自动驾驶论文讲坛：

一种模块化的可替代传感器融合办法

iMorpheus

本周分享

ULM大学的自动驾驶项目旨在提供一种基于概率的不依赖于传感器的融合办法：将环境感知分为栅格地图，自定位和目标跟踪三个模块，各模块之间单向传输数据，传感器的改变不需要修改算法。

星期五 10/11/2017

北京时间 12:00 PM

线上会议直播 - Zoom.us

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Autonomous Driving at Ulm University

Introduction

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- A multi-sensor setup for environmental perception.
- The possibility to replace sensors without changing the core of fusion system.
- Centralized sensor fusion provides more accurate tracking results since no information is lost, compare to tracking to tracking fusion.
- A modular sensor fusion system with generic interfaces.

System Setup

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- The car modification:

1. Steer by wire;
2. Modification of the ESP control unit enables to directly specify brake and acceleration torque via CAN bus;
3. Torque control by a closed-loop controller on a dSpace real-time system;
4. The dSpace system is responsible for synchronization of the sensor measurements

System Setup

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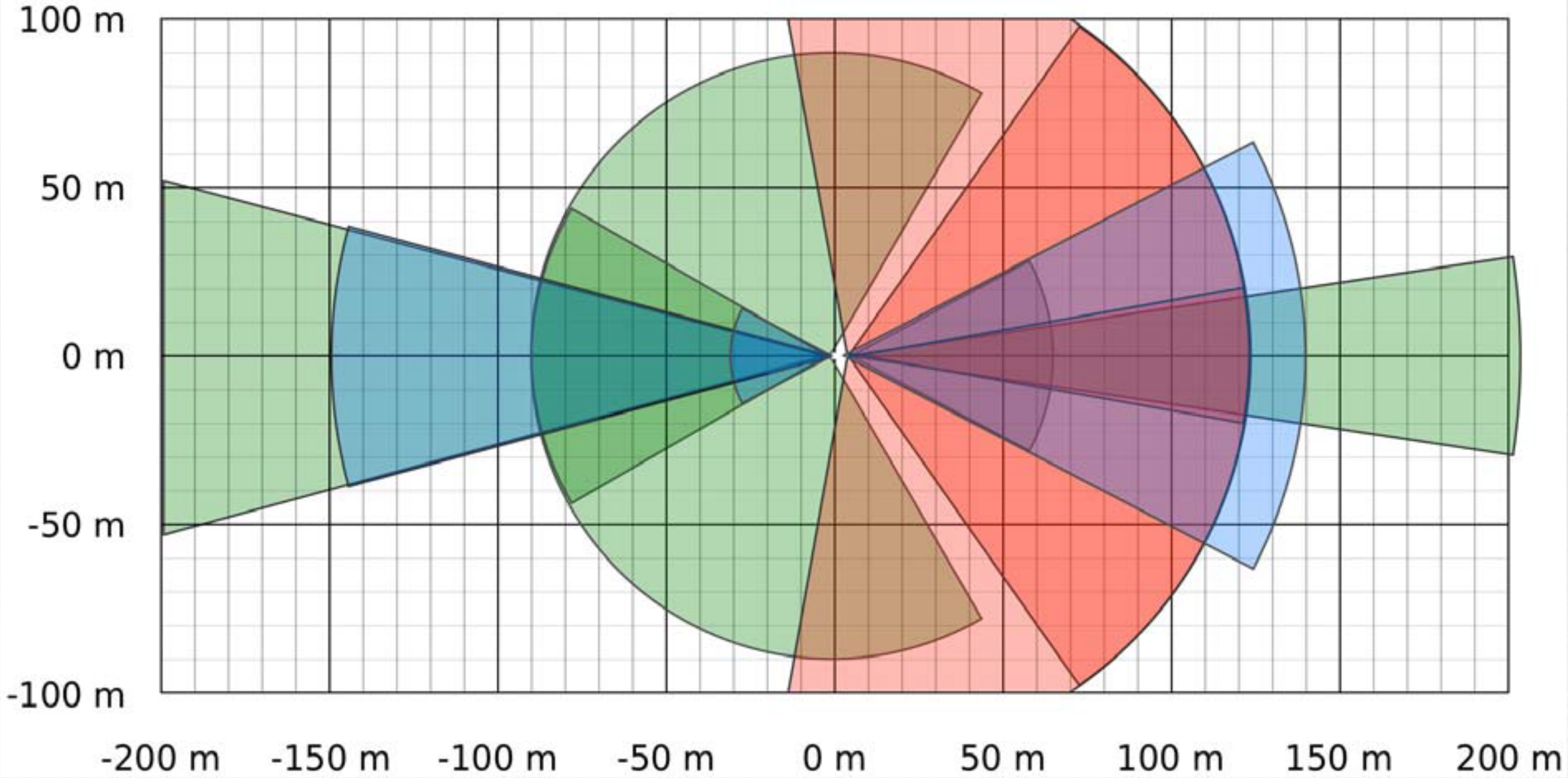
- Sensor setup: cameras (blue, 1 front, 2 rear), laser scanners (red, 3 front, 1 rear), radar sensors (green, 1 front FMCW, 1 rear LRR, 2 rear MRR)



Environment Perception

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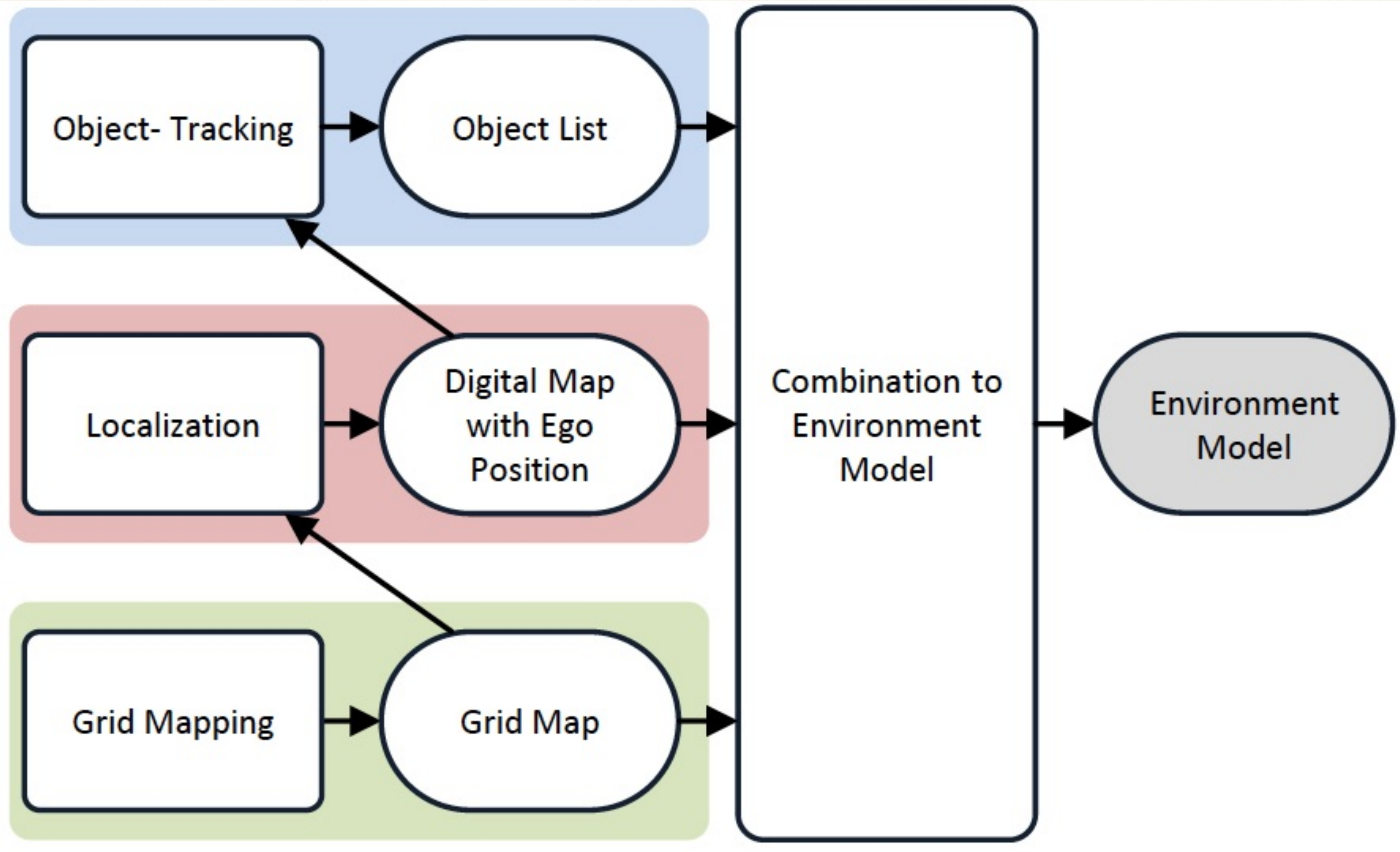
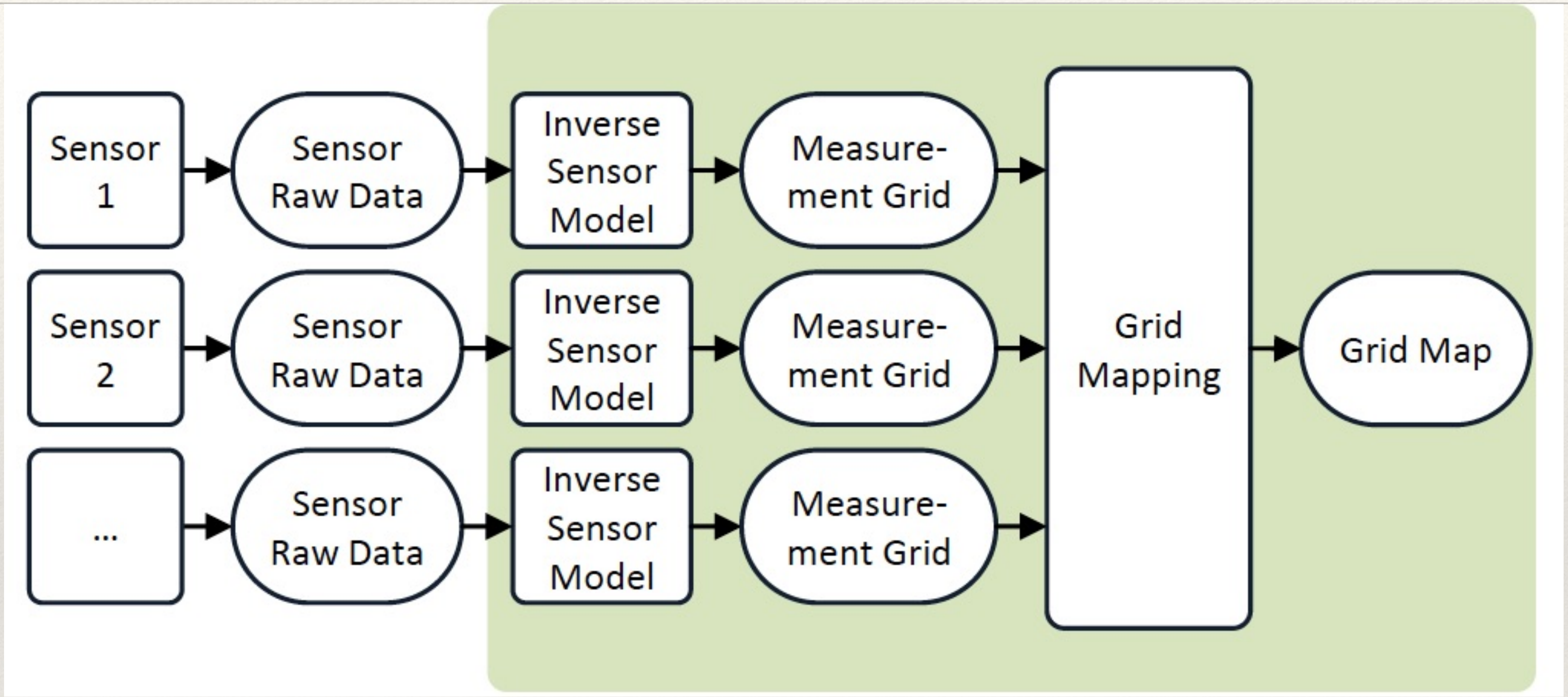


Grid Mapping System



- The classical occupancy grid mapping approach
- Data from the three laser scanners

Occupancy Grid Mapping

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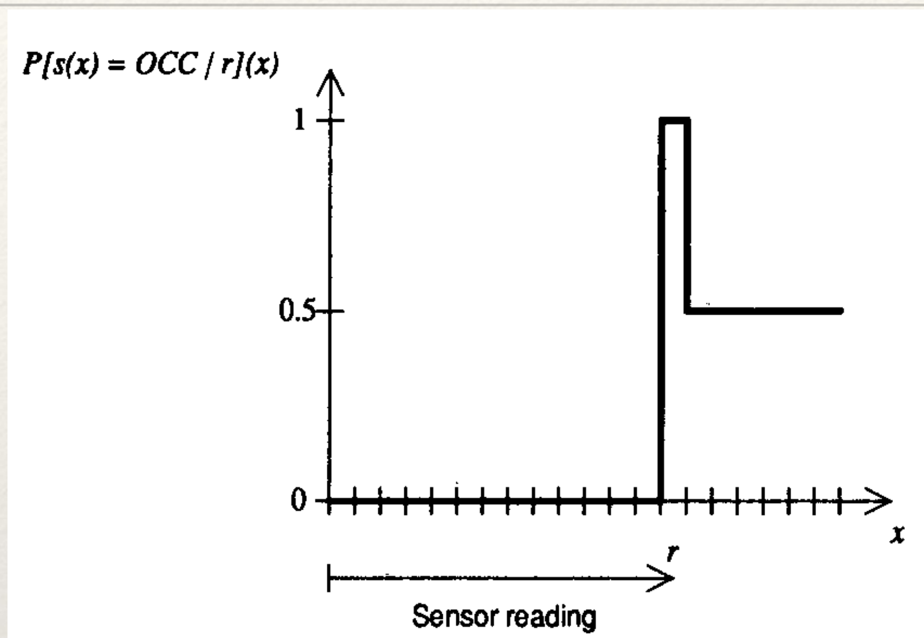
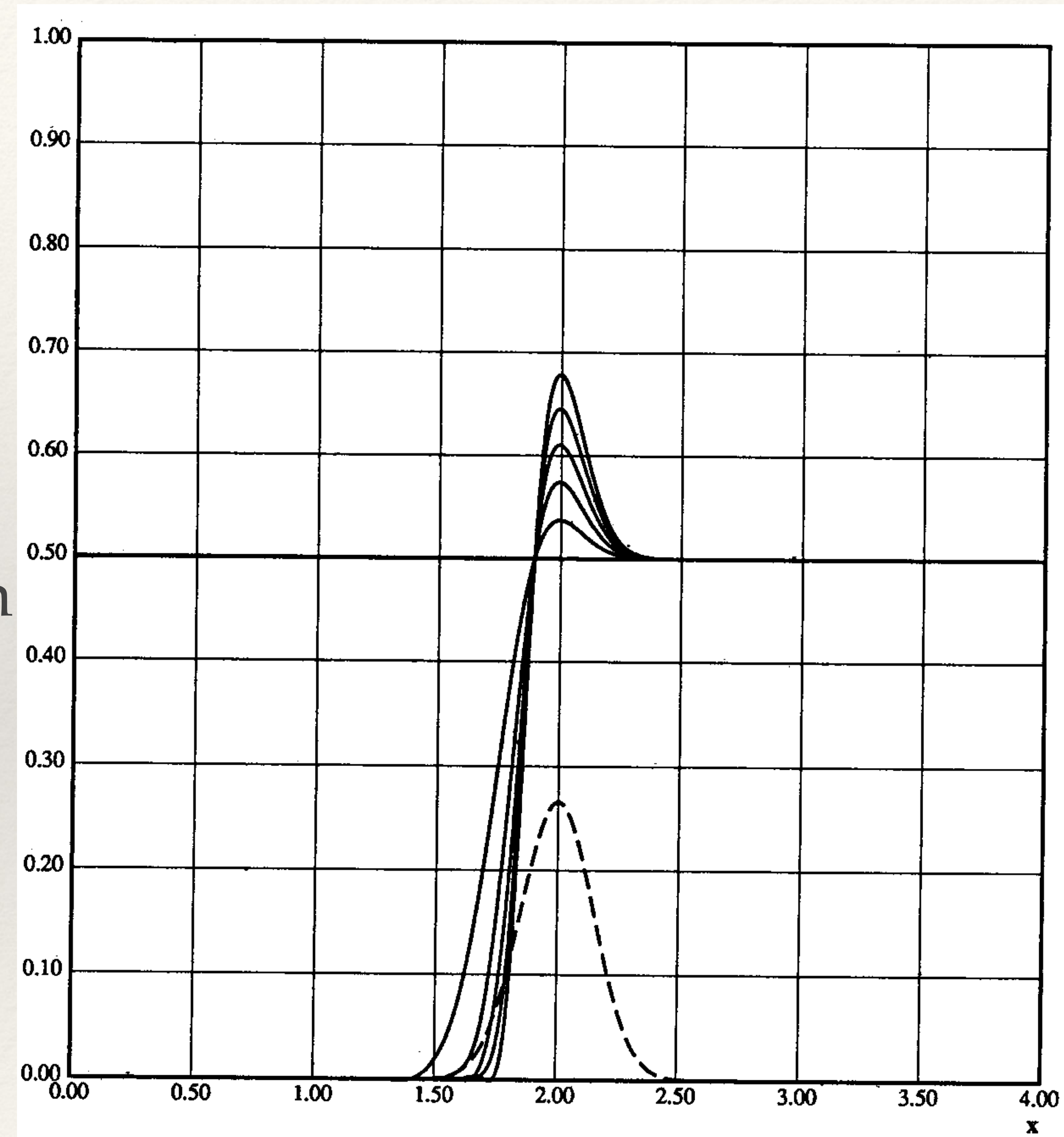


- Cells: empty, occupied, unknown
- ideal states
- gaussian sensor

$$p(r \mid z) = \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left(\frac{-(r-z)^2}{2\sigma^2} \right)$$



Occupancy Grid Mapping

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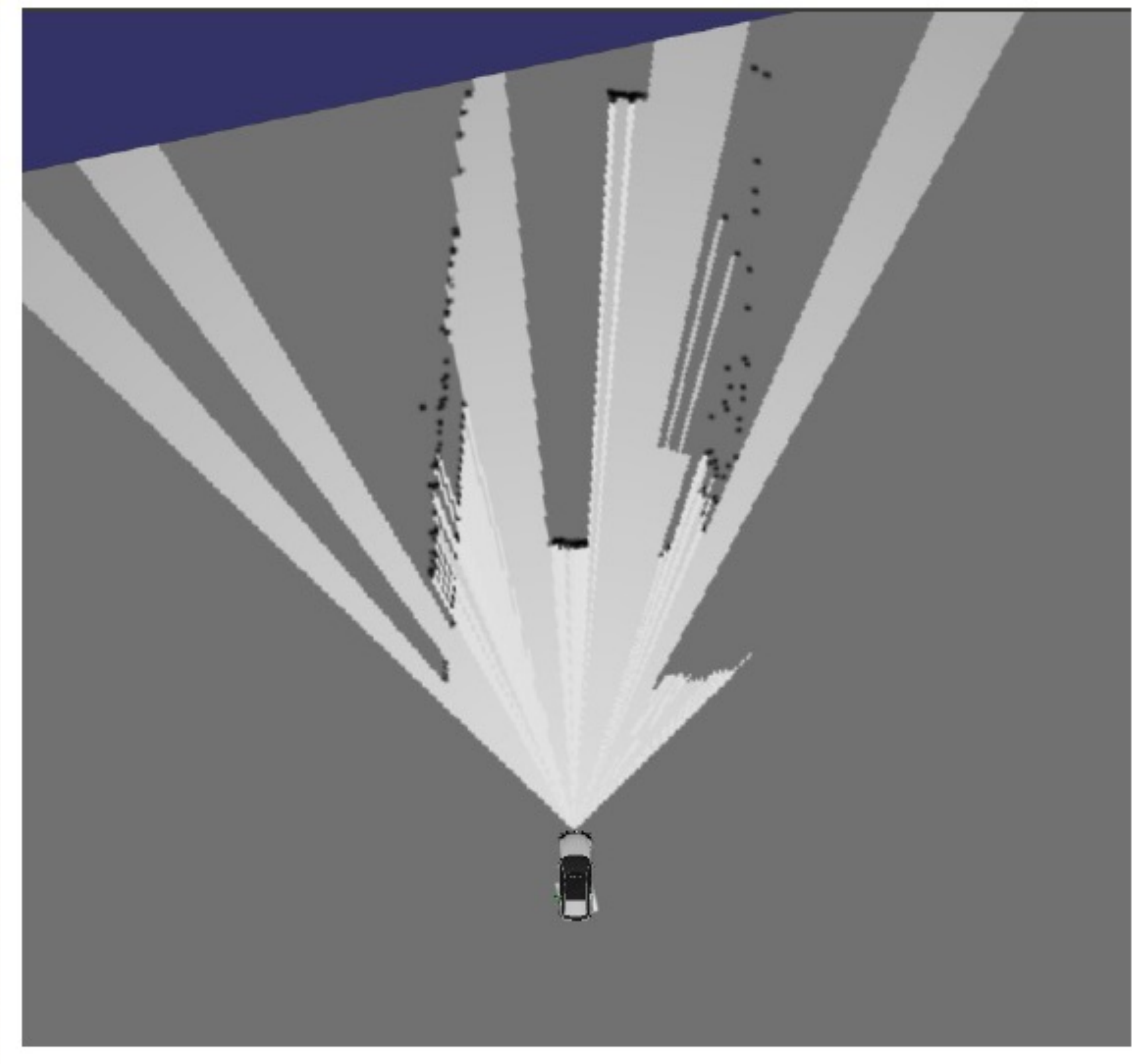
- Vehicle position：RTK + differential GPS， dead reckoning formulation（航迹测算）
- Inverse Sensor Model：each grid cell c has its state (occupancy probability), which is the measurement from a camera or a laser sensor. The state of cell c: *m(c)*
- Combination：Bayesian inference or the Dempster-Shafer rule.

$$m_{1\oplus 2}(A) = m_1(A) \oplus m_2(A) = \frac{\sum_{X\cap Y=A} m_1(X)m_2(Y)}{1 - \sum_{X\cap Y=\emptyset} m_1(X)m_2(Y)} \text{ for all } A \in 2^{\Omega}$$

Occupancy Grid Mapping



Localization System

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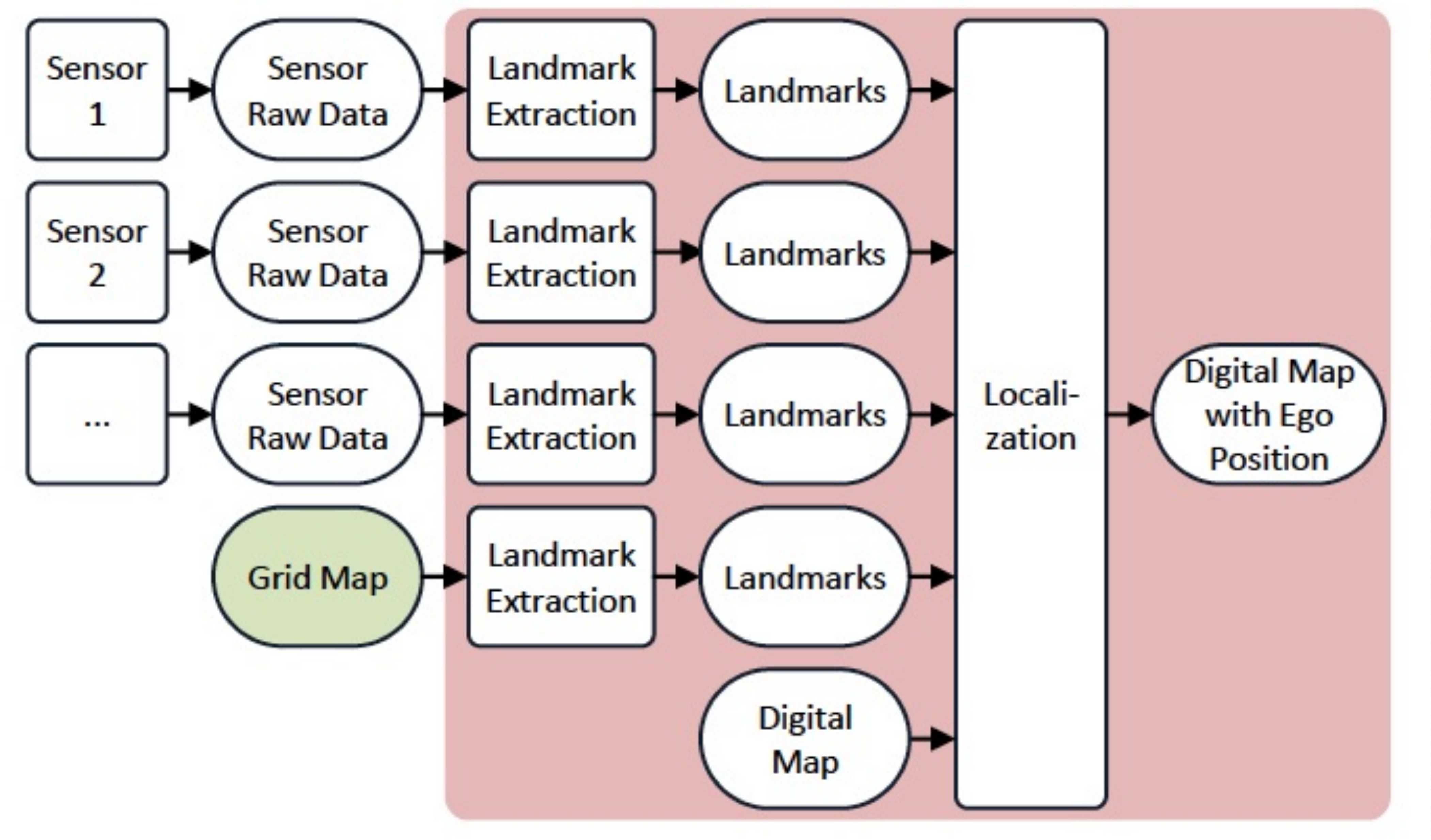
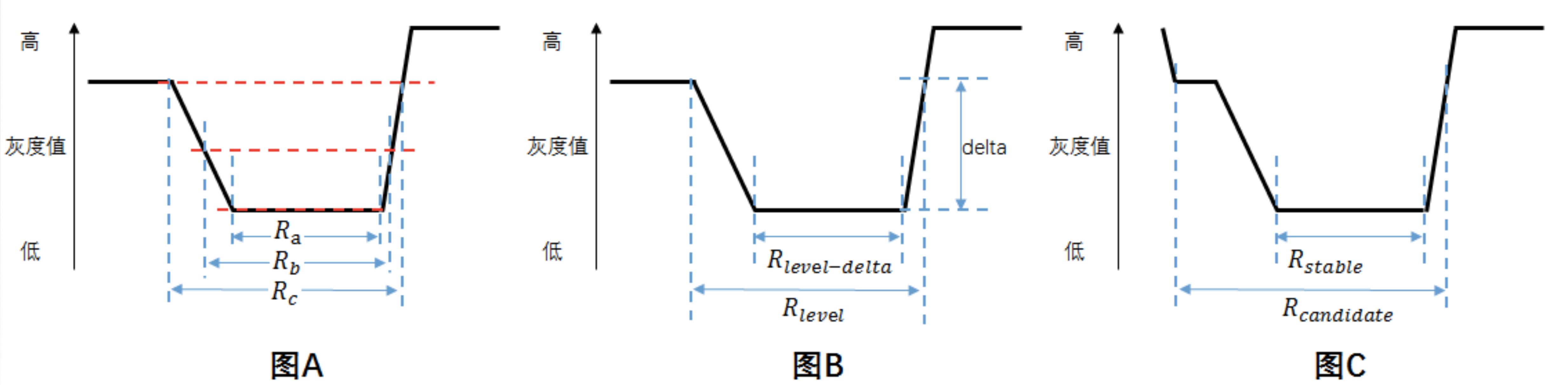


Localization

- Landmarks: Lane markings, road signs and tree trunks.
- Landmarks detection: using MSER(Maximally stable extremal region) from three laser scanners and a front-facing camera

$$\Psi\left(R_i\right)=\frac{\left|R_{i+\Delta}\right|-\left|R_{i-\Delta}\right|}{\left|R_i\right|}$$



Localization

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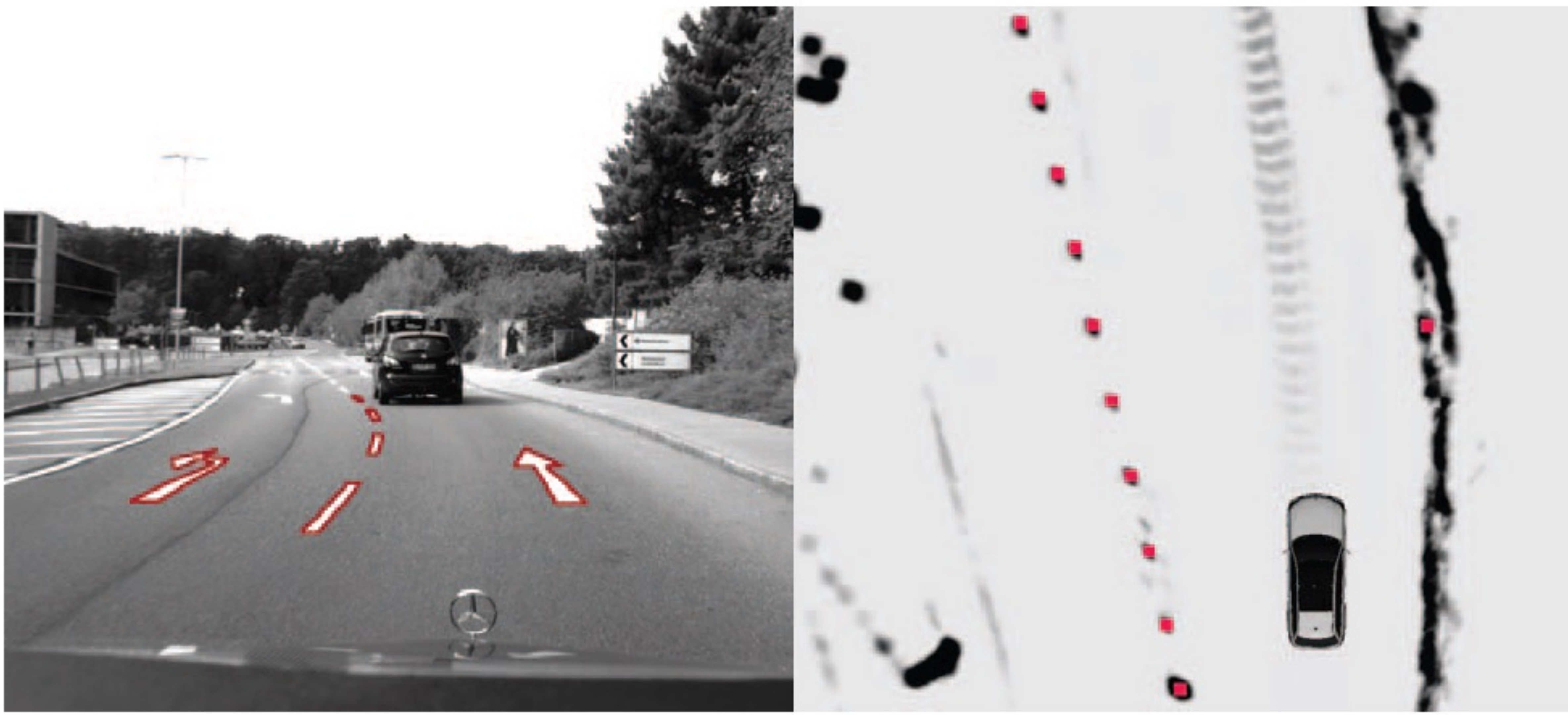

(a) Image (b) Grid map

Localization

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- ~400 Landmarks/kilometer (centroids as global UTM positions) are saved in the database.
- Particle filter: Random poses within an uncertainty ellipsoid around the vehicle pose.
- Particles are predicted by the dead reckoning formulation.
- Weight update.
- Average the weighted particles.

Weight with the landmarks

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- The set of observations at time k $\mathcal{Z}_k = \{z^1, ..., z^{\hat{z}_k}\}$
- The set of stored landmark map $\mathcal{M}_k^{ROI} = \{m^1, ..., m^{\hat{m}_k}\}$
- The likelihood for a transformed m^l and a detection z^j is given:

$$g(z^j|m^l) = \frac{p_D}{(1-p_D)\cdot\kappa(z^j)} \cdot \exp\{-0.5\cdot\Lambda\}, \qquad (8)$$

with

$$g(z^0|m^l) = 1 - p_D$$

$$\Lambda = \frac{{d^l_{j_{lat}}}^2}{{\sigma_{dlat}}^2} + \frac{{d^l_{j_{lon}}}^2}{{\sigma_{dlon}}^2} + \frac{{a^l_j}^2}{{\sigma_a}^2}. \qquad (9)$$

- The Munkres algorithm is used to find the optimal association hypothesis θ.
- Weight and fusion: $w_k^i = \prod_{l=1}^{\hat{m}_k} g(z^{\theta(l)}|m^l)$ $w_k^i = w^i_{k_{Laser}} \cdot w^i_{k_{Camera}}$

Object Tracking System

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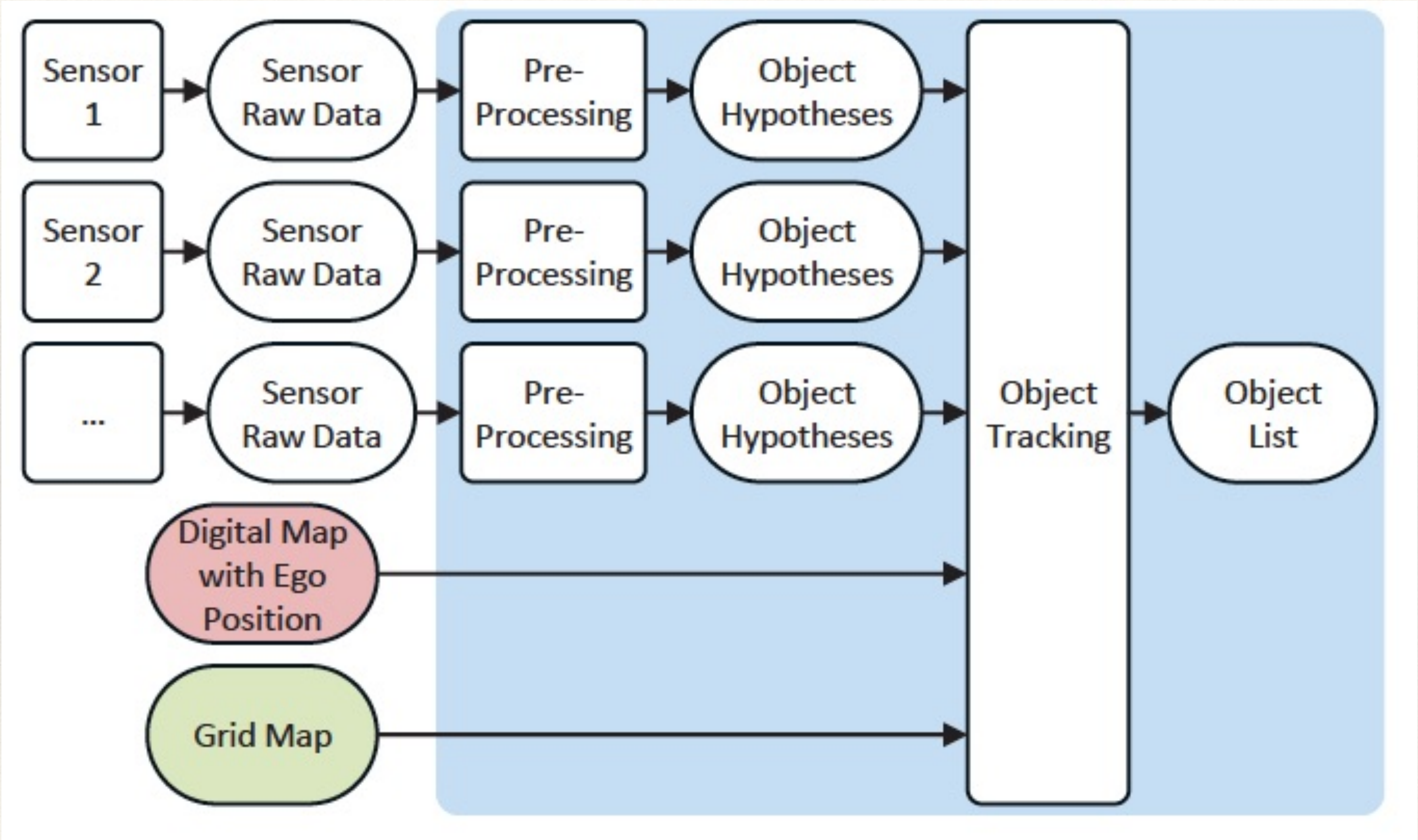

Multi-Object Tracking

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- Vehicles Data from radar, laser and video sensor.
- Random finite sets.
- The Labeled Multi-Bernoulli(LMB) filter outputs an object list containing the spatial distribution and the existence probability of each track.
- A second LMB filter for other road users like pedestrians and bikes using laser and video measurements.

Vehicle Detection in Monocular Images

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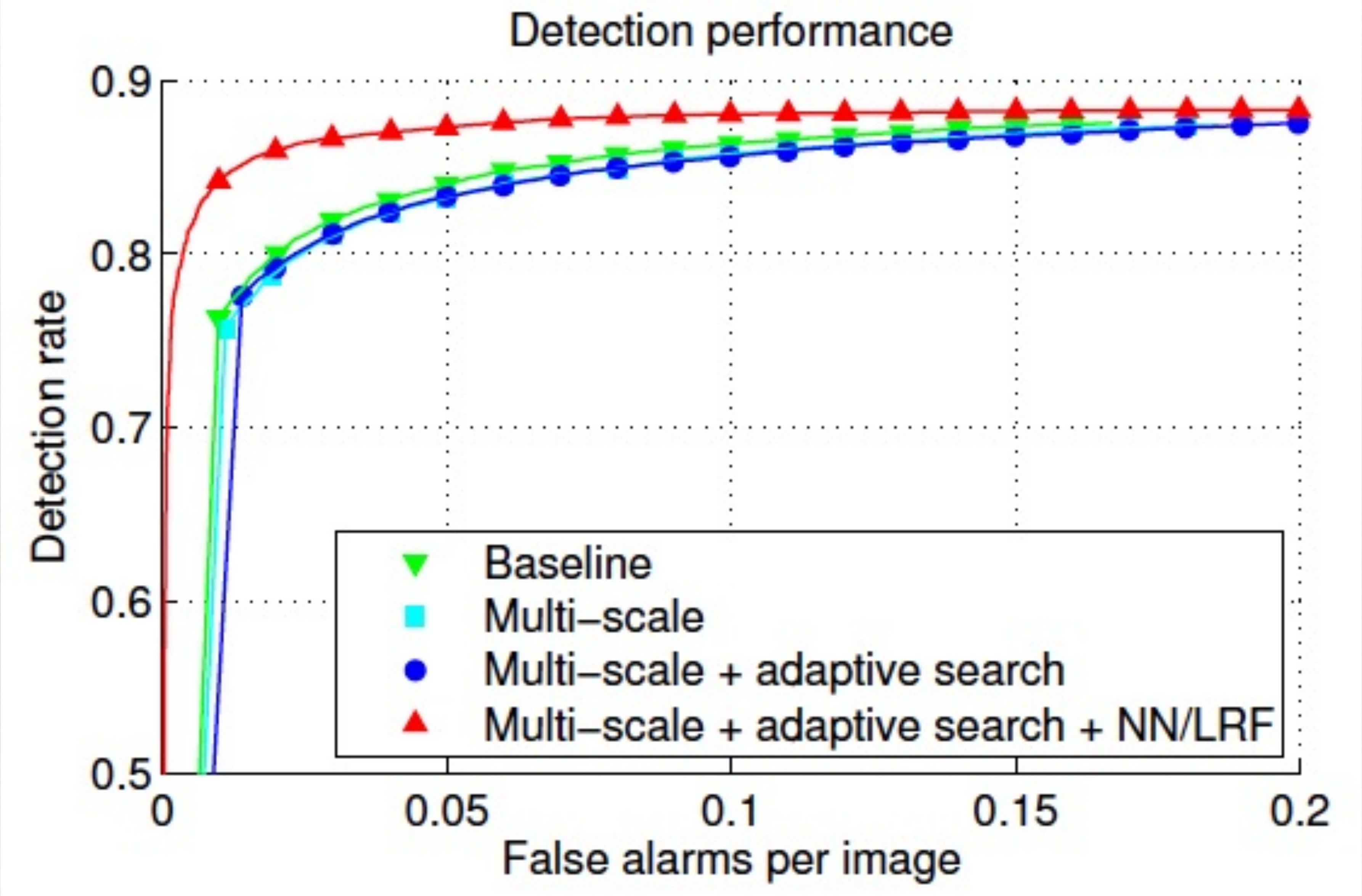

Random Finite Sets

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- Let X and Z denote the state set and observation set with time-varying cardinalities $N(k)$ and $M(k)$, respectively

$$X_k = \{\mathbf{x}_{k,1}, \ldots, \mathbf{x}_{k,N(k)}\}. \tag{1}$$

$$Z_k = \{\mathbf{z}_{k,1}, \ldots, \mathbf{z}_{k,M(k)}\} \tag{2}$$

- The RFS based Bayesian framework for optimal estimation with the multi-target transition density. The random set state transition density and the posterior probability density at time k:

$$\begin{aligned} & p_{k|k-1}(\mathbf{X}_k \mid \mathbf{Z}_{1:k-1}) \\ & \quad = \int f_{k|k-1}(\mathbf{X}_k \mid \mathbf{W})\, p_{k-1|k-1}(\mathbf{W} \mid \mathbf{Z}_{1:k-1})\, \delta\mathbf{W}, \end{aligned} \tag{3}$$

$$p_{k|k}(\mathbf{X}_k \mid \mathbf{Z}_{1:k}) = \frac{p_{k|k-1}(\mathbf{X}_k \mid \mathbf{Z}_{1:k-1})\, g_k(\mathbf{Z}_k \mid \mathbf{X}_k)}{\int p_{k|k-1}(\mathbf{W} \mid \mathbf{Z}_{1:k-1})\, g_k(\mathbf{Z}_k \mid \mathbf{W})\, \delta\mathbf{W}}, \tag{4}$$

Environment Model

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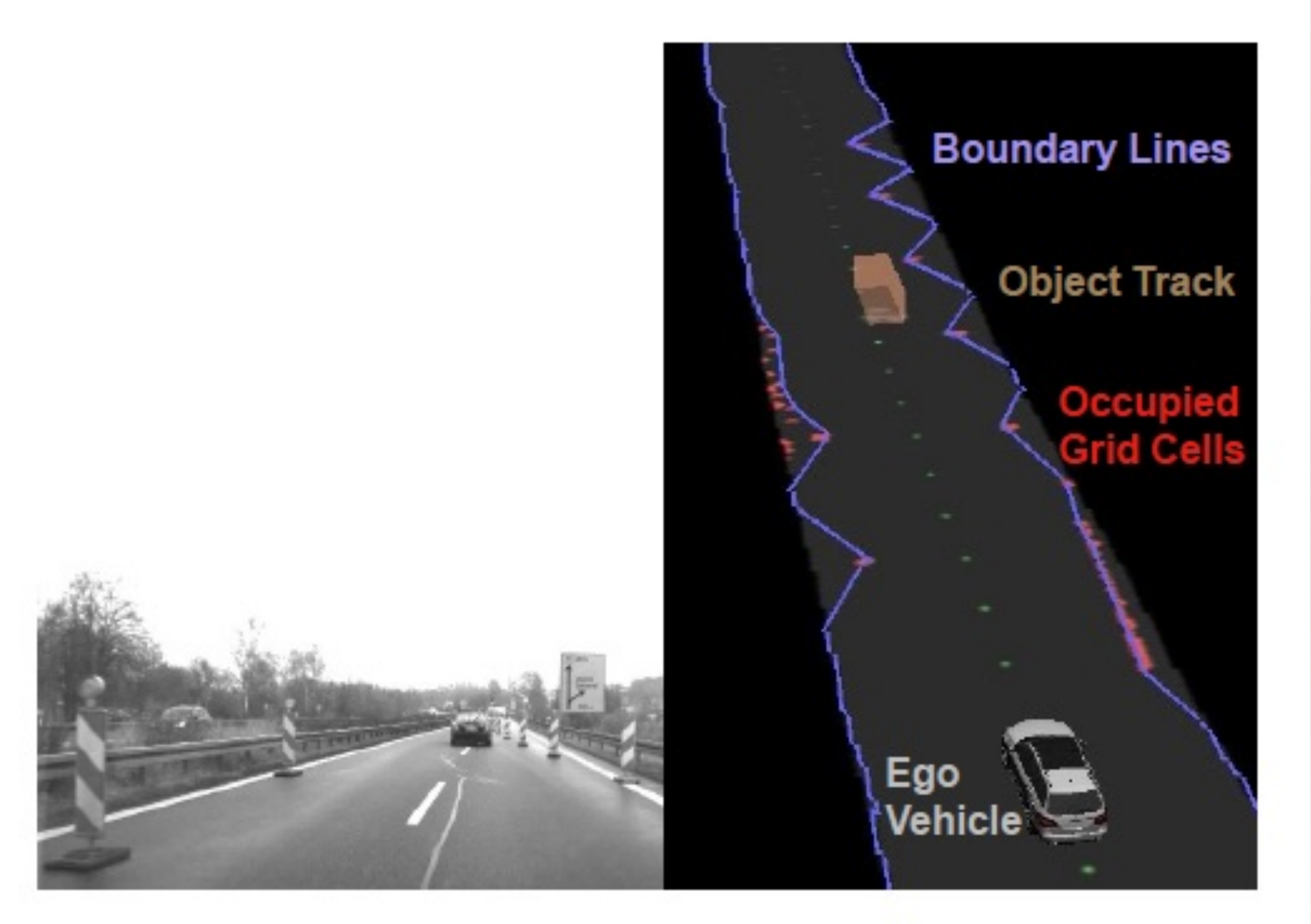
- Replace the grid map with boundary lines, which limit the drivable space.
- Conservative fallback

  behavior

  - Follow a leading car
  - Speed Control (max 50-70k



Motion Plan

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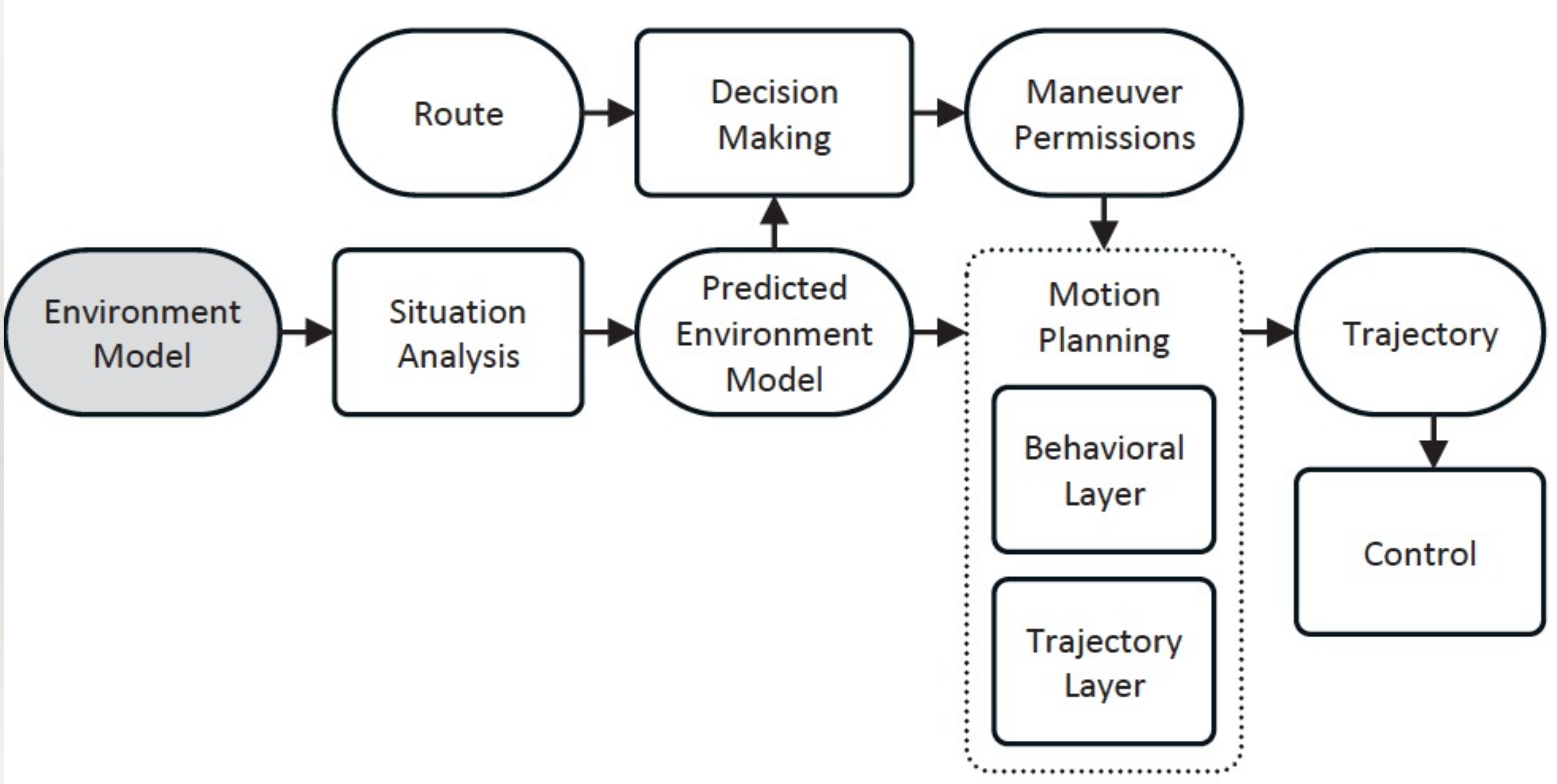

Results and Conclusion

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- The 5km test:
  - The mean LMB state estimation error for the leading vehicle is below 30cm at distances between 30 and 100m.
  - The ego localization error is below 0.09m, with a standard deviation of less than 0.17m.
- Challenging conditions (rain, fog, etc.):
  - Video camera has a poor performance and object classification is diminished.
  - The ego localization relies only on laser measurements (error 0.12m, still sufficient).
- Expectation:
  - A highly-precise digital map is needed.
  - Further improvements of the object tracking module.

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iMorpheus Journal Club (Friday 12:00PM GMT+8, Weekly)

每周五 下午12点 （北京时间）

下周预告：

YOLO9000 : Better, Faster, Stronger

关键词：Real time Object detection, RT Object classification, Wordtree, Joint Training Algorthm

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