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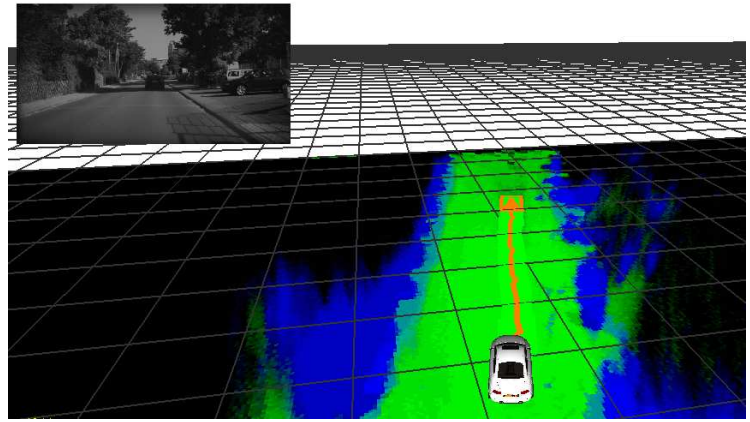

M.Sc. Matthias Schreier

Environment Representation

REGELUNGSMETHODEN UND ROBOTIK rmr

PRORETA

Environment Representations for Intelligent Vehicles – Related Work

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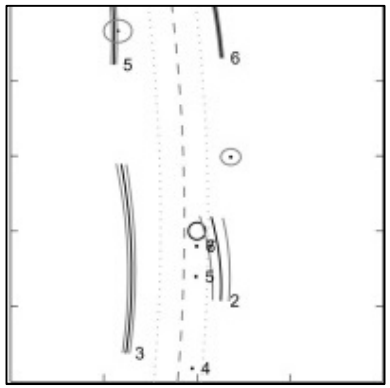
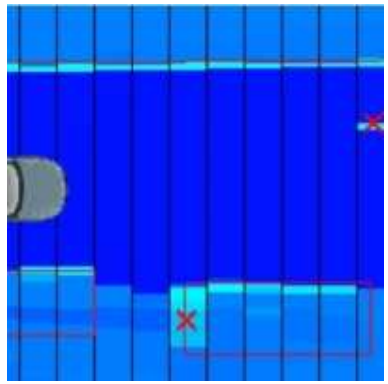
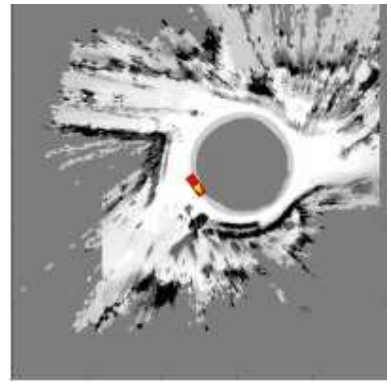
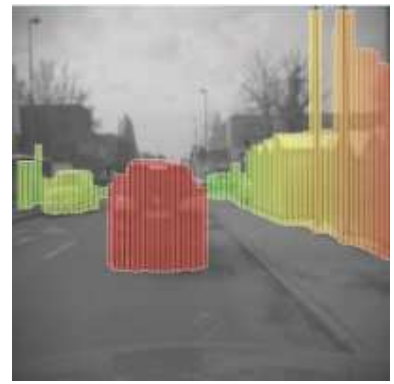


[Lundquist 09]

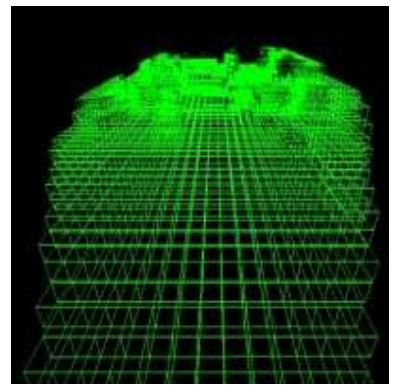

[Weiherer 13]


[Schreier 13]


[Badino 09]


[Danescu 14]


[Triebel 06]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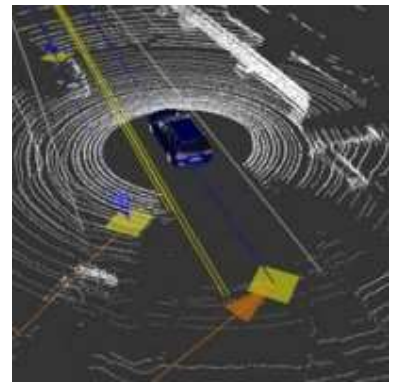
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Environment Representations for Intelligent Vehicles – Related Work

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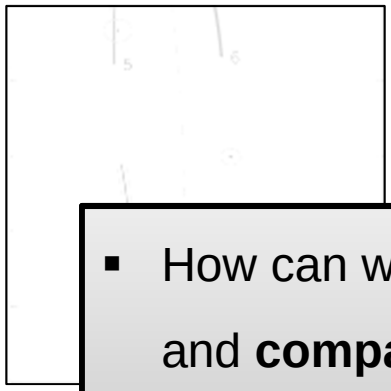
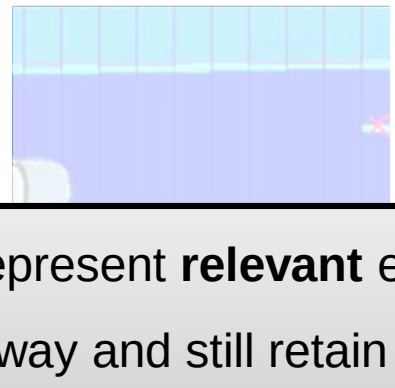
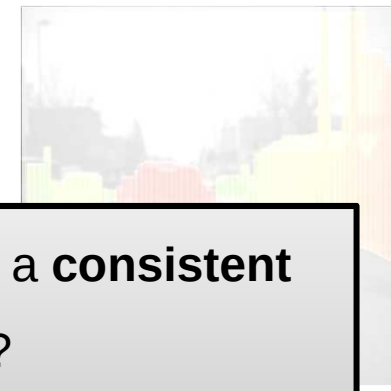
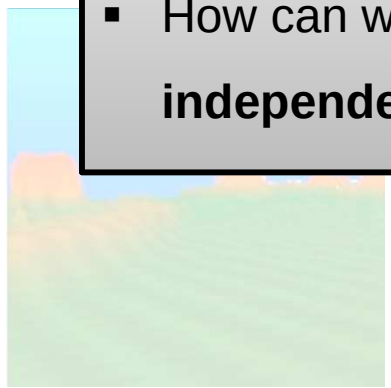
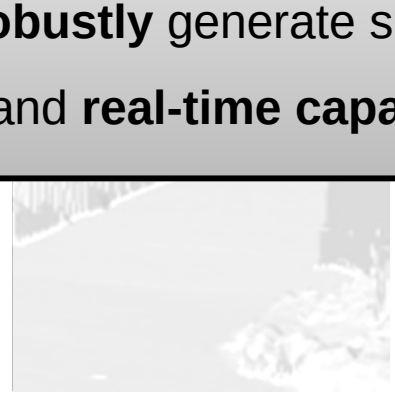
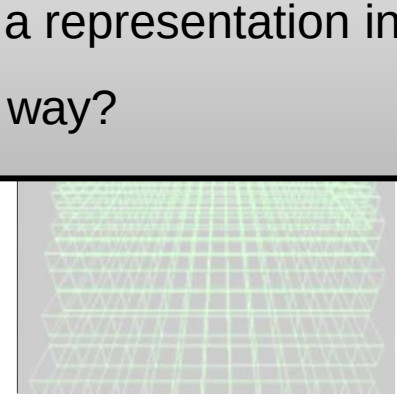
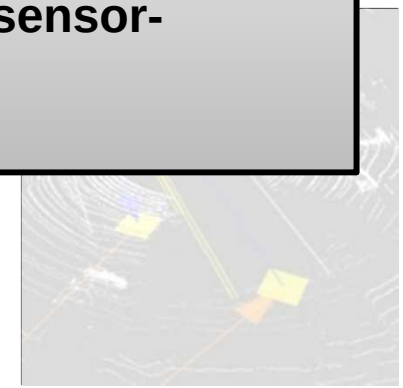





- How can we represent **relevant** environment information in a **consistent** and **compact** way and still retain **function-independence**?
- How can we **robustly** generate such a representation in a **sensor-independent** and **real-time capable** way?

[Danescu 14] [Triebel 06] [Broggi 13] [Petrovskaya 09]

REGELUNGSMETHODEN UND ROBOTIK rmr PRORETA

Environment Representation of PRORETA 3

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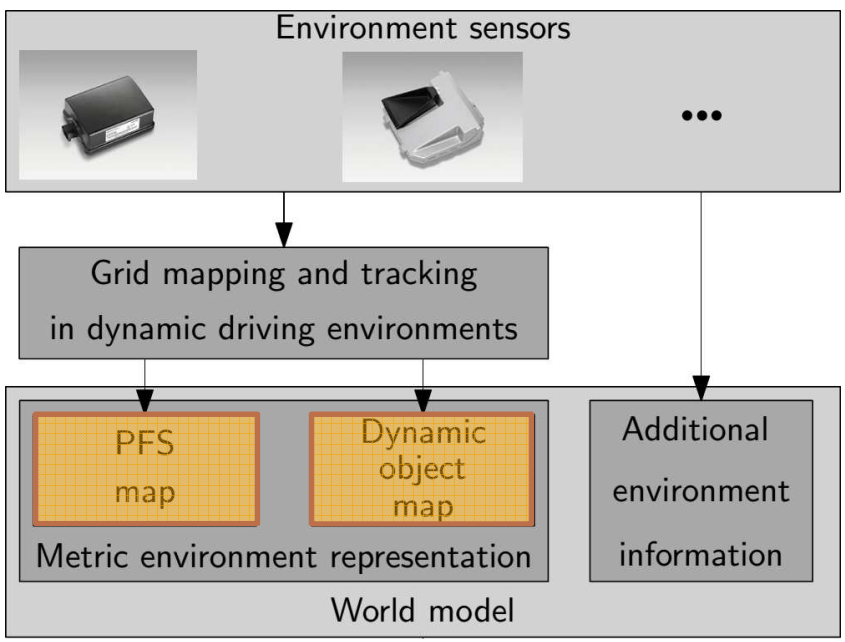
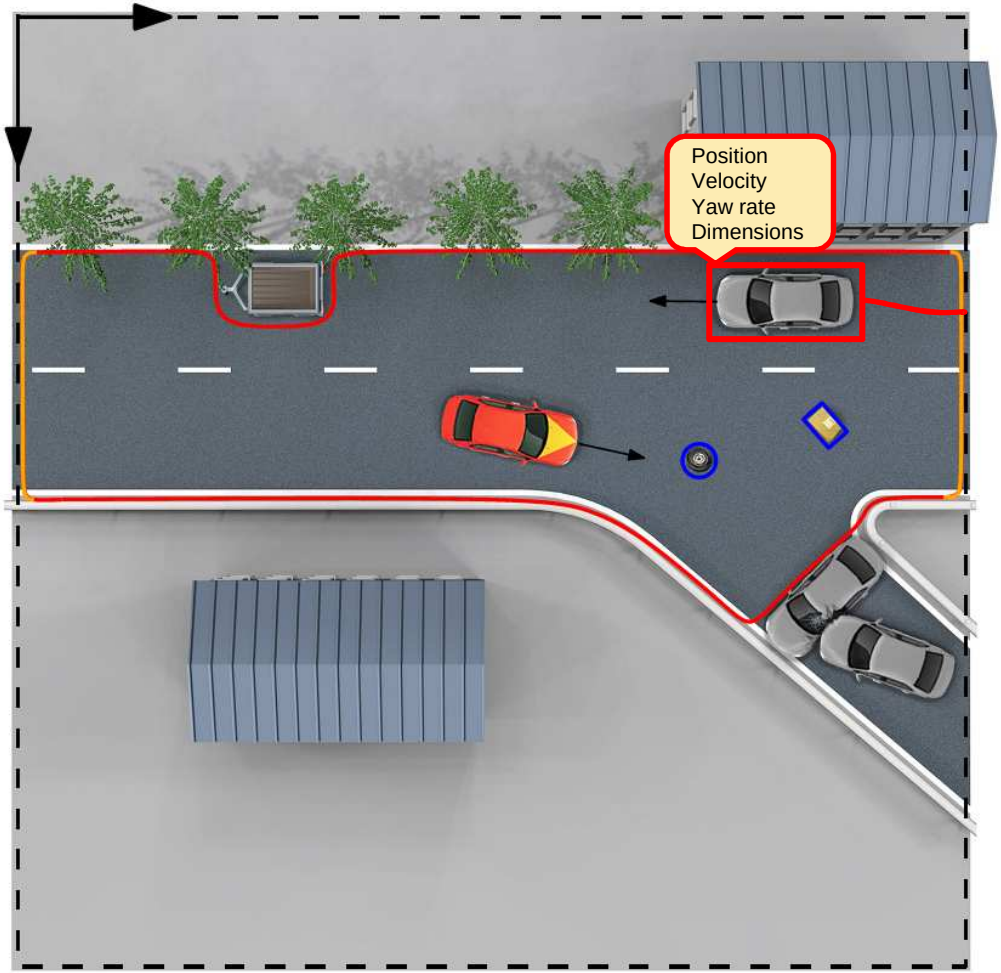
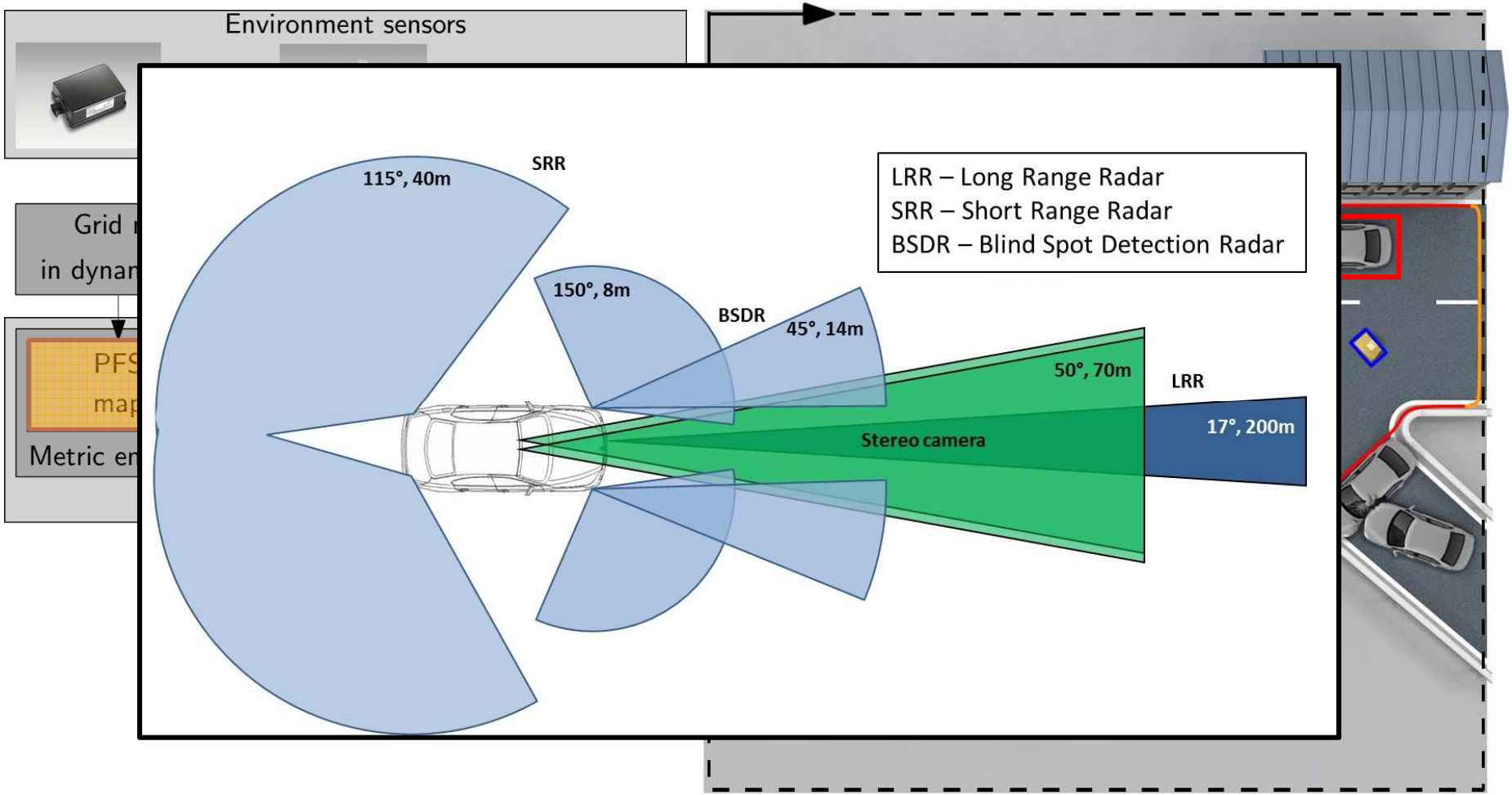




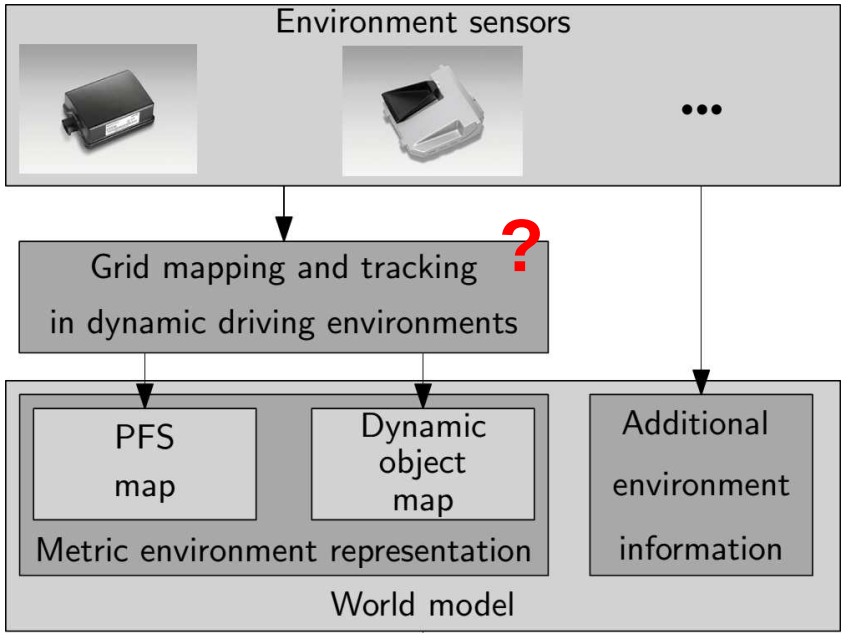
REGELUNGSMETHODEN UND ROBOTIK rmr

PRORETA

Environment Representation of PRORETA 3



Environment Representation of PRORETA 3



Grid Mapping in Dynamic Environments – Motivation and Aim

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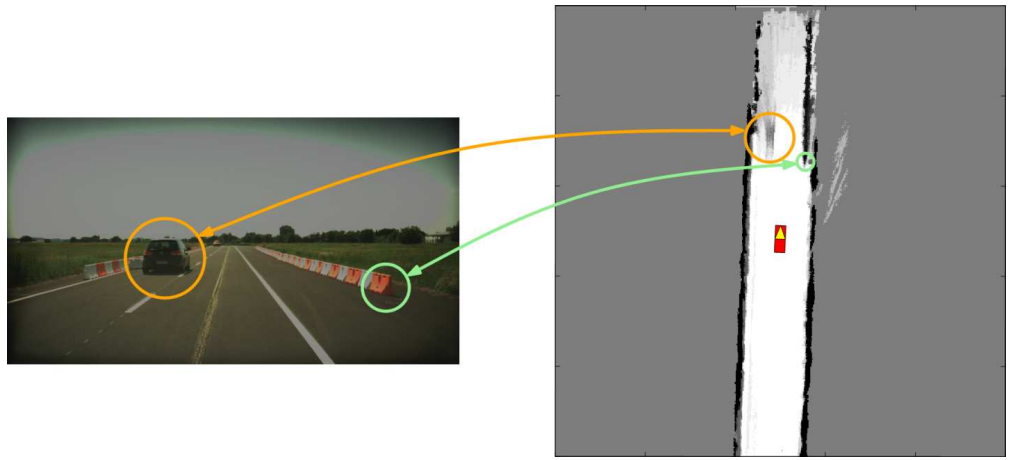
Standard Filter: Dynamic objects cause undesired **mapping errors**



→ Development of a **real-time** capable, **sensor-independent** method for mapping **dynamic** driving environments in the presence of

- only partially visible dynamic objects
- merged static and dynamic environment in the grid
- noise and ego motion

Grid Mapping in Dynamic Environments – Algorithm

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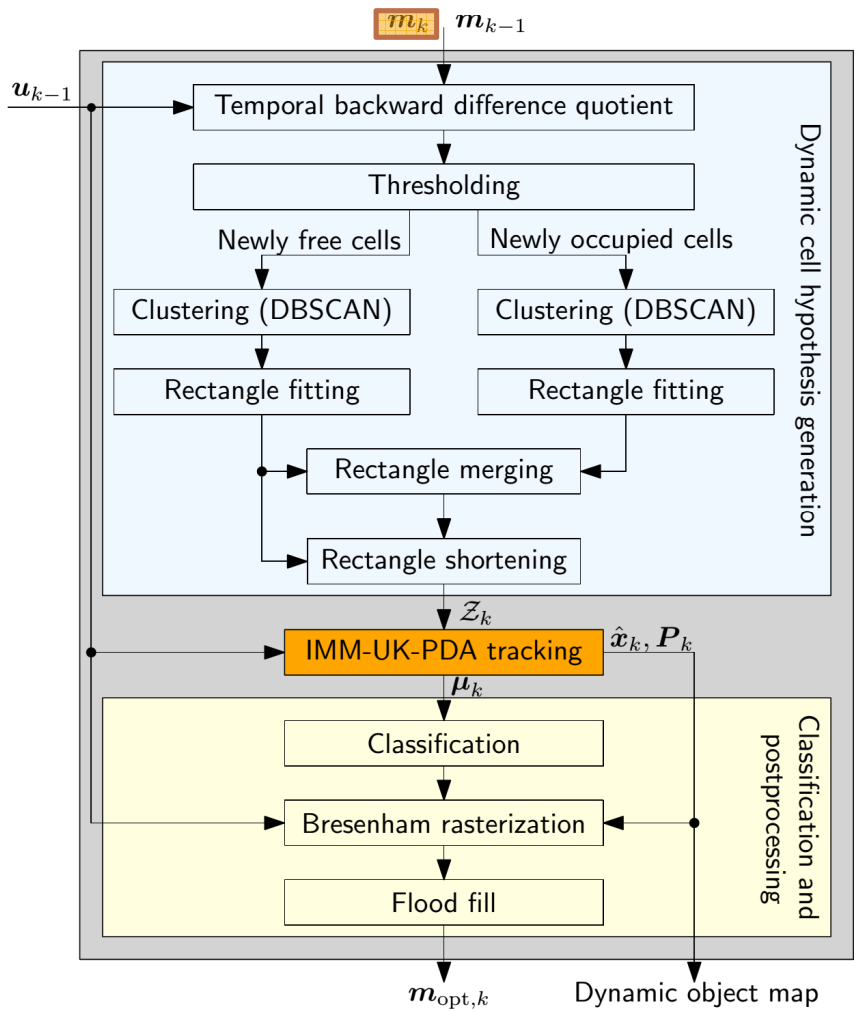

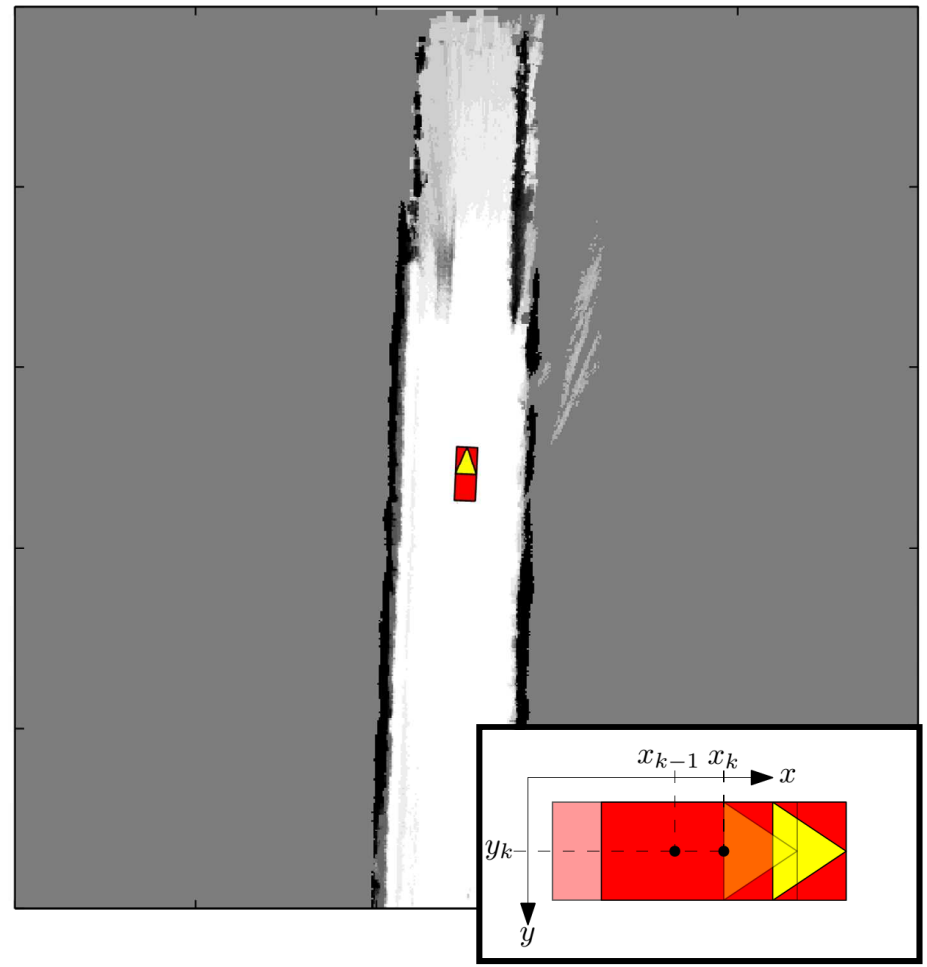

REGELUNGSMETHODEN UND ROBOTIK rmr

PRORETA

Grid Mapping in Dynamic Environments – Algorithm

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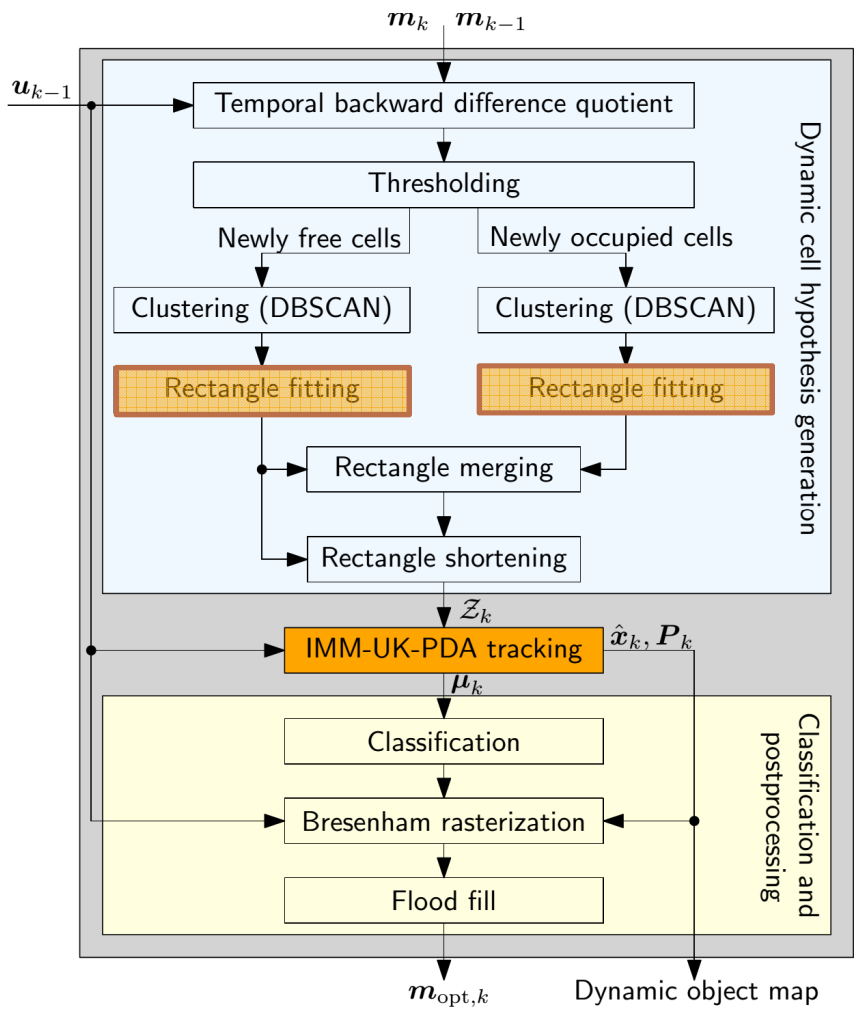
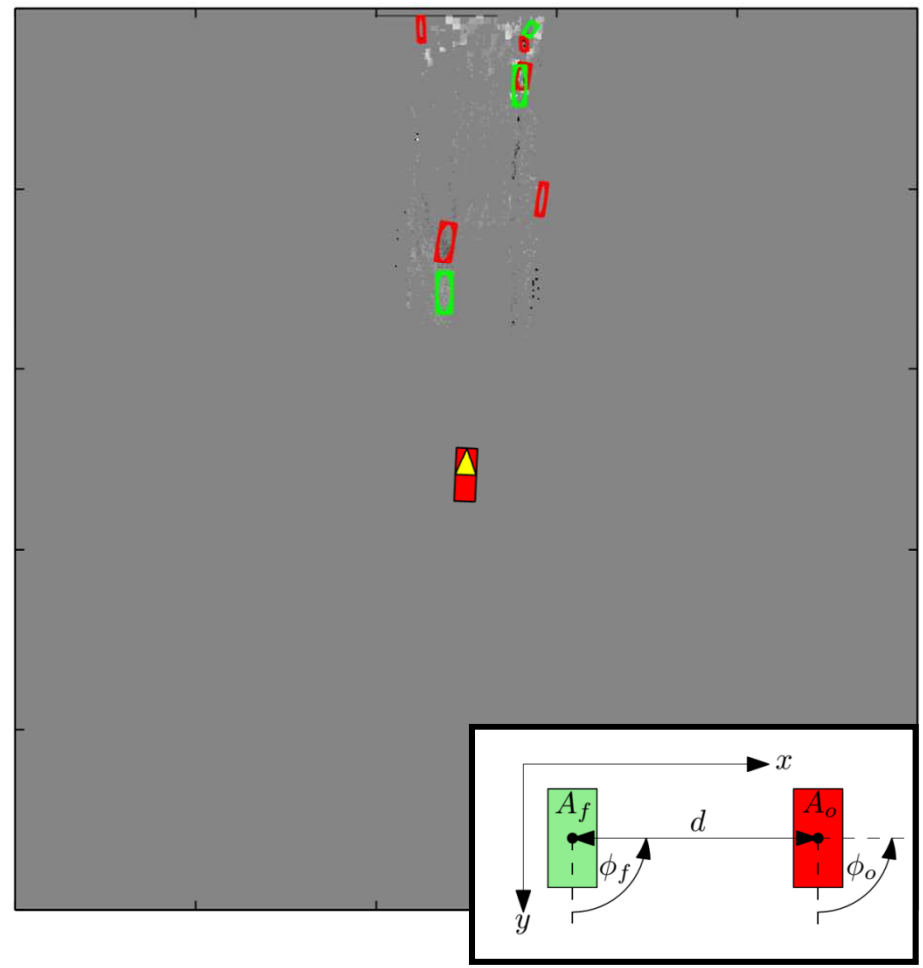
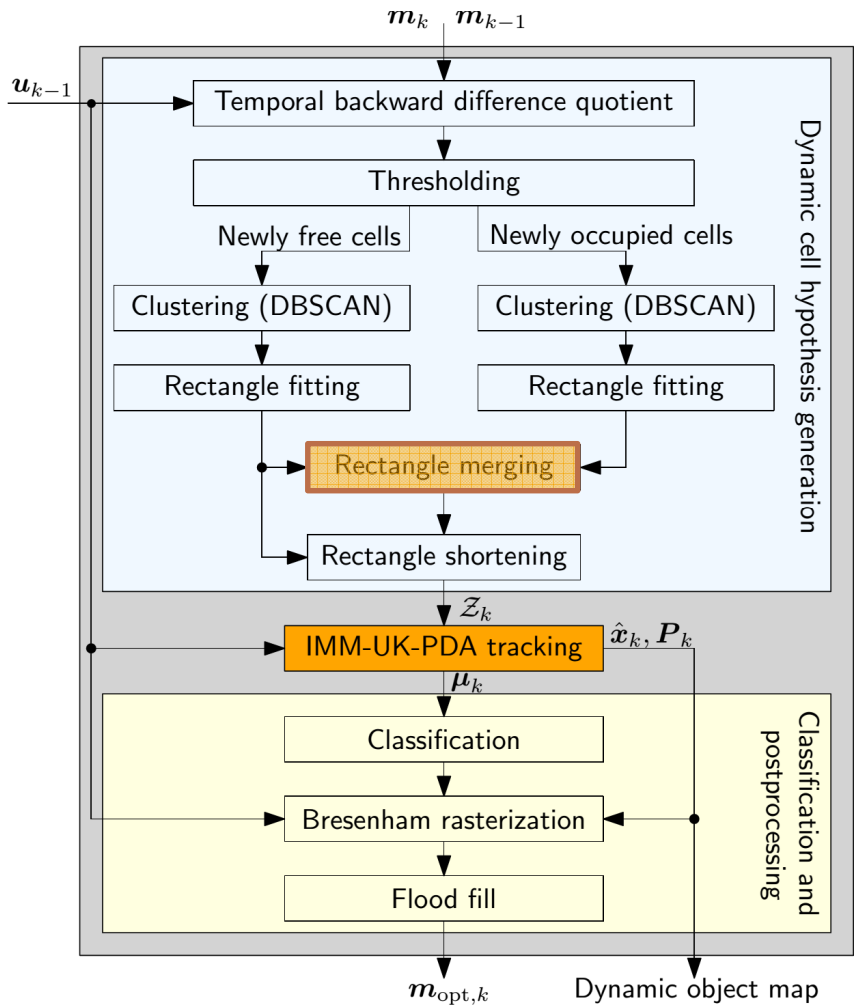


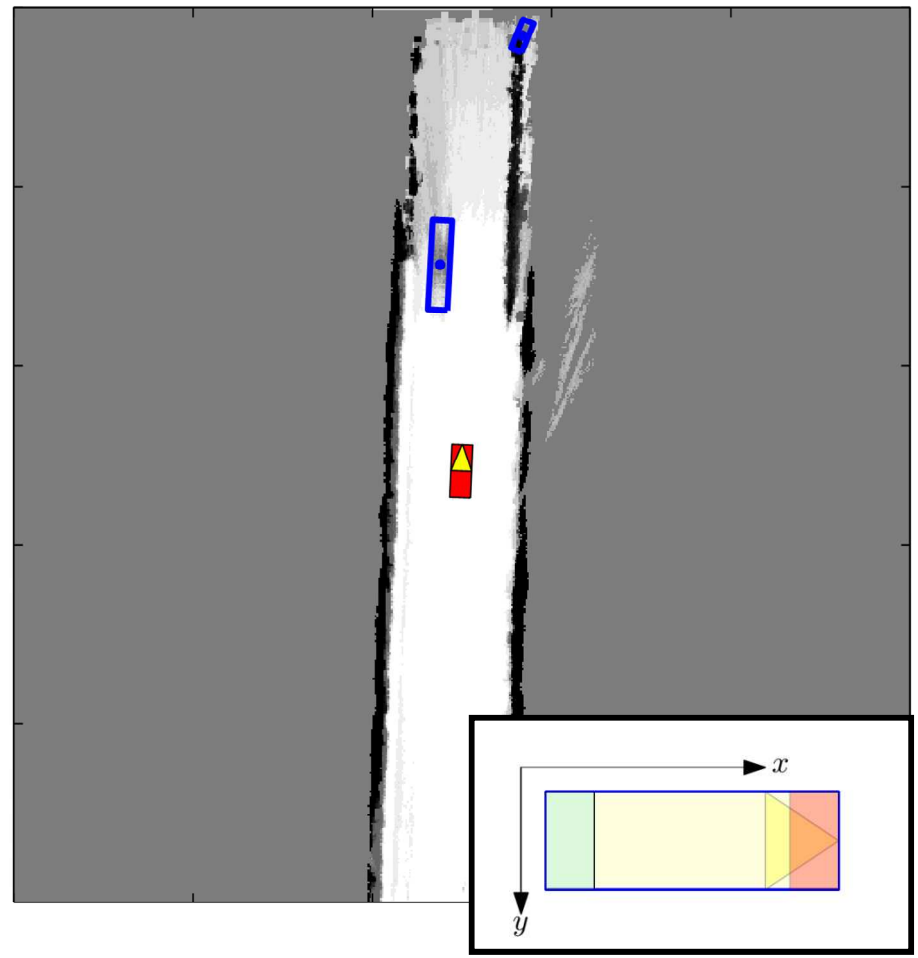


REGELUNGSMETHODEN UND ROBOTIK rmr

PRORETA

Grid Mapping in Dynamic Environments – Algorithm





Grid Mapping in Dynamic Environments – Algorithm

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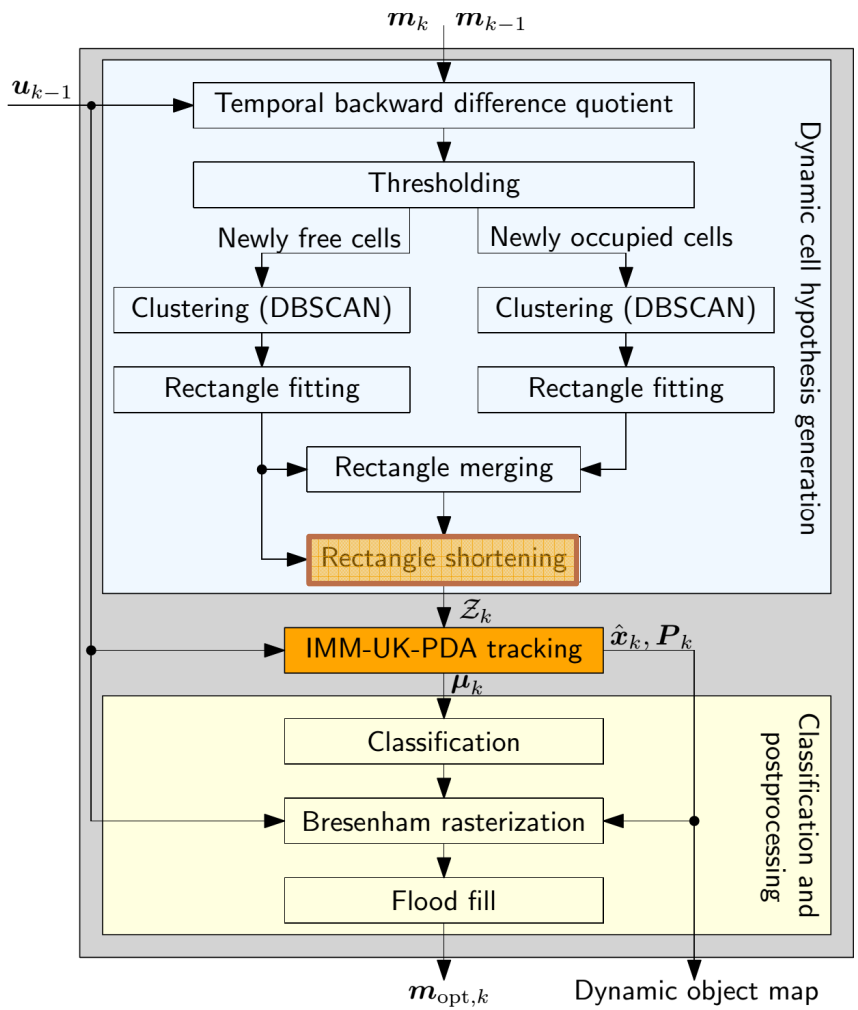

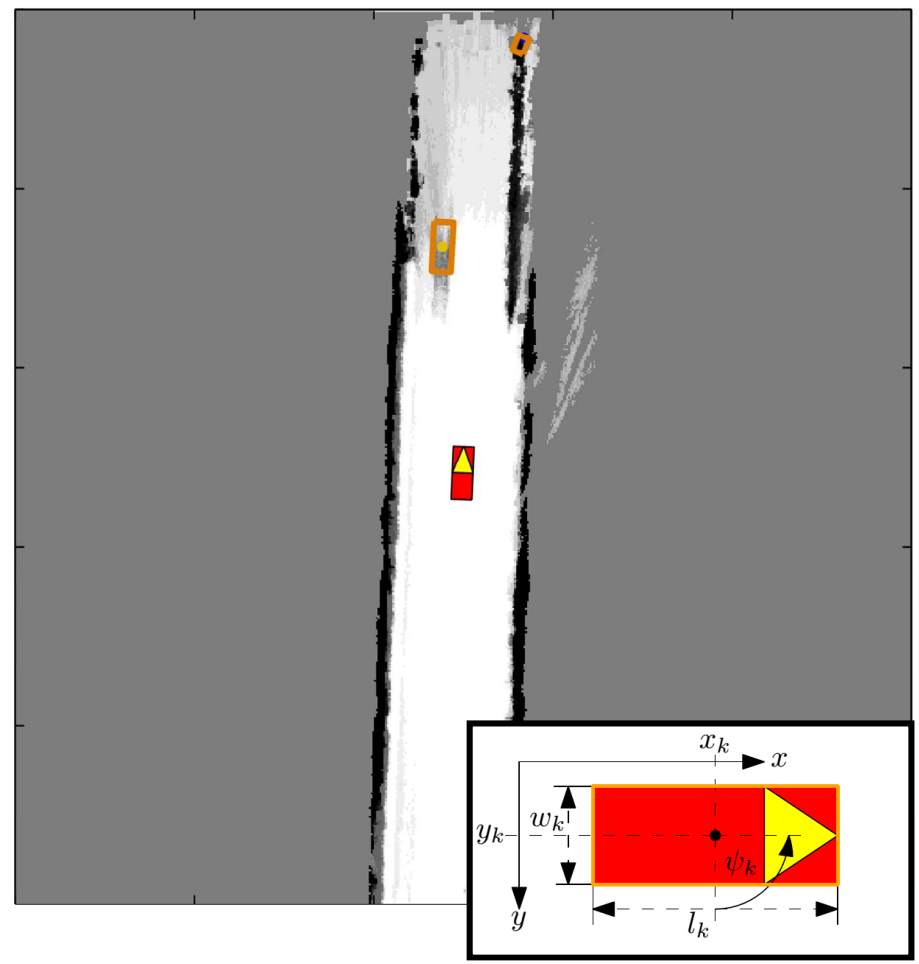

REGELUNGSMETHODEN UND ROBOTIK rmr

PRORETA

Grid Mapping in Dynamic Environments – Tracking via IMM-UK-PDA Filter

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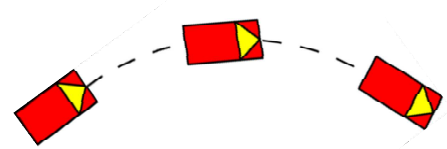
Motion models of type

≈ Constant Velocity (CV)

$$\boldsymbol{x}_{k+1} = \begin{pmatrix} x_k + \frac{v_k T \sin\psi_k}{c} \\ y_k + \frac{v_k T \cos\psi_k}{c} \\ \psi_k \\ v_k \\ 0 \\ l_k \\ w_k \end{pmatrix} + \boldsymbol{u}_k + \boldsymbol{w}_k$$

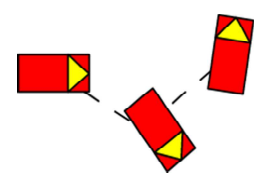
≈ Constant Turn Rate and Velocity (CTRV)

$$\boldsymbol{x}_{k+1} = \begin{pmatrix} x_k + \frac{v_k}{c\omega_k}(\cos\psi_k - \cos(\omega_k T + \psi_k)) \\ y_k + \frac{v_k}{c\omega_k}(\sin(\omega_k T + \psi_k) - \sin\psi_k) \\ \psi_k + \omega_k T \\ v_k \\ \omega_k \\ l_k \\ w_k \end{pmatrix} + \boldsymbol{u}_k + \boldsymbol{w}_k$$



Random Motion

$$\boldsymbol{x}_{k+1} = \begin{pmatrix} x_k \\ y_k \\ \psi_k \\ 0 \\ 0 \\ l_k \\ w_k \end{pmatrix} + \boldsymbol{u}_k + \boldsymbol{w}_k$$



→ Robust estimation of states and mode probabilities in clutter via combination of Interacting Multiple Model (**IMM**), Unscented Kalman (**UK**) and Probabilistic Data Association (**PDA**) tracking filter (**IMM-UK-PDA**)

REGELUNGSMETHODEN UND ROBOTIK rmr PRORETA

Grid Mapping in Dynamic Environments – Algorithm

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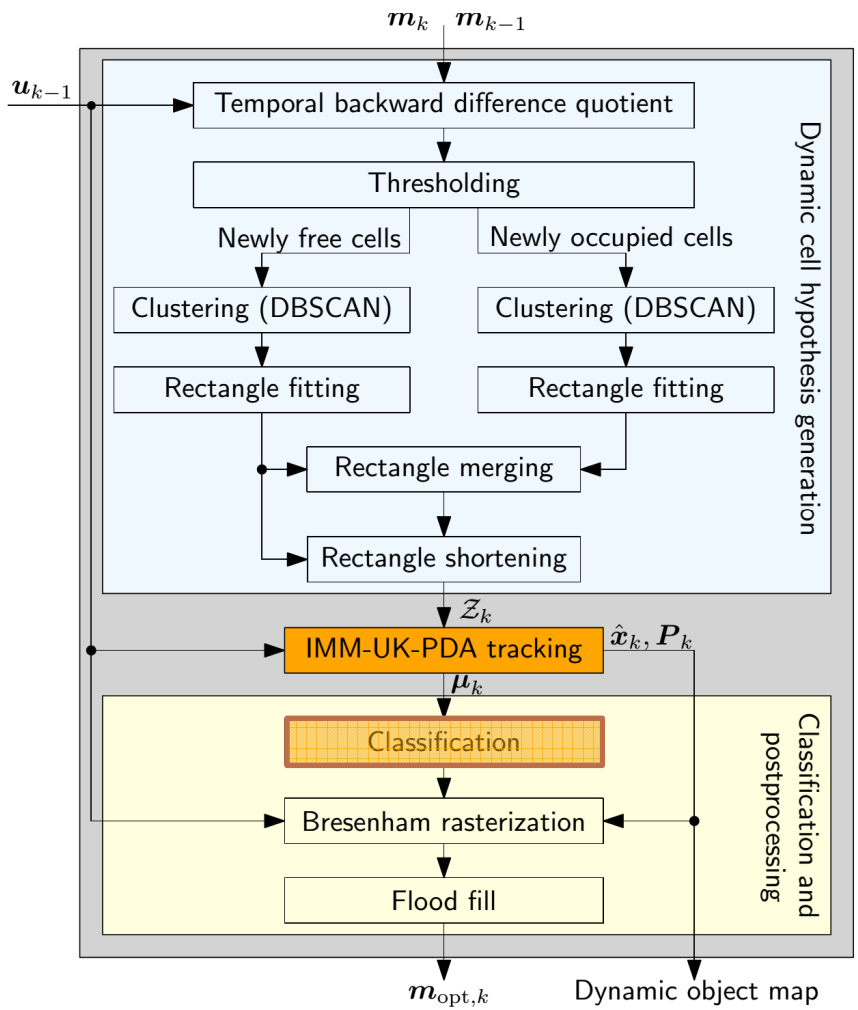

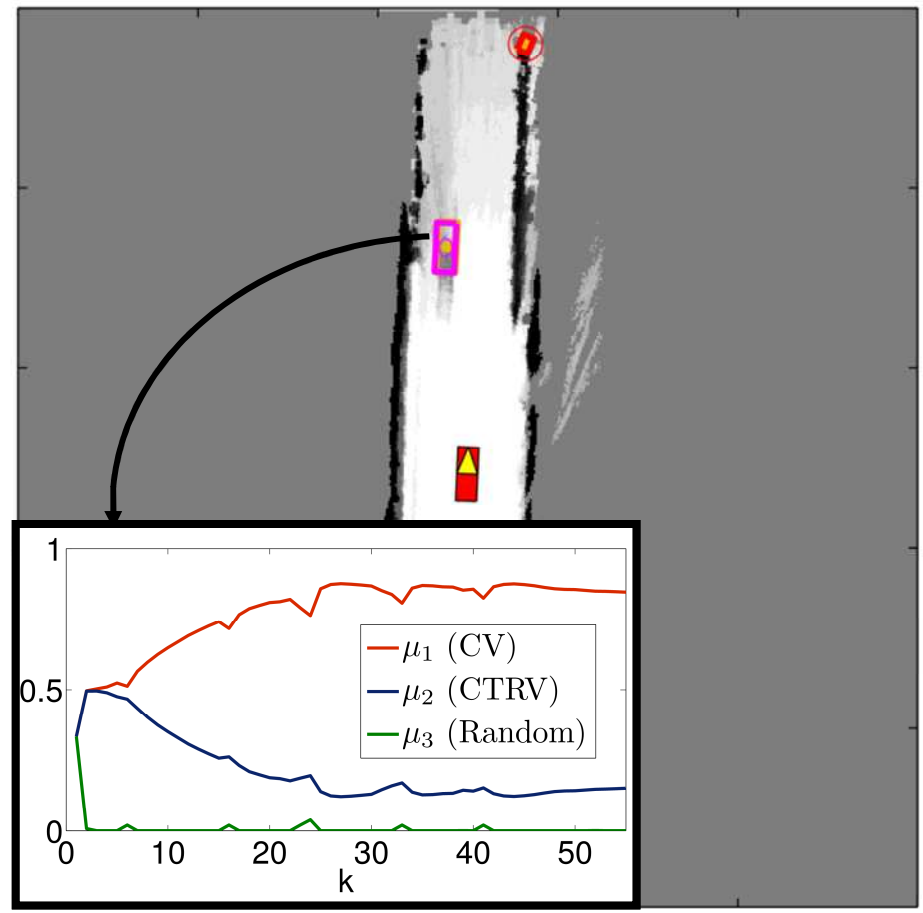

REGELUNGSMETHODEN UND ROBOTIK rmr

PRORETA

Grid Mapping in Dynamic Environments – Algorithm

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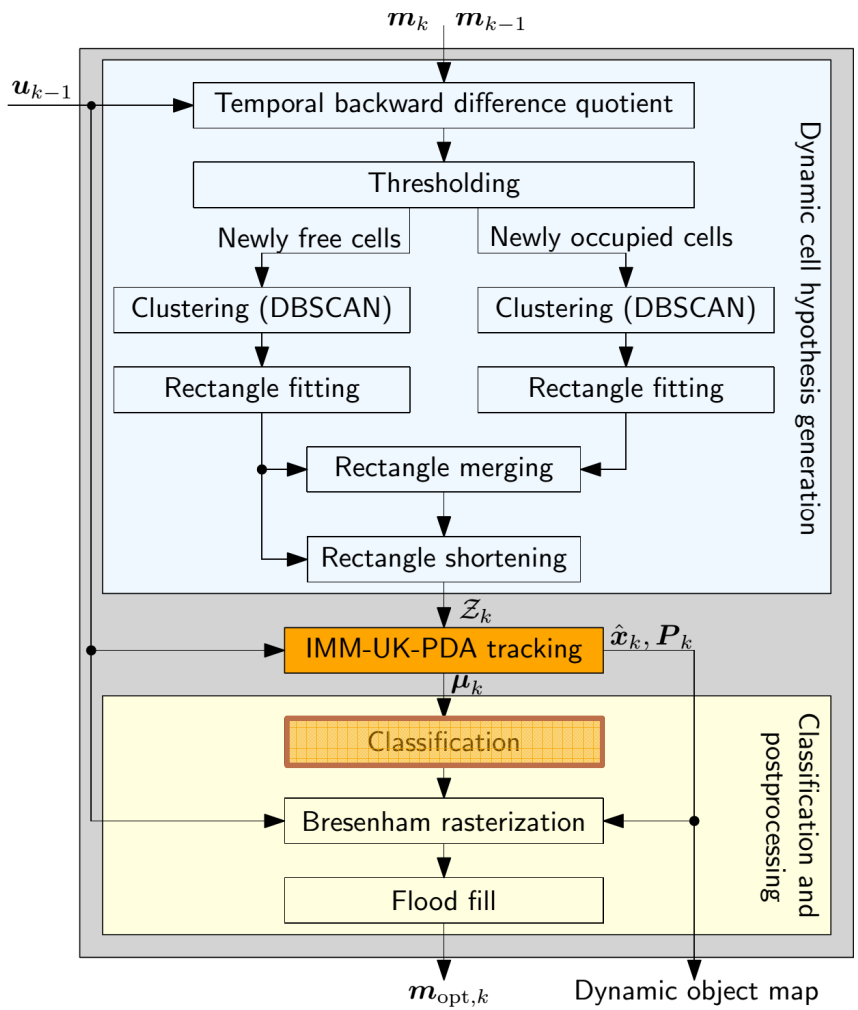
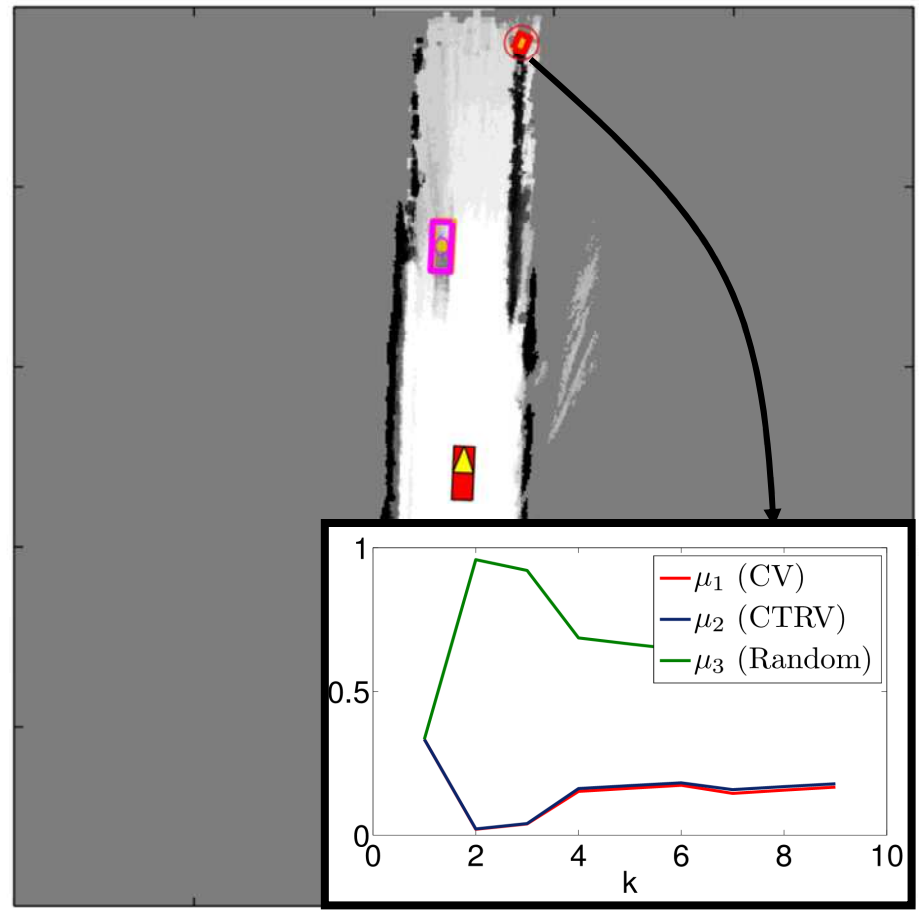
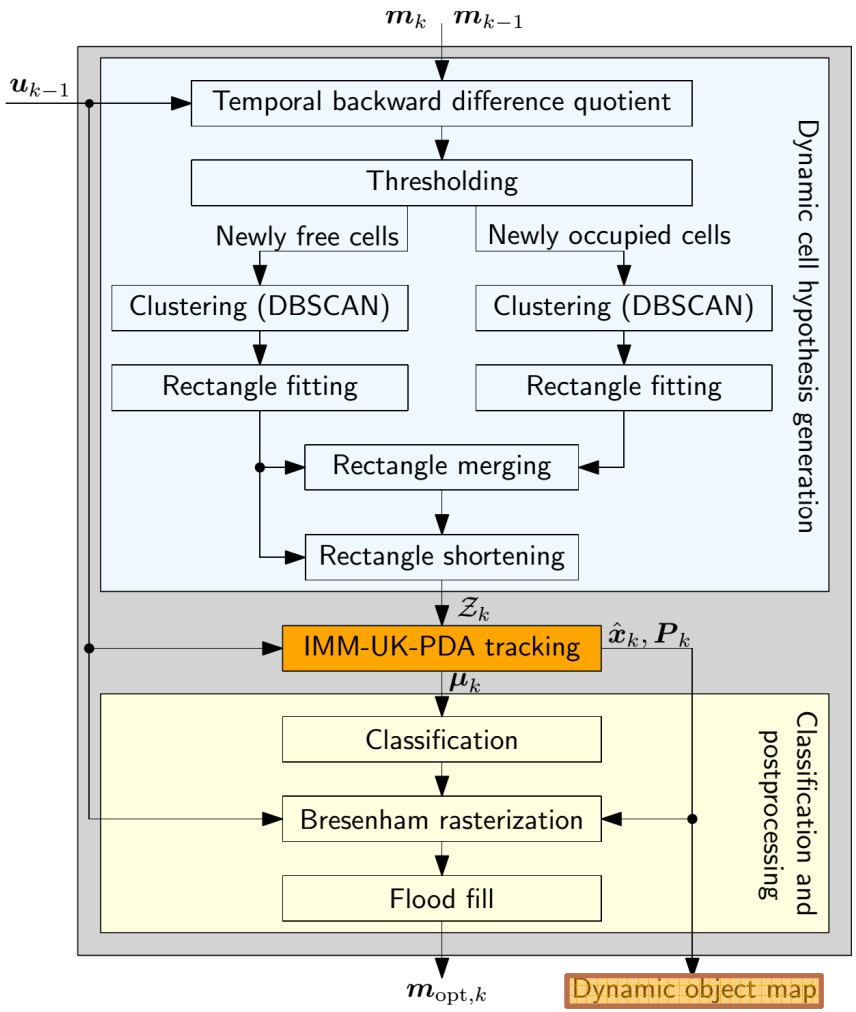


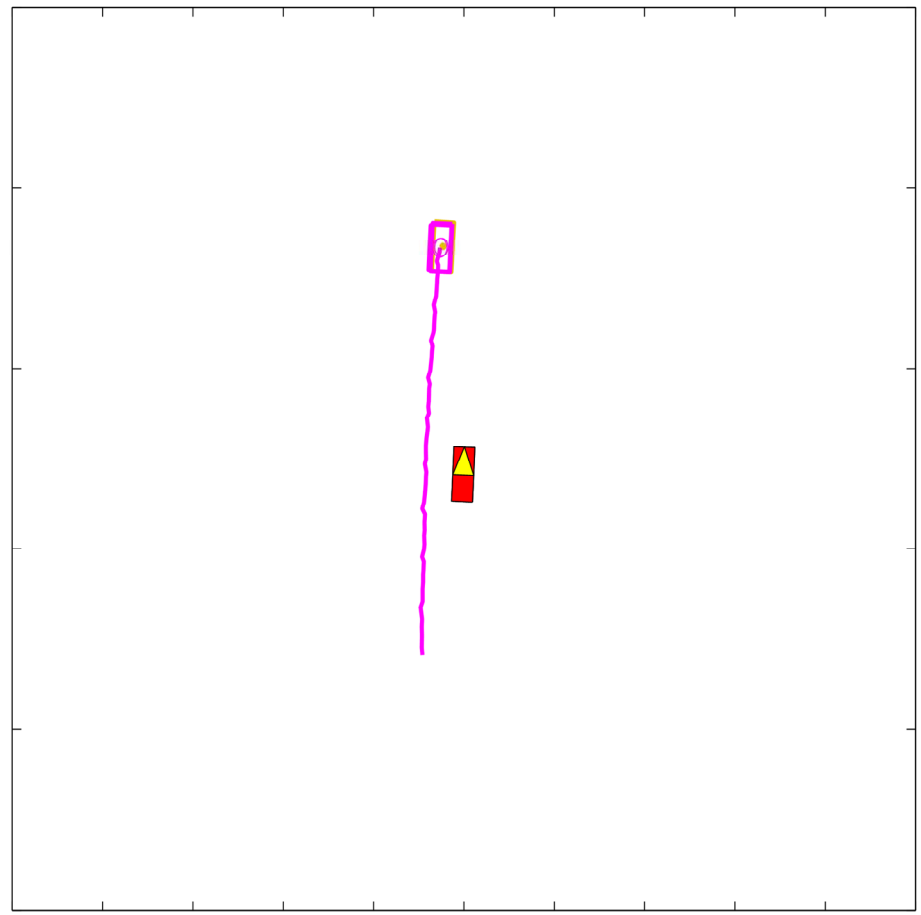


REGELUNGSMETHODEN UND ROBOTIK rmr

PRORETA

Grid Mapping in Dynamic Environments – Algorithm





Grid Mapping in Dynamic Environments – Algorithm

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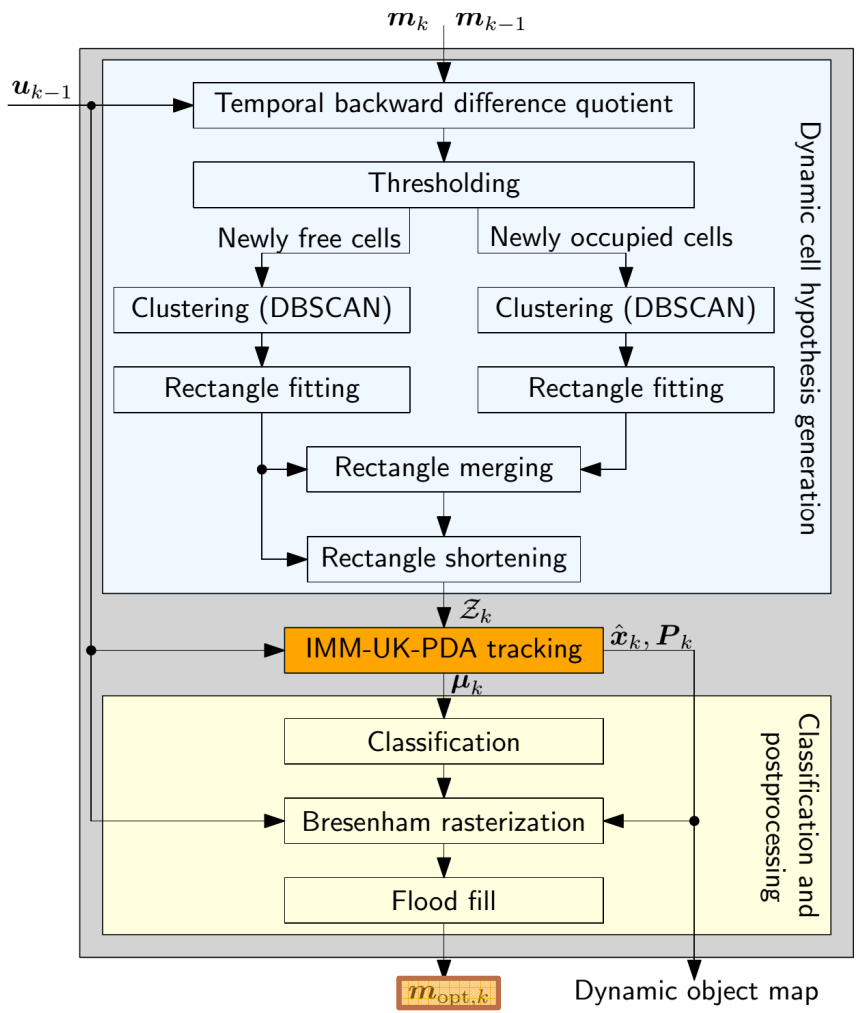

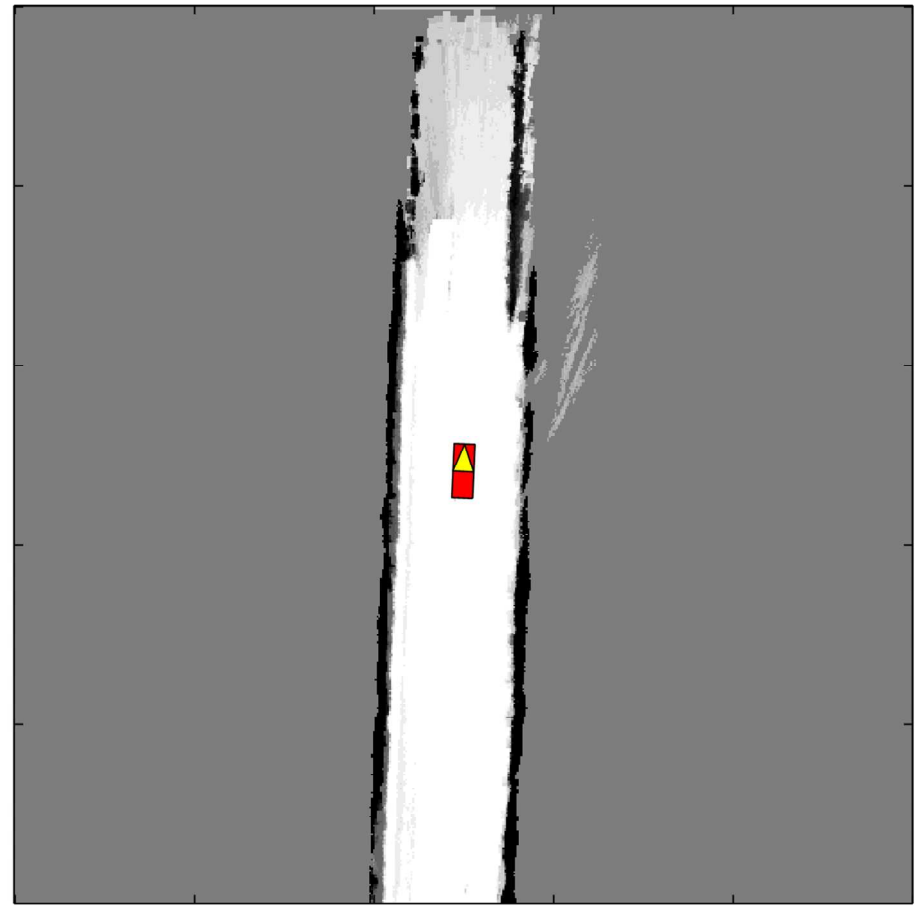

REGELUNGSMETHODEN UND ROBOTIK rmr

PRORETA

Grid Mapping in Dynamic Environments – Examples

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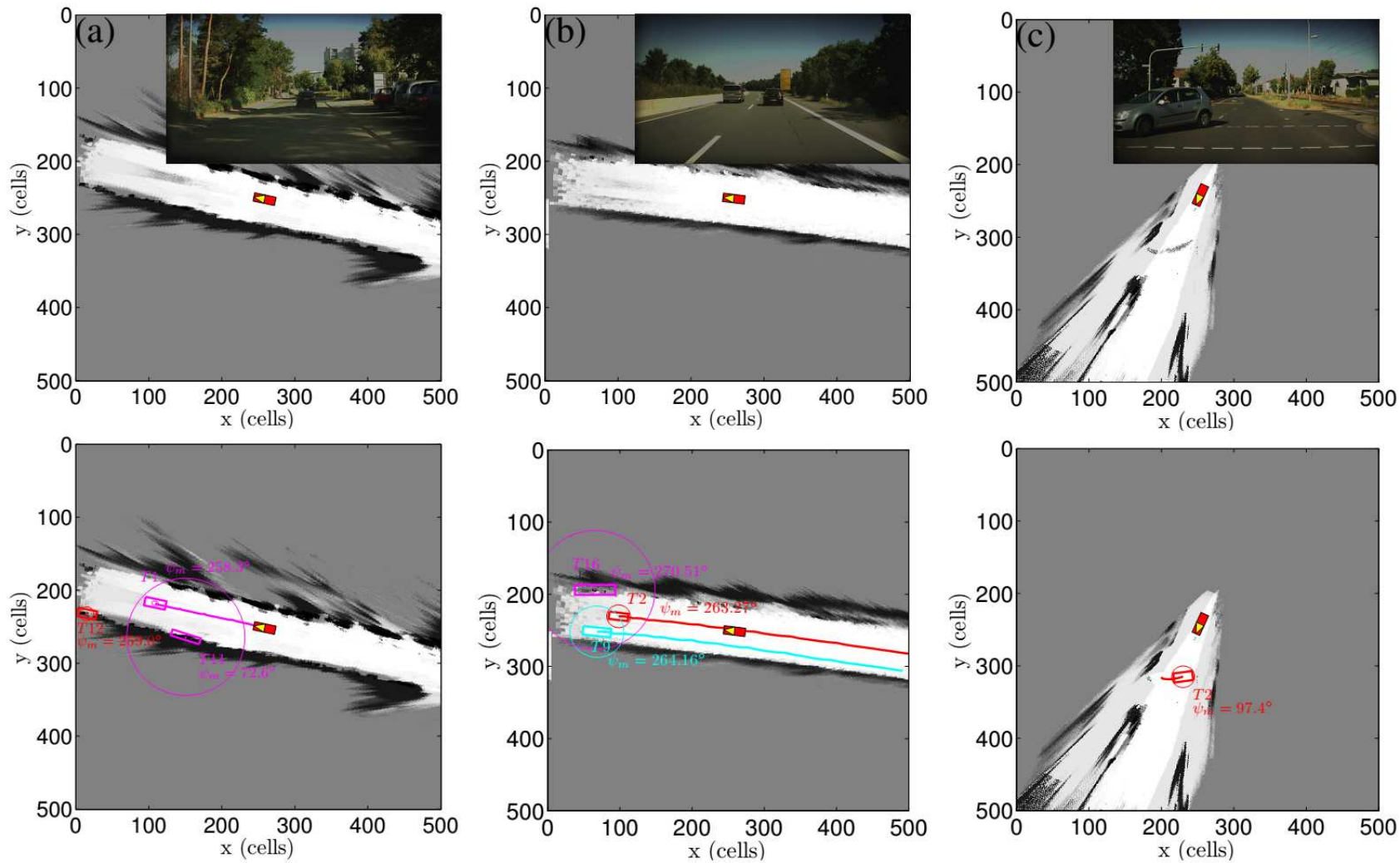
Standard Mapping

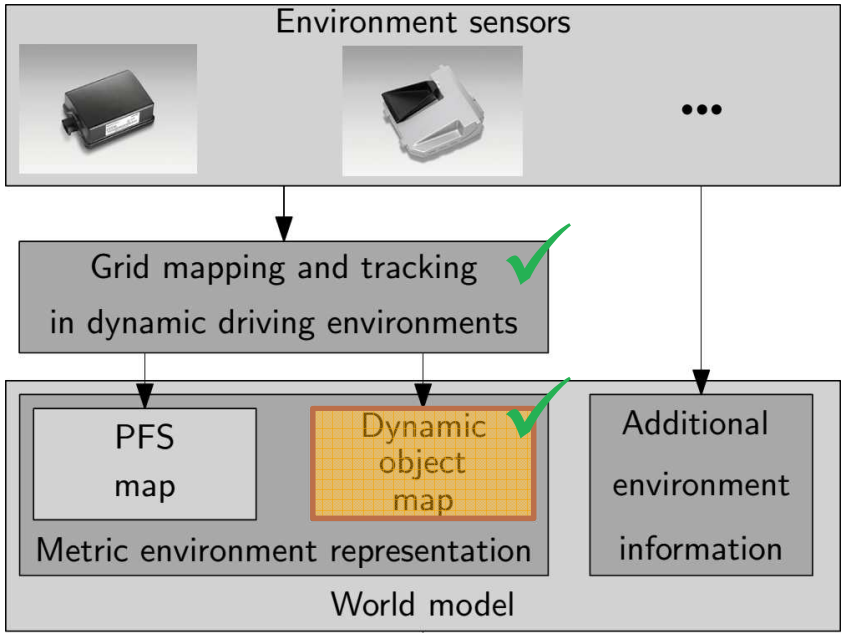
Proposed Approach



REGELUNGSMETHODEN UND ROBOTIK rmr

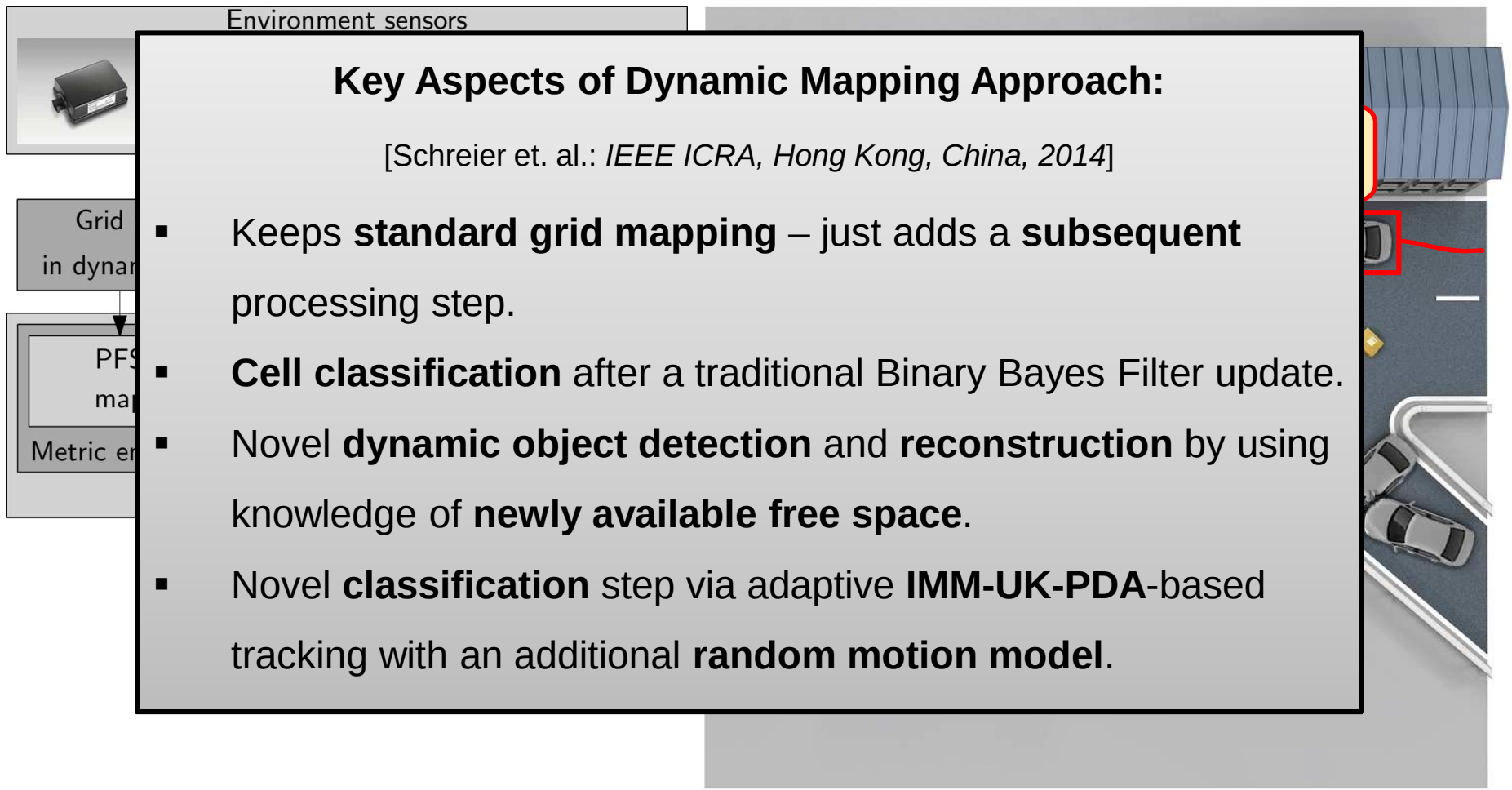
PRORETA

Environment Representation of PRORETA 3



Environment Representation of PRORETA 3

TECHNISCHE UNIVERSITÄT DARMSTADT



Key Aspects of Dynamic Mapping Approach:

[Schreier et. al.: *IEEE ICRA, Hong Kong, China, 2014*]

- Keeps **standard grid mapping** – just adds a **subsequent** processing step.
- **Cell classification** after a traditional Binary Bayes Filter update.
- Novel **dynamic object detection** and **reconstruction** by using knowledge of **newly available free space**.
- Novel **classification** step via adaptive **IMM-UK-PDA**-based tracking with an additional **random motion model**.

REGELUNGSMETHODEN UND ROBOTIK rmr

PRORETA

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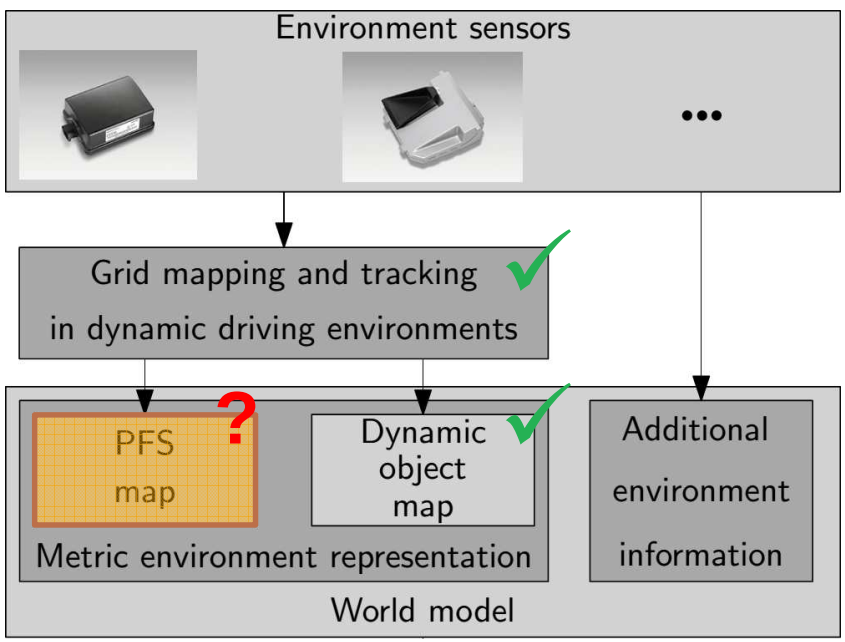
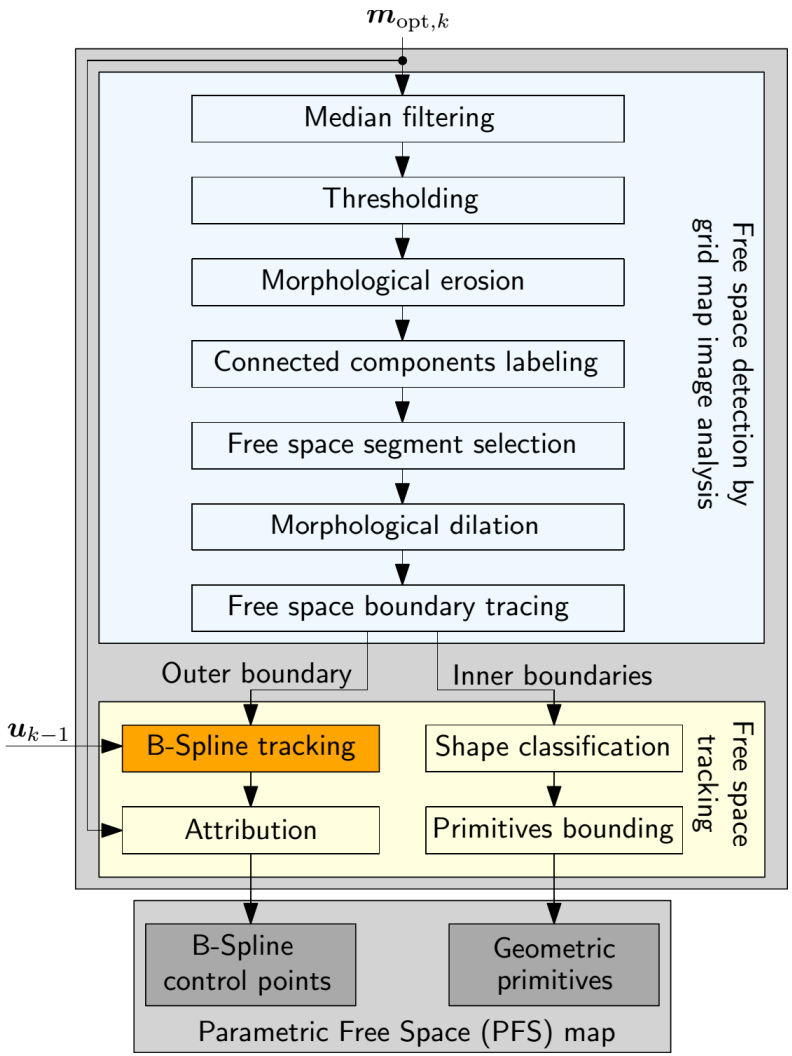


Parametric Free Space (PFS) Maps – Algorithm



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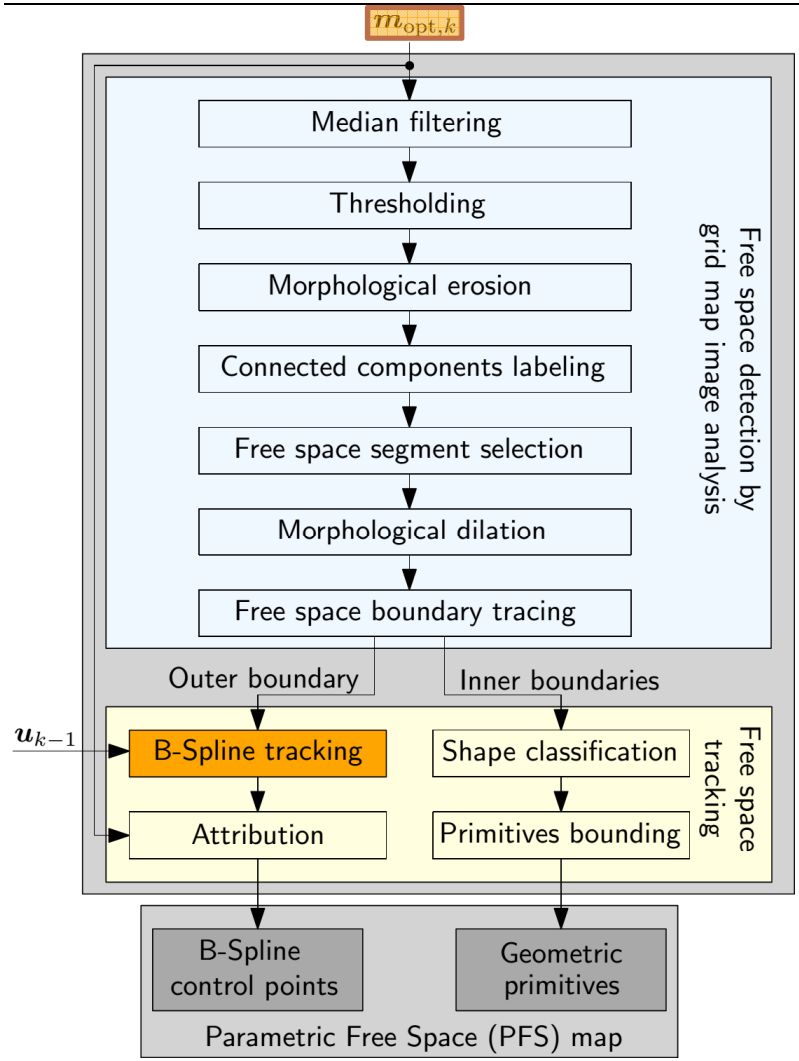

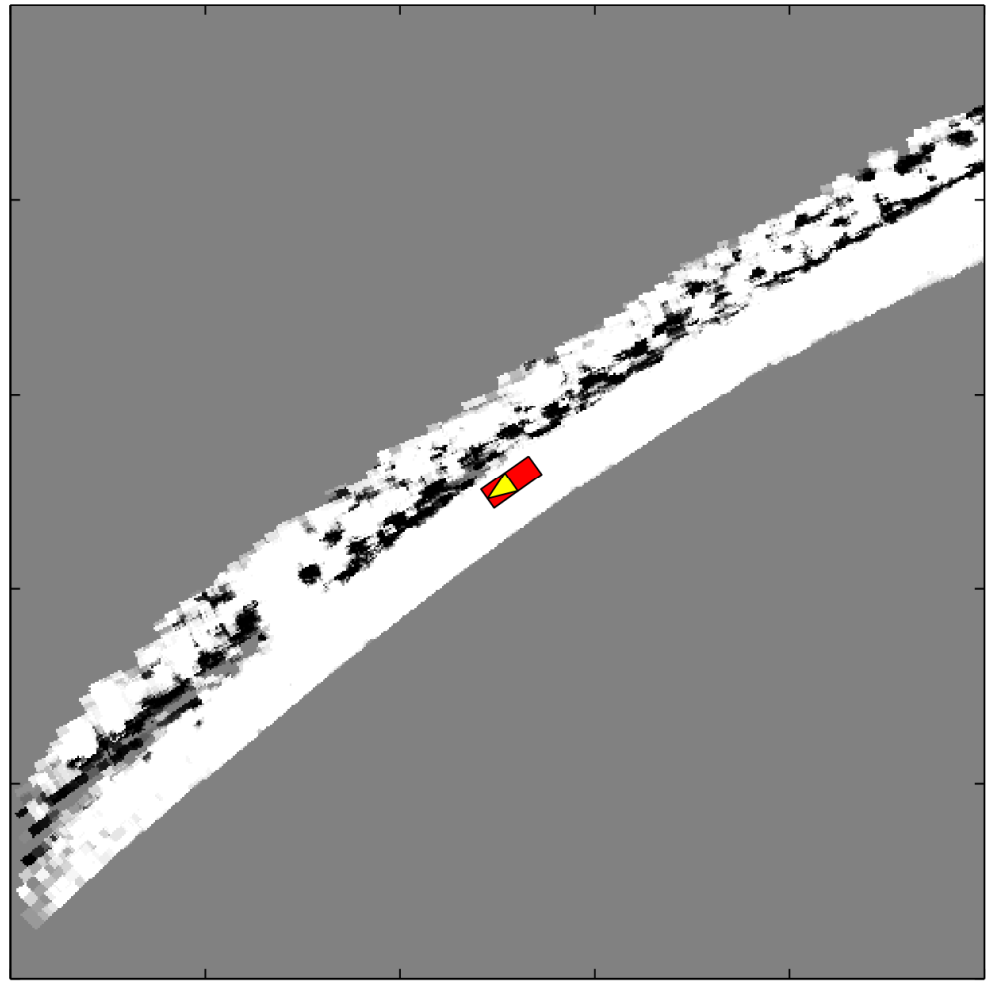

Parametric Free Space (PFS) Maps – Algorithm

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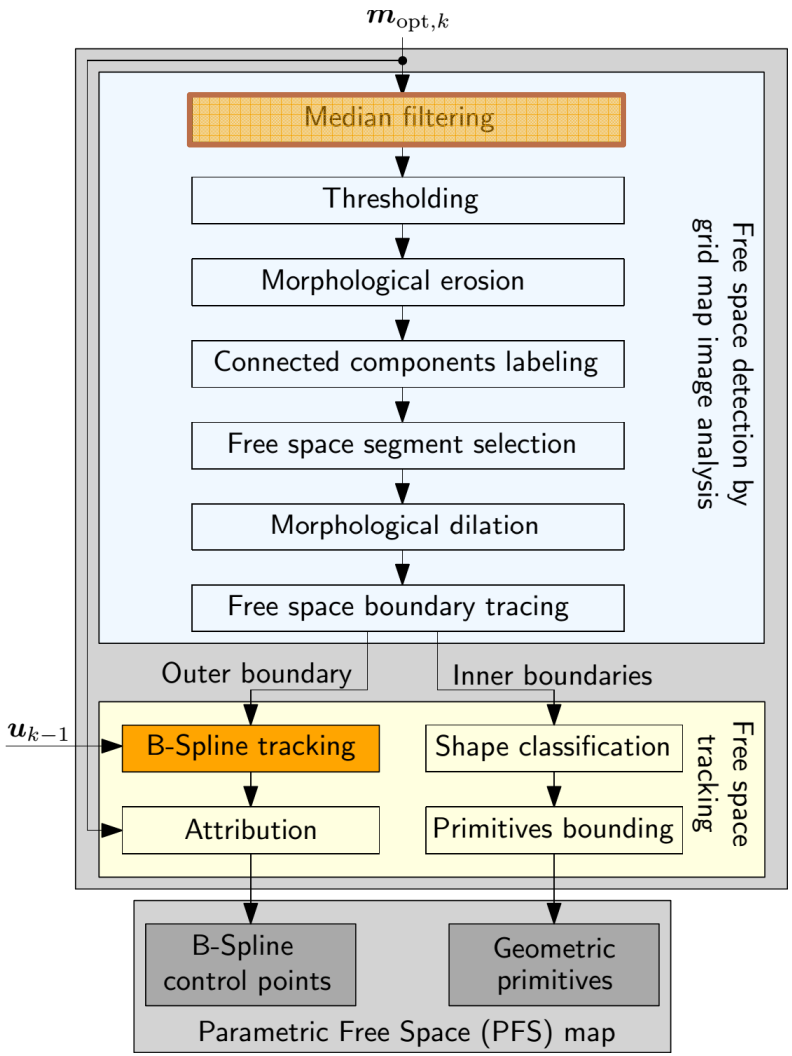

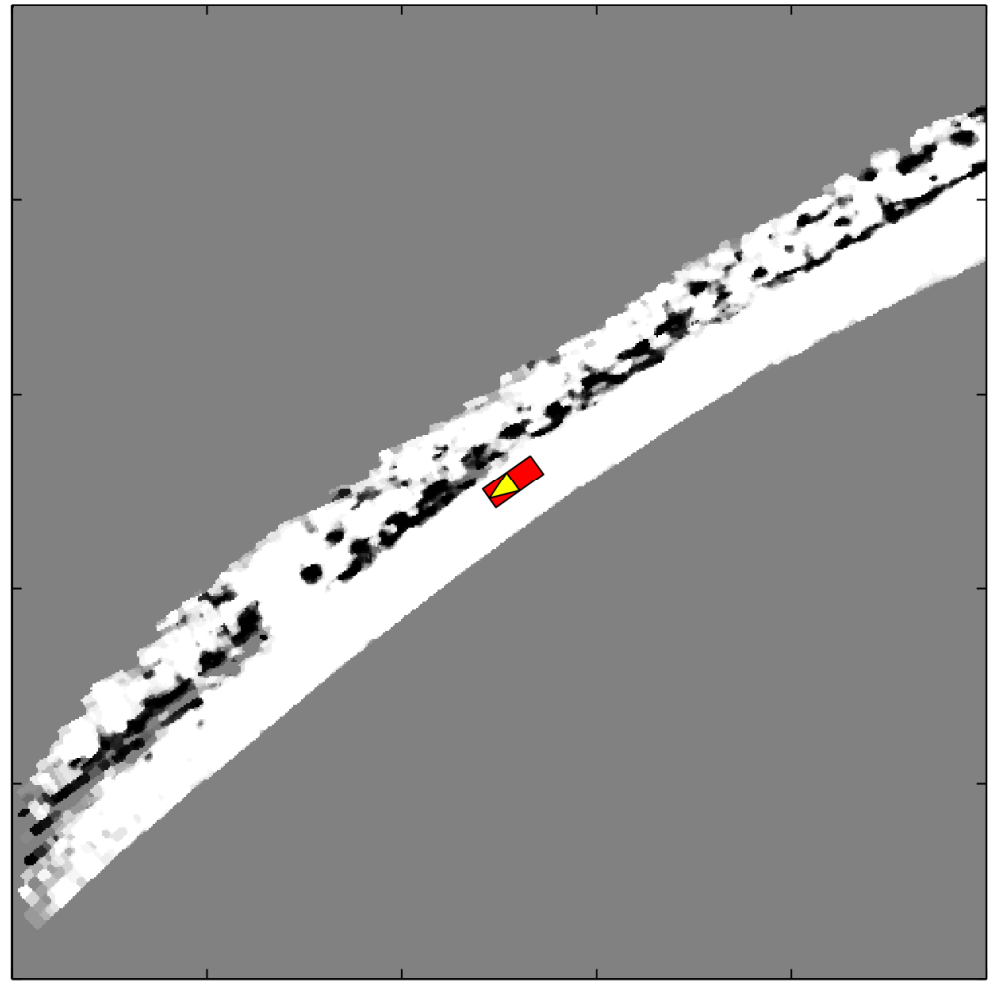

REGELUNGSMETHODEN UND ROBOTIK rmr

PRORETA

Parametric Free Space (PFS) Maps – Algorithm

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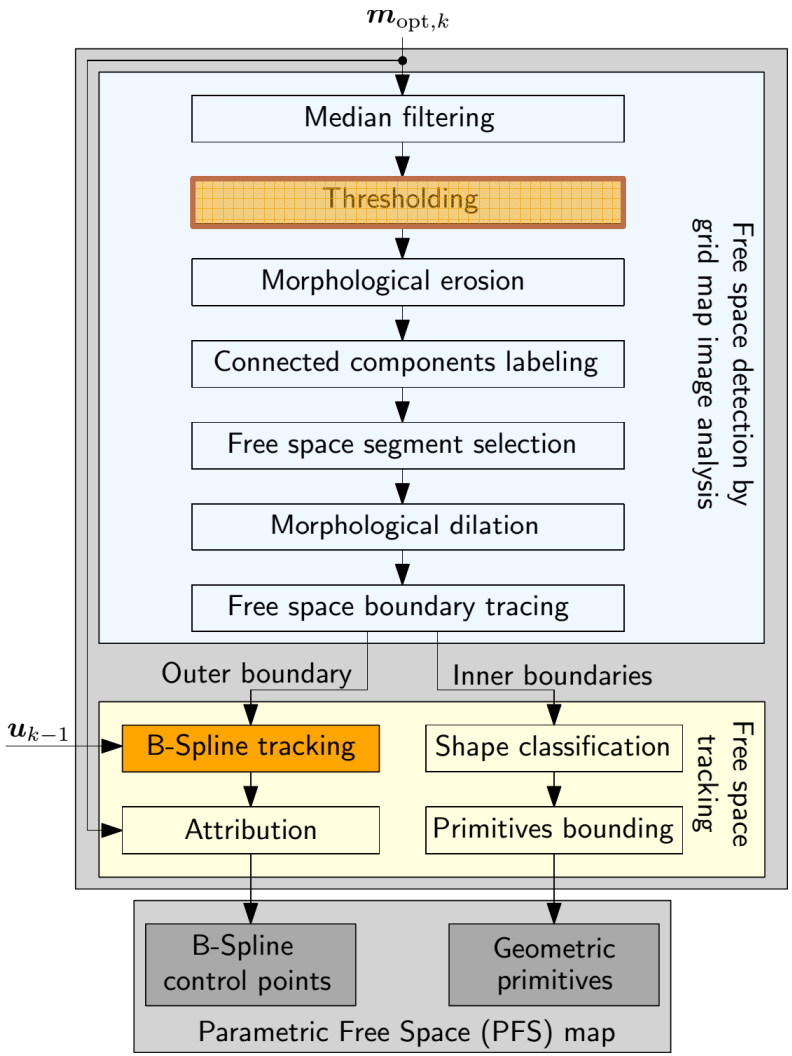
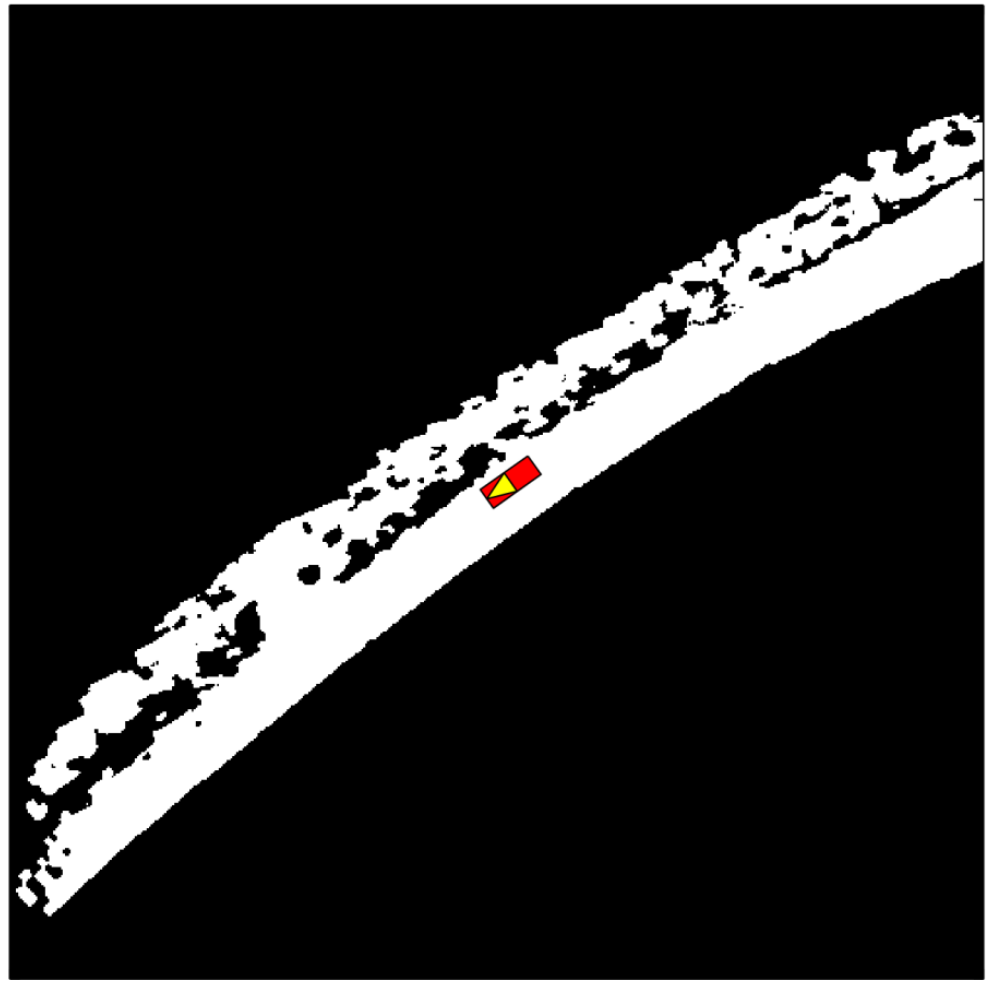
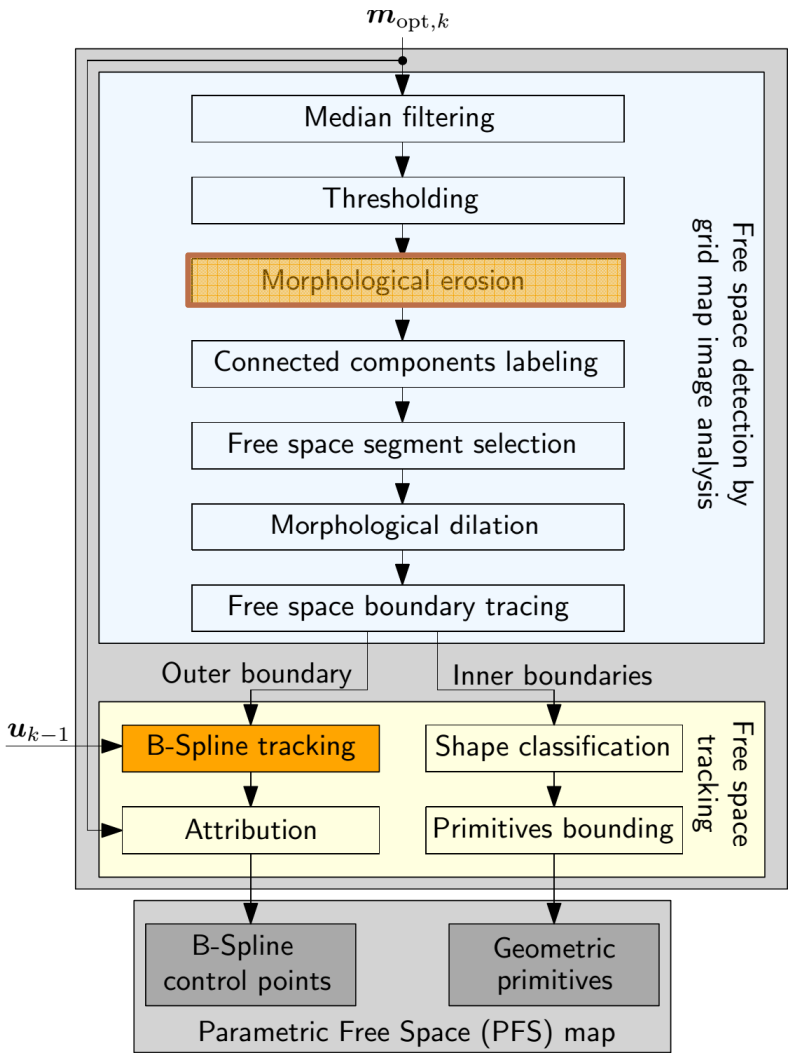
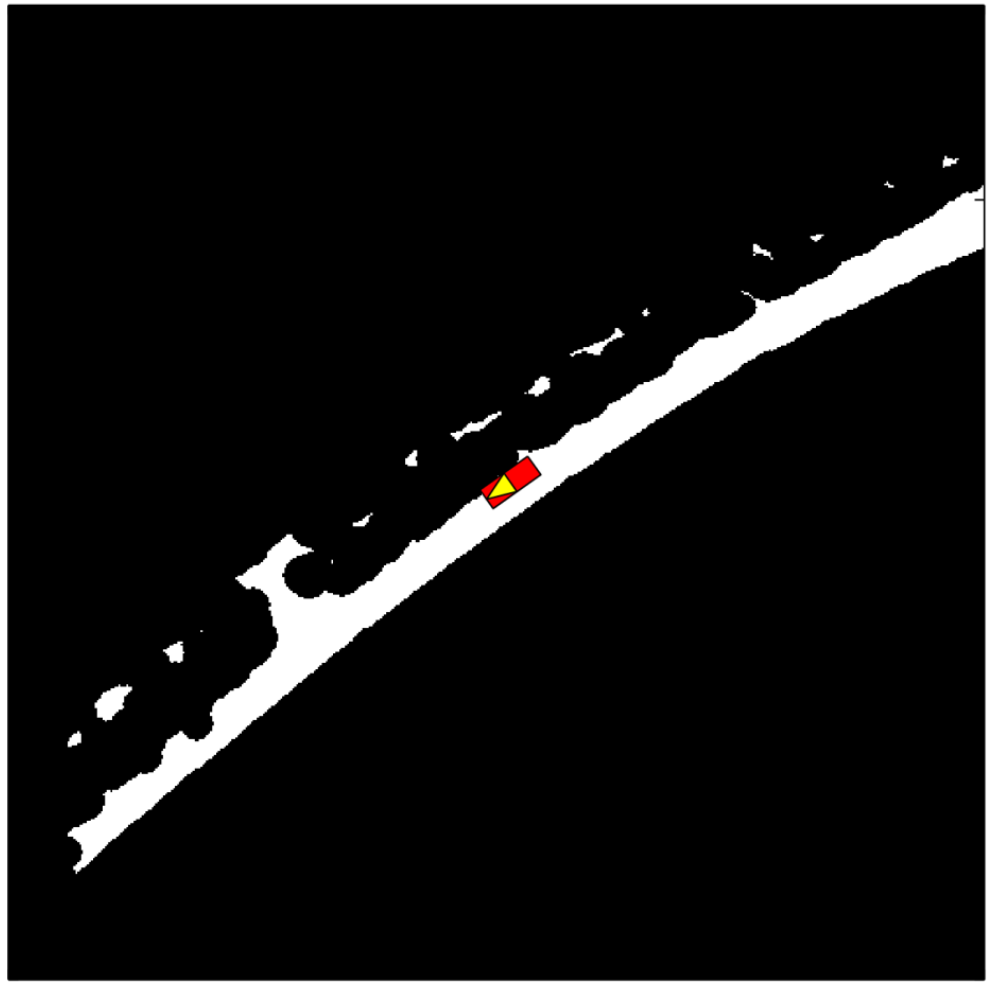




REGELUNGSMETHODEN UND ROBOTIK rmr PRORETA

Parametric Free Space (PFS) Maps – Algorithm





Parametric Free Space (PFS) Maps – Algorithm

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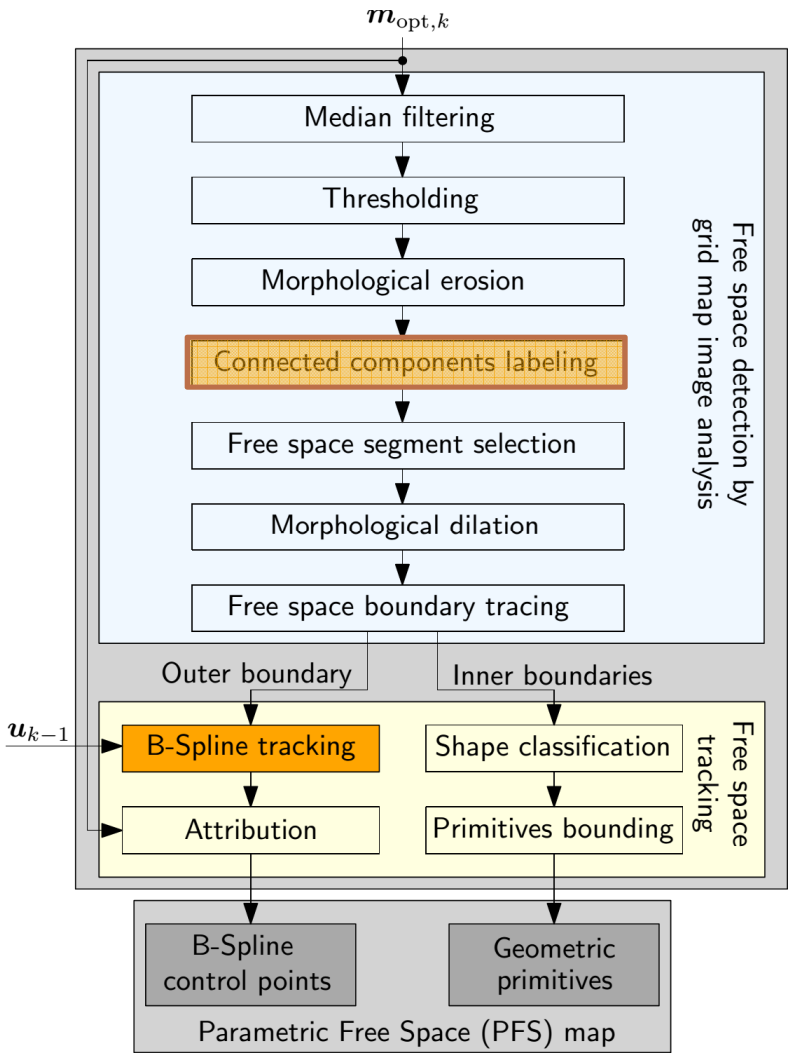

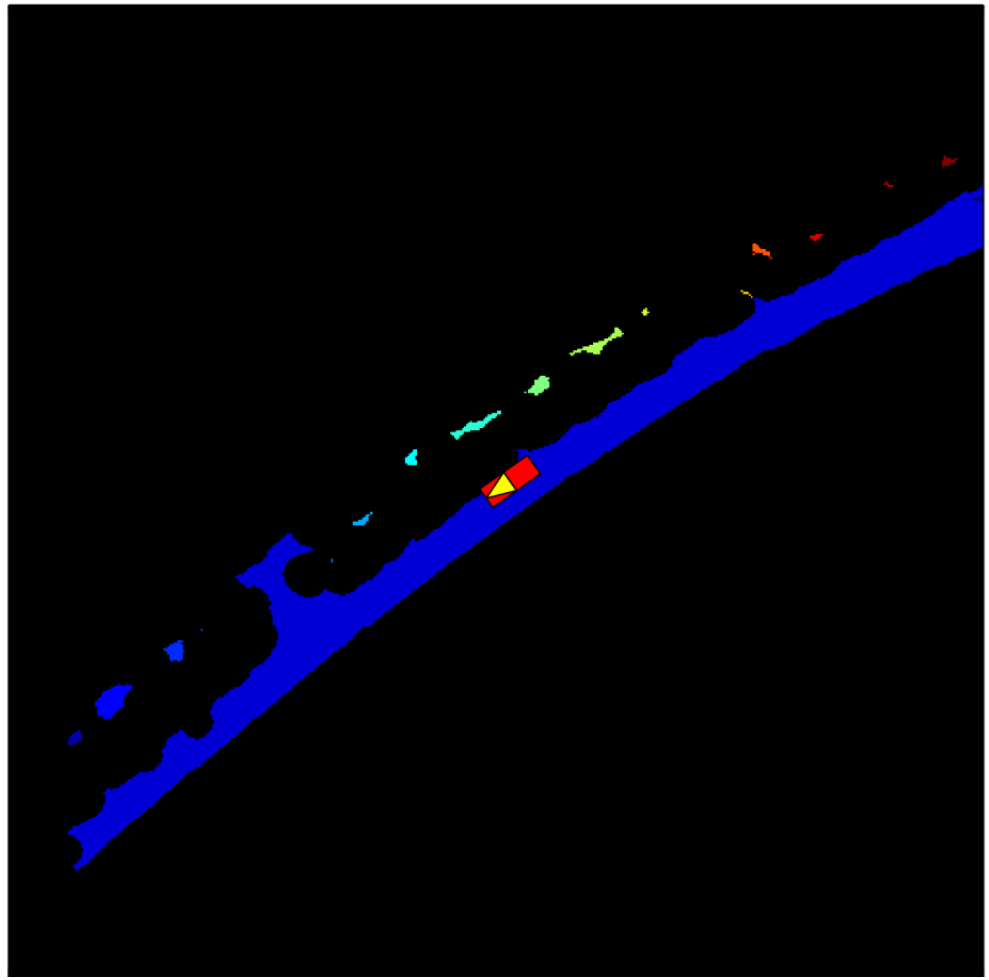

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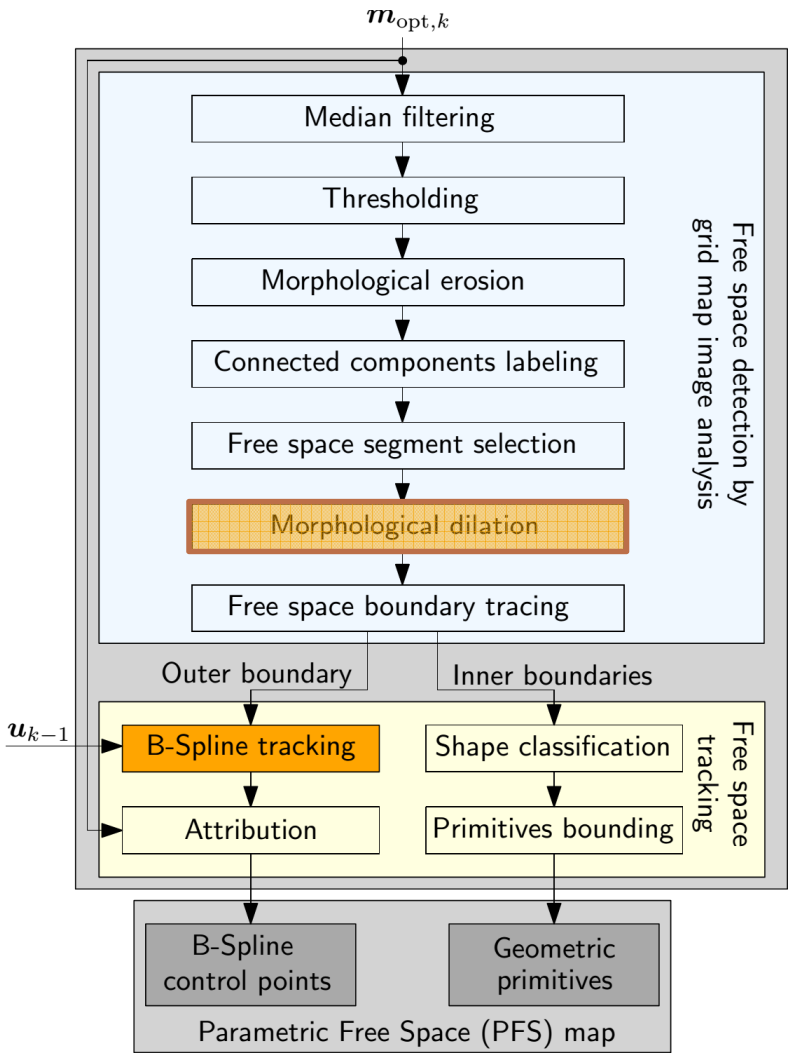

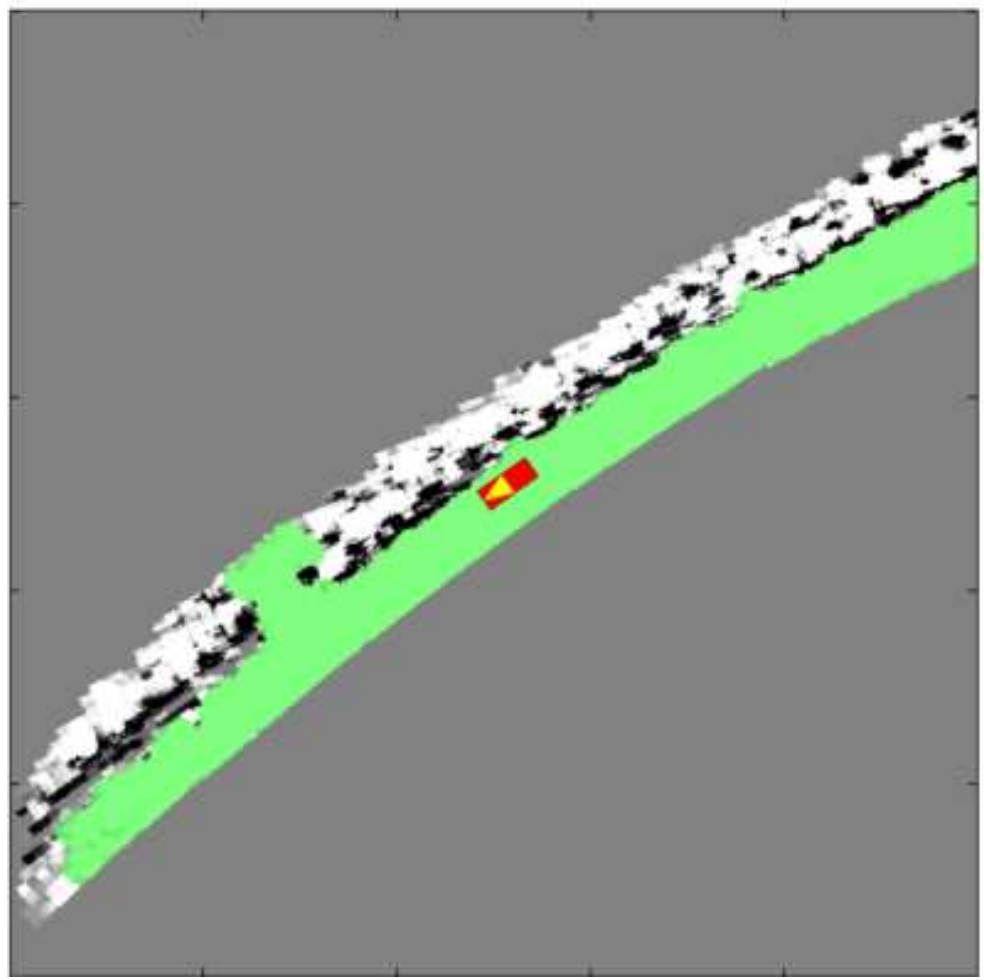

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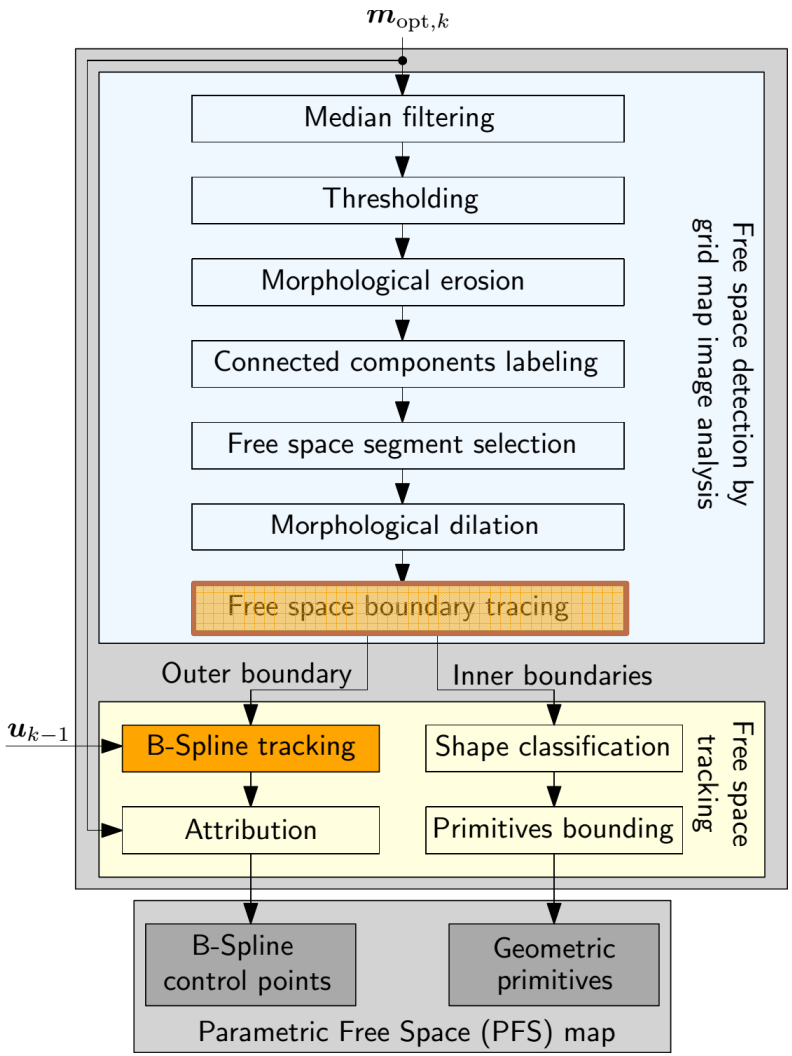

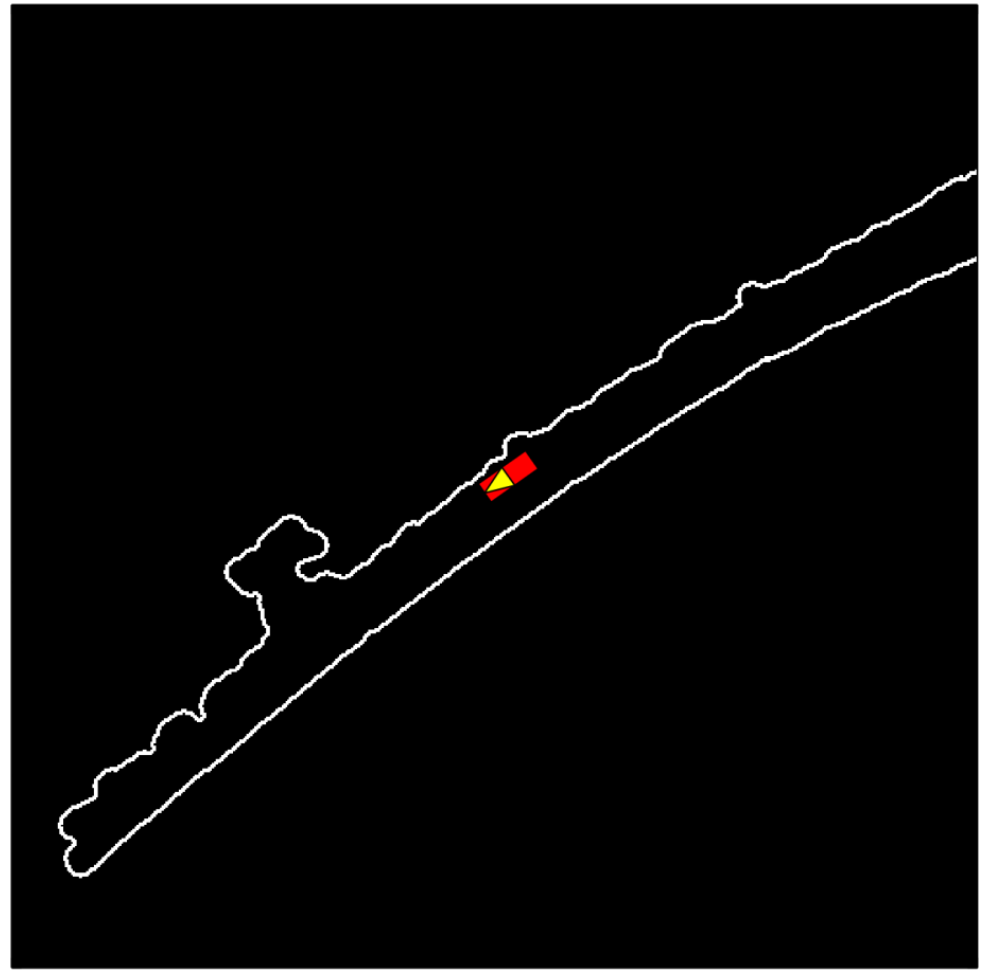

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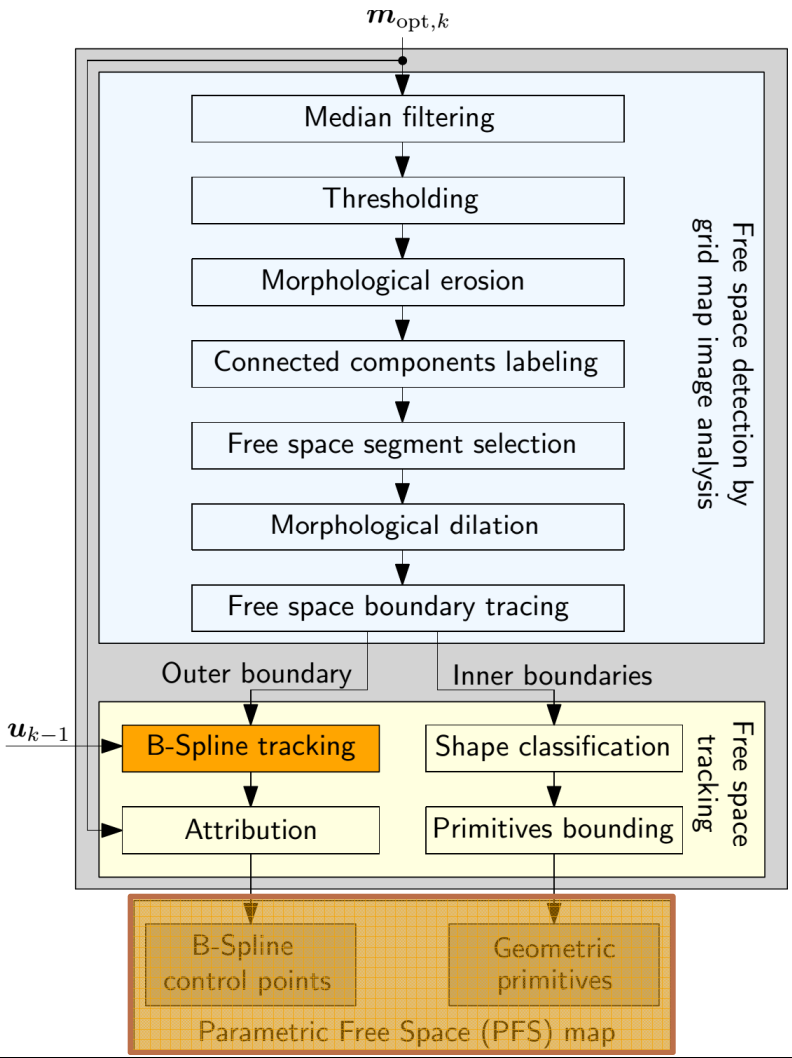

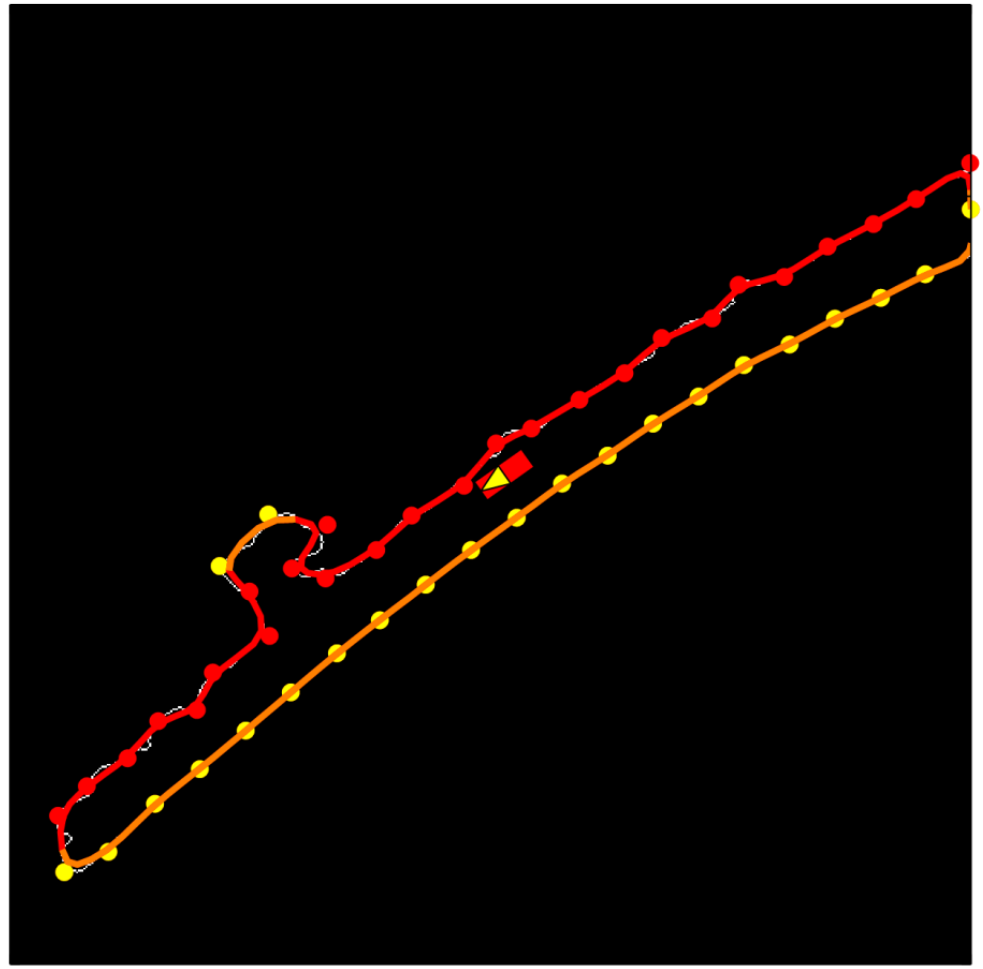

Parametric Free Space (PFS) Maps – Algorithm

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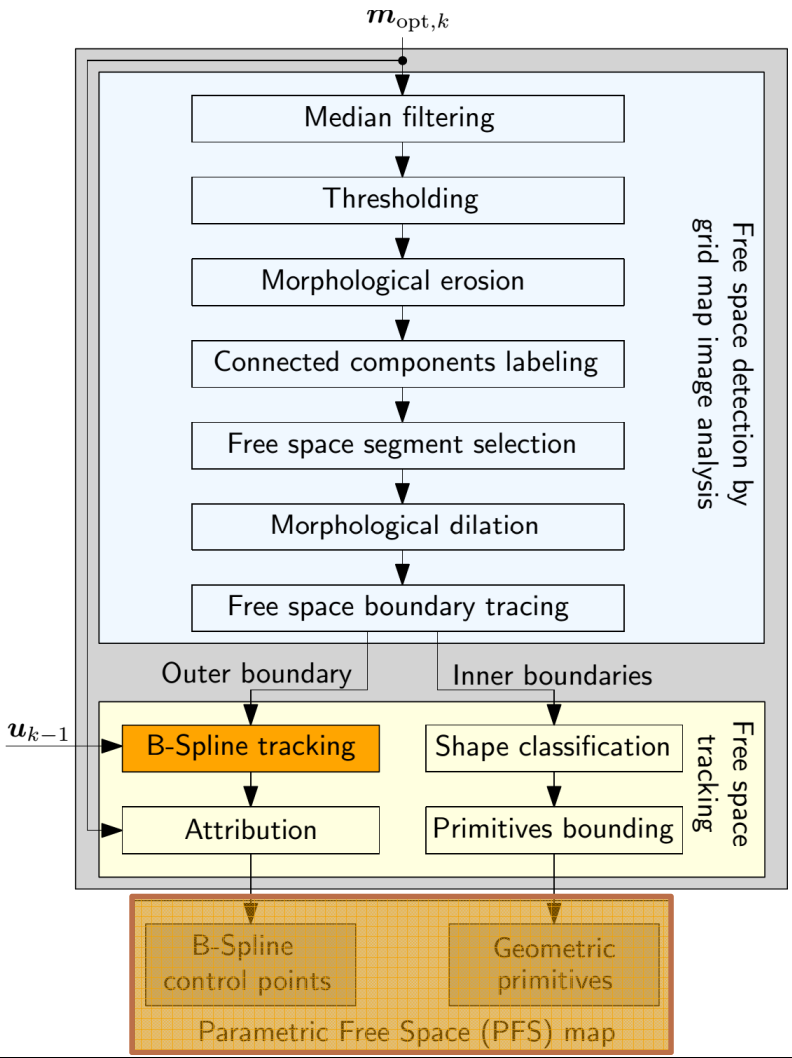

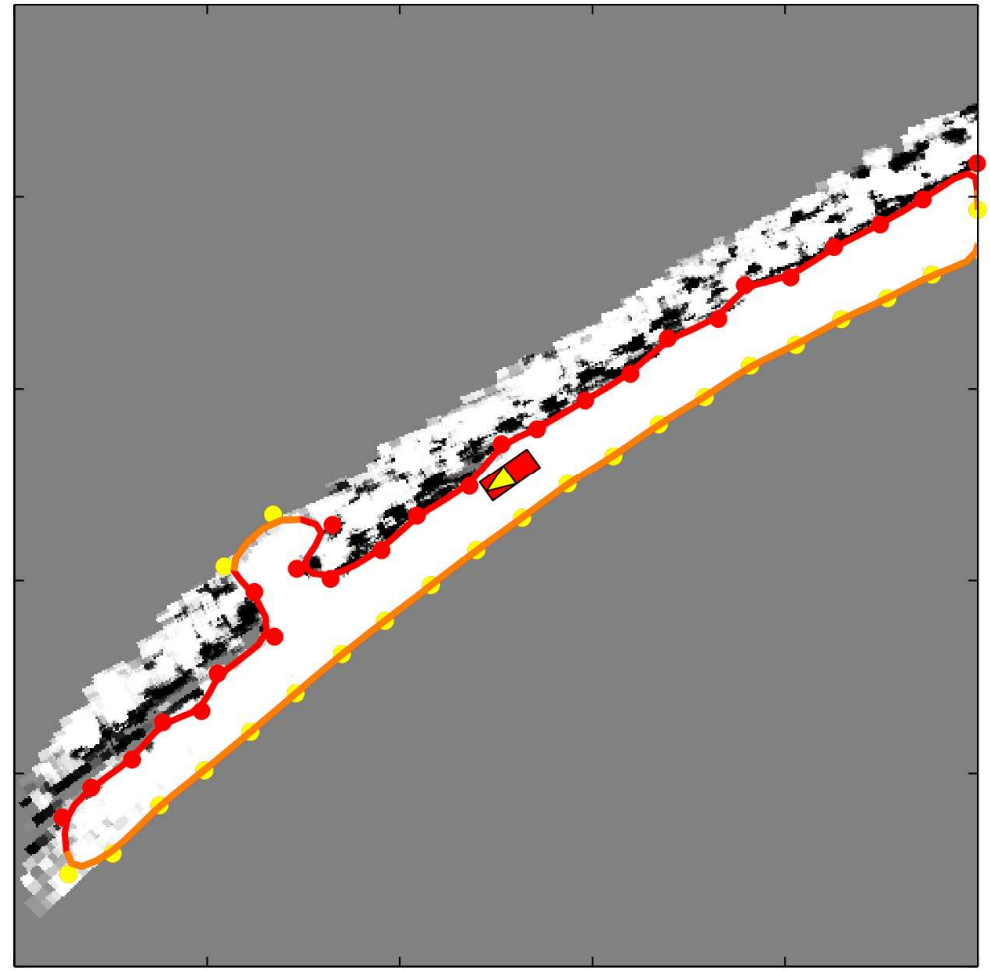

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Parametric Free Space (PFS) Maps – Examples

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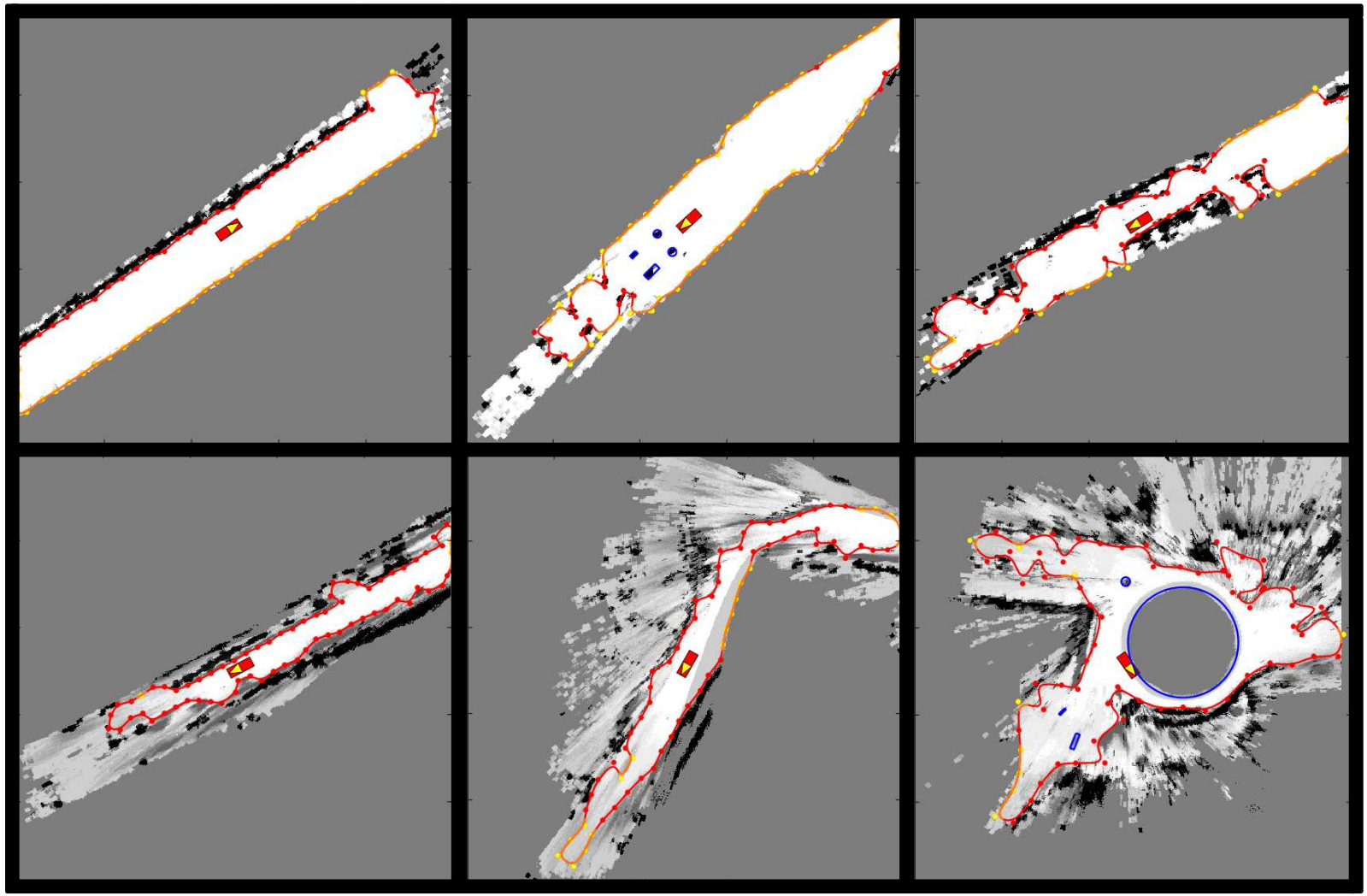
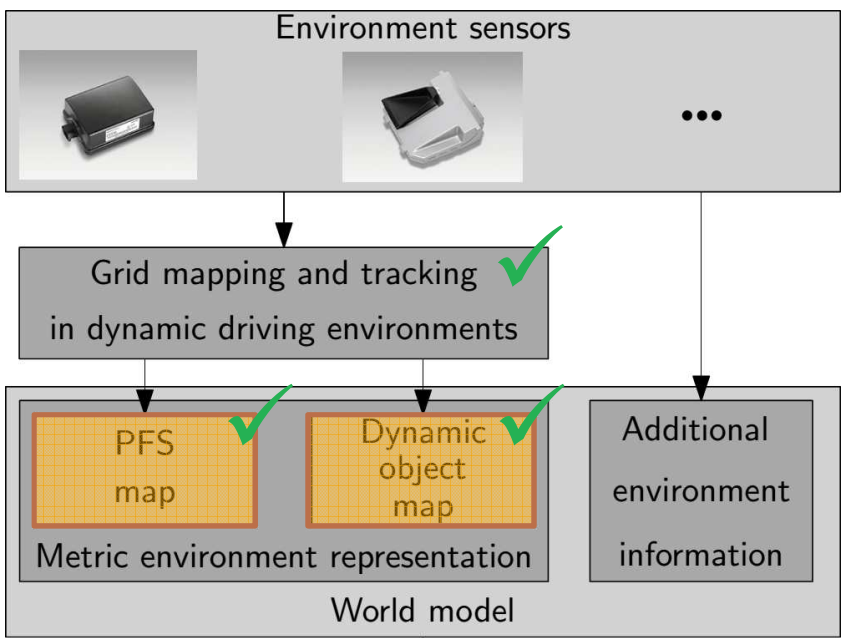
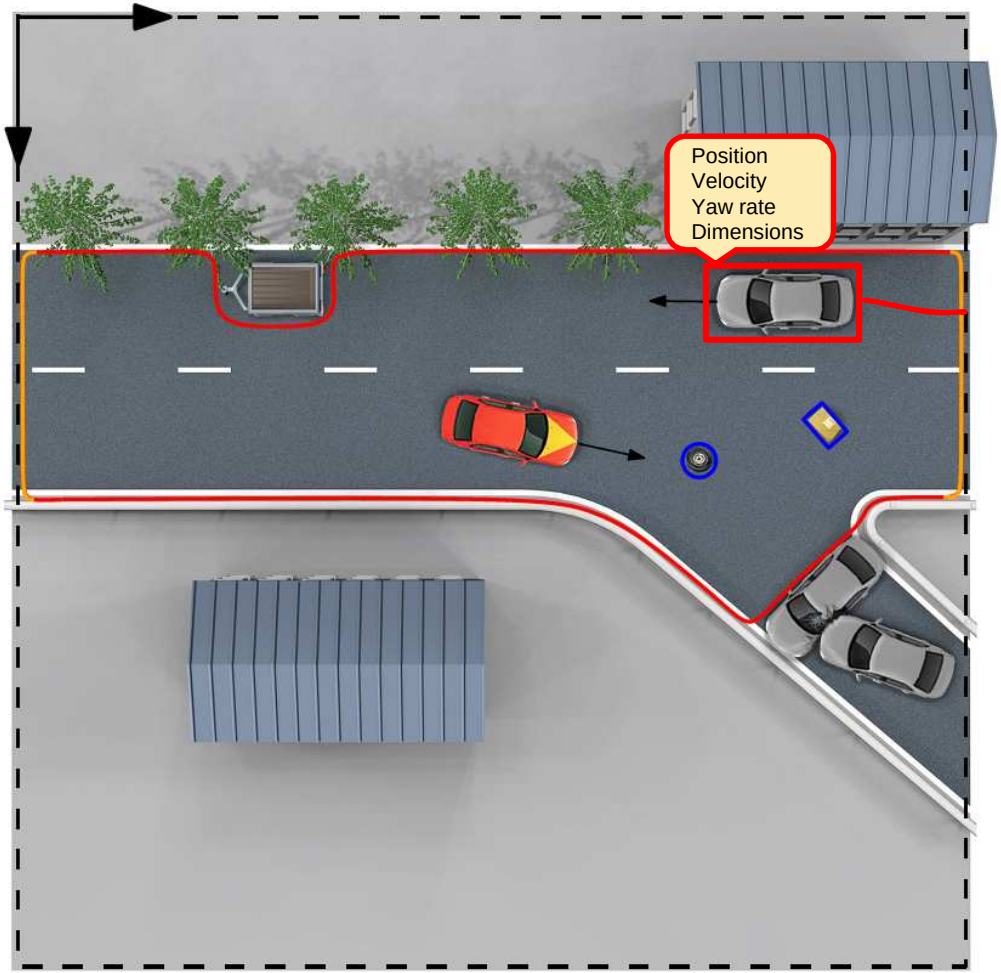
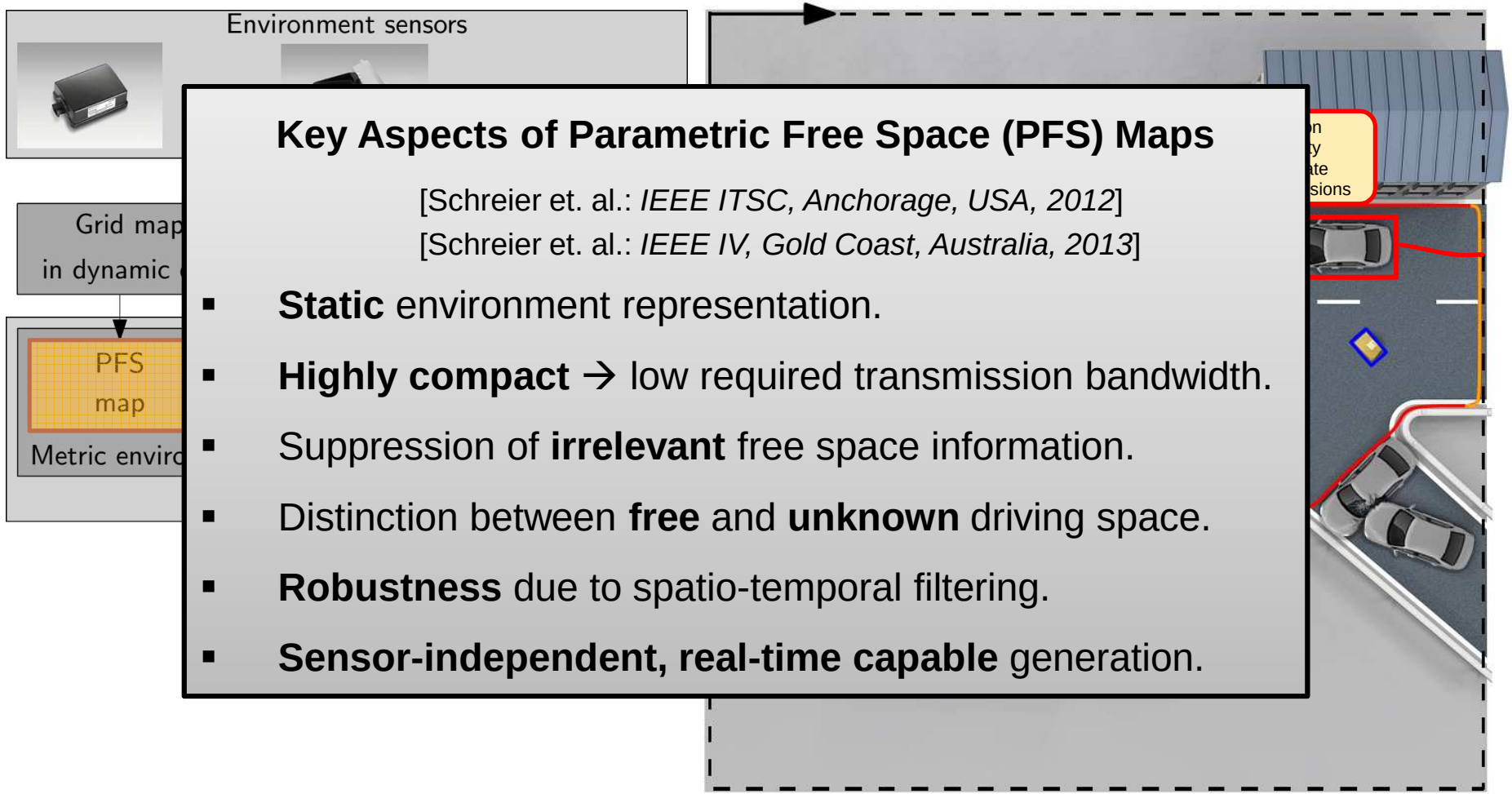


Environment Representation of PRORETA 3





Environment Representation of PRORETA 3



Key Aspects of Parametric Free Space (PFS) Maps

[Schreier et. al.: *IEEE ITSC, Anchorage, USA, 2012*]
[Schreier et. al.: *IEEE IV, Gold Coast, Australia, 2013*]

- **Static** environment representation.
- **Highly compact** → low required transmission bandwidth.
- Suppression of **irrelevant** free space information.
- Distinction between **free** and **unknown** driving space.
- **Robustness** due to spatio-temporal filtering.
- **Sensor-independent, real-time capable** generation.

Environment Representation of PRORETA 3

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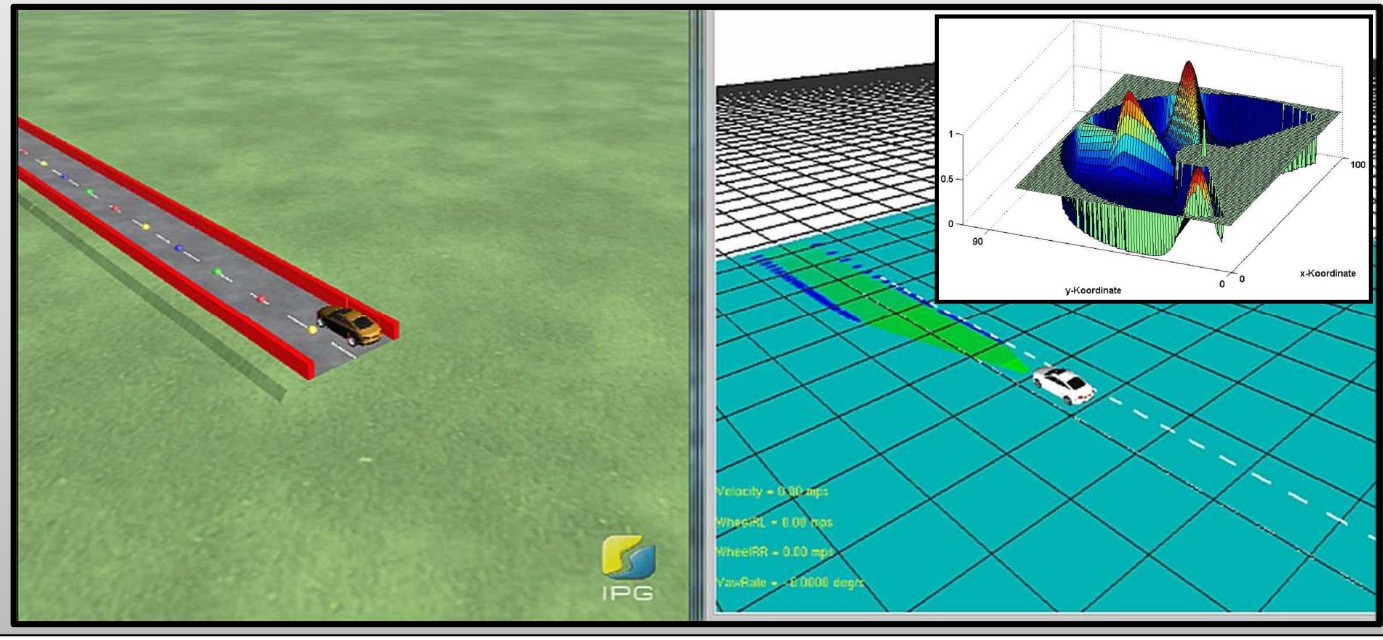
- Implementation in **PRORETA 3 prototype vehicle**.

- Development of an **environment simulator extension** (for IPG Carmaker).



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From Representation to Prediction

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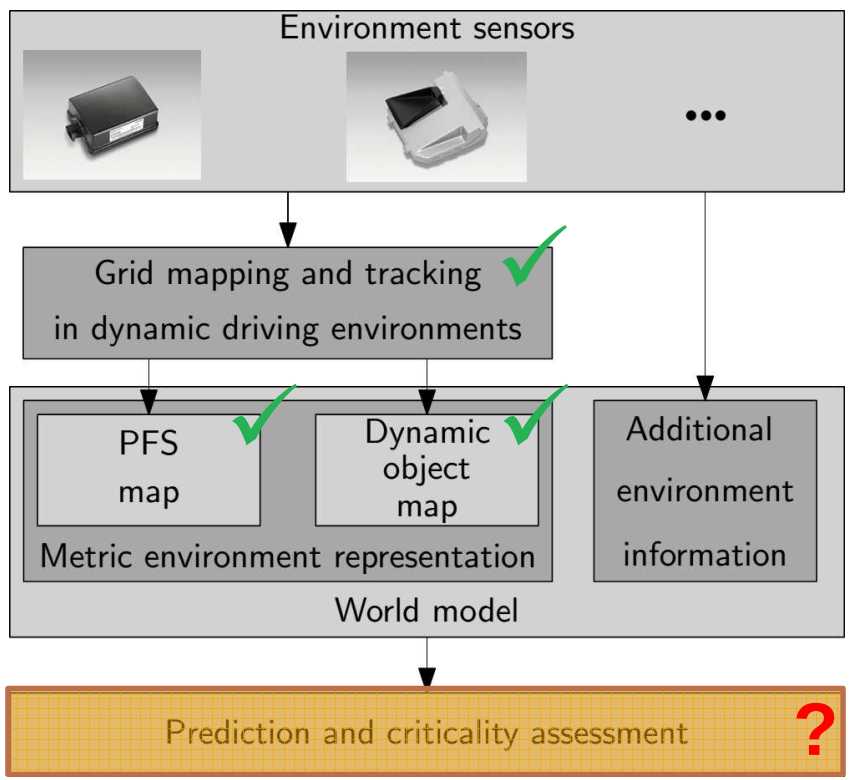

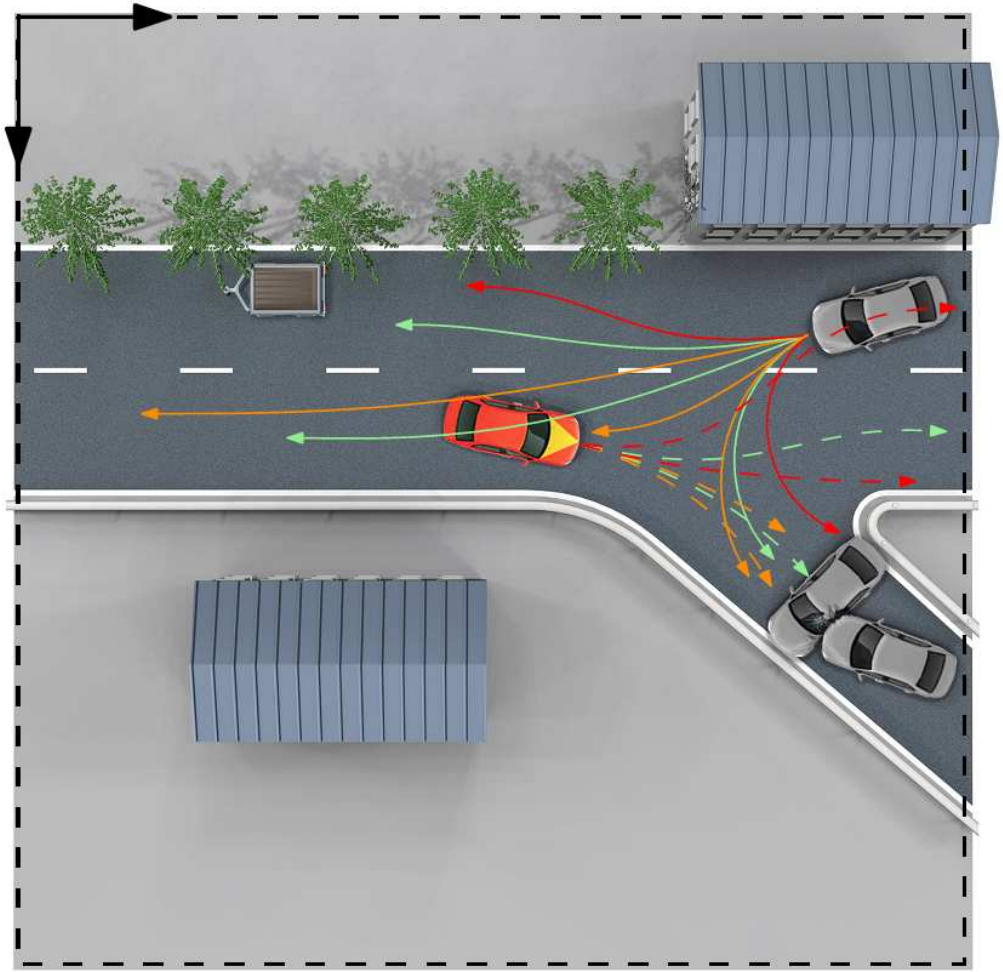

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Prediction and Criticality Assessment

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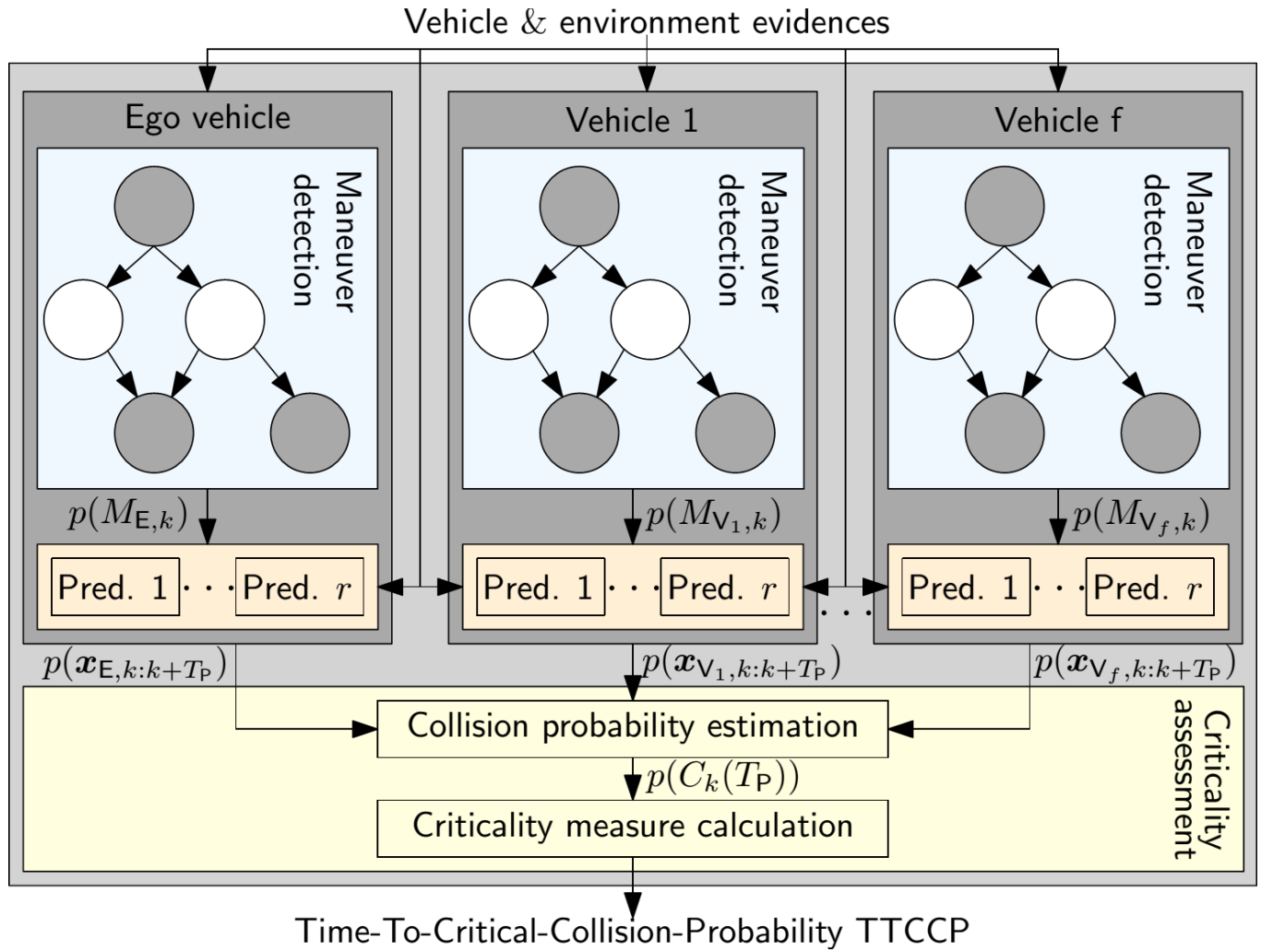

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Environment Representation and Prediction

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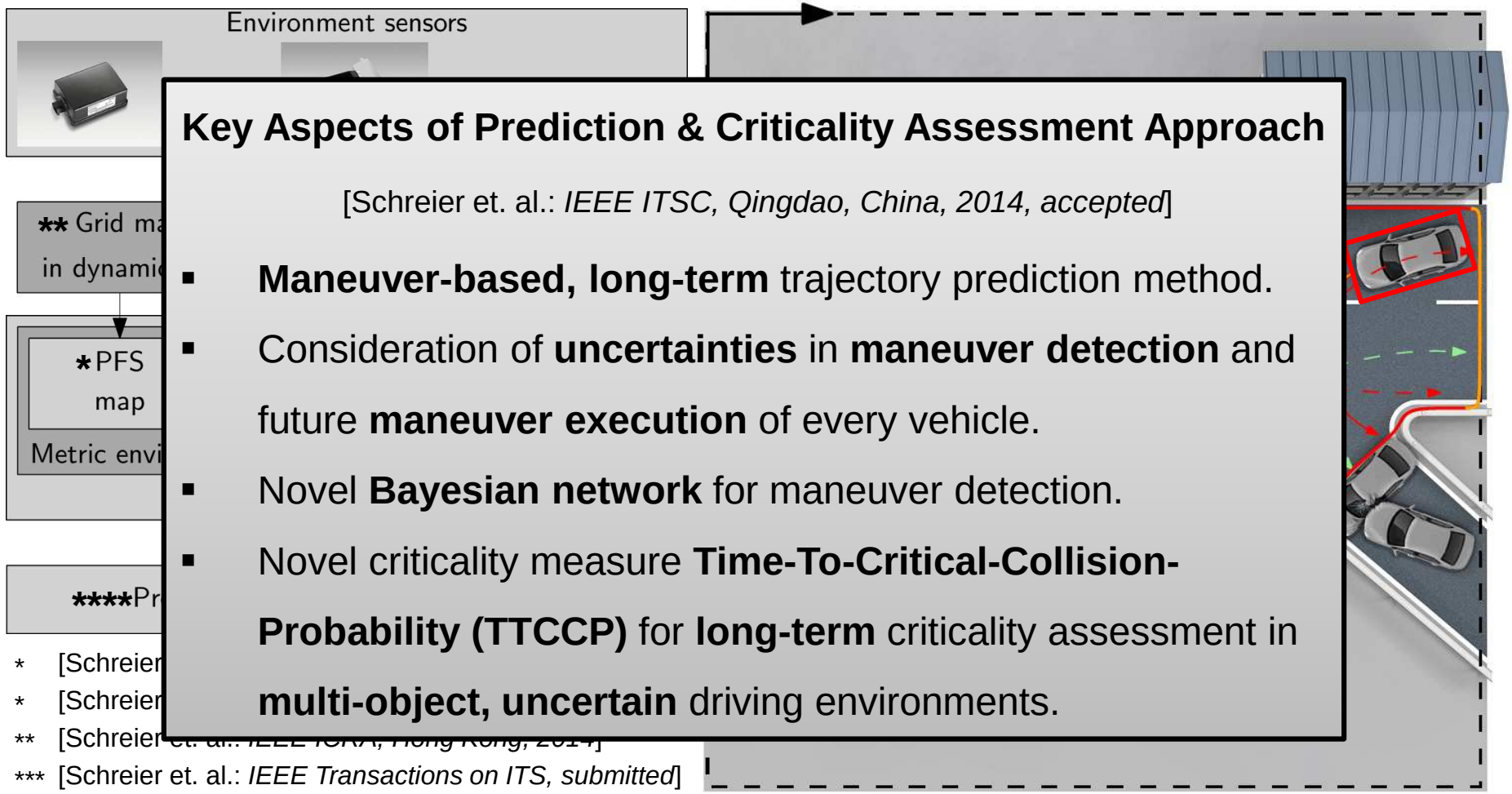


Key Aspects of Prediction & Criticality Assessment Approach

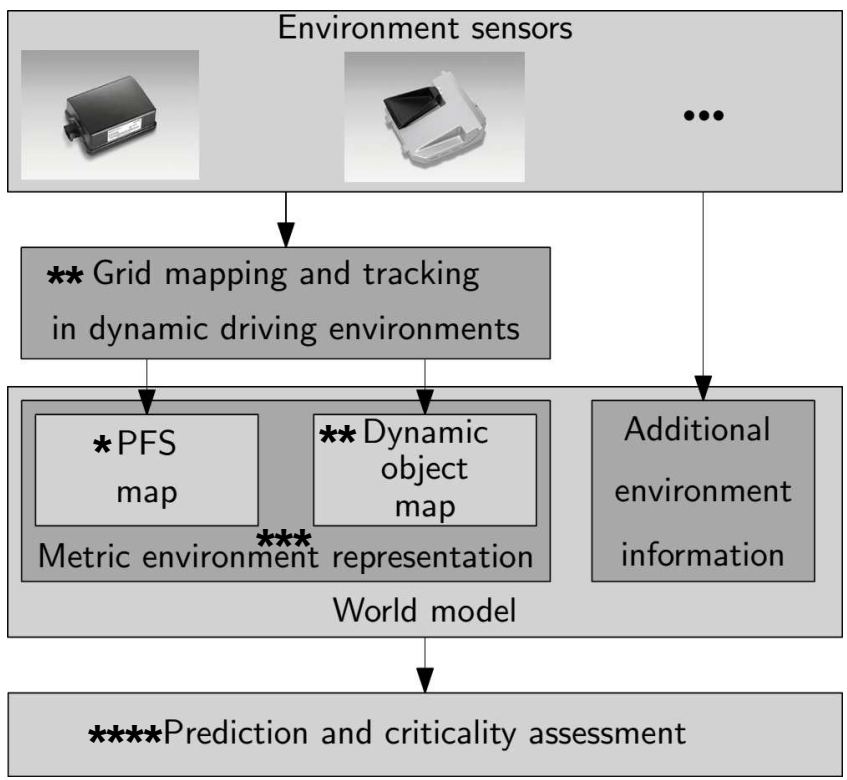
[Schreier et. al.: *IEEE ITSC, Qingdao, China, 2014, accepted*]

- **Maneuver-based, long-term** trajectory prediction method.
- Consideration of **uncertainties** in **maneuver detection** and future **maneuver execution** of every vehicle.
- Novel **Bayesian network** for maneuver detection.
- Novel criticality measure **Time-To-Critical-Collision-Probability (TTCCP)** for **long-term** criticality assessment in **multi-object, uncertain** driving environments.

* [Schreier
* [Schreier
** [Schreier et. al.: *IEEE IGNA, Hong Kong, 2014*]
*** [Schreier et. al.: *IEEE Transactions on ITS, submitted*]
**** [Schreier et. al.: *IEEE ITSC, Qingdao, 2014, accepted*]

REGELUNGSMETHODEN UND ROBOTIK rmr PRORETA

Environment Representation and Prediction



* [Schreier et. al.: *IEEE ITSC, Anchorage, 2012*]
* [Schreier et. al.: *IEEE IV, Gold Coast, 2013*]
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**** [Schreier et. al.: *IEEE ITSC, Qingdao, 2014, accepted*]

PRORETA 3 includes...

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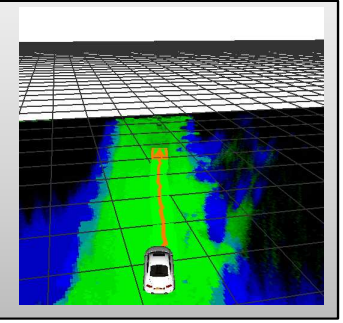
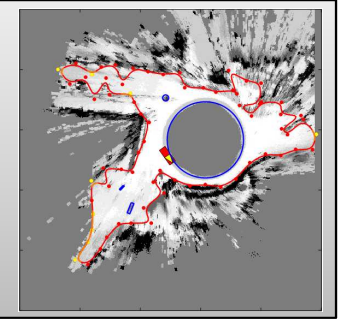
- a novel, real-time capable method for **grid mapping** and **tracking** in **dynamic environments**.



- a novel, compact representation of static environments in form of **Parametric Free Space** (PFS) maps.



- a novel approach for long-term **motion prediction** and **criticality assessment.**