



# Intelligent Vehicles localization integrity with HD map, Lidar and GNSS

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for Ground, Seaborne, and Airborne Vehicles  
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# Outline

1. Intelligent vehicles
2. Autonomous navigation
3. Localization for what?
4. Map errors
5. The data association problem with Lidar
6. Robust data fusion for integrity

# Intelligent Vehicles

Any kind of homologated motorized vehicle operating on roads opened to public traffic in the general framework of Intelligent transportation Systems (ITS)

If we focus on the mobility of people, the vocabulary is very diverse:

- Autonomous vehicles
- Self-driving cars
- Driver-less cars
- Robotic cars
- Automated driving vehicles
- Connected and automated vehicles
- ...

# Intelligent Vehicles

- Unsupervised vehicles for private use

- Traditional customers
- ADAS: traffic jam assist, etc.



- AD: valet vehicle, etc.



- Supervised vehicles

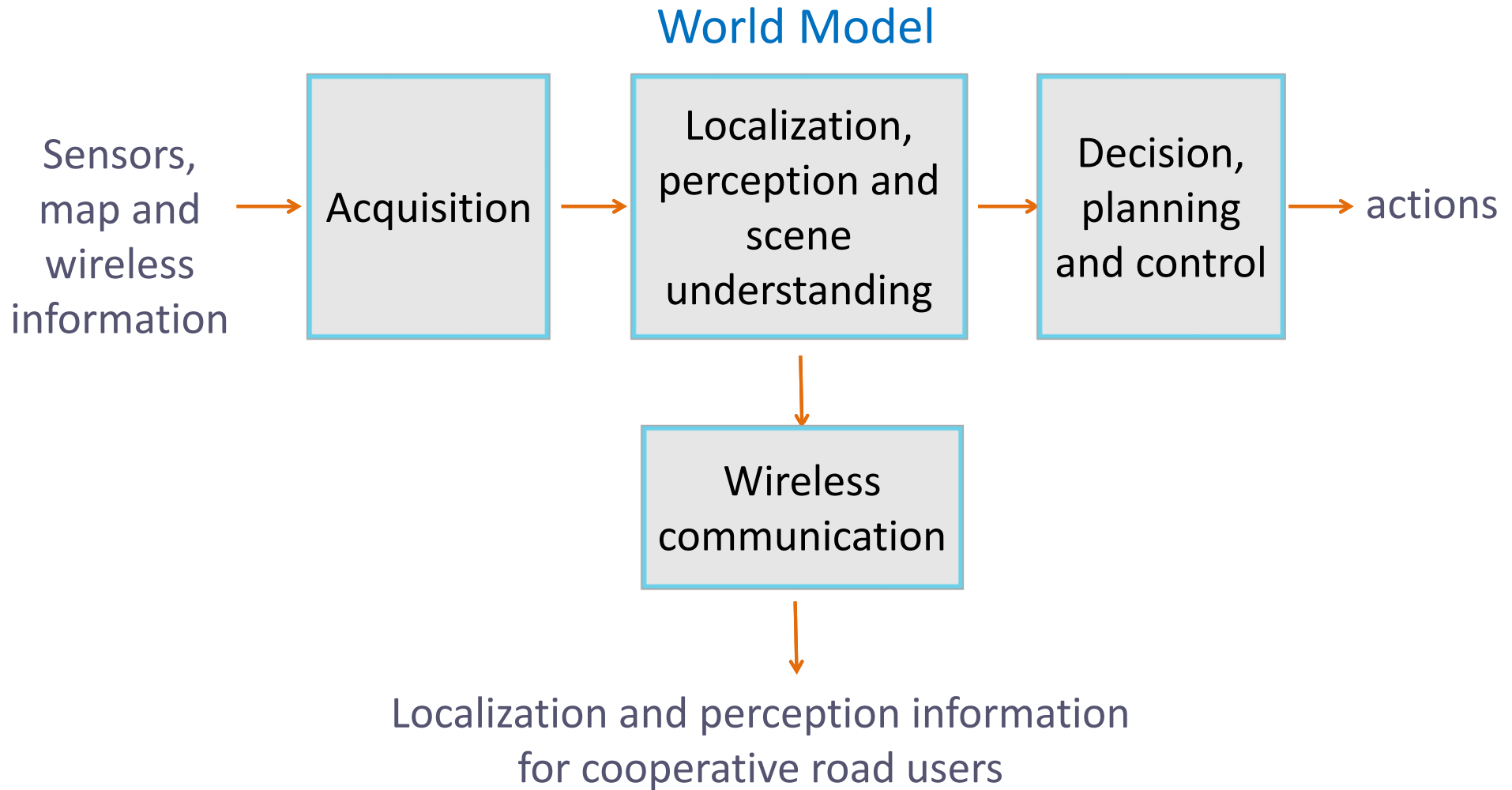
- New mobility services
- Shuttles



- Robot taxis



# Typical Processing Loop in Real-Time



# Autonomous vehicles

Ability to function independently of a human operator in a Operational Design Domain (ODD)

## Operational autonomy

- Feedback to control the motion to follow a computed trajectory, while rejecting disturbances

## Decisional autonomy

- Ability to understand and take safe decisions despite the uncertainties of localization and perception including incomplete information about the environment
  - hidden areas or areas outside the range of sensors

# Decisional autonomy example

## Roundabouts crossing



S Masi, P Xu, P Bonnifait. Roundabout crossing with interval occupancy and virtual instances of road users  
IEEE Transactions on Intelligent Transportation Systems 2022

# Localization for what?

A localization system enables a vehicle

1) To reach a destination, usually far away

— Strategic level

– Turn by turn navigation

2) To build a World Model for scene understanding with the help of maps and a perception system

— Tactical level

– Short term maneuvers

3) To provide state information for planning and control

— Operational level

– e.g. Path following

At each level, there are different requirements



# Localization Requirements

Localization has to be

- Accurate enough for the tasks to be performed
- Available at a sufficiently high rate
- Non-misleading and Trustworthy
  - Integrity monitoring in real-time

Integrity monitoring depends on the navigation tasks to be performed

# The concept of integrity

The information delivered by a system is non-misleading

- if it is of higher quality to what is expected
- to successfully perform the navigation task

Integrity is intended to serve as a real-time decision-making

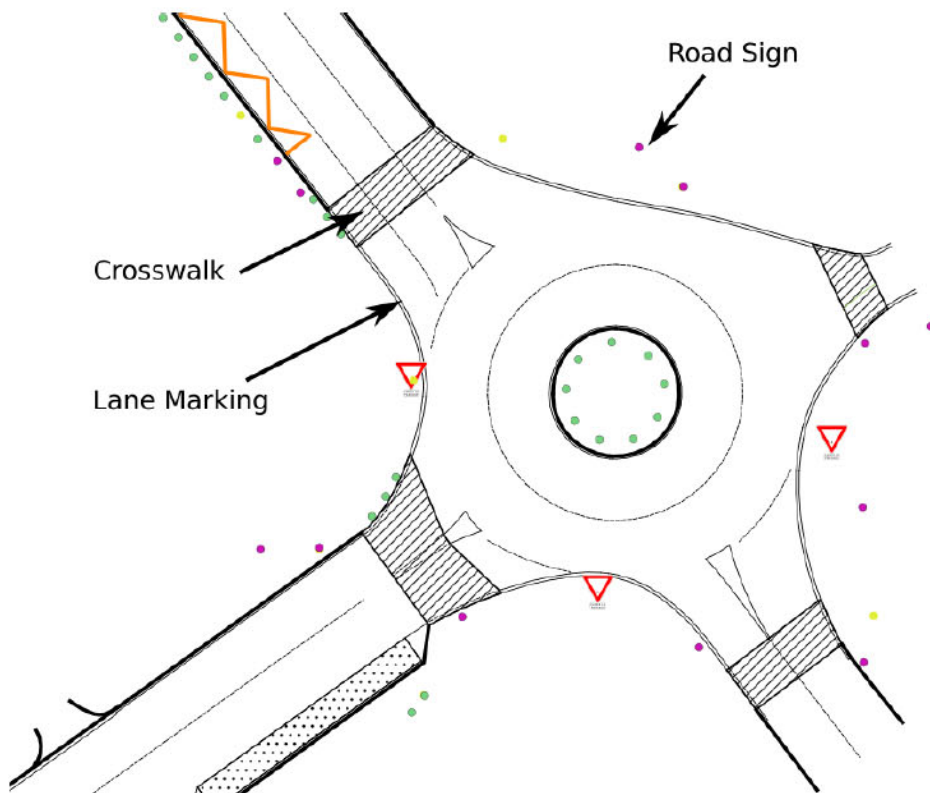
- For the use or non-use of the system

A high integrity system is a system that provides miss-leading information with a very low rate

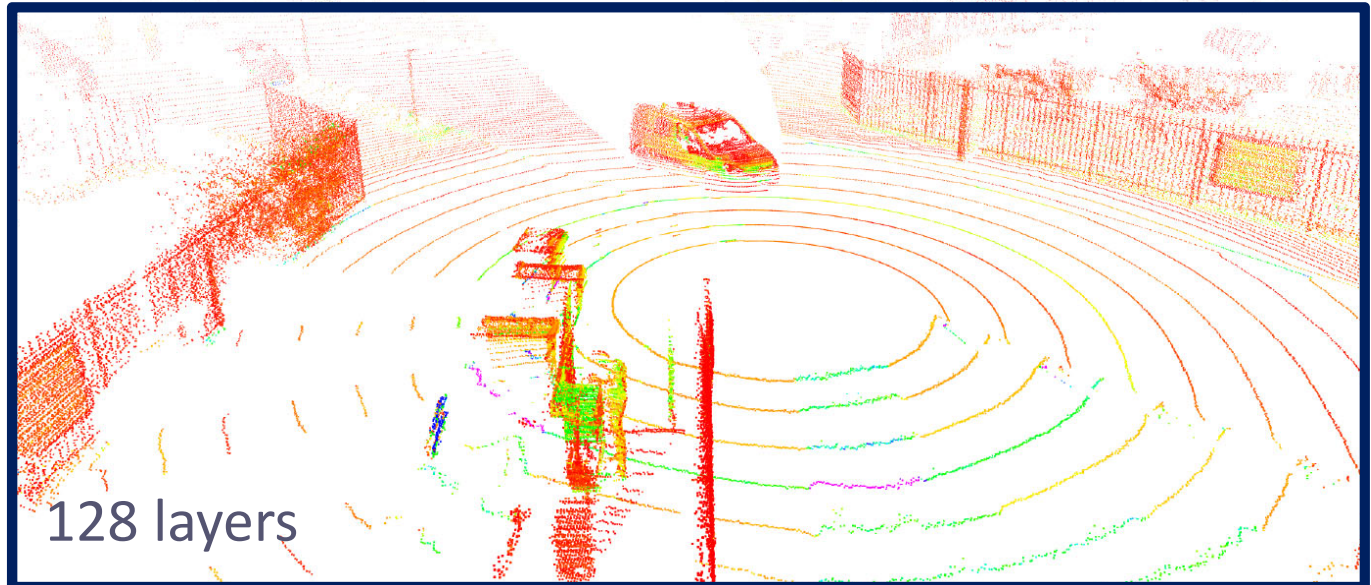
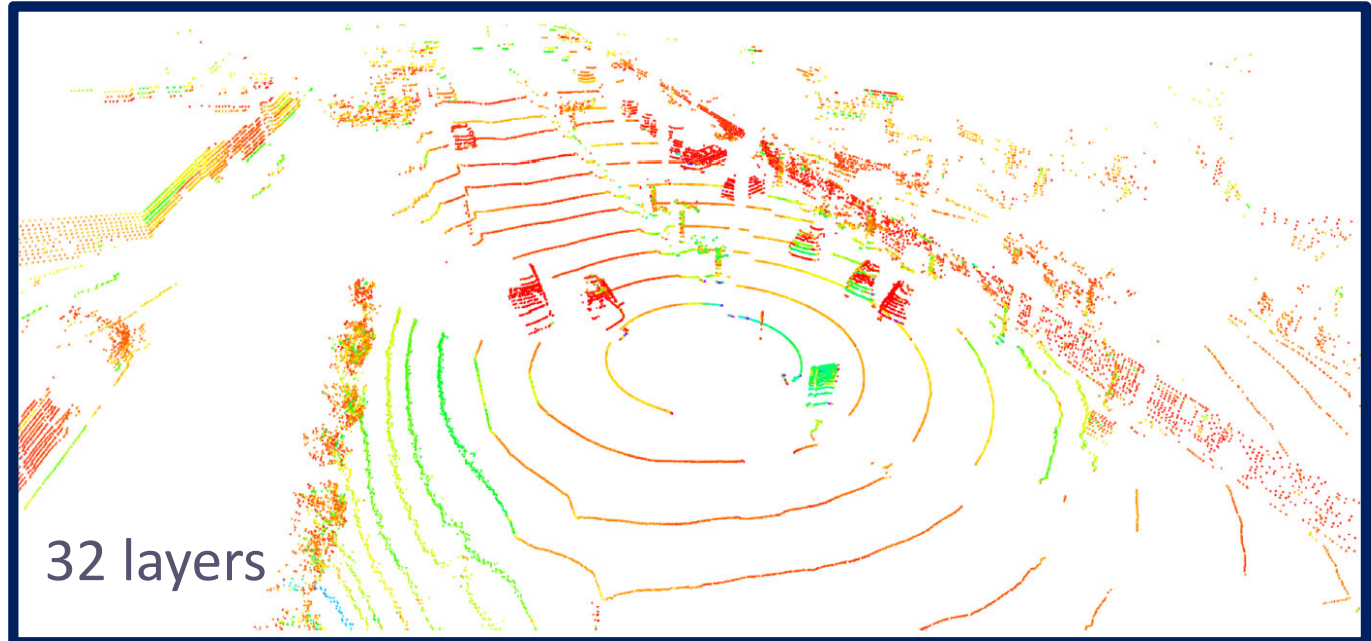
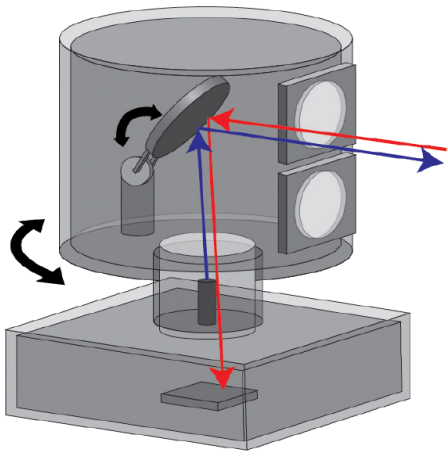
- The probability of hazardous situations (that would possibly put at risk human lives) is in general very small (e. g.  $10^{-6}/h$ )

# Map-aided localization

## Geo-referenced features



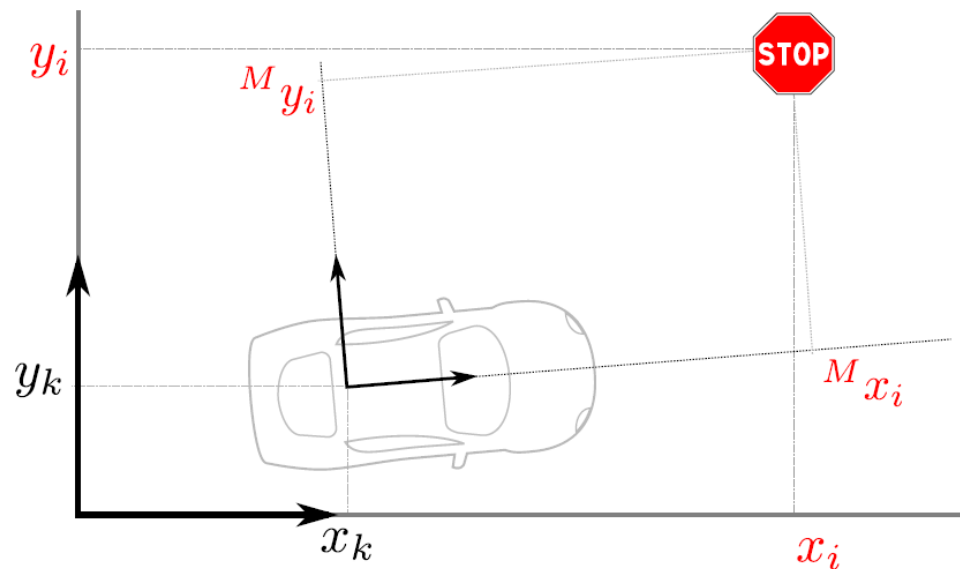
# Localization with 3D Lidar



# Road features

## Traffic signs

- Easy to map
- Easy to detect with Lidar thanks to the intensity
  - They are located high above the ground and therefore often far from the reflective parts of cars (license plate)
  - → Few outliers



# Map Errors

Maps always contain errors:

- Mapping errors
- Map features can be modified and they can get damaged

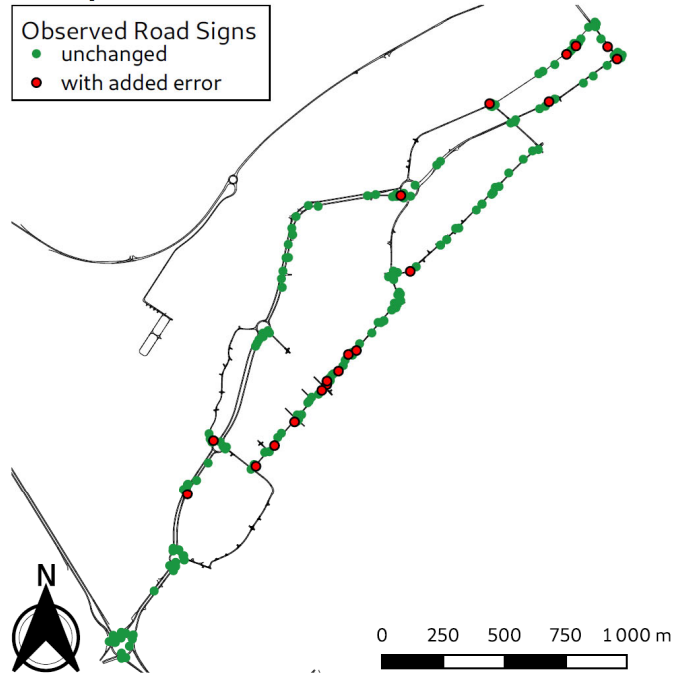


Approach for map error detection:

- Kalman Smoothing Residuals using multiple drives

# Map Errors Detection using Multiple Drives

## Map Errors



- 207 traffic signs
- 20 with added error

The method is able to

- Validate correct signs that have been seen and matched
- Detect most of the faulty ones, particularly with small errors down to 50cm

A Welte, P Xu, P Bonnifait, C Zinoune. HD Map Errors Detection using Smoothing and Multiple Drives. IEEE Intelligent Vehicles Symposium 2021

# The association problem

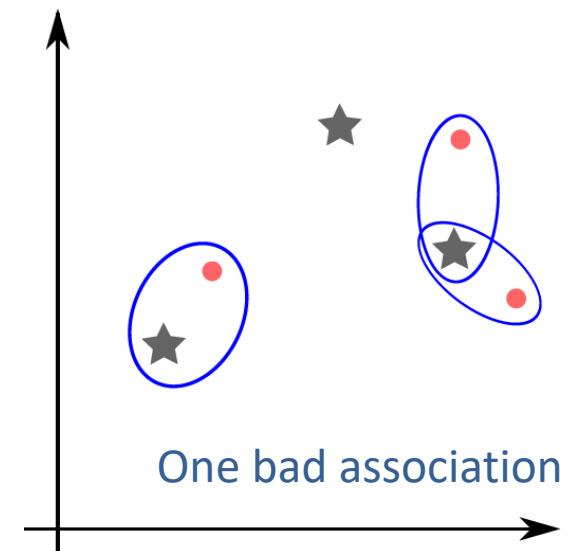
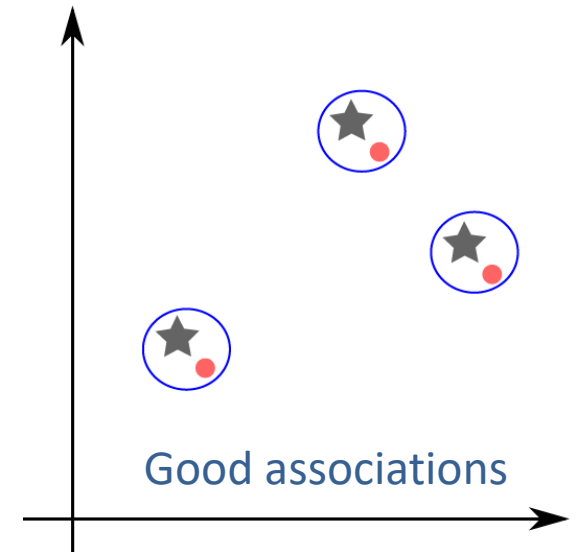
Lidar features are not very discernable

- Few elements that distinguish them from each other

It is necessary to map-match them

Data association is not straight forward

- Even if some map errors can be detected, it remains always some errors
- There are false positive detections
- There are ambiguities





# Usual method for Data Association

Nearest Neighbor using Mahalanobis distance:

$$D_{mah} = \sqrt{(x - \hat{x})^T Q^{-1} (x - \hat{x})}$$

$$\hat{x} \sim \mathcal{N}(x, Q) \Rightarrow D_{mah}^2 \sim \chi_2^2$$

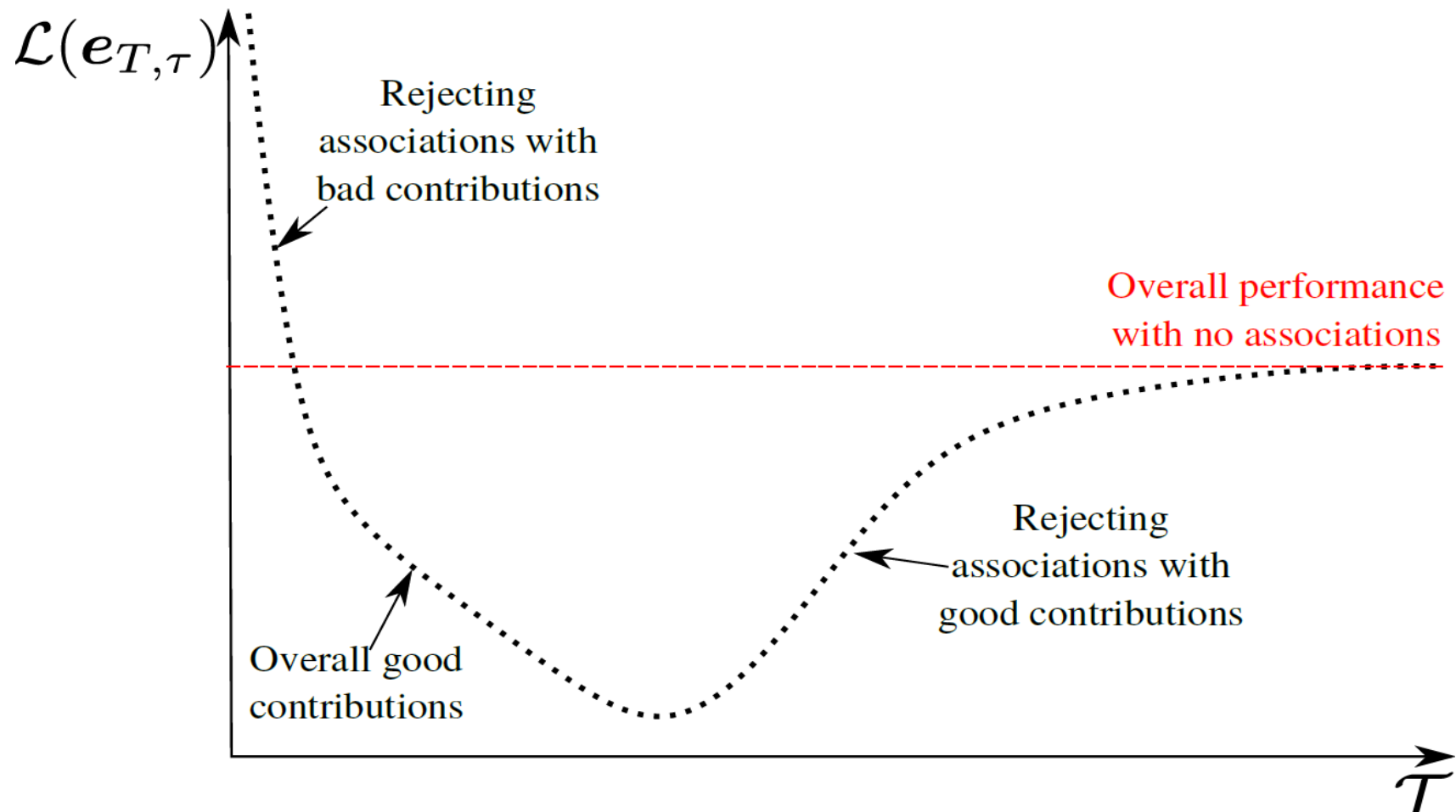
Common choice:

Exclusion using a  $\chi_2^2$  percentile as 95th percentile  $D_{mah}^2 < 6$

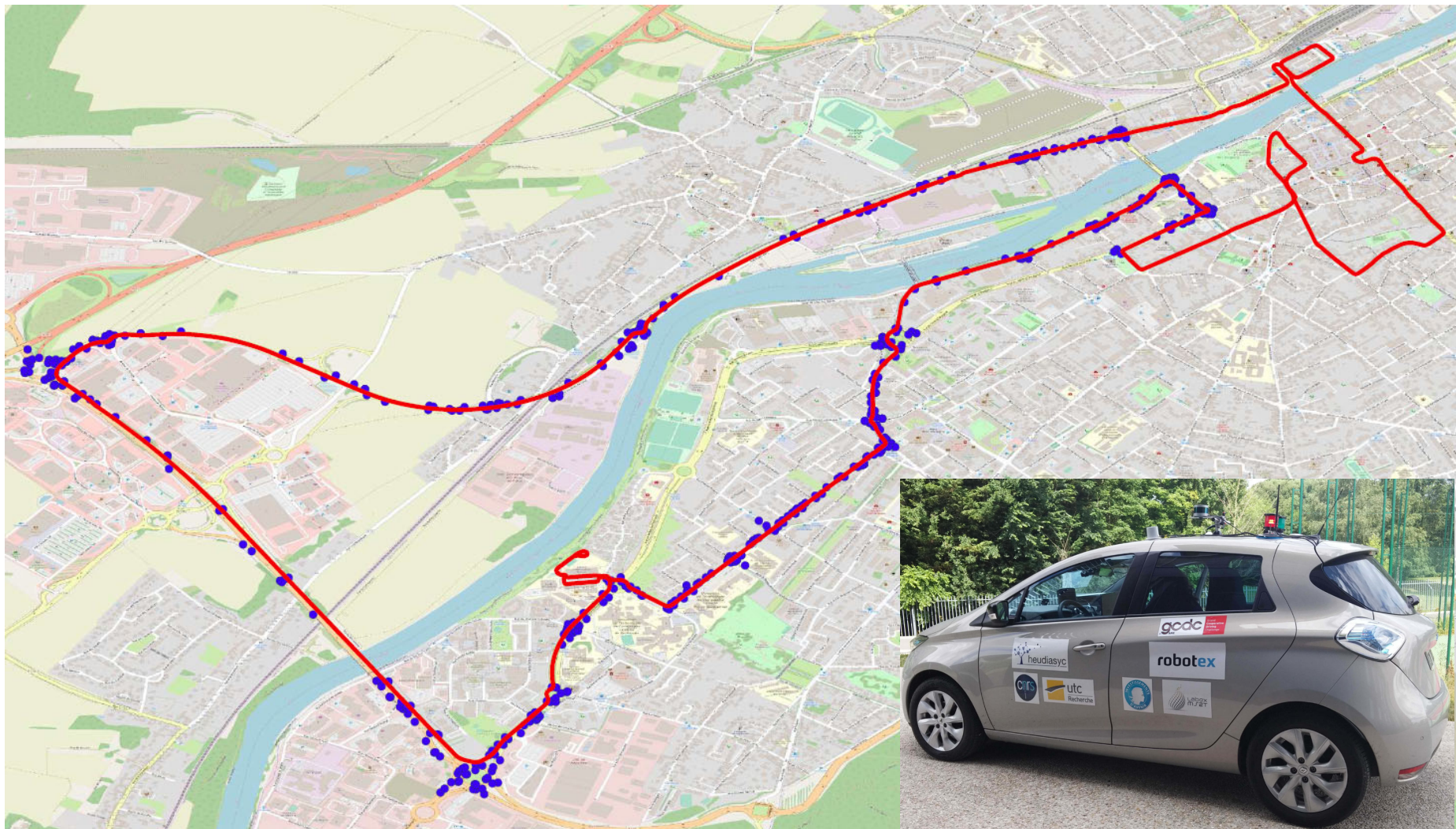
- Which means excluding 5% of good associations  
Arbitrary choice

# Threshold Tuning for Road Features Map-matching

Data-driven approach with optimization scoring given a chosen accuracy metric with localization ground truth



# Experiments



Compiègne, France

# Results

## Dataset:

- 7 driving sequences (5h30 of recording)
- Dual frequency, quad-constellation GNSS receiver without differential corrections
- 40-layer Lidar

## Mean Absolute Error (MAE)

	$\mathcal{L}_{\text{MAE}}$
$\tau = +\infty$	1.73
$\tau = 1/\sqrt{6}$	1.26
$\tau^*$	0.97

No Lidar

Usual tuning

Optimized threshold

- 23% gain in accuracy

# Multi-sensor data fusion

Objective: merge all information sources with integrity

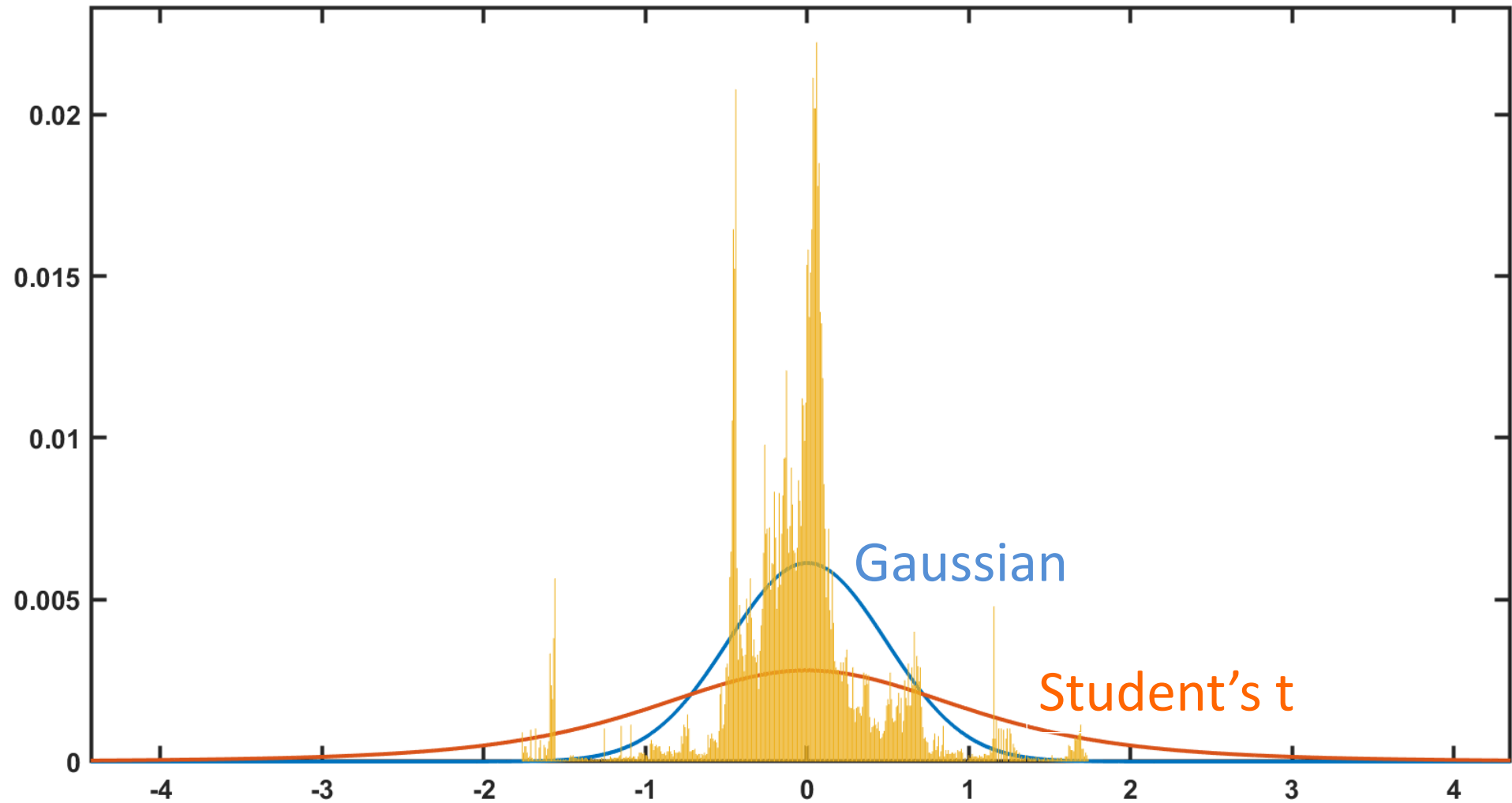
Faults are due to:

- GNSS multipath and NLOS
- Errors in georeferenced features
- False Positive Lidar detections
- Wrong Data association

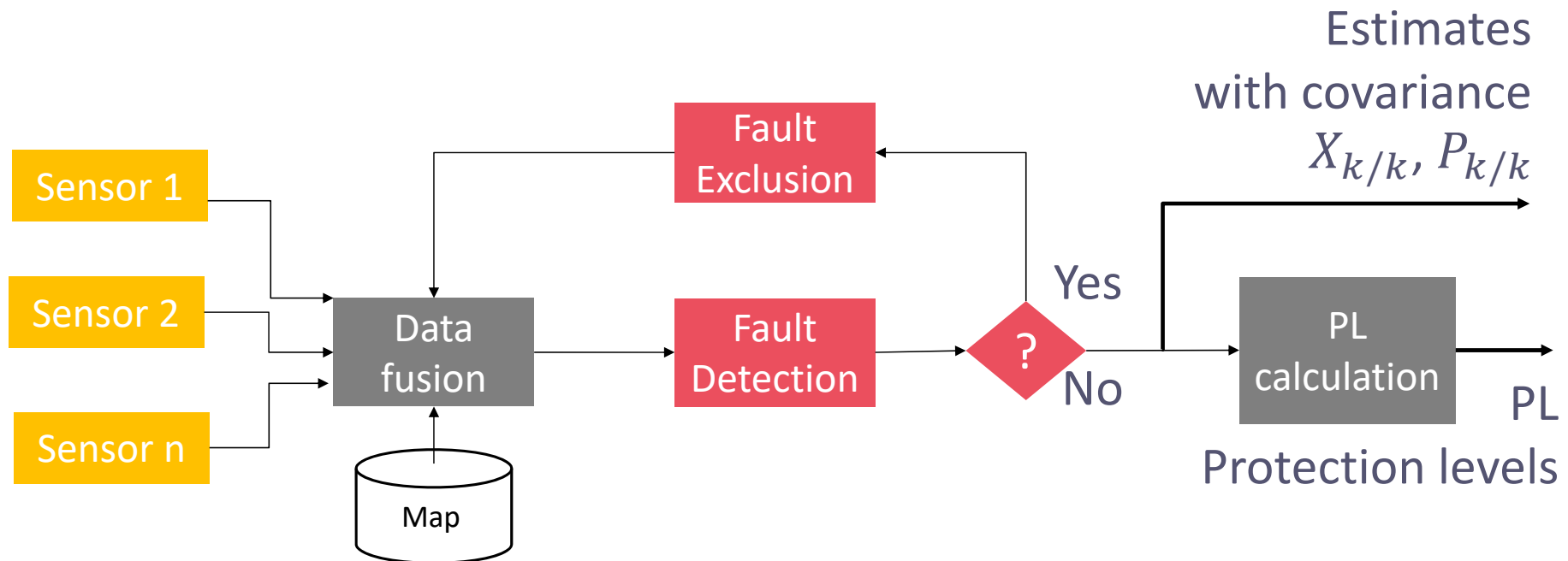
Two kinds of processing are required

- Fault Detection and Exclusion (FDE)
  - Informational filter
- A robust data-fusion engine is necessary to avoid overconfidence due to remaining faults (Protection Level computation)
  - Student's t filtering

# Heavy Tail Distribution



# Robust Multi-sensor data fusion with integrity



## Data fusion engine: Student's t filtering

- J Al Hage, P Xu, P Bonnifait, J Ibañez-Guzmán. Localization integrity for intelligent vehicles through fault detection and position error characterization. IEEE Transactions on Intelligent Transportation Systems 2022.
- J Al Hage, P Xu, P Bonnifait. Student's Information Filter with Adaptive Degree of Freedom for Multi-Sensor Fusion. International Conference on Information Fusion 2019.

# Conclusion

What is the significance of localization for autonomous navigation?

- If used for control
  - PL and TIR must be very small
  - Difficult to reach this level of performance in open and uncontrolled environments
- If used for decision making
  - Lane level localization, cooperative systems, etc.
  - The accuracy and integrity requirements are lower, which is easier to achieve

## Map-aided Lidar Localization

- Important issues
  - Map features accuracy and integrity
  - Data association

## Integrity method for Intelligent Vehicles

- Faulty measurements and associations rejection (FDE)
- Error bound (PL) with heavy tailed distributions (like Student's t)



# Thank you for your attention!

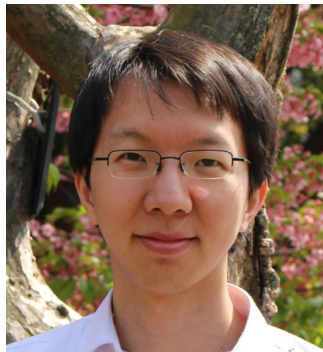
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