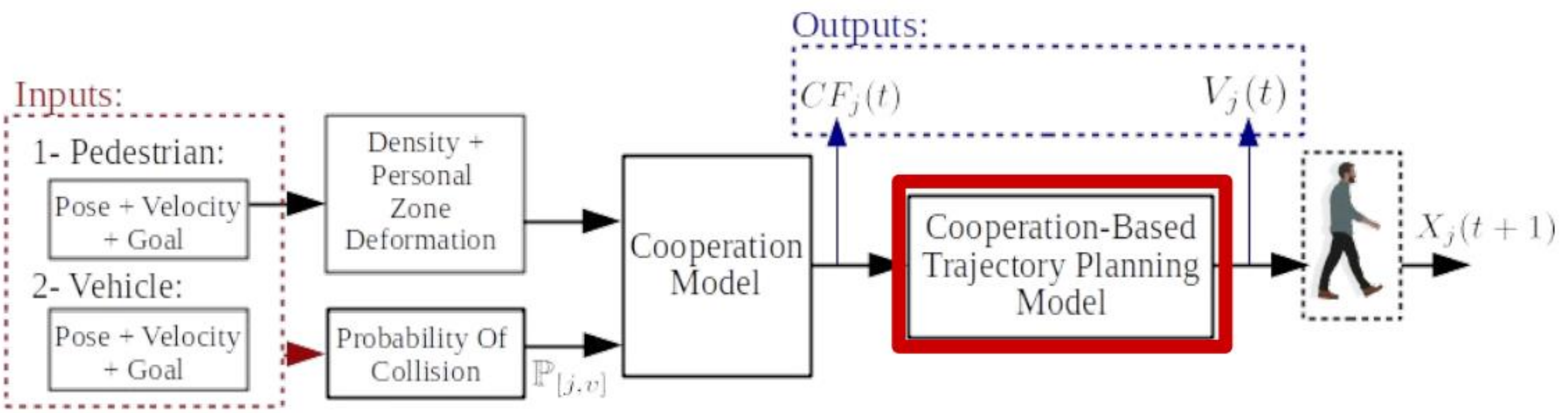
Proposed Pedestrian Model







Proposed Pedestrian Model



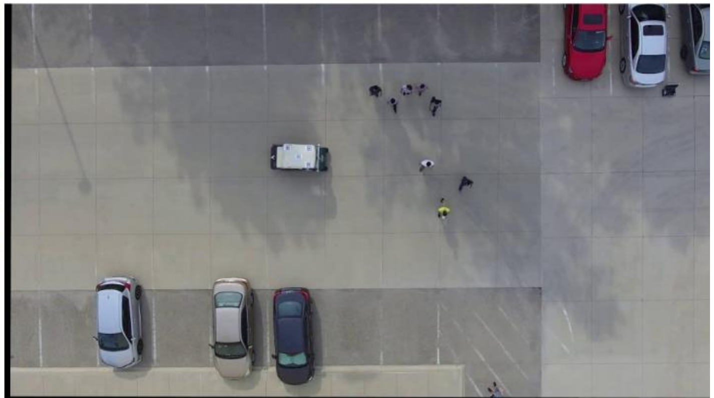
Cooperation-Based Behavioural Model: **Input parameters**

$$P_m(t) = \begin{bmatrix} CF_a(t).I_V(t) \\ CF_a(t).\Theta_V(t) \\ [1 - CF_a(t)].\Theta^a_{goal}(t) \\ [1 - CF_a(t)].D^a_{goal}(t) \\ \dot{CF}_a(t) \\ I^a_P(t) \\ \theta^a_P(t) \end{bmatrix}$$

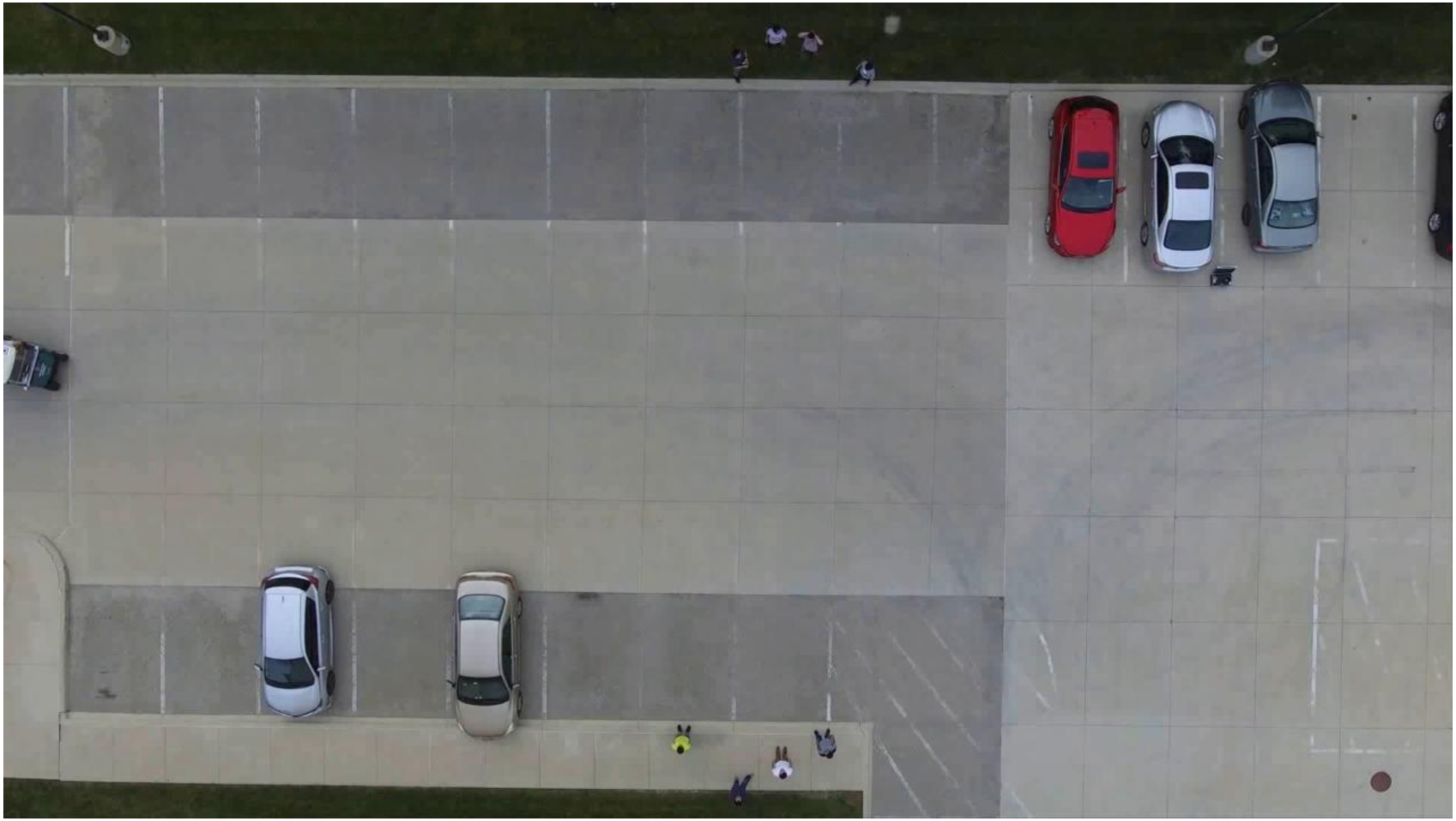
Destination Influence

Pedestrian model parameters estimation

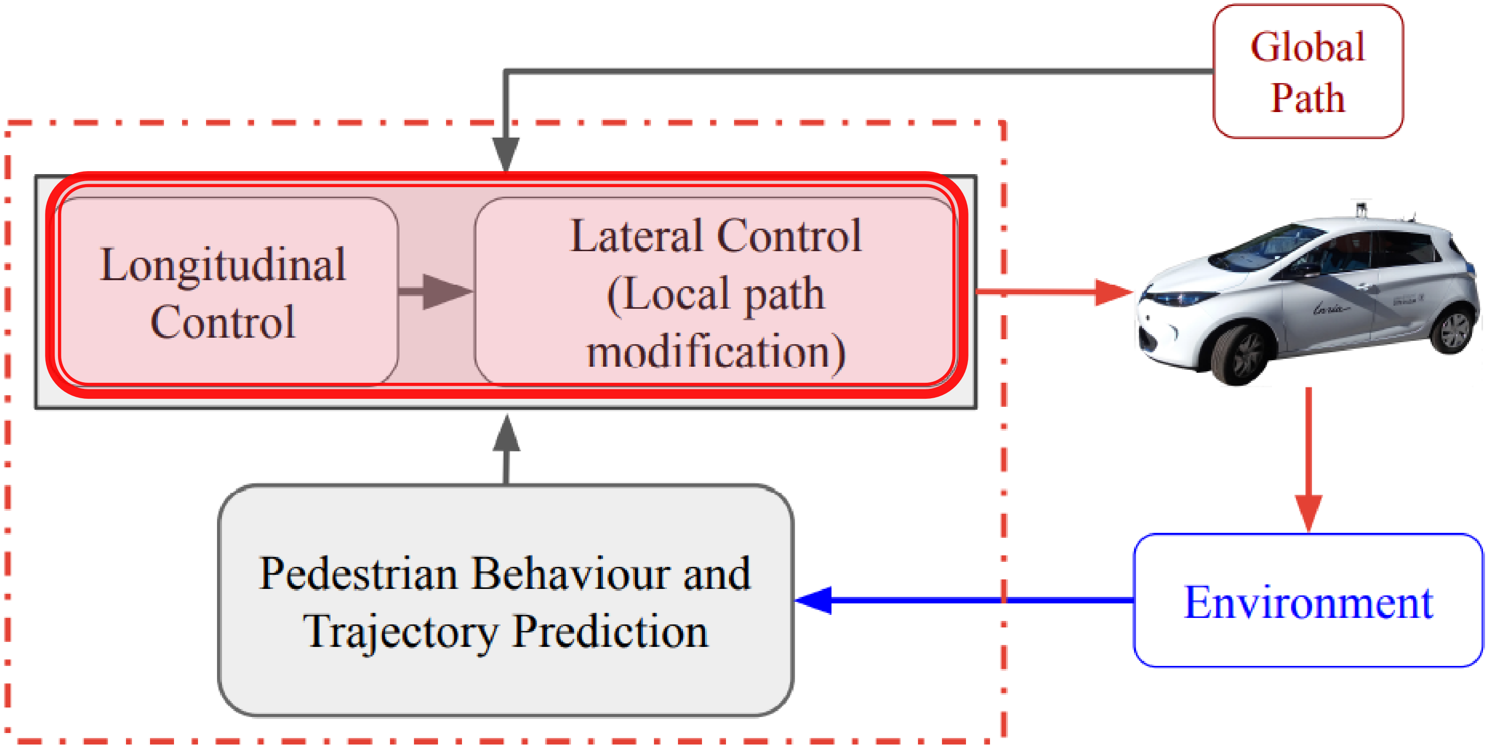
- Using 2 pedestrian-vehicle interaction datasets
- Manual annotation for the agent's cooperation
- Cooperation model found while
  - Minimizing the error in the mean values of CF
  - Maximizing the cross-correlation between similarly annotated agents in one simulation
- Trajectory Model obtained using the pedestrian trajectories as the ground-truth



Cooperation model : results



Proactive navigation



The Proactive Navigation Policy

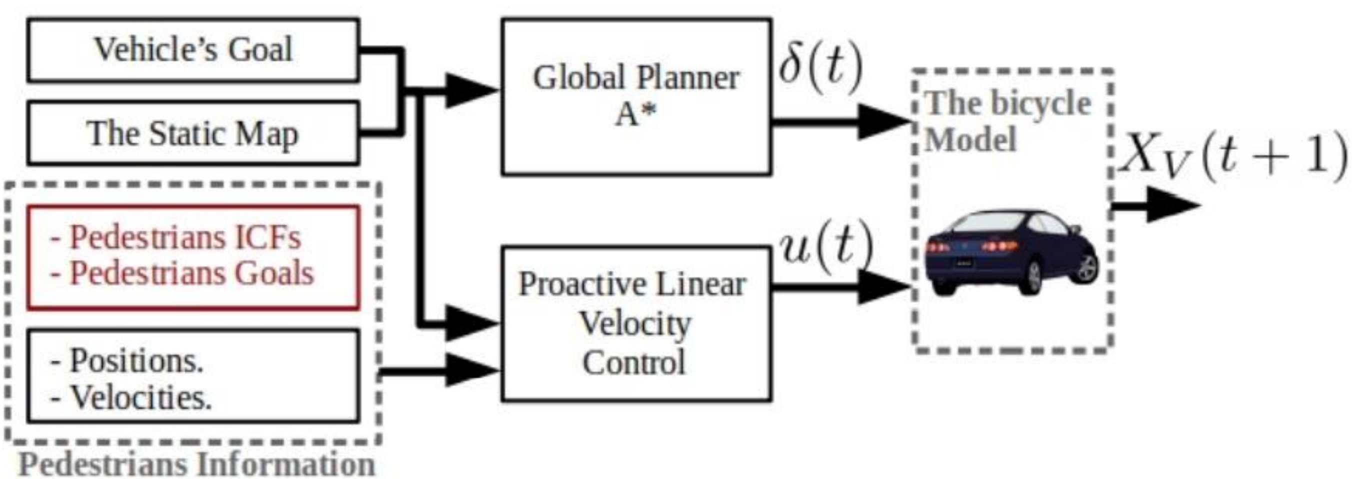
- Find the longitudinal control that
  - maximizes the pedestrians cooperation
  - while ensuring the safety constraints

$$J = \frac{1}{M} \sum_{j=1}^{M} \alpha_1 \left(1 - CF_j(t)\right) - \alpha_2 SI_j(t)$$

Number of pedestrians in the influence zone

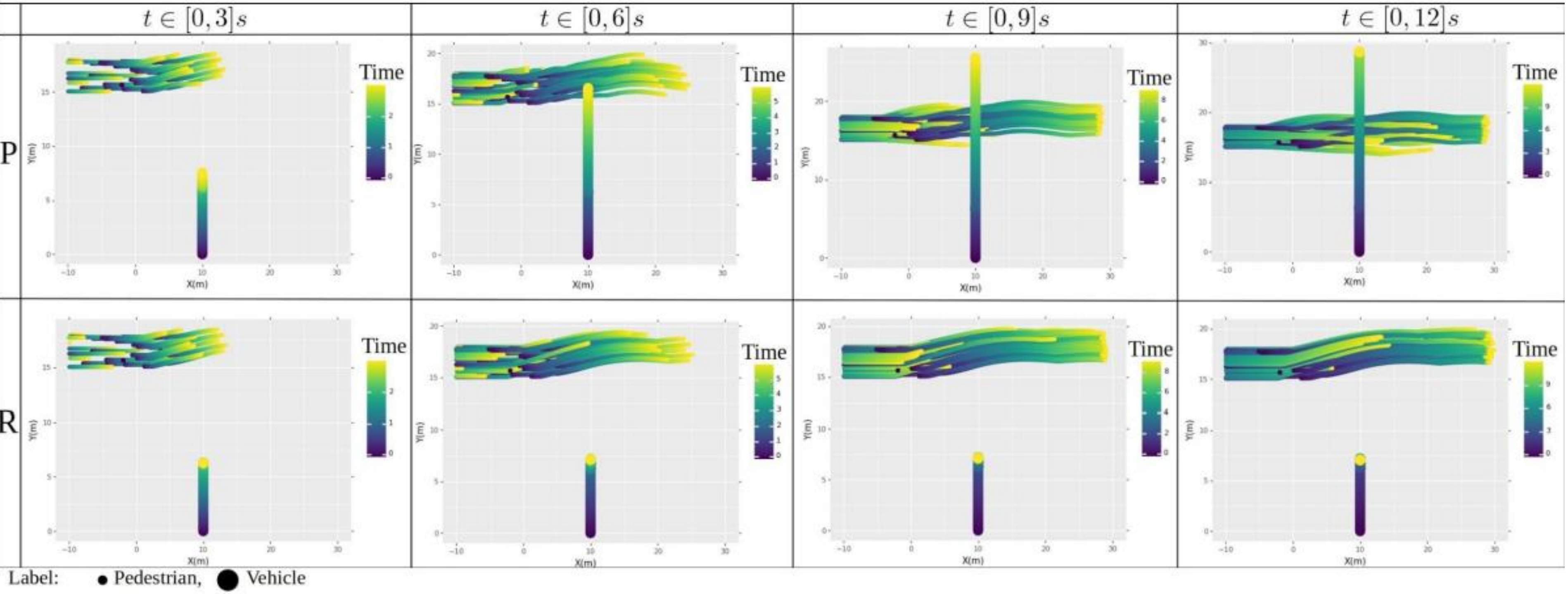
The Cooperation Factor

The safety Index (Distance Based)

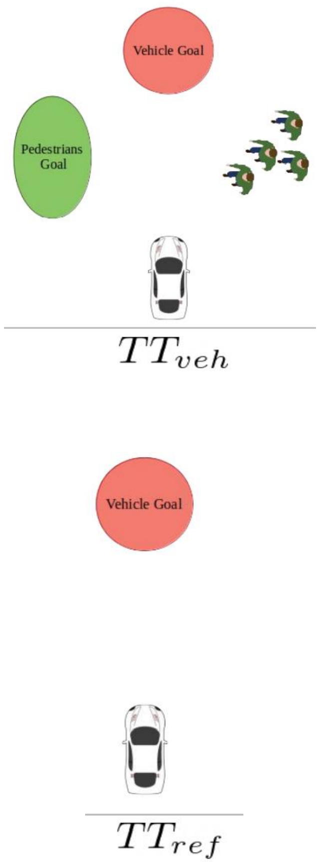


Proactive vs Reactive

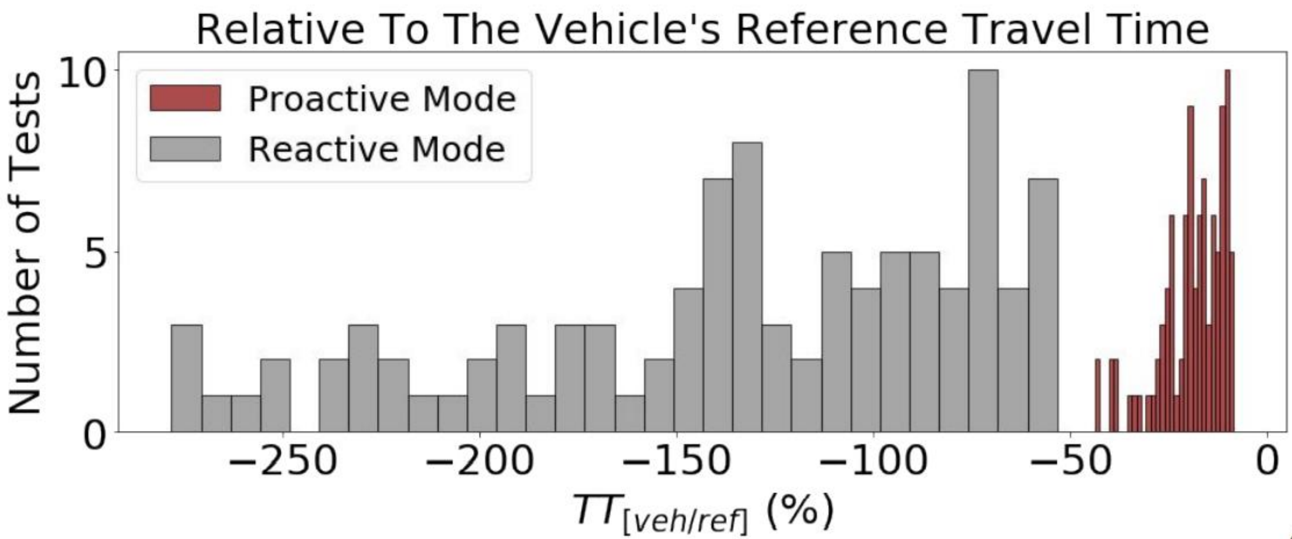
- 66 pedestrians with various CF



Quantitative results



100 proactive tests, 100 reactive tests simulating a mixed crowd.

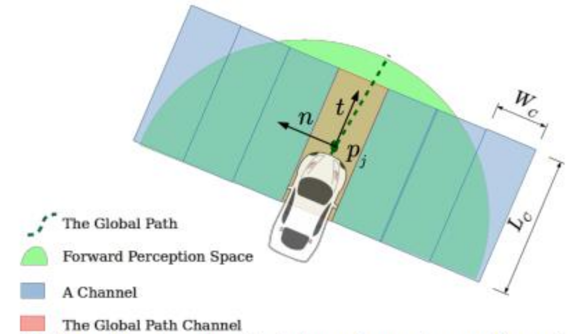


Benefits of the proactivity

- Results showed that even this one-degree of proactive control improves the navigation performance significantly.
- The main advantages of the method include:
  - avoiding the freezing robot problem in dense scenarios,
  - major efficiency gains in terms of the travel time,
  - navigating socially by incorporating the pedestrian cooperation behavioral model and maintaining pedestrian safety.

Lateral control

- Find the lateral control that minimizes the deviation from the global path, while maintaining pedestrian comfort.
  - Dividing the space into channels
  - Computing the cost of each channel



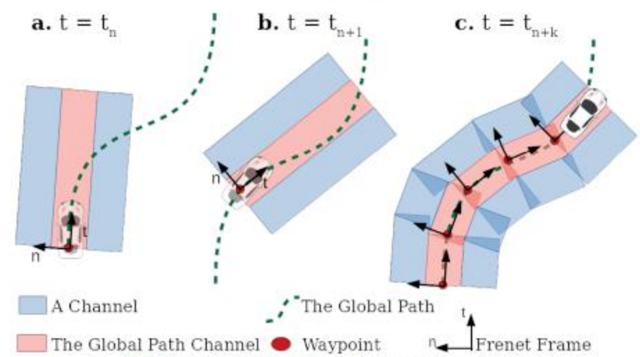
(a) The resulting channels within the forward perception range for a path waypoint p_j

$$w_C(t) = \beta_0 \left[w_{fuzzy}(t) + \beta_1 w_{local}(t) + \beta_2 w_{global(t)} \right]$$

The cost of disturbing the pedestrians in the selected channel

The cost of going from the current location to the goal channel

The cost of going back to the global path from the selected channel



(b) The resulting channels at different time instances

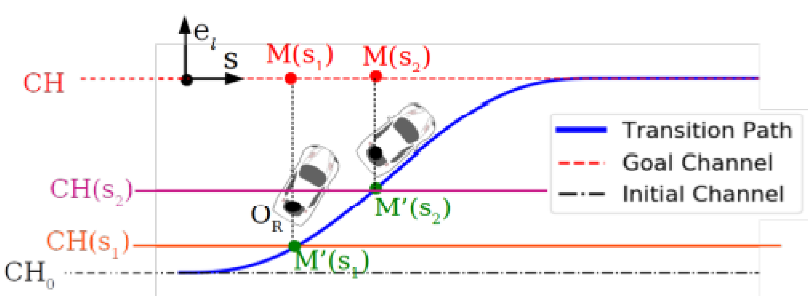
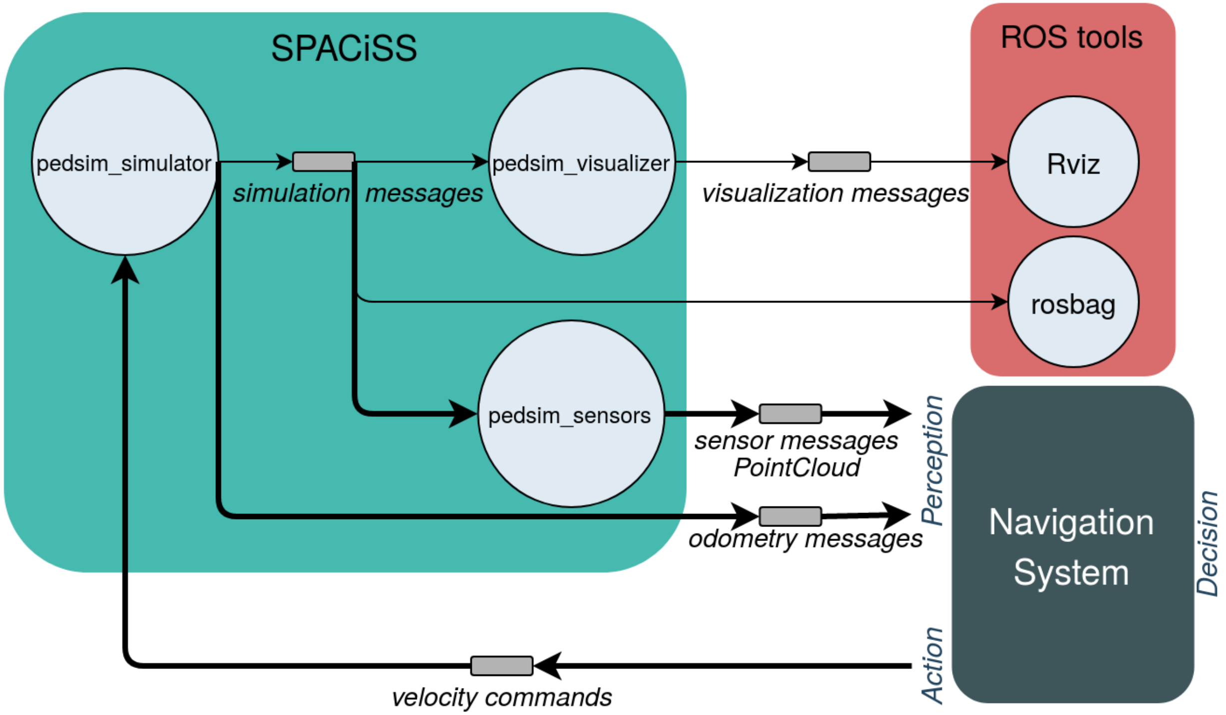


Fig. 5.9.: Goal channel center shifting using the Quintic transition path

Combining crowds simulation and proactive navigation



Simulation results

Focus on 3 problems

1. How to predict crowds' and pedestrians' behaviors ?
2. How to navigate crowds ?
3. **How to test experimentally our algorithms?**

Validation using virtual pedestrians

Thomas Genevois, Jean-Baptiste Horel, Alessandro Renzaglia, Christian Laugier.

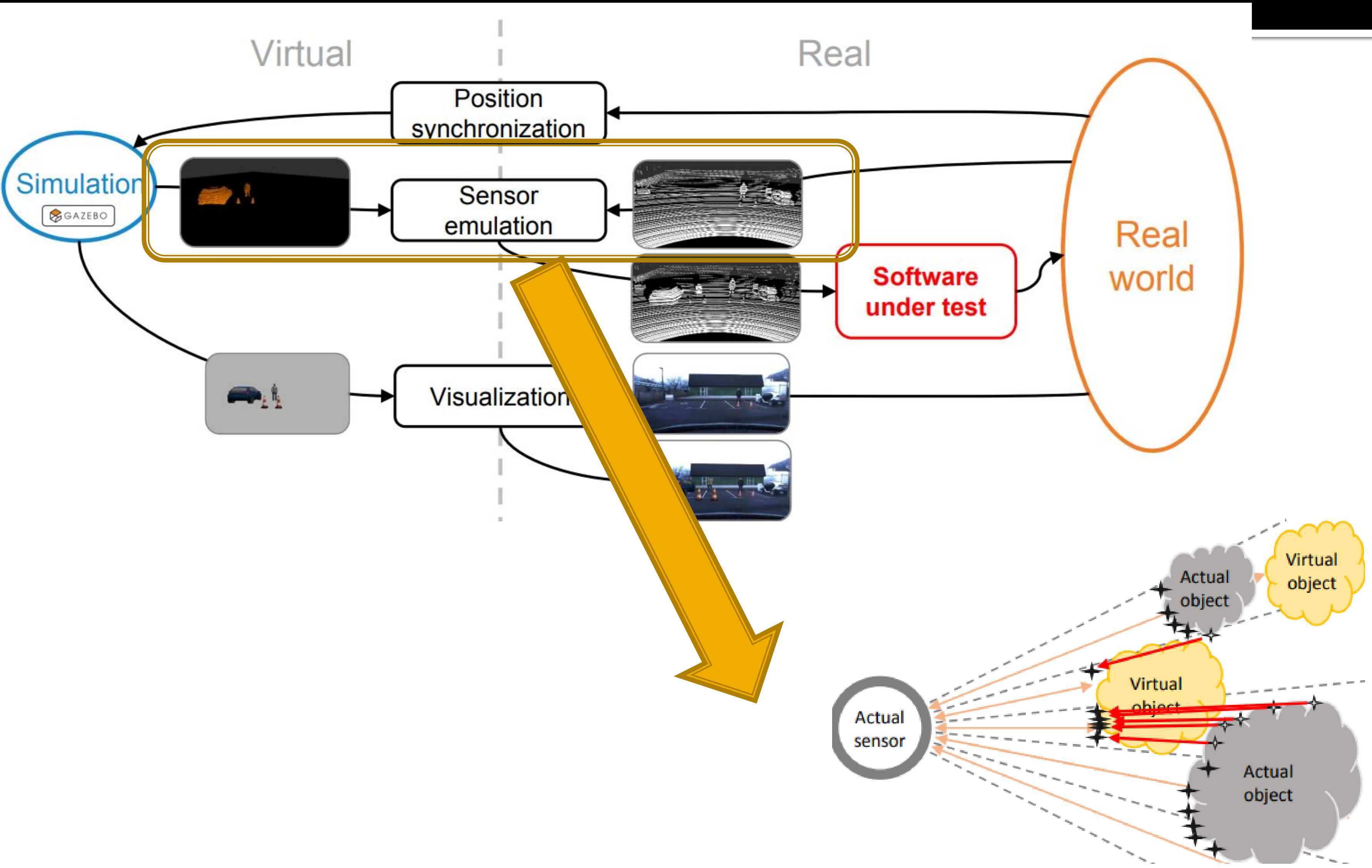
Augmented Reality on LiDAR data: Going beyond Vehicle-in-the-Loop for Automotive Software Validation. IV 2022 - 33rd IEEE Intelligent Vehicles Symposium IV, Jun 2022, Aachen, Germany. Best paper award.

Motivation : Validate complex AI-based automotive software

- Simulation based testing : flexible, fast, cheap, safe BUT not entirely realistic
- Real world testing : realistic BUT complex, time consuming, costly and dangerous

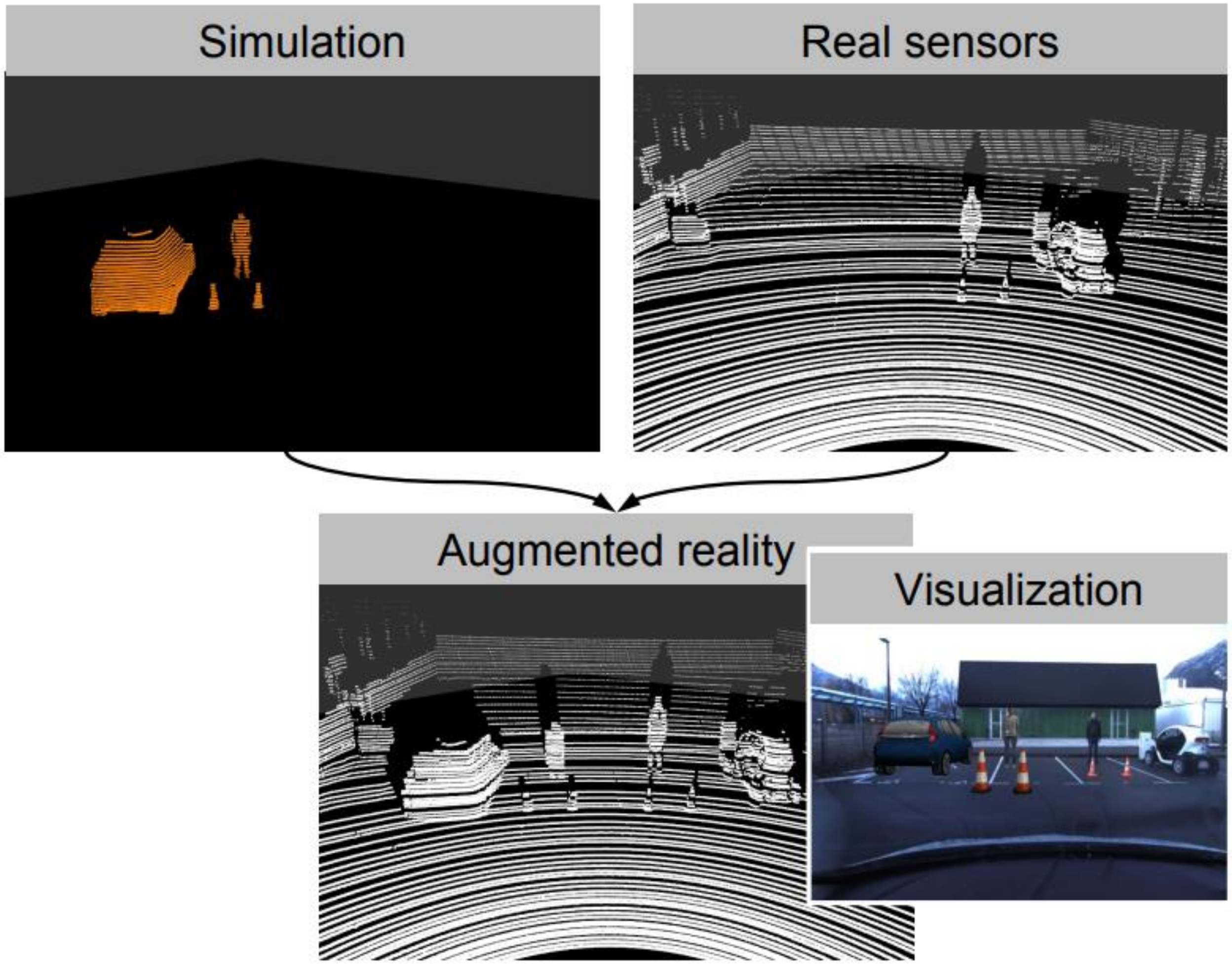
➢ Augmented reality to replace sensor outputs and test seamlessly all software from perception to control

Framework

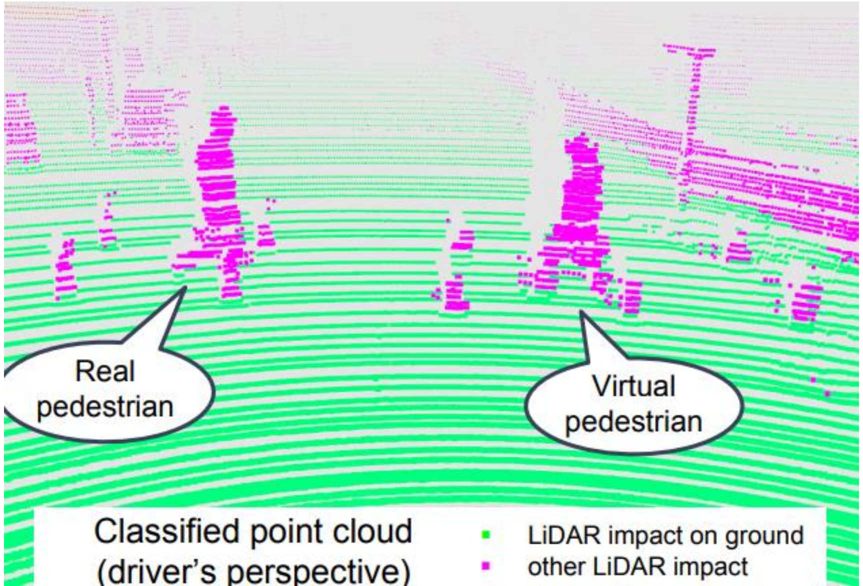


Virtual
Real
Position synchronization
Simulation
GAZEBO
Sensor emulation
Software under test
Real world
Visualization
Actual object
Virtual object
Virtual object
Actual sensor
Actual object

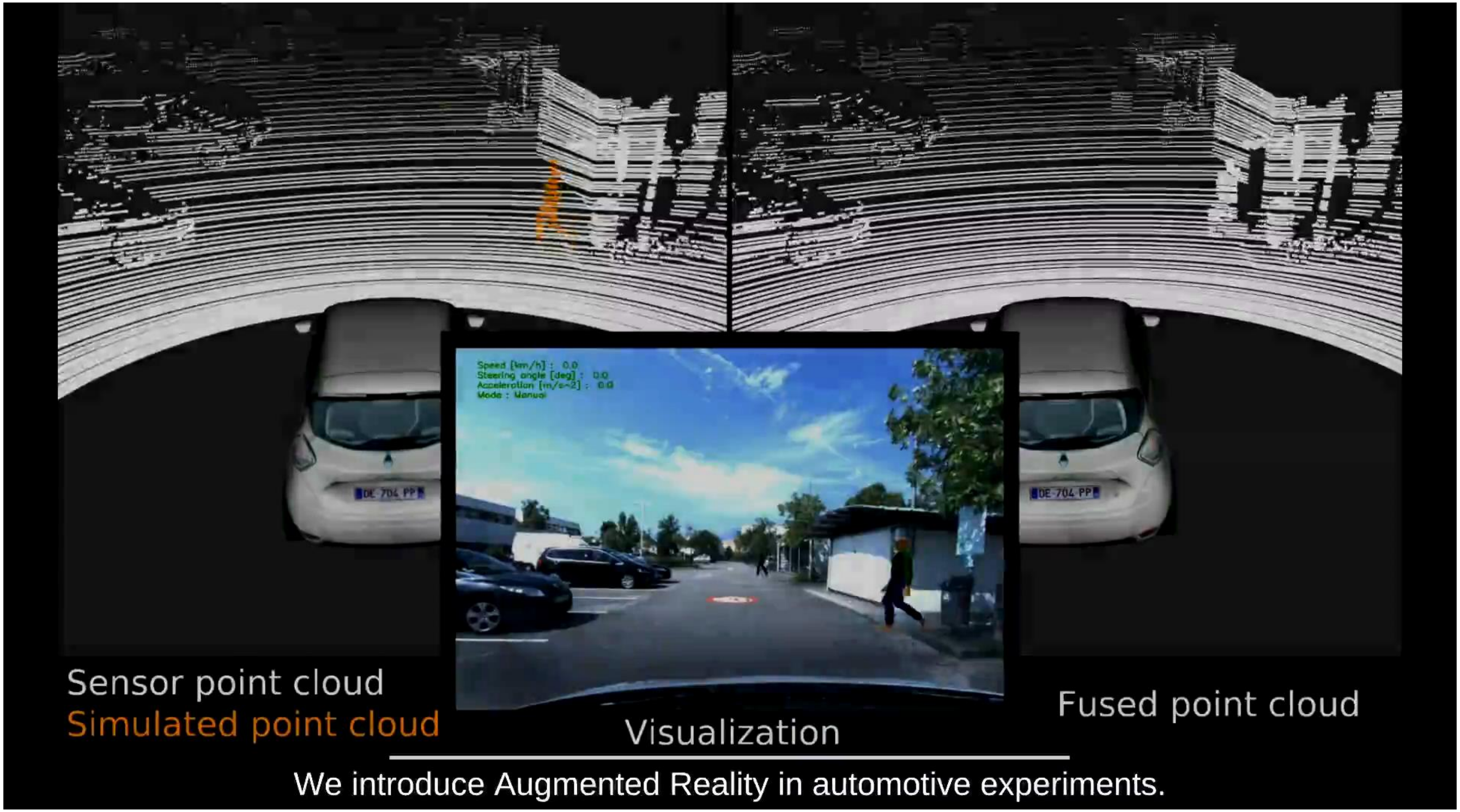
Fusing simulated data with real data



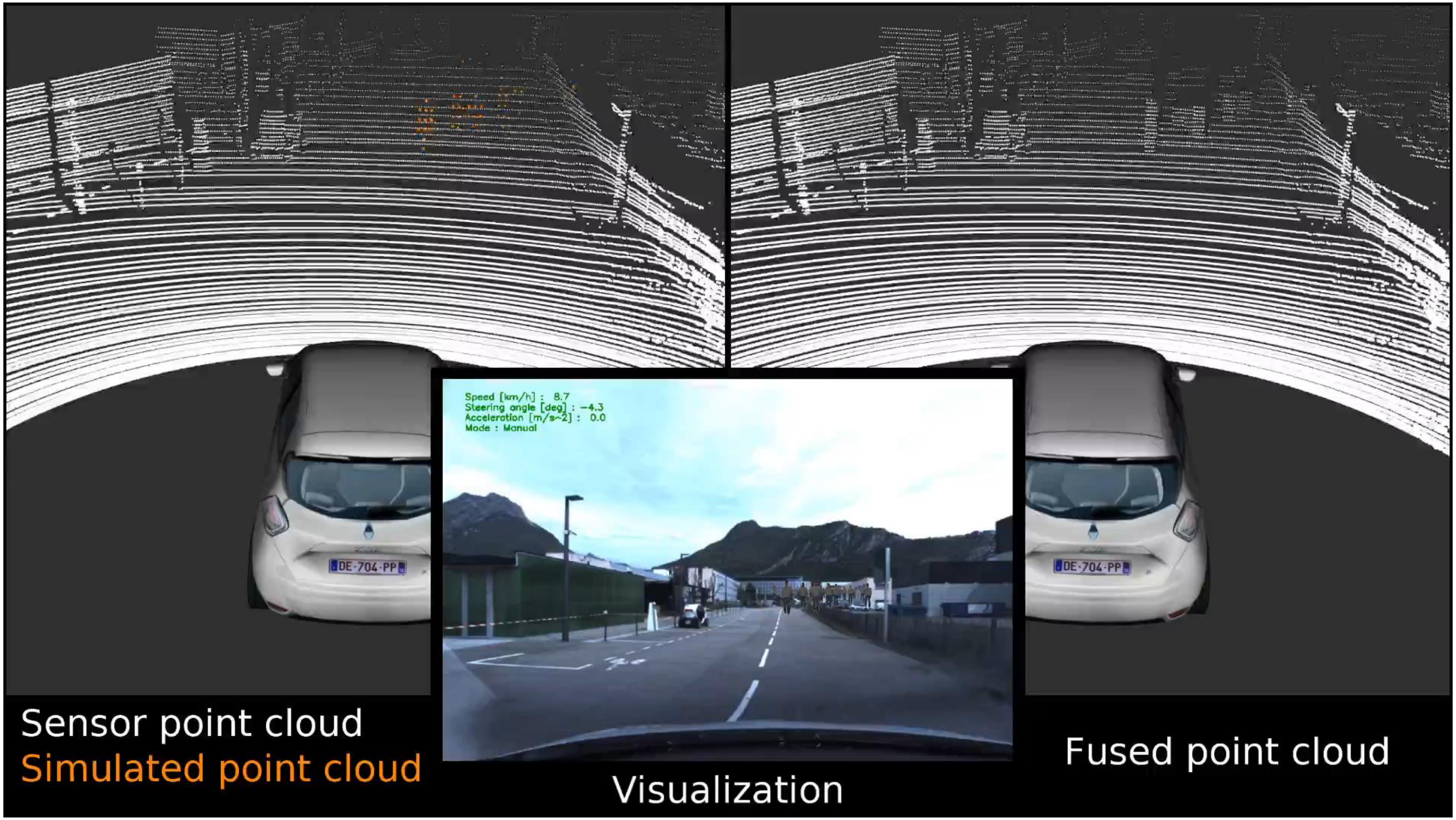
- virtual data introduced in the augmented reality is similar to real data.
- The software under test will behave similarly in real, virtual or hybrid scenes.



Qualitative results

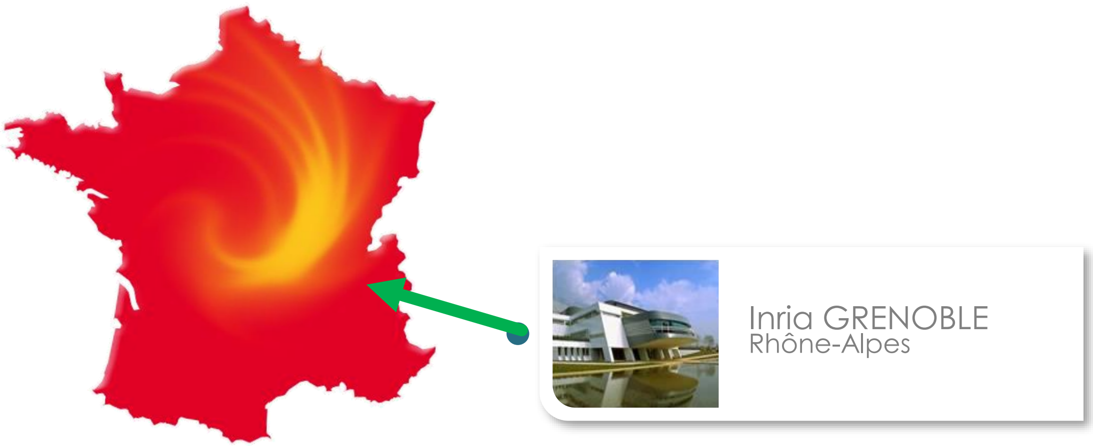


Navigating crowds



- Interested in a PhD, Postdoc or engineer position ?

- anne.spalanzani@inria.fr



publications

M. Prédhumeau, L. Mancheva, J. Dugdale, A. Spalanzani, Agent-Based Modeling for Predicting Pedestrian Trajectories Around an Autonomous Vehicle, Journal of Artificial Intelligence Research (JAIR). 2022.

M. Prédhumeau, L. Mancheva, J. Dugdale, A. Spalanzani. An Agent-Based Model to Predict Pedestrians Trajectories with an Autonomous Vehicle in Shared Spaces, AAMAS 2021 - 20th International Conference on Autonomous Agents and Multiagent Systems, International Foundation for Autonomous Agents and Multiagent Systems (IFAAMAS), May 2021. Best Student paper Award.

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