interactIVe

Accident avoidance by active intervention for Intelligent Vehicles

Fusion in EU projects and the Perception Approach

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  - EUCLIDE
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Introduction

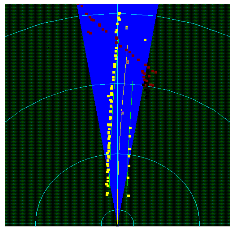
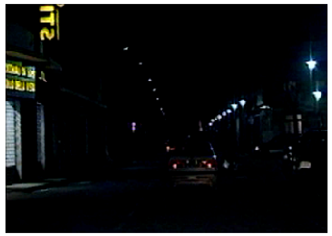
- Data fusion central role in current & future ITS
- Stand alone sensors not sufficient (physical limitations)
- Fusion of information from heterogeneous sources
  - Perception sensors: radars, cameras, laserscanners etc.
  - Digital maps
  - Wireless communication (V2X)
- Fusion evolvement through European projects
  - EUCLIDE
  - PReVENT – ProFusion2
  - SAFESPOT
  - HAVEit
  - interactIVe

EUCLIDE

- COMPETITIVE and SUSTAINABLE GROWTH PROGRAMME
- 9 partners from *industry* & *academia*
- Enhanced human machine interface for on vehicle integrated driving support system

- Development of an on-vehicle warning system in order to support the driver in **avoiding collision** under reduced visibility conditions and in several traffic scenarios

- Two different sensors used to enhance system performance
  - far infrared camera
  - microwave radar

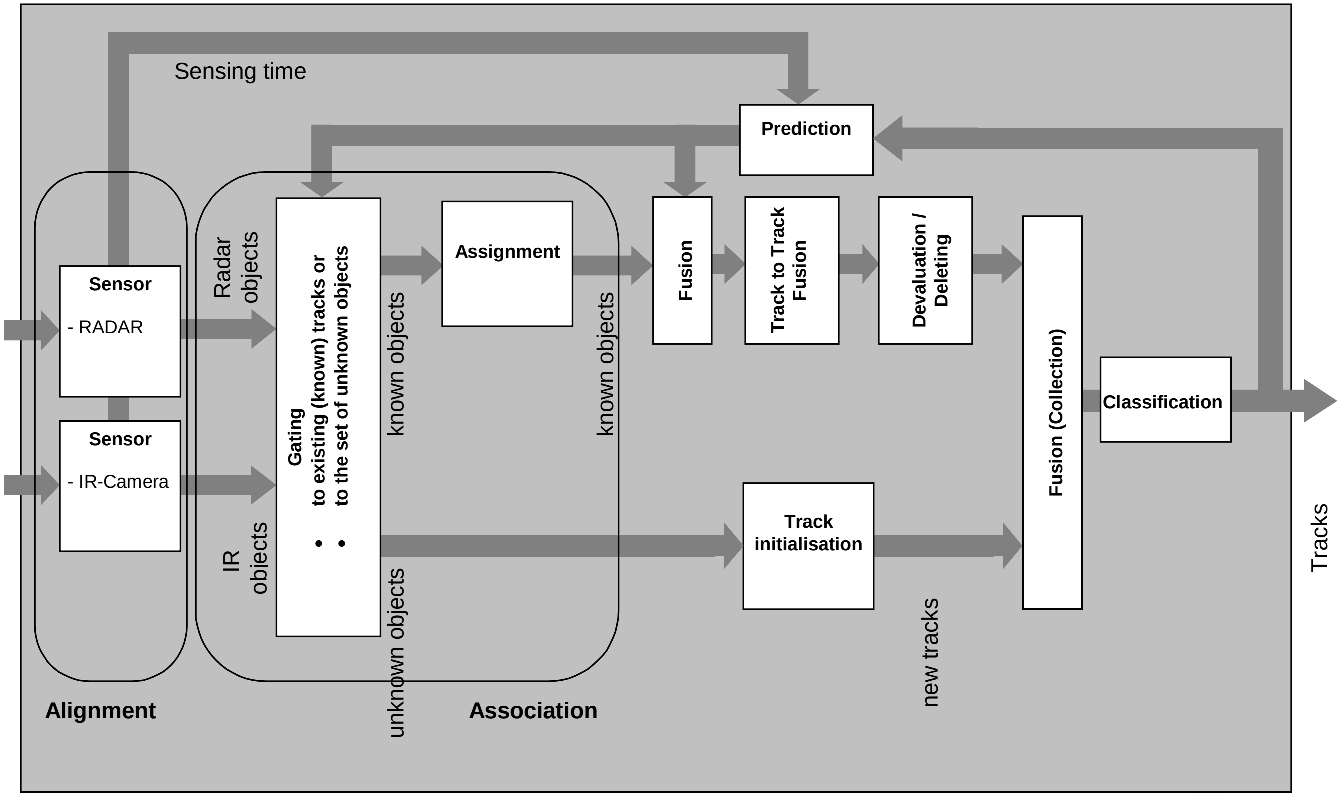




EUCLIDE – Innovation

- One of the first multi-sensor data fusion systems in automotive safety (facing the shortcomings of single sensor projects like DARWIN and AWARE)
- Integration of Far infrared sensor with radar sensor offering a detailed representation of the vehicle environment able to operate under almost every weather condition
- Enhanced situation awareness due to combination of information from two completely different sensors
- Threat assessment was implemented using dynamic models for the prediction of the future position of the ego vehicle and of other detected objects
- Optimum HMI integration keeping drivers' workload low

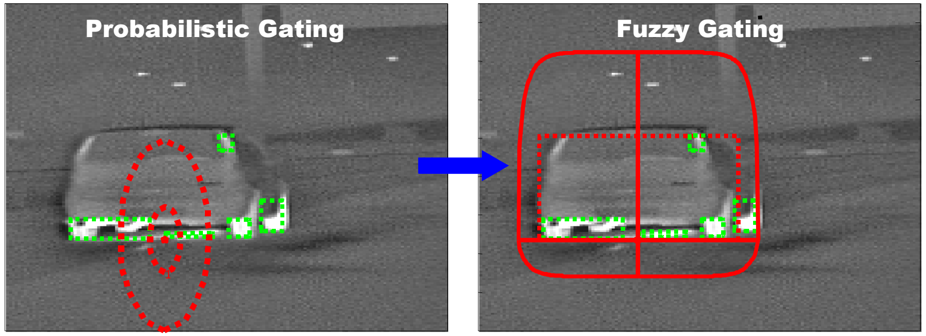
EUCLIDE – Data fusion architecture

- Fusion of data generated from an infrared camera and a radar sensor (Kalman filters, weighted arithmetic mean method)
- Deal with the tracking of multiple targets

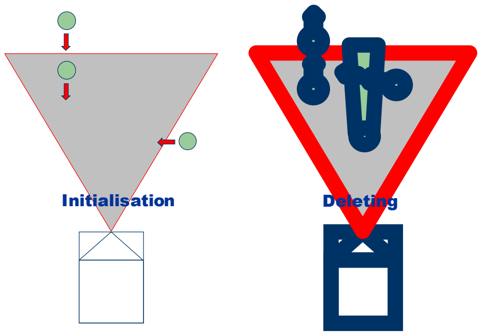


EUCLIDE – Gating, association & track management

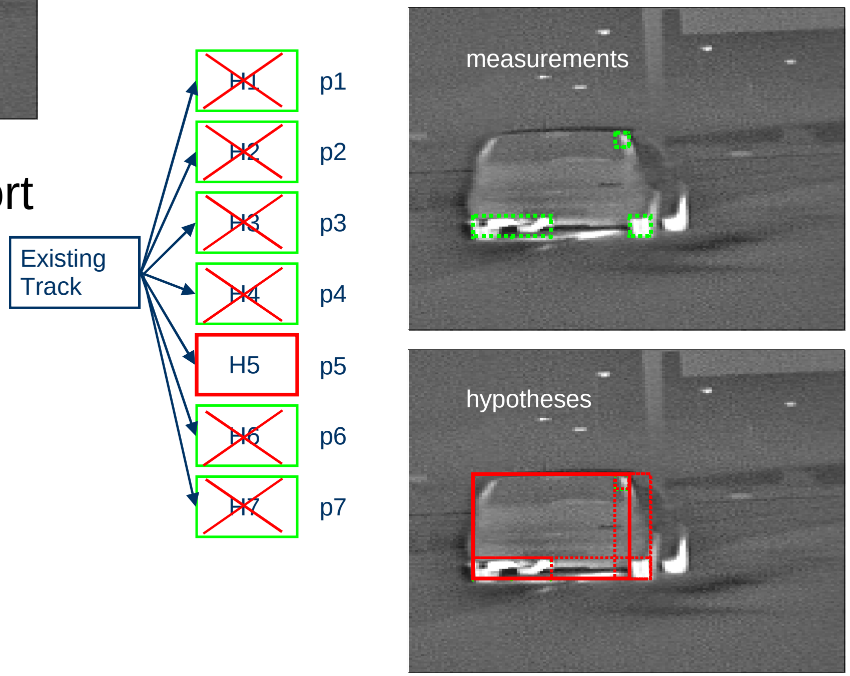
- Fuzzy gating instead of probabilistic gating



- Reducing false alarms while keeping short reaction delays of the automatic warning system (smart track management)

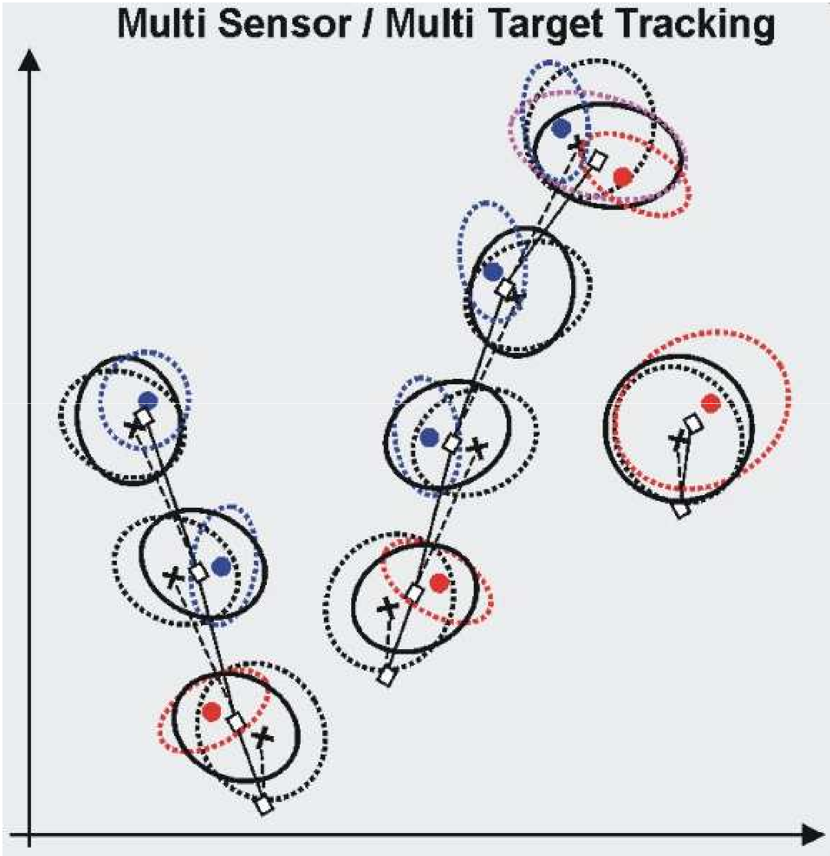


- Data association based on Multi Hypothesis Assignment



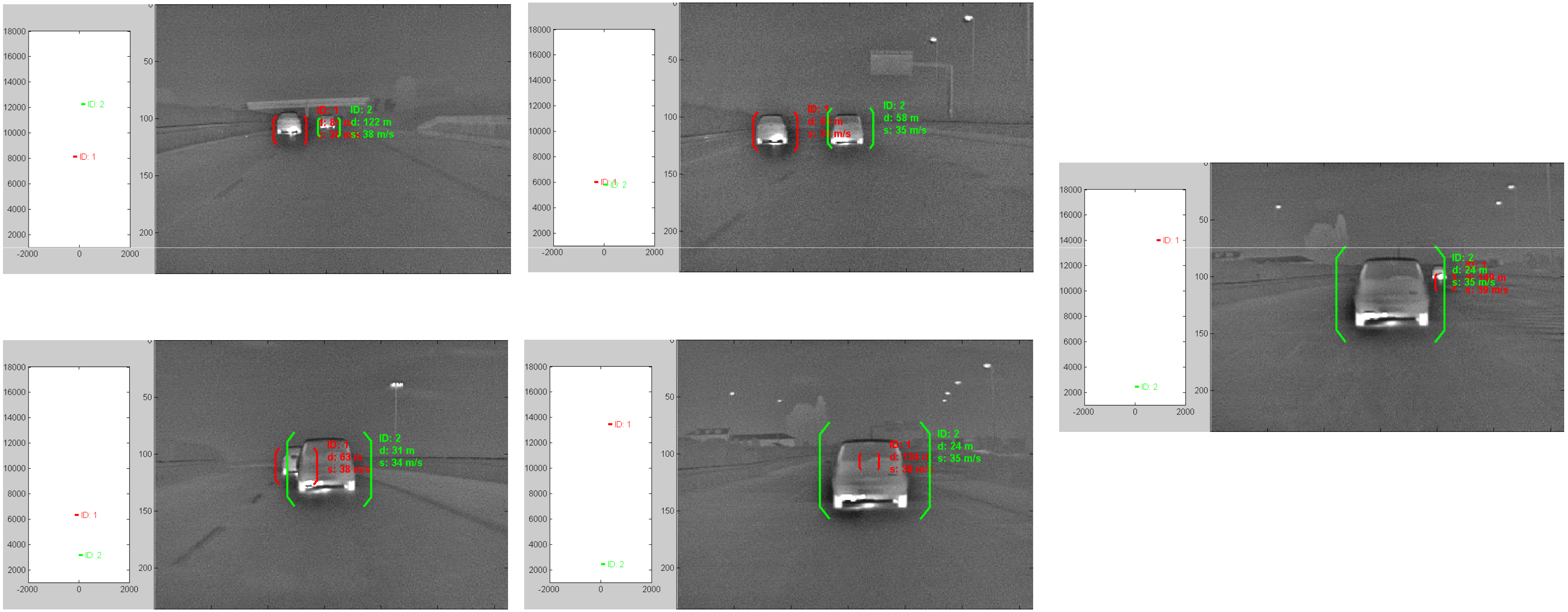
EUCLIDE – Track to track fusion

- More than one tracks can be initialised by one physical object (splitting of detections)
- These two or more tracks belonging to that one physical object must be first recognized as tracks of one physical object and then fused
- This can be done on the basis of estimated parameters as the dynamic parameters (i.e. velocity, acceleration, other significant features etc.)
- If two tracks are recognized as near enough according to the position-, dynamic- and feature distance they are fused with a weighted arithmetic mean method



EUCLIDE – Results using real data

- Overtaking scenarios with two vehicles



EUCLIDE – Lessons learned

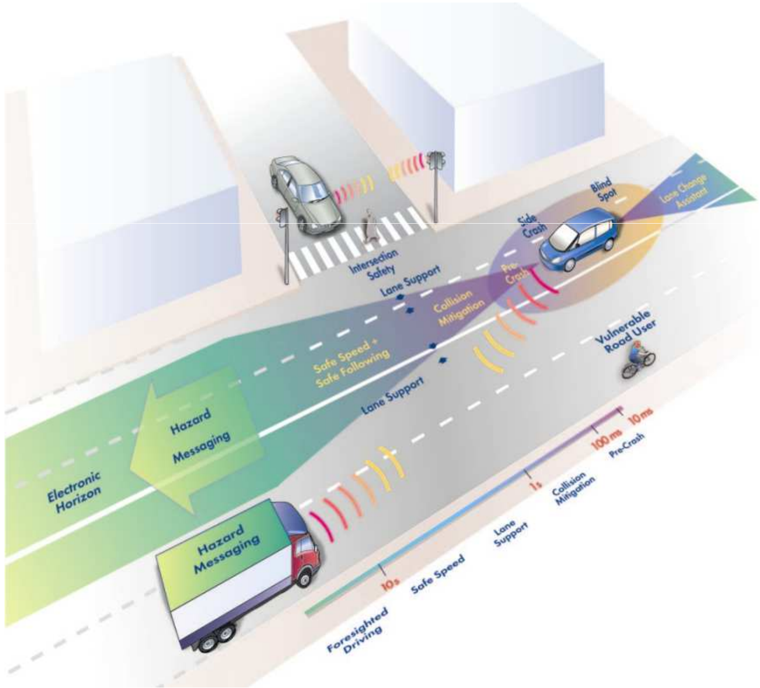
- Sensors used were expensive and unsuitable for integration and exploitation in commercial automobiles
- Sensor coverage was limited; EUCLIDE system dealt with frontal area only
- Data Fusion algorithms were adapted only for the limited case of this specific system; they were not generic adaptable to other architectures and sensors topologies
- The performance of the military radar was outstanding (incl. also an internal algorithm for detecting road borders)
- However, the radar faced some problems with ghost effects
- For a random specific target it detected also a mirrored version of this target

PReVENT – ProFusion2

- Integrated Project co-funded by the European Commission **(FP6)**
- 54 partners from *industry* & *academia / research*
- Contribution to road safety

- Development and demonstration of preventive safety applications and technologies

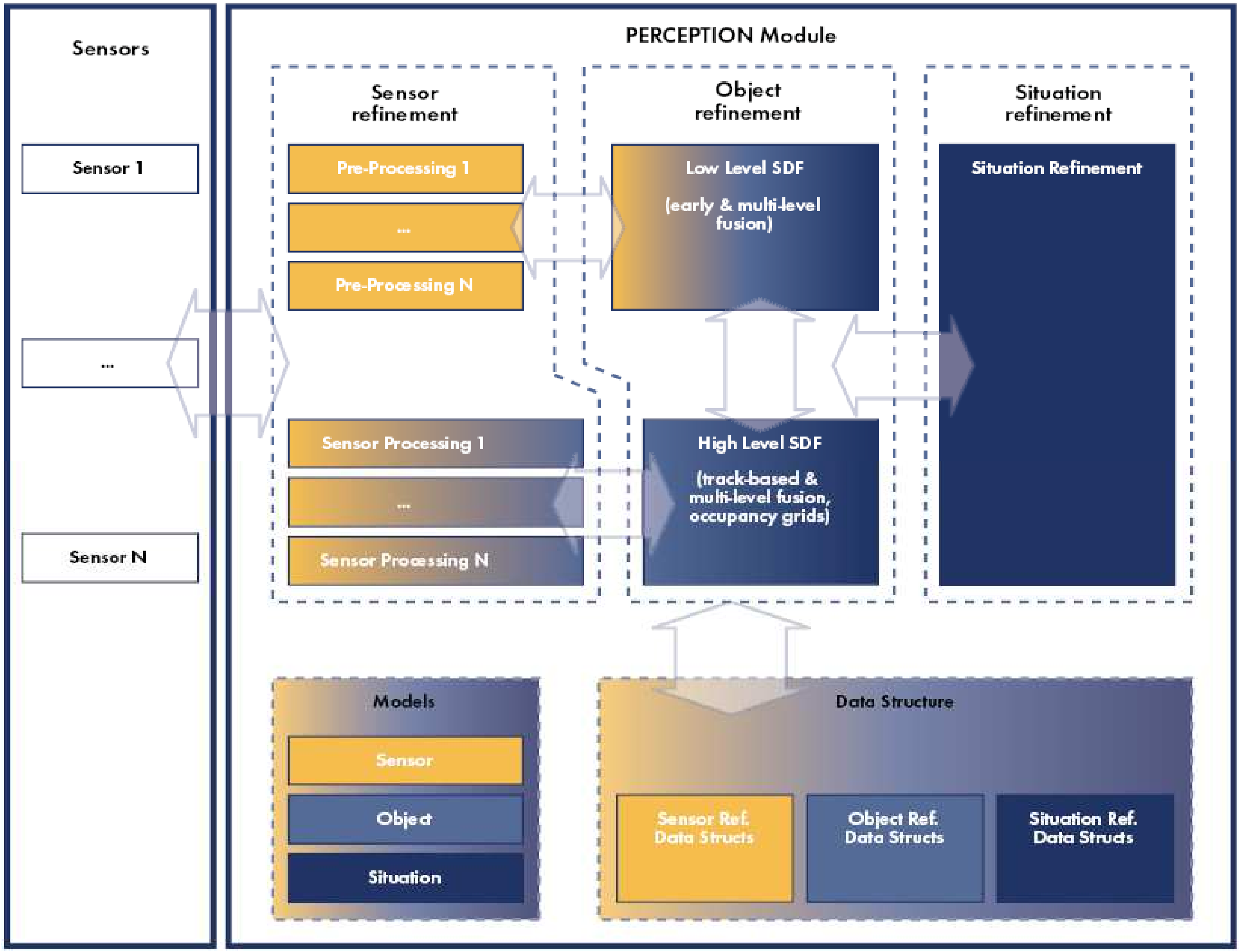
- **ProFusion2 SP**
  - Focus on sensor data fusion
  - Different fusion approaches
  - Several demonstrators



ProFusion2 – Innovation

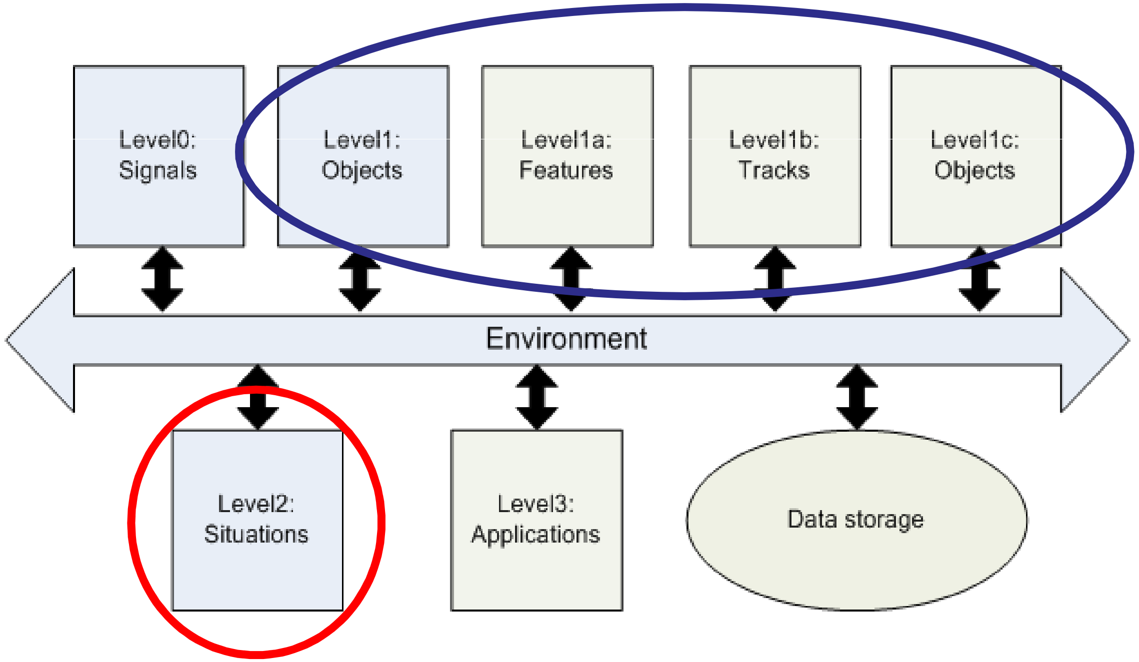
- The first systematic attempt to introduce data fusion research in automotive European projects
- Development of different fusion approaches
- Proposal of Sensor Data Fusion (SDF) framework and functional architecture
- First attempt to take into account wireless communications in cars (WILLWARN) using WiFi technology
- Test and evaluation using several different demonstrators running different applications
- Close cooperation between PF2 and vertical SPs

ProFusion2 – SDF framework



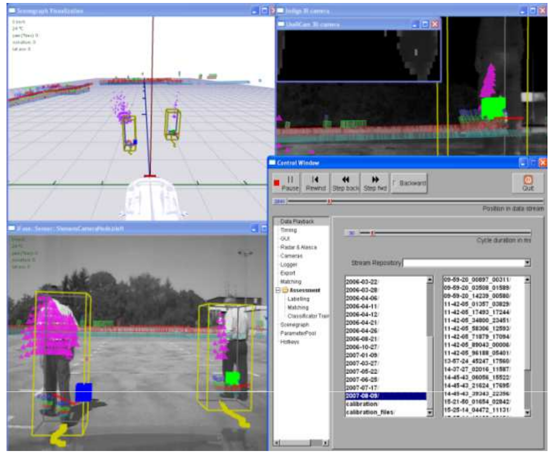
ProFusion2 – Functional model

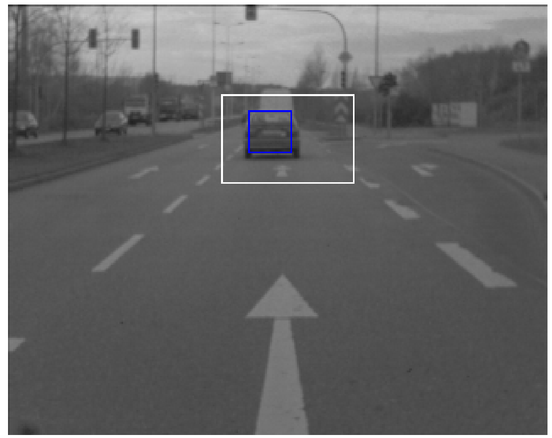
- Based on Joint Directors of Laboratories (JDL) model
- Object Refinement level
- Situation Refinement level



ProFusion2 – Fusion approaches (1)

- Four different fusion approaches
  - ***Early Fusion*** **(FORWISS)**
    - use of slightly pre-processed data
    - processing of all data from different sensors "as a whole"
    - exploitation of redundant sensor information on a lower level
  - ***Multi-level Fusion*** **(TUC)**
    - fuse data of multiple sensors on multiple levels
    - covers the sensor data level up to the situation level
    - high-level to low-level and/or vice versa signal flow directions

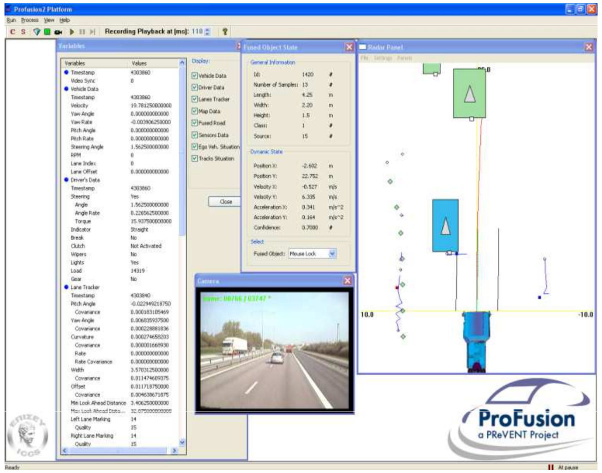




ProFusion2 – Fusion approaches (2)

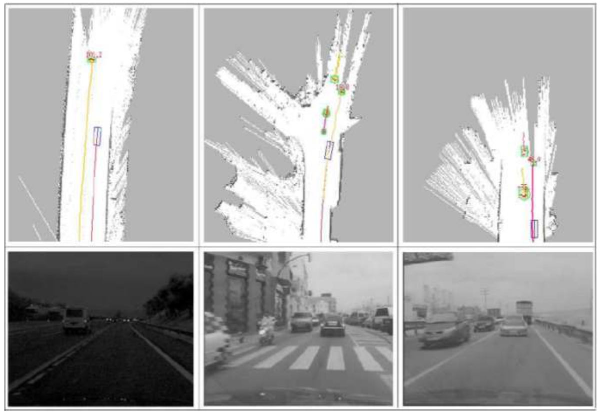
❖ ***Track Level Fusion & Situation Refinement* (ICCS)**

- one level of processing (i.e. tracking) is carried out inside each sensor
- track arrays feed the track level fusion algorithm
- situation analysis included (e.g. path prediction, maneuver detection, driver intention etc.)



❖ ***Grid Based Fusion* (INRIA)**

- occupancy grid framework
- map the surrounding environment of the vehicle and perform perception in this occupancy grid
- the grid is built using all the data available at a given time

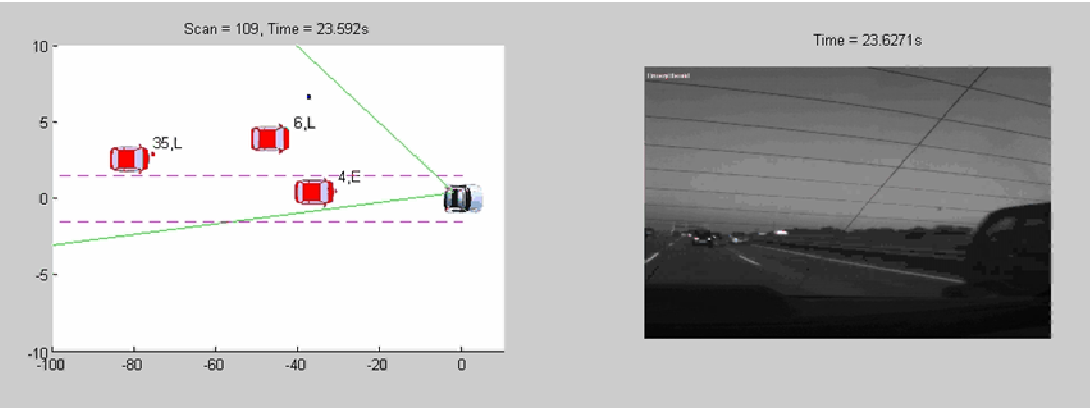


ProFusion2 – Demonstrators

Use Cases \ Fusion Approaches	Early Fusion (Universität Passau)	Multi-Level Fusion (Chemnitz University of Technology)	Grid-Based Fusion (INRIA)	Track-Level Fusion
PF2 COMPOSE (BMW Group Forschung und Technik)				
PF2 INSAFES (Centro Ricerche Fiat)				
PF2 SASPENCE (Centro Ricerche Fiat)				
PF2 APALACI (DaimlerChrysler)				
PF2 COMPOSE & SAFELANE Truck (Volvo)				

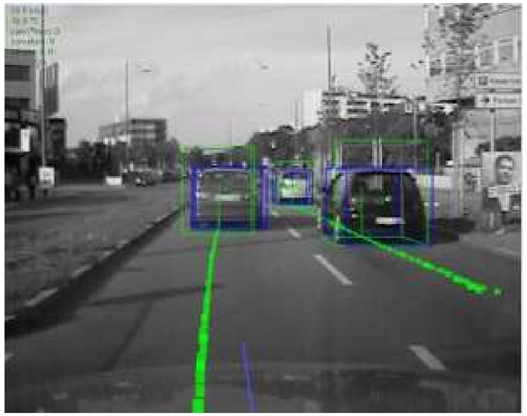
ProFusion2 – Lessons learned

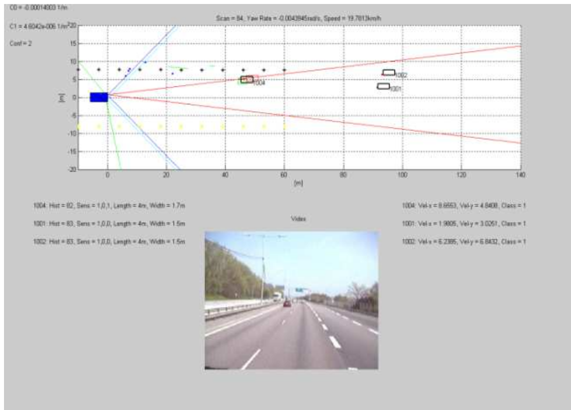
- Difficult to automate the perception process
- Some sensors are designed for frontal applications and when used in rear ones false alarms or missed targets was the result
- Sensor mounting and definition of sensor interfaces are crucial issues
- A lot of space is needed for the fusion processing units
- Image processing is a demanding task (significant processing power is needed)



ProFusion2 – Conclusions

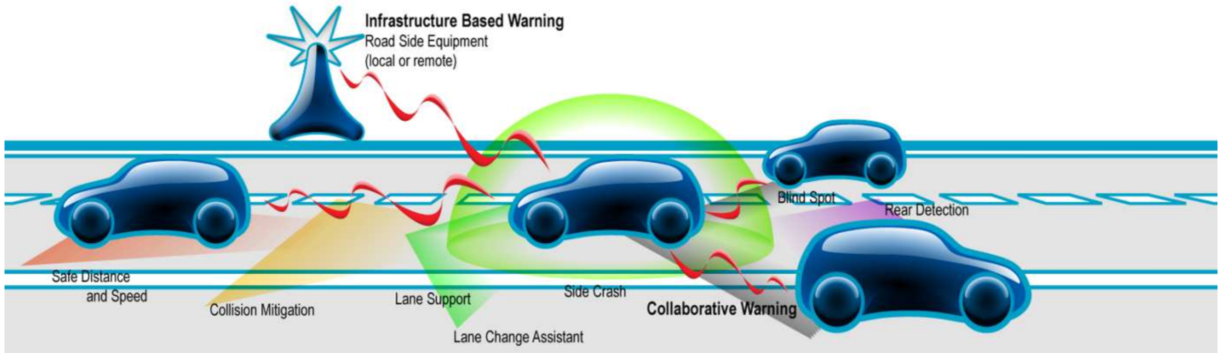
- ❑ Each fusion approach has its pros and cons in terms of processing power, ease of adaptation in different demo cars etc.
- ❑ Several SPs (SAFELANE, INSAFES, SASPENCE etc.) where data fusion tested and validated
- ❑ All approaches showed good performance
- ❑ Deficiencies highlighted and addressed in successor projects (e.g. HAVEit, interactIVe)





SAFESPOT

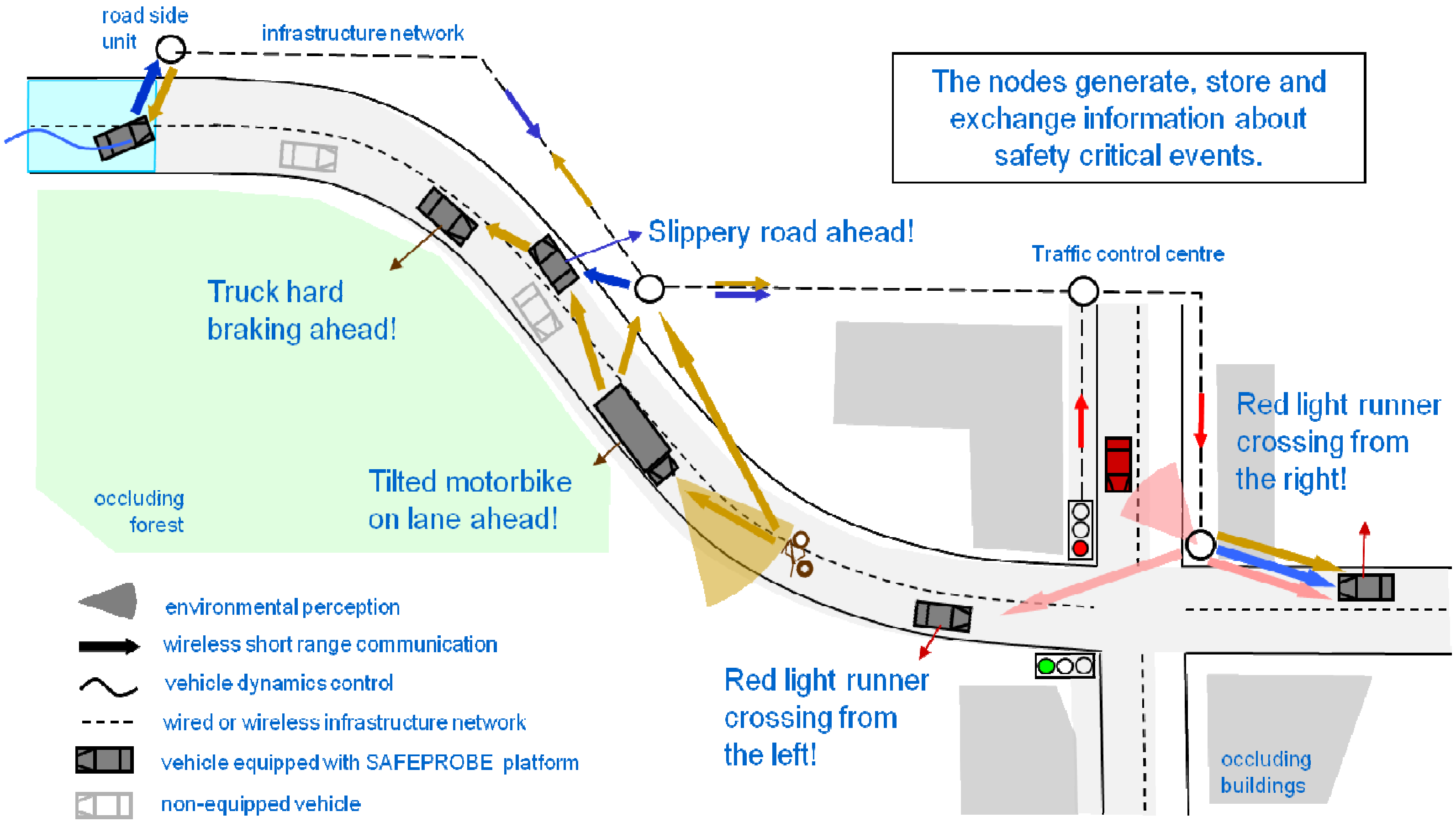
- Integrated Project co-funded by the European Commission **(FP6)**
- 53 partners from *industry* & *academia*
- Cooperative applications for enhancing road safety
- Road accidents prevention via a SAFETY MARGIN ASSISTANT to detect in advance potentially dangerous situations and extend, in space and time, drivers' awareness of the surroundings



SAFESPOT – Innovation

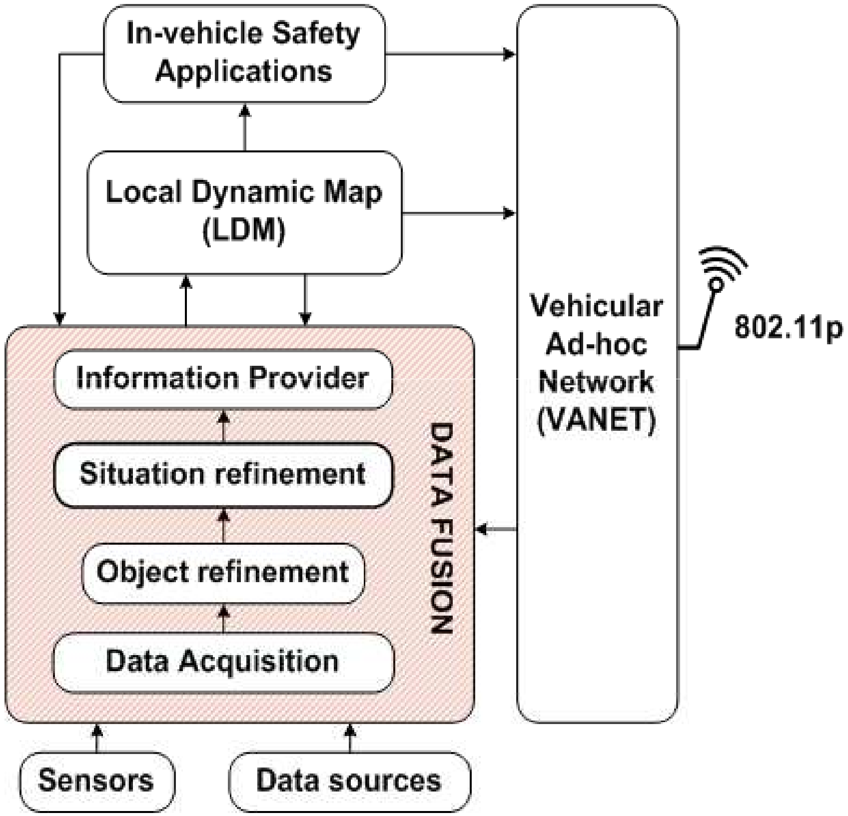
- SAFESPOT used PF2 SDF functional model (Situation Refinement – SR, Object Refinement – OR) and the experience gained in PReVENT
- Incorporation of cooperative data fusion techniques
- Wireless communications using 802.11p technology
- Close cooperation with CVIS based on CALM5
- Cooperative Pre-Data fusion laserscanner-based
- Advanced situation awareness (SR algorithms) of the vehicular environment (incl. traffic estimation, fog detection etc.)

SAFESPOT – Scenario

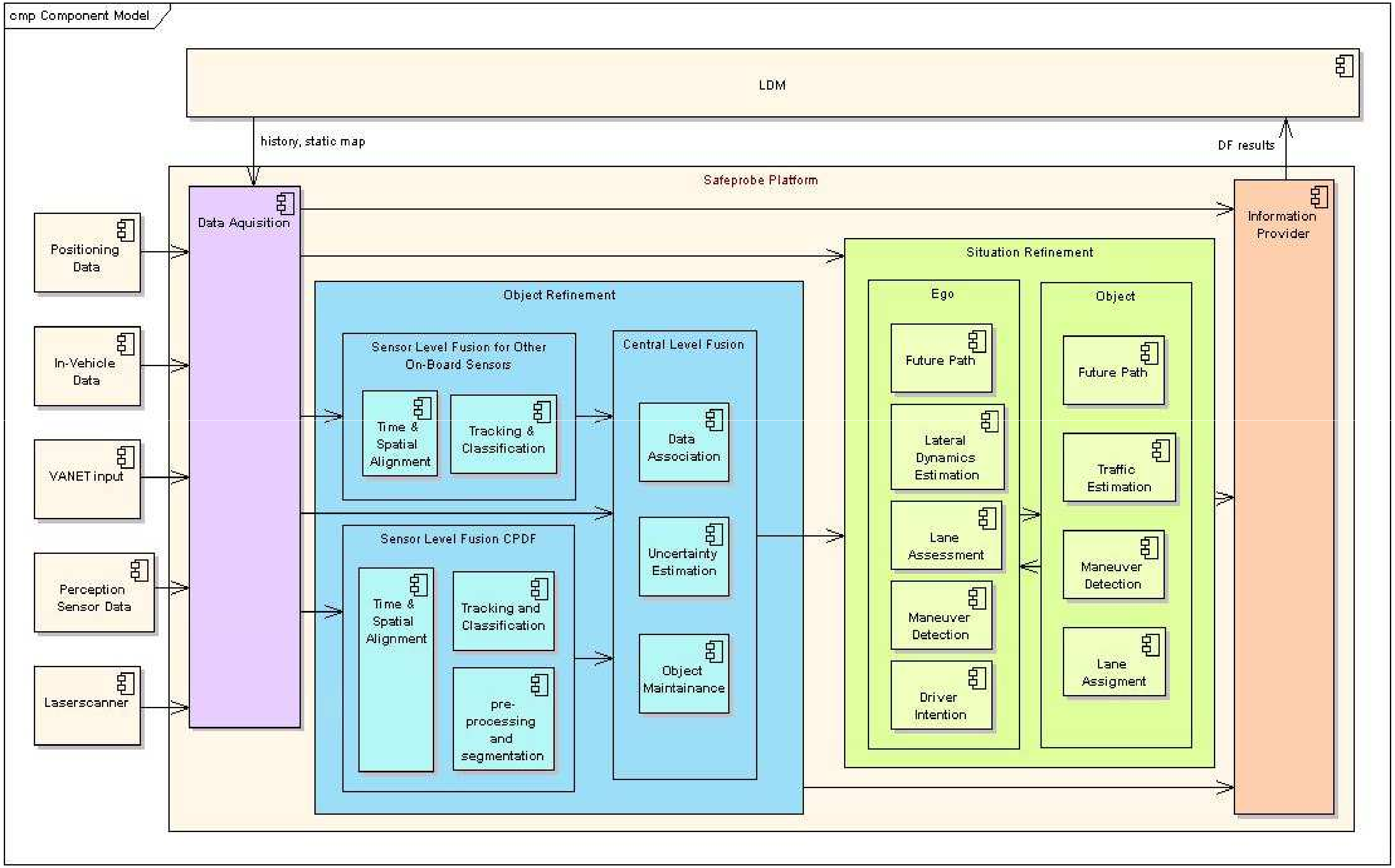


SAFESPOT – Fusion in Cooperative Systems

- Vehicle-to-X communication and data fusion techniques make the core of the system.
- Sensor data fusion systems are employed, to get an improved picture of the host vehicle's surrounding.
- Research findings include a data fusion structure and architecture, tracking methods as well as vehicle and road models and related parameter estimation.

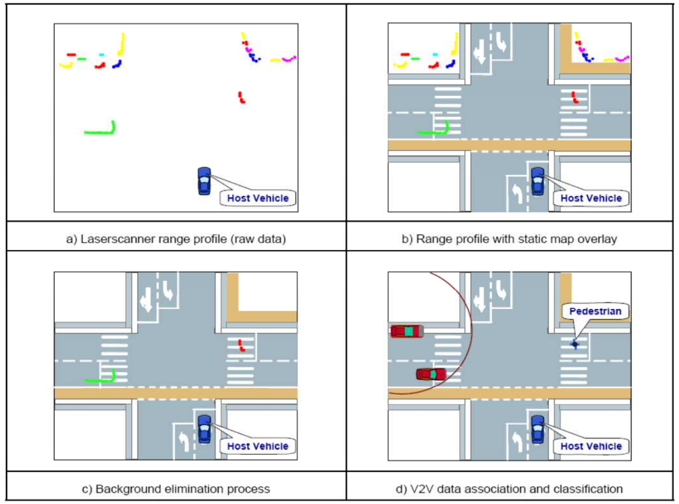


SAFESPOT – Fusion Architecture

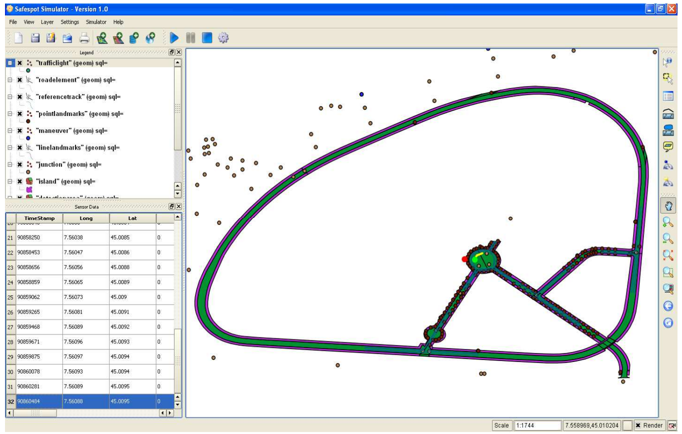


SAFESPOT – Main Data Fusion blocks

- **Co-operative pre data fusion (IBEO)**
  - Laserscanner-based fusion module
  - Objects' detection in host vehicle's vicinity
  - V2V data association
- **Object refinement (CRF)**
  - Temporal and spatial alignment
  - Uncertainty estimation & object maintenance
  - Central level fusion approach
- **Situation Refinement (ICCS)**
  - Future path estimation
  - Maneuver detection
  - Assignment of objects to lanes
  - Detection of high level events (i.e. fog, traffic)

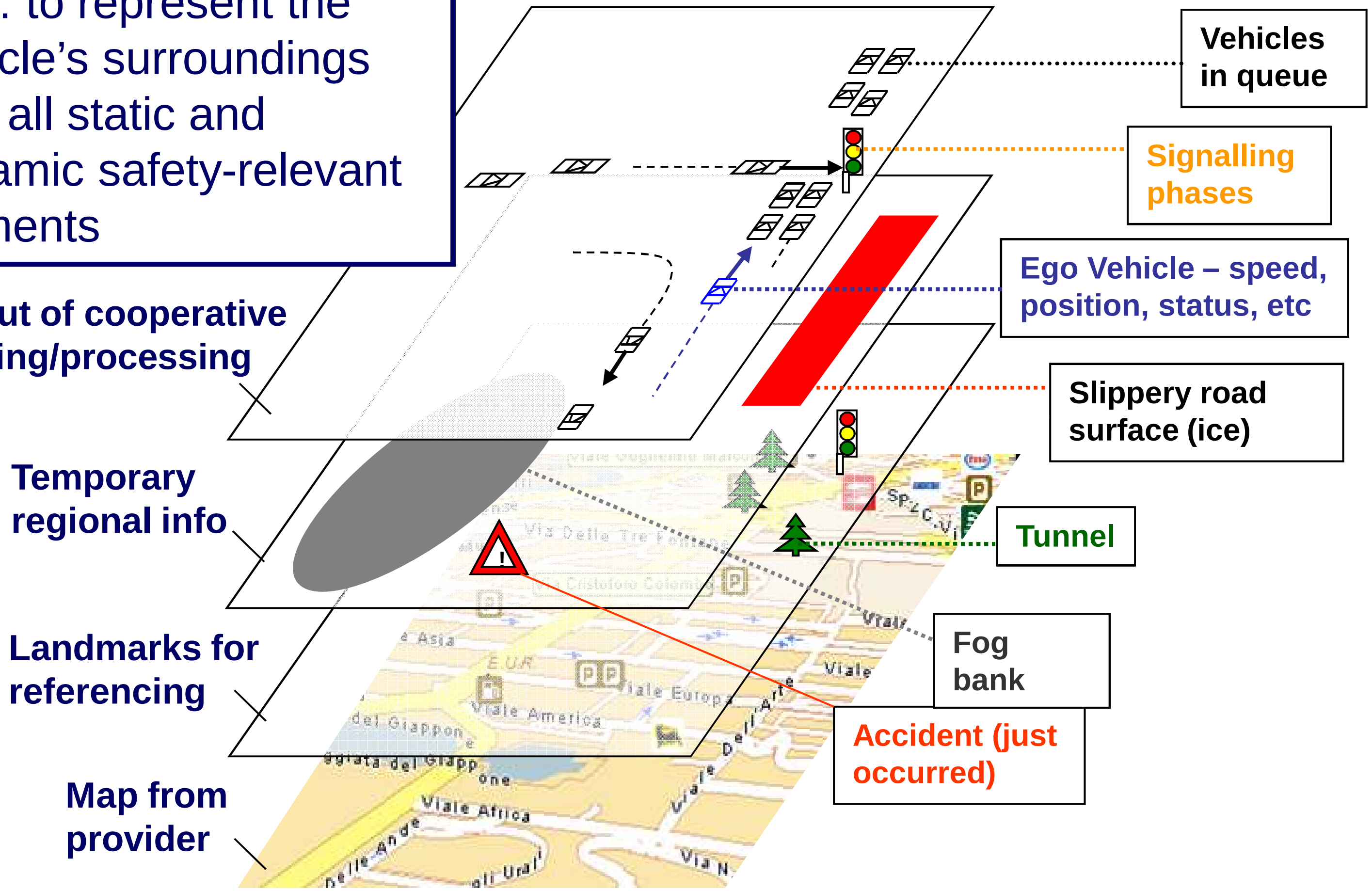


a) Laserscanner range profile (raw data)
b) Range profile with static map overlay
c) Background elimination process
d) V2V data association and classification

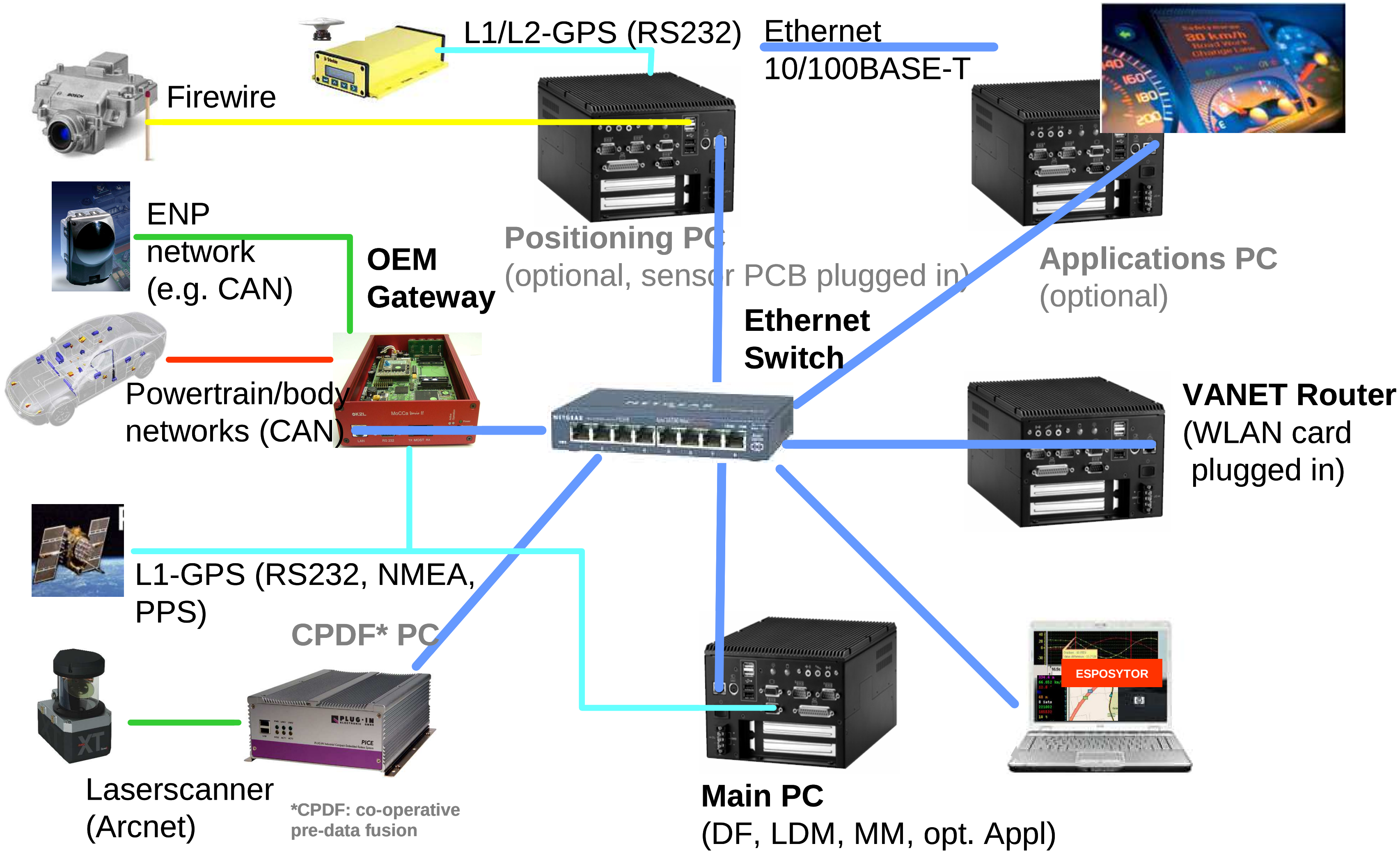


SAFESPOT – Local Dynamic Map

Aim: to represent the vehicle's surroundings with all static and dynamic safety-relevant elements



SAFESPOT – In-vehicle HW architecture

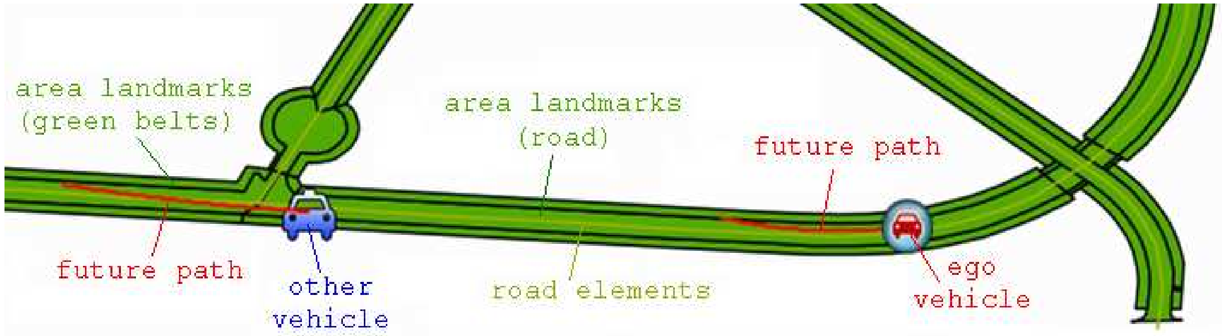


SAFESPOT – Lessons learned

- More research is needed for handling delayed information received from the wireless medium
- Further investigation is needed for cooperative tracking and data association
- Synchronization of vehicles-nodes of the VANET is not trivial and critical for the fusion process
- The creation and the management of a database (LDM) for safety related applications need more investigation and customization

SAFESPOT – Conclusions

- The data fusion functional model adopted from PReVENT
- Results showed a good performance of cooperative fusion
- Cooperative Data Fusion challenging
- Wireless communication enhances road safety
- Validation of results in different test sites and in different demonstrators



HAVEit

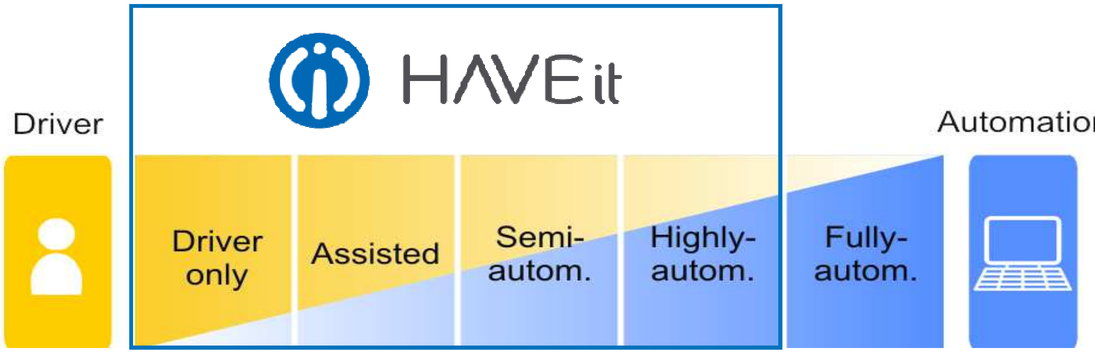
- Integrated Project co-funded by the European Commission **(FP7)**
- 23 partners from *industry* & *academia*
- Highly automated driving

- Real-time perception requirements
- Multi sensor platforms
- Scalable architecture

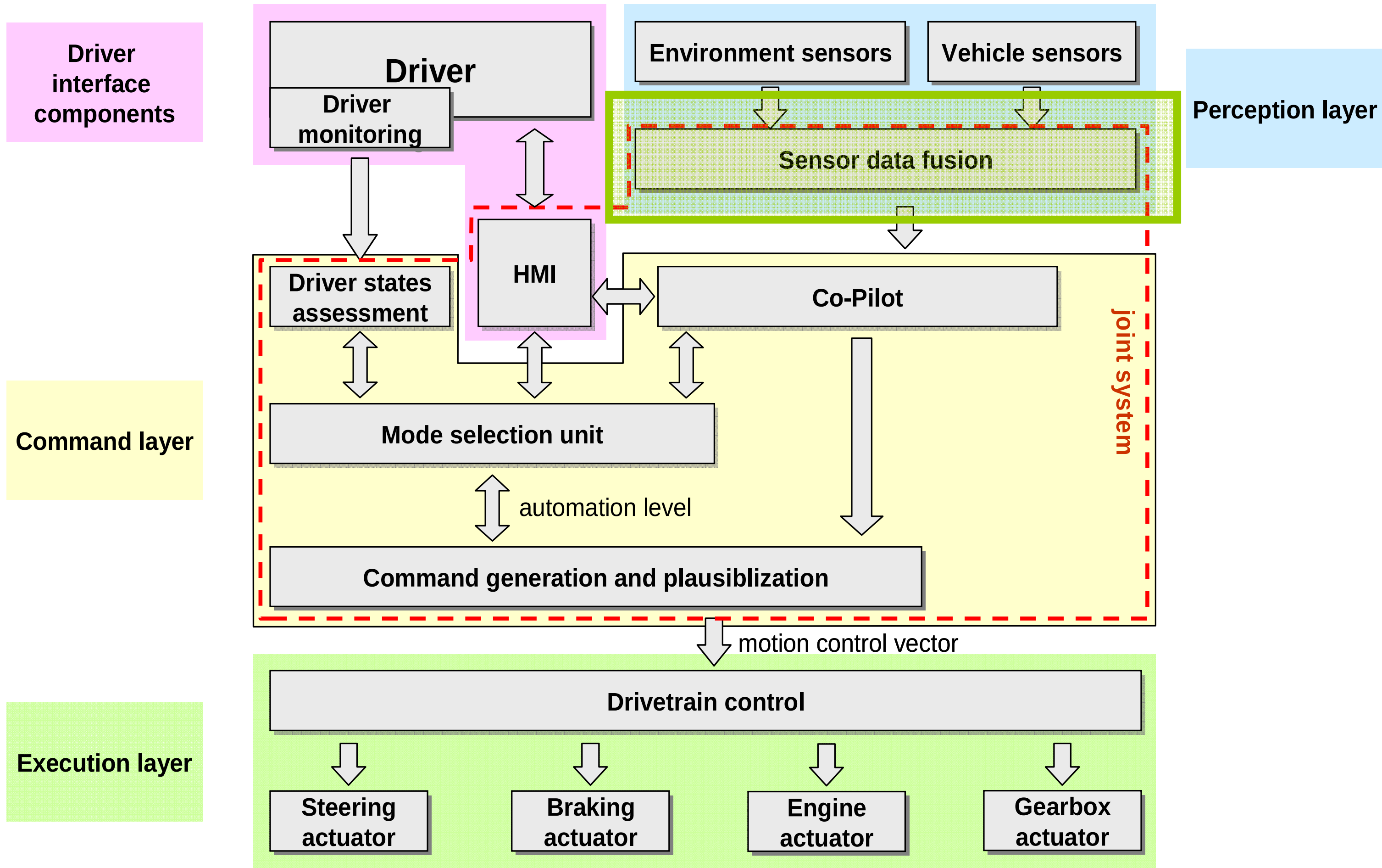
- Different kind of applications:
  - Safety enhancement
    - Driver overload
    - Driver underload
  - Energy optimization and emission reduction

HAVEit – Innovation

- Hard real-time perception algorithms (highly automated vehicles)
- Fusion of the individual sensor data into a unified perception output
- Improved estimation accuracy and robustness
- Development of generic fusion modules
- Use of common interfaces



HAVEit – Joint System & Data fusion

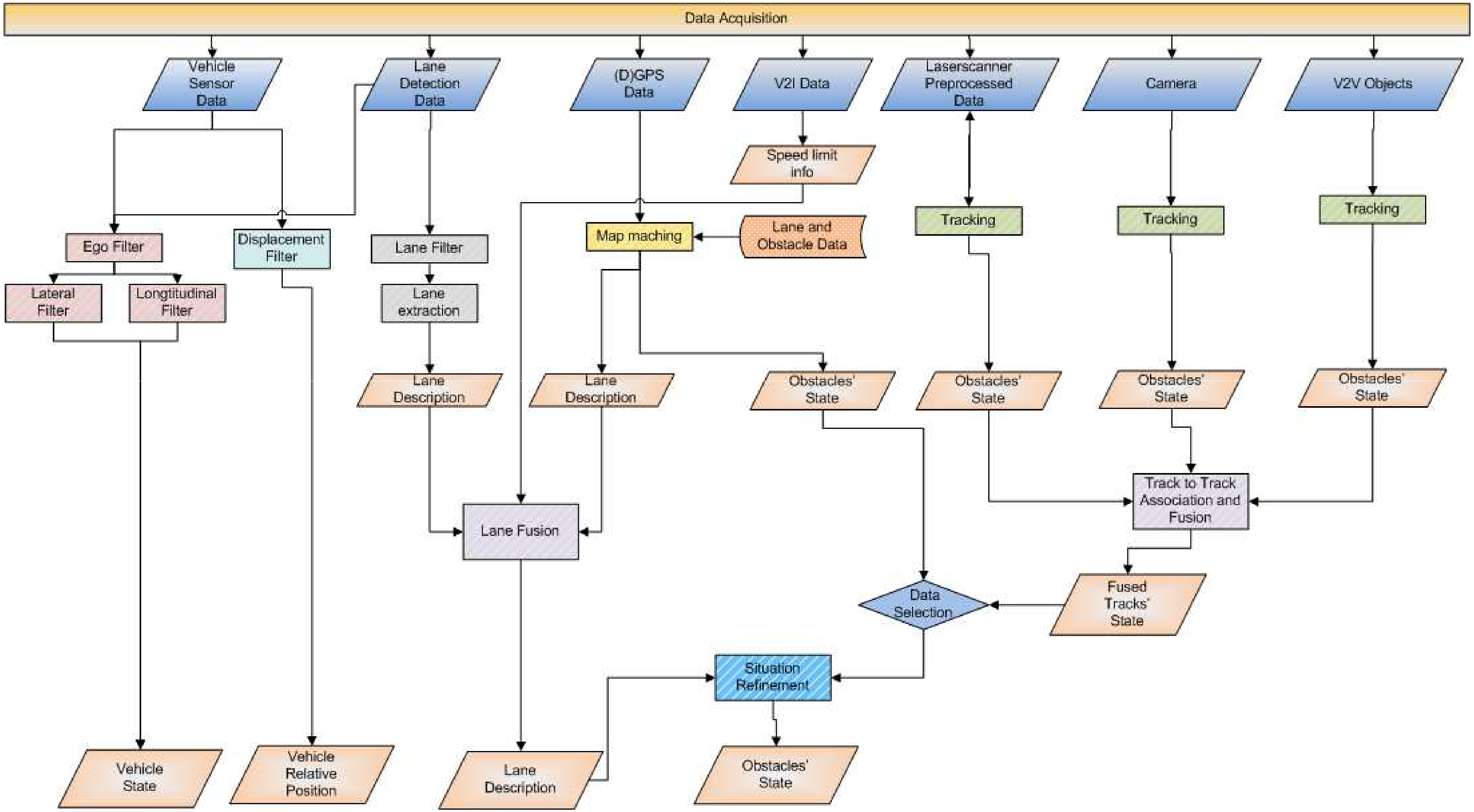


HAVEit – Data fusion overview

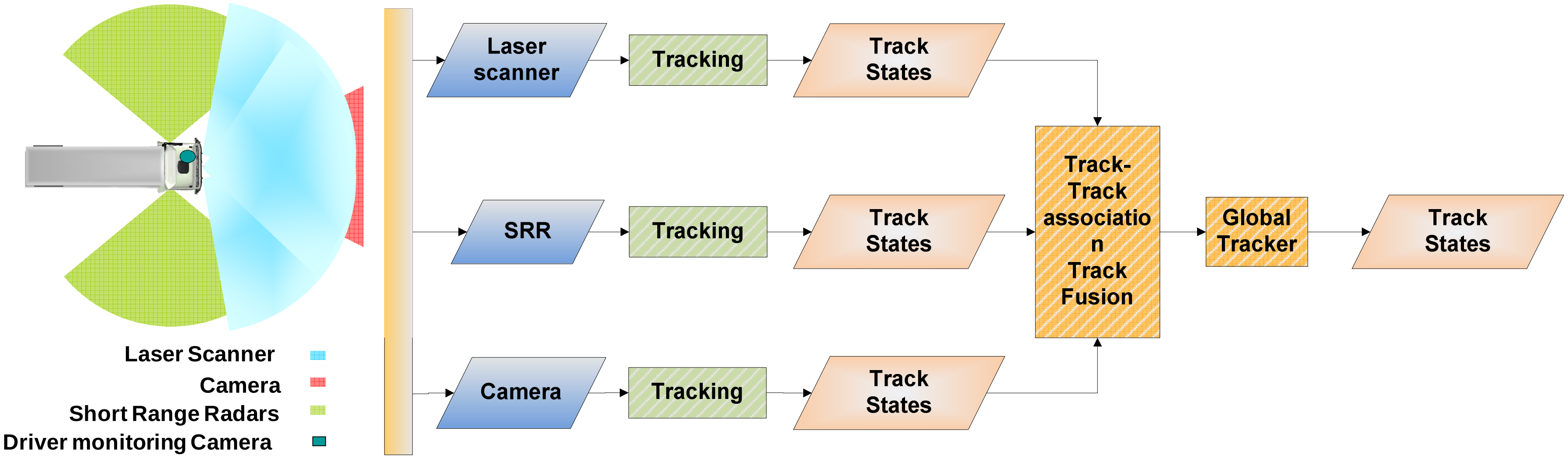
- **Perception layer**
  - Ego vehicle state
    - Kinematic
    - Relative to the road
  - Road Environment
    - Lanes
    - Objects
  - Additional information

- **The Generic data fusion concept**
  - 2 levels of processing hierarchy
  - Implementation of the same algorithms for different demos
  - Implementation of SW modules applicable to many HW platforms

HAVEit – Data fusion architecture



HAVEit – Tracking architecture



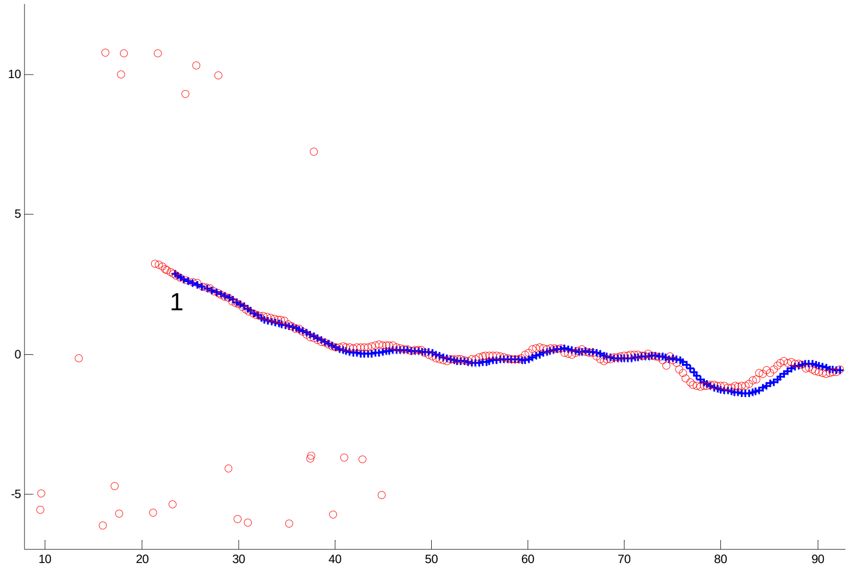
2 Levels of tracking

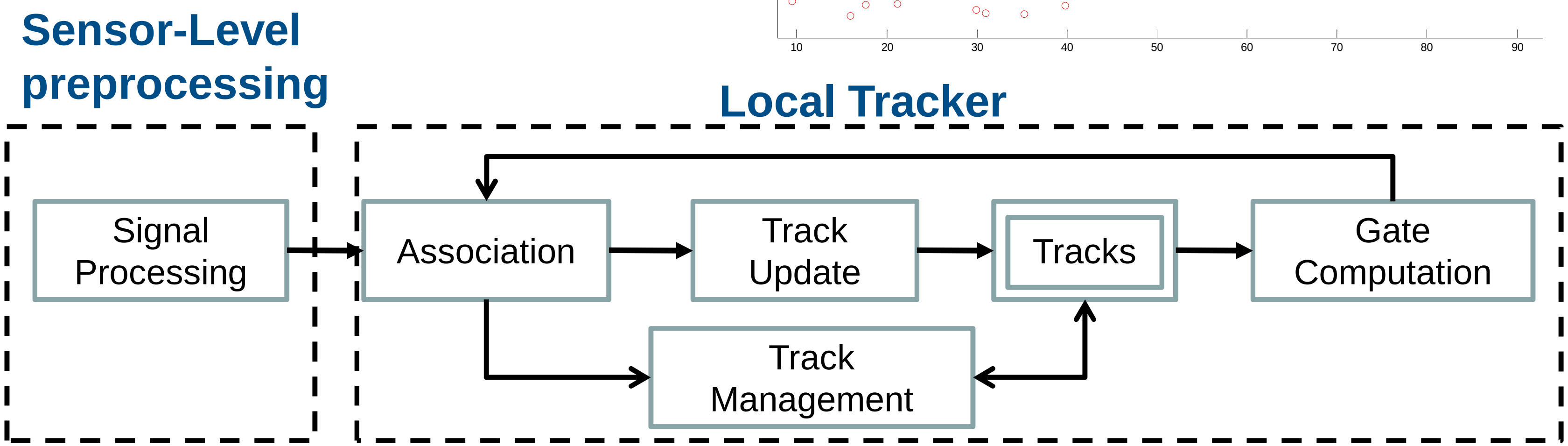
- Sensor Level
- Central Level

HAVEit – Sensor level tracking

HAVEit

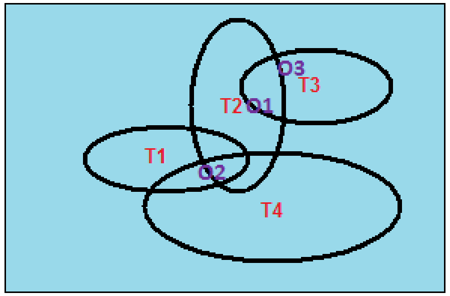
- Association of consecutive sensor observations of the same targets into tracks





HAVEit – Tracking and state update

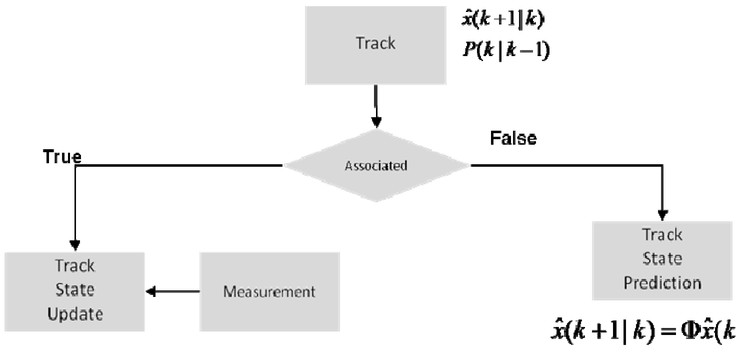
- Gate Calculation
- Measurement to track assignment using auction algorithm
- Track confirmation and deletion is done using “hit” and “miss” based rules
- Track state update is done using the standard Kalman filter



$$\begin{array}{c} T1 \\ T2 \\ T3 \\ T4 \end{array} \begin{bmatrix} 0 & 3.45 & 0 \\ 6.7 & 1.2 & 2.1 \\ 1.6 & 0 & 5.1 \\ 0 & 0.2 & 0 \end{bmatrix}$$

Gate Computation

$$a_{ij} = G_{ij} - d_{ij}^2$$

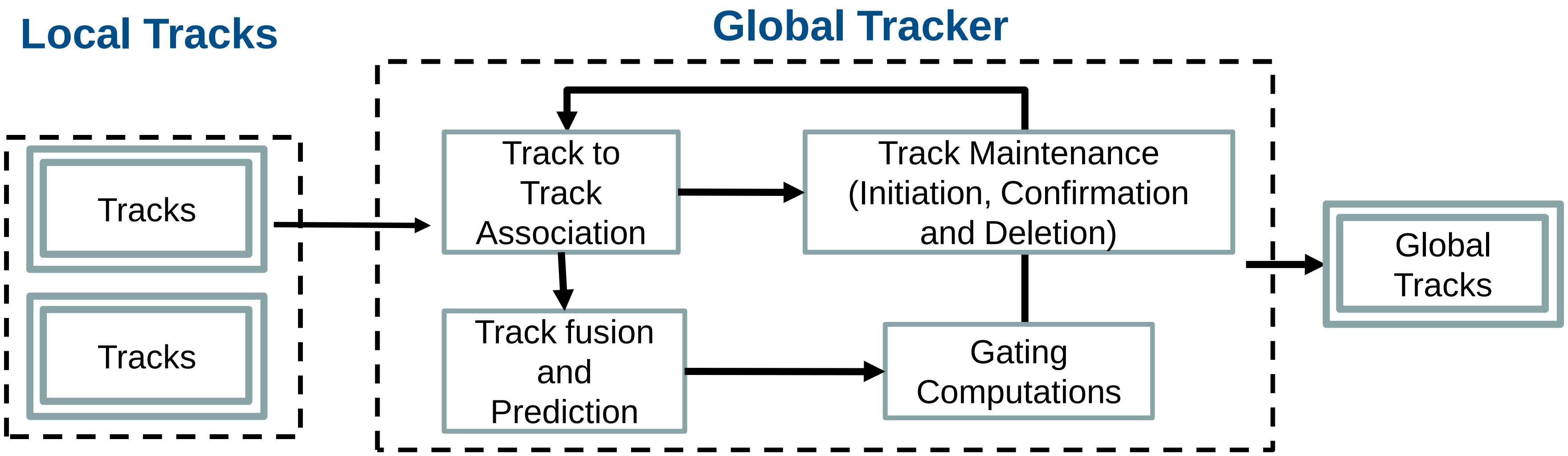


$$\hat{x}(k+1|k) = \Phi\hat{x}(k|k-1)$$
$$P(k+1|k) = \Phi P(k|k-1)\Phi^T$$

$$\hat{x}(k+1|k) = \Phi\hat{x}(k|k-1) + K_p(k)\left[y(k) - H\hat{x}(k|k-1)\right]$$
$$K_p(k) - \Phi P(k|k-1)H^T\left[HP(k|k-1)H^T + R\right]^{1}$$
$$P(k+1|k) = \left[\Phi - K_p(k)H\right]P(k|k-1)\Phi^T + Q$$

HAVEit – Central level tracking

- Identify local tracks that represent the same object
- Fuse local track estimates
- Track ID maintenance in track transitions between sensor FOVs



HAVEit – Track fusion

- Takes as input the track lists of the local trackers and gives a single track list in the output.
- The track-to-track association module identifies which tracks from different tracks list represent the same object.
- The Mahalanobis distance of the two tracks (x_i, x_j) is calculated as follows:

$$d_{ij}^{2} = \tilde{x}_{ij}' \left(P_i + P_j - P_{ij} - P_{ij}'\right)^{-1} \tilde{x}_{ij} = \tilde{x}_{ij}' S_{ij}^{-1} \tilde{x}_{ij}$$

- The fused estimate of the two independent estimates is

$$\tilde{x} = \tilde{x}_i + \left(P_i - P_{ij}\right)\left(P_i + P_j - P_{ij} - P_{ji}\right)^{-1}\left(\tilde{x}_j - \tilde{x}_i\right) = \tilde{x}_{ij}' S_{ij}^{-1} \tilde{x}_{ij}$$

HAVEit – Lane estimation

- Lane geometry
  - Clothoid model
  - Kalman filtering

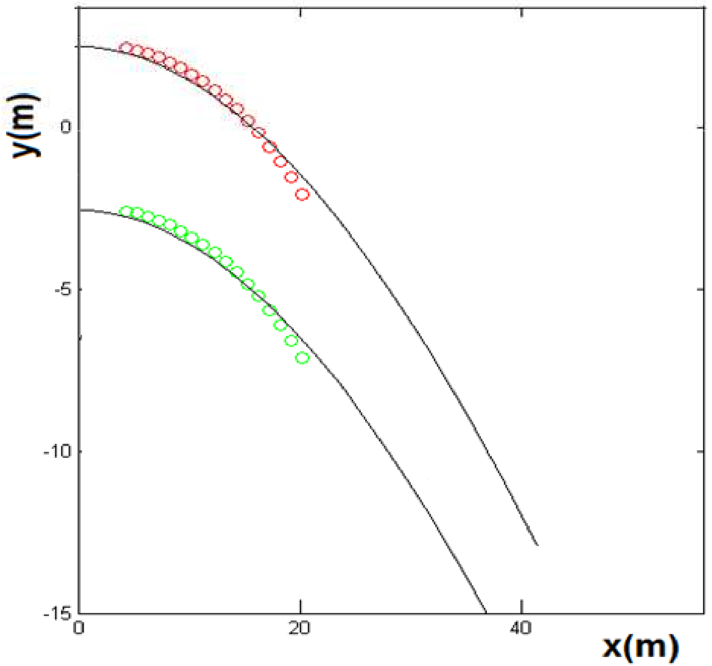
$$y(l) = y_0 + \int_0^l \sin(c_o\tau + \frac{c_1\tau^2}{2})d\tau \qquad x(l) = \int_0^l \cos(c_o\tau + \frac{c_1\tau^2}{2})d\tau$$

$$y(x) = y_0 + \tan(h)\cdot x + c_0 \cdot \frac{x^2}{2} + c_1 \cdot \frac{x^3}{6}$$

- Lane description

$$\begin{bmatrix} Curv \\ Curv_{rate} \\ y_{offs} \\ head \\ width \end{bmatrix}$$

Lane Geometry - Maps (black) - Camera (red, green)



- Lane estimation is based on the camera sensor (proved to be more reliable)
- Lane estimation based on laserscanner measurements was used as a back-up solution

HAVEit – Lessons learned

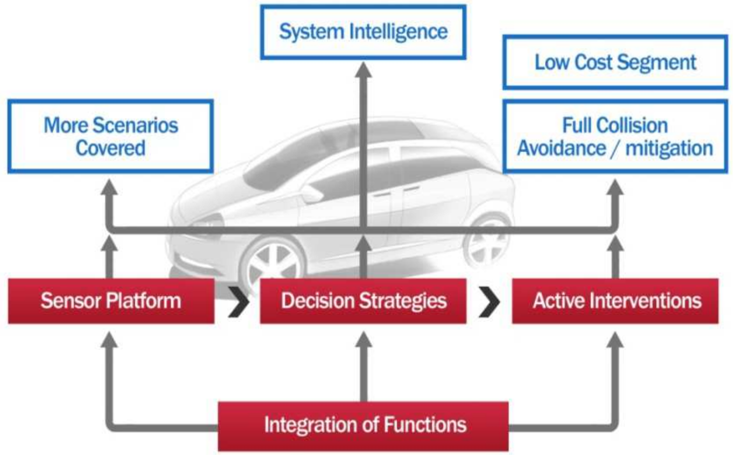
- Further investigation is needed for taking into account cooperative tracking and data association in highly automated driving
- More research is needed for handling delayed information received from the wireless medium
- Development of generic perception modules with well defined interfaces will be the challenge for future in-vehicle perception platforms
- Miniature and low cost sensors will support the deployment of automated vehicles since many sensors are required for reliable and accurate perception

interactIVe

- Integrated Project co-funded by the European Commission **(FP7)**
- 29 partners from *industry* & *academia*
- Integration of different applications
- Holistic environment perception (ADASIS v2, V2X)

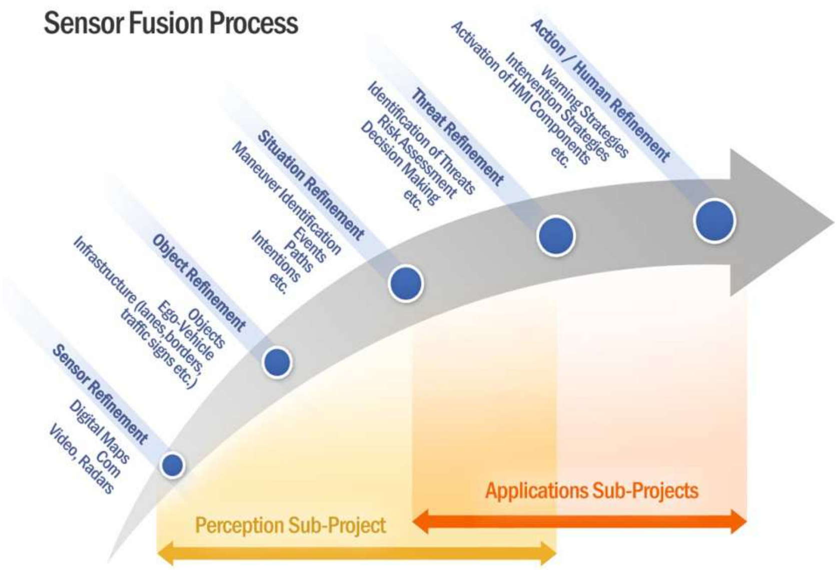
- ***Perception SP*** has central role (ICCS, DELPHI)
- Active intervention poses “hard” real-time requirements

- Different kind of applications:
  - Continuous driver support
  - Collision avoidance
  - Collision mitigation



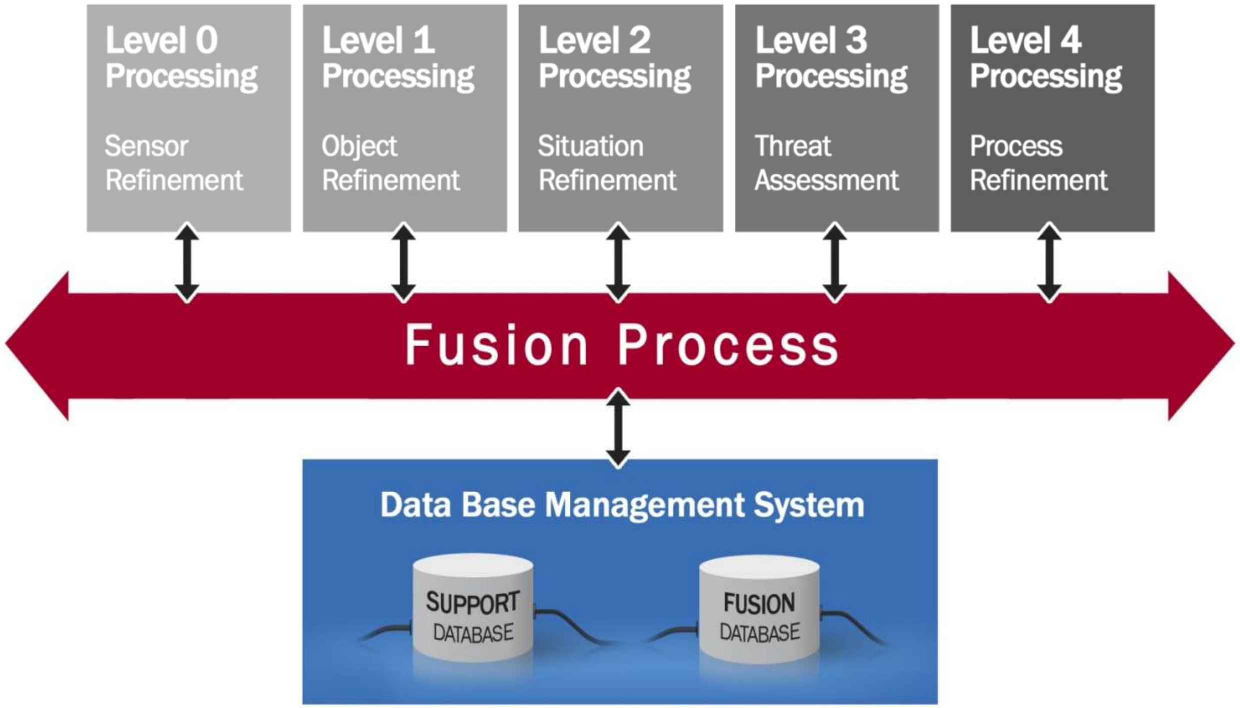
interactIVe – Innovation

- ❑ Based on PReVENT/PF2, SAFESPOT & HAVEit experience (common key partners)
- ❑ General interfaces for different sensor groups to minimize effort in the next levels of processing
- ❑ Reference perception platform implementation
- ❑ Closer to the "plug & play" approach
- ❑ Applicable to different demos and applications with minor adaptation
- ❑ Integration of different safety related applications



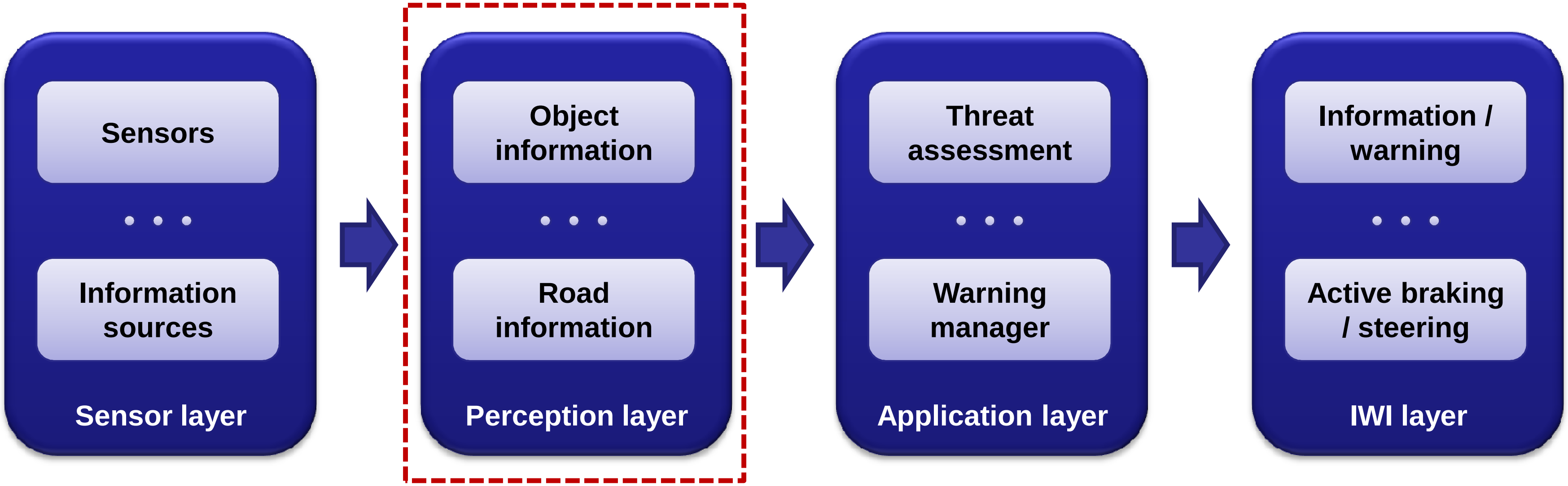
interactIVe – JDL model for safety apps

- The PReVENT/PF2 proposal is followed here also



interactIVe – System architecture

- **Sensor layer:** vehicle sensors, GPS, camera, lidar, radar, ultrasonic, digital maps, V2X
- **Perception layer:** perception platform, perception modules
- **Application layer:** development of functions for building applications
- **Information Warning & Intervention (IWI) layer:** human machine interface (HMI) incl. visual, audible & haptic signals, functions to optimize this interaction (active intervention)

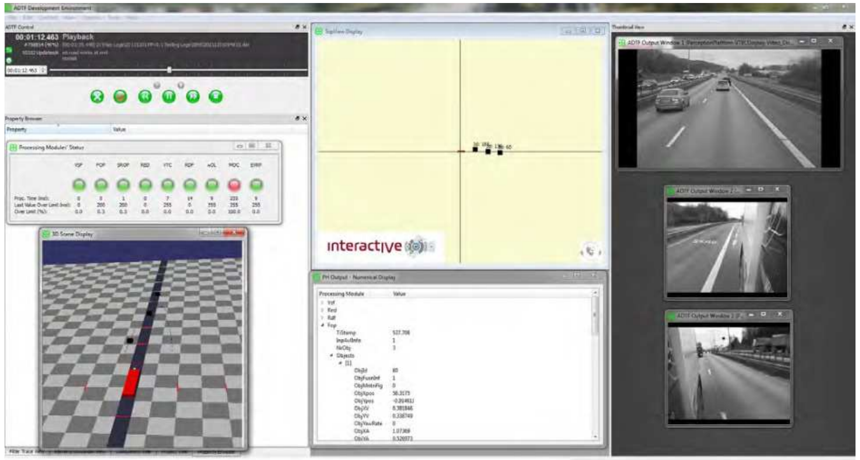


interactIVe – Perception layer

- Perception will advance the multi-sensor approaches
- Focus on sensor data fusion processes
- A common perception framework for multiple safety applications
- Unified output interface from the perception layer to the application layer will be developed
- Integration of different information sources
  - sensors,
  - digital maps,
  - communications
- Multiple integrated functions and active interventions
- Development of an innovative model and platform for enhancing the perception of the traffic situation in the vicinity of the vehicle

interactIVe – Perception platform (1/2)

- Reference implementation
- Common *interface structure* for every sensor type or information source
- Different sensor types and products attached based on the *plug-in concept*
- Development of a variety of *perception modules*, e.g.
  - object perception & classification
  - lane detection & road geometry extraction
- Output: *Perception Horizon*



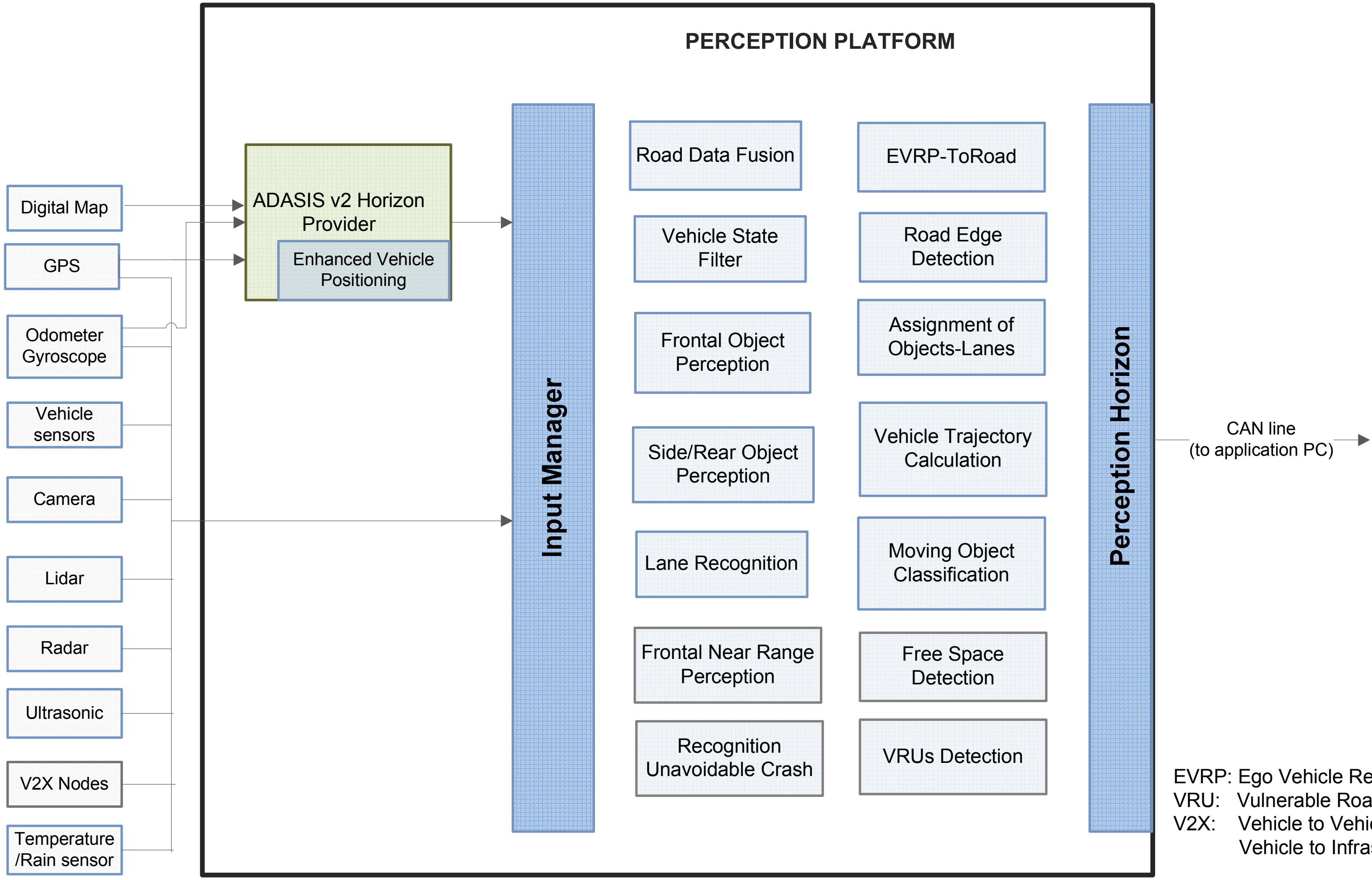
interactIVe | Snapshots depicting perception fusion modules' functionality

Lane recognition and object lane assignment

Road data fusion module (digital map-matched road attributes extracted from vision sensors)

Frontal object detection

interactIVe – Perception platform (2/2)



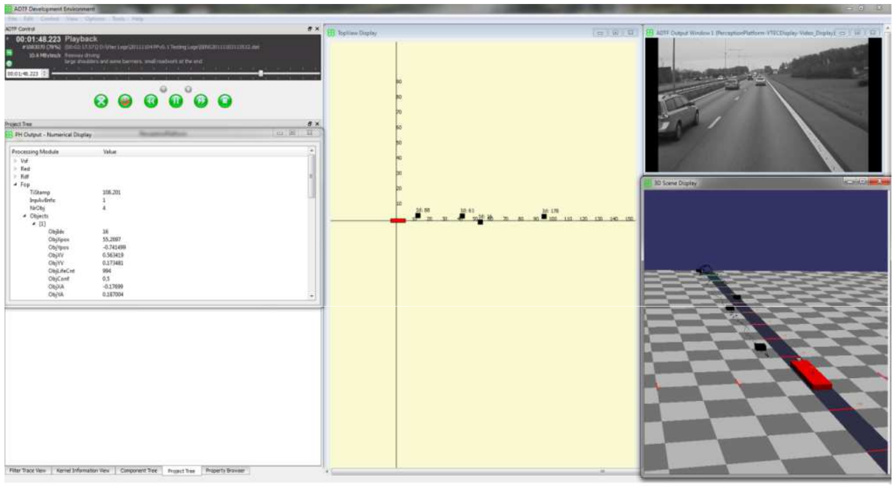
EVRP: Ego Vehicle Relative Position
VRU: Vulnerable Road User
V2X: Vehicle to Vehicle or Vehicle to Infrastructure

interactIVe – Perception modules

Vehicle State Filter	Road Data Fusion
ADASIS Horizon	Enhanced Vehicle Positioning
Recognition of Unavoidable Crash Situations	Relative Positioning to the Road of the Ego Vehicle
Frontal Near Range Perception	Assignment of Objects to Lanes
Frontal Object Perception	Vehicle Trajectory Calculation
Side/Rear Object Perception	Moving Object Classification
Lane Recognition	Detection of Free Space
Road Edge Detection	Vulnerable Road Users

interactIVe – Frontal object perception

- Detection of objects in the front area of the ego vehicle
- Stationary & moving objects
- Relevant information
    - identity (ID)
    - position, velocity, acceleration
    - confidence value
    - static/moving flag
    - moving direction
    - estimated object size



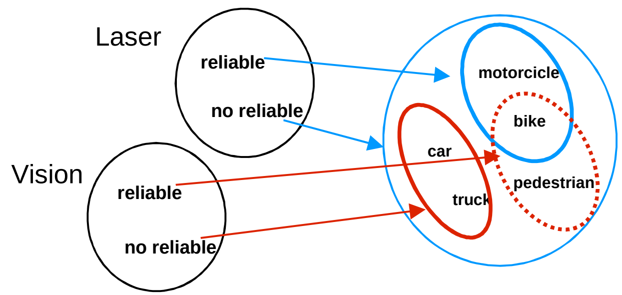
- Sensor data fusion & advanced filtering techniques
    - reliable object perception
    - additional information not directly observed from a sensor

interactIVe – Perception Horizon (PH)

- Output interface of the perception platform
- Union of the following three elements:
  - **Synchronized subset** of the perception modules outputs
  - **Configuration files** for each demonstrator vehicle (available sensors, mounting position etc.)
  - **Output manager functionality** (software module translating Perception Horizon data to the communication line between perception platform and applications)
- Modular handling of data
- Avoiding duplicate structures
- Minimization of passing through information

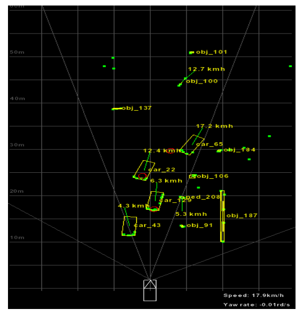
interactIVe – Advanced future research

Processing / Fusion algorithms (maps, radar, lidar, camera):



- Multi-sensor tracking in sensor networks
- Maintenance of Track ID @ rear-side-frontal
- Instantaneous fusion using Evidential occupancy grids

  (degrees of belief for detection, tracking and classification)



- Efficient object classifier for pedestrian, cars and trucks
- Robust Road Boundary Detection + Advanced Lane Tracking
- Frontal Near Range Perception for collision avoidance

interactIVe – Lessons learned so far

- The research work performed in previous EU projects and the gained experience were an important asset
- Reference perception platform close to the plug & play concept is feasible
- Interoperability of the perception platform in different demonstrator vehicles was shown
- The time synchronization and in-time data exchange among a significant number of perception modules within the perception's platform framework is a challenging task
- The definition of the interfaces among the different layers (sensor, perception, application and IWI) of the system proved to be a non-trivial task
- The use of wireless communication for perception was limited, so further investigation is needed in the future

Open research issues in data fusion

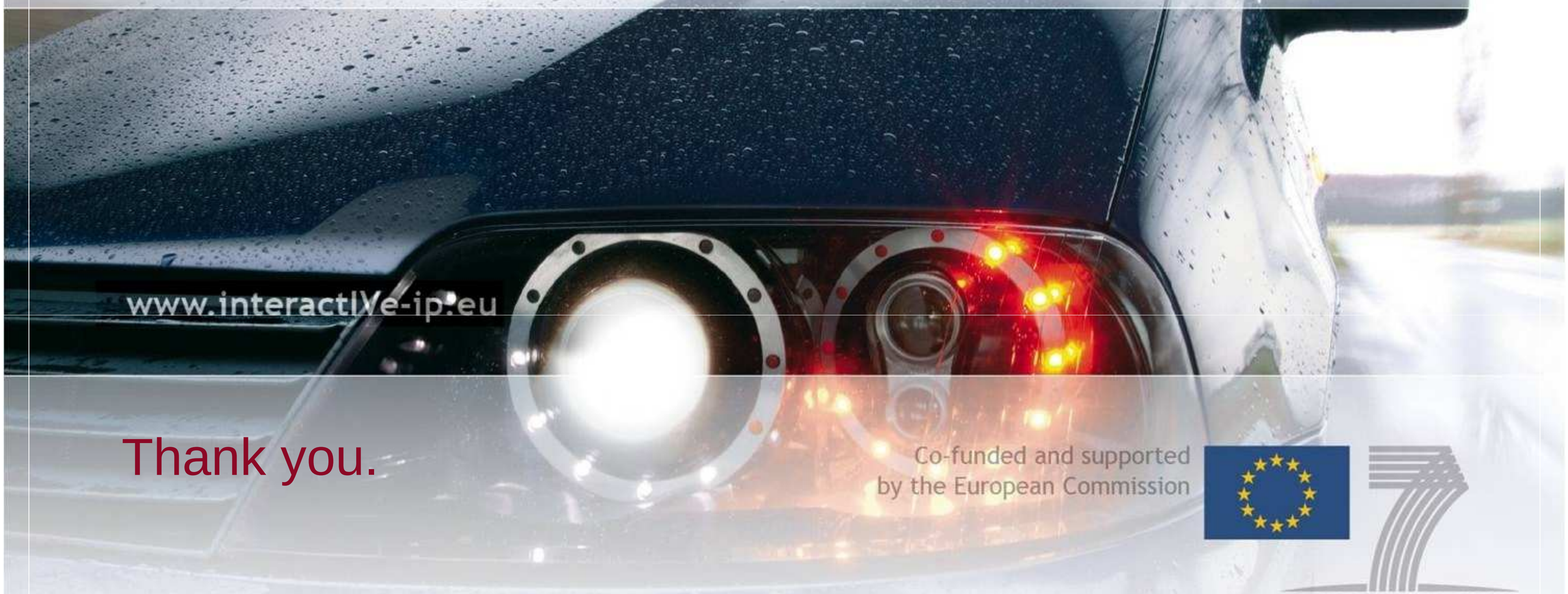
- Robust sensors are needed (no perfect sensors available)
- Fusion of heterogeneous information from different sources (images, radar/lidar measurements, wireless messages etc.)
- Calculation and usage of uncertainty values (non-standard method for selecting the best method)
- Except for object and situation refinement other levels of the JDL model need further research (e.g. process refinement)
- Future approaches should focus on human-centric analysis and improvements (include human in the data fusion loop)

Conclusions

- Important role of data fusion in automotive applications
- Perception of automotive environment (highly dynamic) difficult and challenging task
- The development and the experience in European research projects was outlined
- PReVENT/PF2 functional architecture adopted
- Cooperative systems pose several challenges
- Integration of different applications in interactIVe exploiting advanced fusion techniques
- Generic perception platform with well defined I/O interfaces
- Central fusion architectures are more suitable for generic perception modules and platform development

interactIVe

Accident avoidance by active intervention for Intelligent Vehicles



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