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The challenge of on-board Perception and Decision-making for Autonomous Driving in Mixed traffic conditions

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The challenge of on-board Perception & Decision-making for Autonomous Driving in Mixed traffic conditions

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Interactive session on “Future advances and research directions for autonomous robotics”
Workshop on “Perception & Navigation for Autonomous Robotics in Unstructured and Dynamic Environments”
IROS 2021, Prague, September 27th 2021



Autonomous Driving: Where are we now ?

- A Technological breakthrough & Numerous AV experimentations in real traffic conditions



Commercial Autopilot L2 system
(tested by customers)



• Large fleet & 20 Million miles covered
• **Self-driving taxi service L3**
(1st in US, Phoenix, Dec 2018)



• Similar **Self-driving taxi service L3**
• Experimented in several cities



Increasing number of
Autonomous Shuttle service
experiments

- Millions of miles driven last decade... but **SAFETY** is still not fully guaranteed !

=> Several benign or fatal accidents involving AVs (Perception failure & Takeover difficult)



Tesla Autopilot level 2
=> Human Driver killed (May 2016)



Self-driving Uber L3
=> Pedestrian killed (March 2018)

- Additional R&D work is still mandatory on 2 main research lines

1- Improving "Perception & Decision-making" technologies (*in particular for Robustness & Scalability issues*)

2- Developing new "Validation & Certification" approaches for making future deployment feasible (*in addition to traditional testing approaches*)



Mixed traffic: AVs have to face two main challenges

1st Challenge: *The need for Robust, Self-diagnosing & Explainable **Embedded Perception***



Video Scenario (*Tesla Autopilot L2*)

- *The Tesla perception system failed to detect the barriers blocking the left side route.*
- *The human driver has to take over & steer the vehicle away from the blocked route (for avoiding the collision) Video source: AutoPilot Review @ youtube.com*

2nd Challenge: *The need for Understandable Driving Decisions (share the road with human drivers !)*

Human drivers actions are determined by a complex set of interdependent factors difficult to model (e.g. intentions, perception, emotions ...)

⇒ Predicting **human driver behaviors is inherently uncertain**

⇒ AV have to reason about **uncertain intentions** of the surrounding vehicles



Video scenario (*Collision: Waymo AV & Human Driven Bus*)

Scene observed by the dash cam of a bus moving behind the Waymo AV

- *Waymo AV is blocked by an obstacle and it decides to execute a left lane change*
- *The bus driver misunderstood the AV intention, and didn't yield*
- *The two vehicles collided !!!*

Video source: The Telegraph

Dynamic scene analysis & Navigation Decisions
Traditional Formulation



Embedded Perception & Decision-making for Safe Intentional Navigation

Detecting & Reacting in real-time to
Unexpected Events



⇒ *Scene interpretation using Sensing & Prior knowledge*
⇒ *Safe Navigation decisions (using semantics & context)*

⇒ *Detect & Predict imminent collision with “something” (unclassified unexpected event)*
⇒ *Activate appropriate reflexive avoidance strategy*

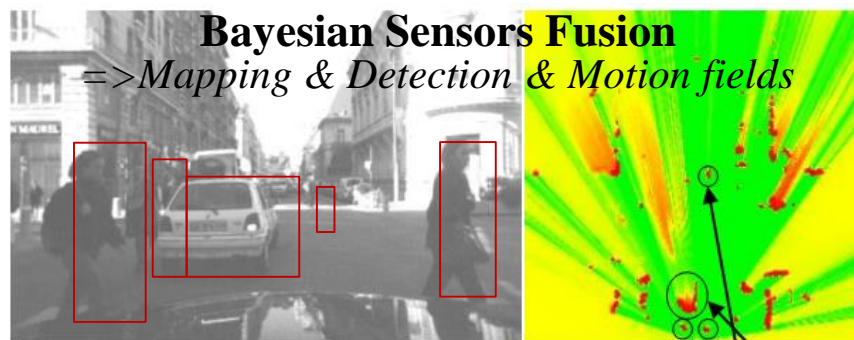
Main difficulties & Open issues

- ❑ Dynamic & Open Environments, Incompleteness & Uncertainty, Sensors limitations, Real-time constraint
... but also Reactivity to Unexpected events (e.g. imminent collision) & Validation issue
- ❑ Mixed traffic (Human in the loop) => *Design a “Human-Aware Decision-making process”*
Taking into account Interactions + Behaviors + Social & Traffic rules

1st Paradigm: Embedded Bayesian Perception



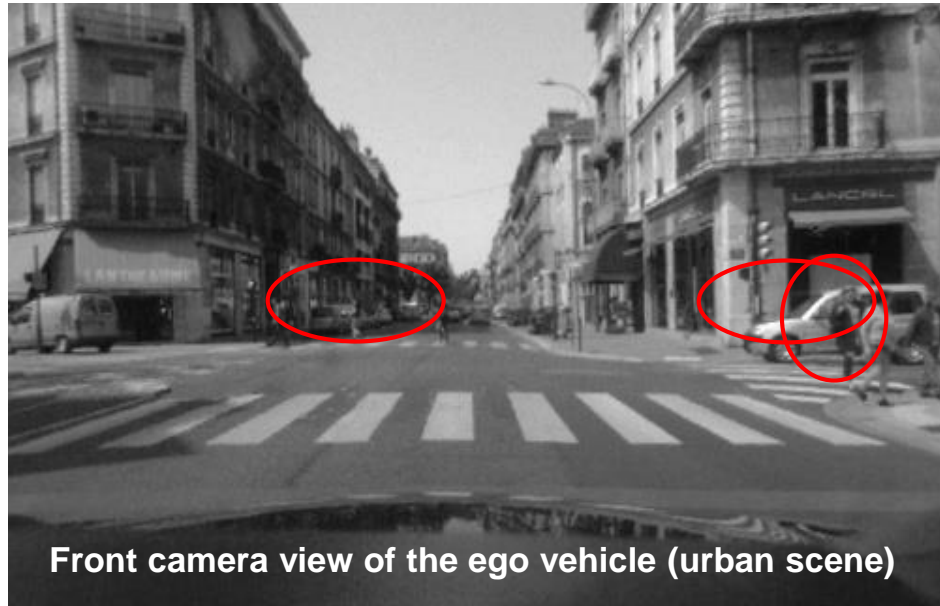
Embedded Multi-Sensors Perception
 ⇒ *Continuous monitoring of the surrounding dynamic environment*



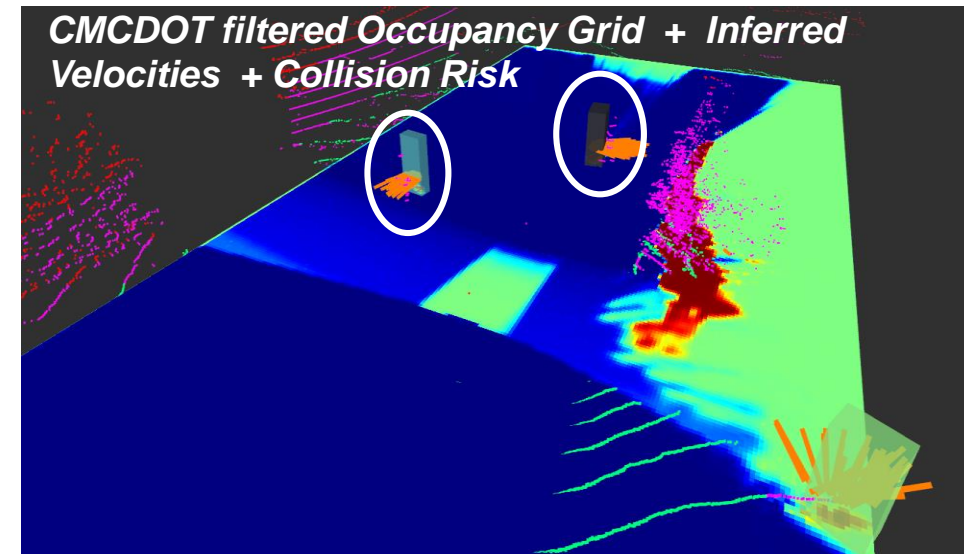
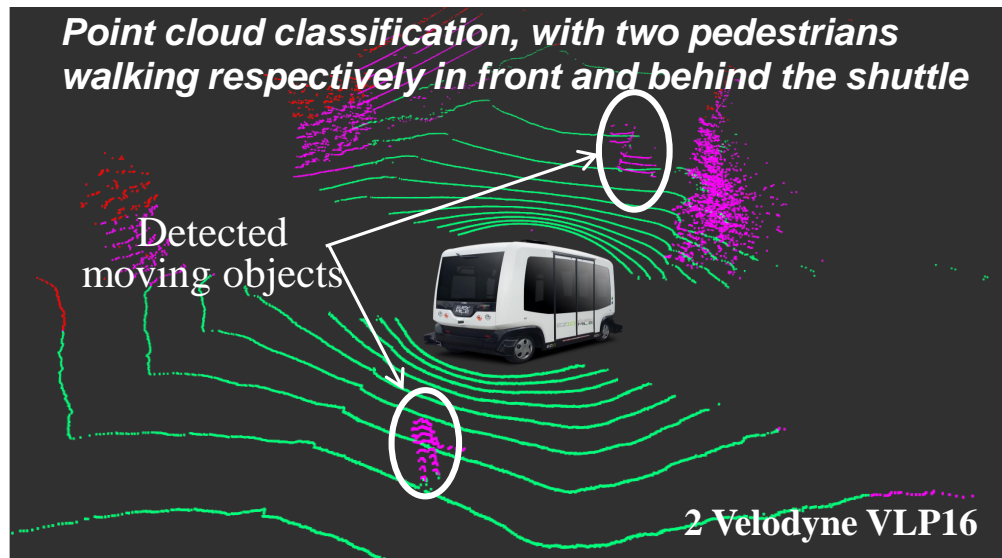
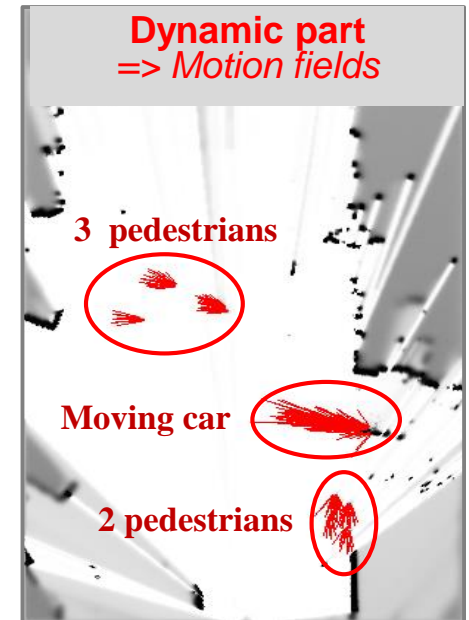
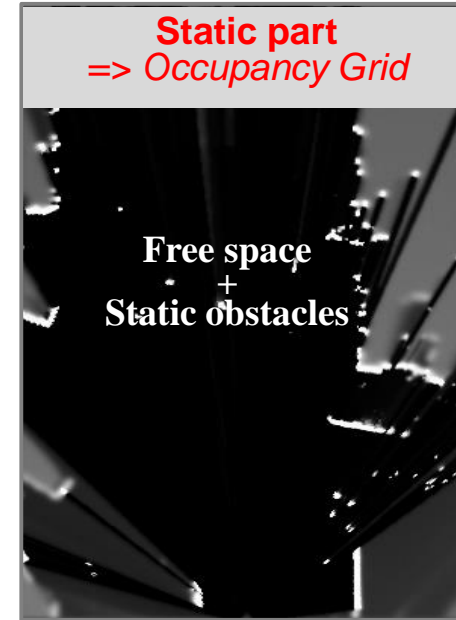
- ✓ *Exploiting the Dynamic information for a better understanding of the scene !!!!*
- ✓ *Reasoning about Uncertainty & Time window => Past & Future predicted events*
- ✓ *Bayesian Sensors Fusion + Scene interpretation using Contextual & Semantic information*
- ✓ *Software / Hardware integration using hardware accelerators (GPU, Multicore, Micro-controllers ..)*

Embedded Bayesian Perception – Illustration

=> Exploiting the dynamic information for a better understanding of the scene



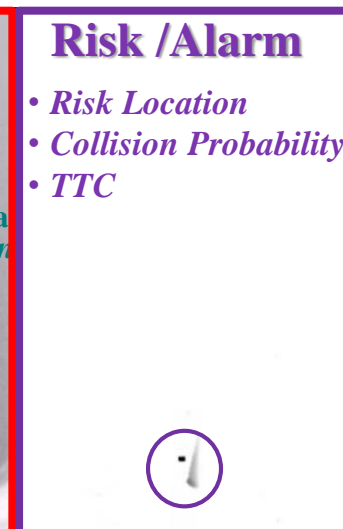
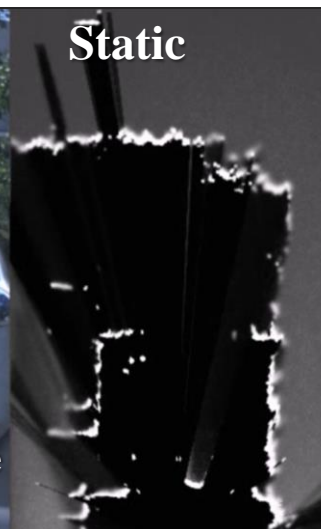
Sensors data fusion
+
Bayesian Filtering
+
Extracted Motion Fields



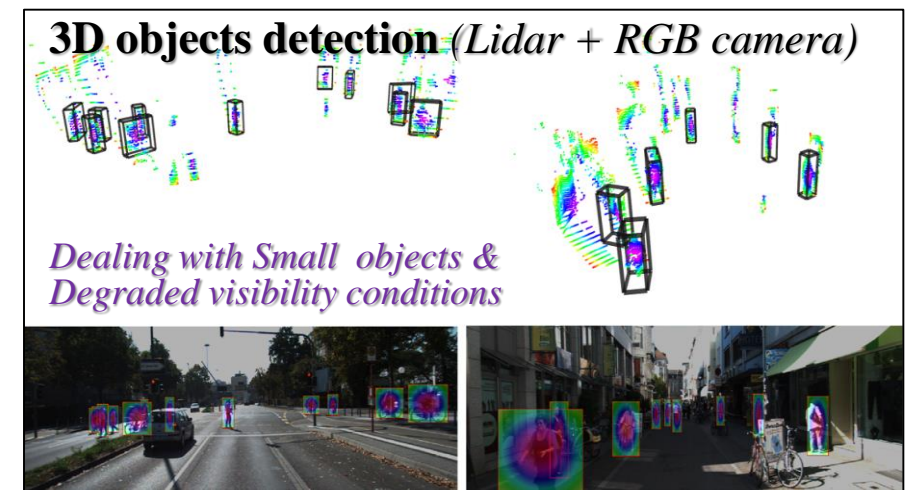
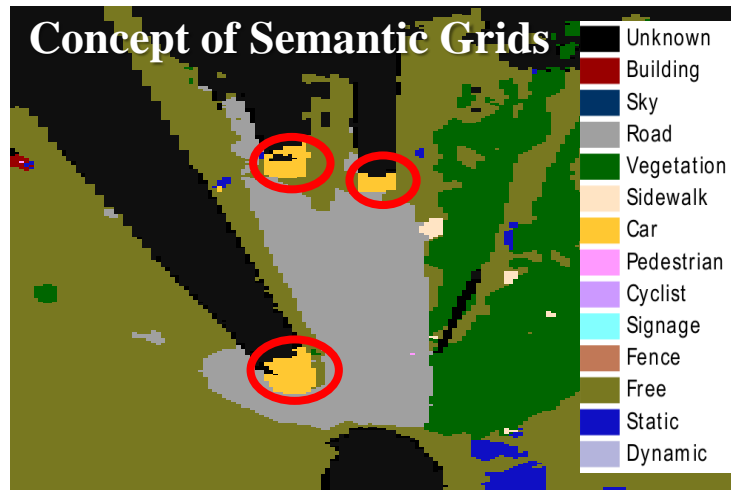
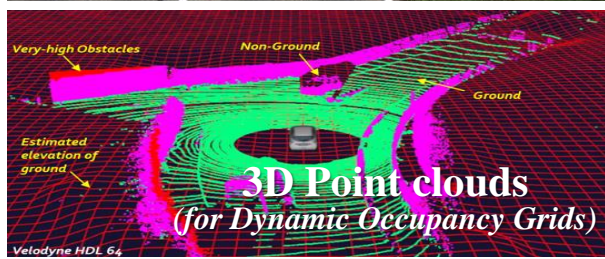
2nd Paradigm: Collision Risk Assessment

How to Avoid both Pending & Future Collisions ?

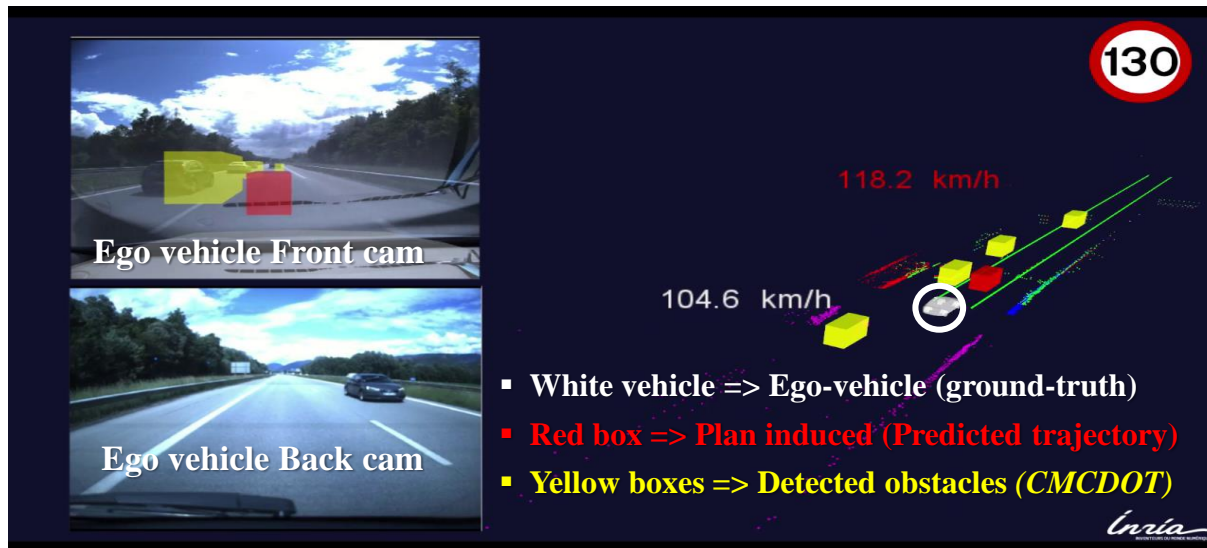
- ✓ Predict environment changes on a given “time horizon $t+\delta$ ” => Using **History & Motion models**
- ✓ Estimate the Probabilistic Risk of Collision at $t+\delta$ (δ = a few seconds ahead)
- ✓ Distinguish **Short-term C-Risk** (Grid level & Conservative) & **Mid-term C-Risk** (Object level & Behaviors)
- ✓ Make Driving Decisions by taking into account the **Predicted behavior** of all surrounding traffic participants (cars, cycles, pedestrians...) & **Social / Traffic rules** (traffic participants interactions)



□ Perception: *Hybrid sensor fusion (DOGMap & Semantically Segmented RGB images)*



□ Prediction & Decision-making (Mixed Traffic): *Learn driving skills for Autonomous Driving*



- 1st Step: Modeling Driver Behaviors using IRL
- 2nd Step:
 - Predict behaviors of surrounding vehicles (using Perception & learned Behavior models)
 - Make “safe & consistent” Driving Decisions for Ego Vehicle (using Learnt models & Dynamic evidences)

Open questions: *Robustness, Scalability, Validation*

- **Perception & Scene understanding:** *Fusing Bayesian & AI approaches should help ... but still some open questions (even if CV community has already reached a quite good level of maturity)*
 - ✓ *Training step (Available Datasets insufficient) & Classification Errors (Hard to process)*
 - ✓ *Degraded perception conditions (Domain adaptation still an open question)*
 - ✓ *Large-scaled scenes (Combine different sensors modalities ... but room for improvements)*

- **Decision-making in Mixed traffic:** *How to better take into account Interactions with other road users (human-driven cars, pedestrians, cyclists, etc.) ?*
 - => *“Human-like models” taking into account Social & Traffic rules ... Still an open question !*

- **Validation & Certification approaches have to be developed**
 - => *Realistic simulators, Augmented Reality approaches, Formal Methods, and also Real-world testing protocols (e.g. EU Enable-S3 project & French project Prissma)*