Localization confidence domains via set-inversion on short-term trajectory

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Positioning confidence information is required, to decide if position information can be used for a given task.

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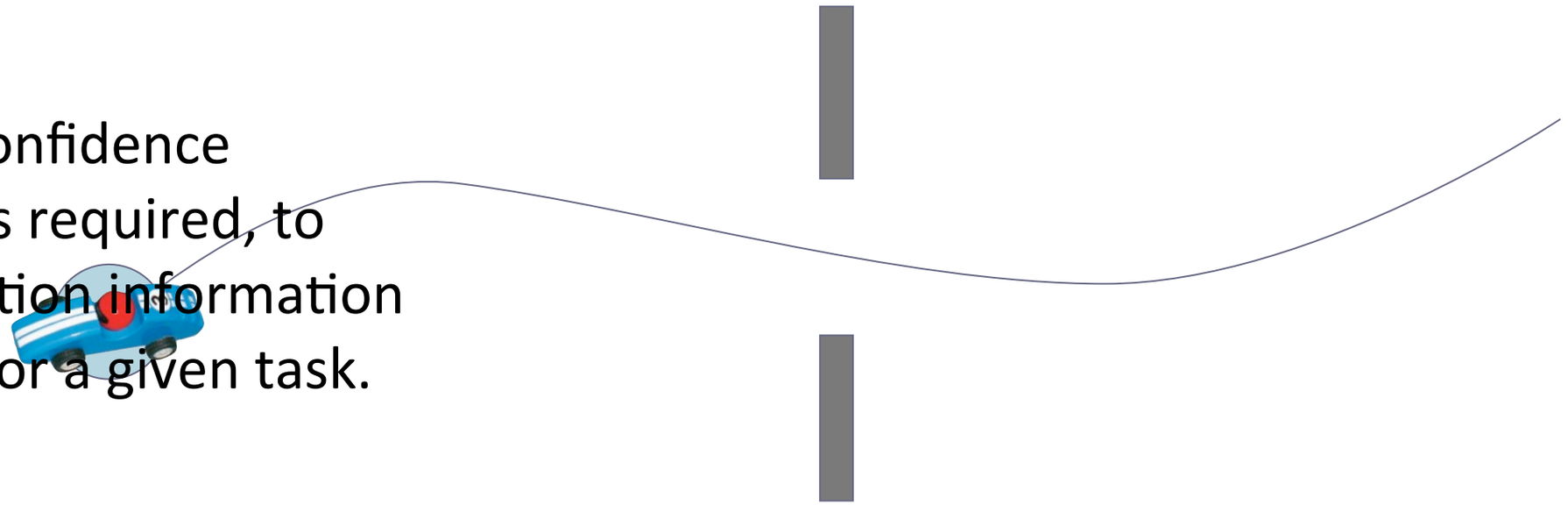

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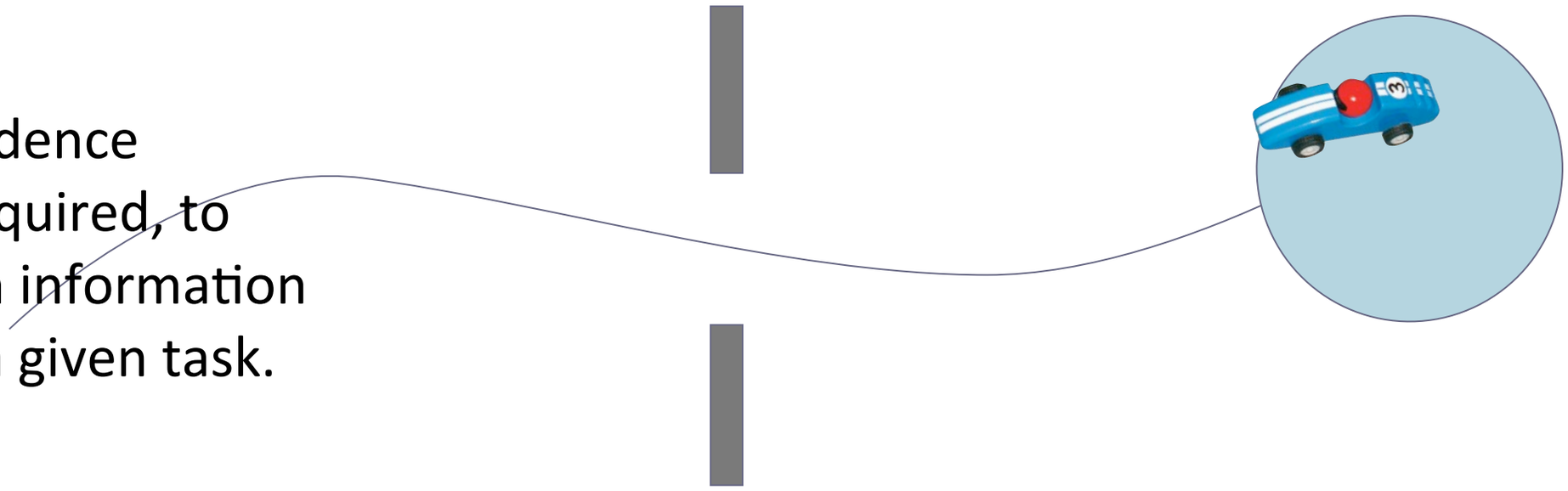

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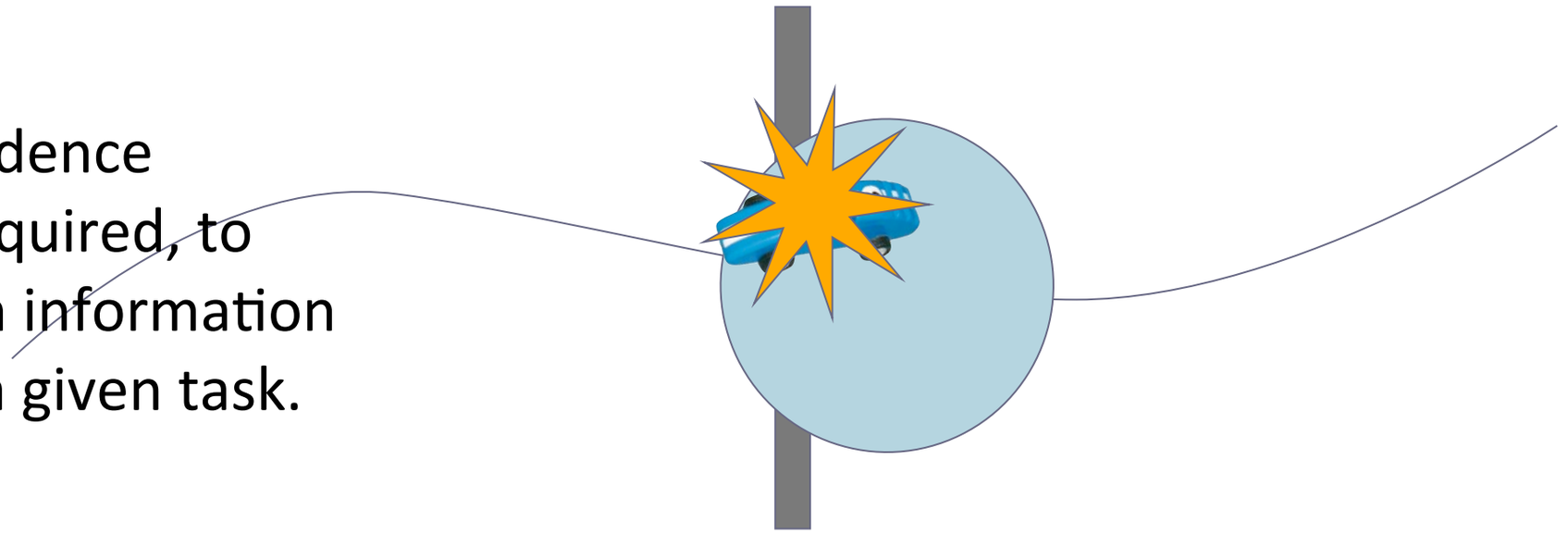

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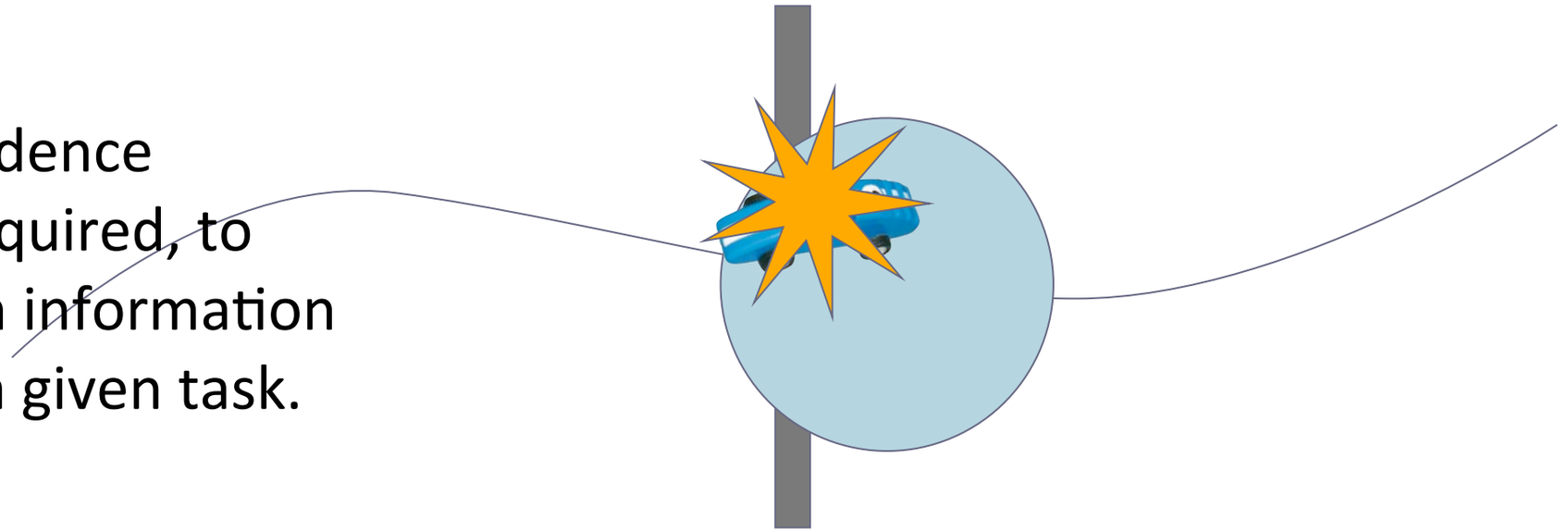
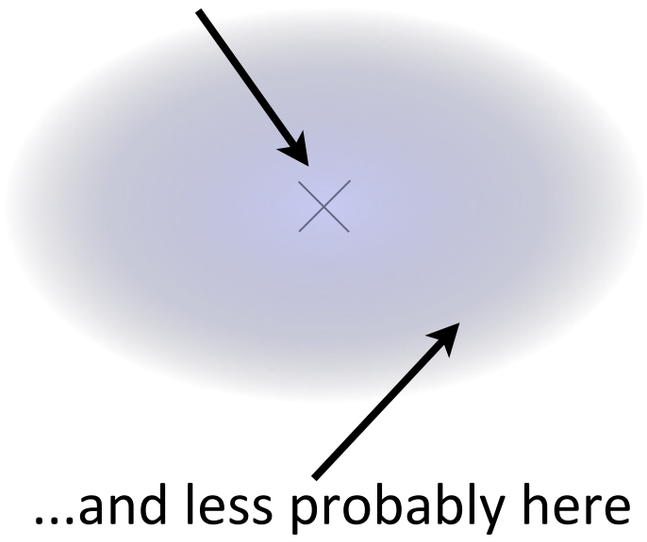


Second order moments

You are probably here...



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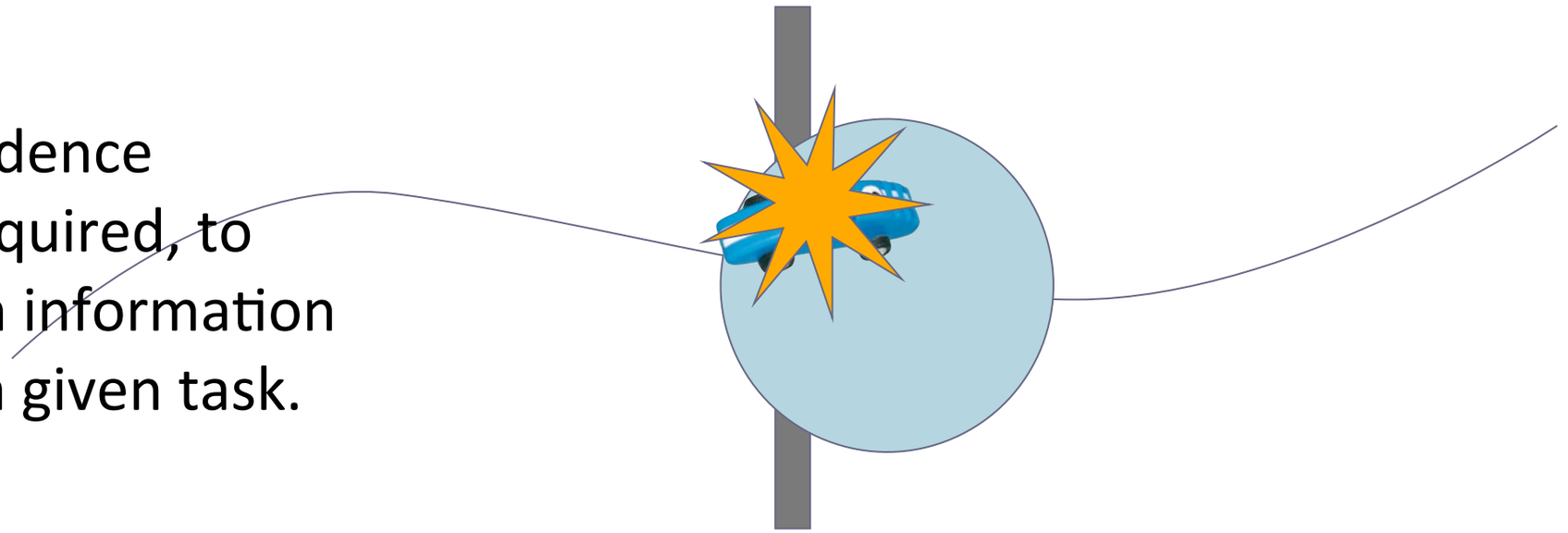

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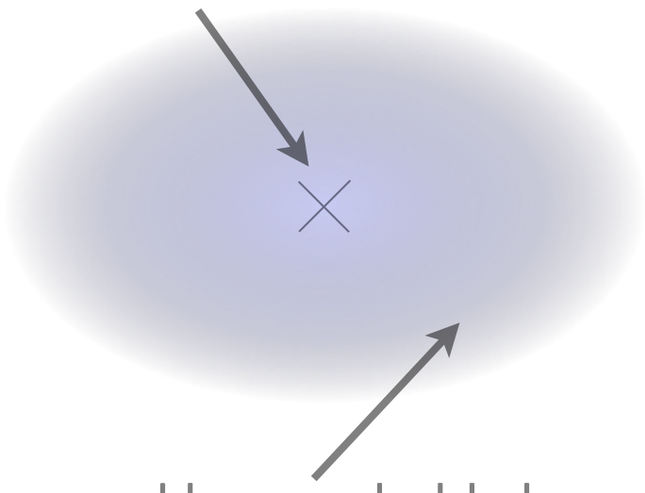
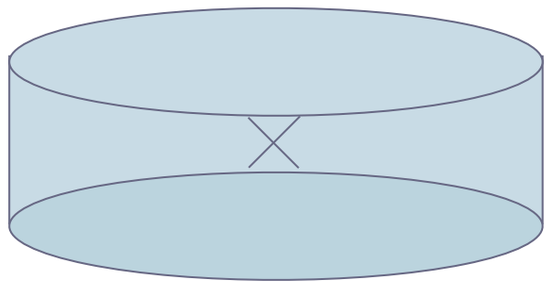


...and less probably here

Protection levels

You are inside this box



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Set-membership approach for localization

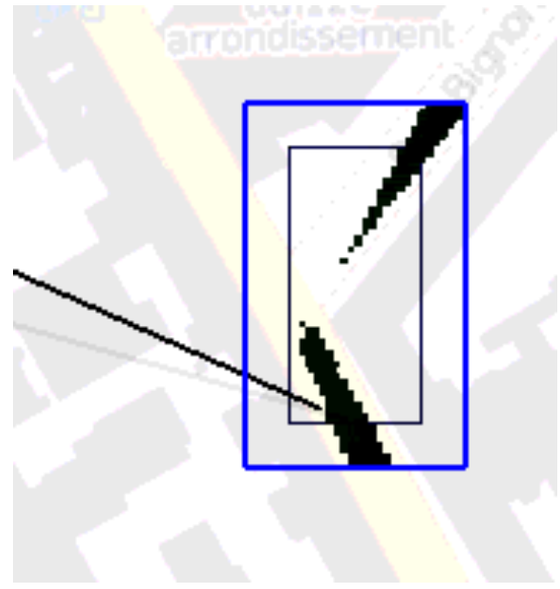
Compute a positioning confidence domain

Set of possible vehicle positions (or poses), associated to the risk that this set does not contain the true position.

Interval analysis, in a bounded-errors context

Arbitrary shaped solution set (subpaving)

Robustness to erroneous data (q-intersection, GOMNE)



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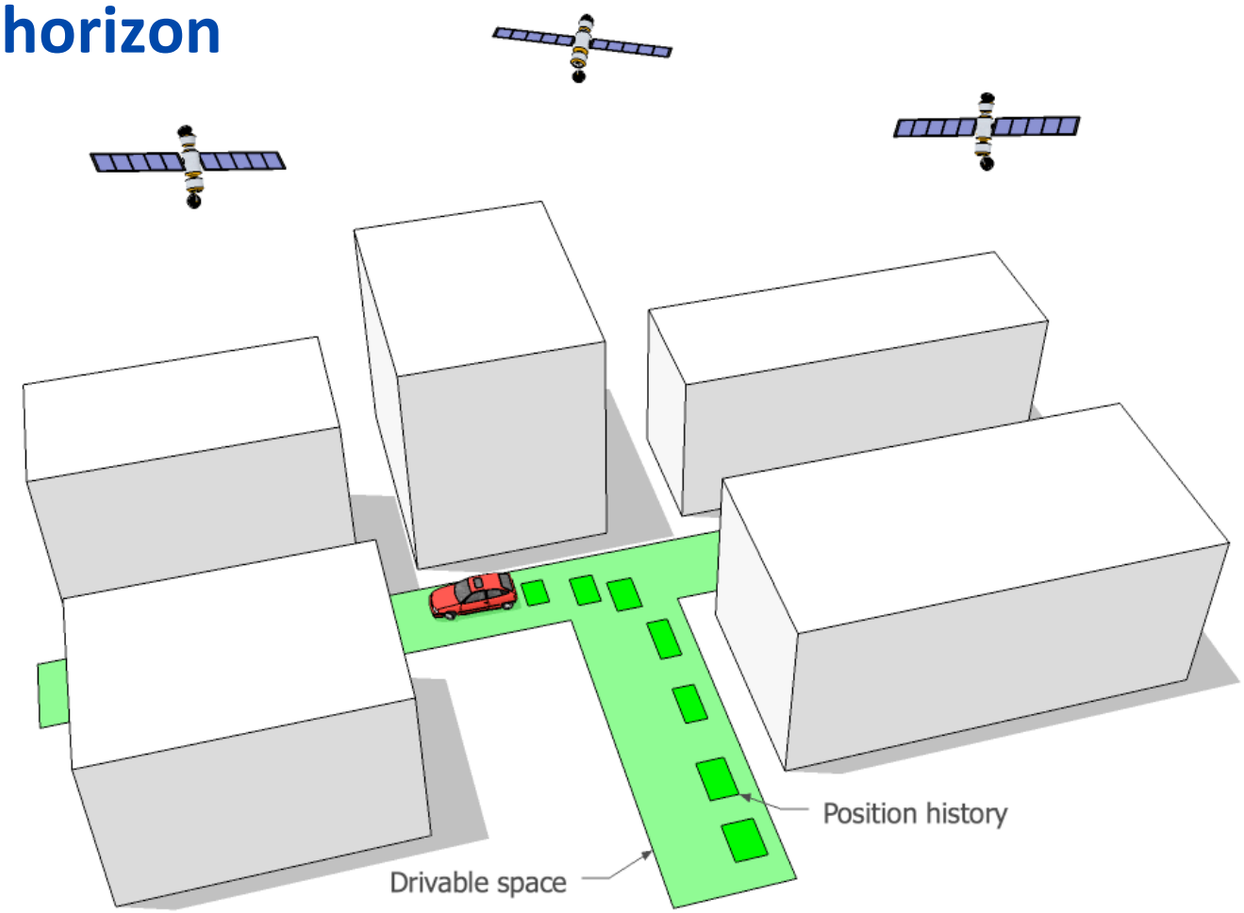
Outline

1. Overview of the positioning system

2. Tightly-coupled GPS and map positioning

3. Robust pose estimation with data horizon



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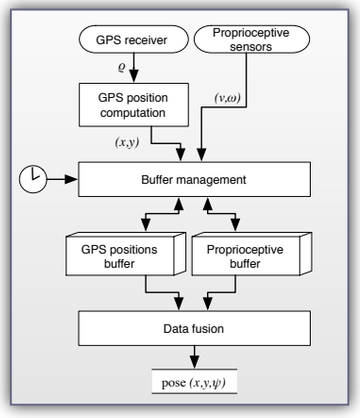
Overview of the positioning system



Information fusion for vehicle localisation in urban areas

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In urban areas:

- GPS measurements *(masking, tunnels)*
- \+ Errors *(multipath, NLoS)*

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Maps (2D, 3D)

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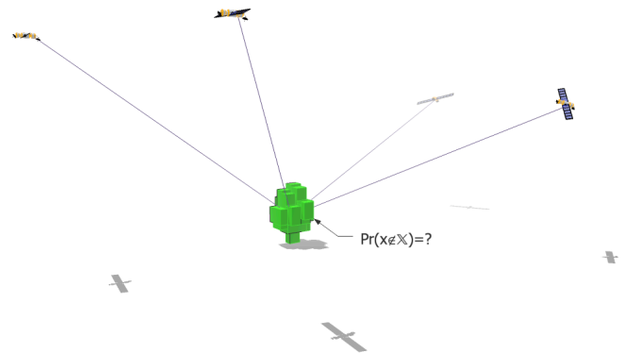
Pose estimation with GPS and proprioceptive measurements

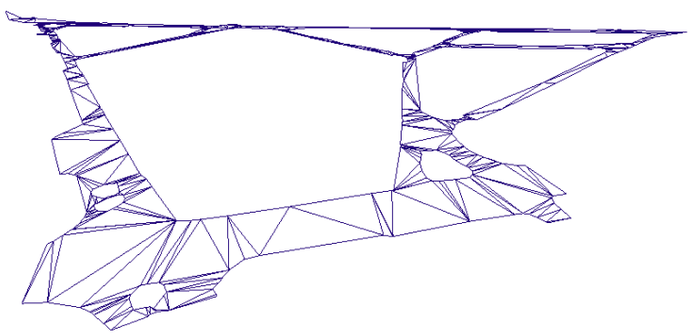
GPS

Absolute position
Unreliable
Masking



3D Map (surface)

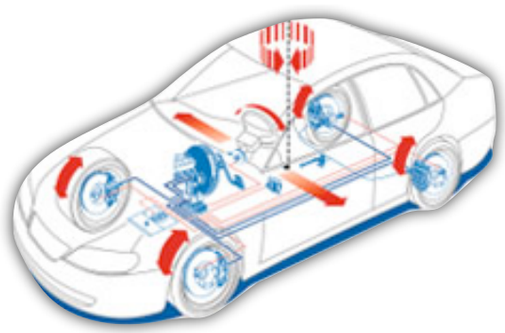
Contrains position on the drivable space



Fusion

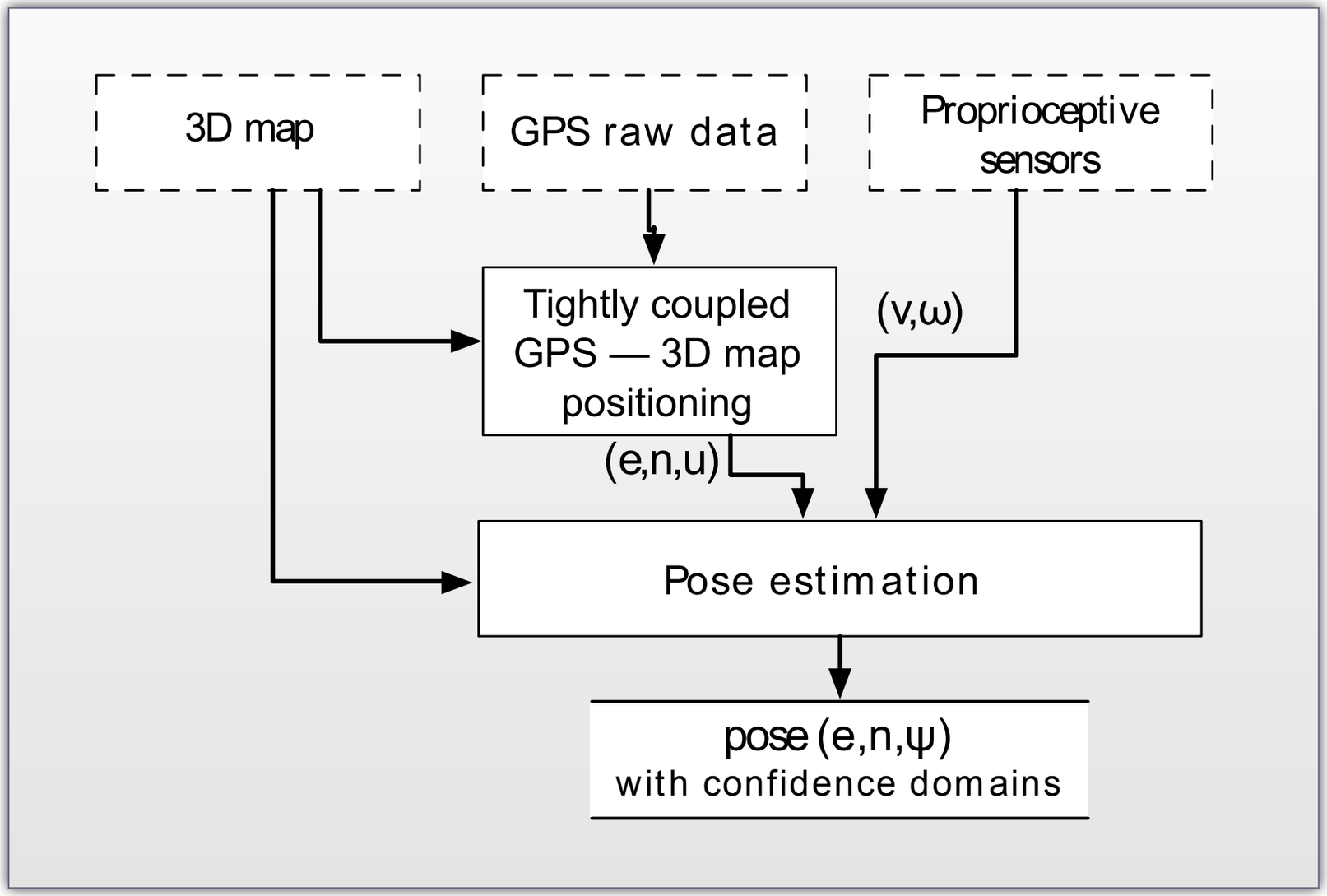
Proprioceptive

Relative motion
High update rate
Drift



Absolute pose at any time

Positioning system overview

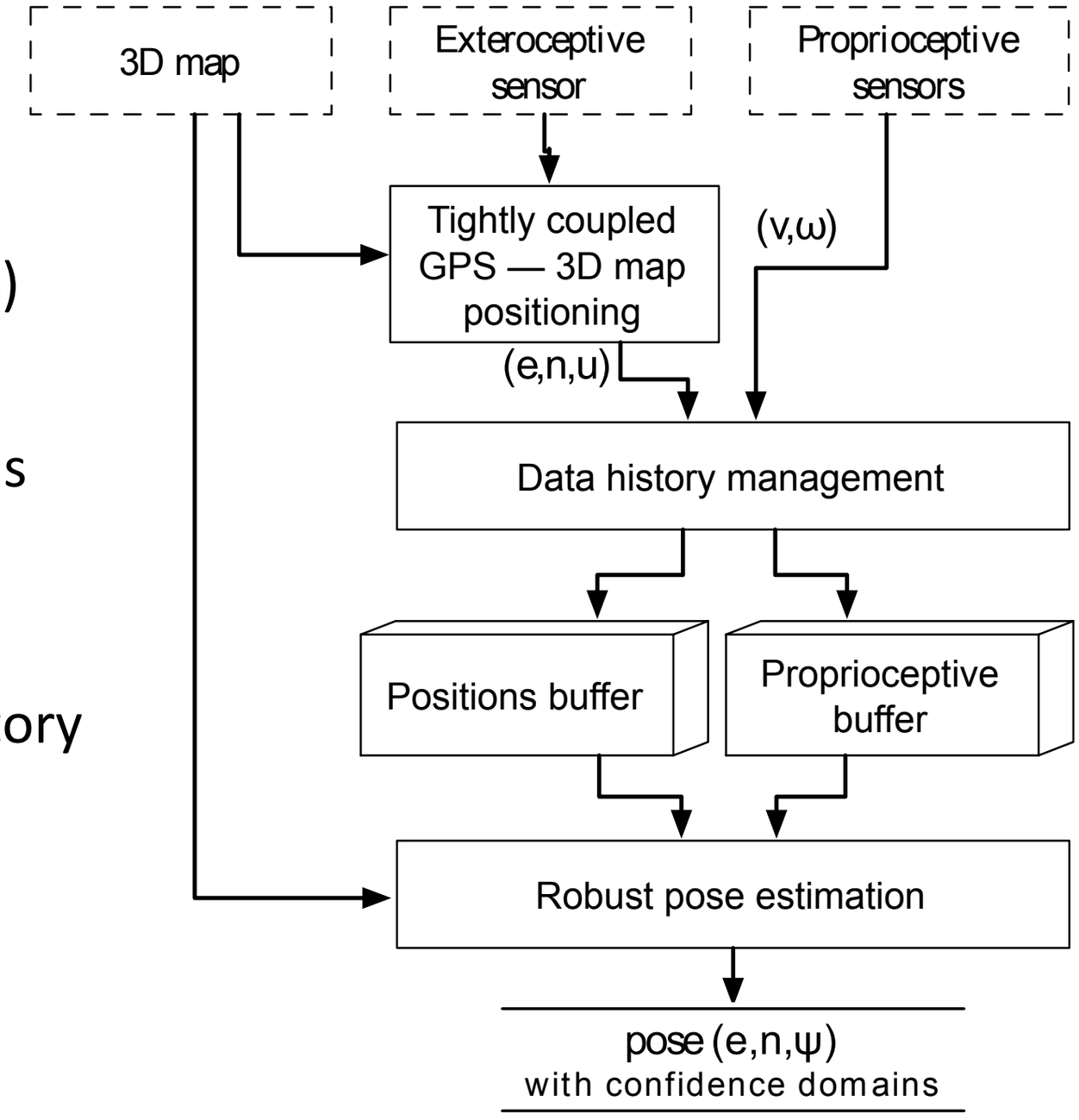


Positioning system overview

Compute GPS positions
(or use receiver computed positions)

Keep a short history of past positions and proprioceptive measurements

Compute current pose from the history



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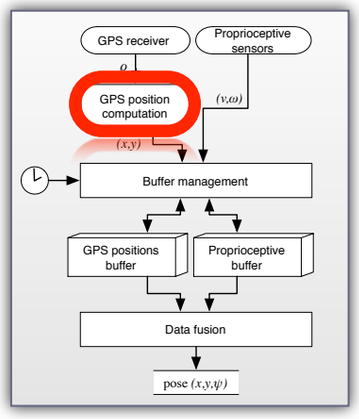
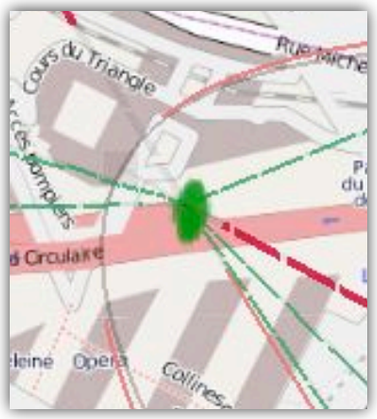
Tightly-coupled GPS and 3D-map positioning





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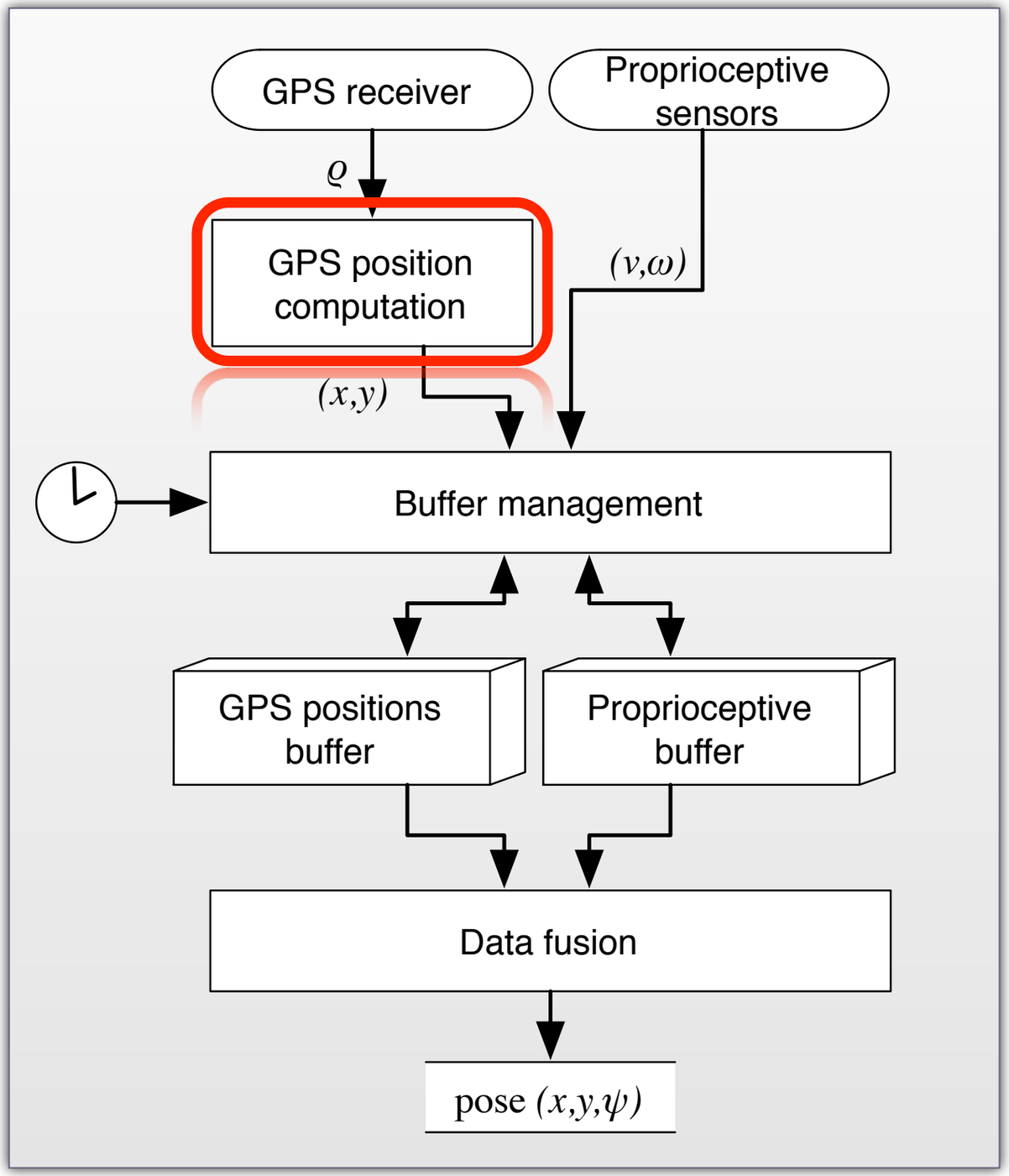

Bounded-error GPS positioning

Bounded-error framework

- Measurements = Intervals
- Intervals are assumed to include the true value

Positioning as a Constraint Satisfaction Problem

- Measurements = Contraints on position
- Map = Constraint on position
- Position belongs to the domain which satisfies the constraints

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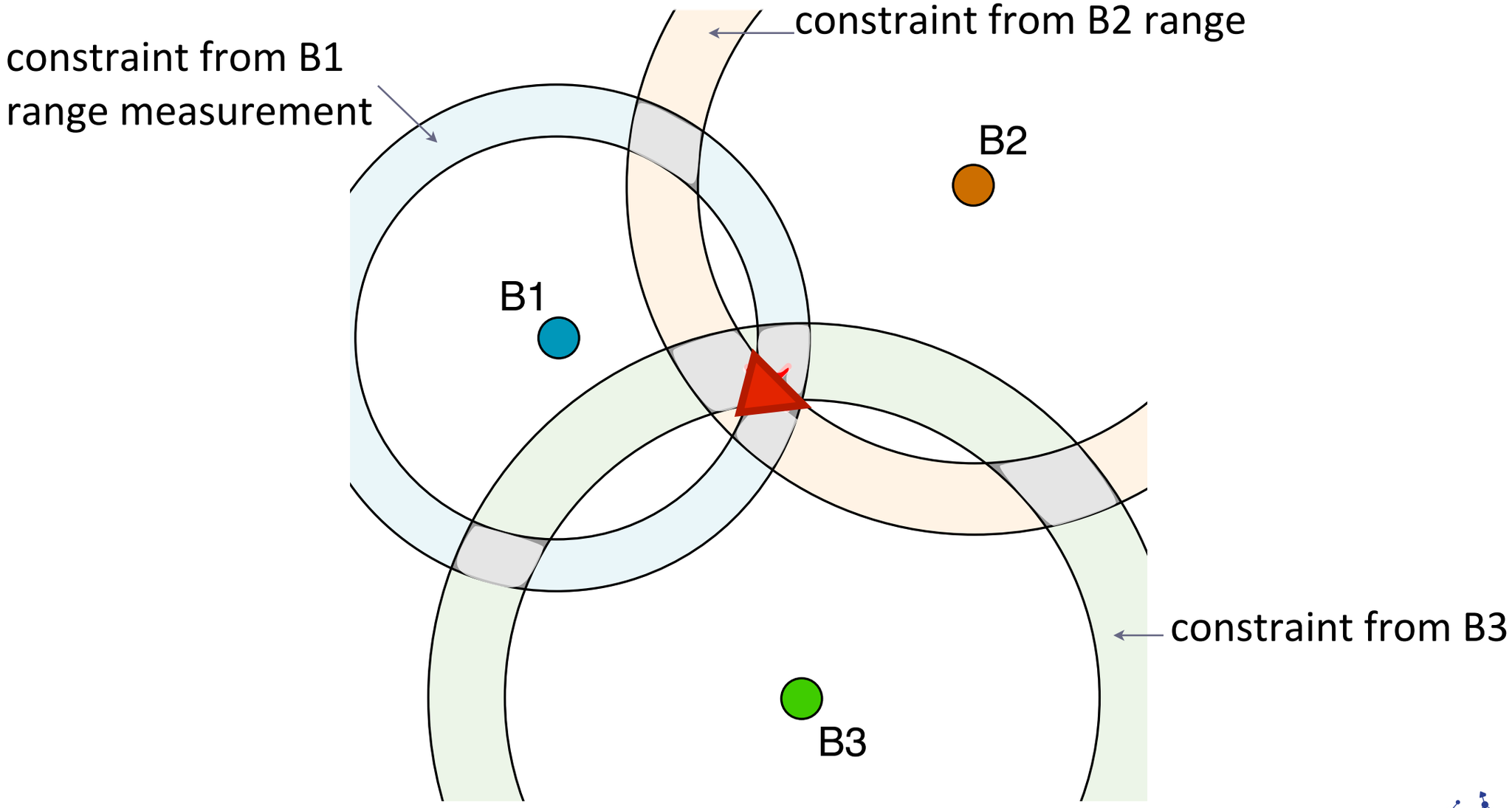
Simplified 2D example: ranging beacons

Distance measurements to known beacons - Intervals represent inaccuracy

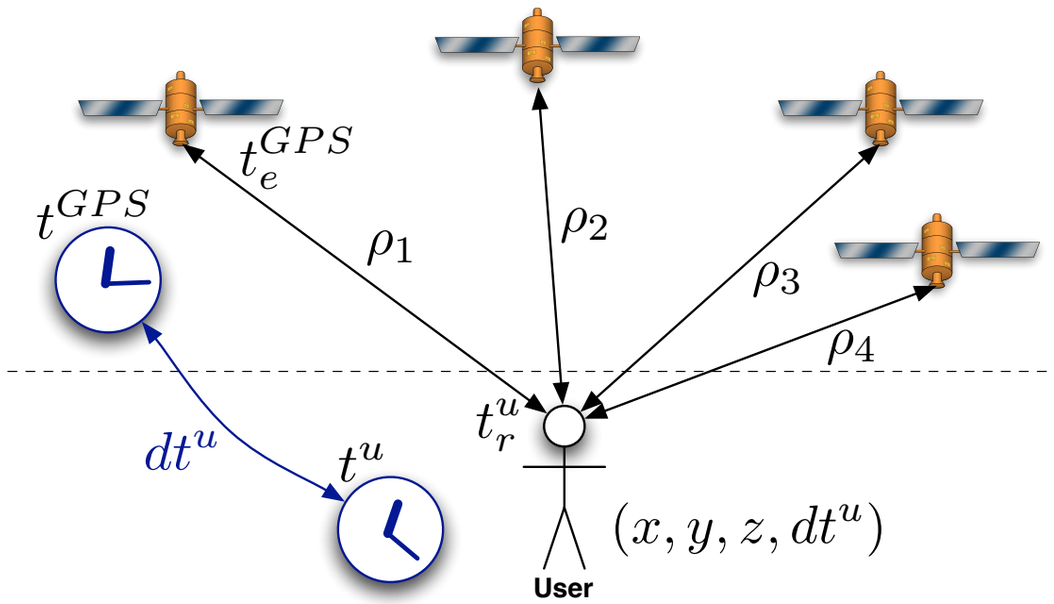


GPS pseudorange observation model

Receiver measures *pseudoranges:*

range + offset

4 unknowns: *x*, *y*, *z*, *dtu* -> 4-D boxes



Pseudorange observation equation

$$\begin{cases} \rho_1 &= \sqrt{(x-x_{s1})^2+(y-y_{s1})^2+(z-z_{s1})^2}+c\cdot dtu \\ \rho_2 &= \sqrt{(x-x_{s2})^2+(y-y_{s2})^2+(z-z_{s2})^2}+c\cdot dtu \\ & \dots \\ \rho_p &= \sqrt{(x-x_{sp})^2+(y-y_{sp})^2+(z-z_{sp})^2}+c\cdot dtu \end{cases}$$

$x_{s_i}, y_{s_i}, z_{s_i}$ are satellite positions (broadcast)

ρ_i are corrected pseudoranges:

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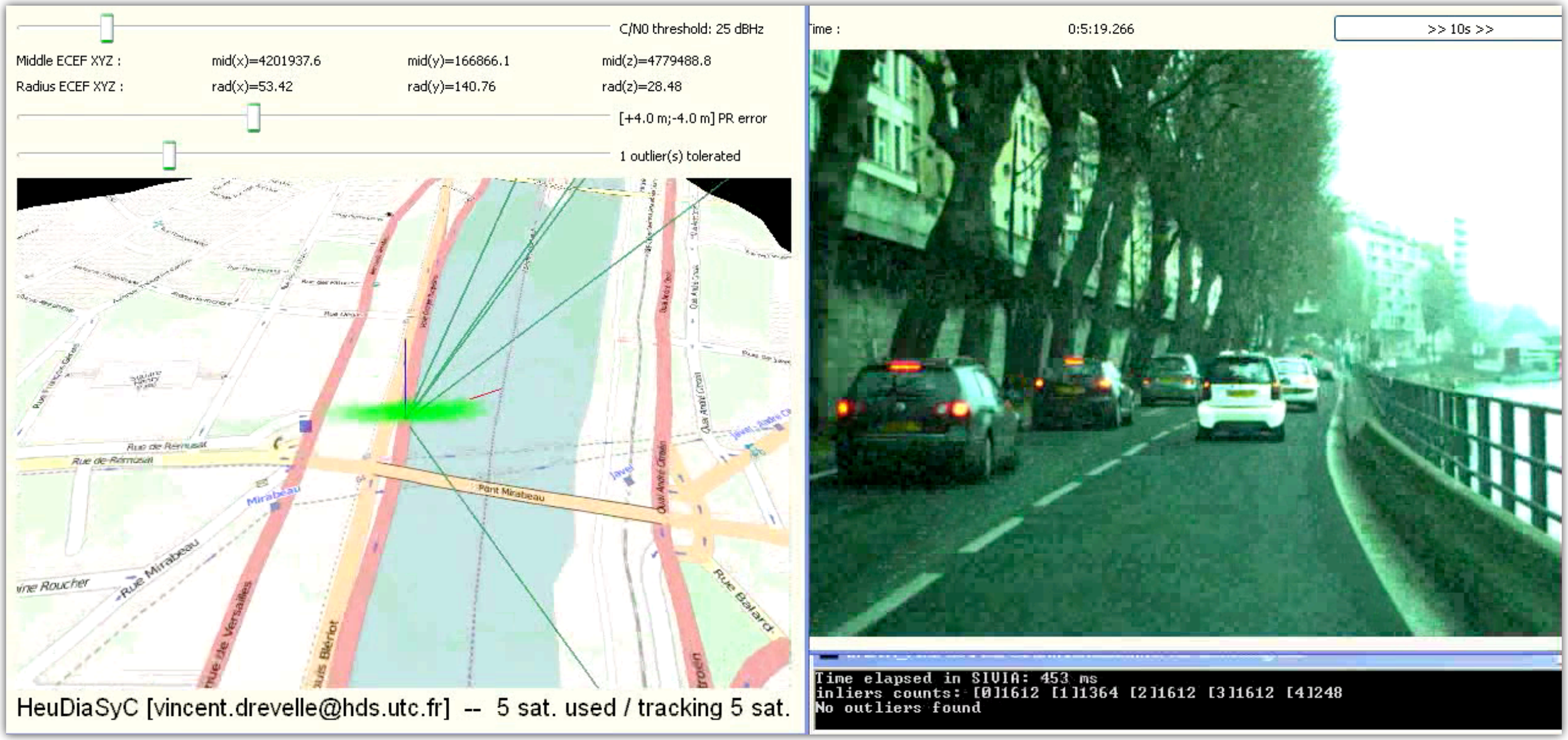
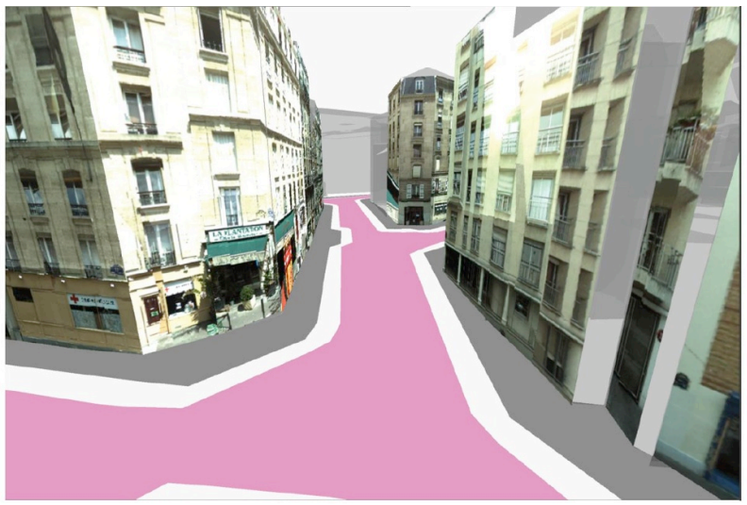
Set-membership GPS positioning, Paris

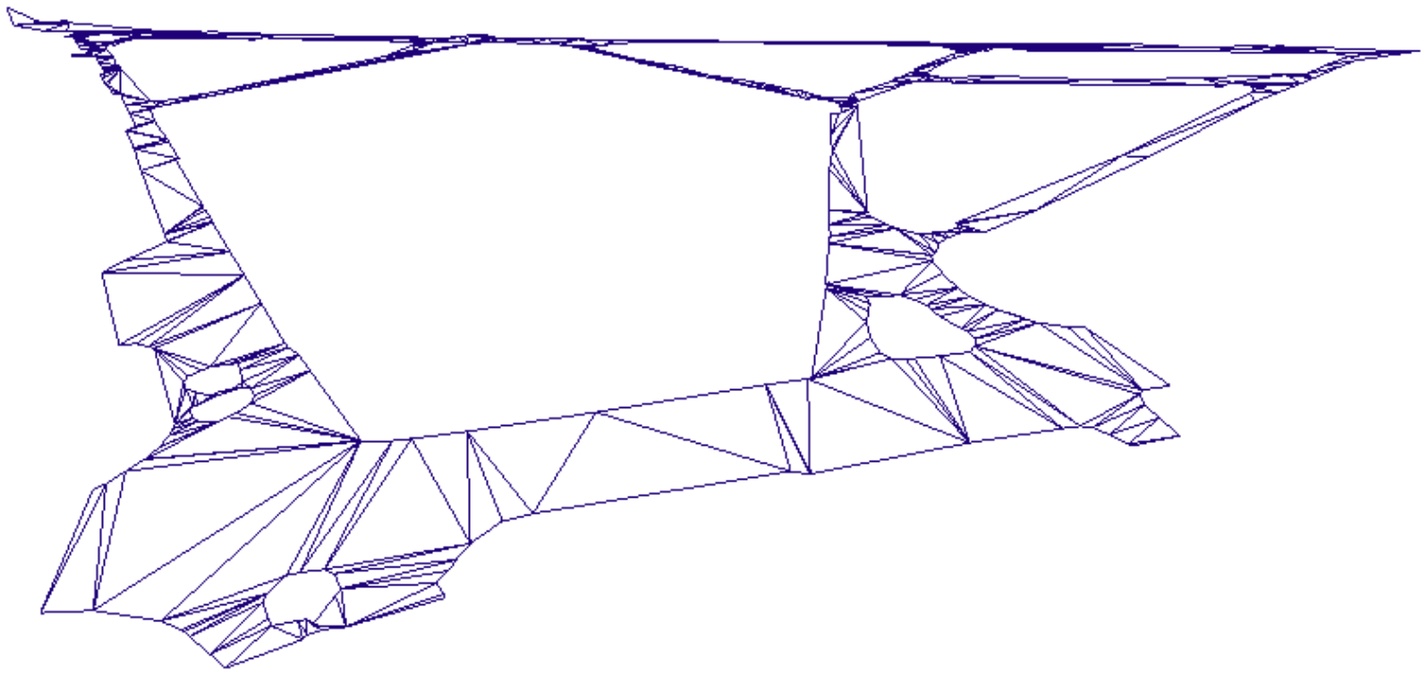


3D map (Paris, XIIth arrondissement)

Produced by the French *Institut Géographique National*

- Photogrammetry from aerial photographs
- Surface generated from sidewalk limits
- Precision of vertices : 5 cm planar / 20 cm altitude
- Triangular facets

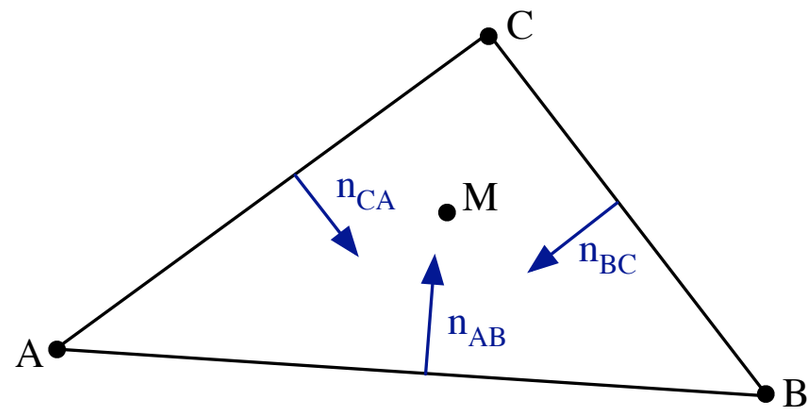




3D facets constraint

Facet constraint

- Vertices coordinates are boxes (uncertainty)



Drivable space constraint

- Union of facet constraints
- Pruning with facet bounding boxes

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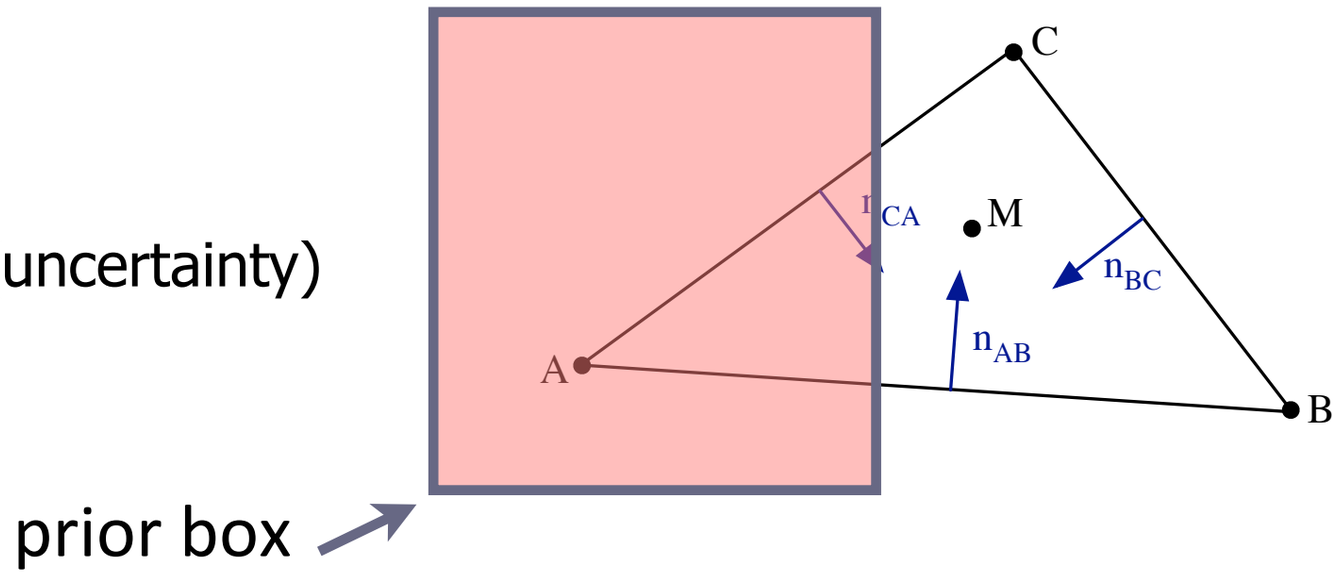

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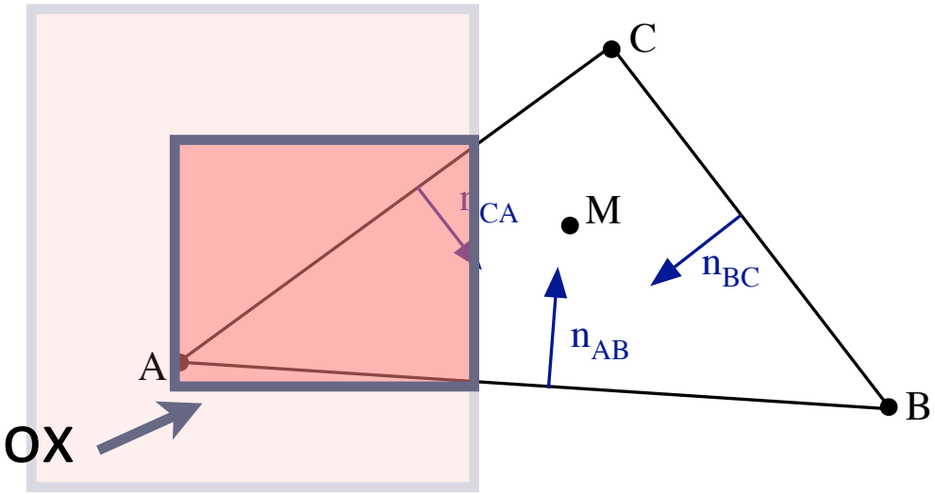

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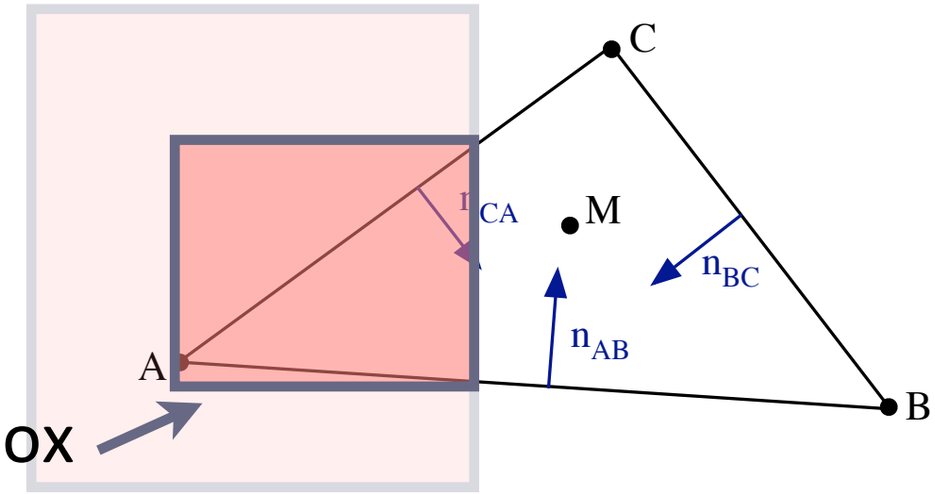

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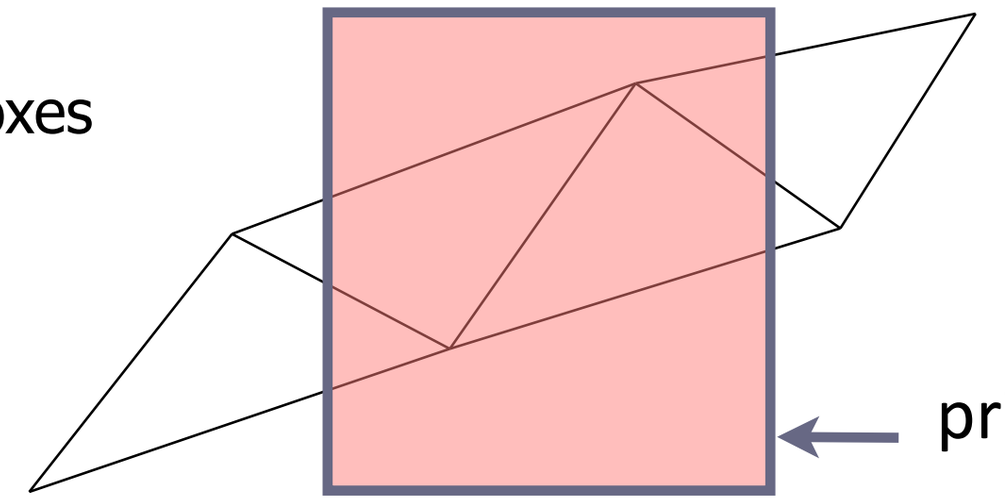

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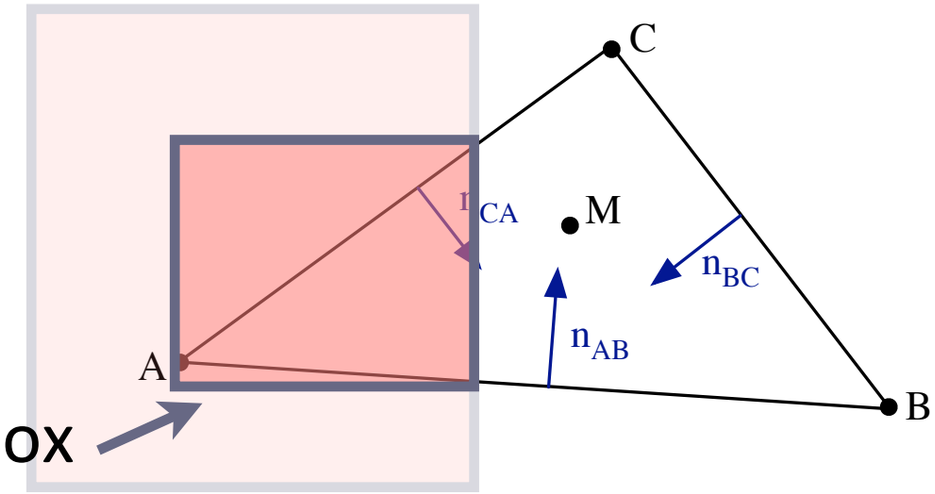

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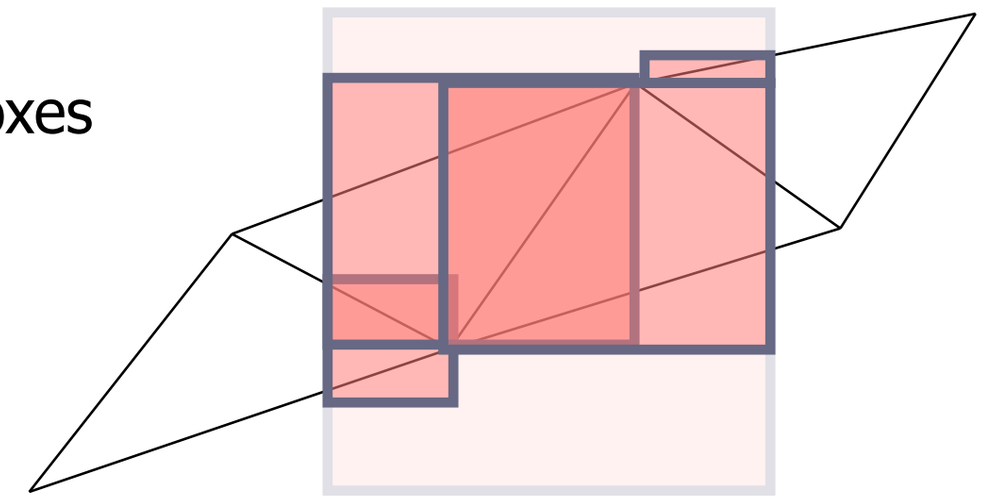

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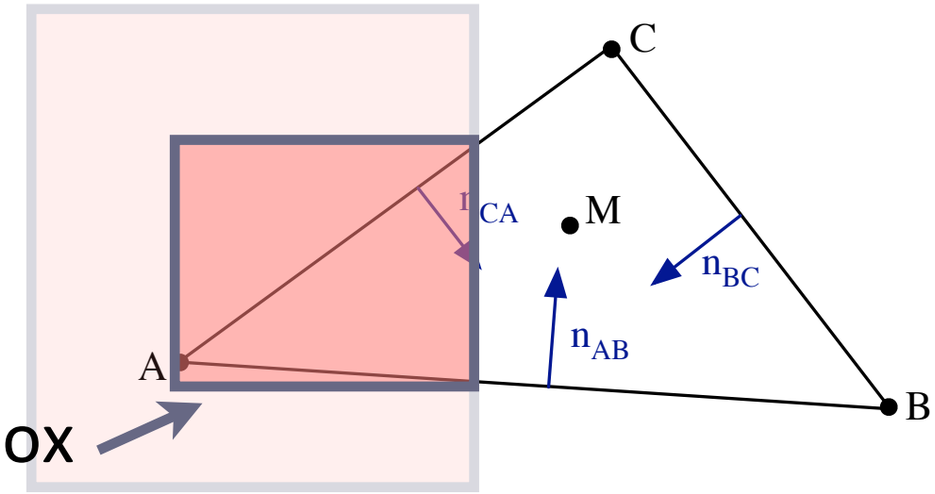

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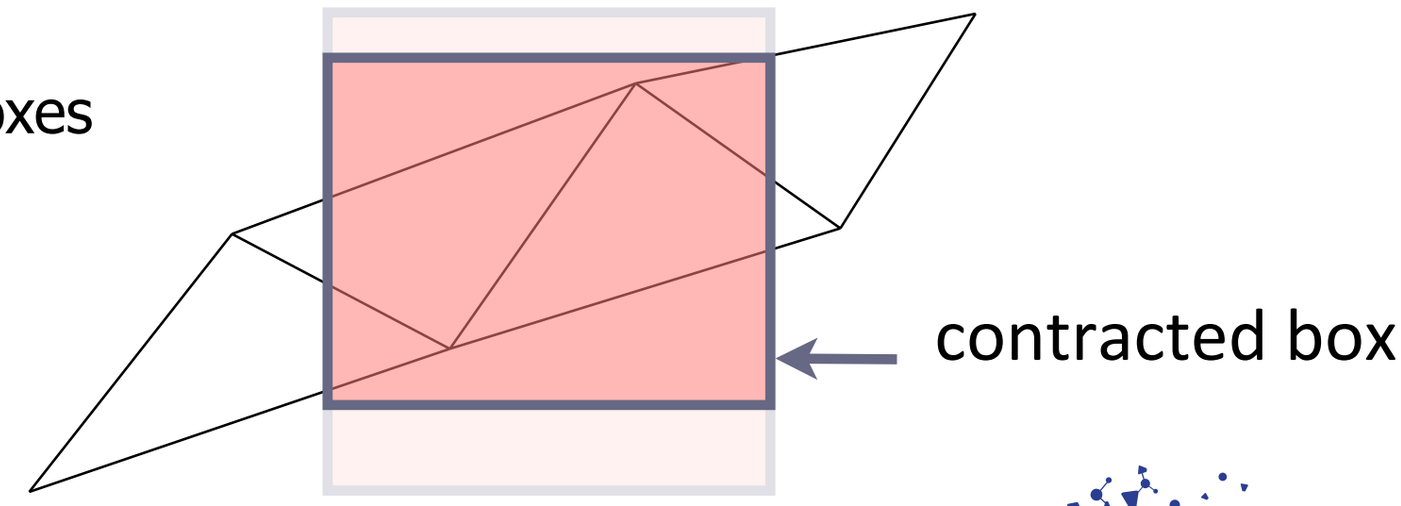

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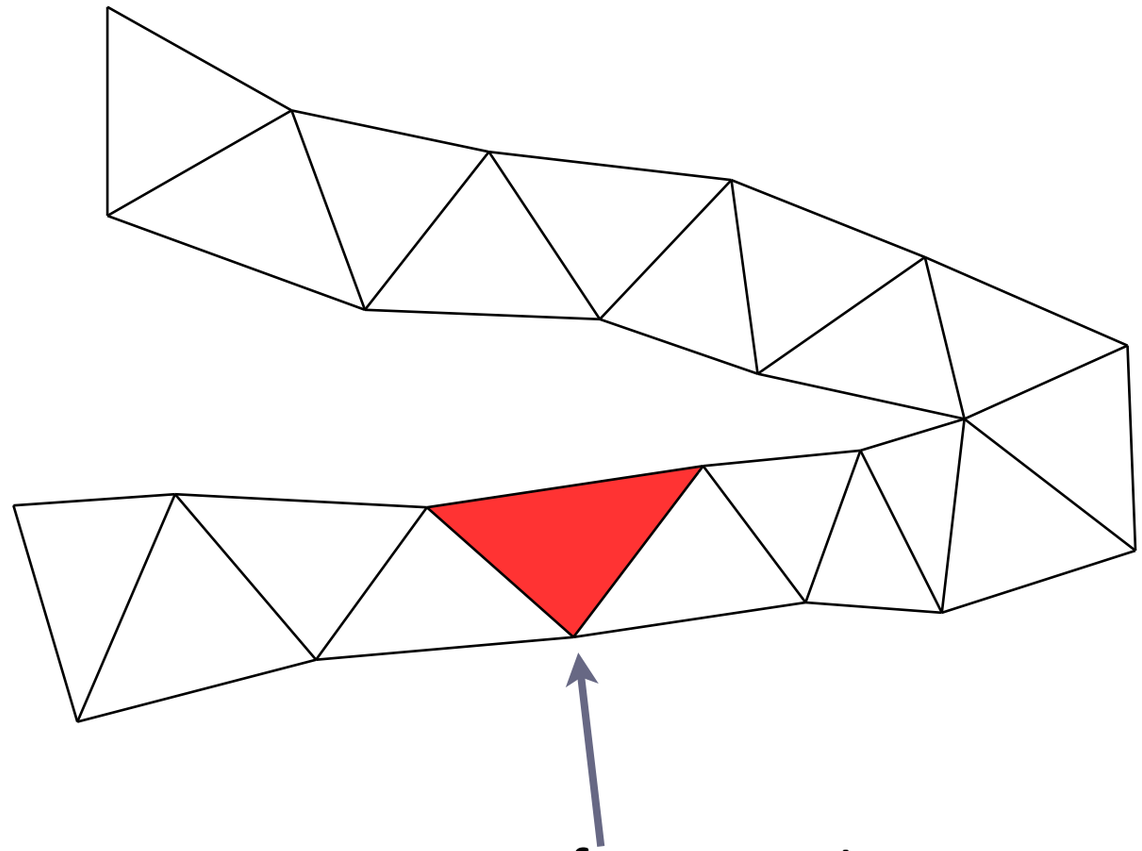
Facet selection (map matching)

Use topology to mark eligible neighbors from previous epoch facets set.

- Speeds up computation
- Limits ambiguous solutions in poor GPS conditions and dense road networks



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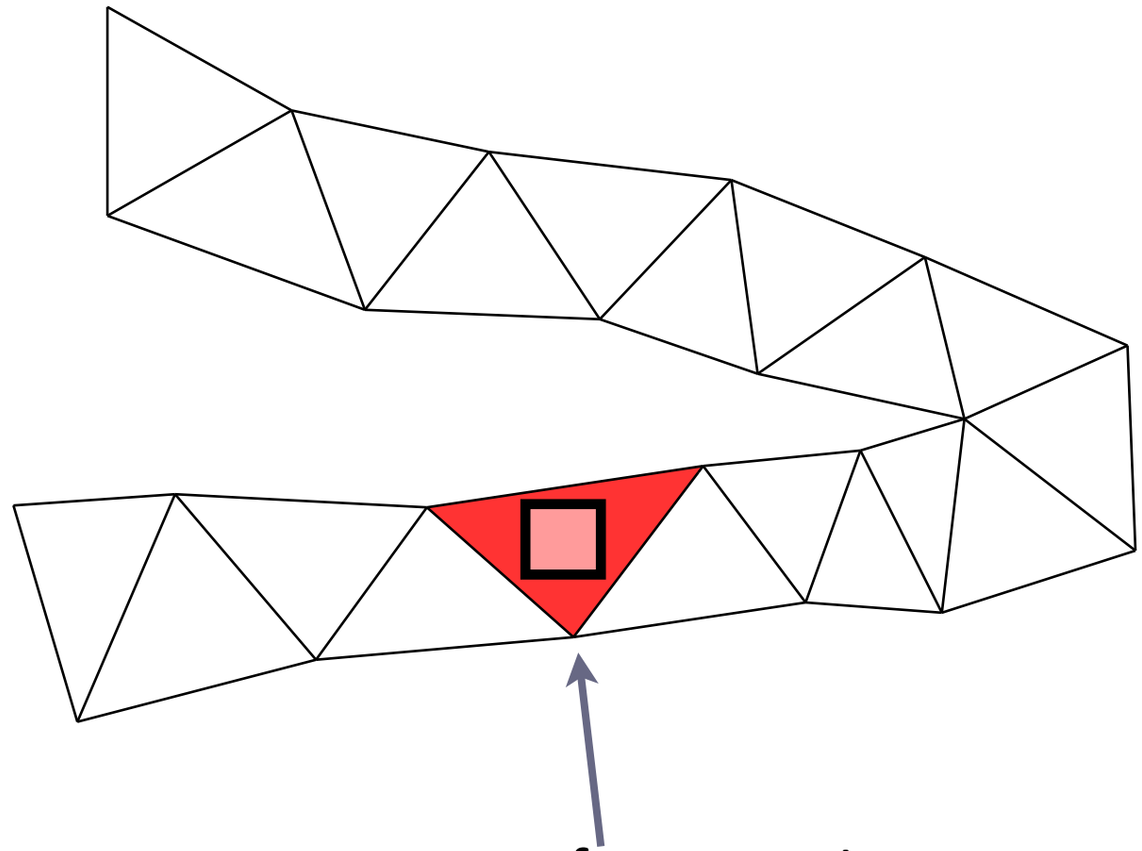

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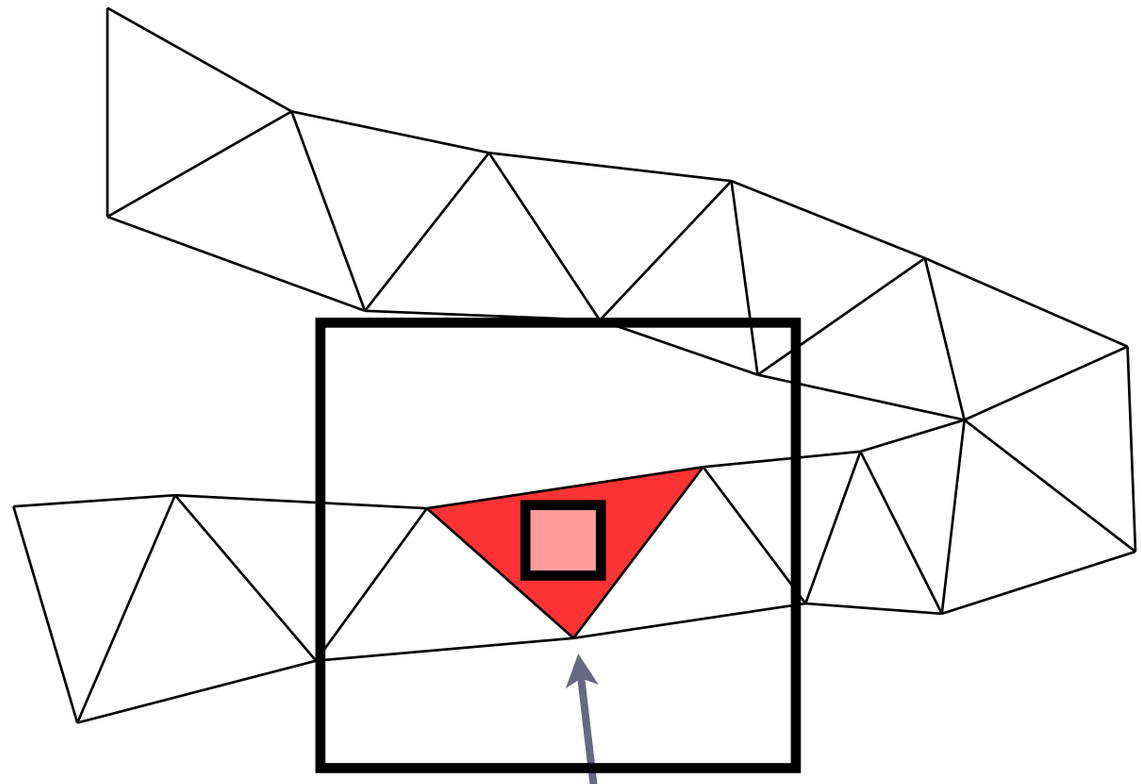

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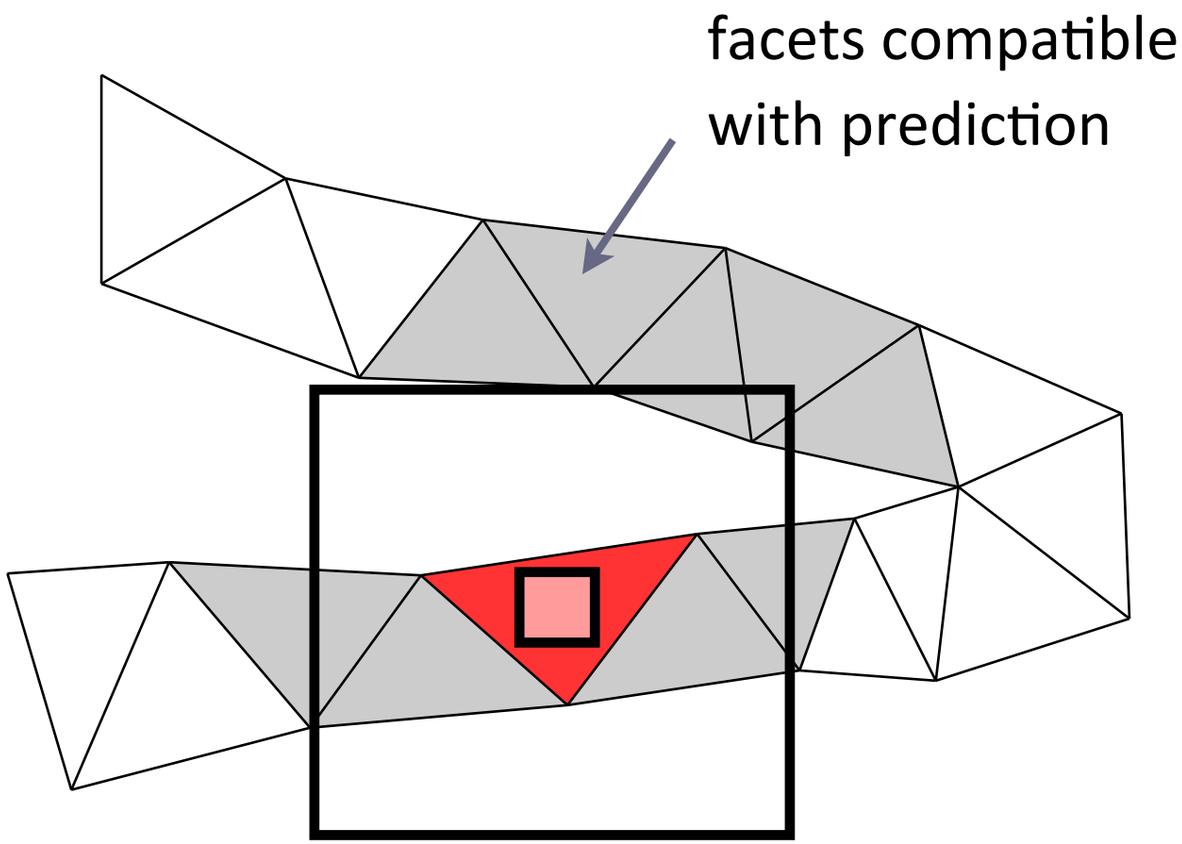

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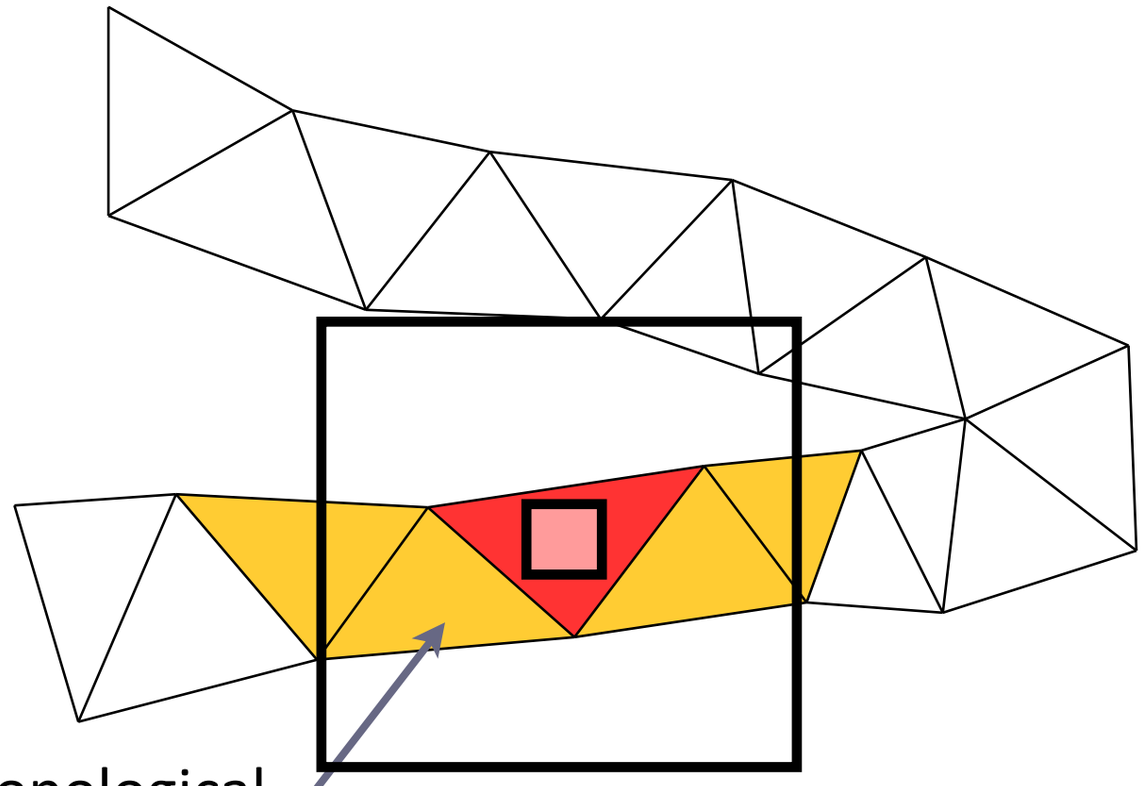
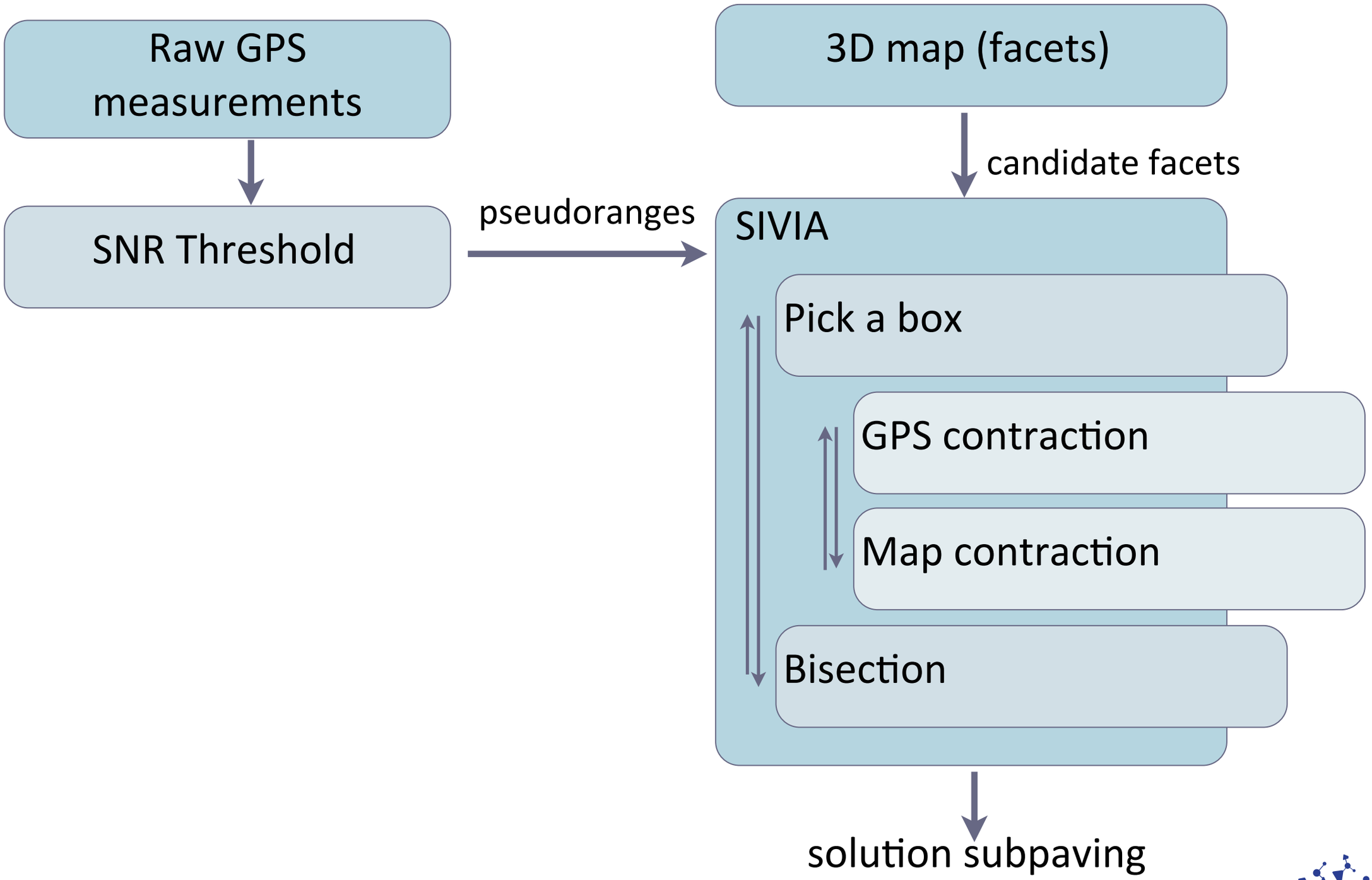
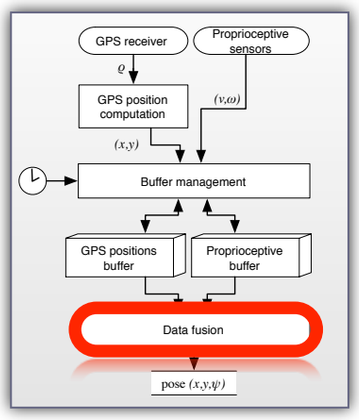
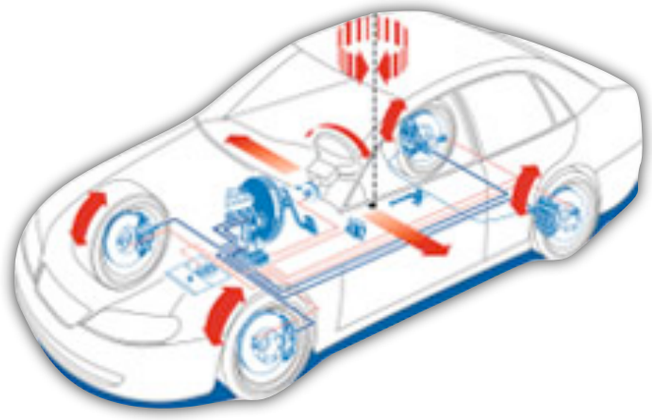


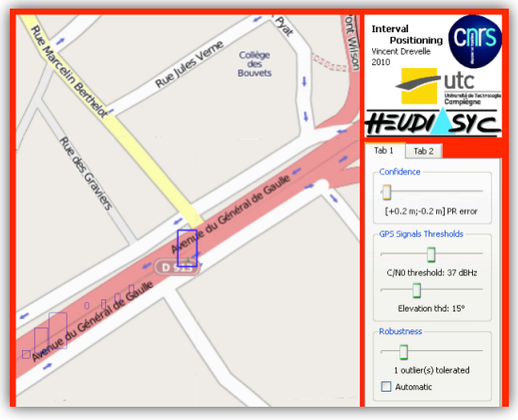
Positioning algorithm



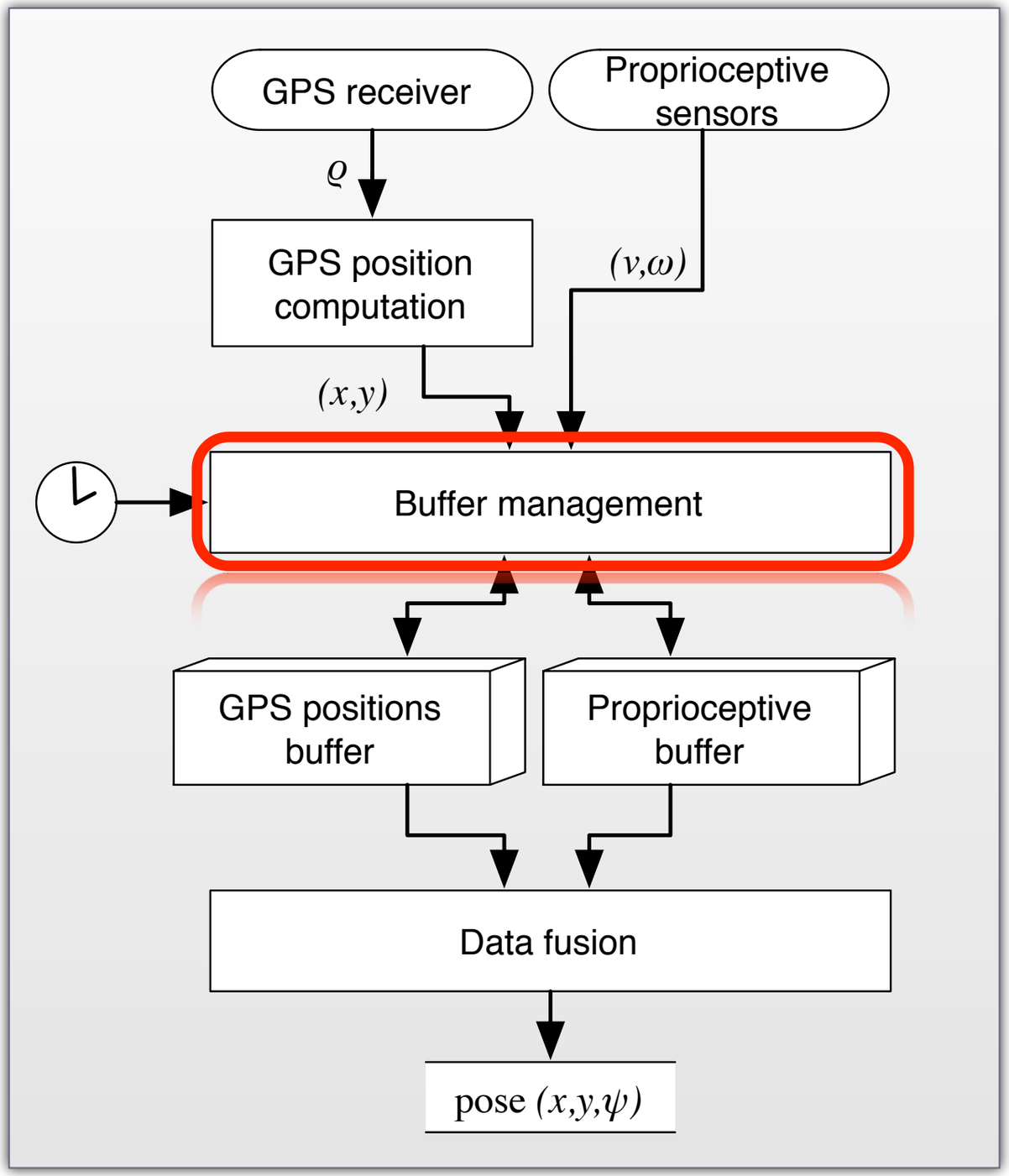
Robust pose estimation with data horizon







Data horizon buffer



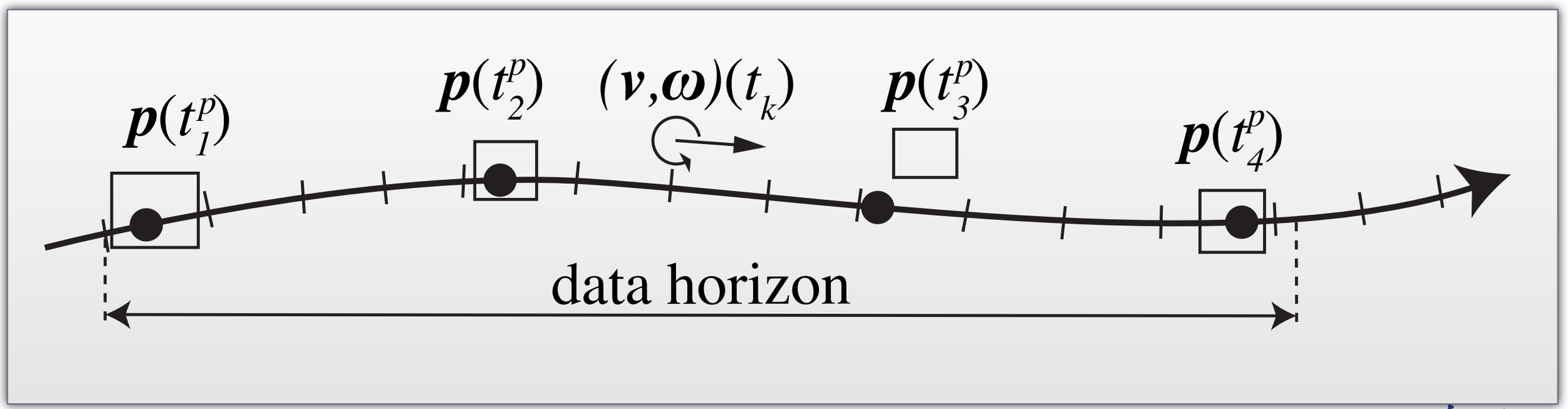
Data horizon buffer

Keep track of previous

- Positions as boxes
- Proprioceptive measurements as intervals

Limited size

All data are timestamped & ordered by date of value



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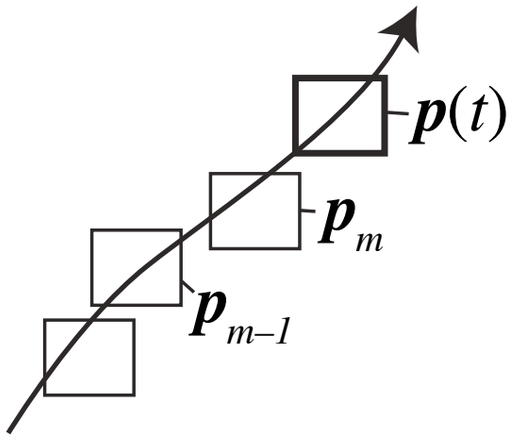
Position buffer management

Try to keep only useful position information in the buffer

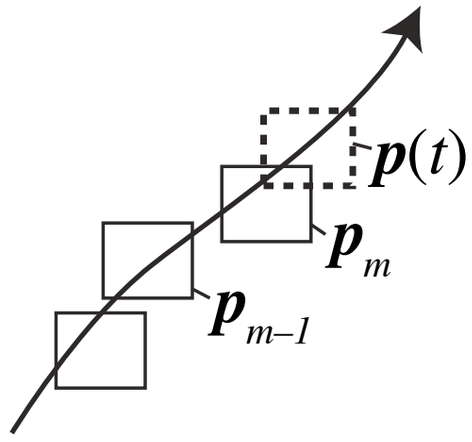
Do not add position if it intersects the previous position

Replace previous position if new position if more precise



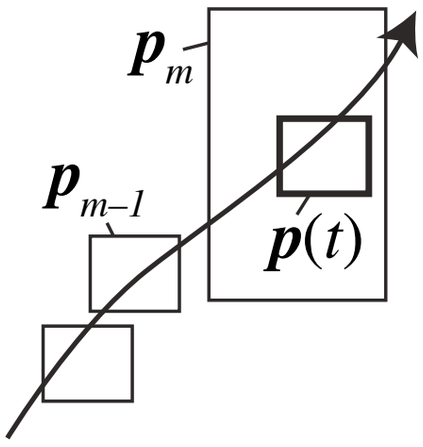
$$\boldsymbol{p}(t) \cap \boldsymbol{p}_m = \emptyset$$

add $\boldsymbol{p}(t)$



$$\begin{cases} \boldsymbol{p}(t) \cap \boldsymbol{p}_m \neq \emptyset \\ \boldsymbol{p}(t) \not\subseteq \boldsymbol{p}_m \end{cases}$$

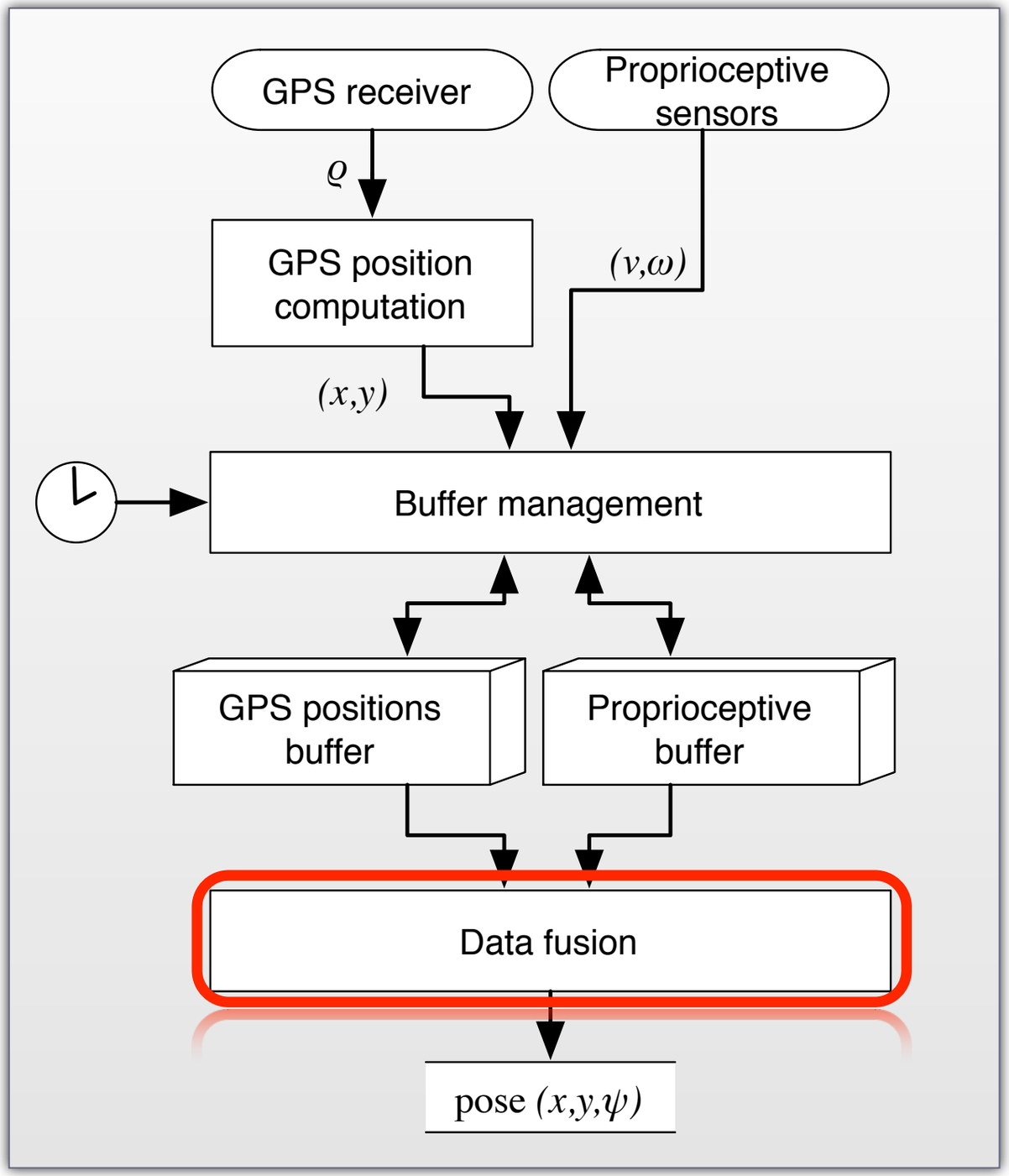
discard $\boldsymbol{p}(t)$



$$\begin{cases} \boldsymbol{p}(t) \subseteq \boldsymbol{p}_m \\ \boldsymbol{p}(t) \cap \boldsymbol{p}_{m-1} = \emptyset \end{cases}$$

discard $\boldsymbol{p}_m$, add $\boldsymbol{p}(t)$

Robust pose estimation with data horizon



(x,y,ψ) Pose estimation

GPS positions constraints (unreliable -> q-relaxed)

$x(t) \in x_{GPS}(t)$

$y(t) \in y_{GPS}(t)$

Map constraints (hard constraint)

$(x,y)(t) \in \text{Map}$

Proprioceptive measurements constraints (reliable -> hard constraints)

$$x(t_{k+1}) = x(t_k) + (t_{k+1}-t_k) \cdot v_{odo}(t) \cdot \cos \psi(t_k)$$

$$y(t_{k+1}) = y(t_k) + (t_{k+1}-t_k) \cdot v_{odo}(t) \cdot \sin \psi(t_k)$$

$$\psi(t_{k+1}) = \psi(t_k) + (t_{k+1}-t_k) \cdot \omega_{gyro}(t_k)$$

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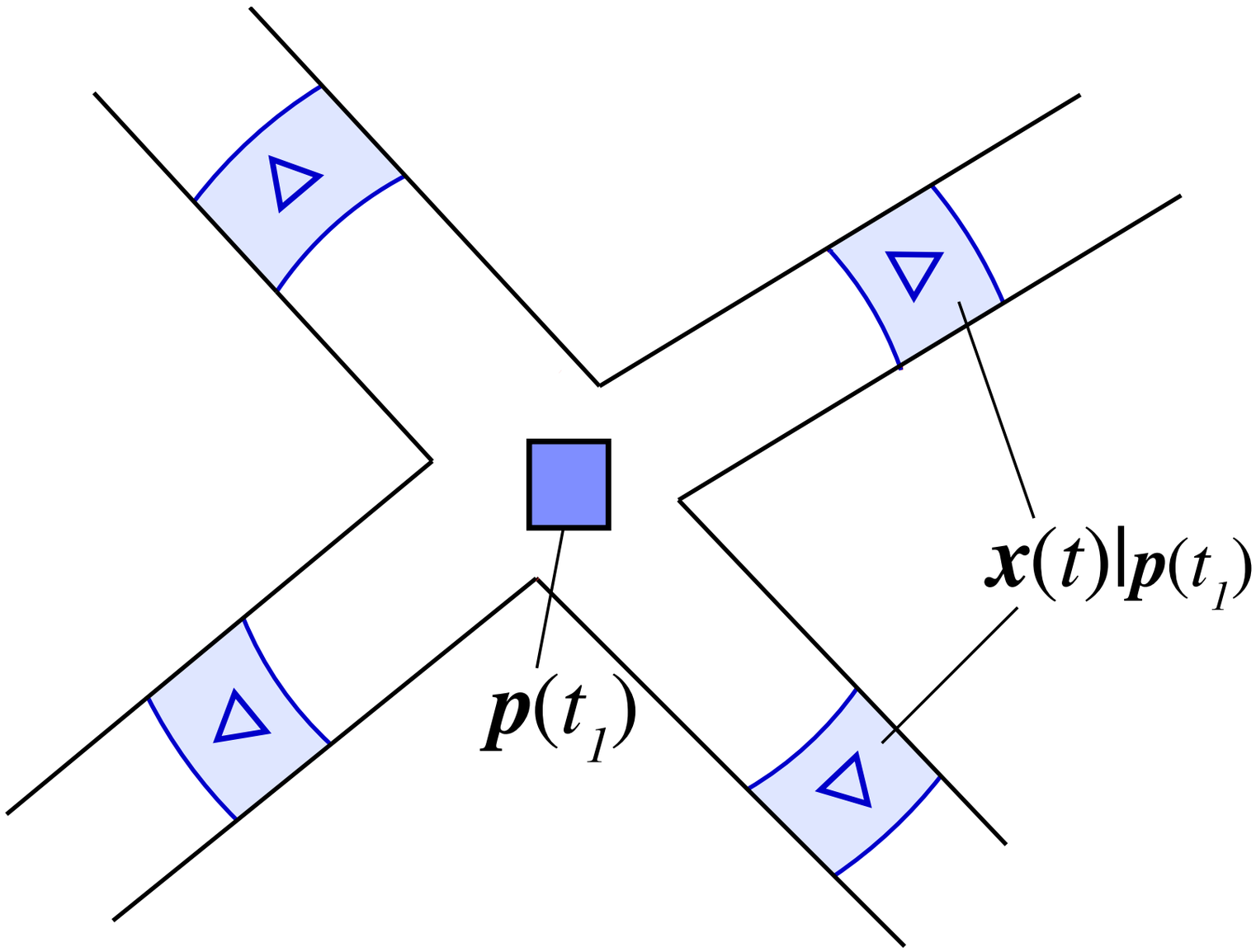
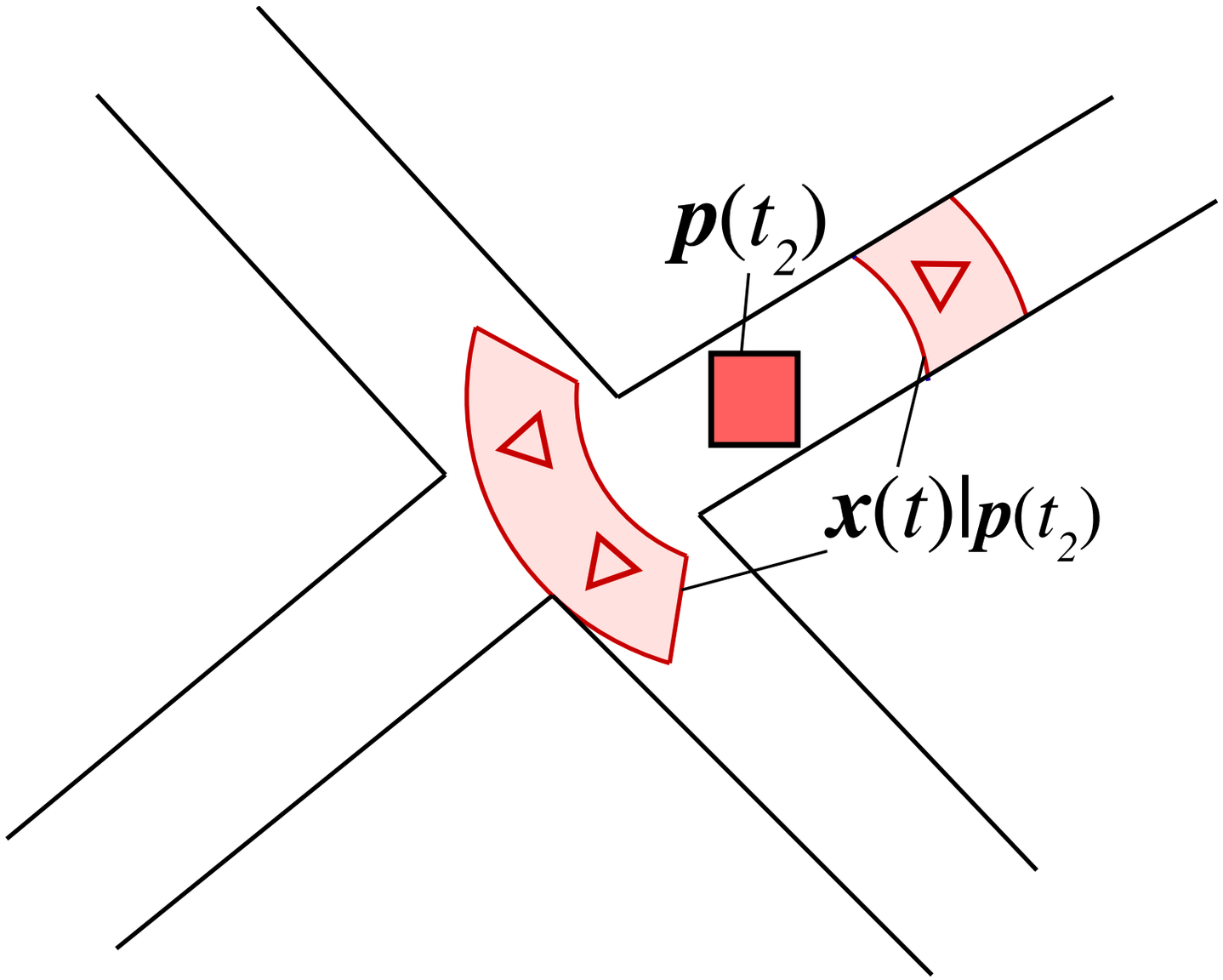
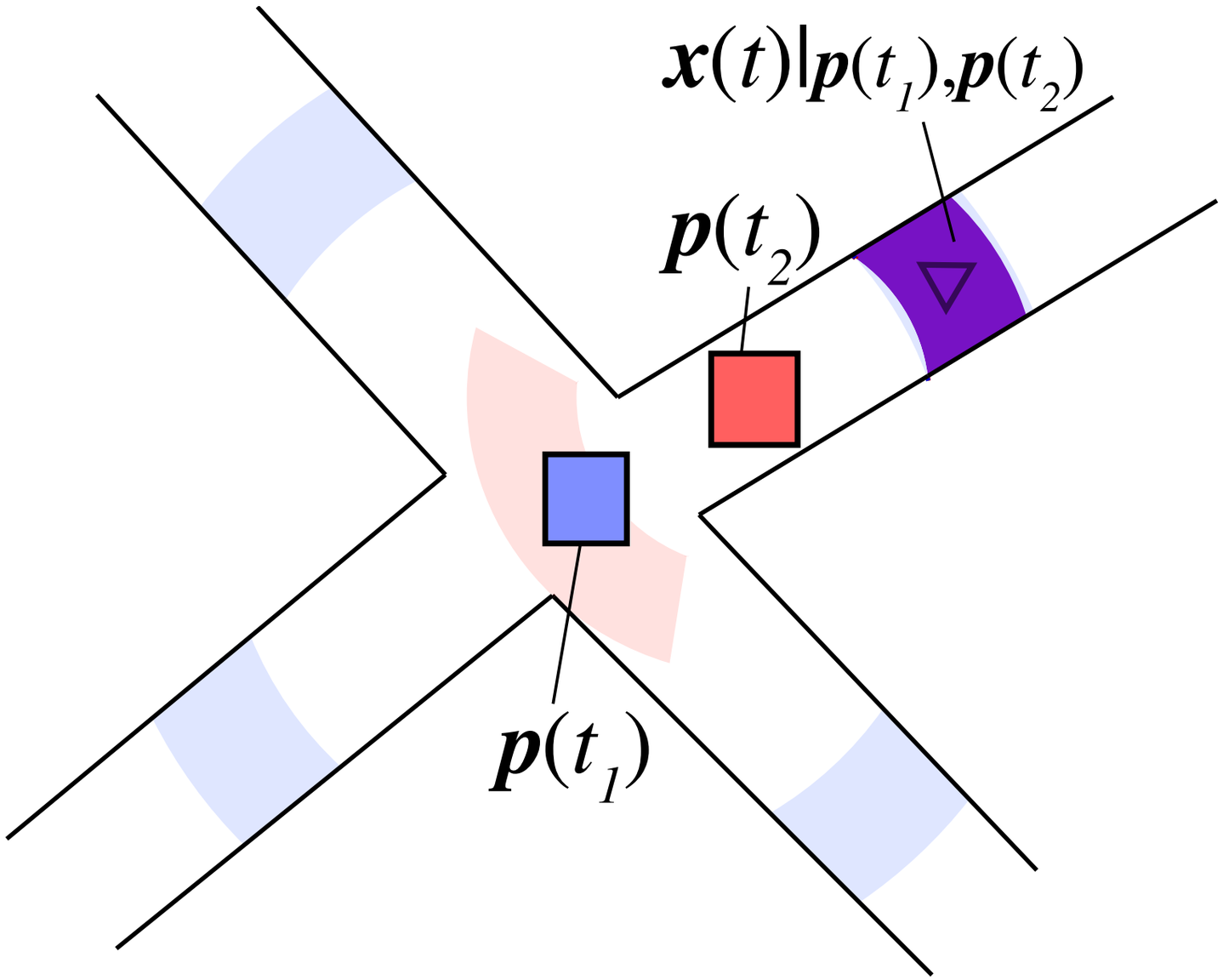
Example: Current pose from a 2-position history



Example: Current pose from a 2-position history



Example: Current pose from a 2-position history

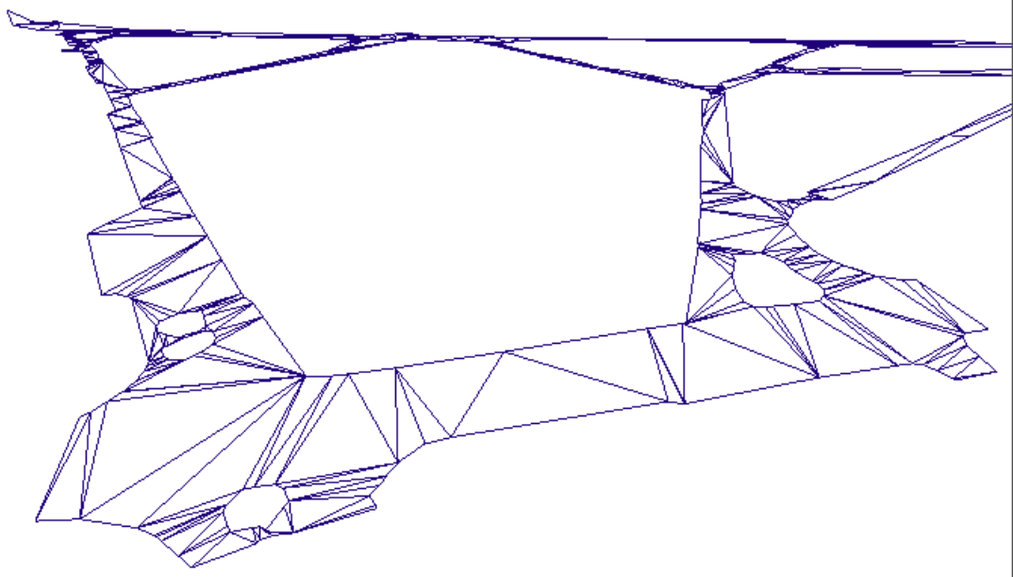


Experimental results (CityVIP project)

16 minutes, 3 km, XIIth arrondissement of Paris

GPS, pseudoranges with SNR ≥ 35dBHz

- 85% of time, less than 4 satellites
- 56% of time, less than 3 satellites



3D map of the drivable space (IGN)

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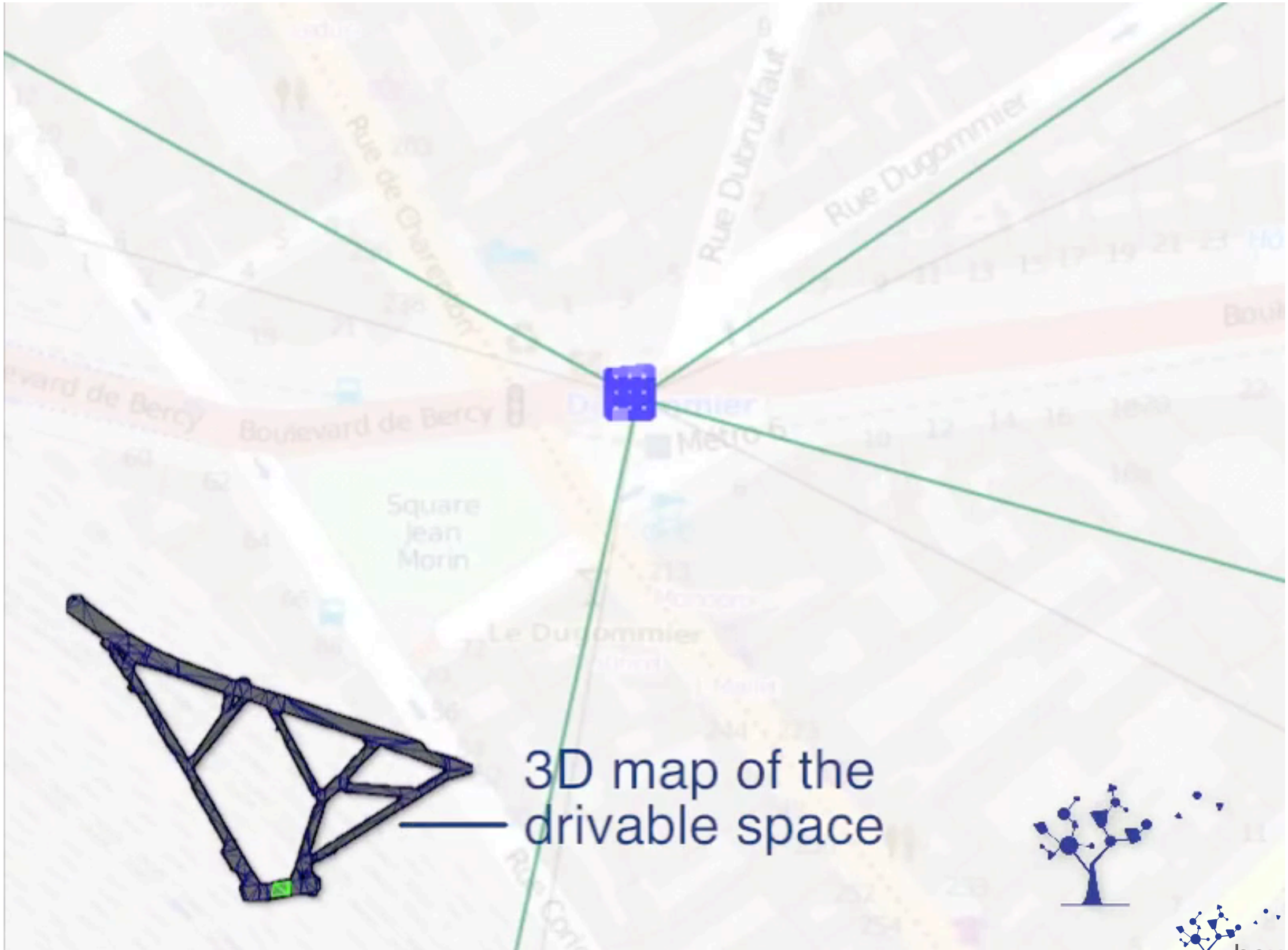
Localization confidence domains via set-inversion on short-term trajectory



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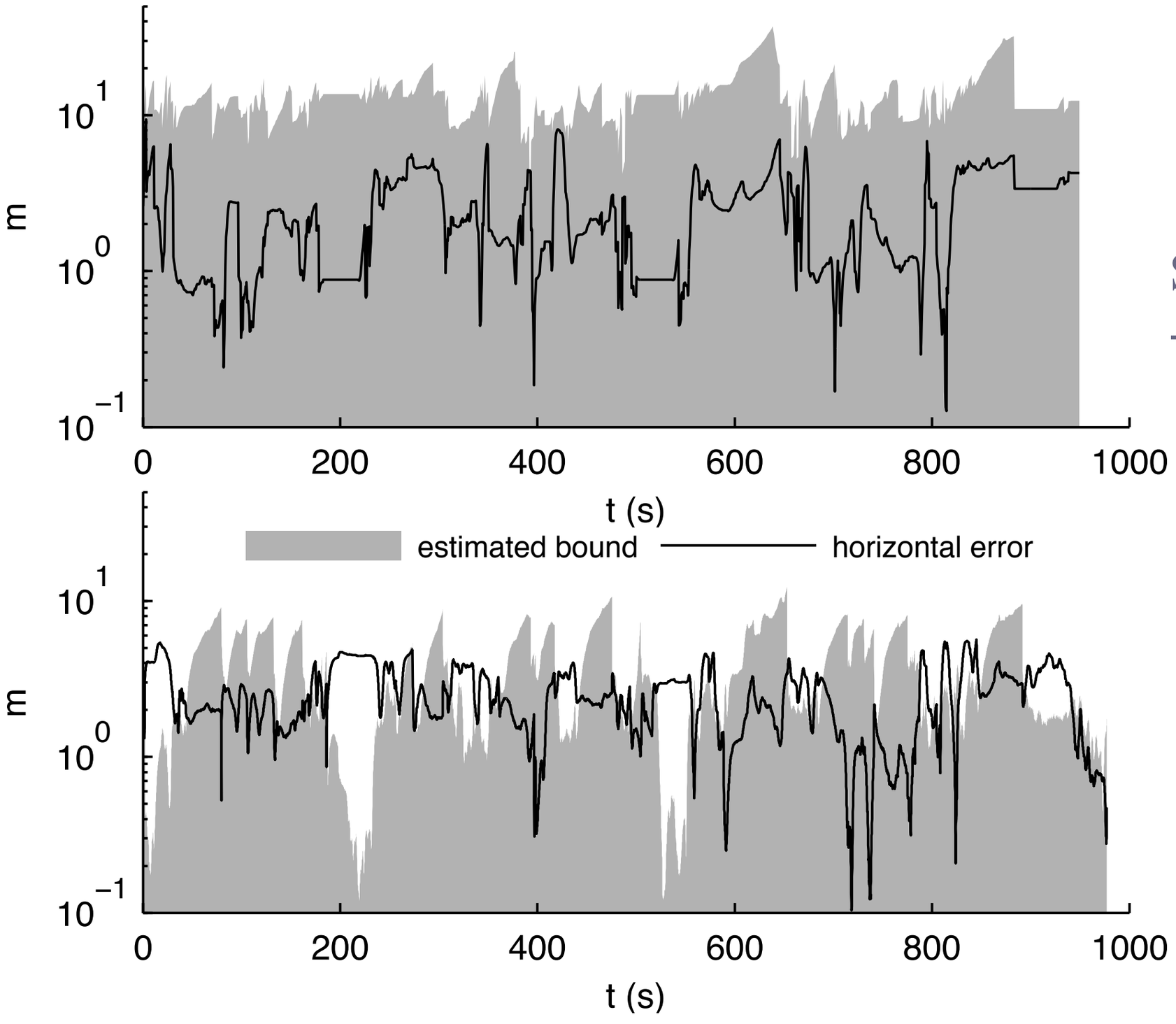
Horizontal Positioning Error vs Confidence Radius (10^{-3} risk)



Set-membership method
- 2.43m mean HPE

Particle filter
- 2.50 m mean HPE
- confidence bounds violated 41% of the time

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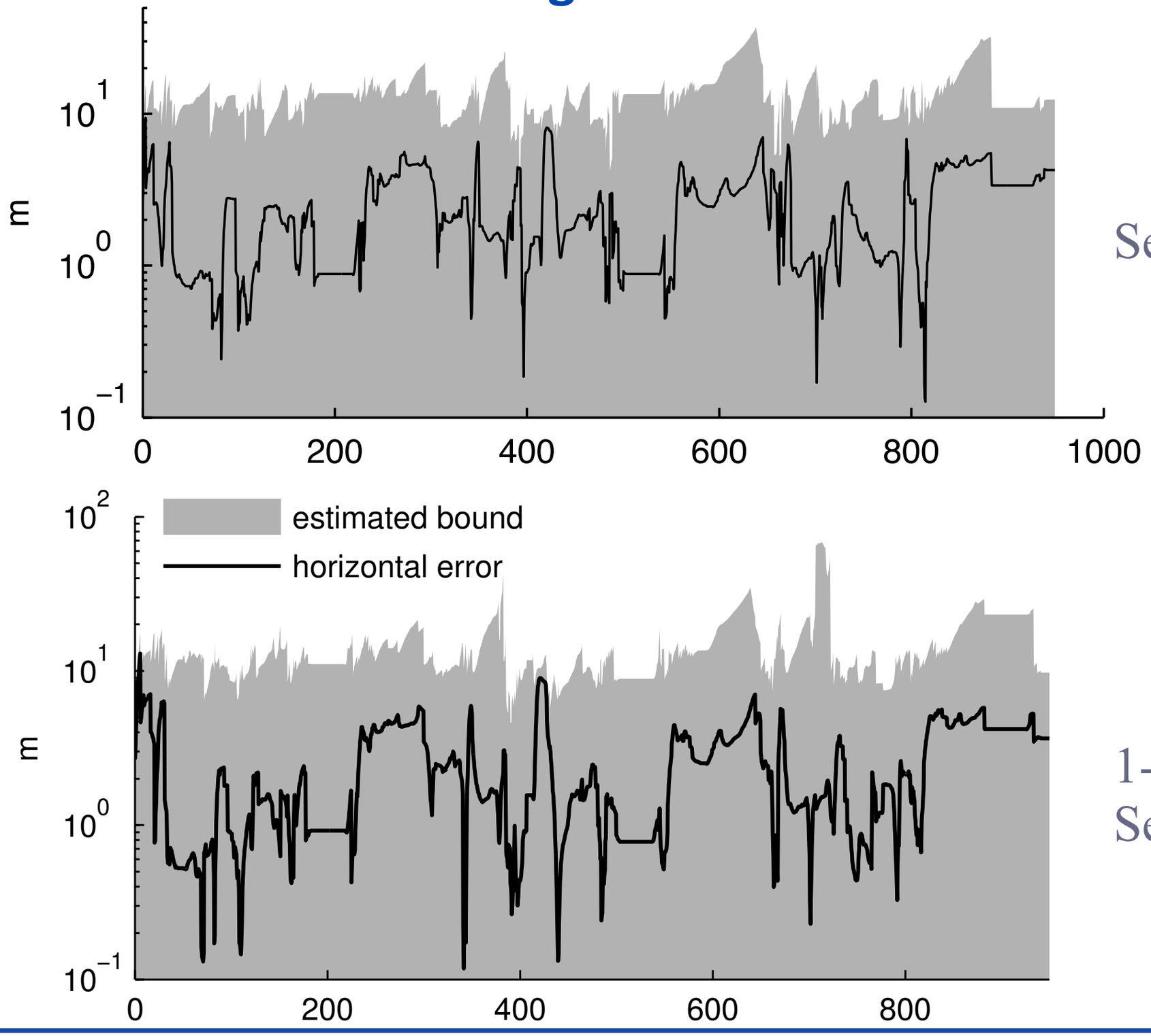
Horizontal Positioning Error vs Confidence Radius (10^{-3} risk)



Set-membership method

1-relaxed
Set-membership method

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Conclusion

Localization confidence domains via set-inversion on short-term trajectory

1) Tightly coupled GPS-3D map positioning

2) Robust estimate of current pose from short term history of positions

- Runs in real-time with true sensors, handles out-of-sequence data
- Point-positioning accuracy similar to constrained particle filter
- Confidence domains are consistent with true position (≠ PF)

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Publications

Drevelle V et Bonnifait P. *Localization confidence domains via set-inversion on short-term trajectory*. IEEE TRO, accepted

Drevelle V et Bonnifait P. *Reliable Positioning Domain Computation for Urban Navigation*. IEEE ITS Magazine, (to appear in 2013)

Drevelle V et Bonnifait P. *iGPS: Global Positioning in Urban Canyons with Road Surface Maps*. IEEE ITS Magazine, 2012

Drevelle V et Bonnifait P. *A set-membership approach for high integrity height-aided satellite positioning*. GPS Solutions, 2011

Thank you!
Questions?

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