Navigation at lane level with GNSS, Dead-reckoning and EMAP

Presented in Paris, 23rd January 2009

Presentation GDR Robotique - GT2

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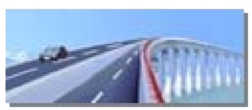
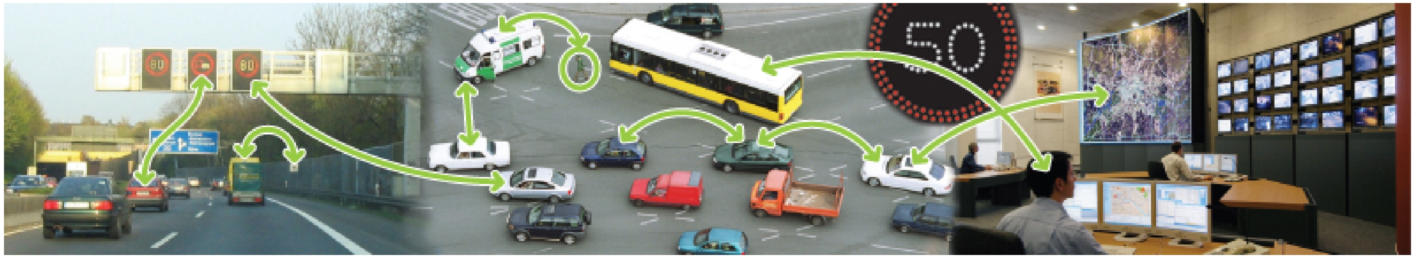


Laboratoire Central des Ponts et Chaussées. Metrology and Instrumentation **LCPC, Nantes, France**

Technical University of Cartagena, Spain, Dept. of Electronics and Computer Technology

University of Murcia, Spain
Intelligent Systems and Telematics,

overview



CVIS *cooperative vehicle infrastructure systems*

EU 6th Framework Program Integrated Project

POMA *sub-project for POSITIONING & MAPPING*

LCPC aims at providing a Map Aided Location service to CVIS, based on Enhanced Maps, for lane-level positioning requiring applications

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1st part) *Emap description and construction*

2nd part) *Lane-level positioning using Emap*

navigation in ITS

the vast majority of ITS applications demands a navigation system

[Du, Masters and Barth in the 2004 IEEE ITSC, Washington]
divided in 3 scales for vehicle navigation:

- **Macroscale** (roadway network, links and nodes)

  Obj: Finding a path between 2 nodes in the network

- **Mesoscale** (link level, lanes)

  Obj: maneuvers such as overtaking, moving out of the way of emergency vehicles…

- **Microscale** (vehicle level)

  Obj: Lane keeping, avoiding obstacles ahead, etc.

navigation in ITS

Most of the applications require a local reference (map) of the vehicle position

- **Macroscale** (roadway network, links and nodes)

  Current commercial maps serve well

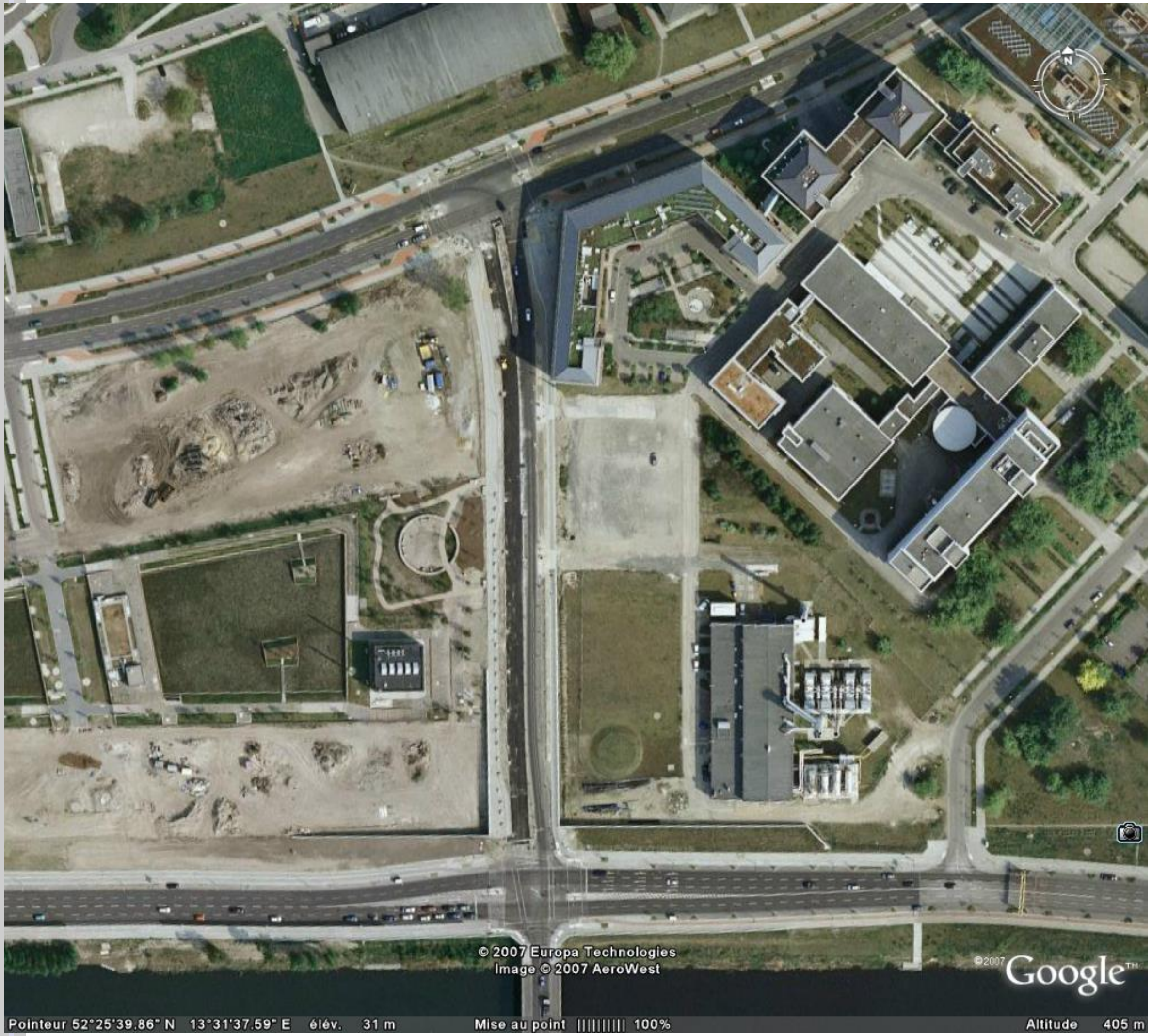
- **Mesoscale** (link level, lanes)

  Need of an enhanced map (Emap)

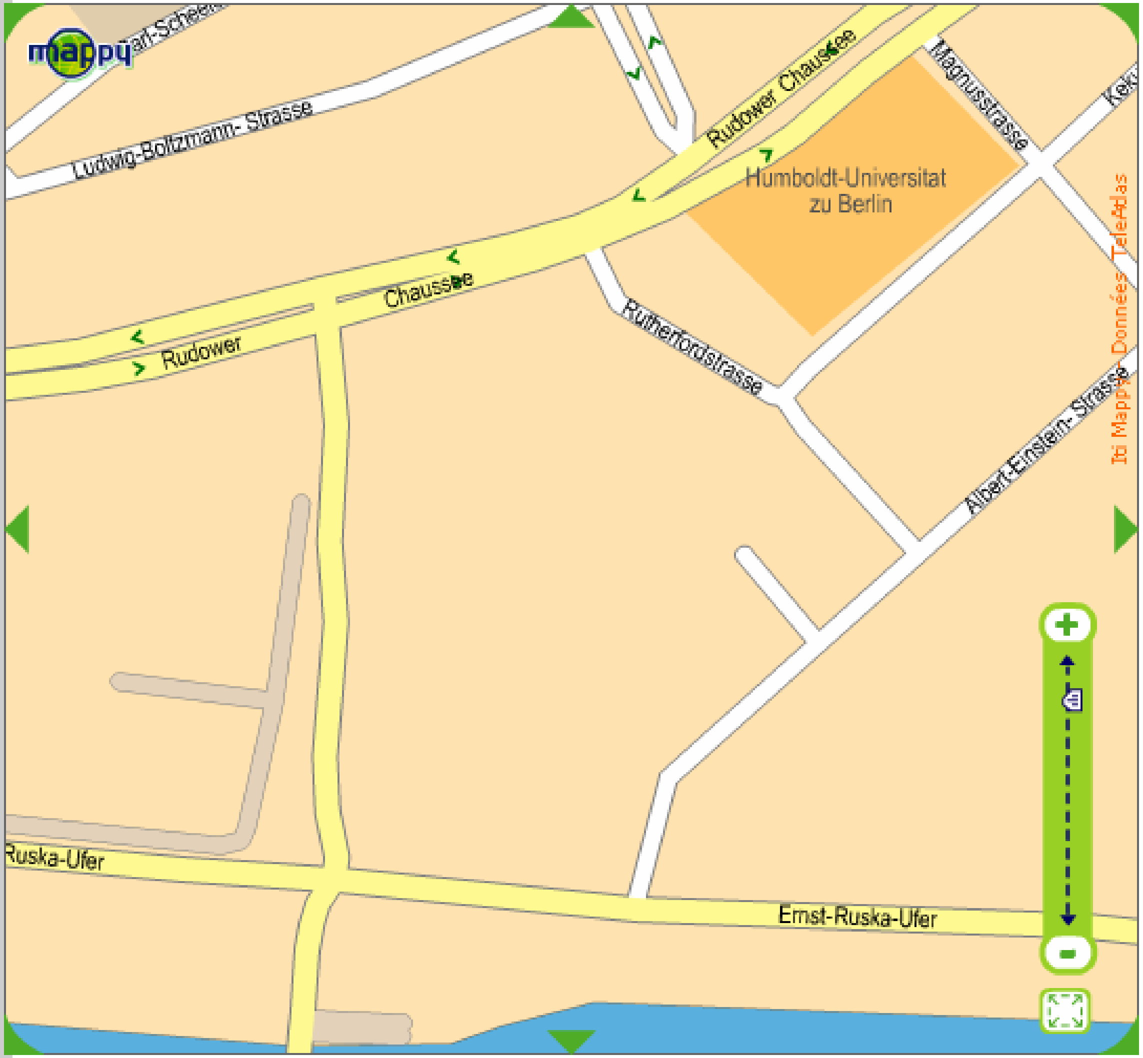
- **Microscale** (vehicle level)

  Need of an enhanced map (Emap) in case of cooperative applications (map data in an absolute reference frame)

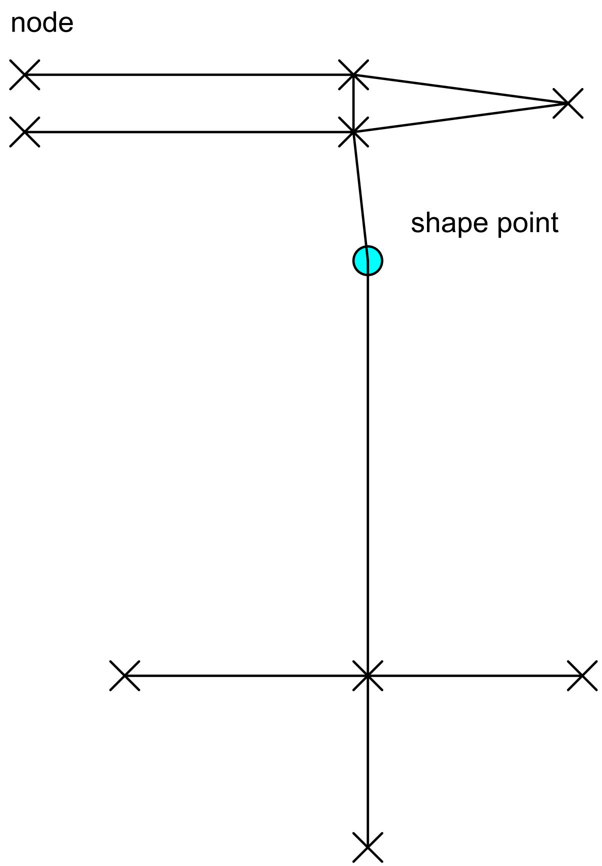
traditional maps



traditional maps

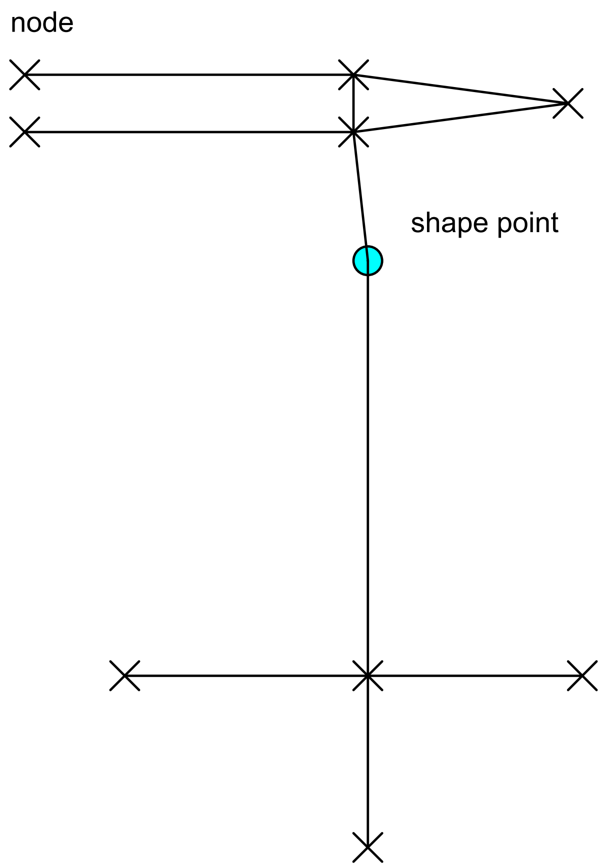


traditional maps



- Set of arcs
- Each arc is piece-wise linear (easy to describe)
- Extremities are **nodes** and the rest shape points
- A node may be
  - A start
  - A dead-end
  - Intersection

traditional maps. errors



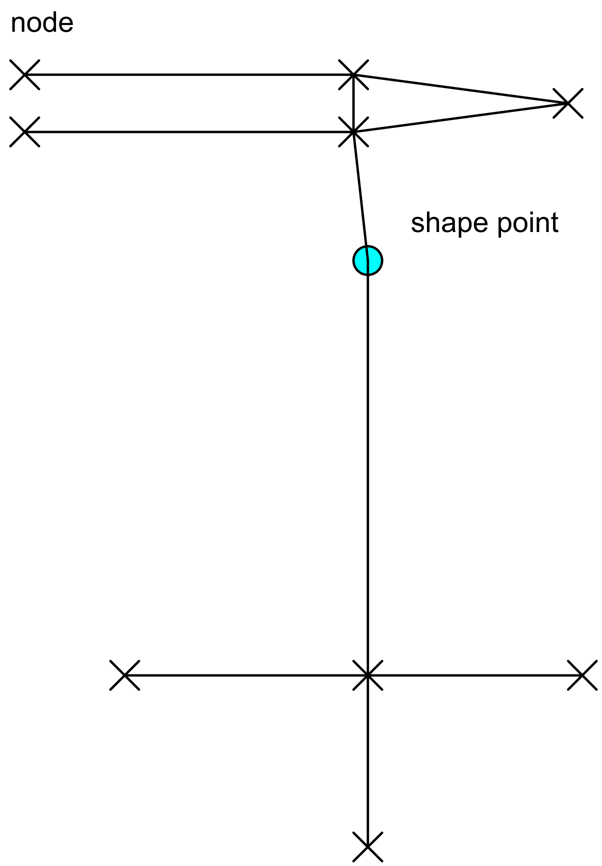
- **Global**. Same inaccuracy as paper version derived from photogrammetry …

  Std map accuracy

  (5-several tens) m

- **Local**. Approximation by series of shape points. Accuracy ≈ 1 m

traditional maps. errors



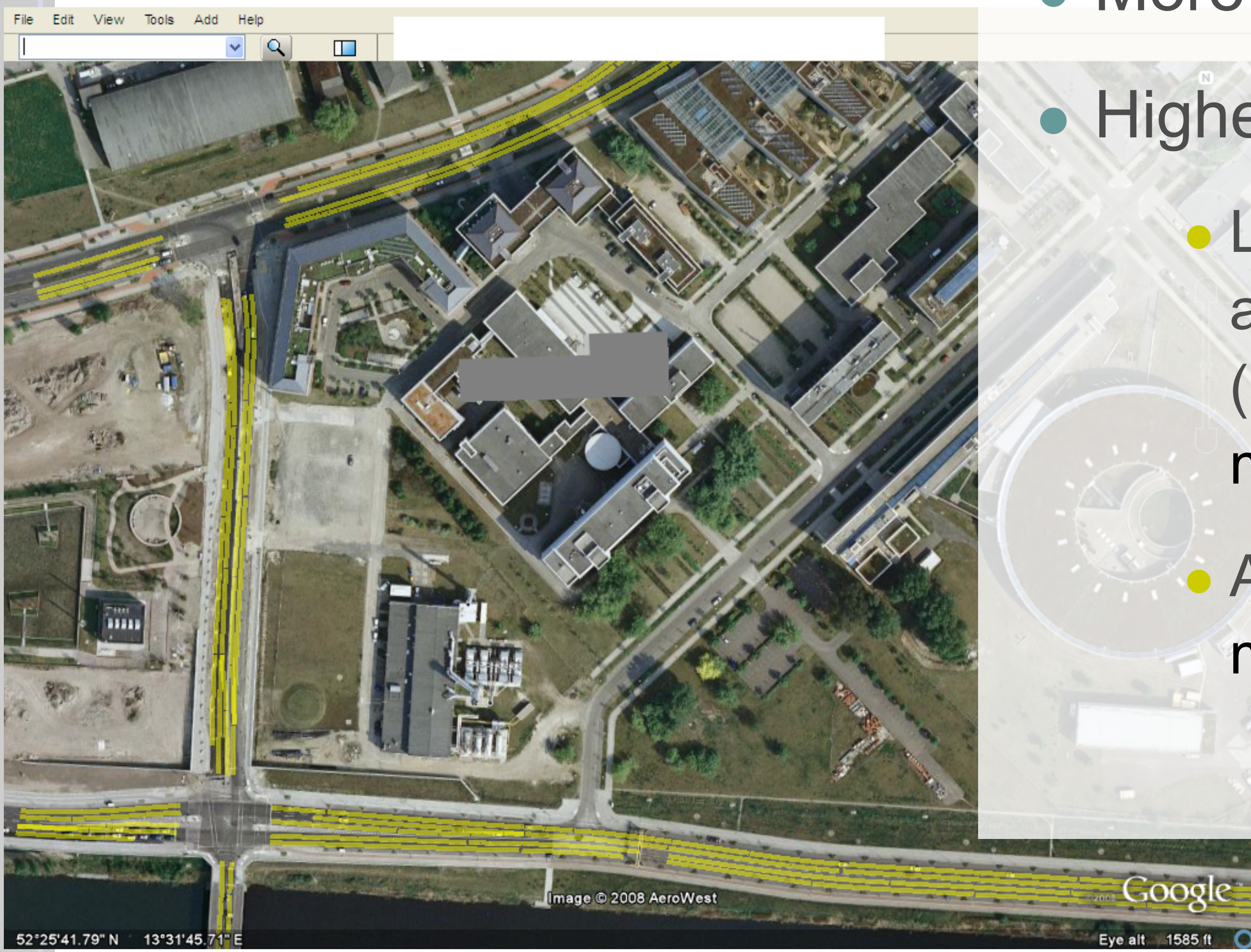
- **Completeness.**

  High simplication of road description.

  1 centerline per roadway,

  roundabouts represented by 1 node

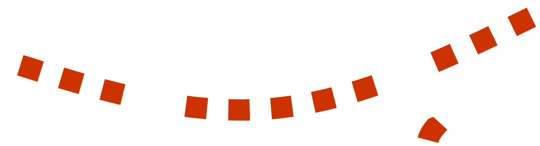
enhanced maps (Emaps)



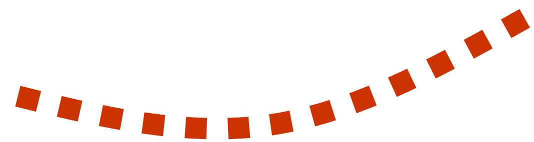
- More contents
- Higher accuracy
    - LANE-LEVEL applications (micro and mesoscale)
    - ADVANCED map-matching

how to create your own Emap?

PHASE 1) *mobile mapping*



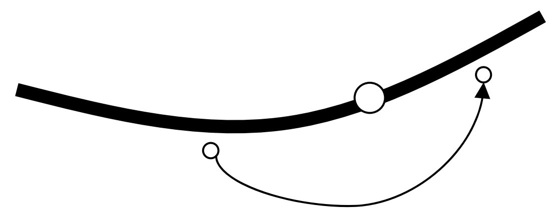
PHASE 2) *preparation of data*



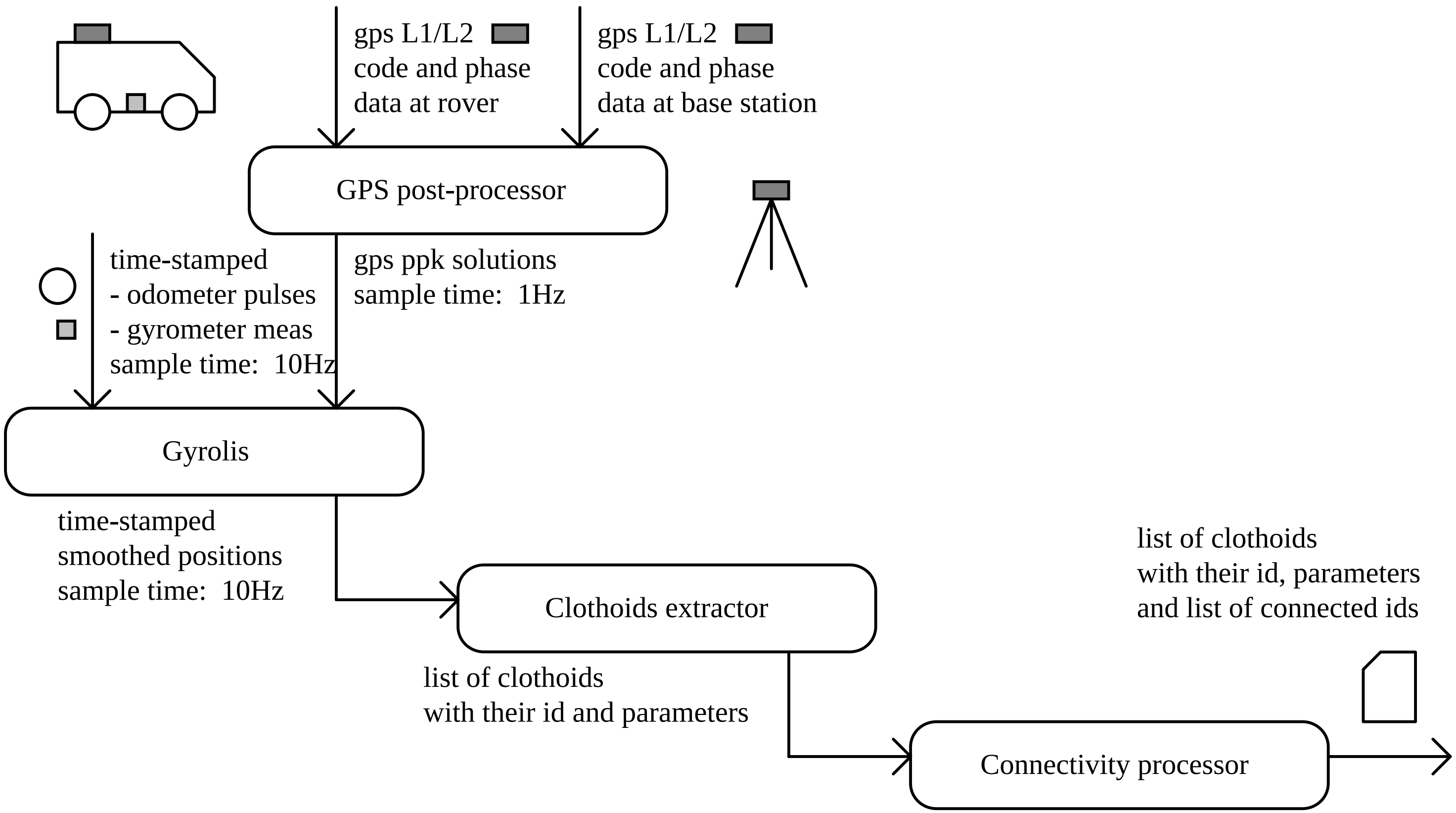
PHASE 3) *road representation:*

extraction of arcs

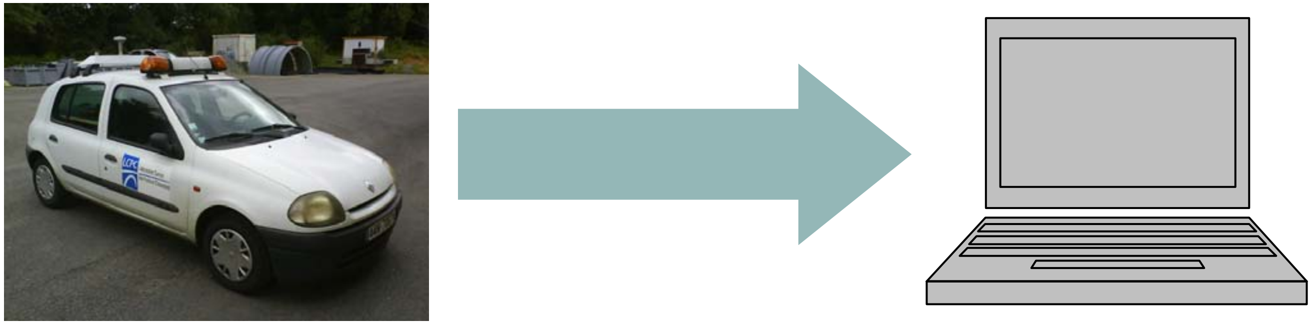
PHASE 4) *connection of arcs*



Emap computing process



phase 1: mobile mapping

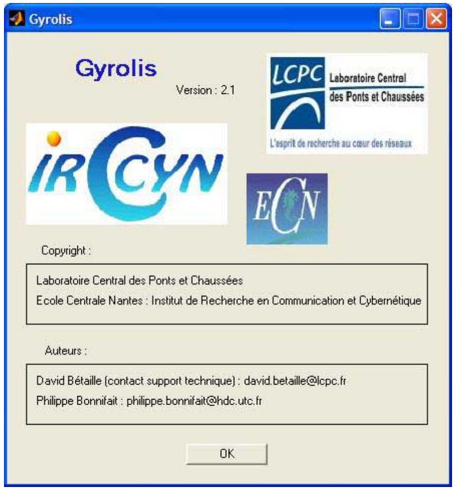


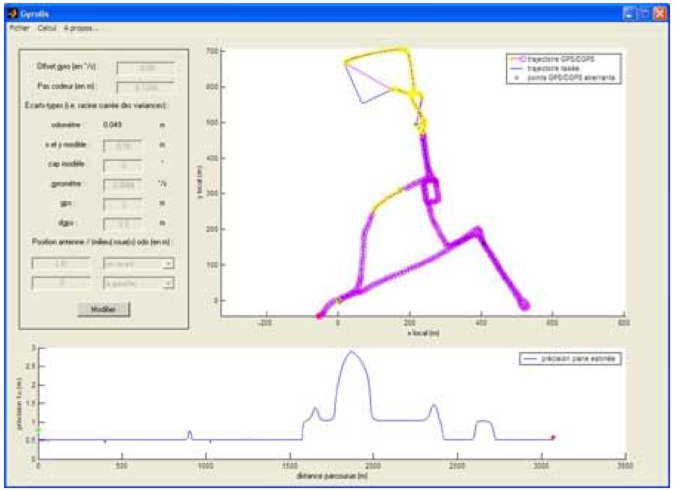
Collecting data by means of probe vehicles

Pro: Almost no bias **Con**: costly sensors

- RTK measurements
- IMU-odometry assistance for lacks of GPS coverage. Drifts depend on IMU quality. With good IMU data are asbolutely reliable

phase 2: preparation of data



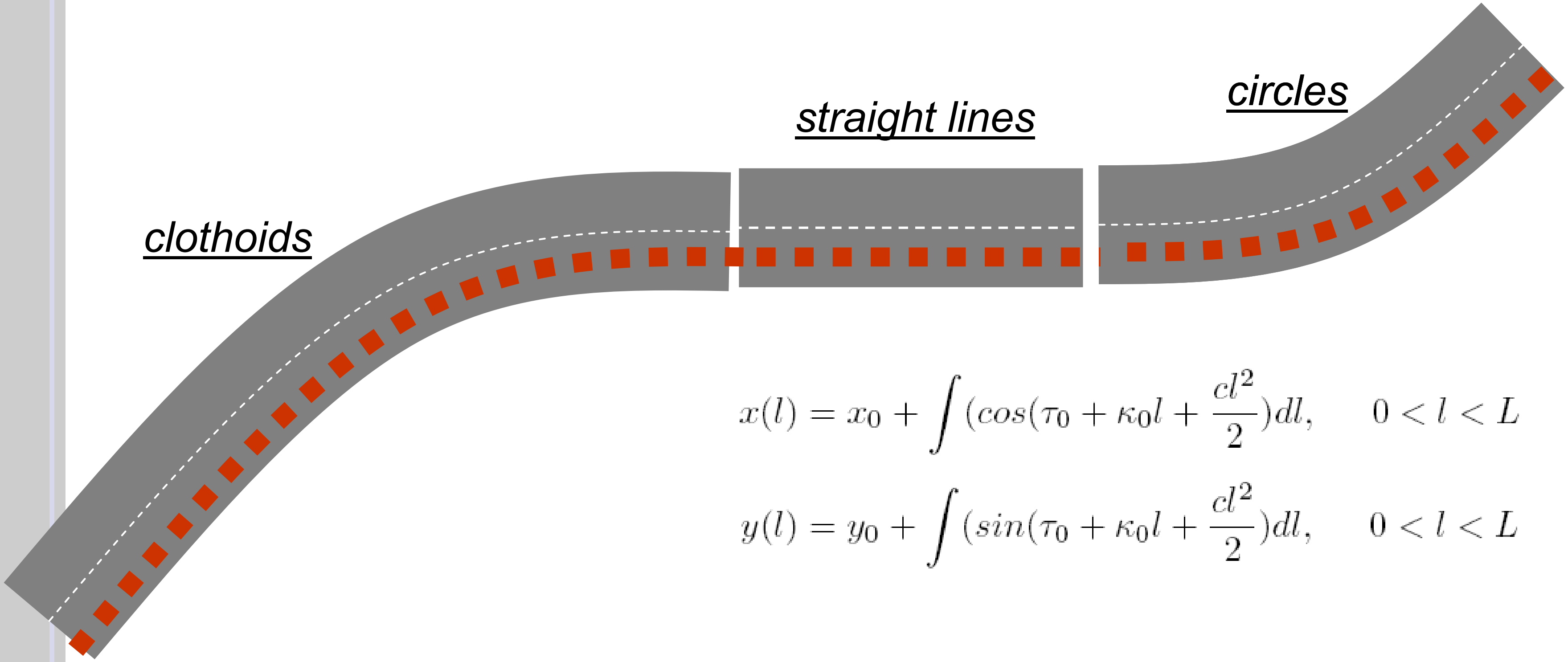


- Selection of trajectories
- Elimination of possible outliers
- Raugh smoothing and filtering (applying GYROLIS tool)

[Bétaille D., *GYROLIS: logiciel de localisation de véhicule en posttraitement par couplage GPS-gyromètre-odomètre*. Bulletin Spécial Instrumentation des Laboratoires de Ponts et Chaussées, 2008.]

phase 3: road representation

When roads are designed, the horizontal arcs are described by straight lines, circles and clothoids



$$x(l) = x_0 + \int (cos(\tau_0 + \kappa_0 l + \frac{cl^2}{2})dl, \qquad 0 < l < L$$

$$y(l) = y_0 + \int (sin(\tau_0 + \kappa_0 l + \frac{cl^2}{2})dl, \qquad 0 < l < L$$

phase 3: road representation

OUR APPROACH: One may expect **similar structures** hidden in mobile mapping data

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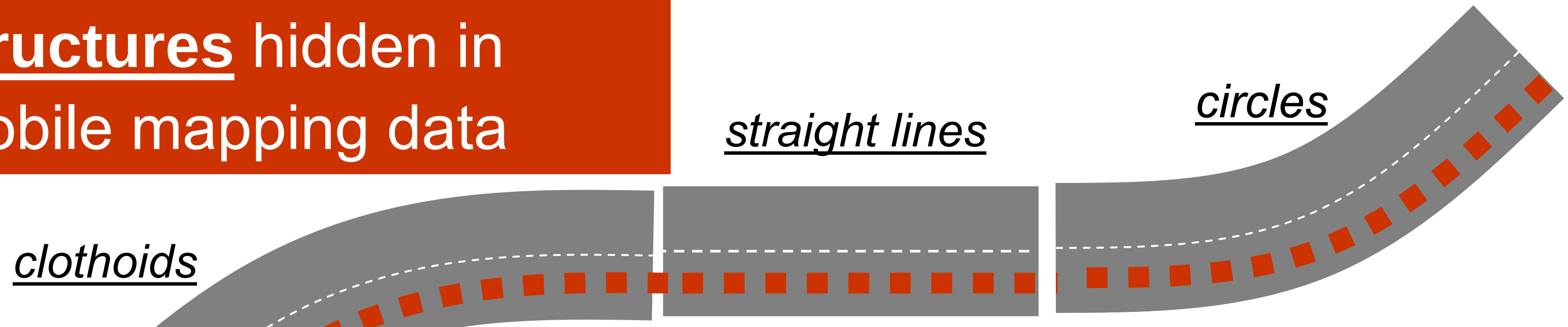


Straight lines, circles, clothoids can be described by the same mathematical expression

$$x(l) = x_0 + \int (cos(\tau_0 + \kappa_0 l + \frac{cl^2}{2})dl, \qquad 0 < l < L$$

$$y(l) = y_0 + \int (sin(\tau_0 + \kappa_0 l + \frac{cl^2}{2})dl, \qquad 0 < l < L$$

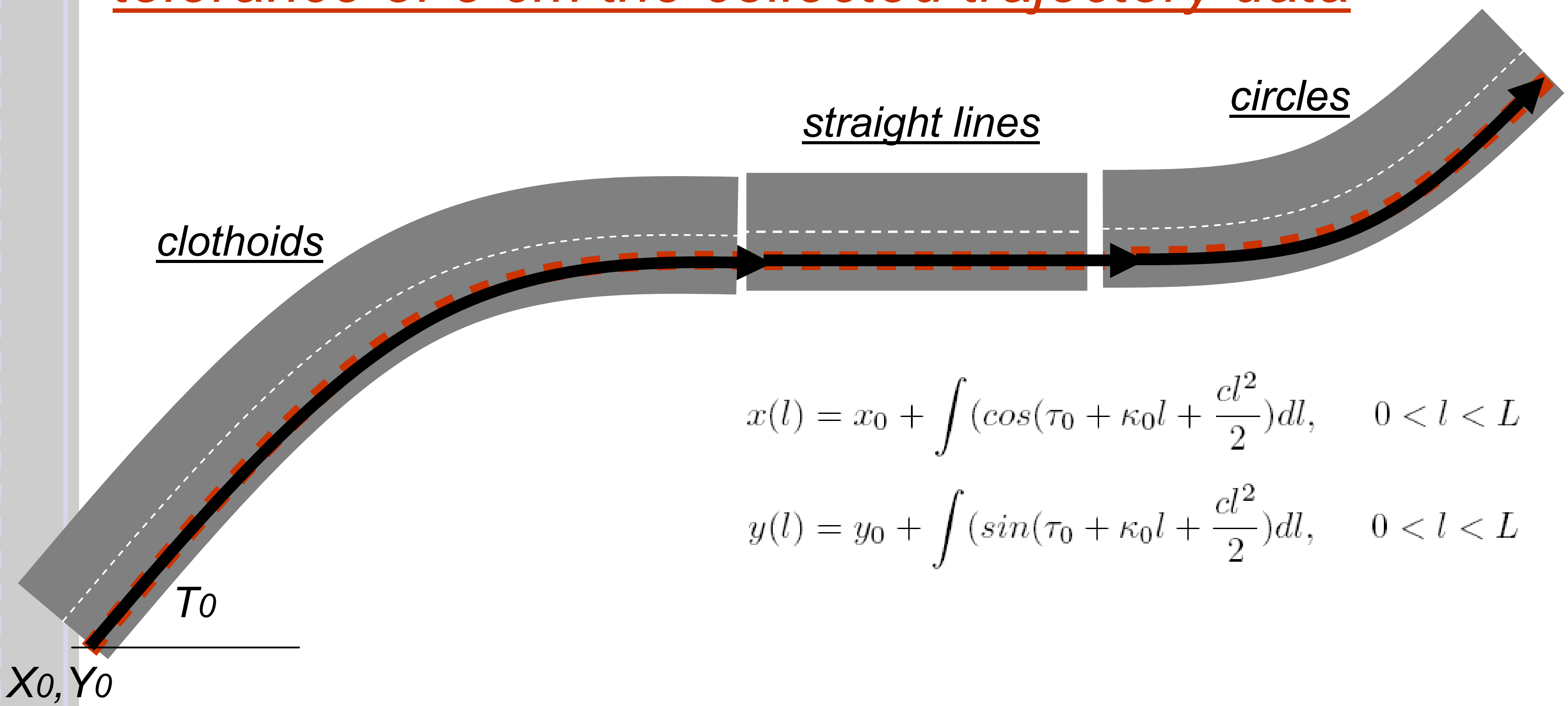
Making *c=0*, curvature remains constant → circle

Making *c=0*, *kappa=0*, nil curvature, → straight line

Making *c!=0*, → clothoid

phase 3: road representation

our task is to find [x_0,y_0,T_0 κ_0 c, L_{max}] that fits with a tolerance of 5 cm the collected trajectory data



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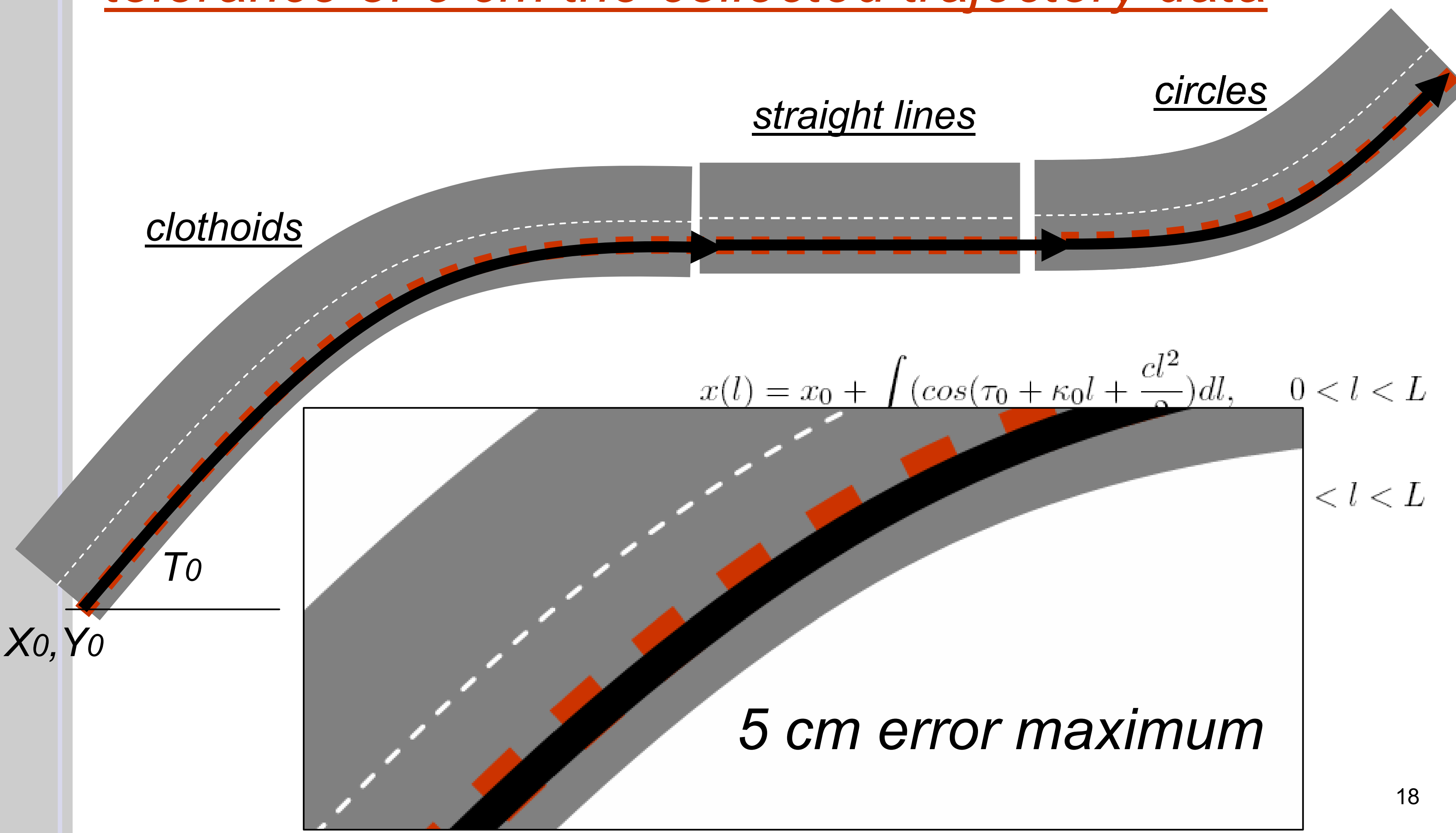

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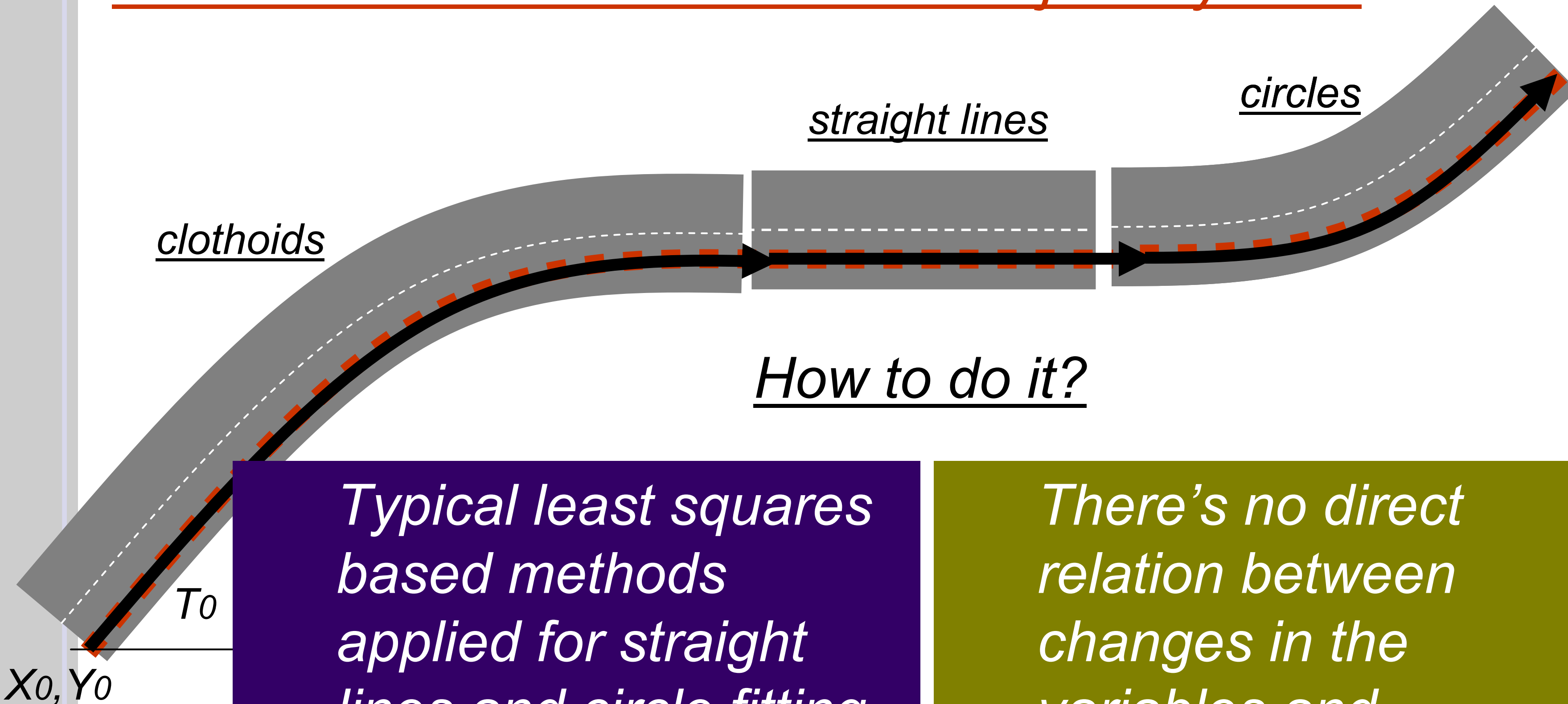
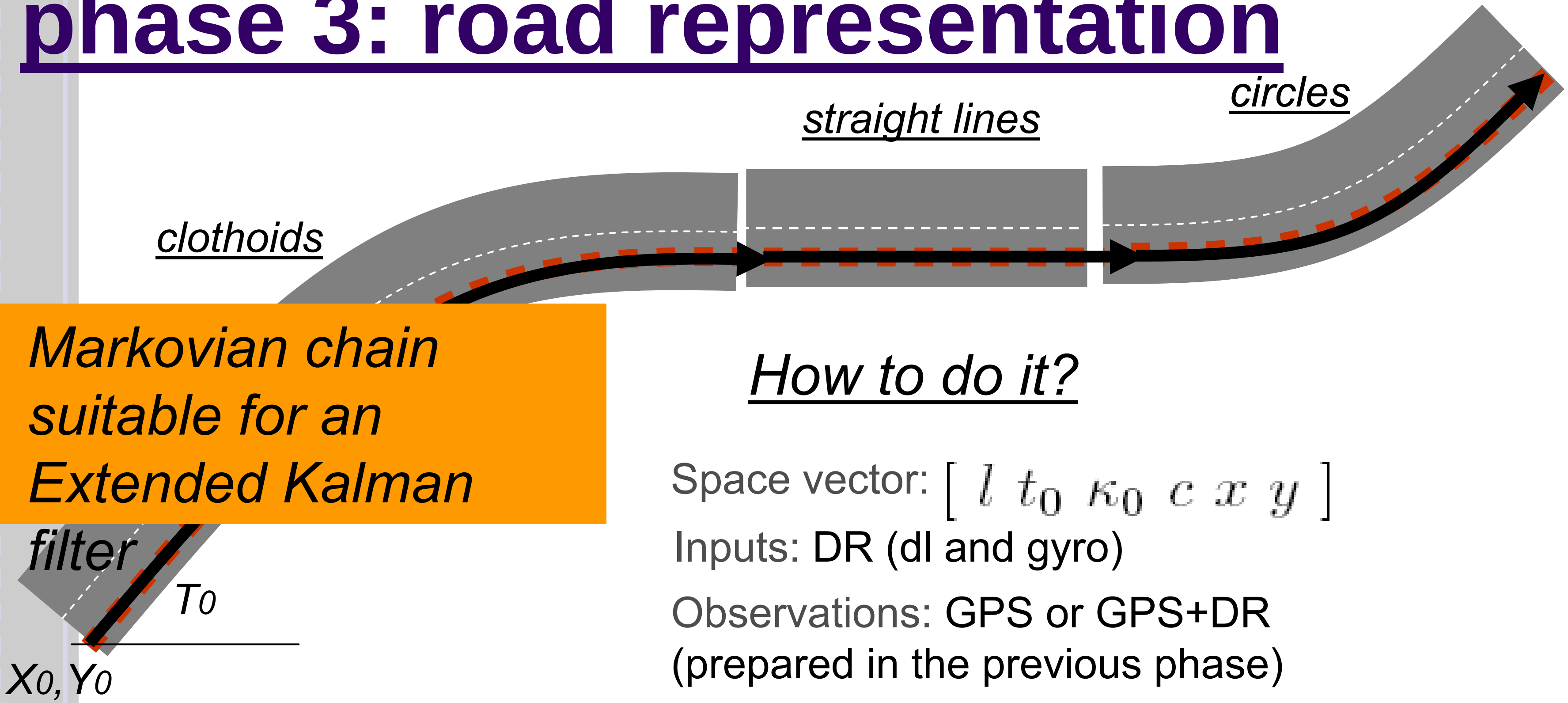


How to do it?

Typical least squares based methods applied for straight lines and circle fitting (Newton-Raphson, Levenberg-

There's no direct relation between changes in the variables and changes in the observations

phase 3: road representation



Markovian chain suitable for an Extended Kalman filter

How to do it?

Space vector: $[\ l\ t_0\ \kappa_0\ c\ x\ y\ ]$

Inputs: DR (dl and gyro)

Observations: GPS or GPS+DR (prepared in the previous phase)

Evolution (2nd order Taylor development from the Fresnel Integrals):

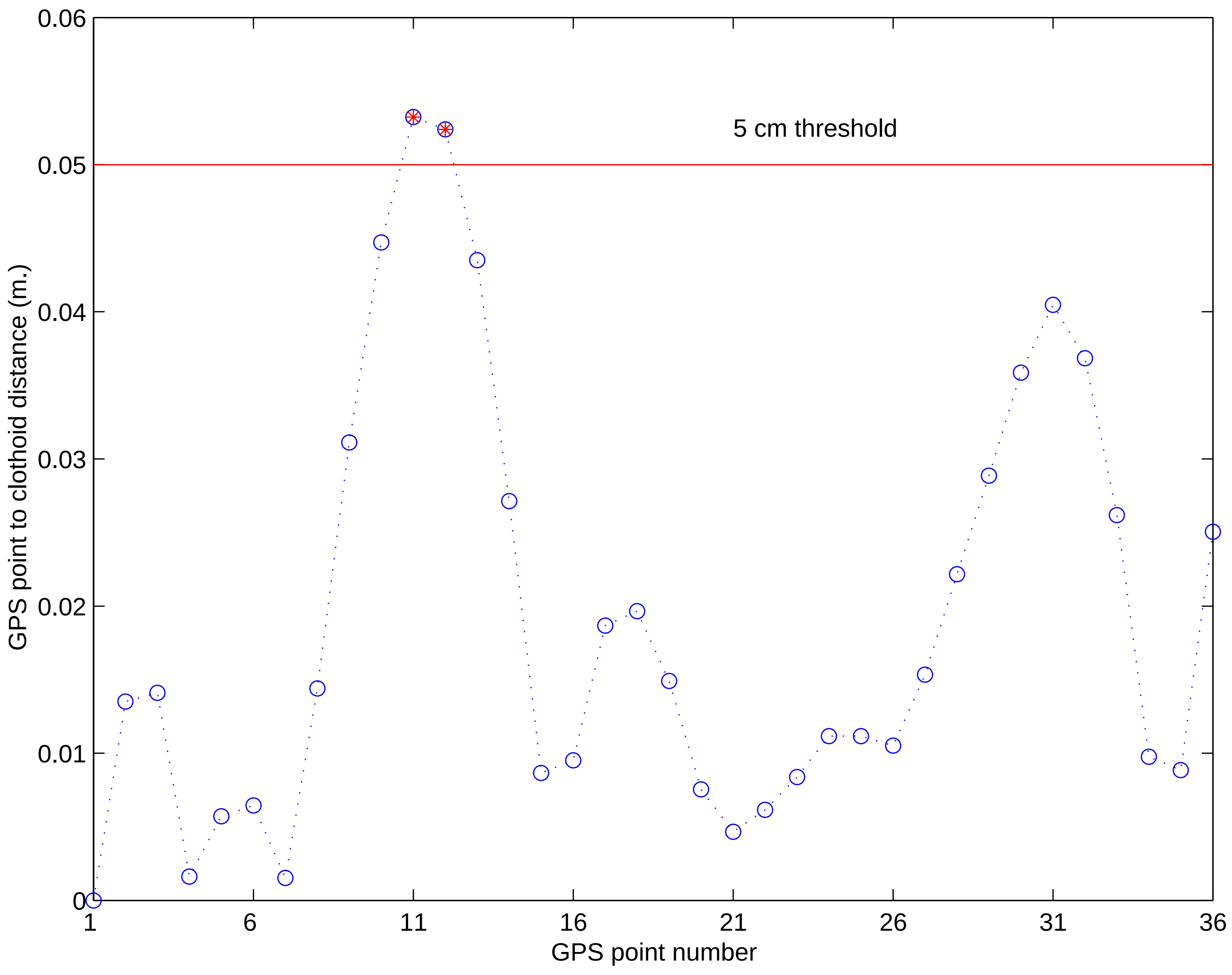
$$l(k+1|k) = l(k|k) + dl$$

$$x(l+dl) = x(l) + cos(t)\ dl - 0.5 \cdot \kappa\ sin(t)\ dl^2$$

$$y(l+dl) = y(l) + sin(t)\ dl + 0.5 \cdot \kappa\ cos(t)\ dl^2$$

$$t = t_0 + \kappa_0 l + 0.5 \cdot c l^2 \qquad \kappa = \kappa_0 + cl$$

phase 3: road representation



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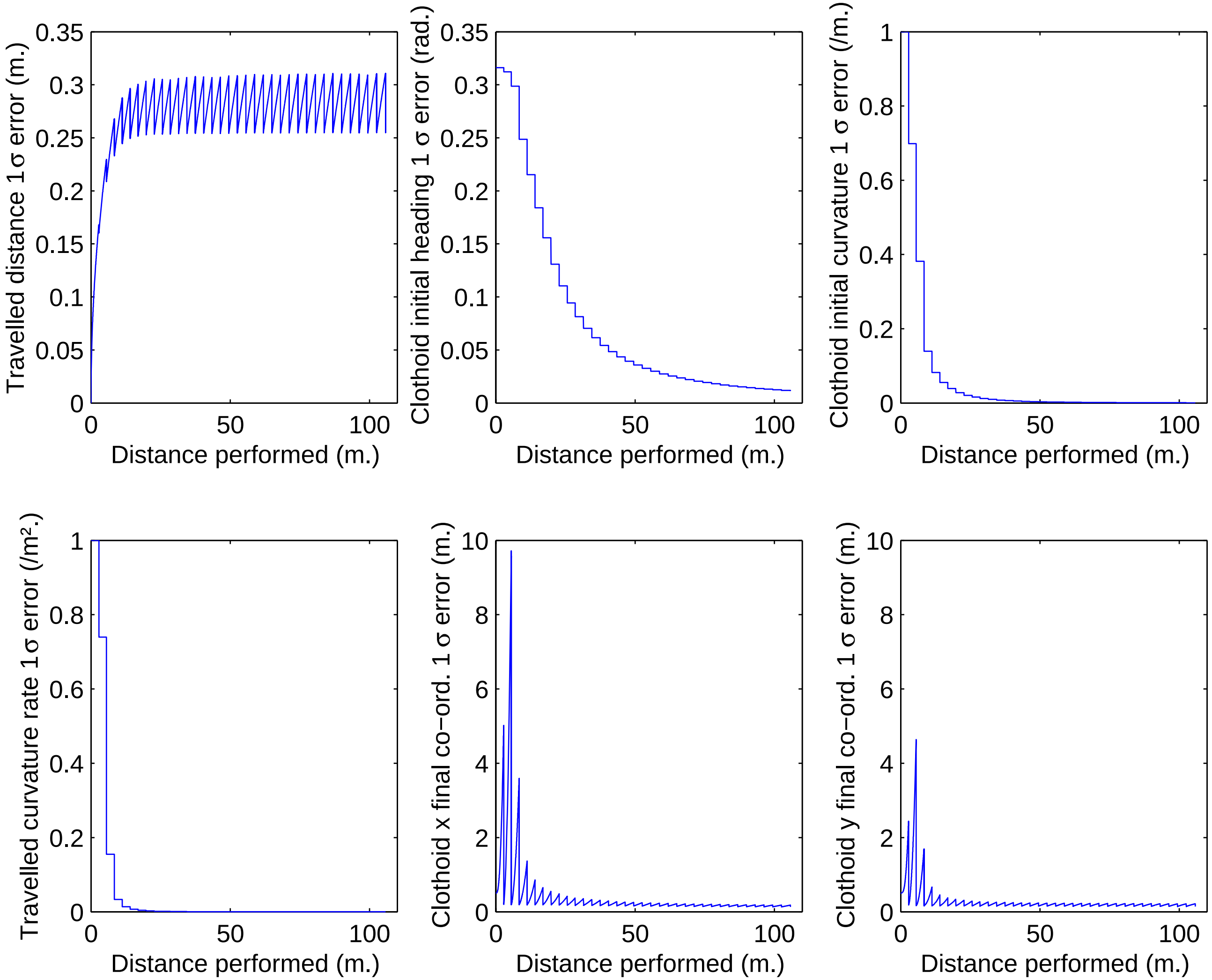
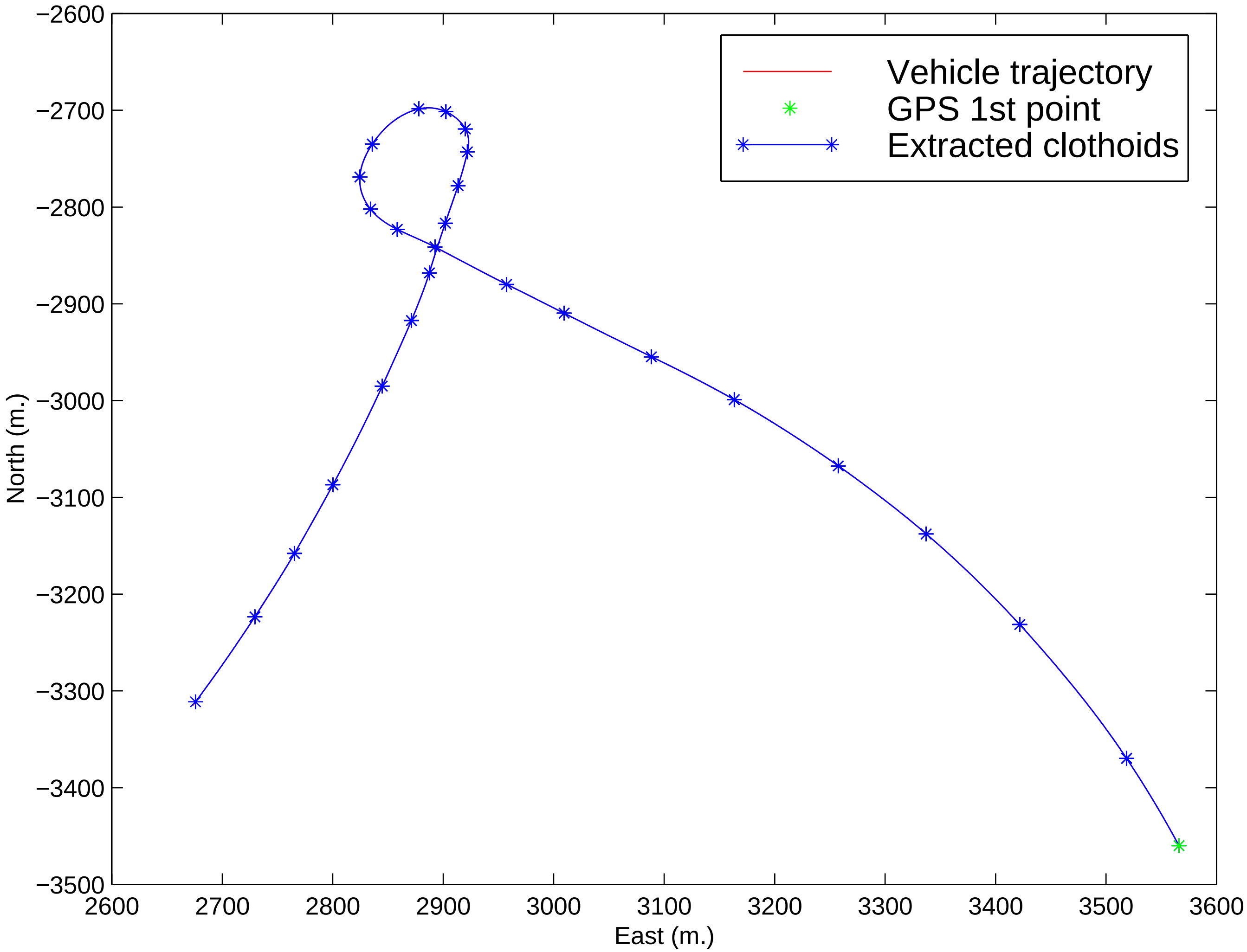


phase 3: road representation



phase 3: road representation

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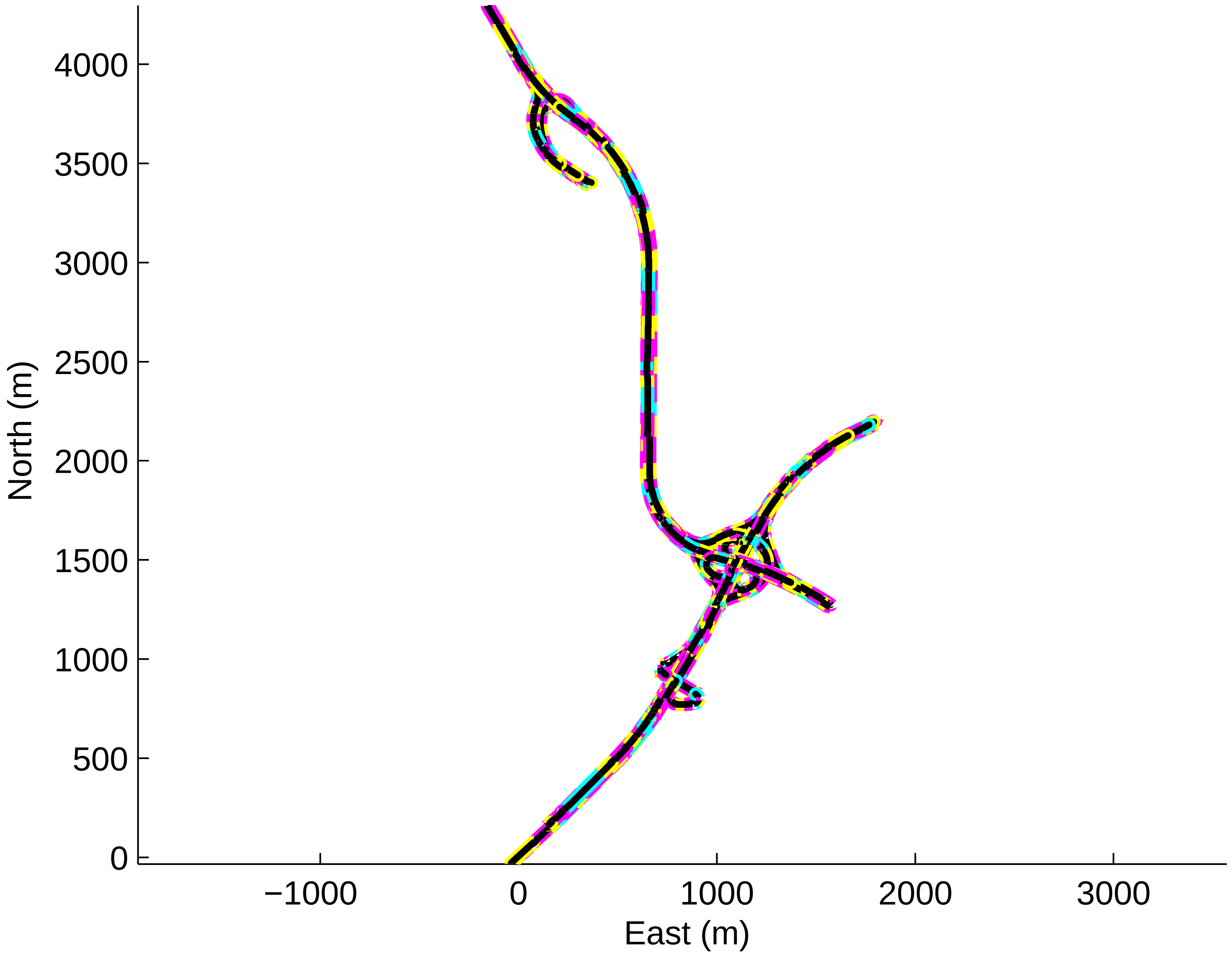

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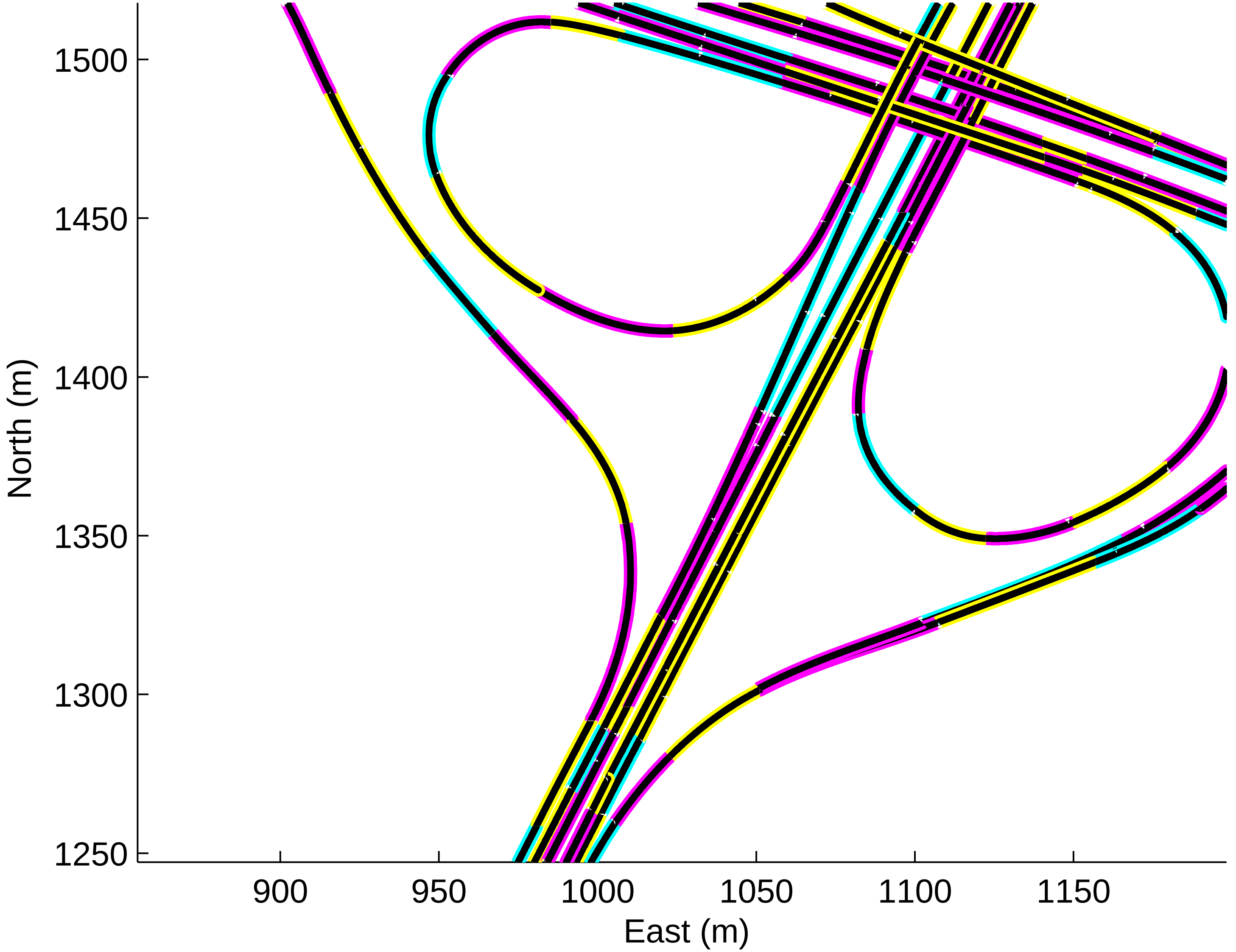
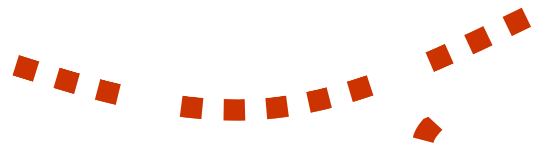


how to create your own Emap?

PHASE 1) *mobile mapping*



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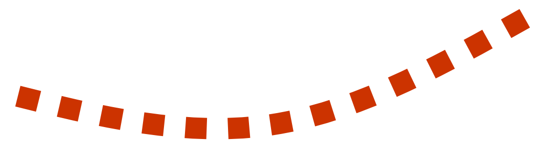

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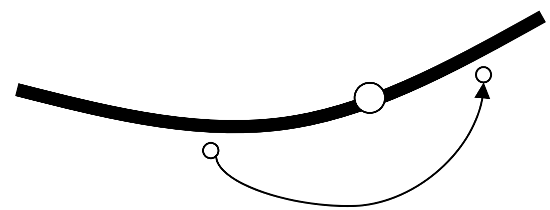
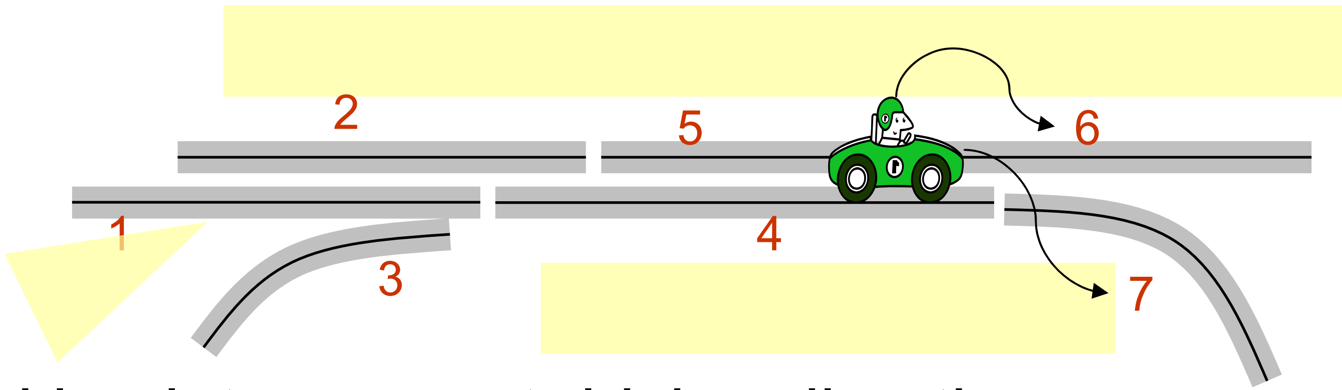
extraction of arcs

PHASE 4) *connection of arcs*



phase 4: arc connections

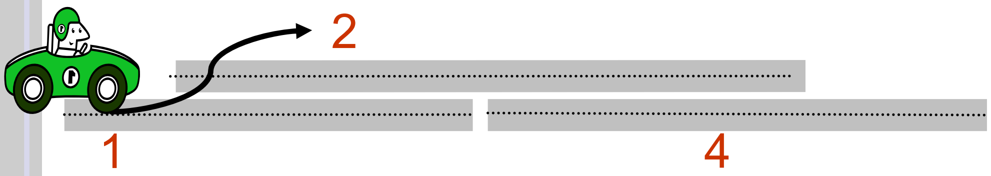
Our task: to find the segments in which the vehicle could be when it'll leave the given one



- Taking into account driving directions
- Some traffic regulations, while
- Giving priority to the real feasibility of the maneuver
- As automatically as possible (more than 500 segments in the Cheviré Bridge Emap)

phase 4: arc connections

Example of automatic segment connection



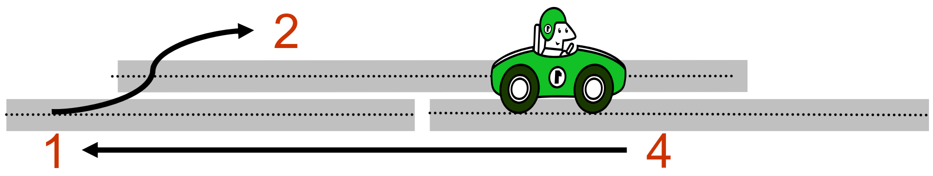
- *The final point of 1 is "very close" to segment 2*
- *The initial point of 2 is "very close" to segment 1*
- *The final point of 1 is NOT "very close" to initial point of 2*

…

It is possible to move from segment 1 to 2

phase 4: arc connections

Example of automatic segment connection



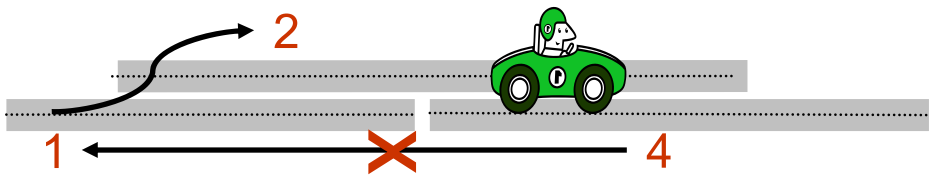
- *The initial point of 4 is “very close” to segment 1*
- *The final point of 1 is “very close” to segment 4*
- *The final point of 1 is “very close” to initial point of 4*

…

It is NOT possible to move from segment 4 to 1

phase 4: arc connections

Example of automatic segment connection



From geometrical aspects of the deployment of 2 segments under consideration and based on logic rules it is possible to determine automatically the relation of connectivity among the segments of the Emap

[Bétaille D., Toledo-Moreo R. *Making an Enhanced map for lane location based services*, ITSC Conference 2008.]

example of Emap file

EmapBerlin.txt - WordPad

Archivo Edición Ver Insertar Formato Ayuda

```
55 786.581326 126.144411 863.110997 119.165582 -0.082972 -0.000229 0.000001 76.857775 4 1 3 56 73 74 1 2 2 0 0 0 0 0 0 0 0 0 0 0 0
56 863.110997 119.165582 943.147070 112.073952 -0.092076 0.000556 -0.000017 80.358858 4 1 2 57 74 1 2 0 0 0 0 0 0 0 0 0 0 0 0 0
57 943.147070 112.073952 997.611883 107.182357 -0.088702 -0.000180 0.000008 54.690172 4 1 2 74 75 2 2 0 0 0 0 0 0 0 0 0 0 0 0 0
58 707.154392 555.853495 677.817788 533.185309 -2.491451 0.001584 -0.000094 37.079778 2 1 2 59 76 1 2 0 0 0 0 0 0 0 0 0 0 0 0 0
59 677.817788 533.185309 638.715871 503.587566 -2.491110 -0.000068 -0.000002 49.044844 2 1 2 60 76 1 2 0 0 0 0 0 0 0 0 0 0 0 0 0
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61 616.661856 488.976200 577.174033 472.416478 -2.648147 -0.007106 0.000183 42.865122 2 1 3 62 77 78 1 2 2 0 0 0 0 0 0 0 0 0 0 0 0
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overview

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1st part) *Emap description and construction*

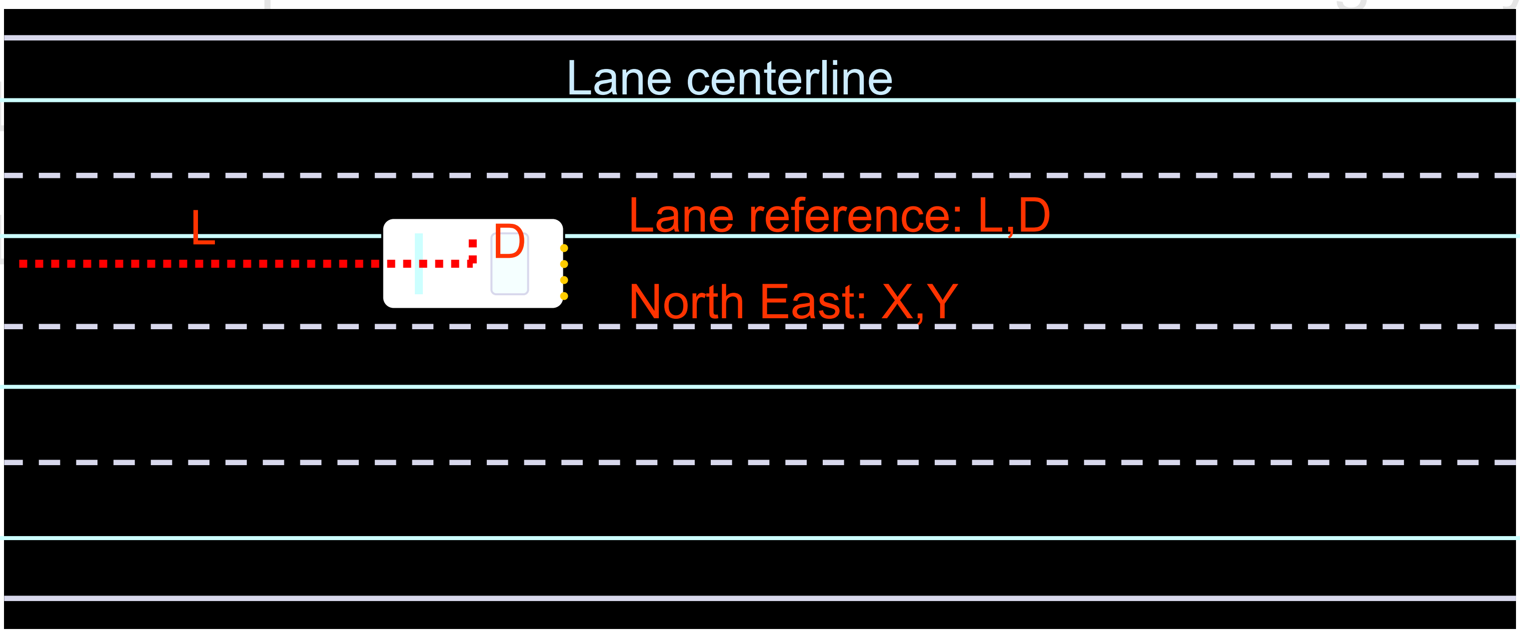
2nd part) *Lane-level positioning using Emap*

our lane positioning features

- Vehicle positioning on the lane (no projection on the road after map-matching)
- Curent lane ID
- Relative position of the vehicle on the carriageway
- Level of confidence on the position
- Level of confidence on the segment assignment

our lane positioning features

- Vehicle positioning on the lane (no projection on the road after map-matching)
- Curent lane ID
- Relative position of the vehicle on the carriageway



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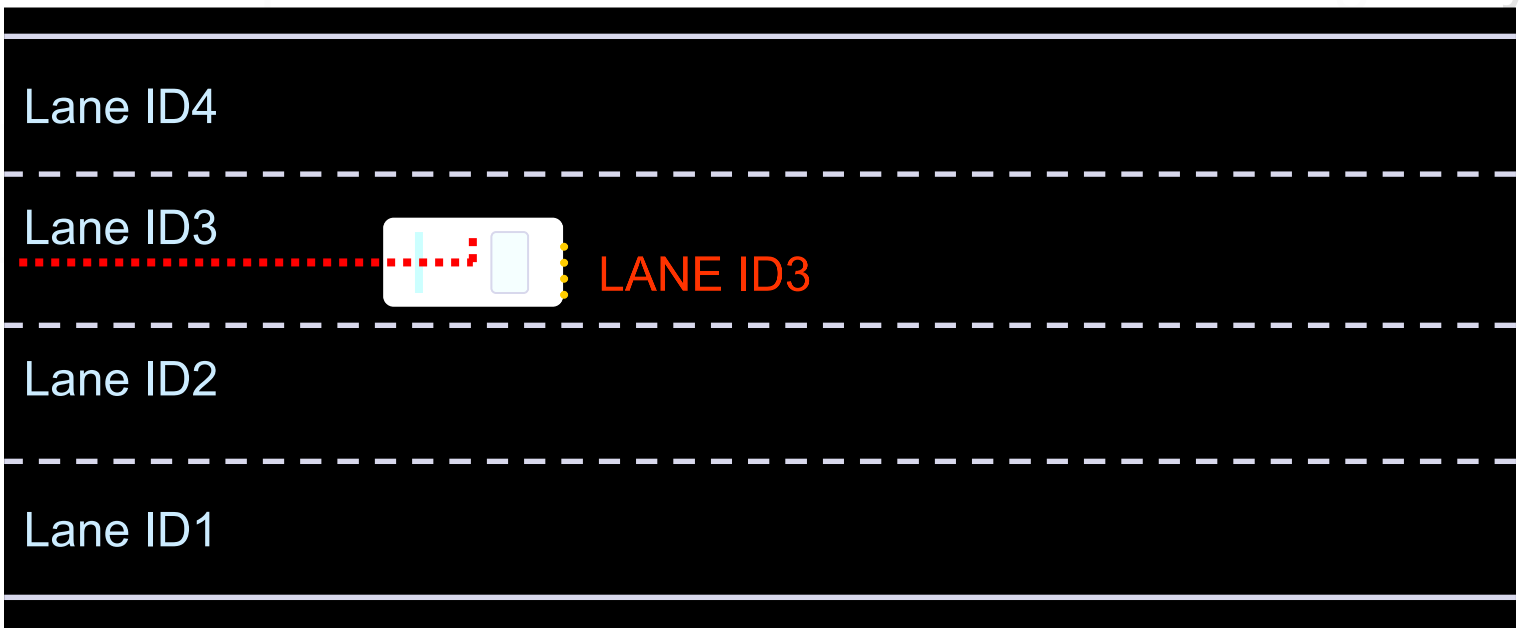

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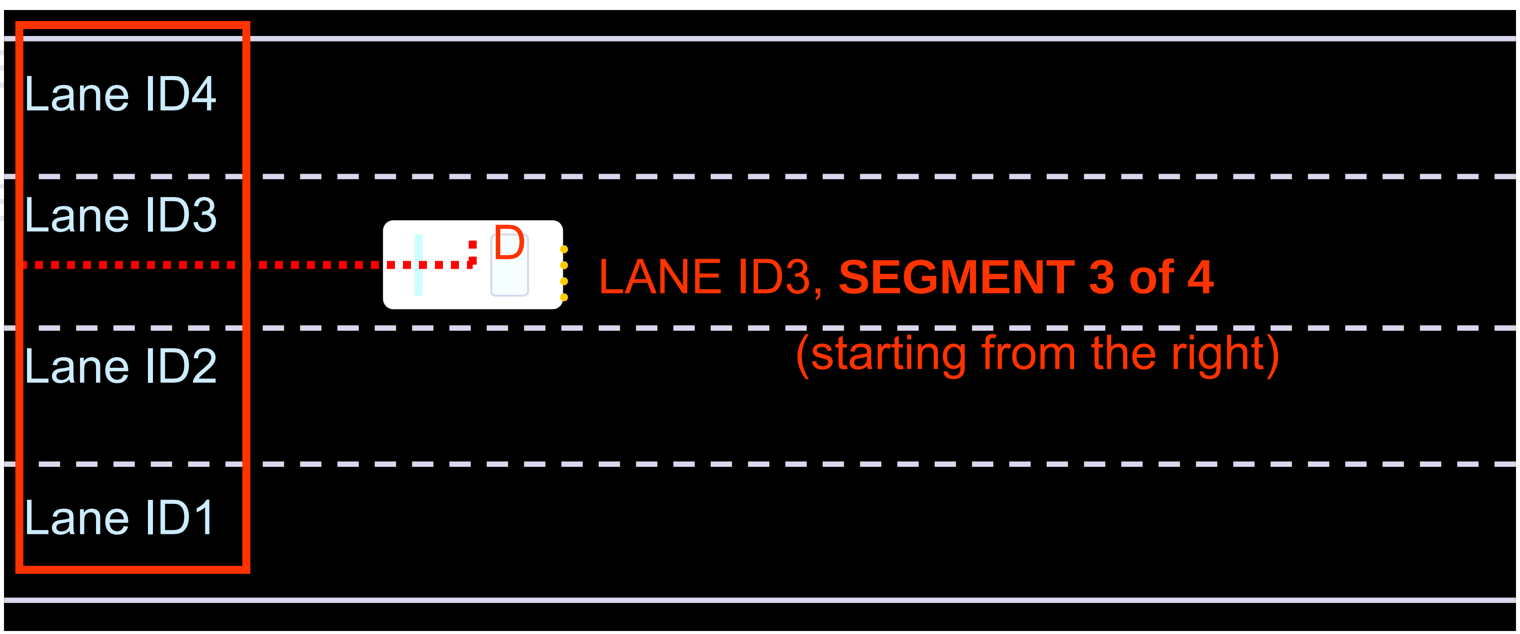
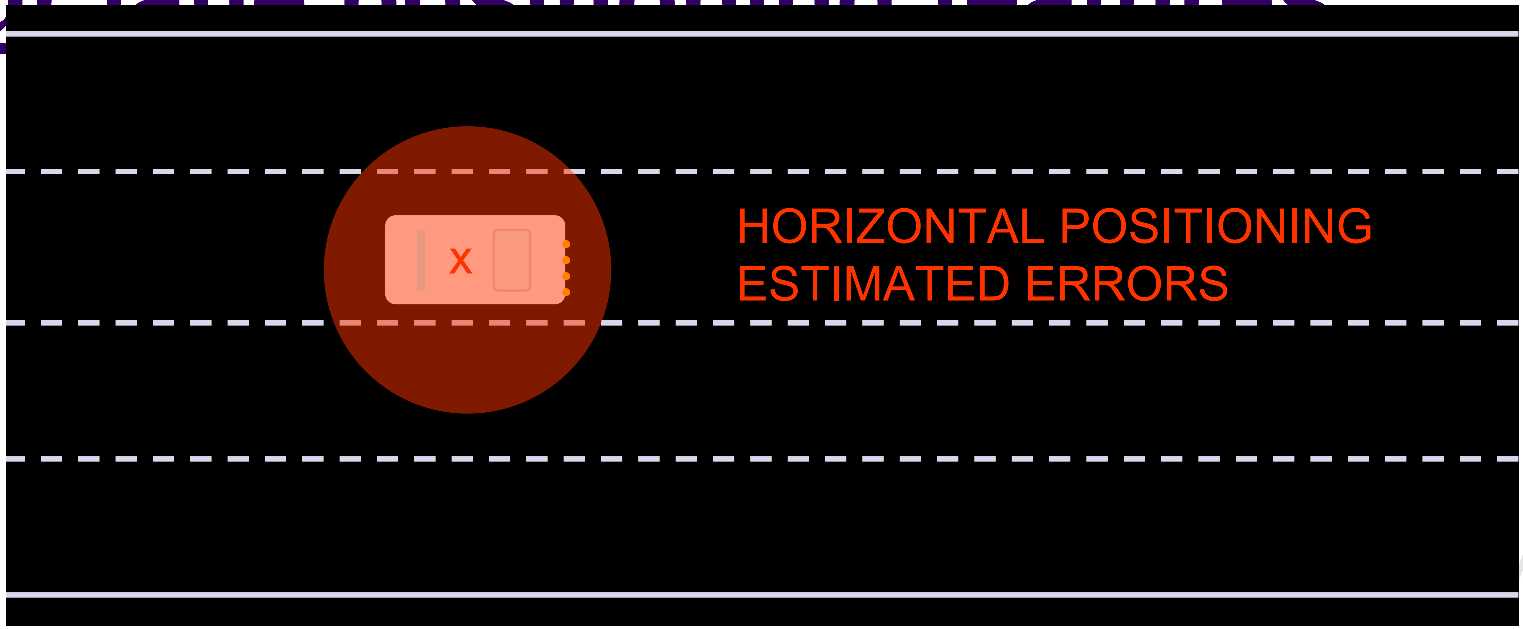
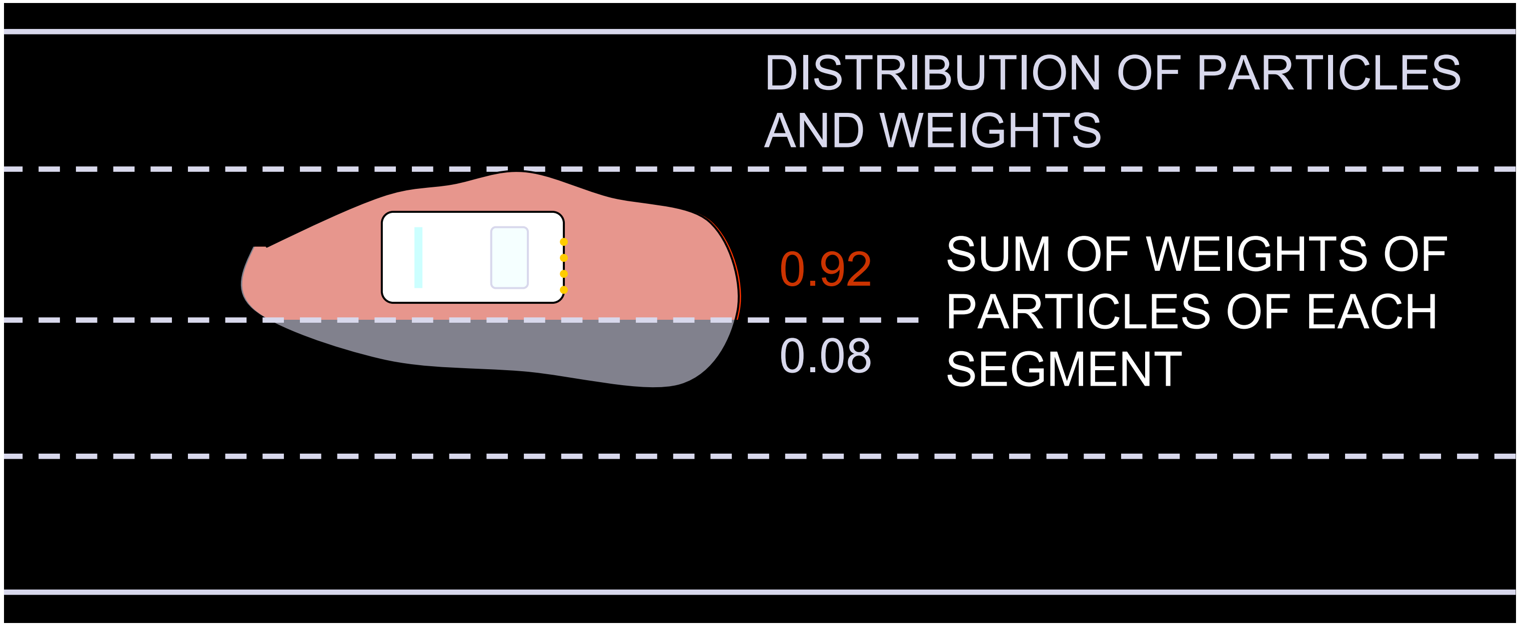


our lane positioning features



- Level of confidence on the position
- Level of confidence on the segment assignment

our lane positioning features



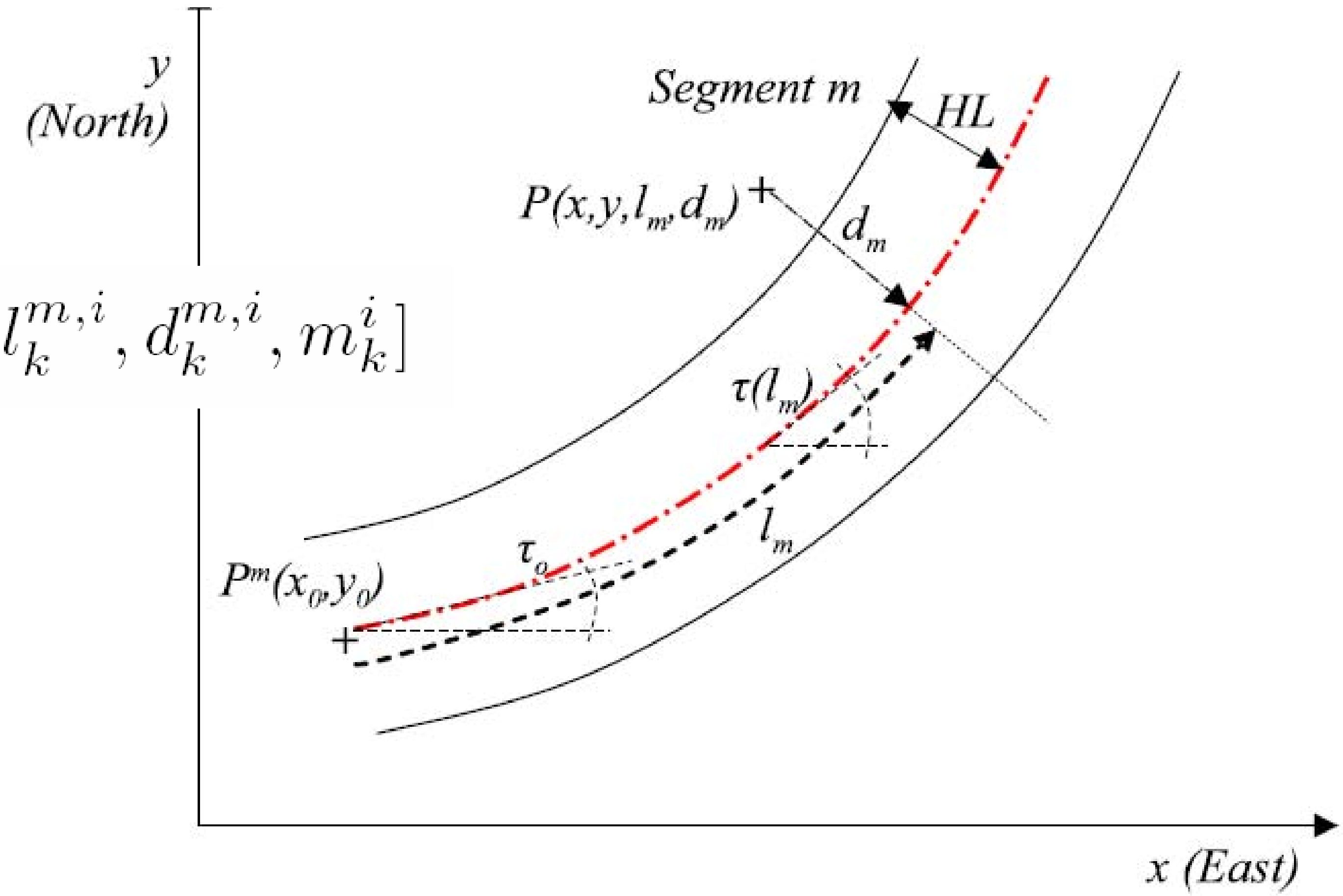
- Level of confidence on the segment assignment

dual representation

$$x = x_0^m + \int_0^{l^m} cos(\tau^m(l^m))dl \quad - d^m sin(\tau^m(l^m))$$

$$y = y_0^m + \int_0^{l^m} sin(\tau^m(l^m))dl \quad + d^m cos(\tau^m(l^m))$$

$$X_k^i = [x_k^i, y_k^i, \psi_k^i, l_k^{m,i}, d_k^{m,i}, m_k^i]$$



dual representation

Why the Frenet reference (to the road segment)?

- Much more convenient for using the Emap
- Much faster computations in transitions between segments

L>Lmax ?

|D|>Half Lane ?

- Relative position of the vehicle with its environment: useful for a number of ADAS applications based on lane

dual representation

Why the Cartesian reference then?

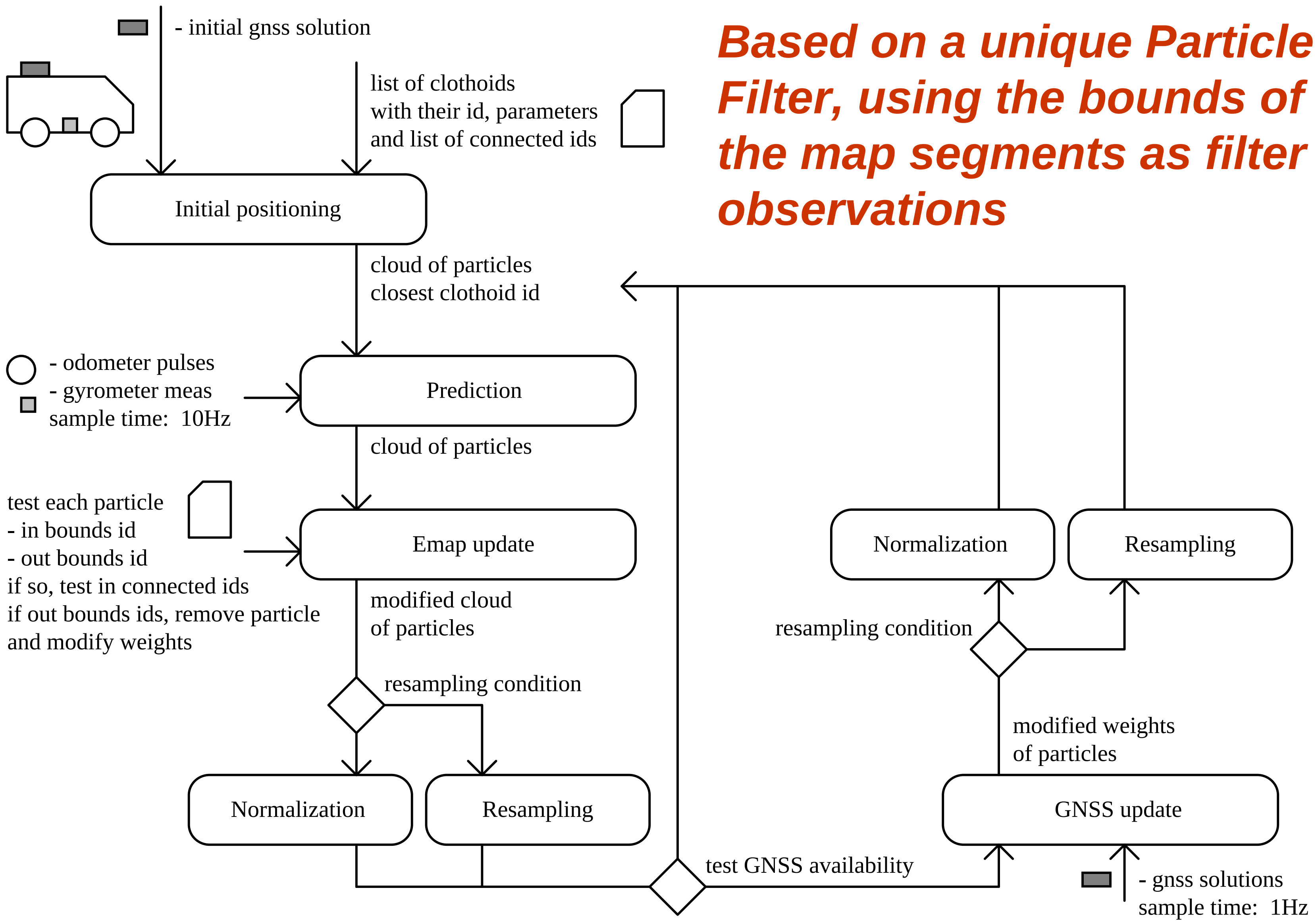
- Could we navigate only with a L,D reference?

  Yes, but only within the limits of our Emap

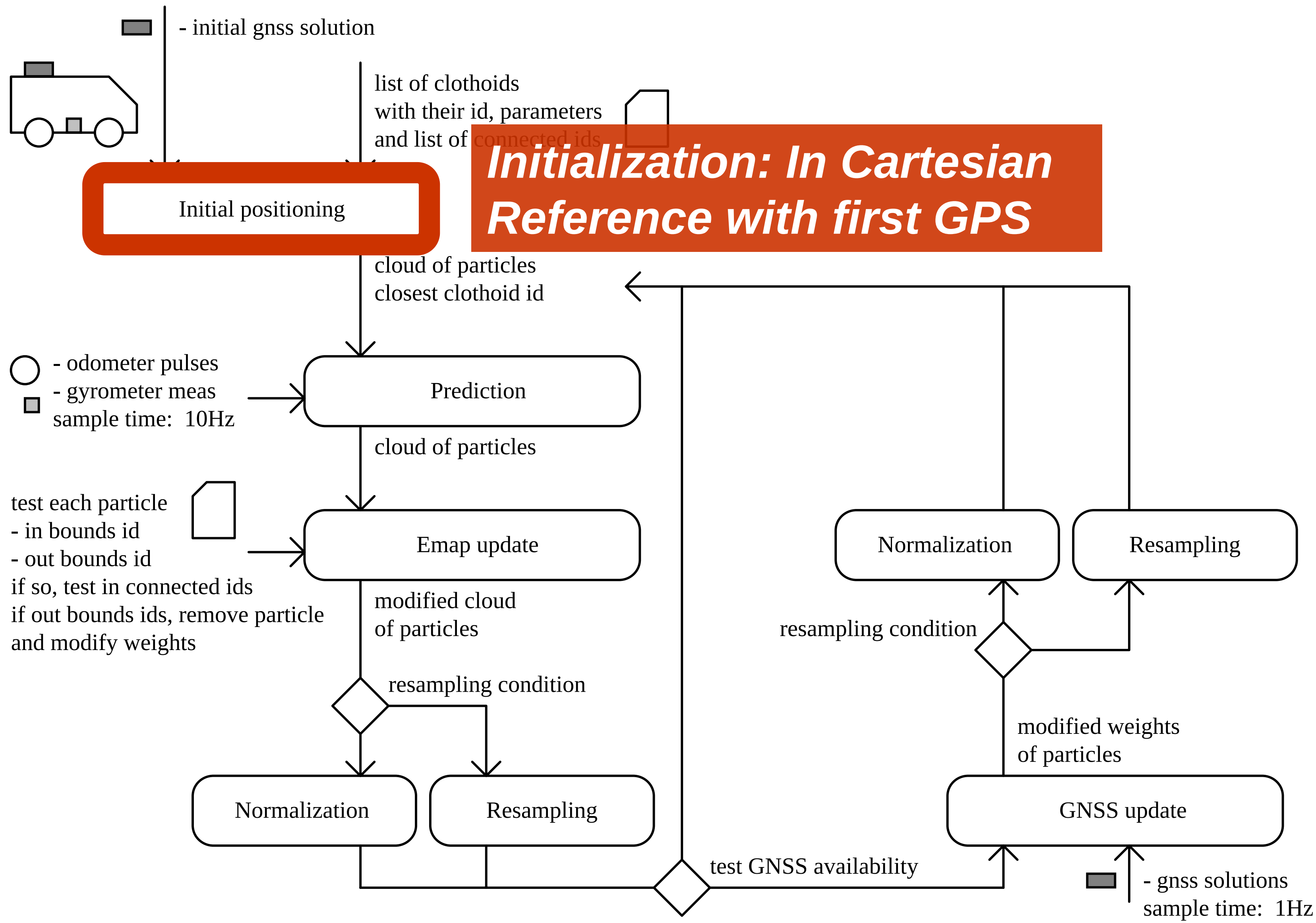
- Crucial for areas out of the Emap limits (such as complex crossroads)
- East and North coordinates are still demanded by many Location Based Services
- Interaction with standard maps

positioning and mm in one cycle!

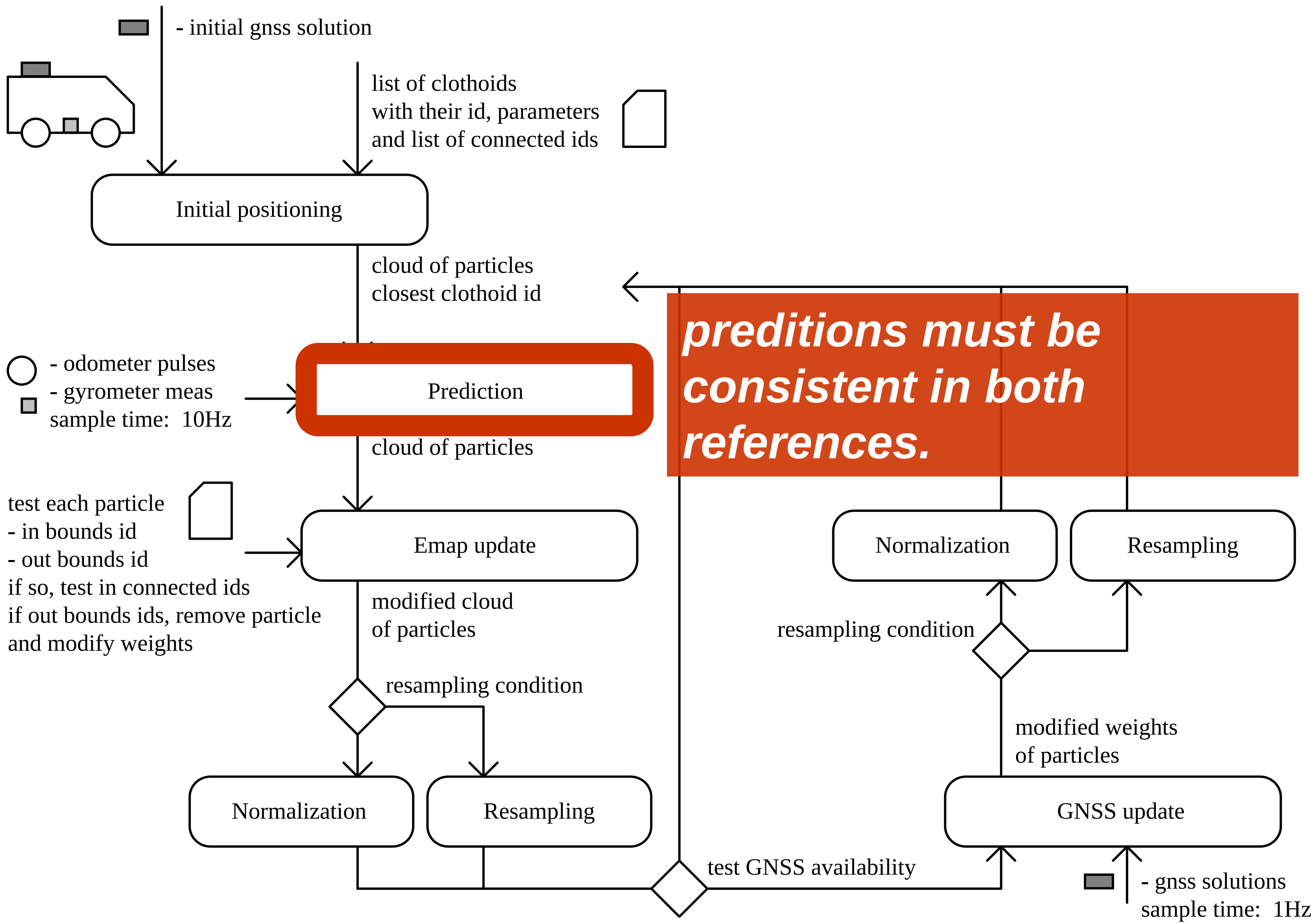
Based on a unique Particle Filter, using the bounds of the map segments as filter observations



positioning and mm in one cycle!

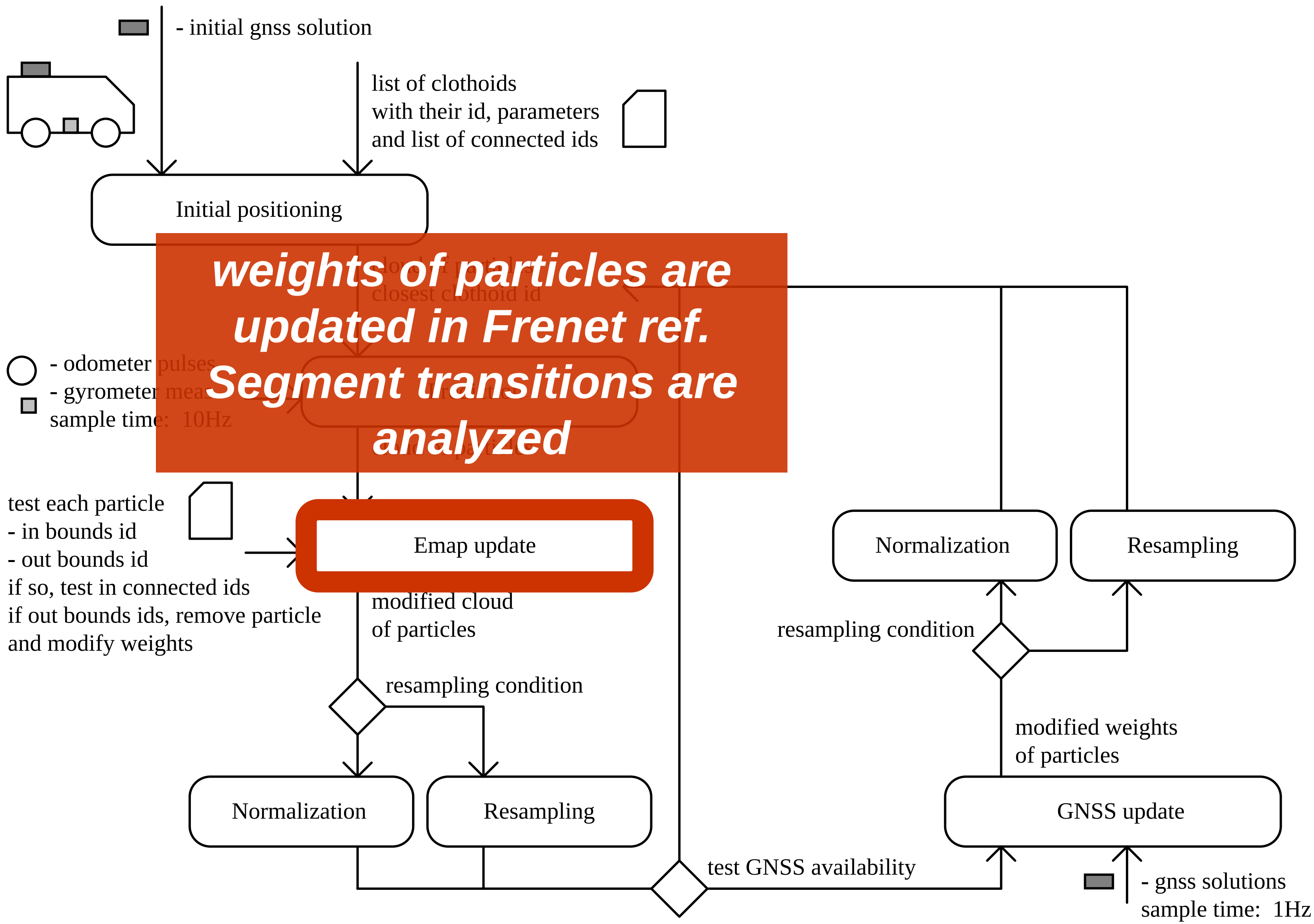


positioning and mm in one cycle!



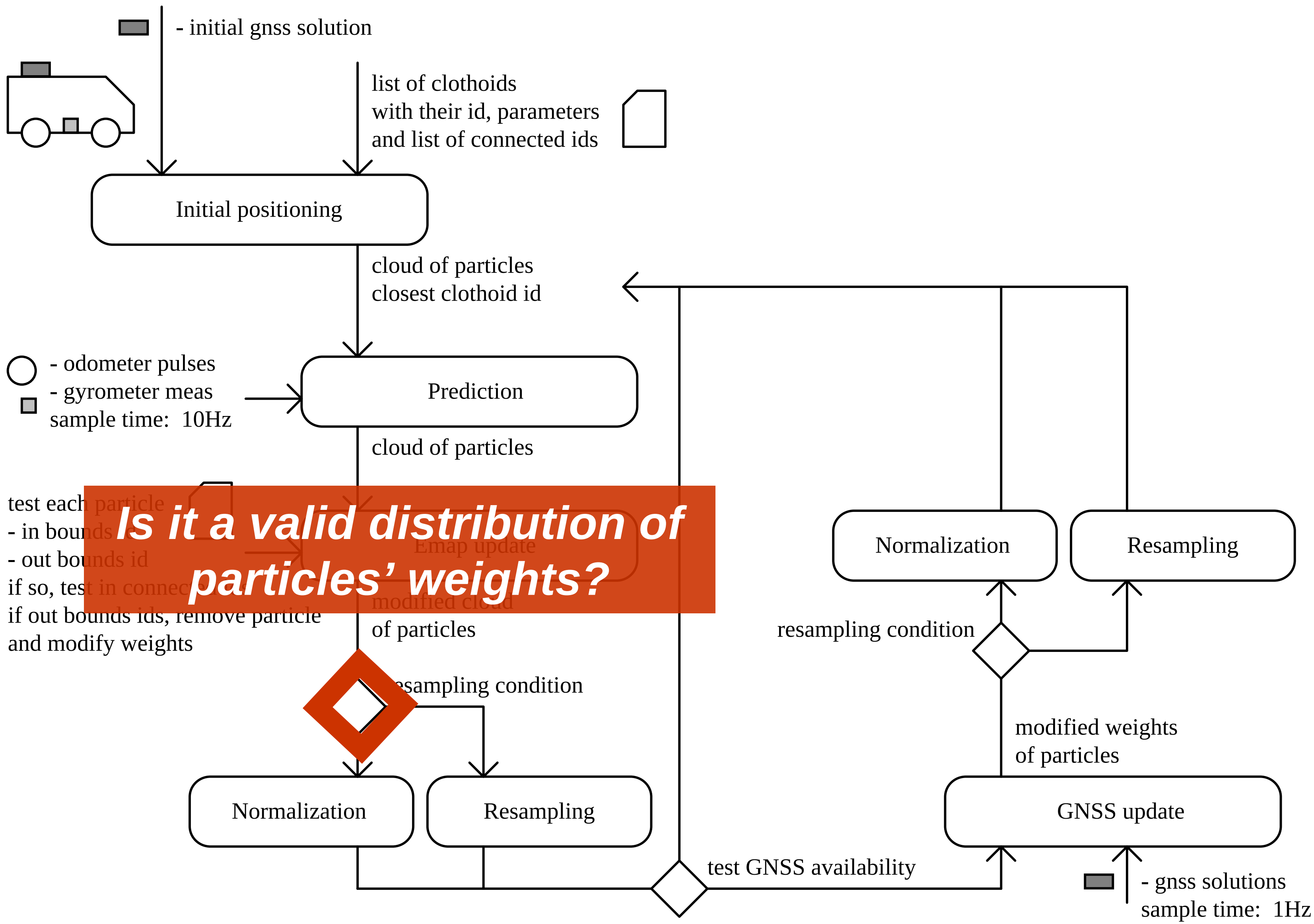
preditions must be consistent in both references.

positioning and mm in one cycle!



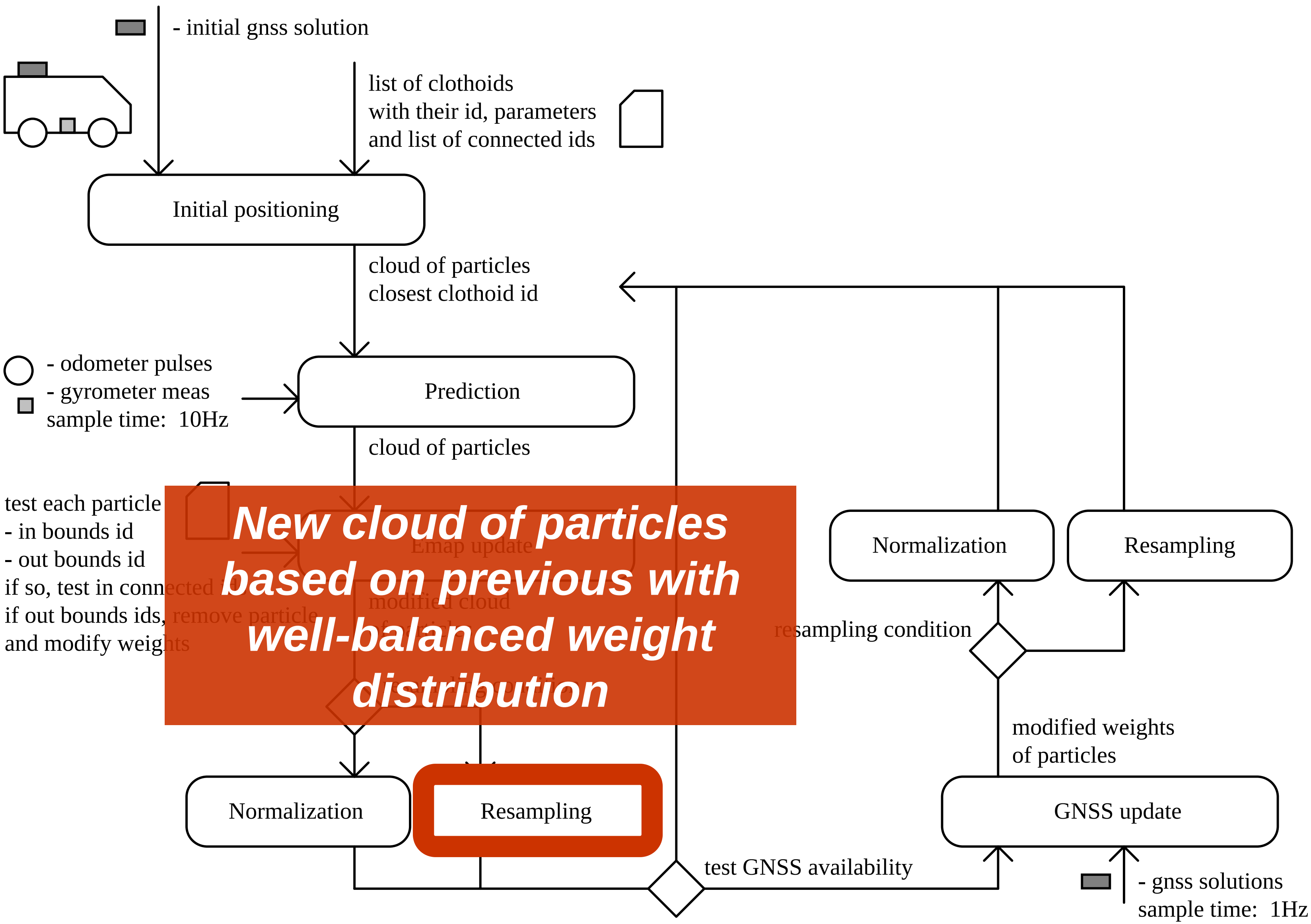
weights of particles are updated in Frenet ref. Segment transitions are analyzed

positioning and mm in one cycle!

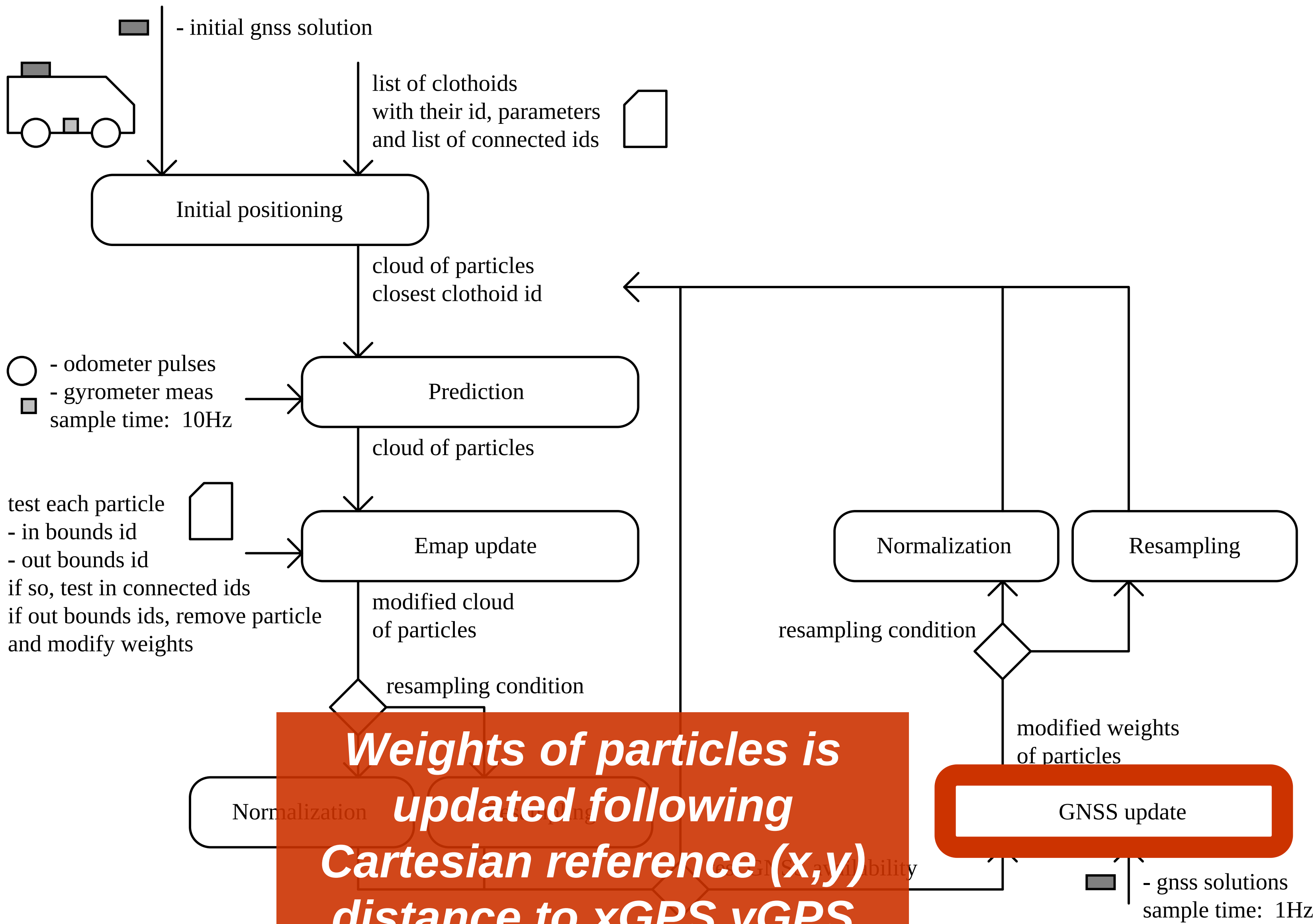


Is it a valid distribution of particles' weights?

positioning and mm in one cycle!

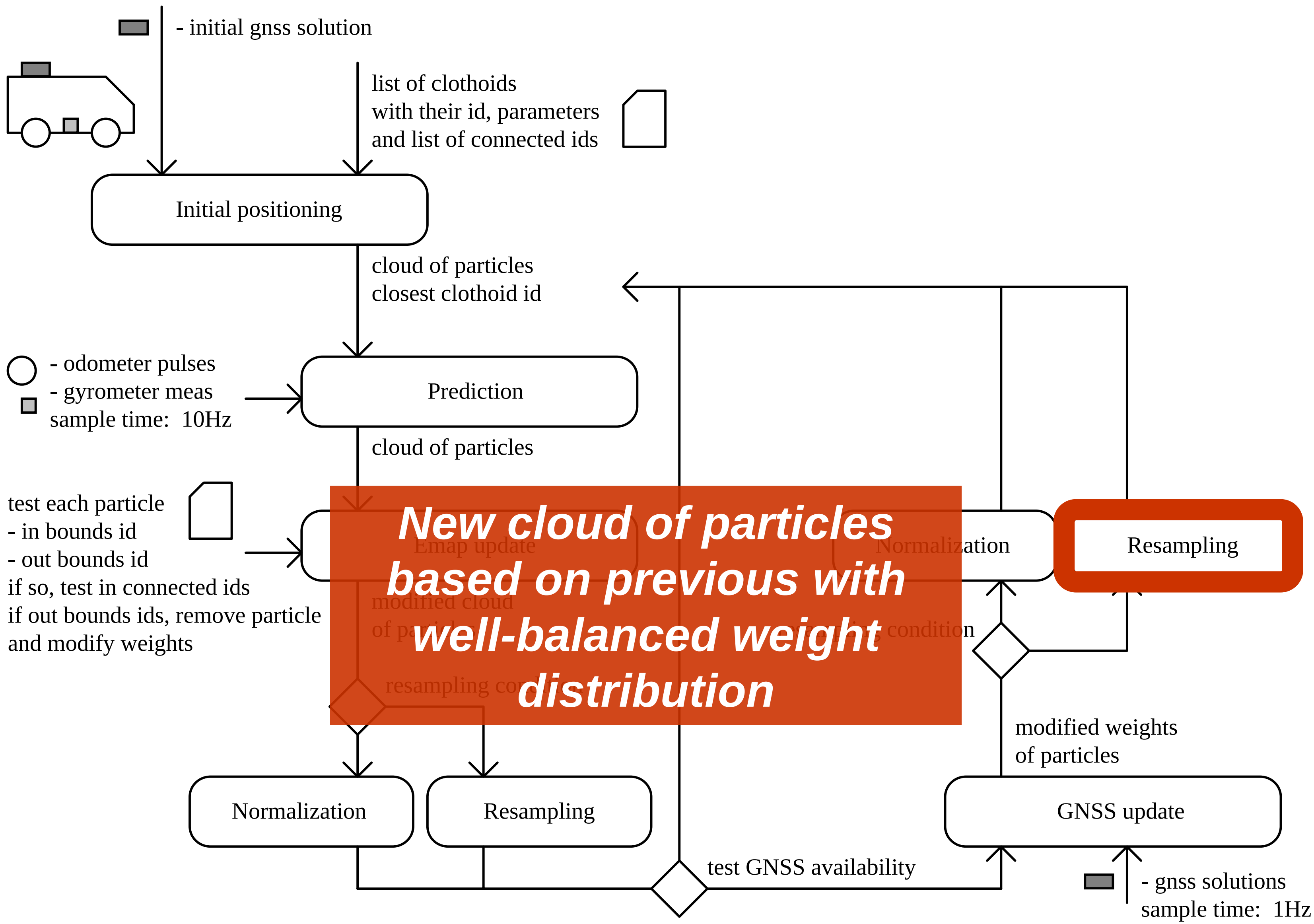


positioning and mm in one cycle!

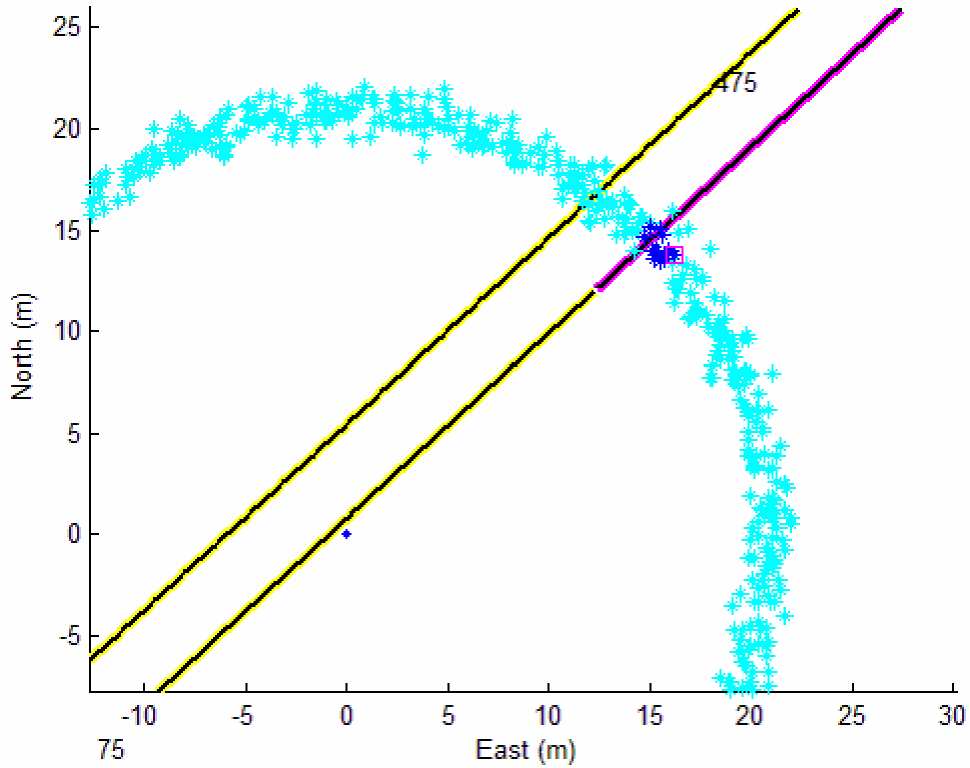


Weights of particles is updated following Cartesian reference (x,y) distance to xGPS,yGPS

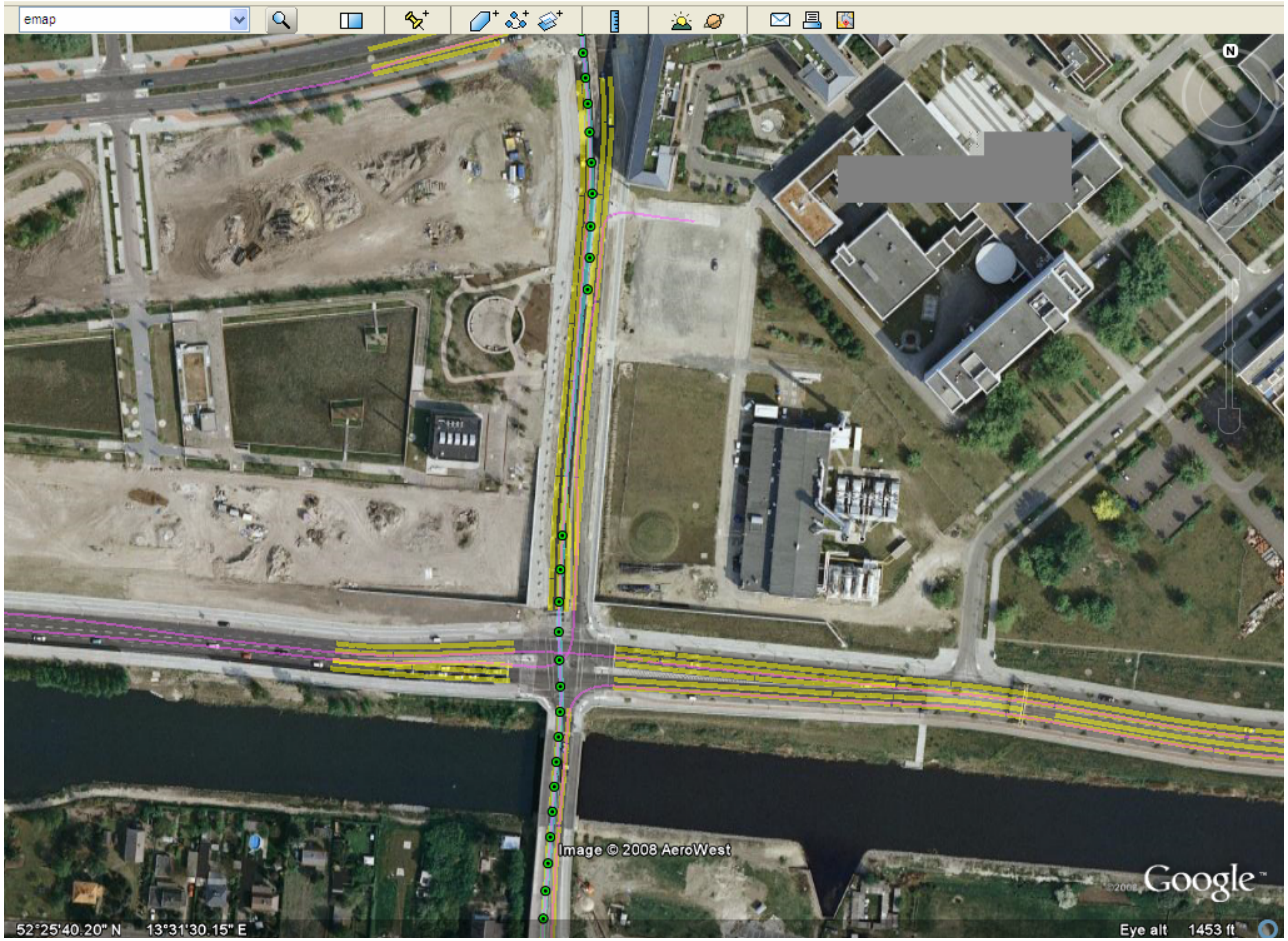
positioning and mm in one cycle!



examples (initialization)

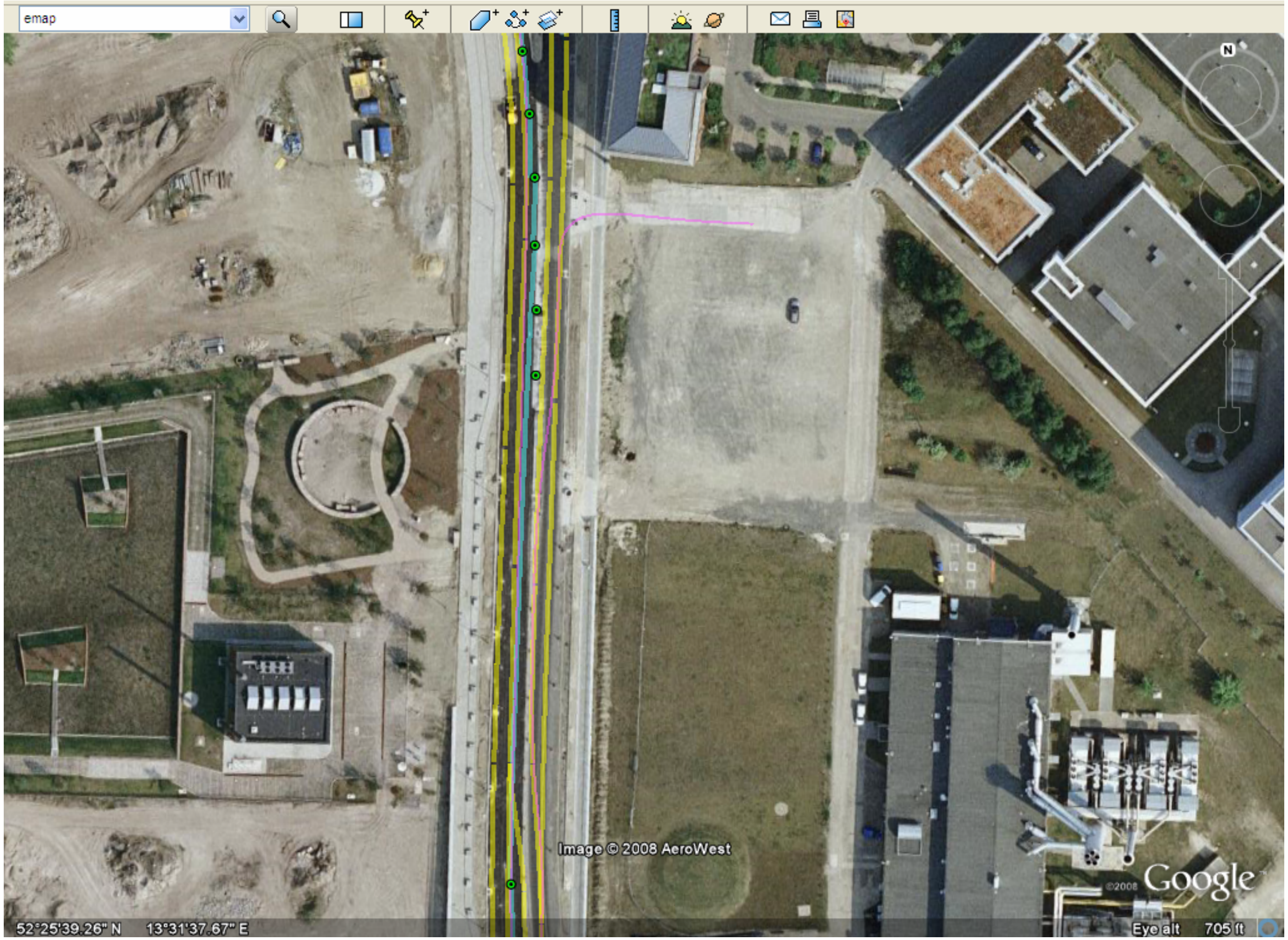


example of multipath removal



example of multipath removal

Zoom : some GPS outliers difficult to detect appear just before one gap



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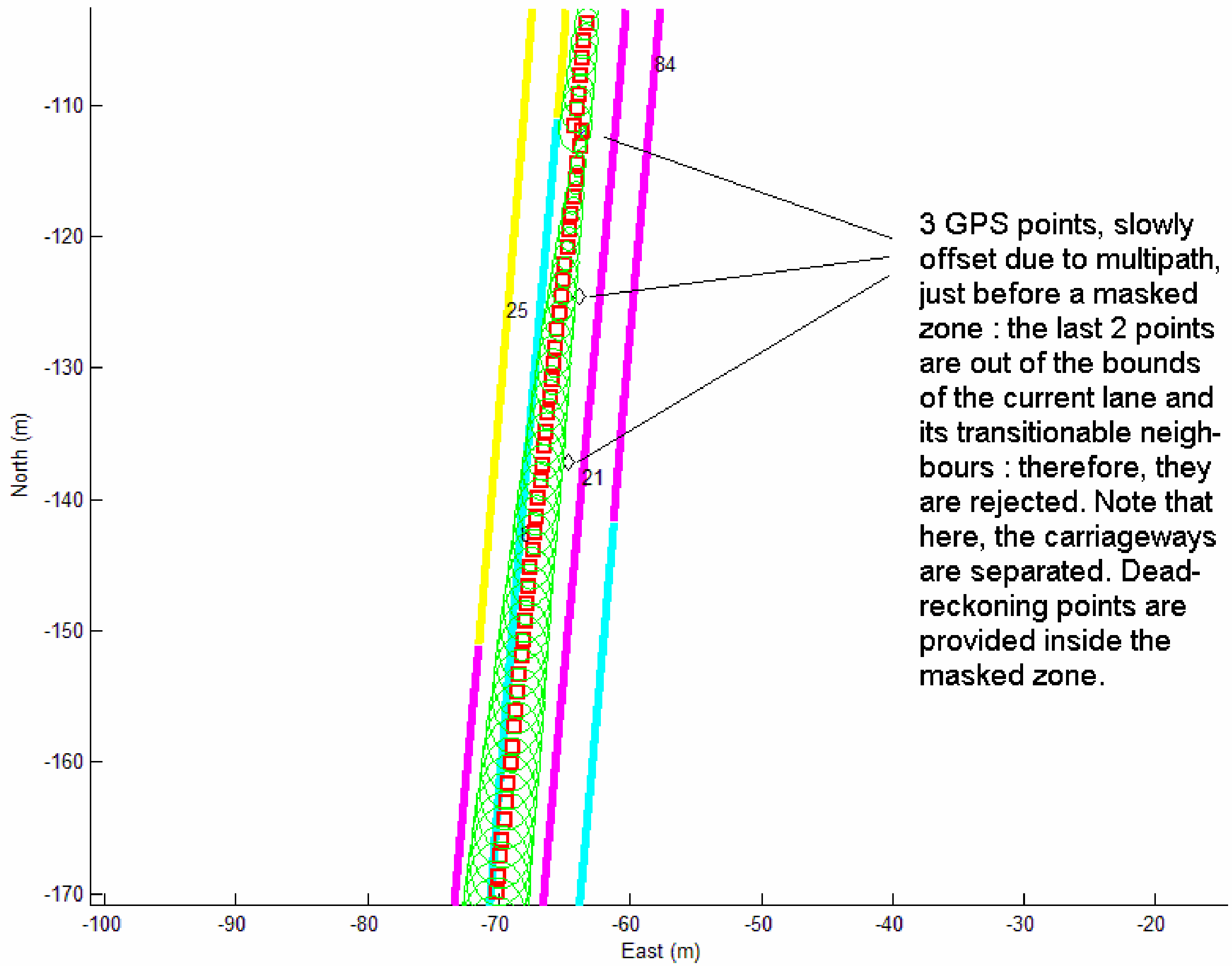

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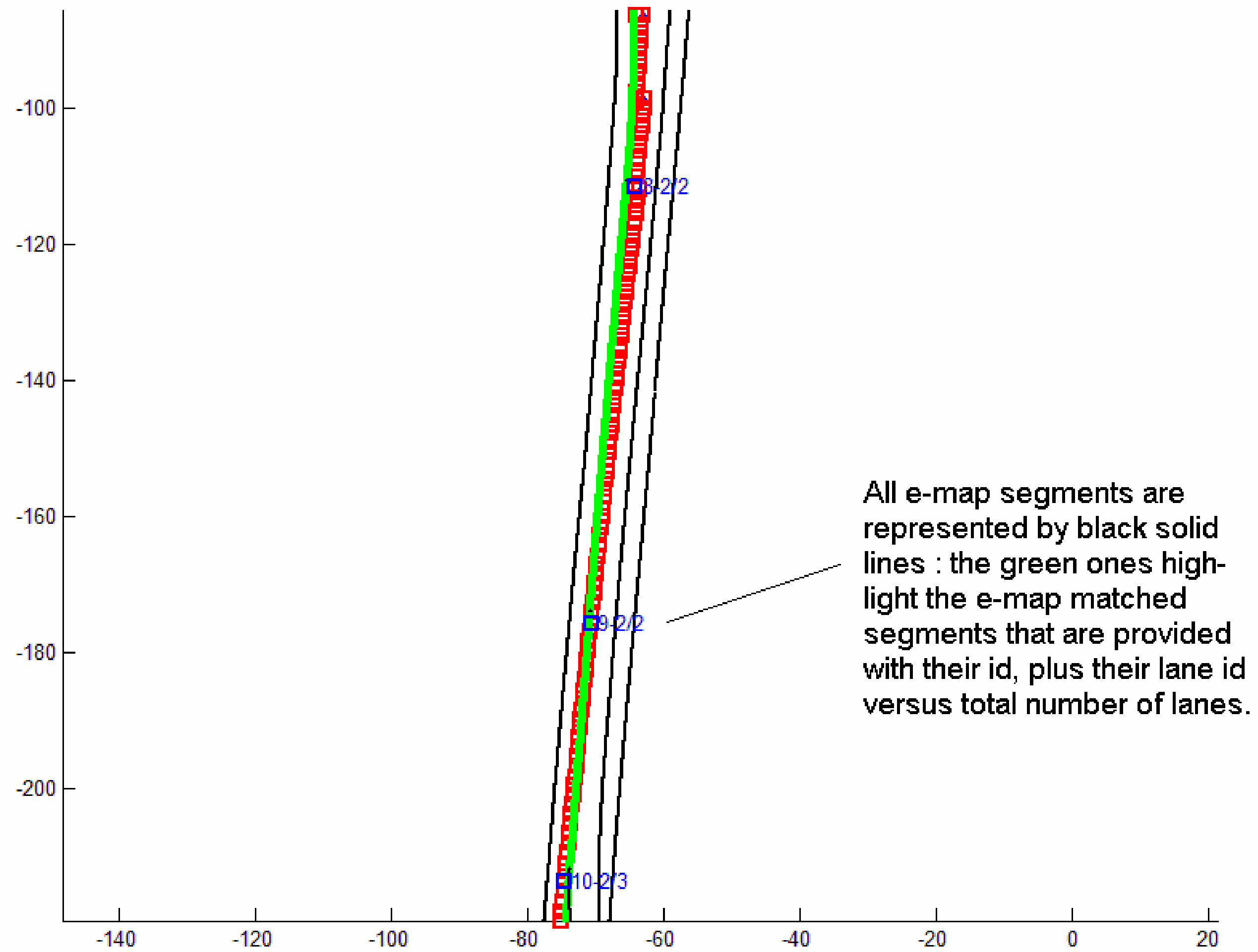
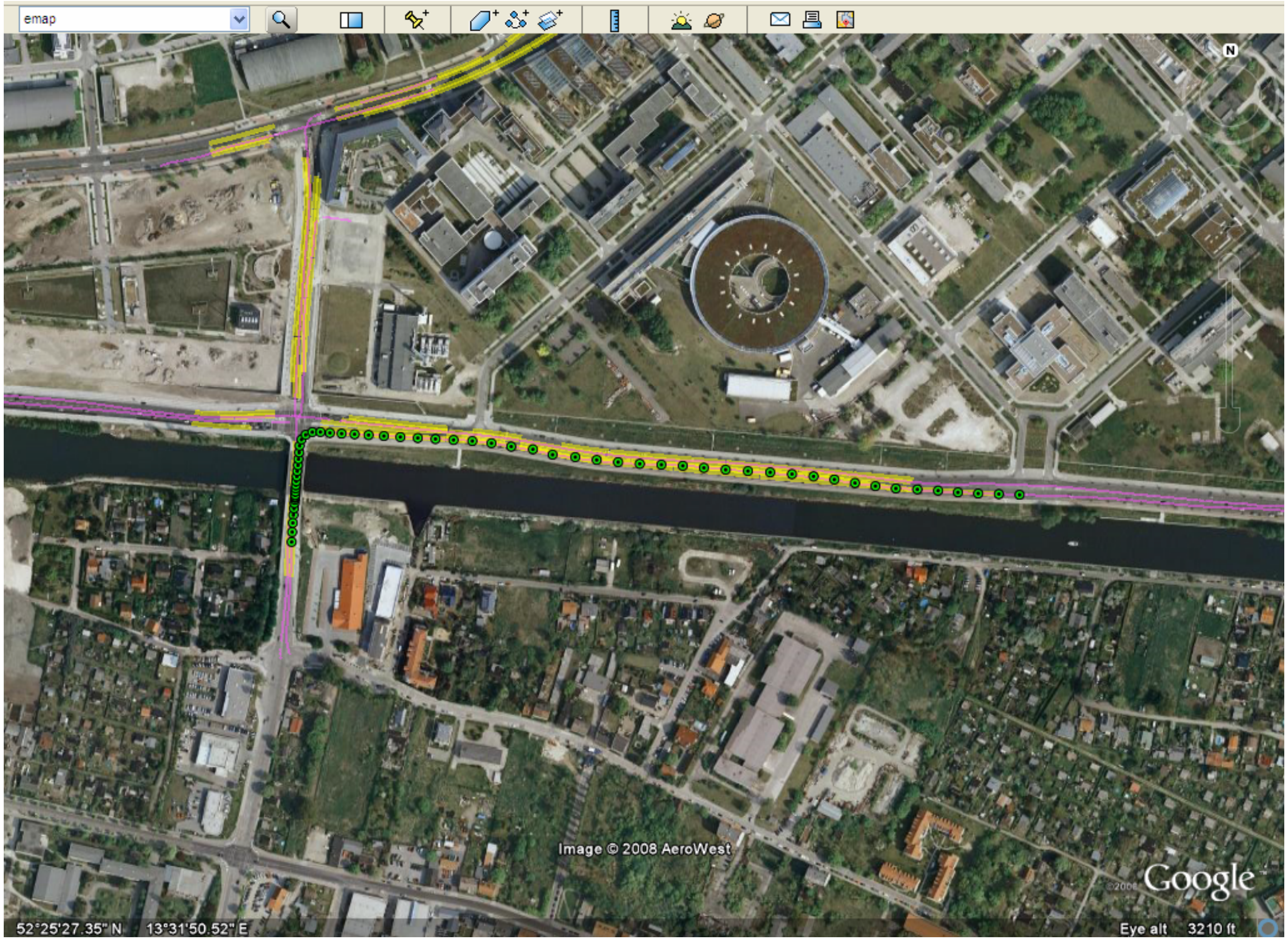
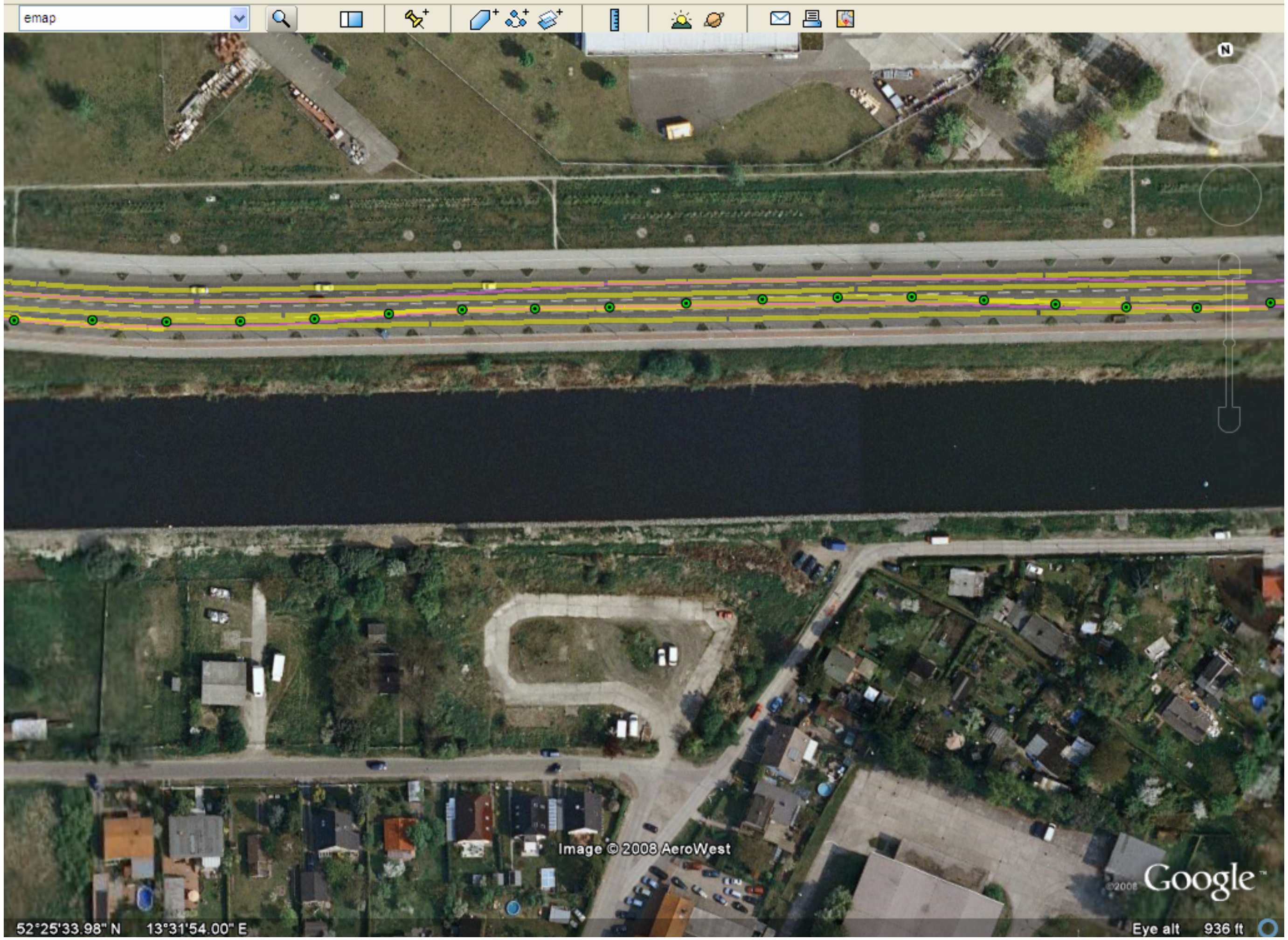


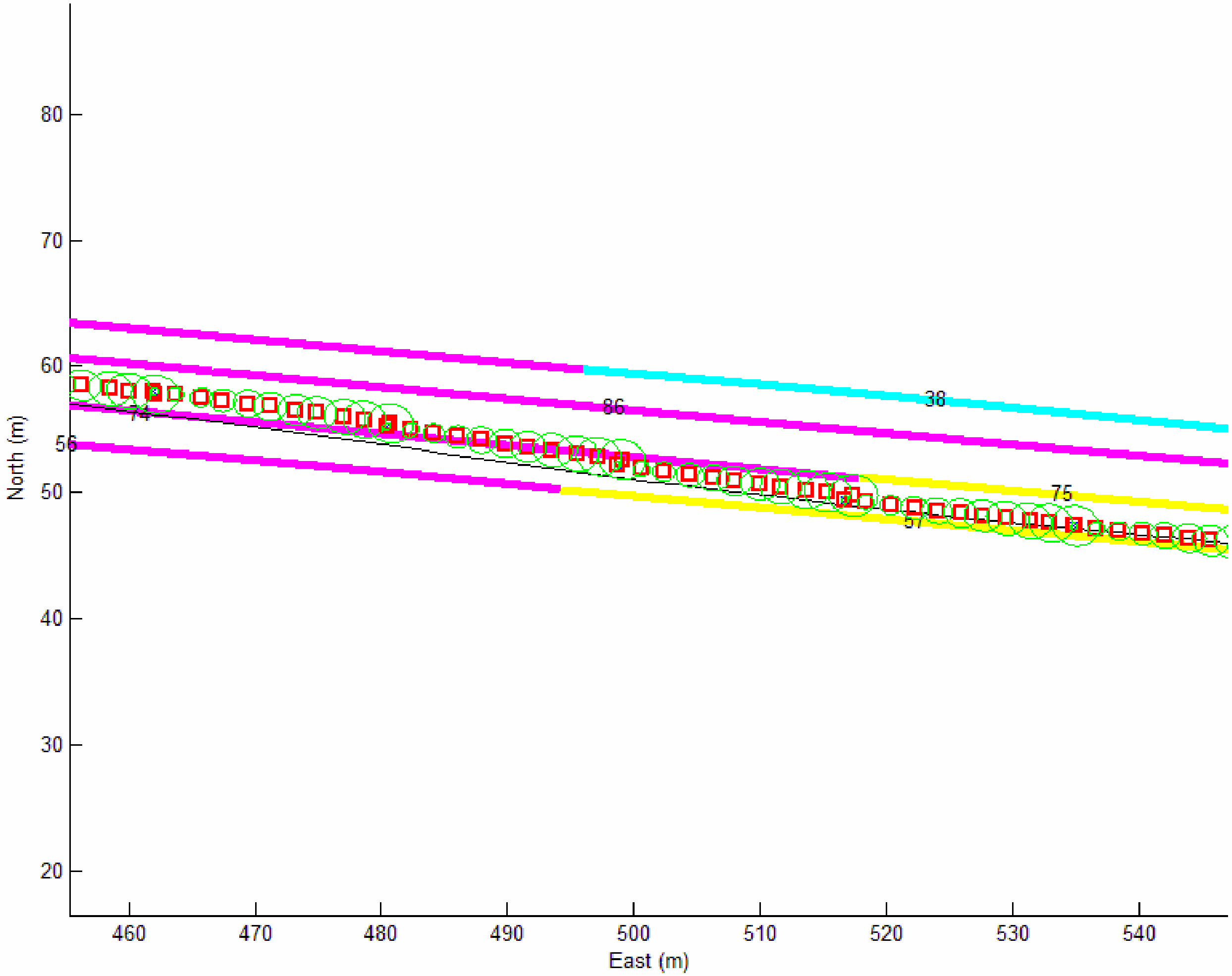
example of lane change



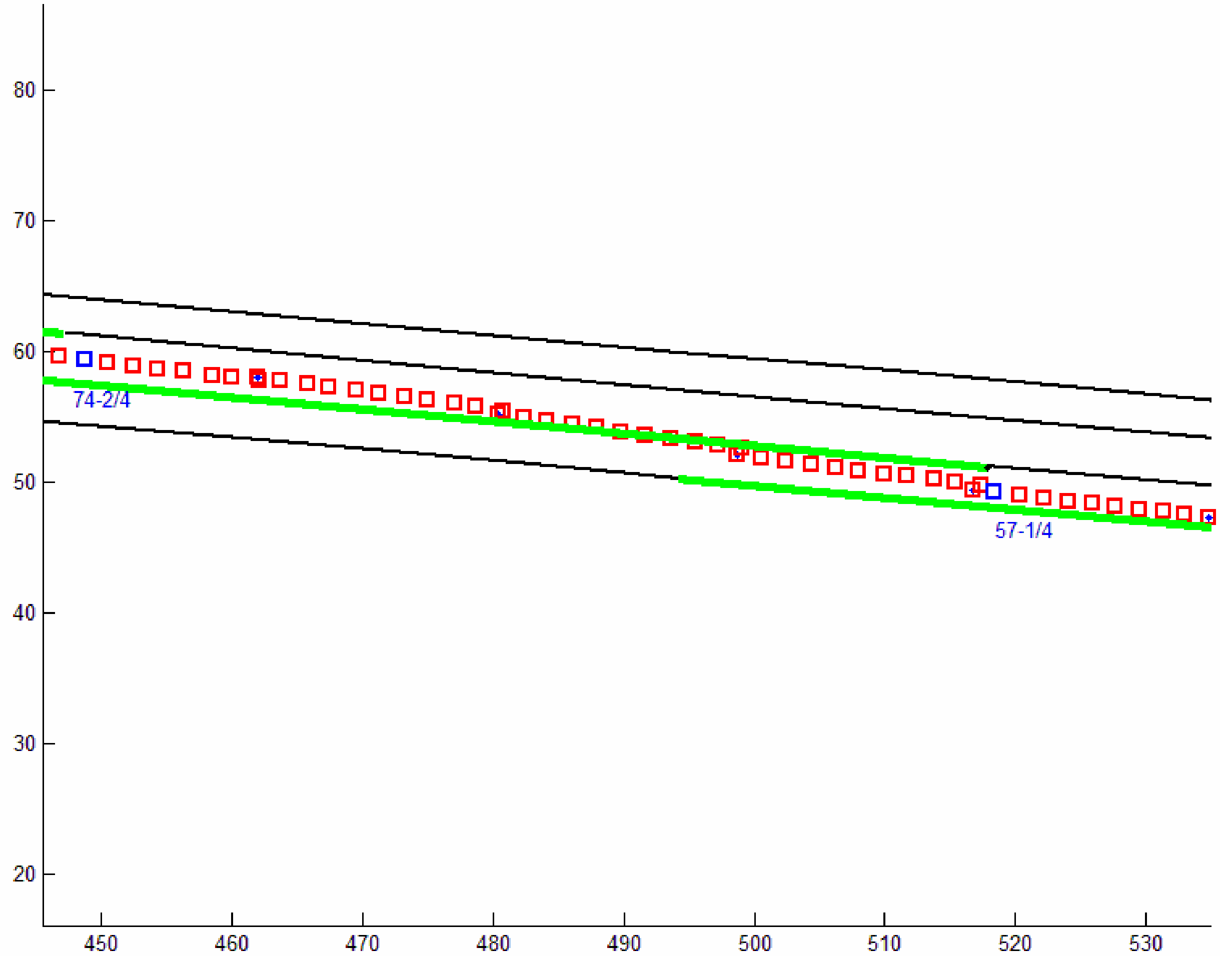
example of lane change



example of lane change



example of lane change



contact

MANY THANKS!!

QUESTIONS?

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