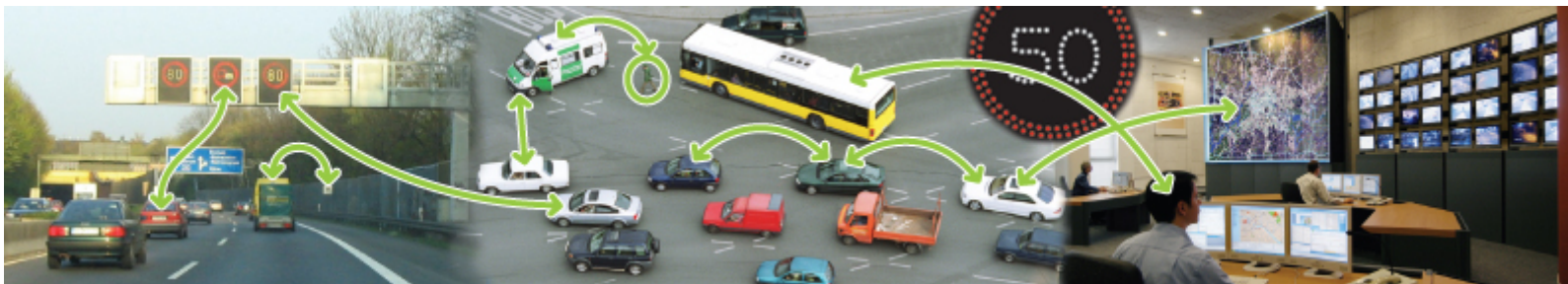




Multi-hypothesis Map-Matching using Particle Filtering

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Sept 2009

ITS Stockholm



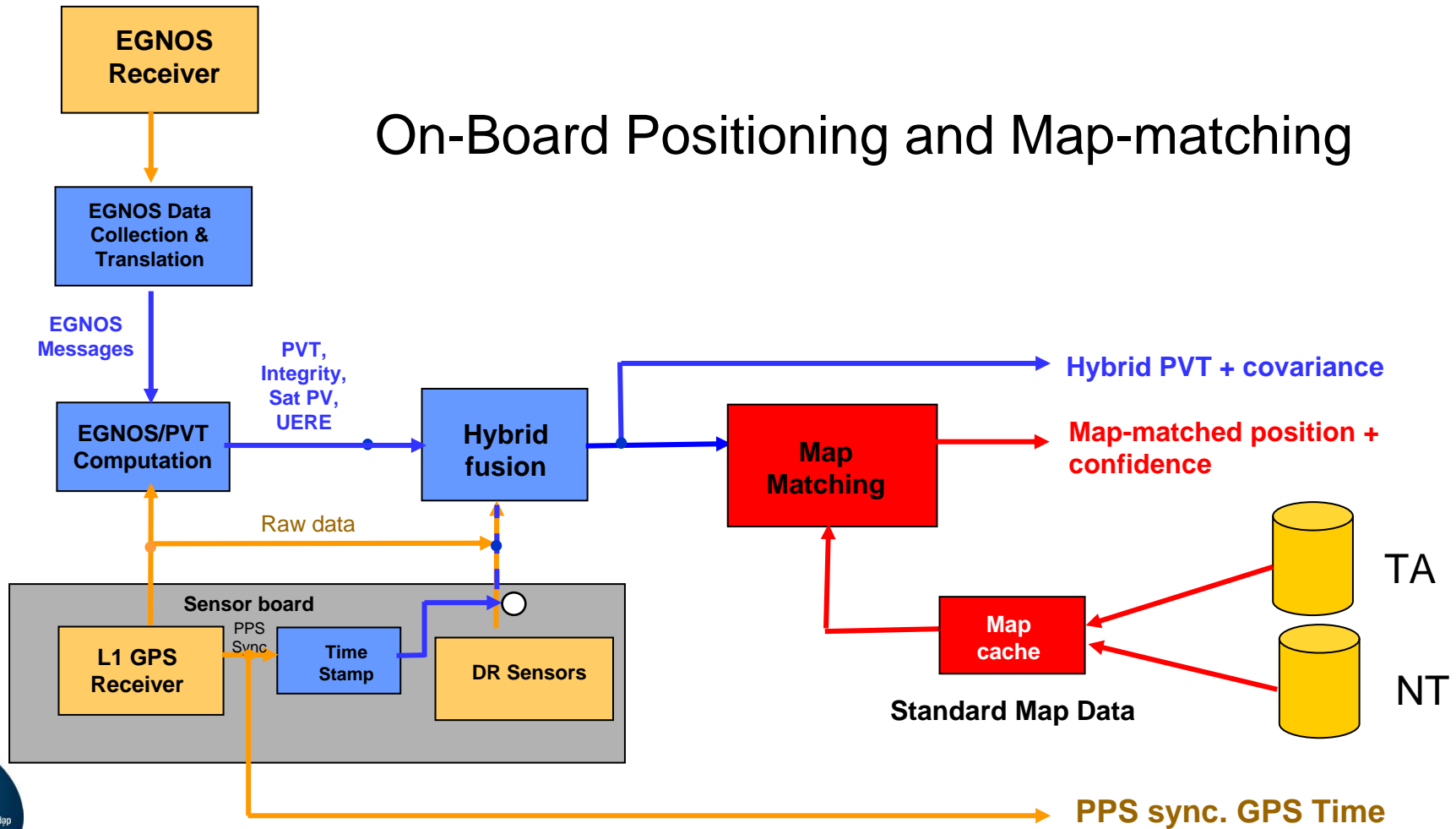
Outline



- Map-matching
 - specifications
 - method
 - integrity monitoring
- Validation method
- Experimental results



POMA / CVIS



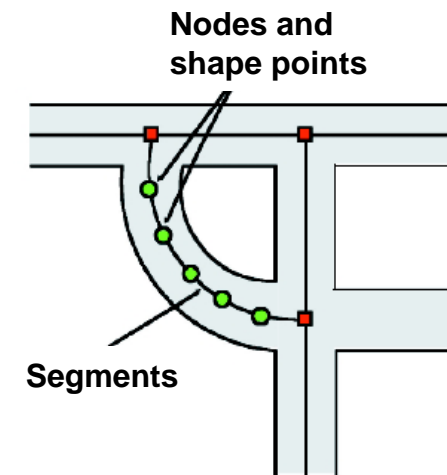
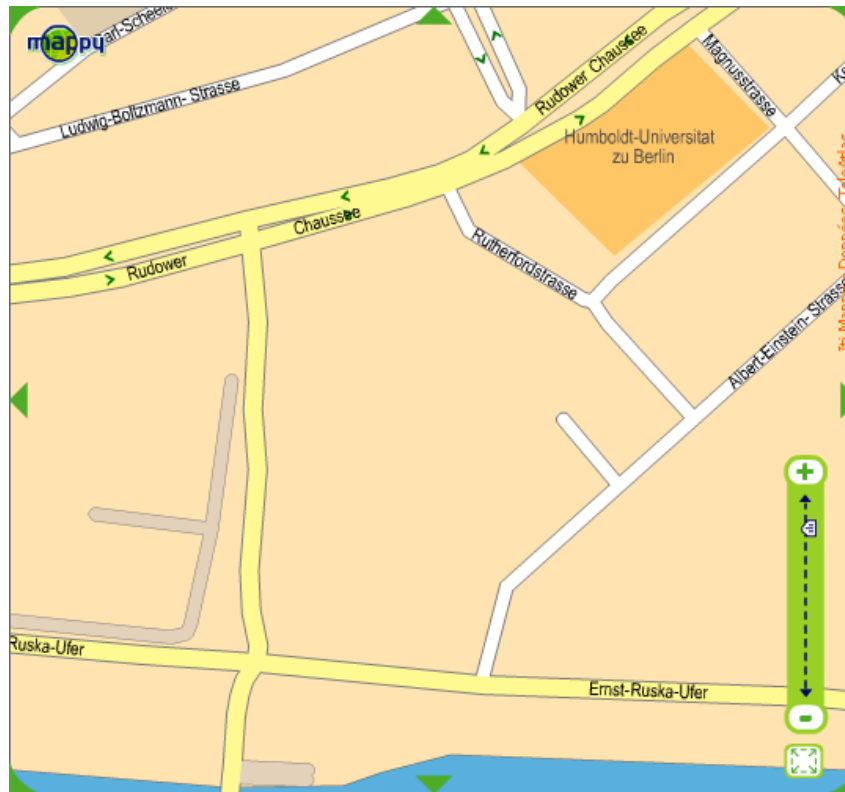


Standard maps



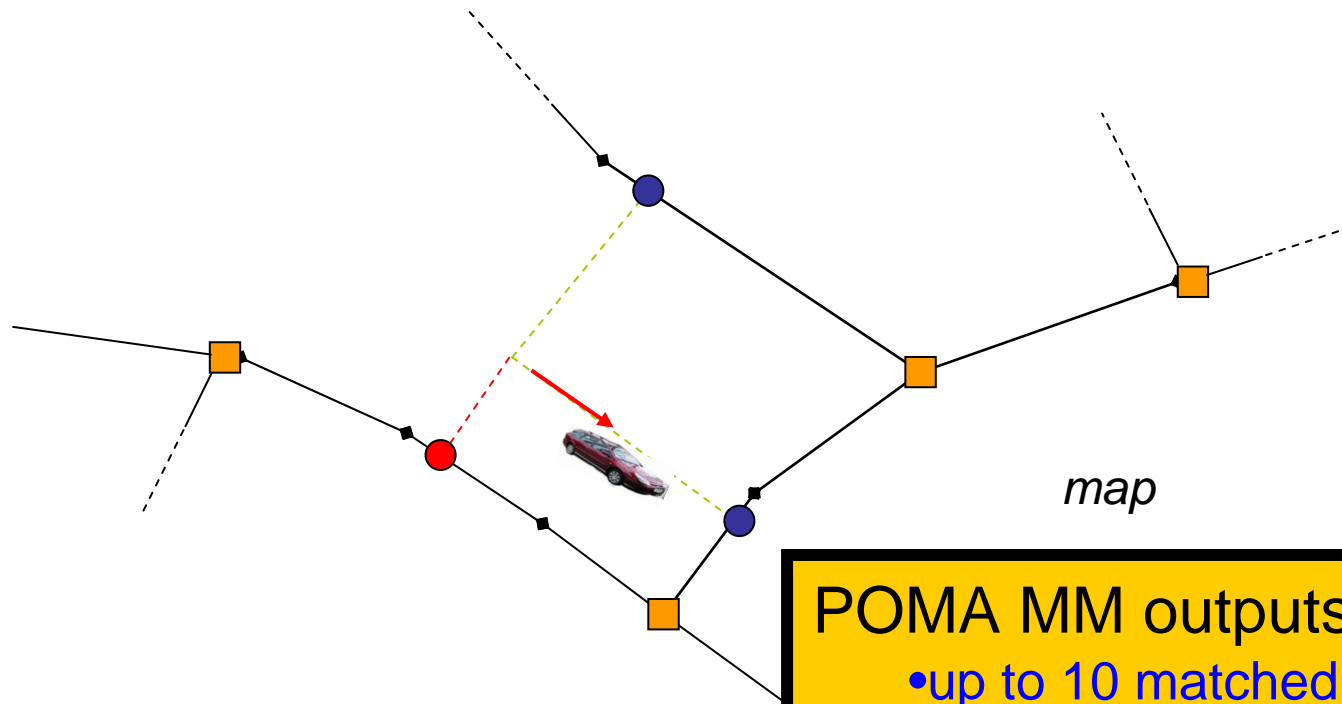
One carriageway = one polyline

Longitudinal topology





Map Matching Specifications



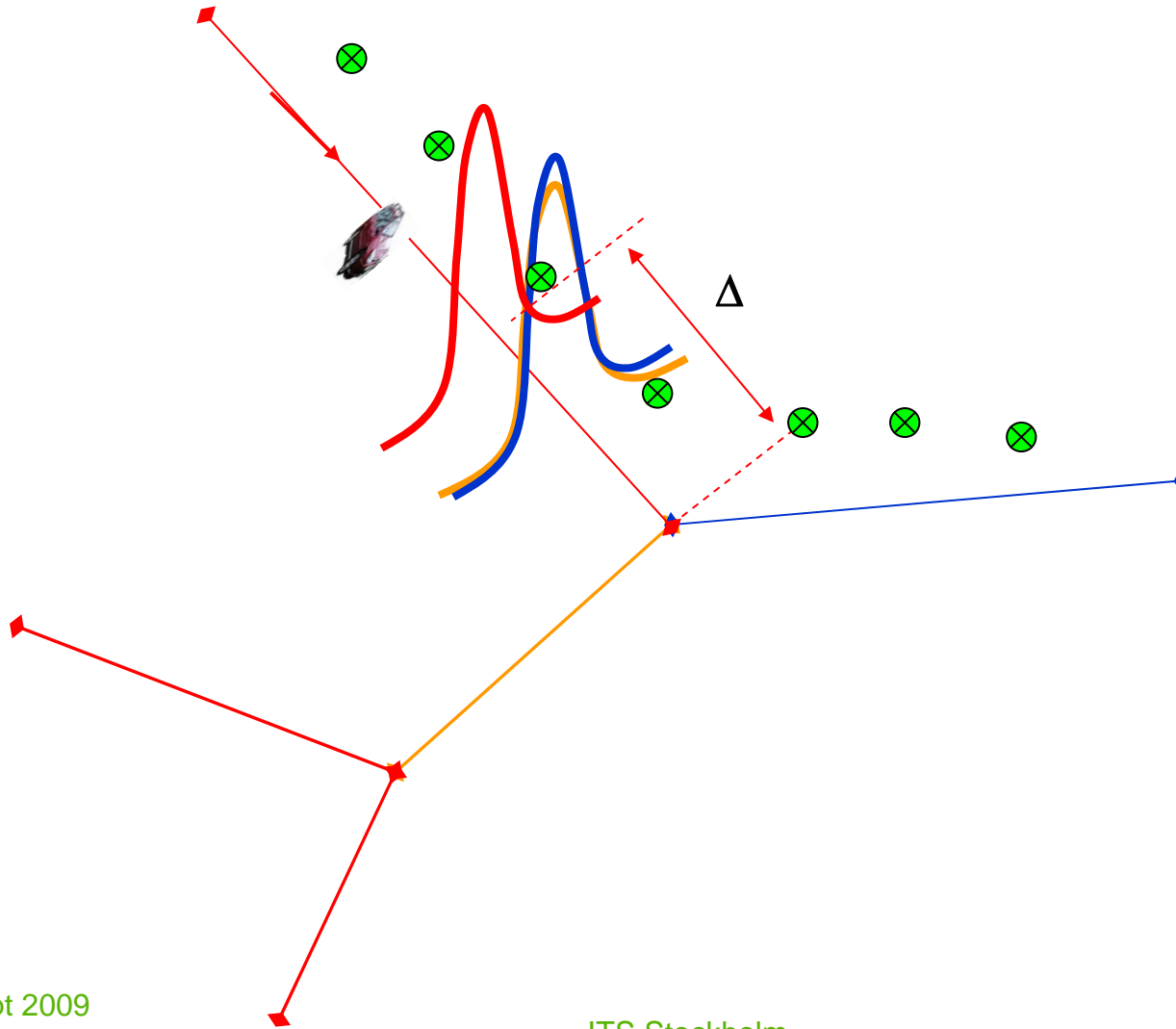
POMA MM outputs :

- up to 10 matched candidates
- with confidence indicators

« *map-matching* » : determining the vehicle's position % a digital road database



Multi-hypothesis Road Tracking



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Solver Used



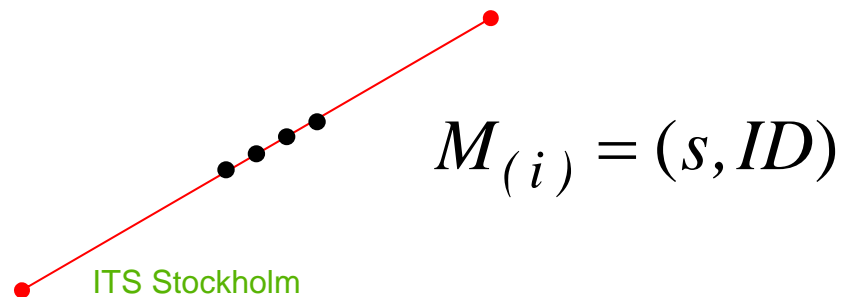
- Particle filter (PF)
- Sequential Bayesian state estimation technique that generalizes the Kalman filter
- Advantages
 - Can cope with non-linear systems and non Gaussian noises
 - Solves efficiently data association problems
 - Can track several hypotheses
 - Handles naturally uncertainty propagation



PF with Multiple Evolution Models



- Road tracking method
- Particles are constraint to follow the poly-lines representing the roads
- Noise is added at each prediction step in order to explore randomly the different hypotheses.
- A map matched position is a hybrid state



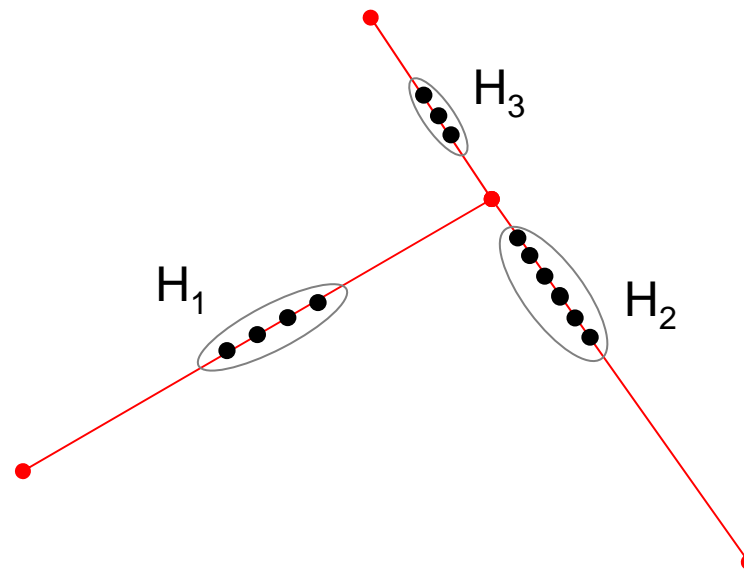


Estimation stage



Hypothesis H_i : approximated by sub-particle sets

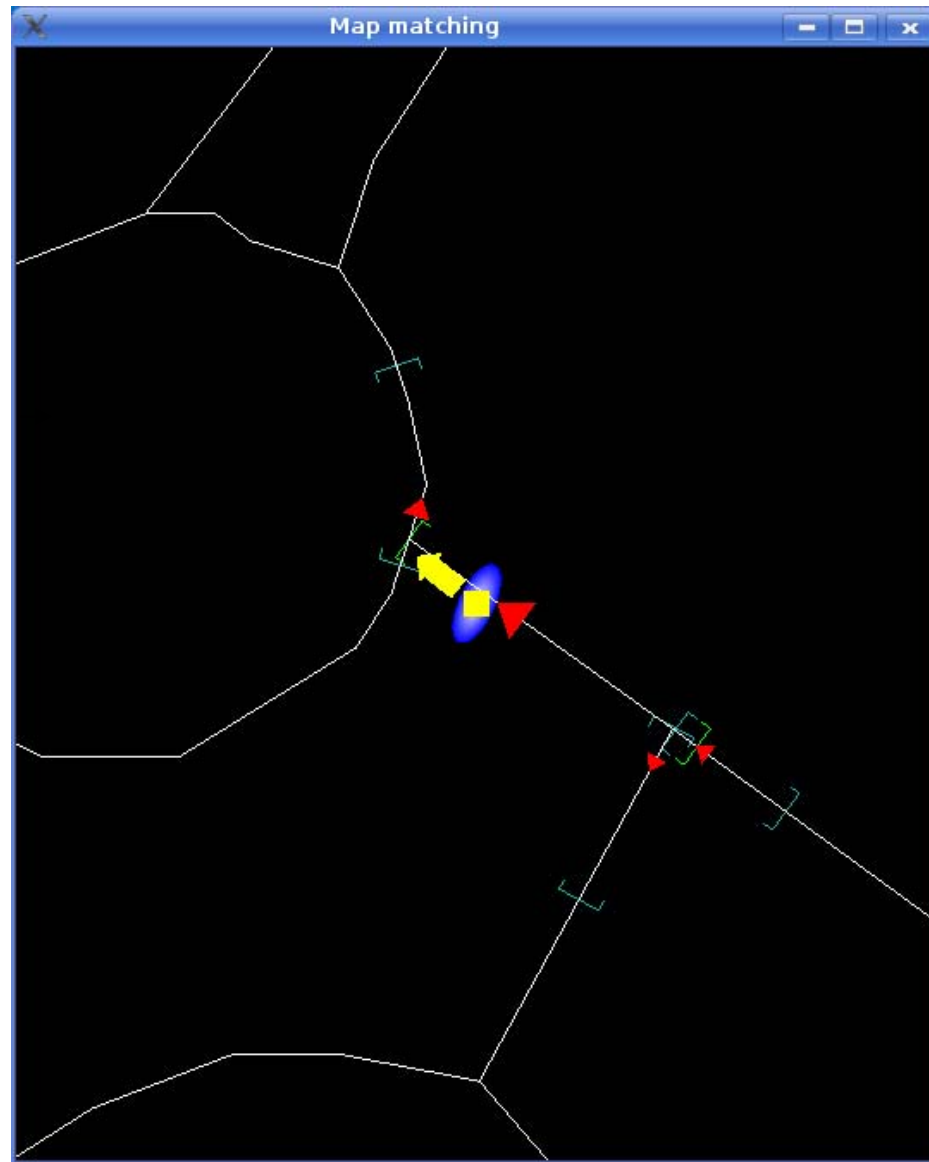
$$\chi_{h,t} = \{ \langle (s, ID)_t^n, w_t^n \rangle / ID = h \}_{n=1:N}$$



The system provides several candidates with confidence indicators



Map-Matching with confidence indicators



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Map-Matching integrity monitoring

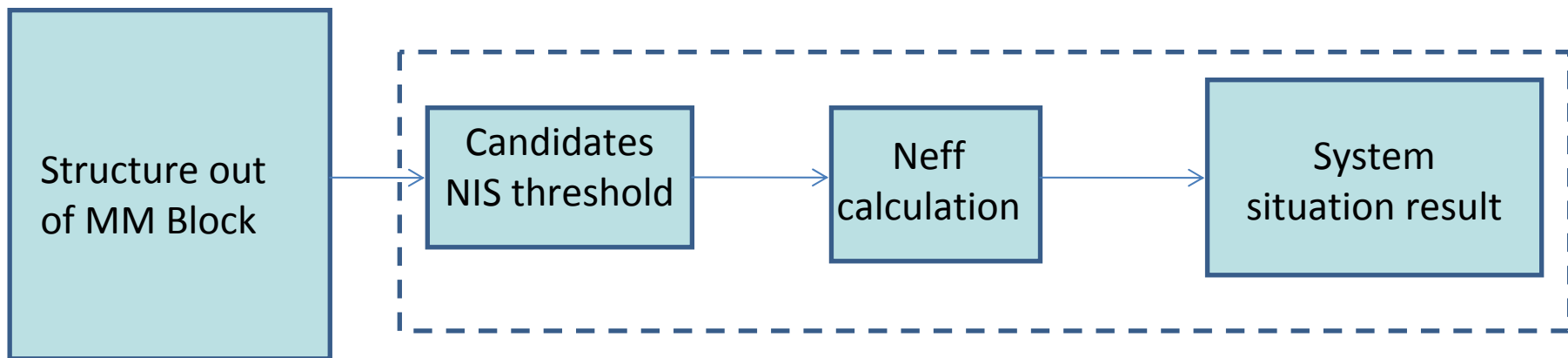


- Estimate the probability of each hypothesis with respect to the others
- Compute Normalized Residuals for each hypothesis
- Apply a decision rule for integrity monitoring
 - the risk depends on the application



Decision Function

- Output:
 - use, don't use, ambiguous
- Stages:
 - Eliminates unlikely candidates
 - Compute an estimate of the number of efficient candidates



Decision Function Diagram



Normal conditions

The screenshot displays a software interface for "Multi-Hypothesis Map Matching - Heudiasyc Lab. UTC/CNRS". The main window shows a map with a blue sphere and a red arrow. A VCR window shows a timestamp of 11:15:54.468. Two Image Viewer windows show a green "USE" text and a road scene. A Studio console output window at the bottom displays log messages for MMDecisionFunc_9.

Studio console output

```
Info : Component MMDecisionFunc_9 : USE  
Info : Component MMDecisionFunc_9 : Residual: 0.1686936473 5  
Info : Component MMDecisionFunc_9 : Residual: 0.1686936473 5Residual: 1.870224627 5  
Info : Component MMDecisionFunc_9 : Neff: 1.28098327  
Info : Component MMDecisionFunc_9 : USE  
Info : Component MMDecisionFunc_9 : Residual: 0.1686936473 5  
Info : Component MMDecisionFunc_9 : Residual: 0.1686936473 5Residual: 1.870224627 5  
Info : Component MMDecisionFunc_9 : Neff: 1.28098327  
Info : Component MMDecisionFunc_9 : USE
```

This product is licensed to: CVIS Project



The vehicle is in a parking lot

The screenshot displays a software interface for "Multi-Hypothesis Map Matching - Heudiasyc Lab.UTC/CNRS". The main window shows a map with a blue and yellow vehicle icon and a red arrow indicating its path. A "VCR" window in the top right shows a timestamp of 08/04/09 11:21:45.041, a duration of 0:06:47.175, and a speed of 100%. Below the VCR, an "Image viewer" window displays the text "DON'T USE" in red. Another "Image Viewer" window shows a grayscale image of a road. The "Studio console output" window at the bottom left contains the following text:

```
Info : Component MMDecisionFunc_9 : DON'T USE  
Info : Component MMDecisionFunc_9 : Residual: 15.28461366 5  
Info : Component MMDecisionFunc_9 : DON'T USE  
Info : Component MMDecisionFunc_9 : Residual: 15.28461366 5  
Info : Component MMDecisionFunc_9 : DON'T USE  
Info : Component MMDecisionFunc_9 : Residual: 15.28461366 5  
Info : Component MMDecisionFunc_9 : DON'T USE  
Info : Component MMDecisionFunc_9 : Residual: 15.28461366 5  
Info : Component MMDecisionFunc_9 : DON'T USE
```

The interface also includes a "Player_1" window and a "POMAMapMat" window. The system tray at the top right shows the user "melkawni" and the date "ven 26 jun, 02:49".

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Approaching a junction

The screenshot displays a software interface for Multi-Hypothesis Map Matching. The main window, titled "Multi-Hypothesis Map Matching - Heudiasyc Lab.UTC/CNRS", shows a map with a blue sphere at a junction. A VCR window in the top right corner shows a timestamp of 08/04/09 11:16:32.319, with a duration of 0:06:47.175 and a speed of 100%. An Image Viewer window in the center displays the word "AMBIGUOUS" in yellow. Another Image Viewer window in the bottom right shows a street view. A Studio console output window at the bottom displays log messages:

```
Info : Component MMDecisionFunc_9 : AMBIGUOUS
Info : Component MMDecisionFunc_9 : Residual: 1.095908285 5
Info : Component MMDecisionFunc_9 : Residual: 1.095908285 5Residual: 1.996242321 5
Info : Component MMDecisionFunc_9 : Residual: 1.095908285 5Residual: 1.996242321 5Residual: 1.730411804 5
Info : Component MMDecisionFunc_9 : Residual: 1.095908285 5Residual: 1.996242321 5Residual: 1.730411804 5Res
Info : Component MMDecisionFunc_9 : Residual: 1.095908285 5Residual: 1.996242321 5Residual: 1.730411804 5Res
Info : Component MMDecisionFunc_9 : Residual: 1.095908285 5Residual: 1.996242321 5Residual: 1.730411804 5Residual: 1.730411804 5Residual: 2.273692603 5
Info : Component MMDecisionFunc_9 : Neff: 2.439688232
Info : Component MMDecisionFunc_9 : AMBIGUOUS
```

This product is licensed to: CVIS Project



Map-Matching Validation

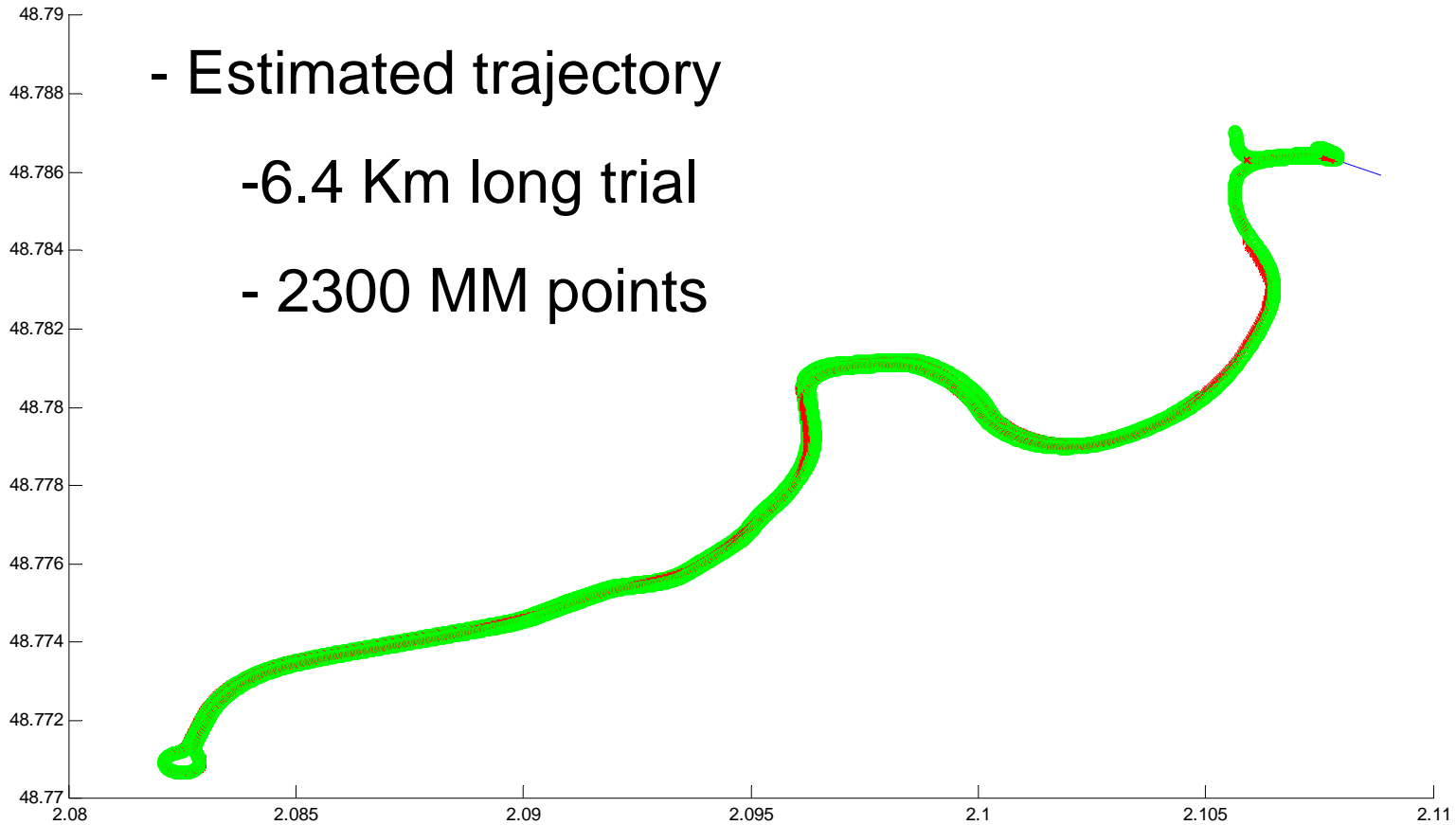


Proposed approach: to use a trajectometer
Method:

1. Extract the traveled roads
2. Match the trajectometer on this path
This is the ground truth for MM
3. Compare the outputs of the real-time Decision Function with the ground truth



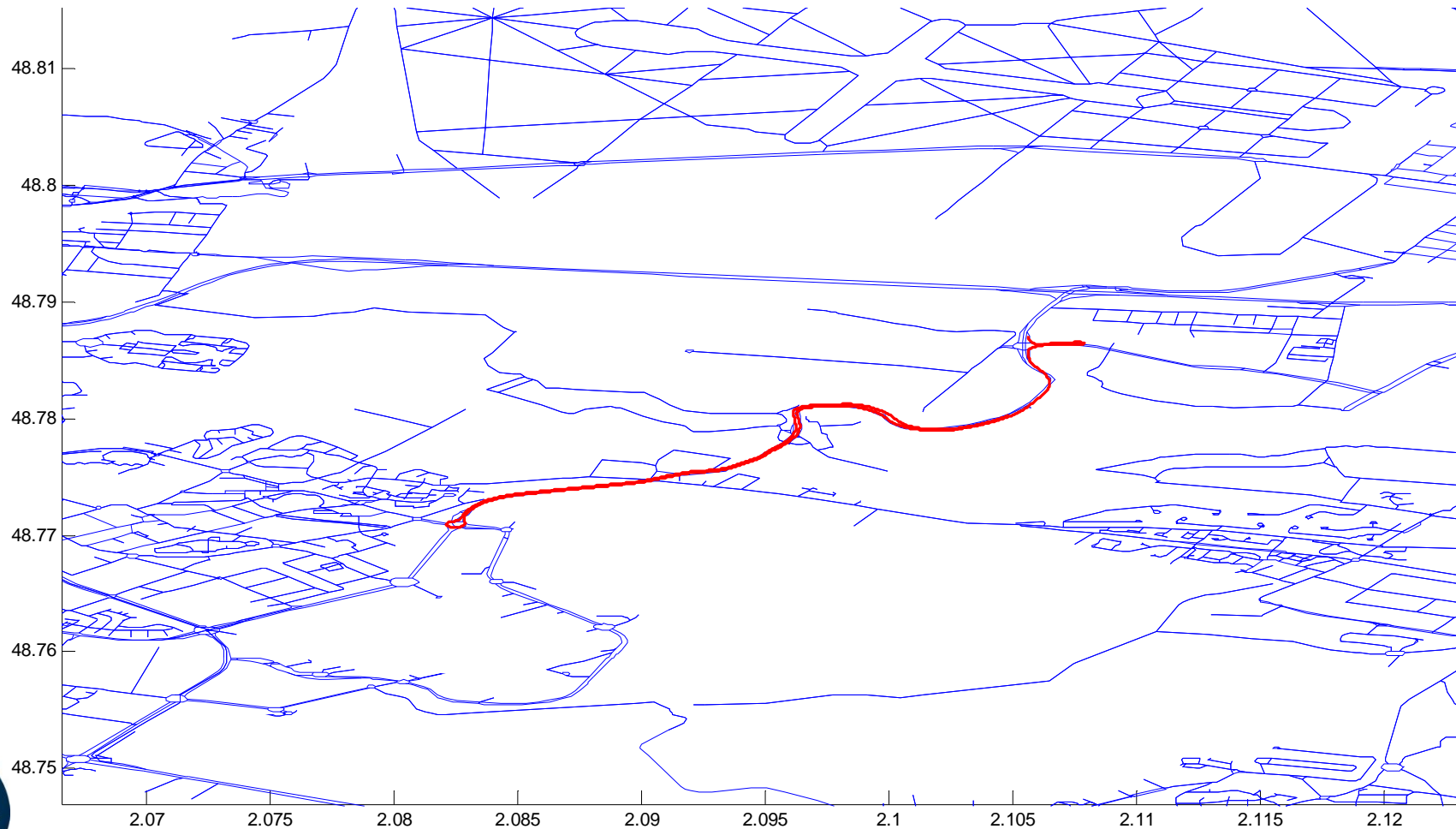
Versailles experiment (March 2009)





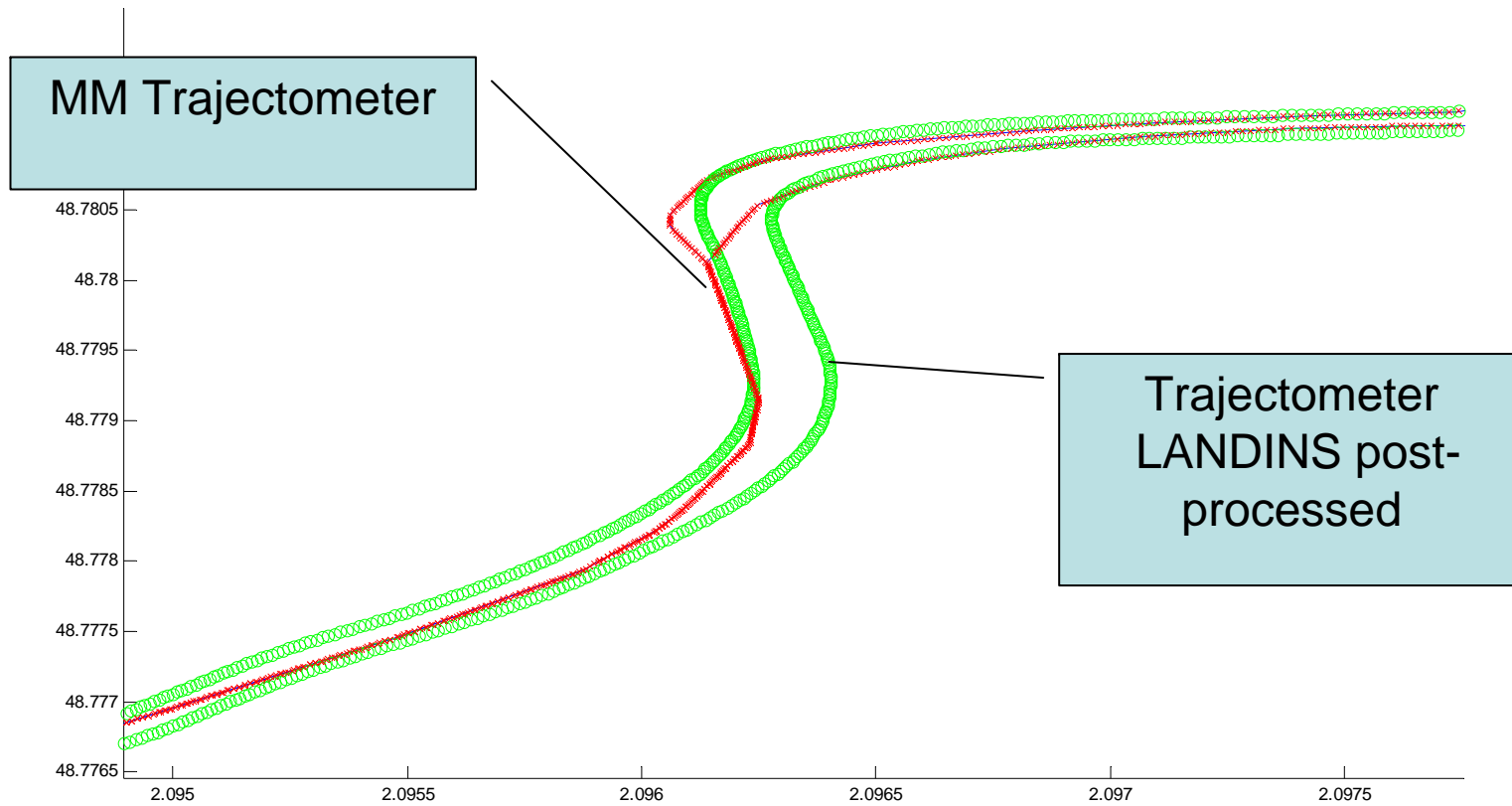
Result of the map path selection

Goal: to select the roads traveled by the vehicle (and only them)



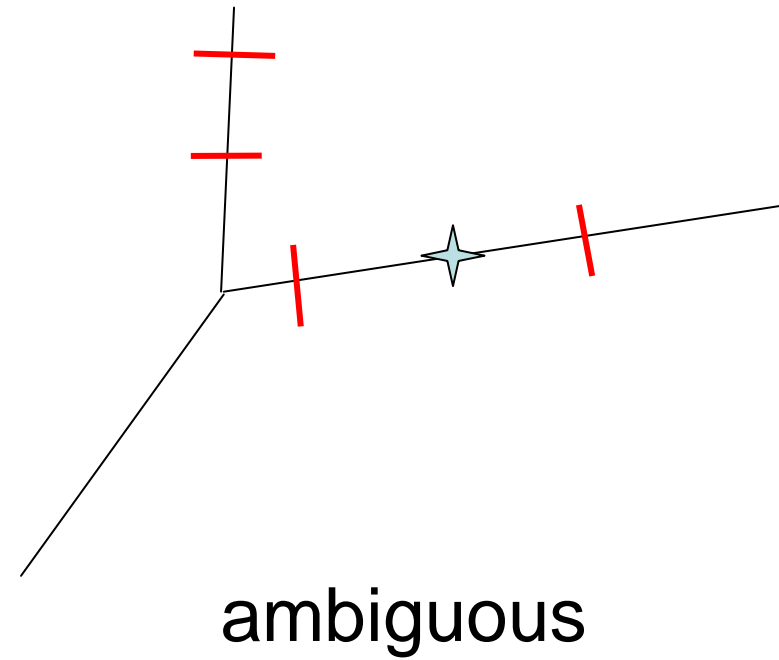
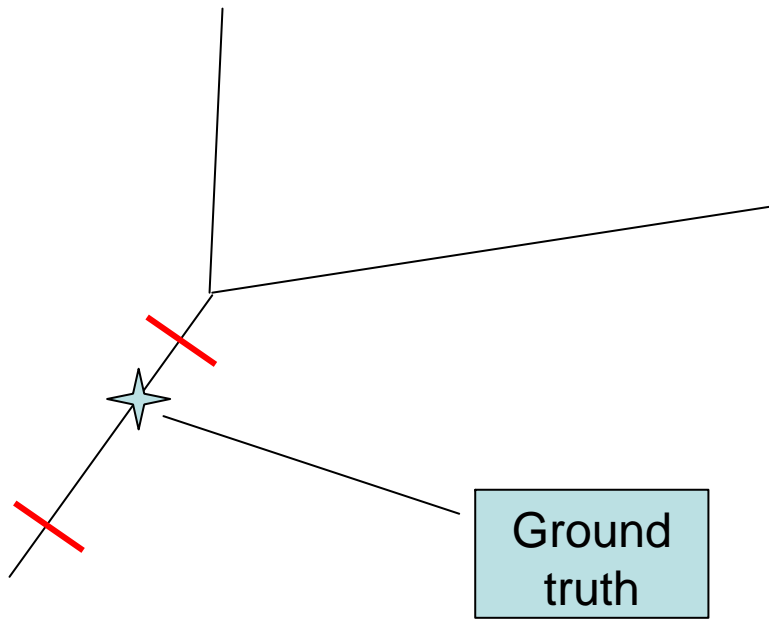


Map-matched reference trajectory



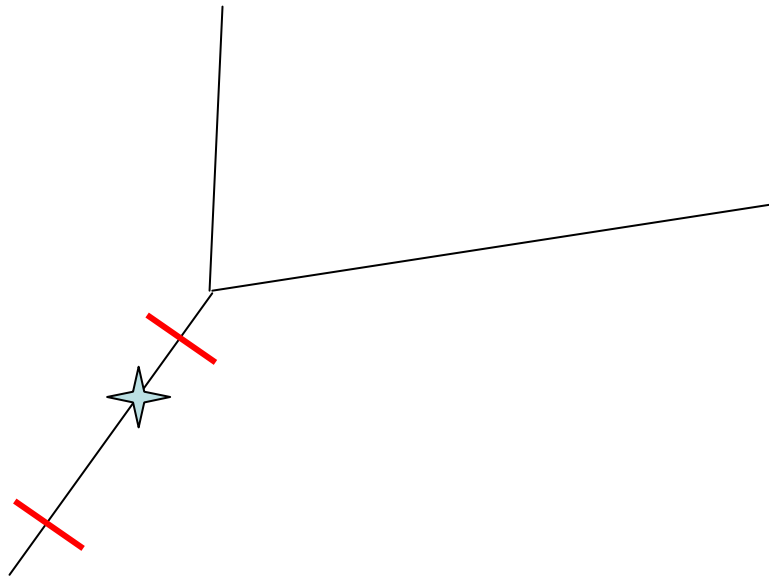


Good match

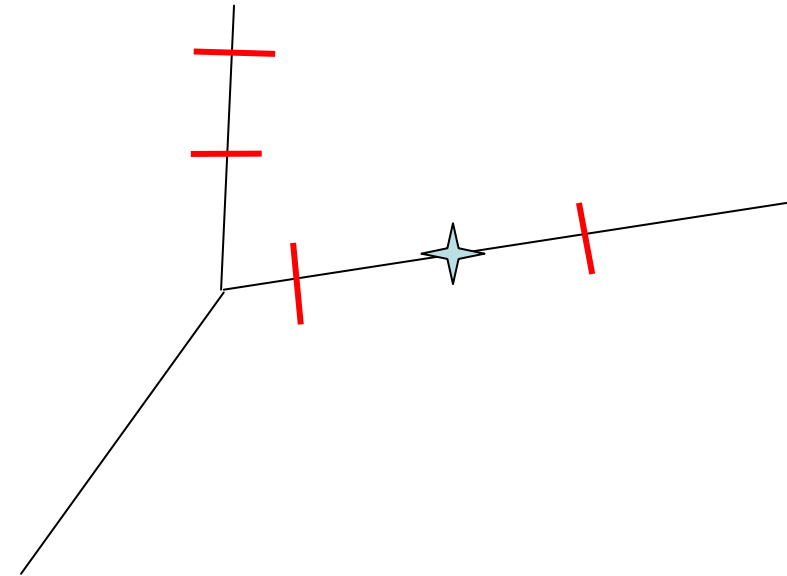




False Alarm



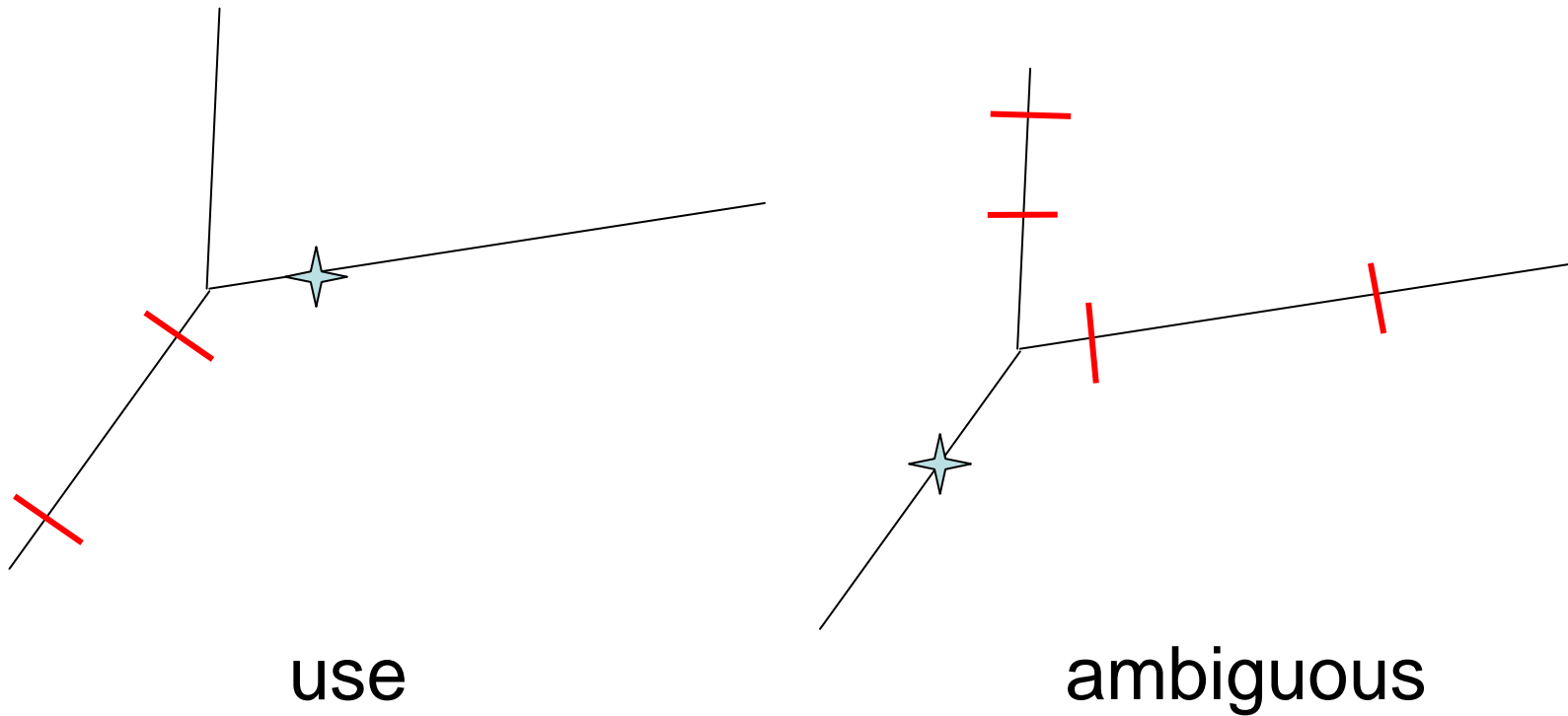
Don't use



Don't use

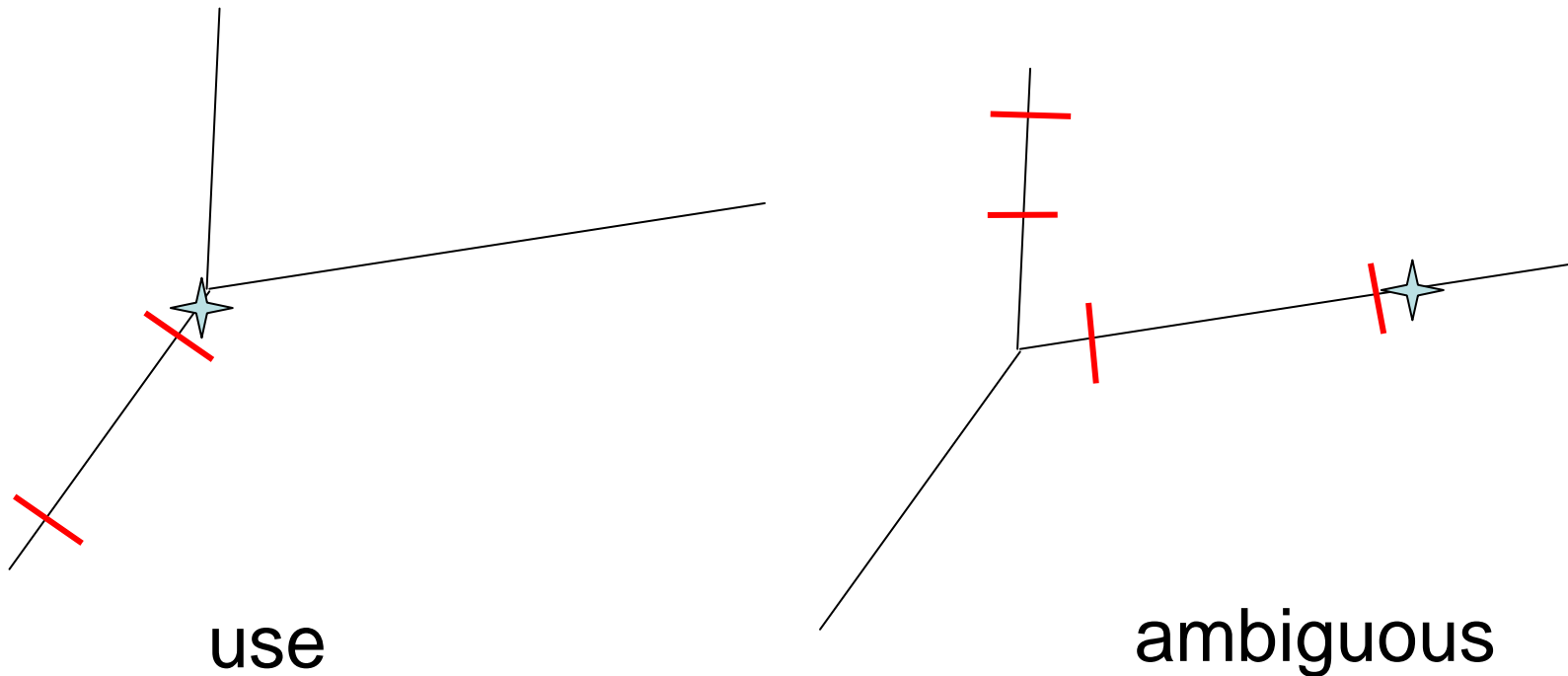


Miss match (miss detection)





Miss match but good ID selection



use

ambiguous

GIDS = Good ID selection



Performance Analysis

~2300 Map-Matched positions

OCDR (overall correct detection rate)

GIDS (Good ID selection)

<i>Map</i>	FAR (%)	MDR (%)	OCDR (%)	GIDS (%)
Map <i>i</i>	0.4	4.3	95.3	99.7
Map <i>j</i>	0.2	6.3	93.6	99.9



Conclusion



- Integrity monitoring is crucial for ITS applications where safety is important
- Multi-hypothesis Map-Matching is essential for integrity monitoring
- This talk has presented
 - an MHMM implementation using PF
 - a decision function for integrity monitoring
 - a validation method