Autonomous cars navigation on roads opened to public traffic: How can infrastructure-based systems help?

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Autonomous cars navigation

Cars don’t drive in opened spaces

The navigation space is constrained
and there are interactions between cars.

Main question addressed in this talk

How can a car see far enough with a reasonable set of embedded sensors?

Outline

1. Level of autonomy of autonomous vehicles
2. Key elements for cooperative autonomous navigation
3. Cooperative navigation example: vehicle2vehicle communication
    1. Intersection crossing
    2. Platooning
4. Infrastructure-aided Systems
    1. Lane Merging
    2. Roundabout crossing
5. Conclusion and perspectives

Level of autonomy of autonomous vehicles

Part 1

Autonomous Vehicles: Trends

- **Driverless vehicles**
  - New Mobility Services
  - Shuttles and Robot taxis

- **Autonomous cars**
  - Traditional customers
  - Valet vehicle
  - Traffic Jam Assist

→ automotive robotics Converge ←

Robot vehicle

Ability to function independently of a human operator in any context

Operational autonomy

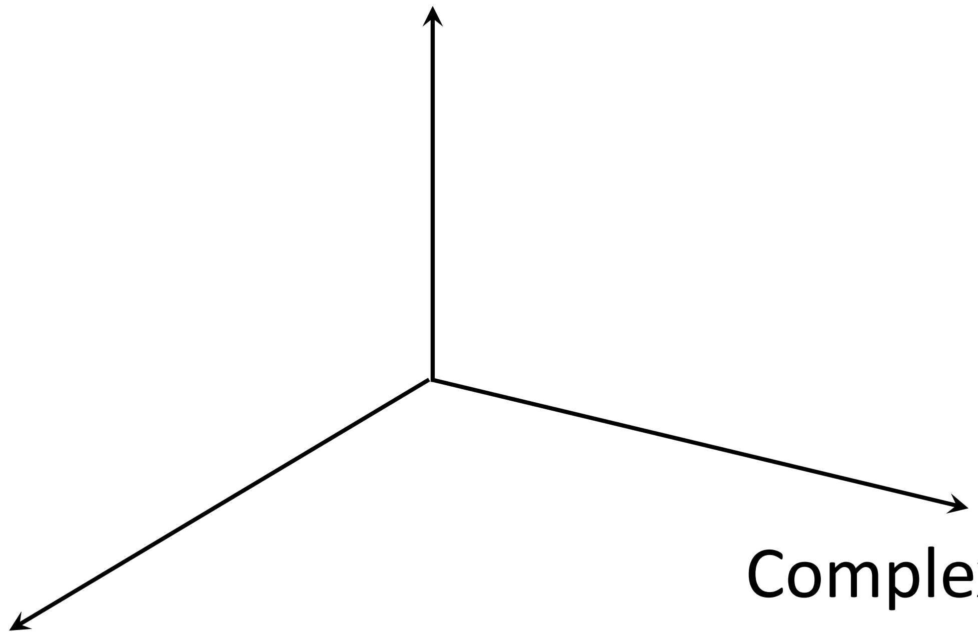
- Feedback mechanisms to control behavior to follow a predefined trajectory, while rejecting disturbances
- No need for user monitoring

Decisional autonomy

- The machine has the ability to understand and take safe decisions despite the uncertainties of perception and localization as well as incomplete information about the environment

The three roboticist axes

Autonomy ability
Independence with respect to human

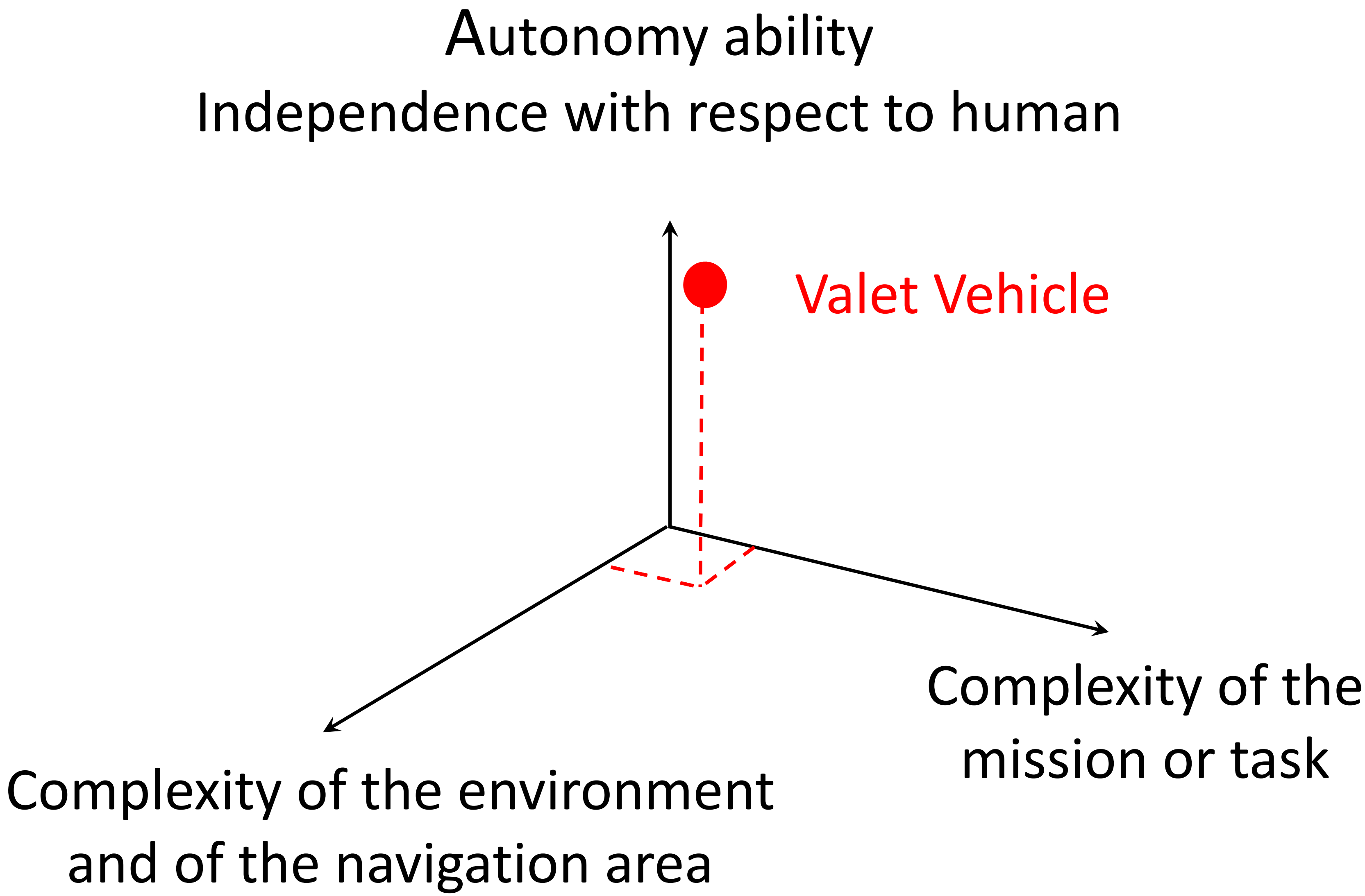


Complexity of the mission or task

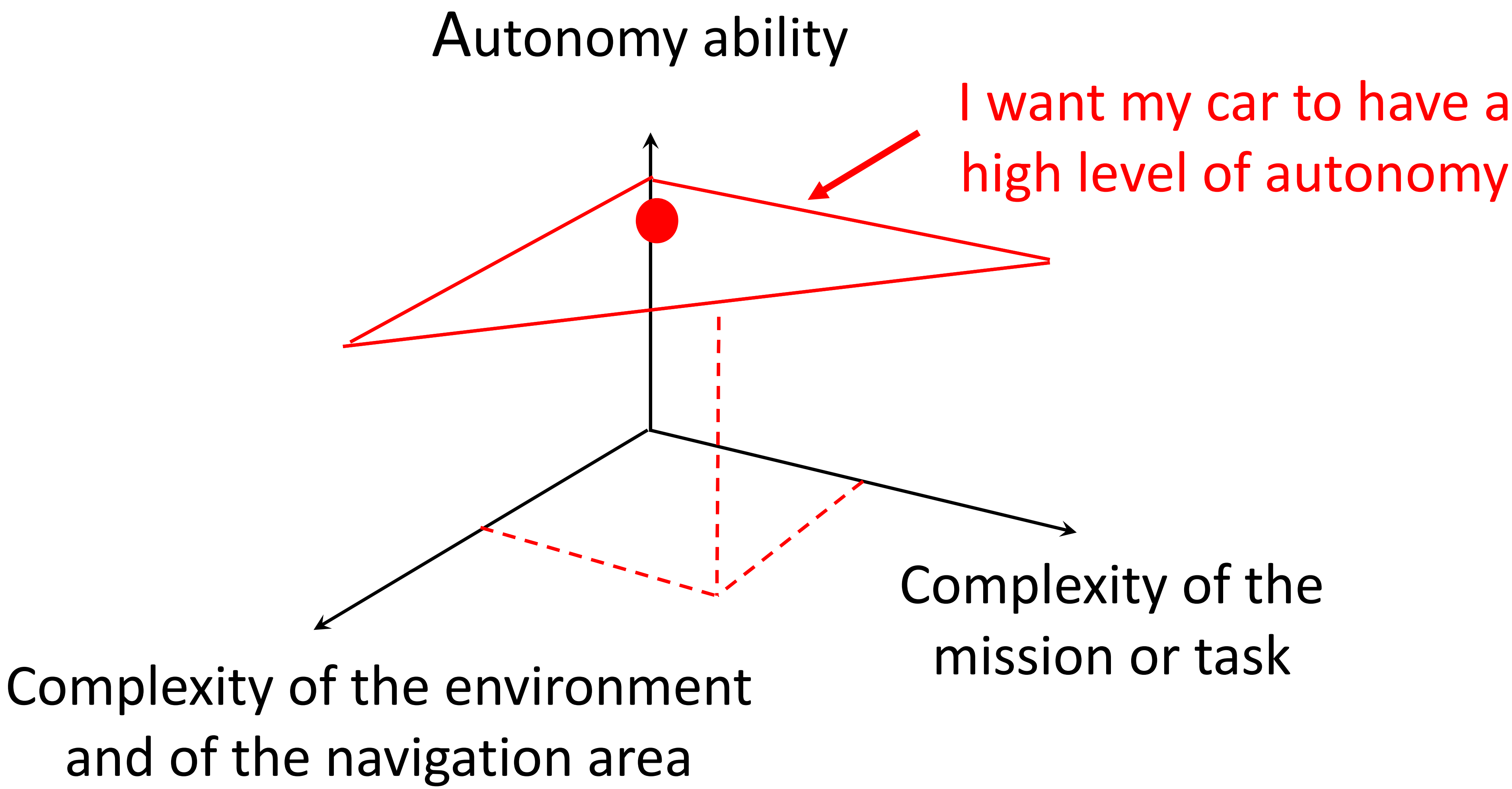
Complexity of the environment and of the navigation area

Example of autonomous car: Valet Vehicle (PAMU Renault)

The valet vehicle of the roboticist axes



Cooperation as a mean to increase abilities of autonomous cars



Key elements for cooperative autonomous navigation

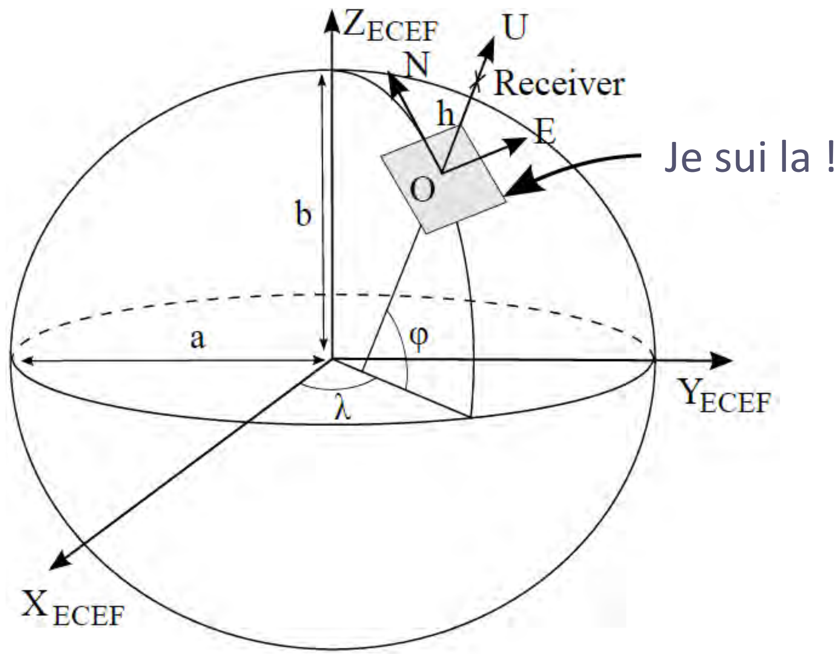
Part 2

Sources of information for autonomous navigation

Localization and perception

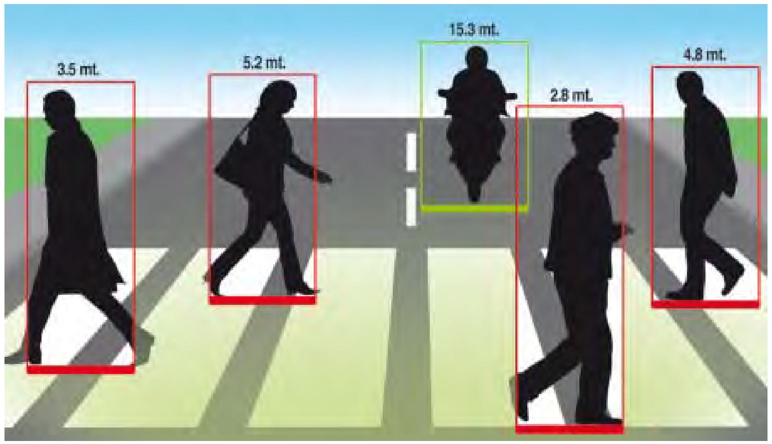
Localization system

— allows the vehicle to position itself spatially, absolutely or relatively, in its evolution environment



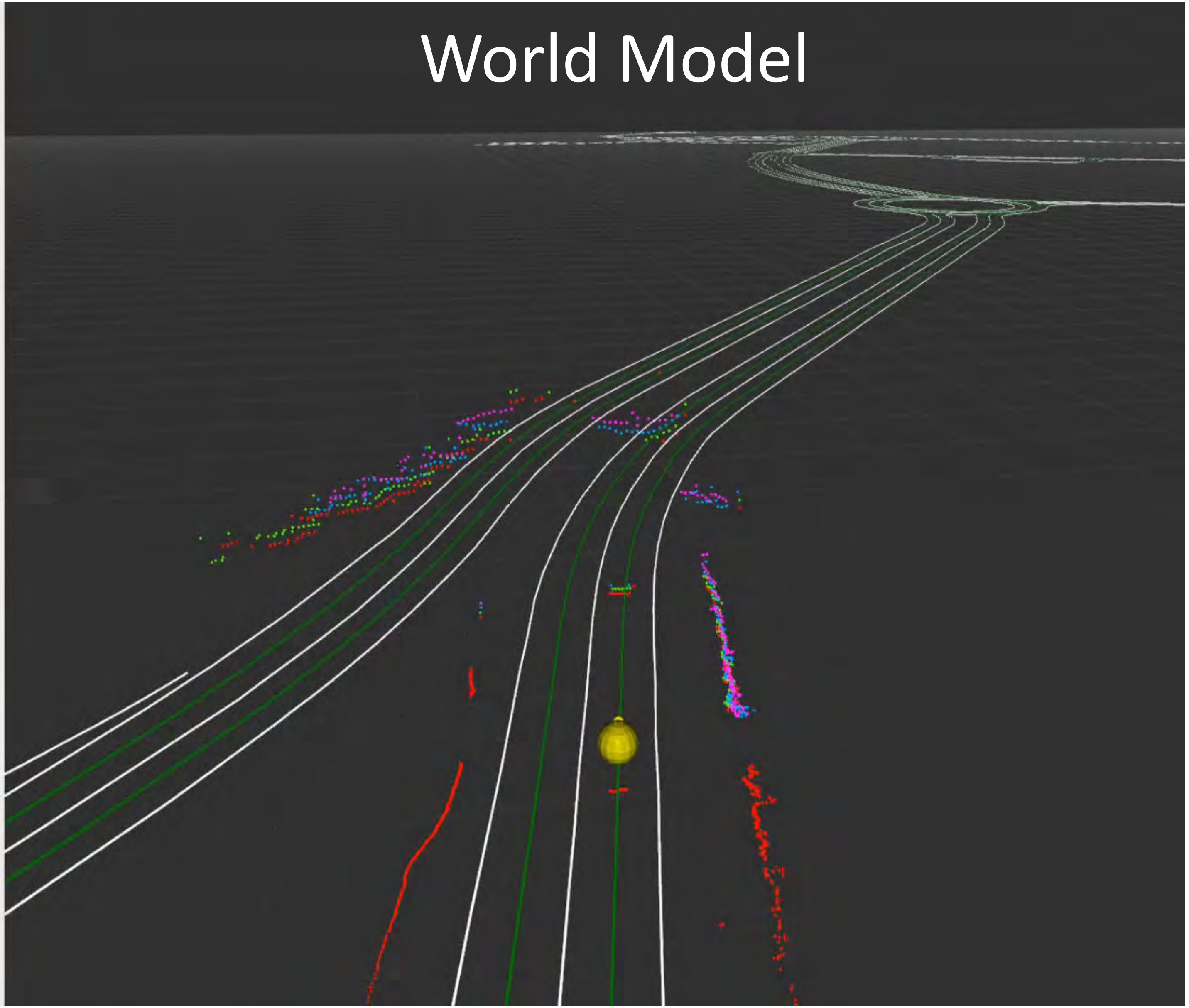
Perception system

— equips the vehicle with understanding and prediction capabilities of its immediate environment. From the sources of information available, the vehicle builds a representation of the environment that allows it to navigate



Localization and perception

Real world



Wireless communication for cooperative autonomous navigation

Wireless Networks for data exchange

Vehicular ad hoc networks (VANETs) allow an augmented perception of the dynamic environment by using wireless communications:

- Vehicle-to-Vehicle (V2V)
- Infrastructure to Vehicle (I2V)

Some typical messages (ETSI standard)

- CAM (Cooperative Awareness Message)
- DENM (Distributed Environment Notification Message)
- CPS (Collective Perception Service - ETSI TR 103 562 under preparation)

Features

- short range radio technologies (Wifi mode), 5.9 GHz band (802.11p)
- Broadcast frequency: 1-10 Hz

CAM Message (V2V)

Vehicle information

- ID
- Vehicle type (car, truck, etc.)
- Vehicle role (emergency, roadwork)
- Vehicle size (length and width)

Time Stamp

- UTC time (in ms, ~1 minute ambiguity)

Pose

- Position (geo) + 95% confidence bound
- Heading

Kinematics

- Speed, drive direction, yaw rate
- Acceleration

DENM Message (I2V)

Sent by Road Side Units (RSU)

Data :

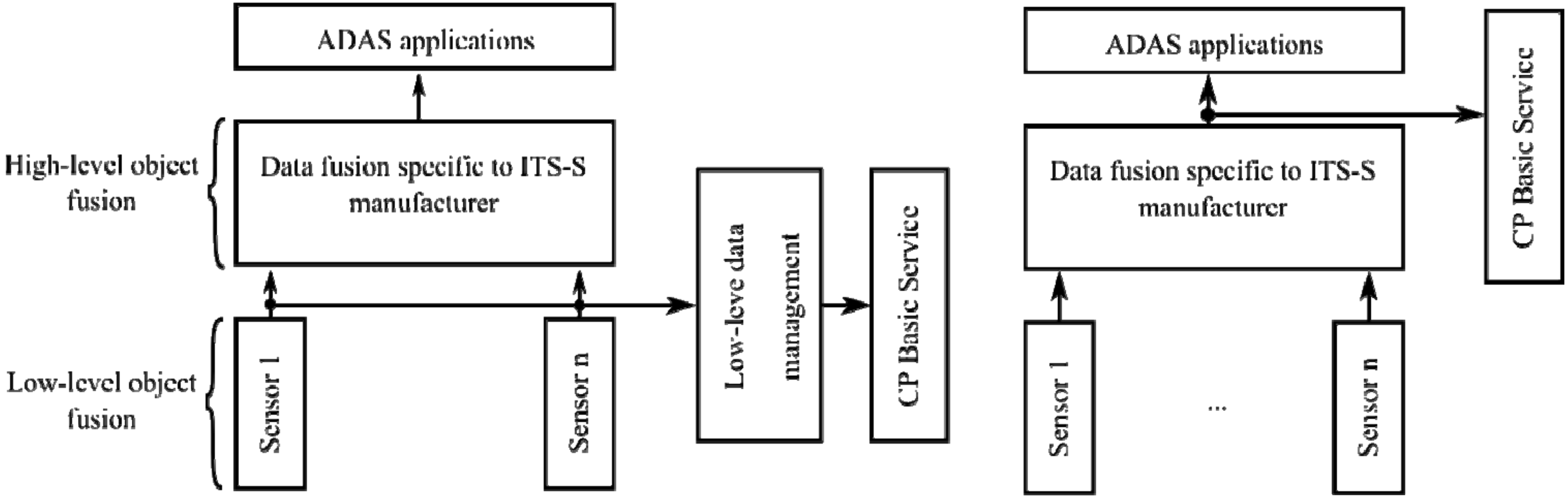
- Station type
- Time Stamp
- Event type
  - Roadworks,
  - Stationary vehicle,
  - Emergency vehicle approaching,
  - Dangerous Situation, etc.
- Lane position
- Lane is closed or not

CPS Message (I2V)

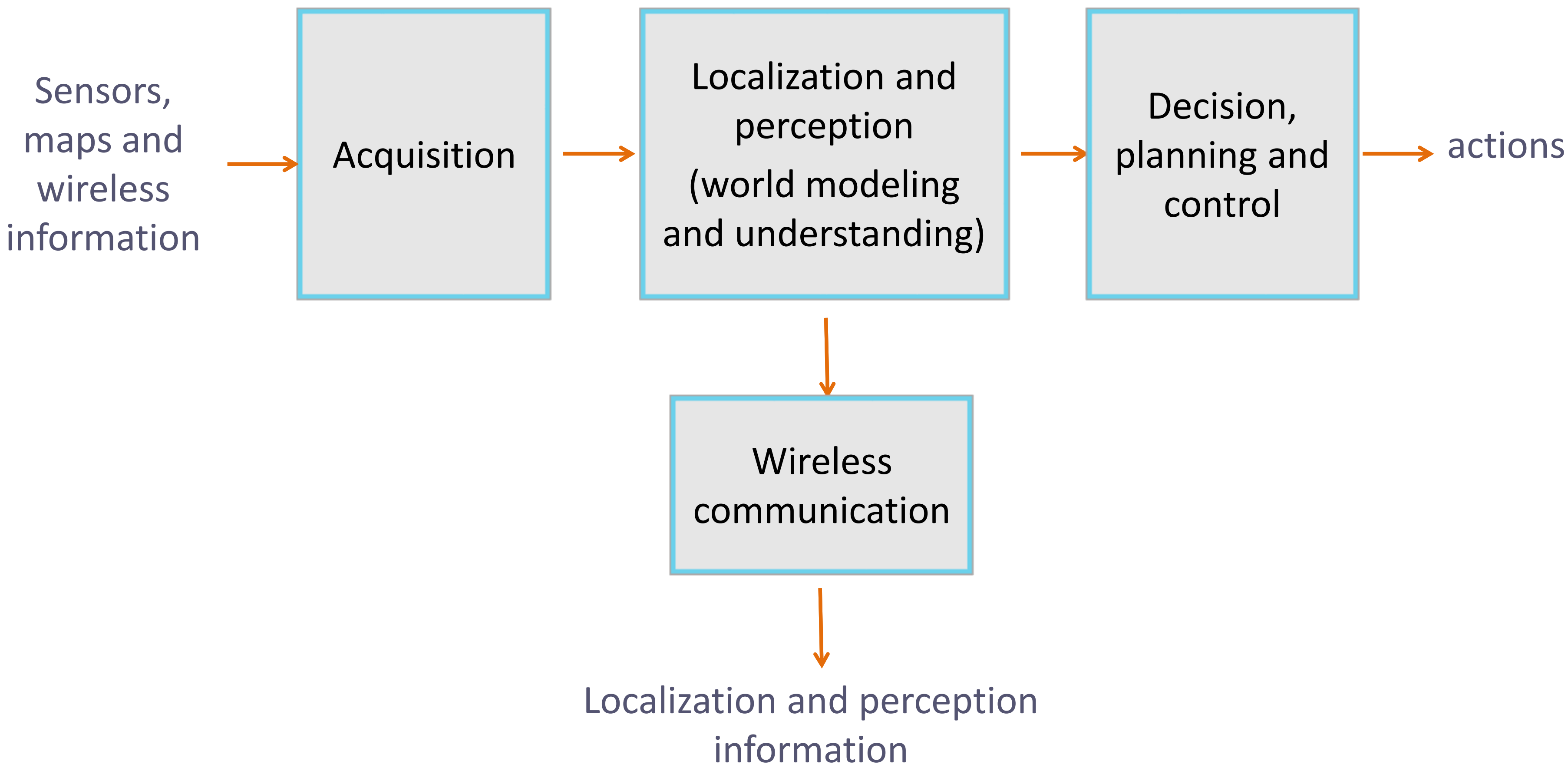
Can be emitted by the infrastructure or the vehicles.

Information:

- List of detected objects
- Position, speed, acceleration
- ID and type of the sensor which provided the measurement data



Typical processing loop



Cooperative navigation example: intersection crossing with V2V data Exchange

Part 3

Grand Cooperative Driving Challenges

GCDC 2011

- A270 highway between Helmond and Eindhoven.
- Cooperative platooning (sensor based-control with speed and acceleration exchange)
- 9 teams (with cars and trucks)

GCDC 2016

- Same place
- May 28-29, 2016
- Autonomous driving with interactions with vehicles and infrastructure
- Three different traffic scenarios
- 10 European teams.

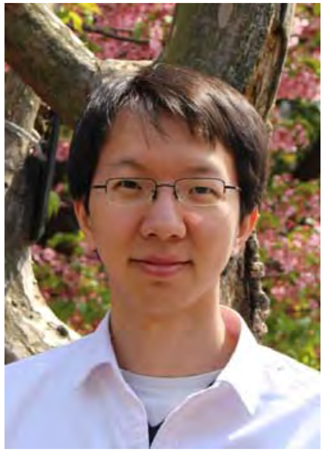
Main Challenge

- Cooperation between heterogeneous systems implementing different algorithms

Heudiasyc team

Team Leader:

Philippe XU



People involved

- 5 Profs and Researchers
- 3 Engineers
- 2 Phd students
- 2 interns
- 12 Master students

Experimental vehicle

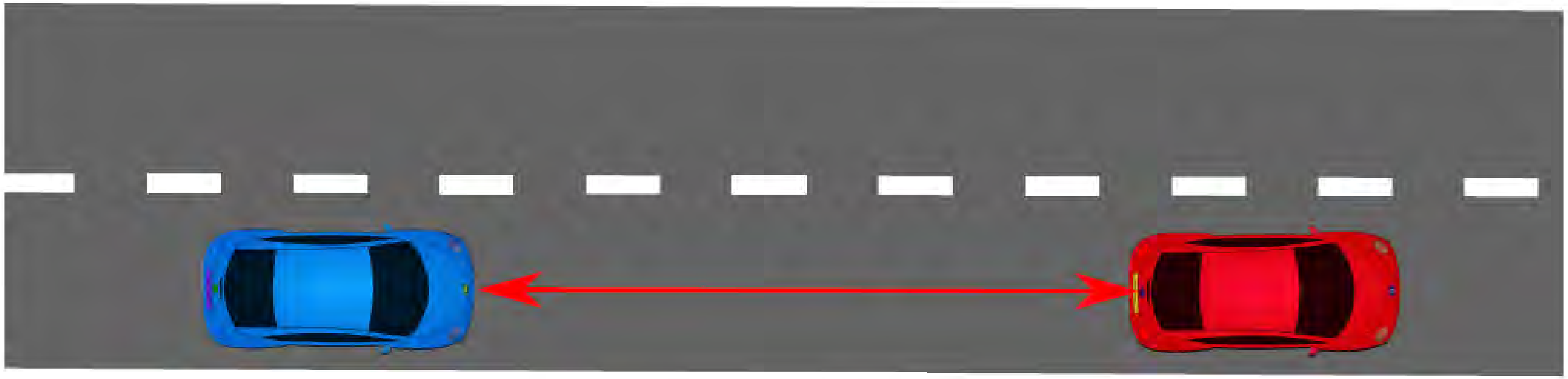
Fully electric car (Renault Zoé)

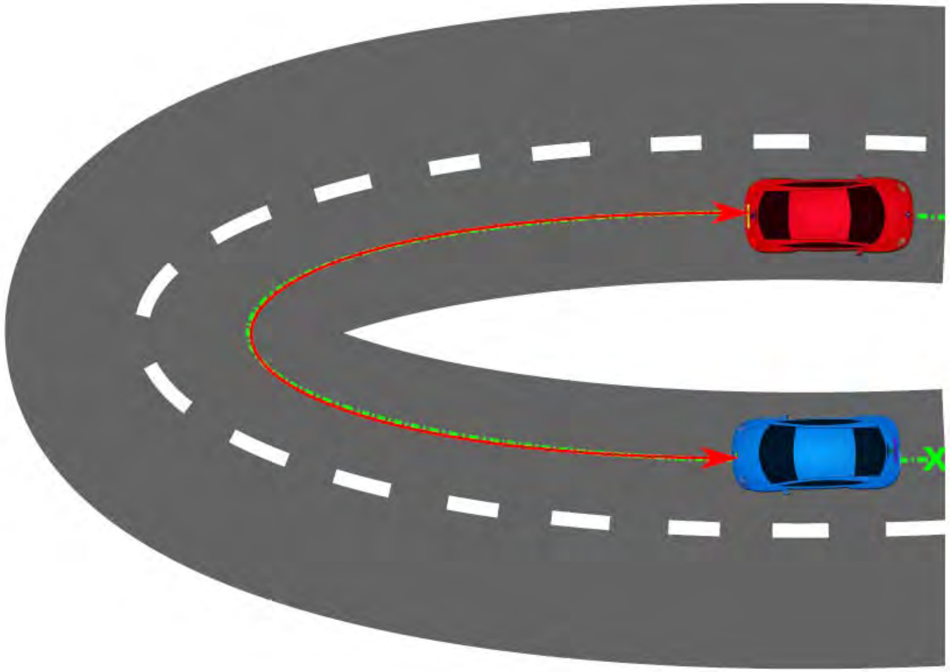
Maximum speed of 50 km/h while driving autonomously

Snapshot of the GCDC 2016

Inter-distance for platooning

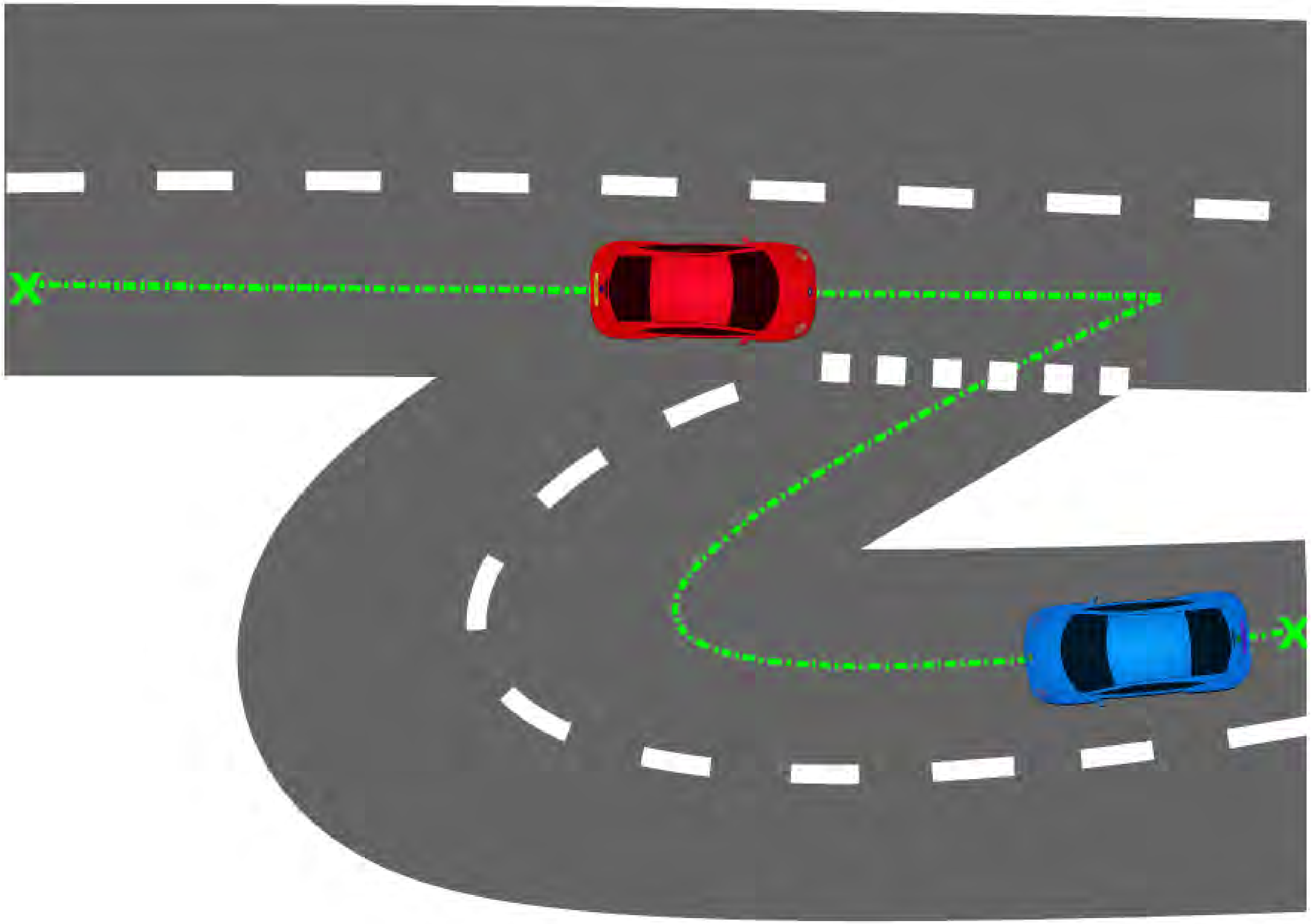
In straight road, inter-distance is easy to measure (e.g. Lidar)





In curved road, compute the inter-distance along the map by using positions exchanged by wireless communication

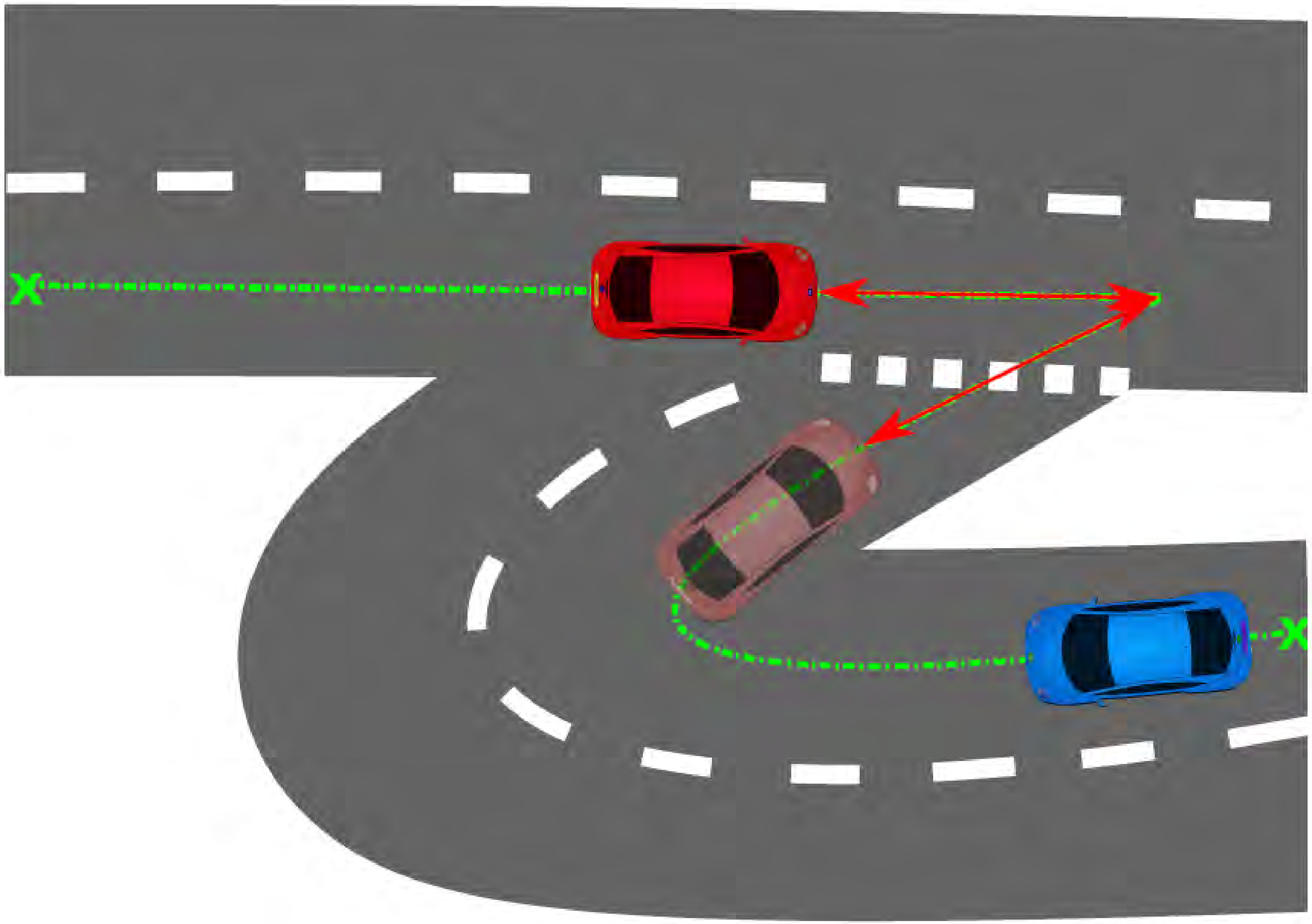
Cooperative merging using virtual platooning



The virtual platooning concept

Every vehicle

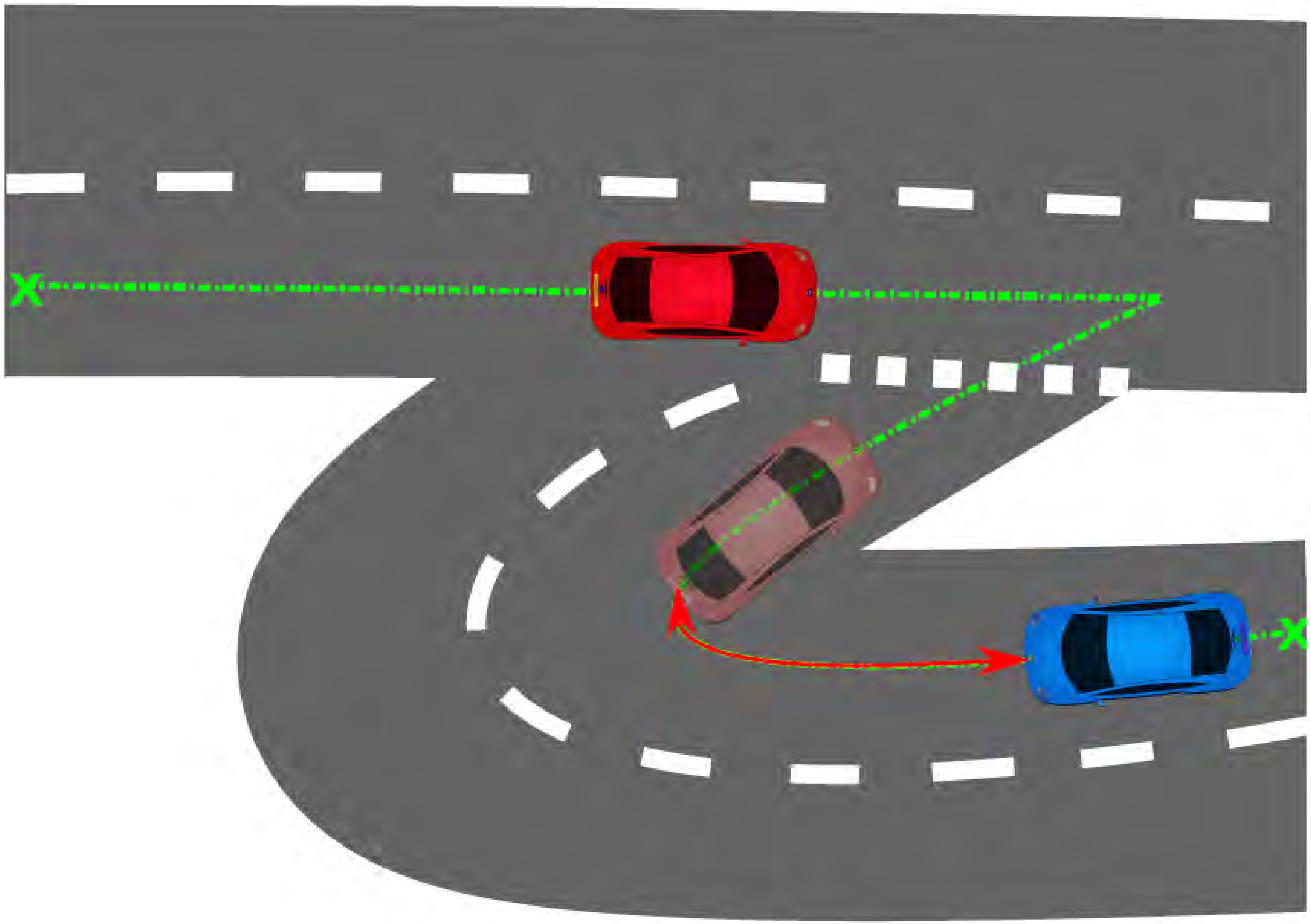
- Computes its distance to the crossing point
- Such that the others can localize it on their own path



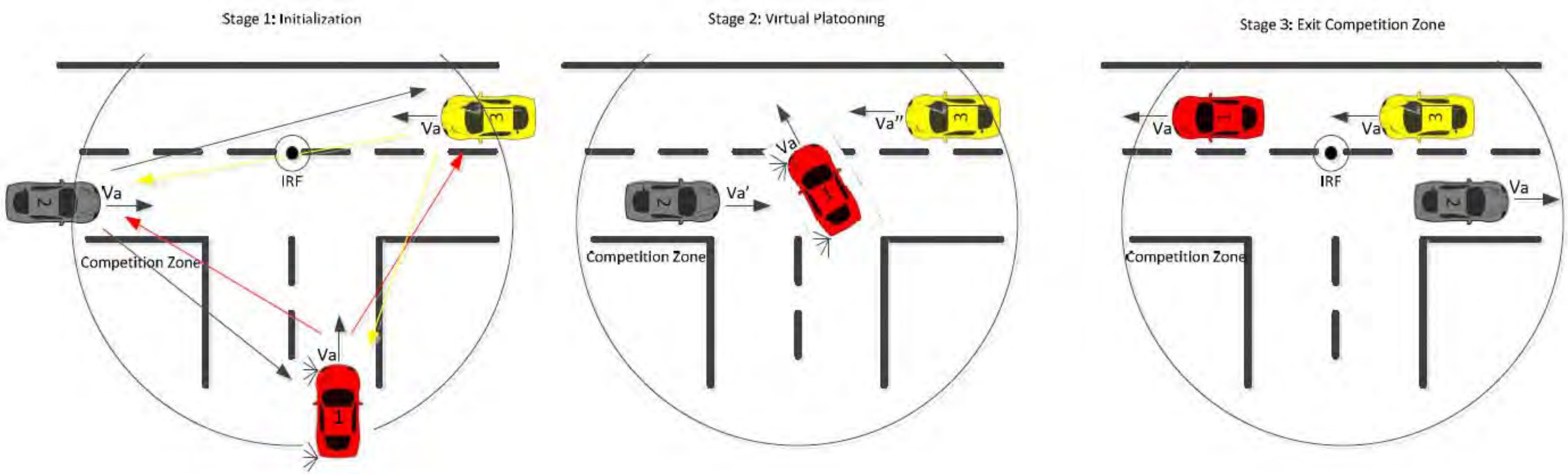
The virtual platooning concept

In this example, the red vehicle is the closest to the intersection point and becomes the (virtual) leader

Then the blue one does platooning



Crossing Scenario at the GCDC



Vehicle 1 is a car of the organizers, the challengers are 2 and 3

Goal:

- Vehicles have to reach the competition zone at a given time with a given speed
- Vehicles 2 and 3 have to let vehicle 1 cross the intersection at constant speed
- The goal of each challenger is to exit the CZ as fast as possible (with no collision)

Snapshot of an intersection crossing during the GCDC

Cooperative Wireless platooning with CAM Messages

Experiments at Compiègne

Cooperative navigation with Infrastructure-based Warning systems

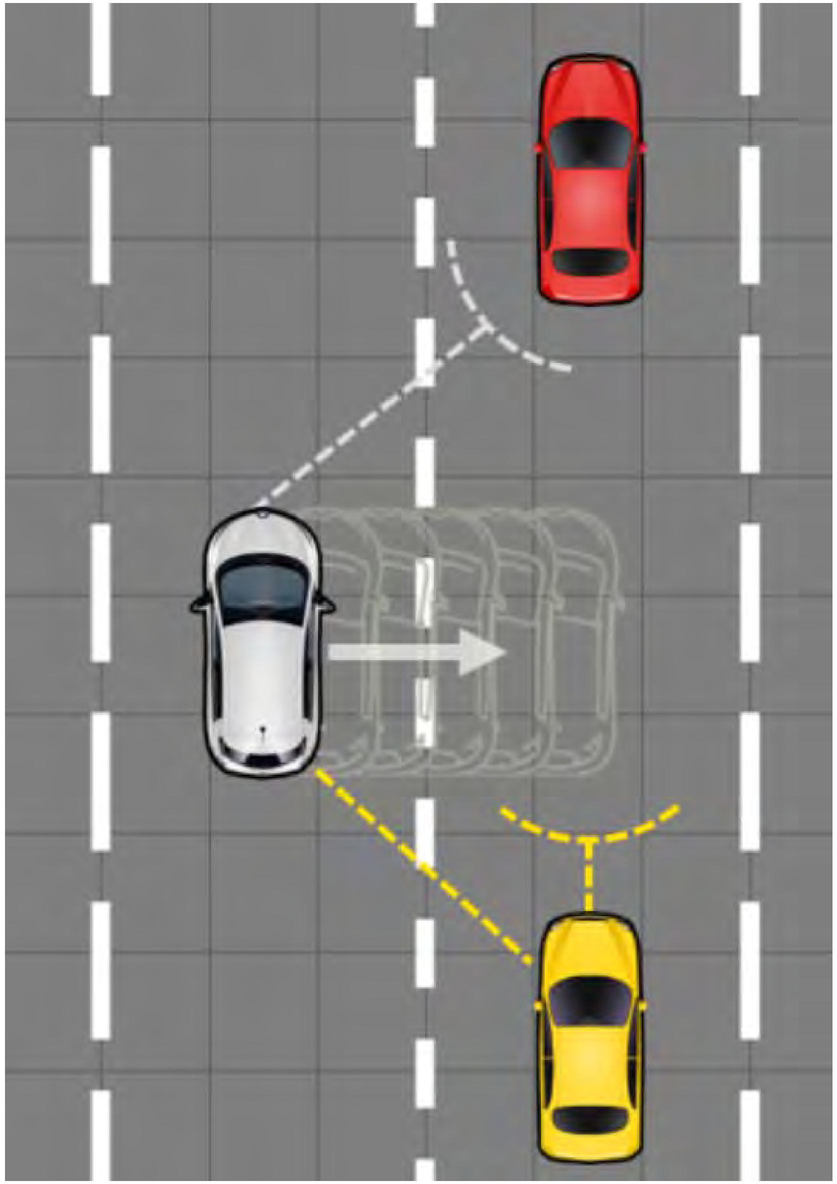
The merging example

During the GCDC

GCDC Scenario: Merging

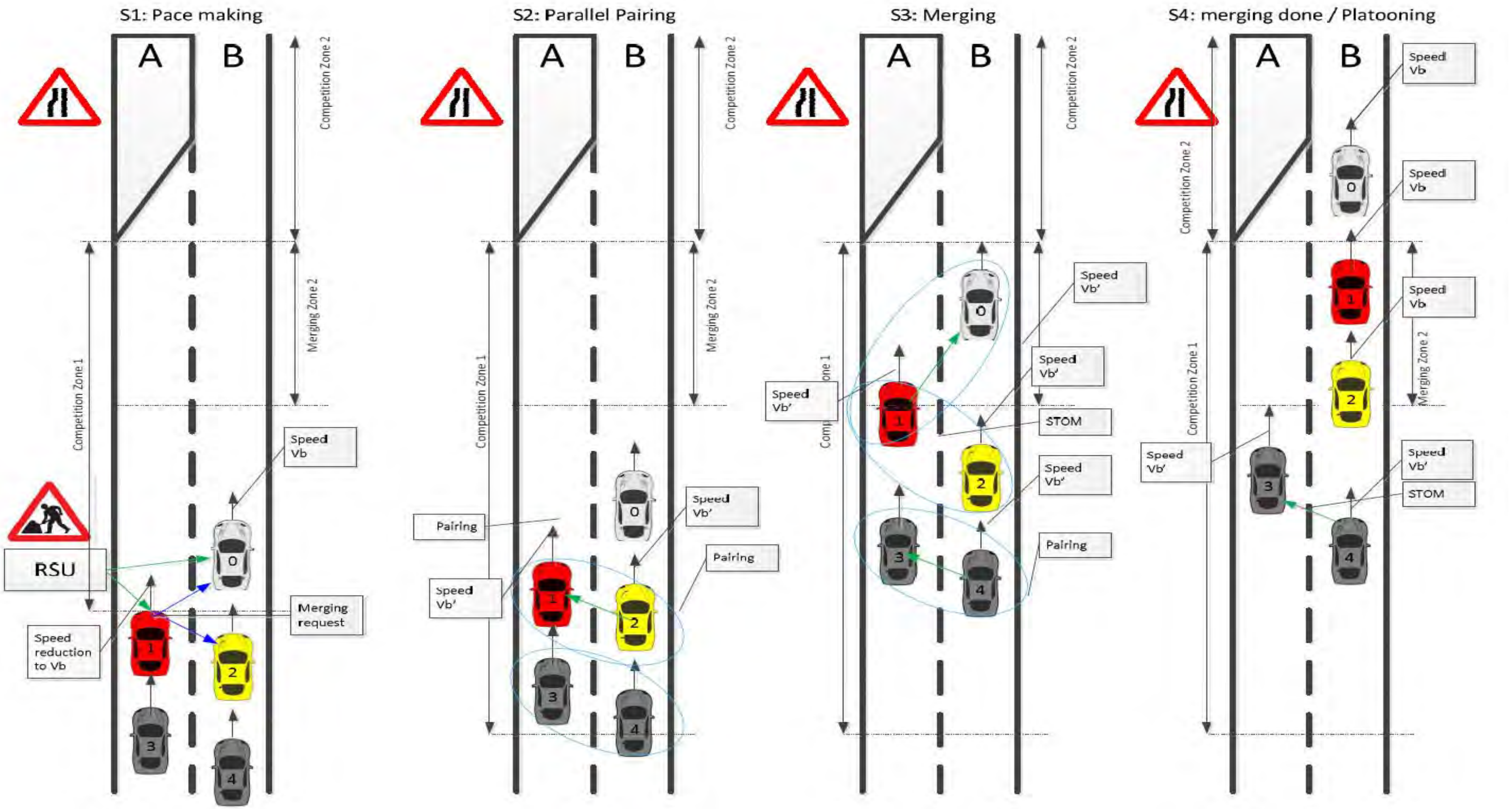
A lane is closed (e.g. road work)

A RSU broadcasts this event using a DENM message.



Lanes merging snapshots

Merging procedure



Merge request

Pairing
Red is the new leader of the yellow

Enough space to merge

3 can start the merging process

Initialization of a merging scenario

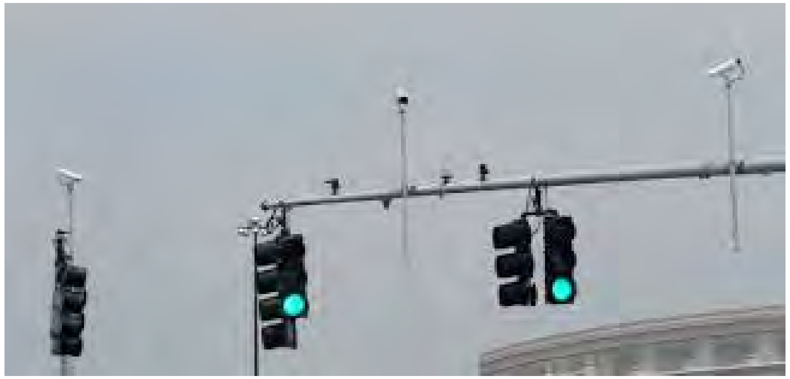
Merging during the challenge

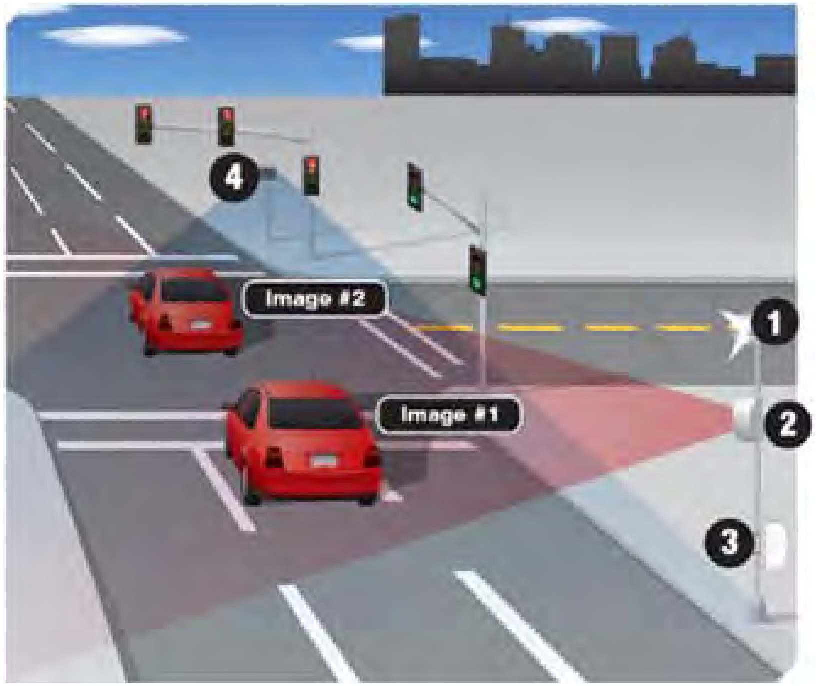
Cooperative navigation with Infrastructure-based perception systems

The roundabout crossing example

Tornado project

Infrastructure-based perception systems





The infrastructure scans the environment and

It shares information about the current traffic participants by broadcasting the locations and speeds of the mobile objects

This reduces the ambient uncertainty by providing contextual information

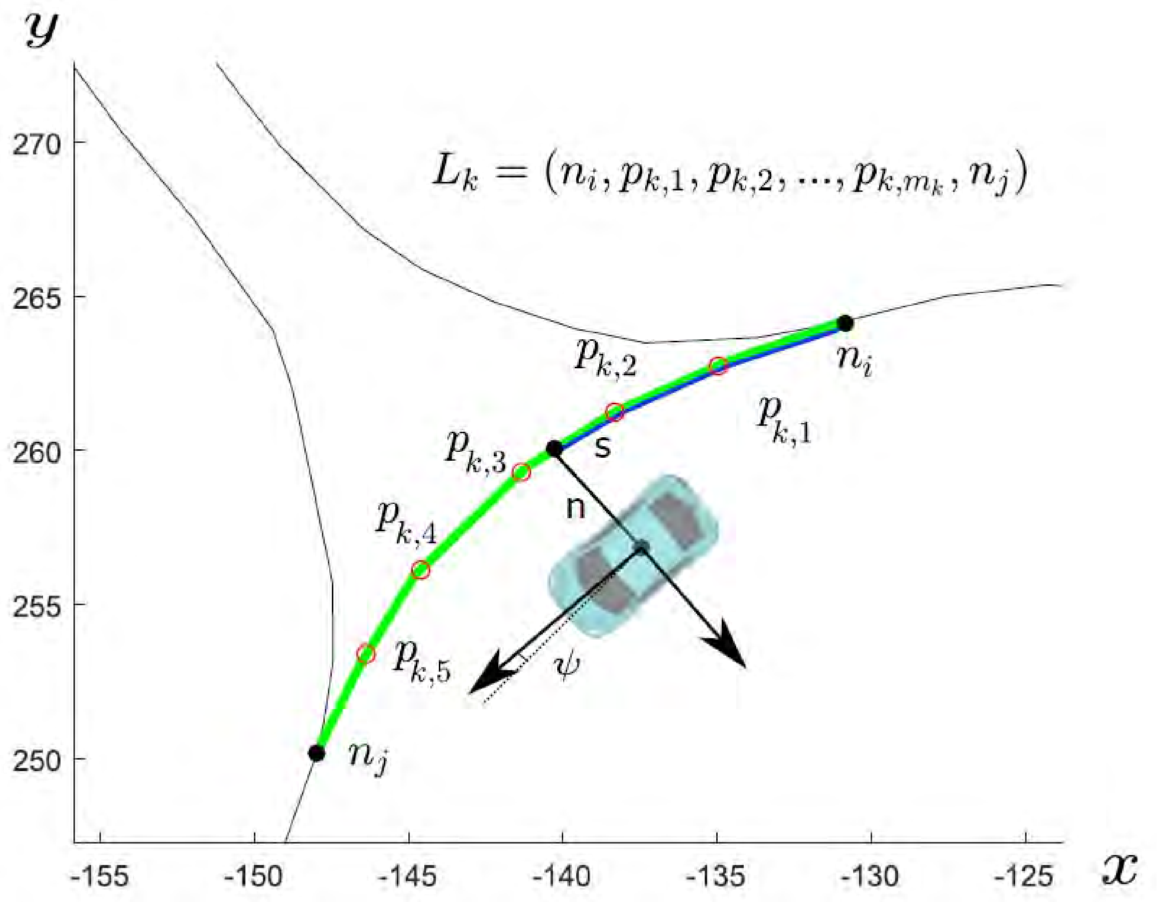
Case study: Roundabout crossing

- Infrastructure can assist autonomous cars to cross roundabouts by detecting and broadcasting CPM messages with vehicles positions and speeds inside the roundabout

- Thanks to this, autonomous vehicles can anticipate crossing the roundabout by adapting their speed

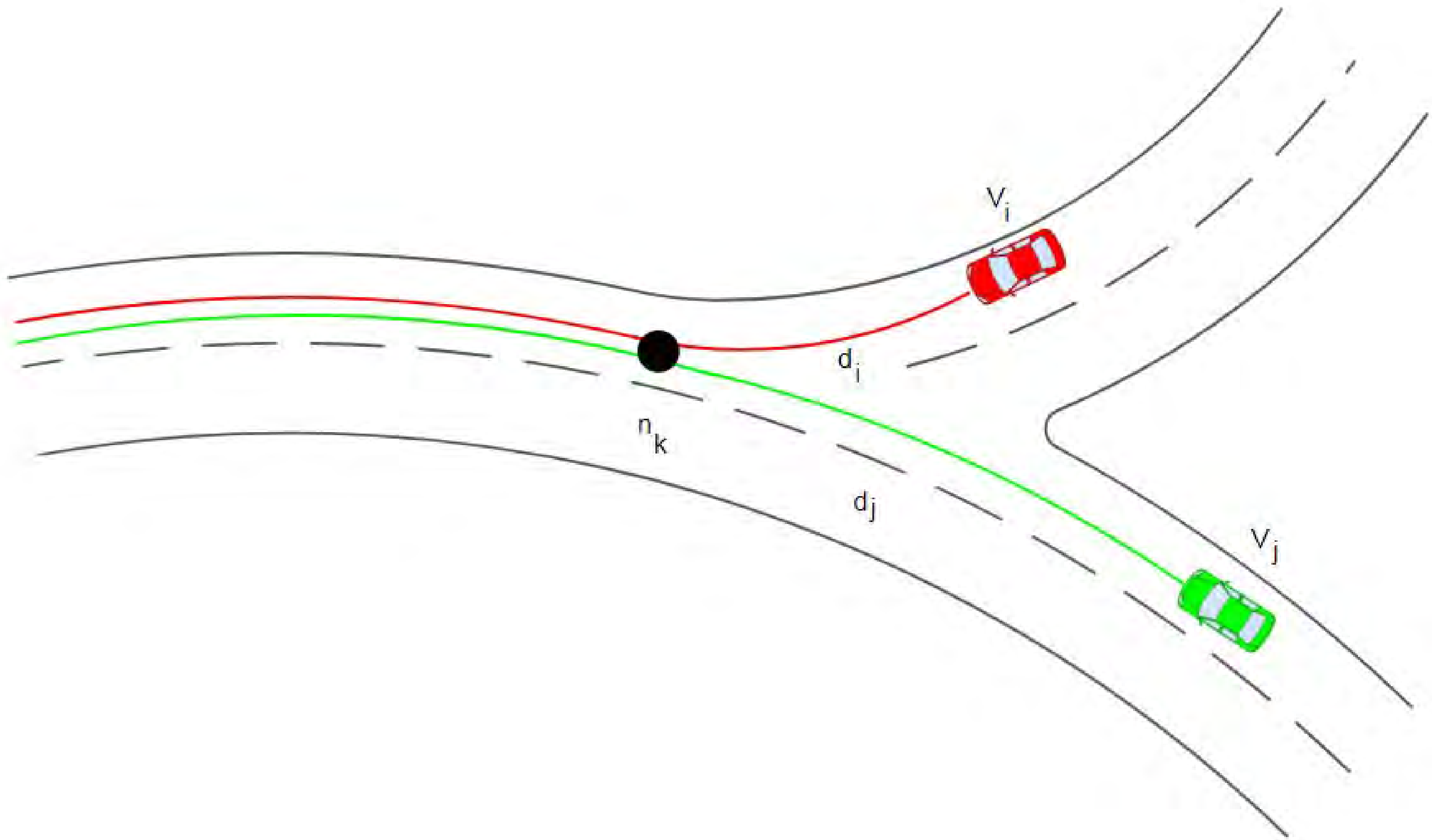
Adapting the Virtual Platooning Concept to Roundabout Crossing

- Use a high-definition map (HD map)
- Map-match every estimated position



Virtual Platooning in a Roundabout

- Compare distances between vehicles and a common node



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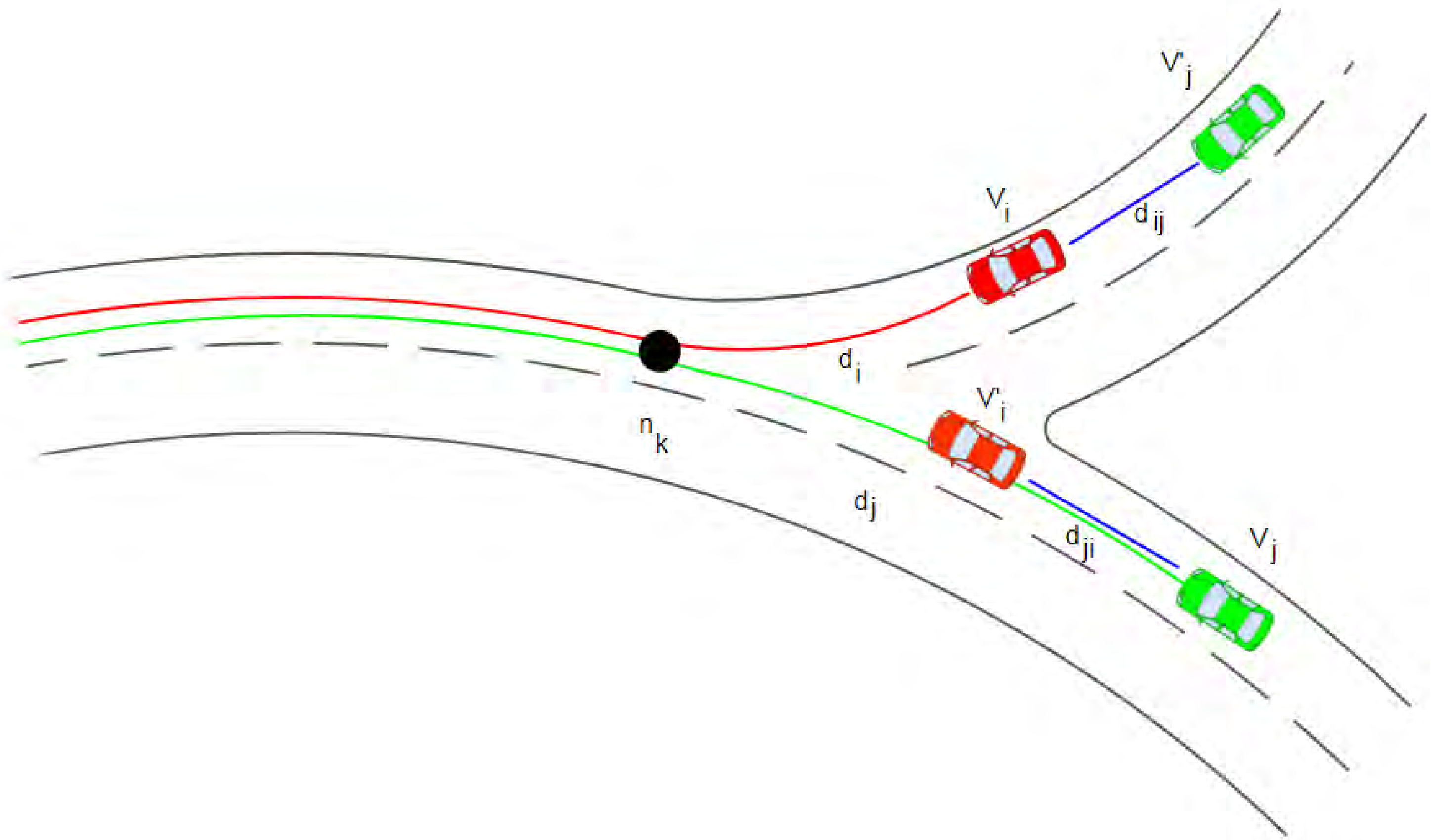
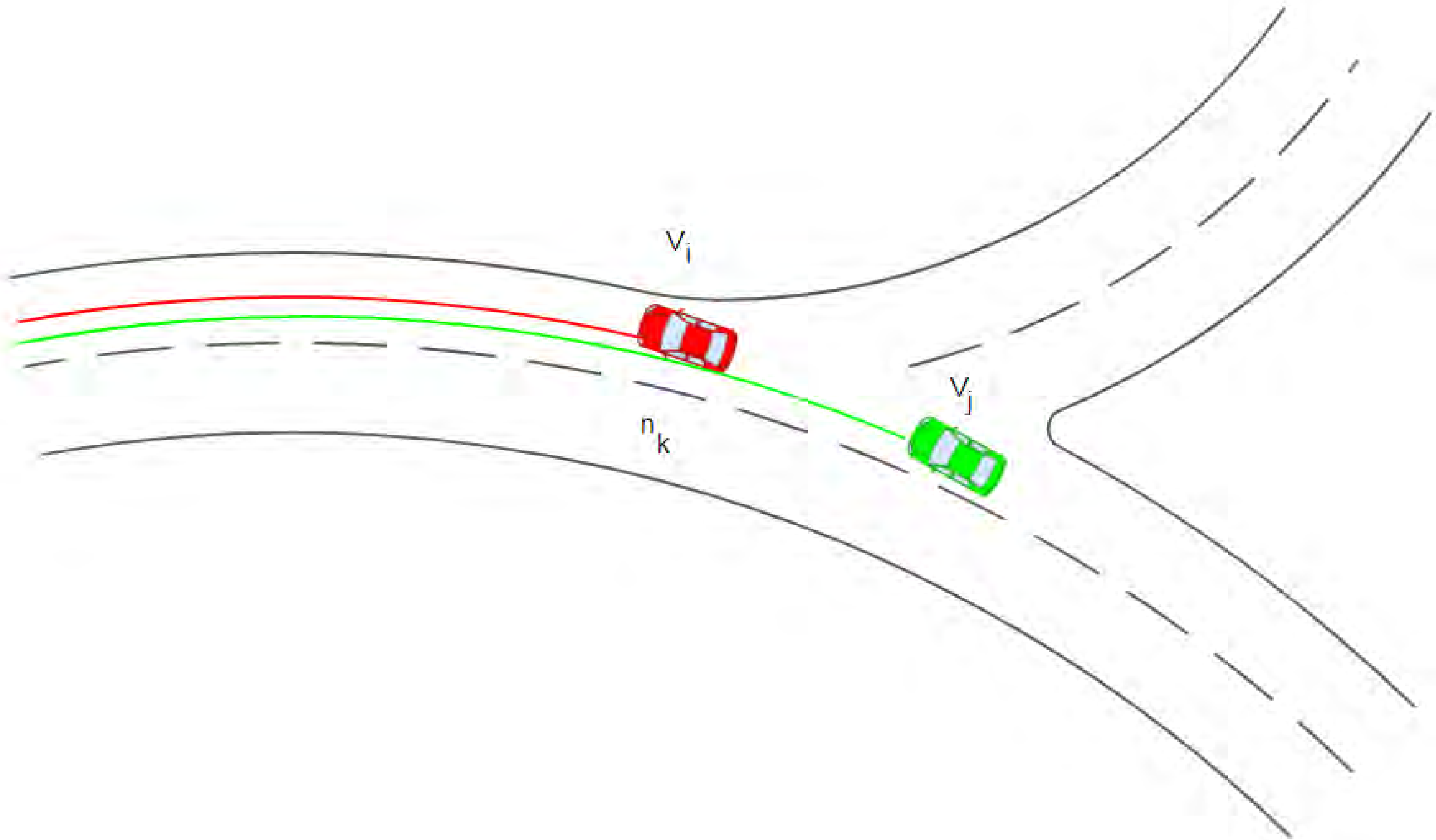
Virtual Platooning in a Roundabout

- Place the other car on your own path.
- Determine the leader

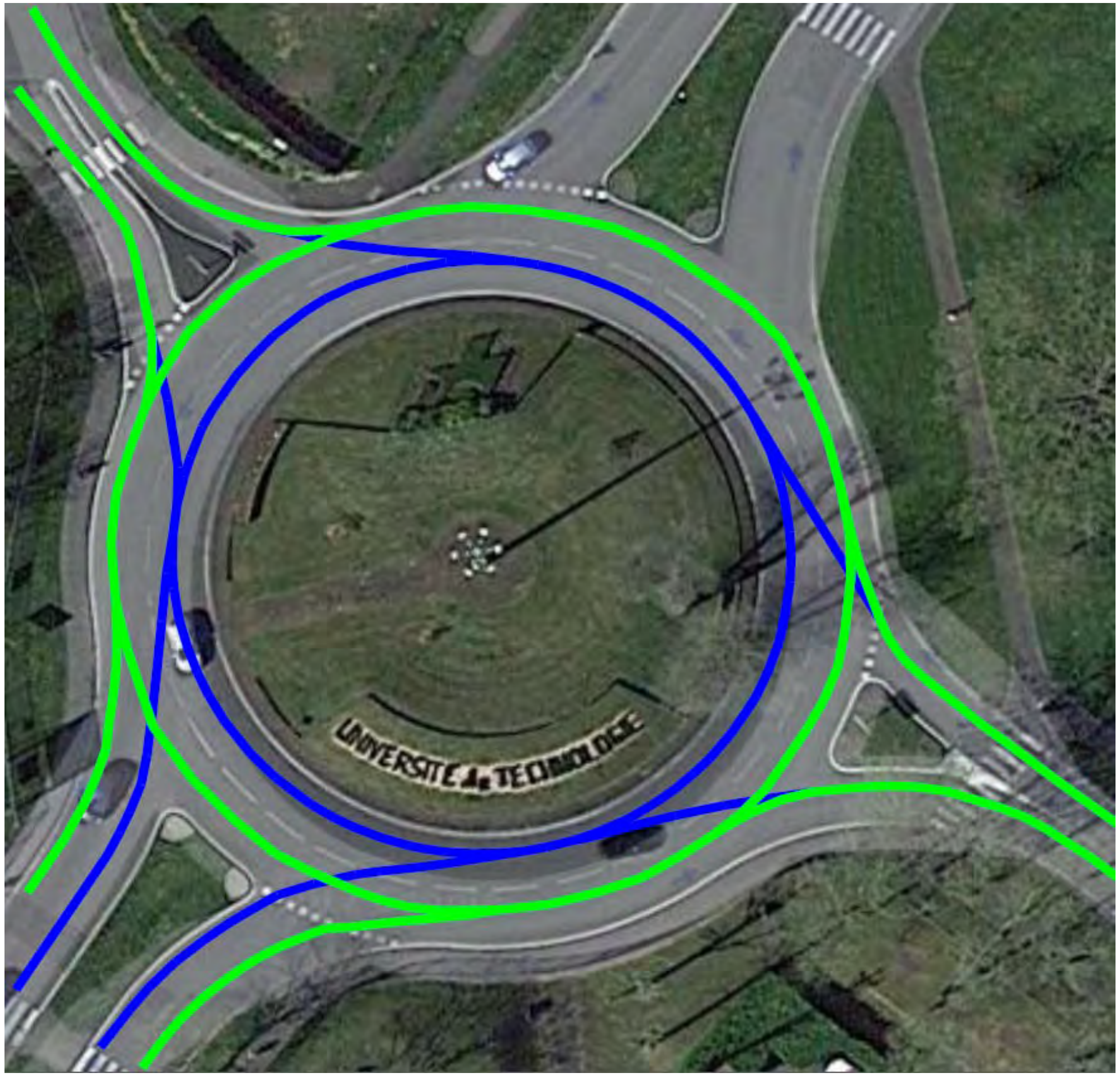


Virtual Platooning in a Roundabout

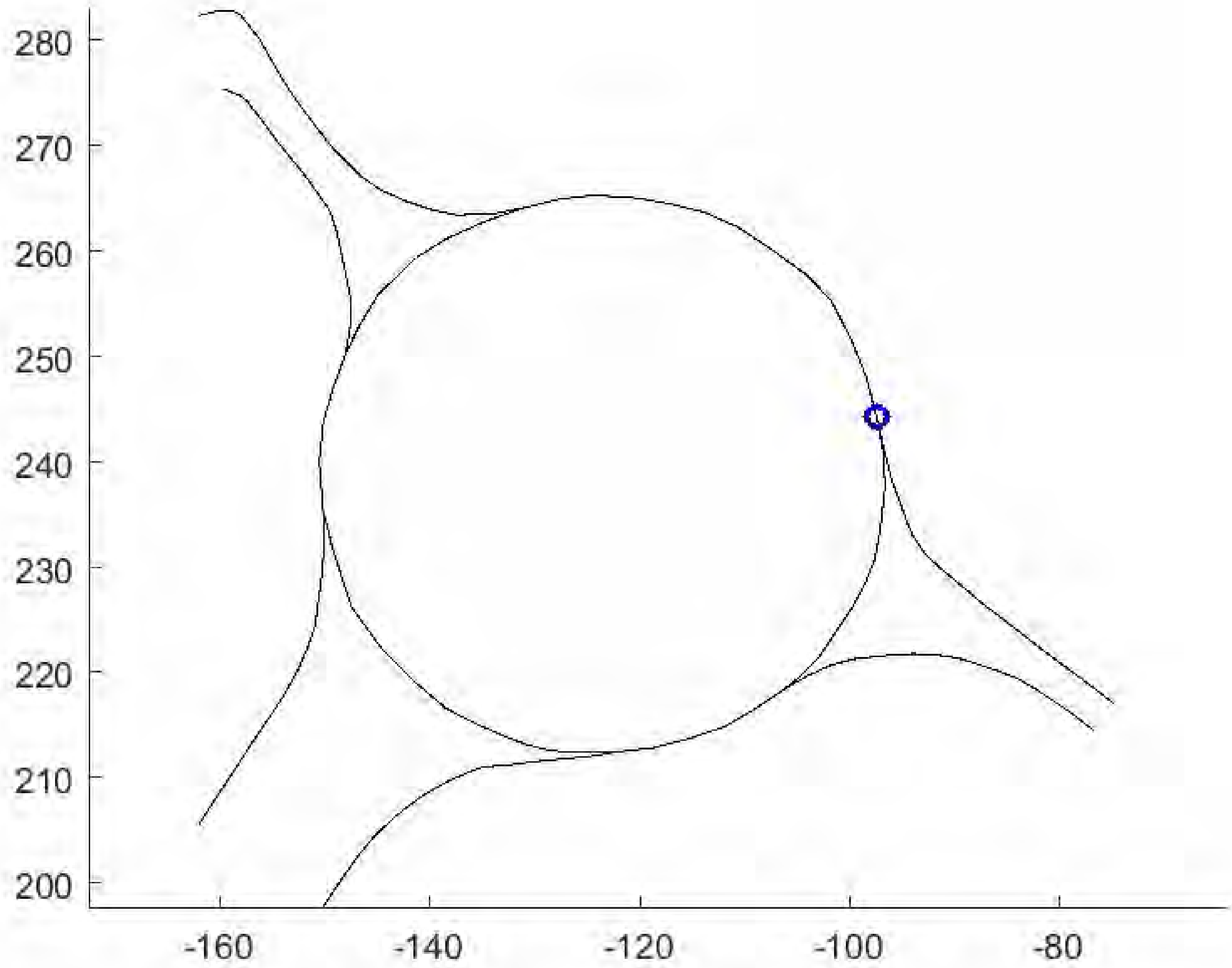
- The red car is the leader which is followed by the green one



Guy Deniélou Roundabout (Compiègne)



Example with cooperative autonomous cars



Conclusion and perspectives

Conclusion

Cooperation is a new paradigm for autonomous vehicles navigation

Thanks to wireless communication, vehicles can

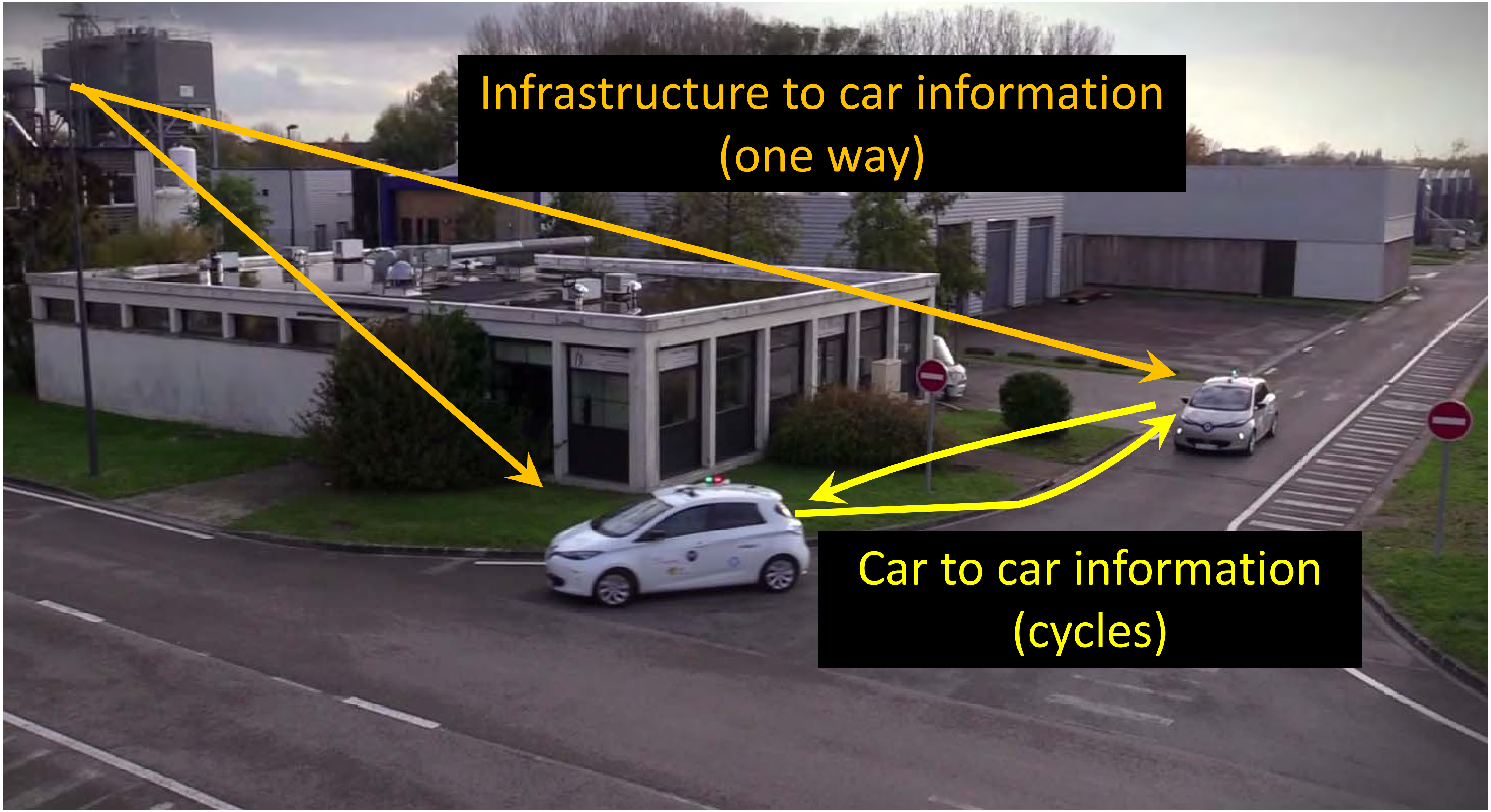
- Receive information from the infrastructure
- Exchange highly dynamic information with the others

Localization is crucial since most of the decisions are based on the location of the vehicle itself and of other vehicles in its vicinity

Cooperation is useful

- For augmented perception
- For anticipation
- For cooperative maneuvers
- To reduce the number of embedded sensors for navigation

Cooperation for autonomous cars



Perspective

Progress to be made

- Methods that guaranty the integrity of the information exchanged and control the propagation of errors and faults
  - In particular, cycles of exchange inducing data incest problems have to be taken into account
- Methods able to compute in real-time reliable bounds of the errors
- Data exchange standards
  - In particular, regarding the uncertainty representation

Thank you for your attention !

Associated publications

- Ph. Xu, G. Dherbomez, E. Héry, A. Abidli, and Ph. Bonnifait.
  "System architecture of a driverless electric car in the grand cooperative driving challenge."
  IEEE Intelligent Transportation Systems Magazine, January 2018.
- E. Héry, Ph. Xu and Ph. Bonnifait.
  "Along-track localization for cooperative autonomous vehicles".
  IEEE Intelligent Vehicles Symposium, Redondo Beach, California, June 2017.
- K. Lassoued, Ph. Bonnifait, and I. Fantoni (2017).
  "Cooperative Localization with Reliable Confidence Domains between Vehicles sharing GNSS Pseudoranges Errors with no Base Station"
  IEEE Intelligent Transportation Systems Magazine, January 2017

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