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RoboticsResearchLab

Hybridisation of Sequential Monte Carlo Simulation with Non-linear Bounded-error State Estimation Based on Interval Analysis Applied to Global Localisation of Mobile Robots

Robin Weiß

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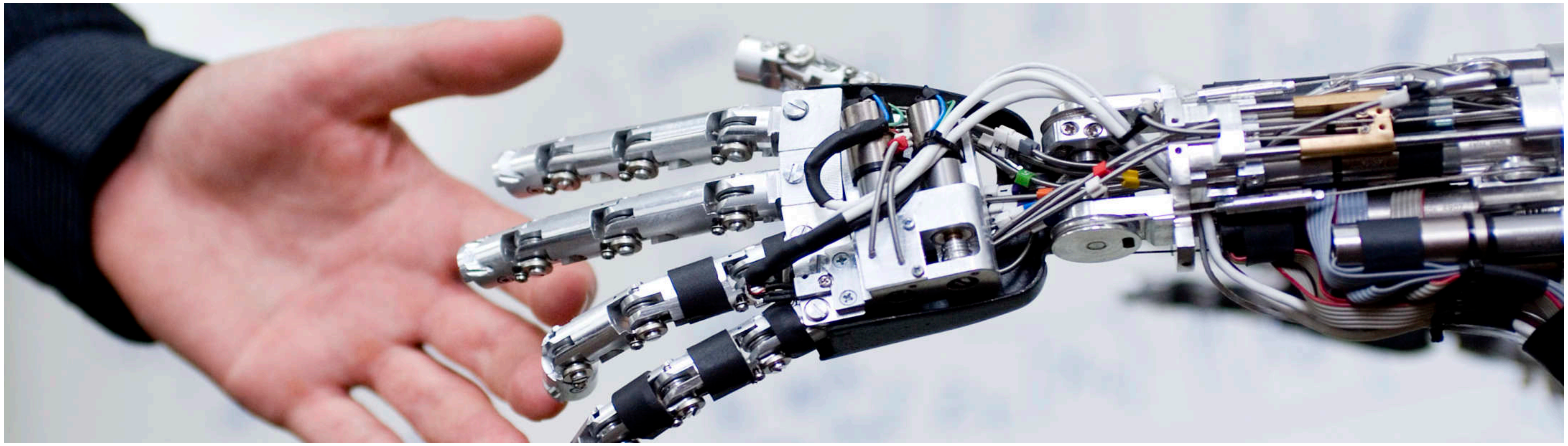
Agenda

- Introduction
- Sequential Monte Carlo
- Bounded-error estimation
- Hybrid localisation algorithms
- Experiments & Results
- Conclusion

Motivation – Why Robotics?

- Enormous potential to change the world for the better
- Automating dangerous tasks protects human lives & renders operation under inhuman conditions possible
- Releases mankind from mundane & repetitive tasks ⇒ improves quality of life
- Frees time and energy to focus on the more interpersonal tasks & the creative aspects of life



Source: Imperial College London

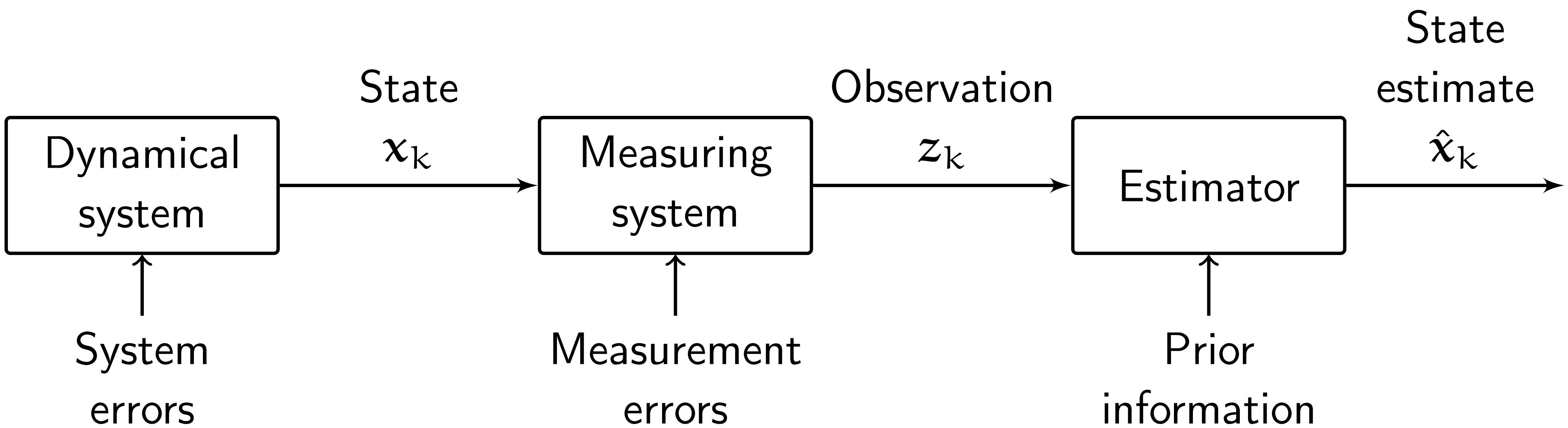
The Global Localisation Problem

- Map: global reference frame + landmarks
- Robot equipped with noisy sensors to measure its distance to each of the landmarks
- Determine the robot’s position with respect to the global frame

Global localisation problem

- Wake-up robot problem
- Kidnapped robot problem

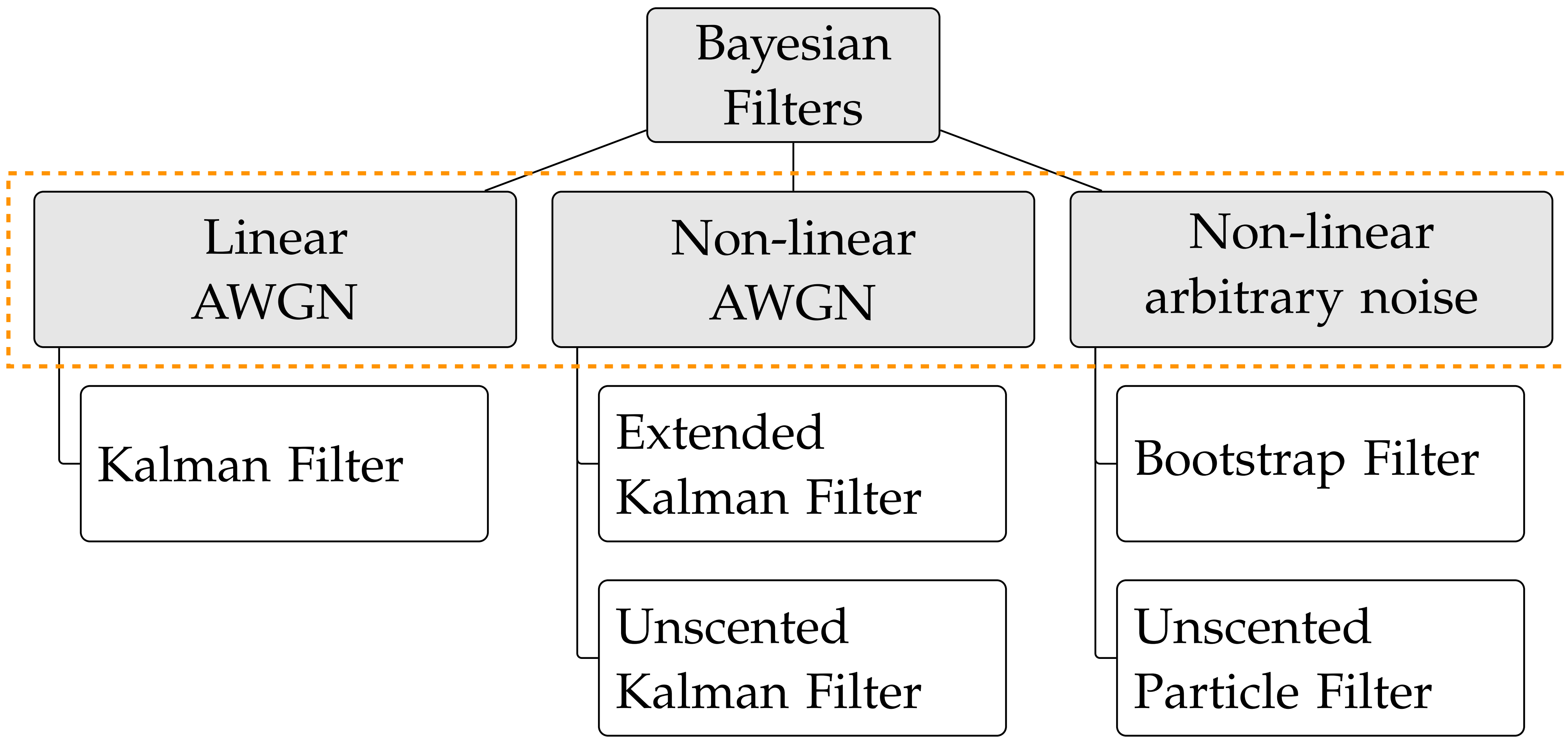
The Filtering Problem



Common solutions:

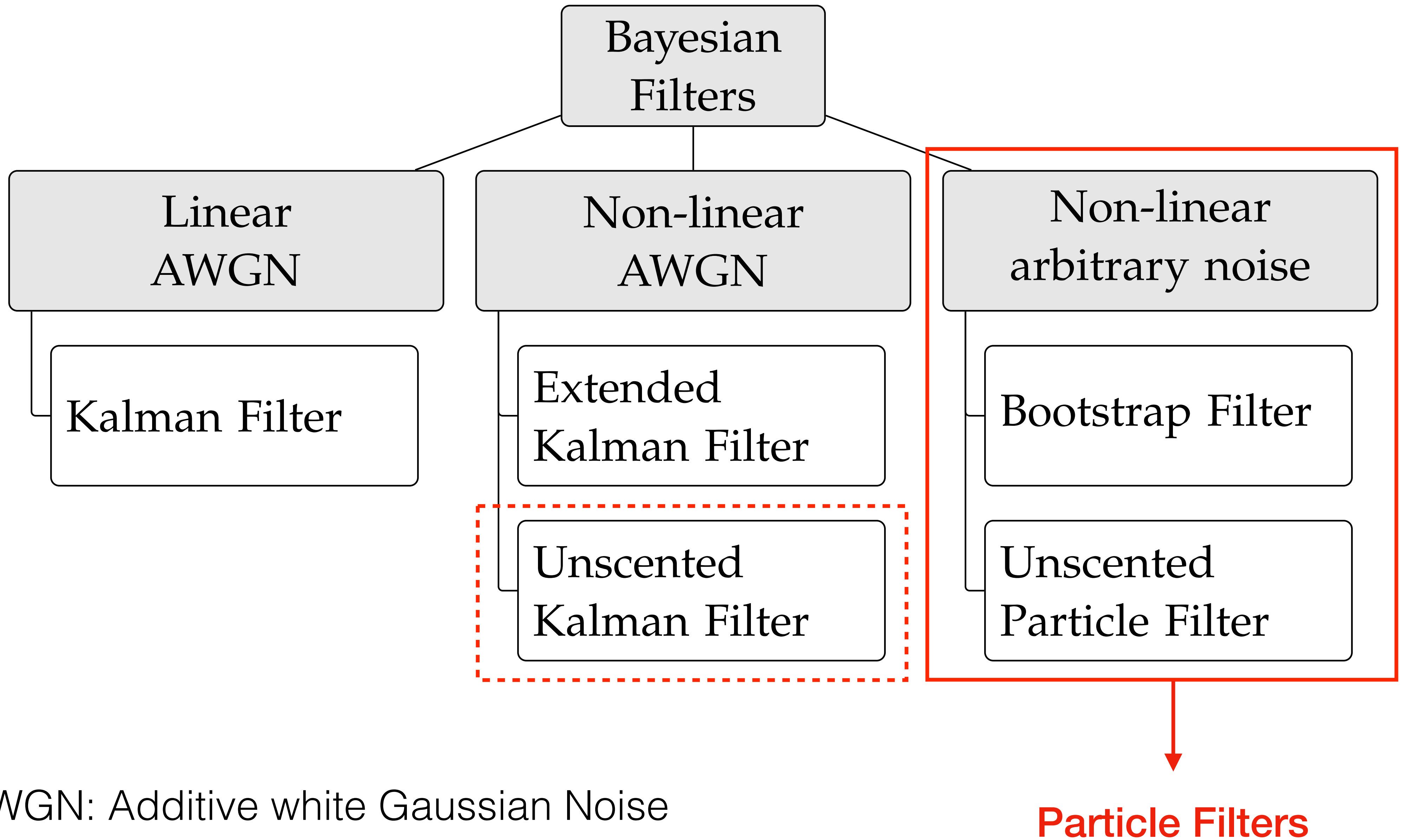
- Probabilistic estimators ⇒ Bayesian filters
- Bounded-error estimators ⇒ Contractors, SIVIA

Taxonomy of Bayesian Filters



AWGN: Additive white Gaussian Noise

Taxonomy of Bayesian Filters

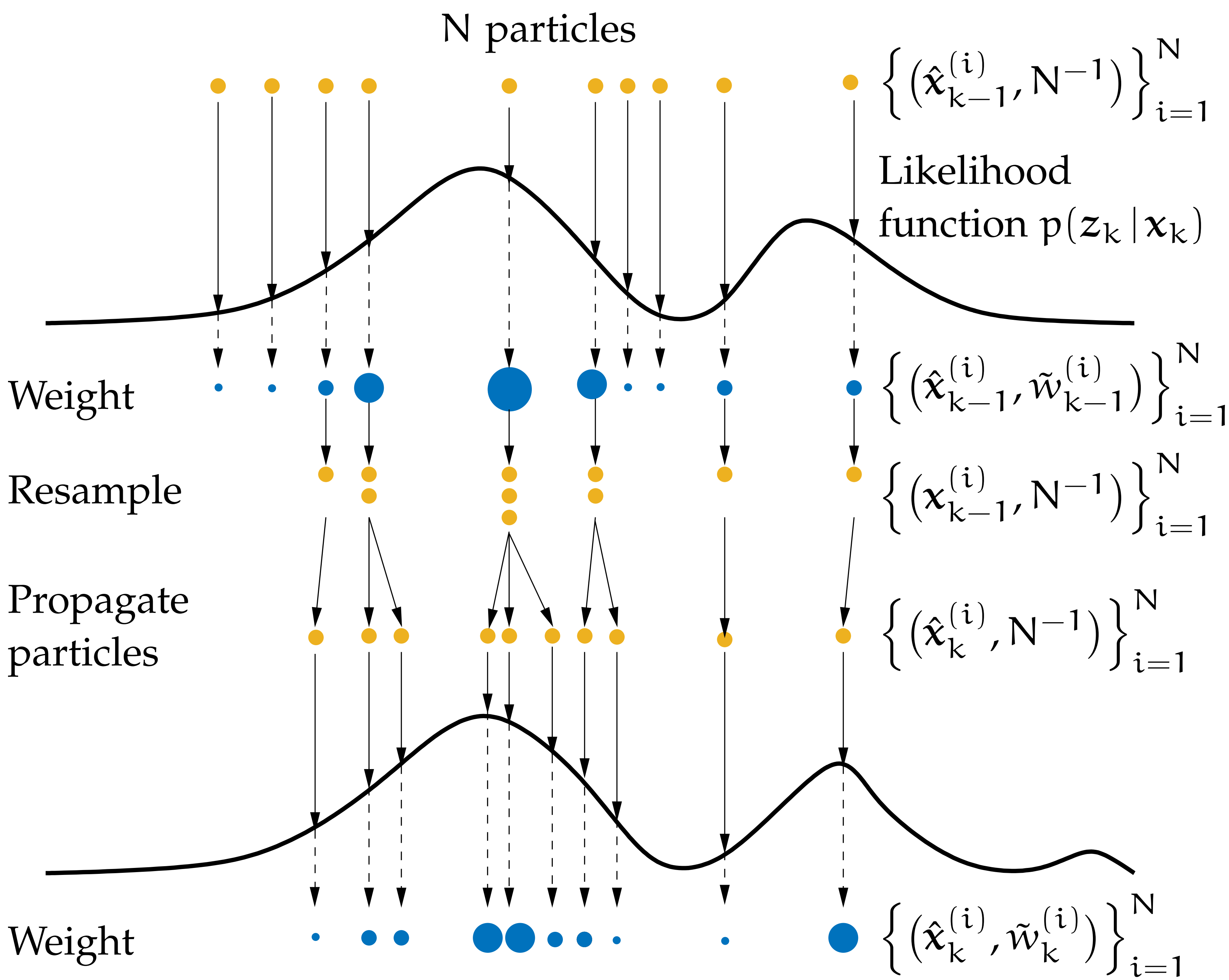


AWGN: Additive white Gaussian Noise

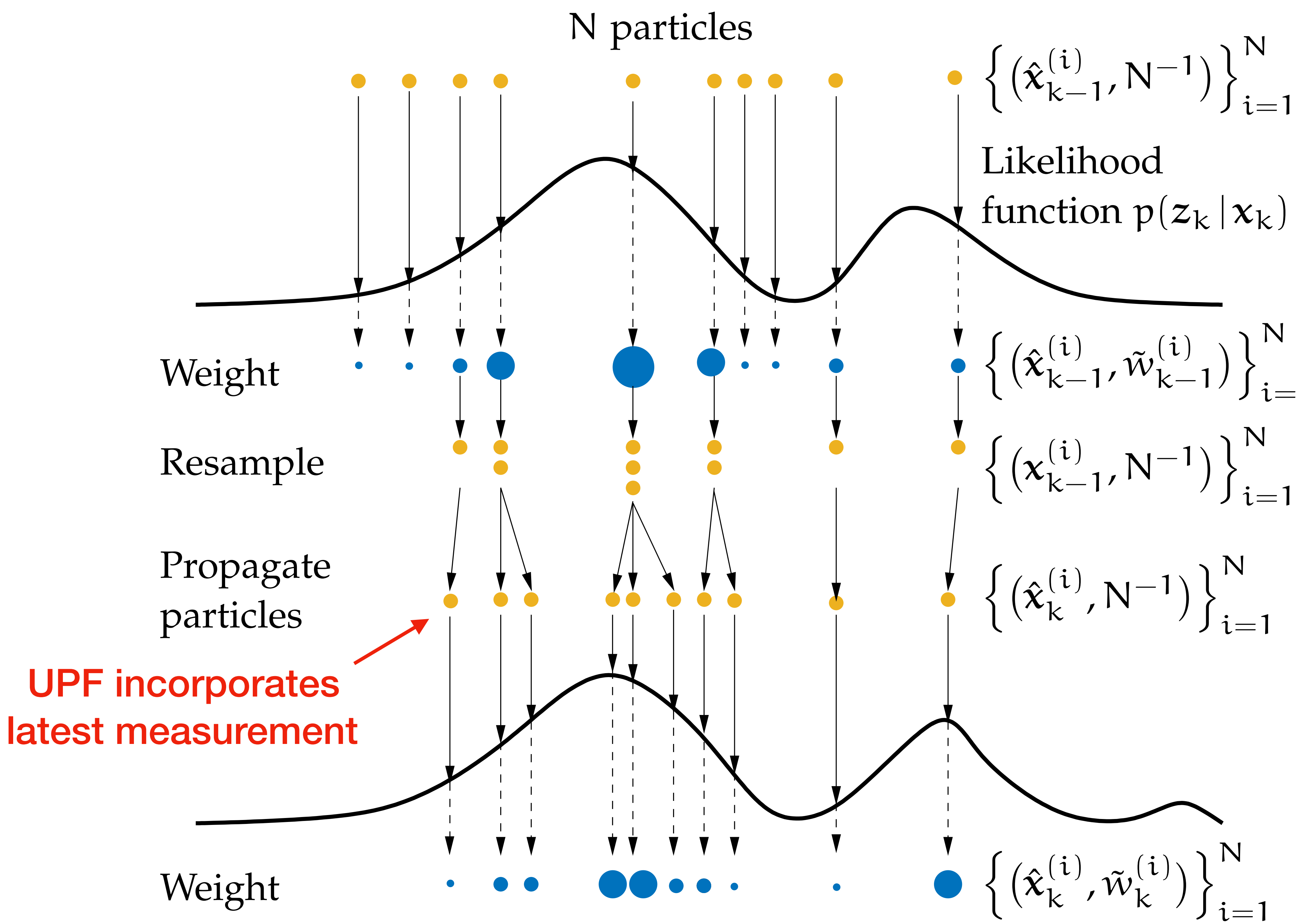
Particle Filters

- Based on sequential Monte Carlo method
- Approximate the posterior probability distribution of the state using a discrete probability distribution (point mass estimate)
- Generate hypotheses of the current state based on the past state (sample from proposal distribution)
- Evaluate the likelihood of these hypotheses using the latest observation (weighting)
- Resample to avoid increasingly skewed posterior distribution

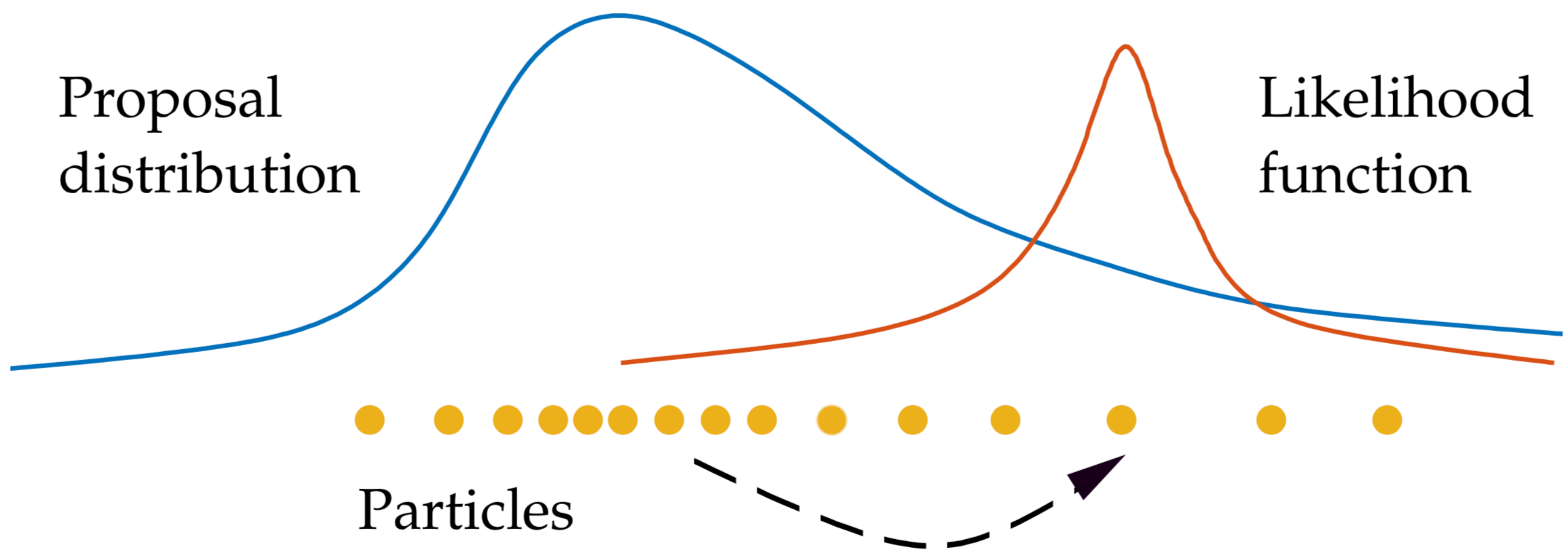
Particle Filters



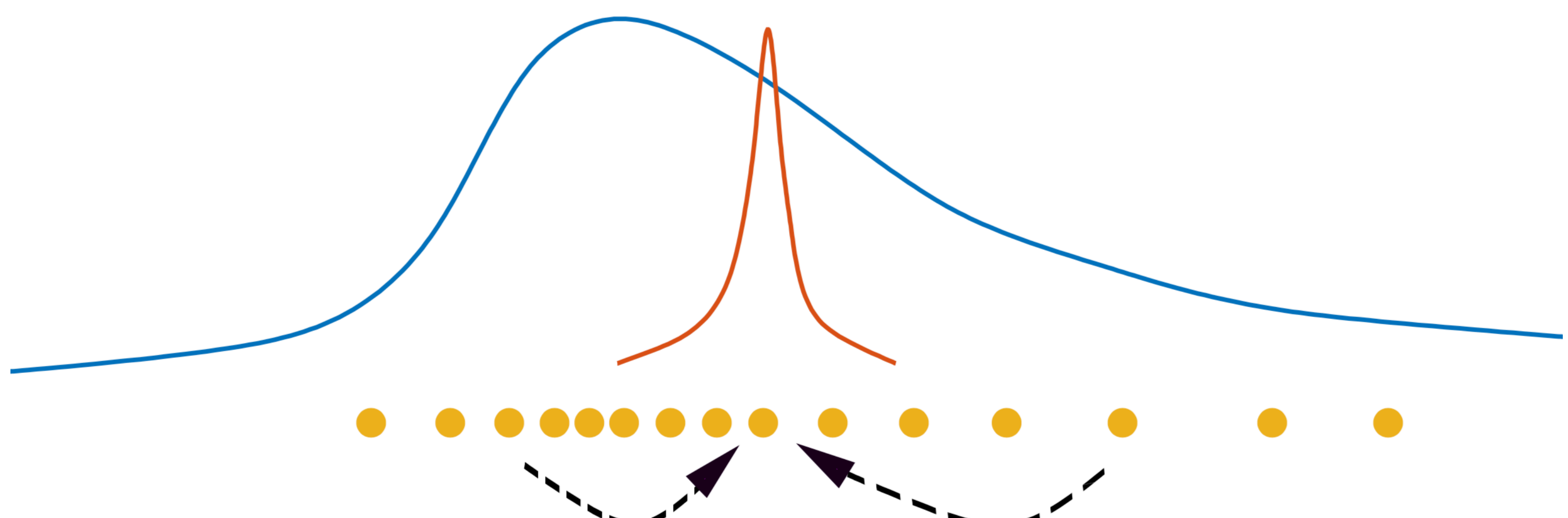
Particle Filters



Unscented Particle Filter



1. Little overlap



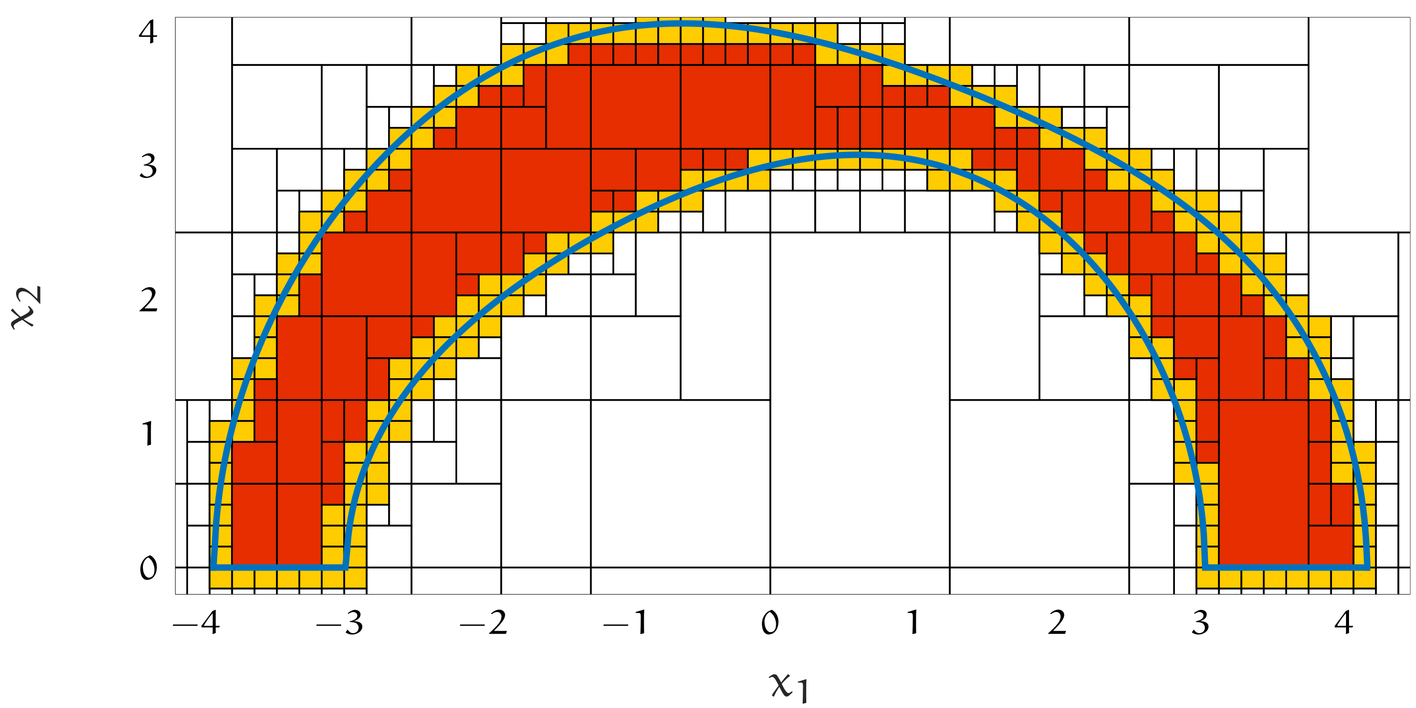
2. Peaked likelihood

Forward-backward Contractor

- Constraint satisfaction problem $\mathcal{H} : \left(\mathbf{f}(\mathbf{x}) = 0, \mathbf{x} \in [\mathbf{x}_0]\right)$
  - Set of constraints describing solution set
  - Initial box $[\mathbf{x}_0]$ containing all feasible solutions
- Replaces initial box with a smaller box without discarding feasible solutions and without bisecting it
- Implemented by the HC4 algorithm (Frédéric Benhamou et. al, 1999)
- Demands little computational resources

Set Inverter Via Interval Analysis

- Set inversion problem $\mathbb{S} = \mathbf{f}^{-1}(\mathbb{Y}) = \{\mathbf{x} \in \mathbb{R}^n \mid \mathbf{f}(\mathbf{x}) \in \mathbb{Y}\}$
- Initial box to which the solution set is guaranteed to belong
- Bisect and test ⇒ narrow down the solution set
- Arbitrarily precise
- Computationally more demanding than the contractor



Probabilistic vs. Bounded-error Localisation

Probabilistic filters

- Point estimate of position, e.g. minimum mean-squared error estimate
- No correct solution ensured ⇒ divergence possible

Bounded-error estimators

- Region that is guaranteed to contain the true robot position
- Constant probability over confined region ⇒ information yield may not be sufficient in practice

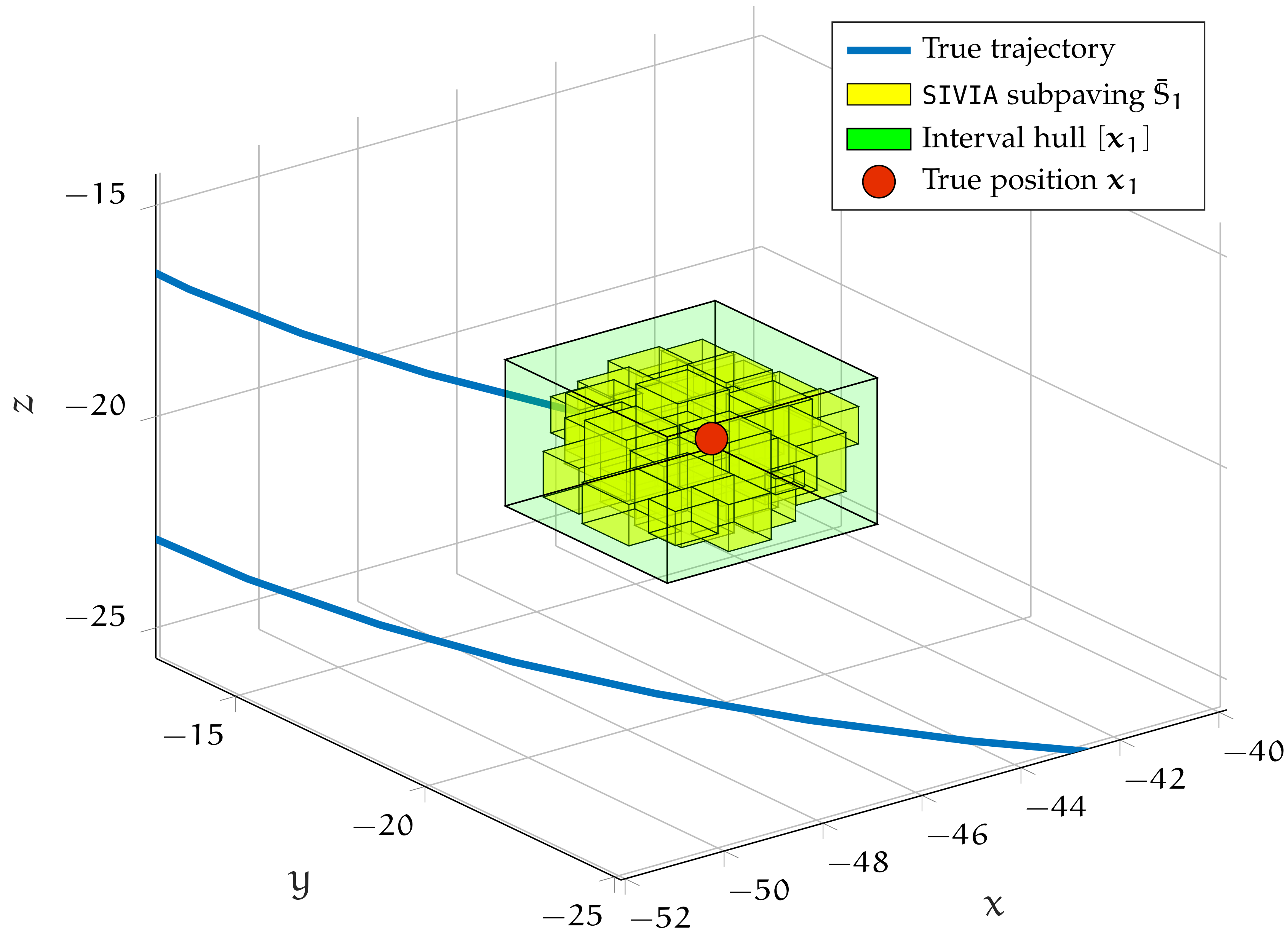
Novel Hybrid Localisation Algorithms

- Rationale is to perform Monte Carlo Localisation over a limited region of the search space
- Increase the particle density in regions of high observation likelihood without increasing the absolute number of particles
- Enhance the localisation accuracy and speed of convergence
- Bounded-error estimate is only computed once in the beginning and once after kidnapping
- Reduce computational complexity compared to previous methods (Neuland et. al 2014)

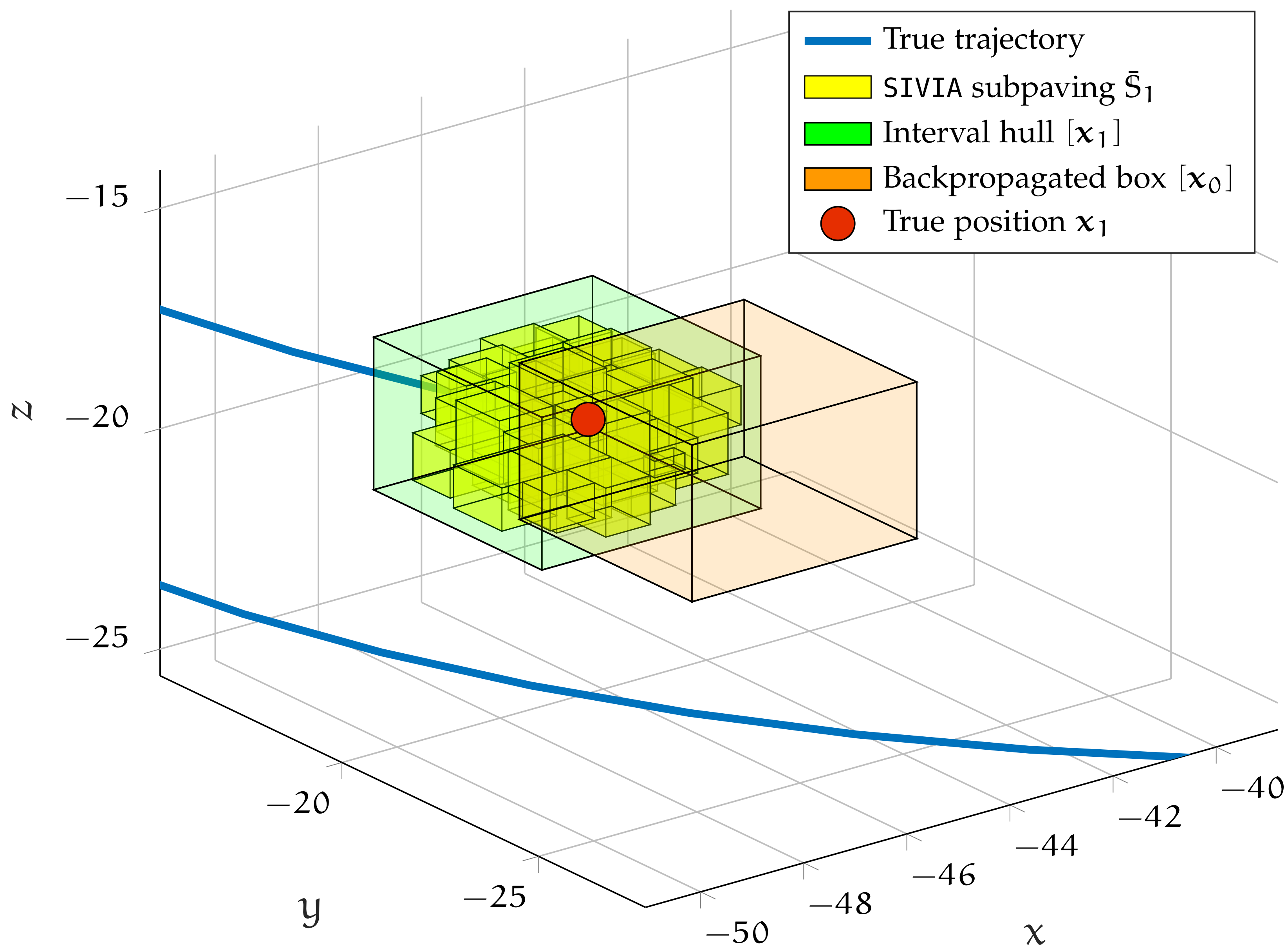
Novel Hybrid Localisation Algorithms

- Satisfaction of given constraints that are based on geometrical considerations of the environment are tested
- The particles not satisfying the constraints receive a weight of zero
- Zero-weighted particles are not resampled
- When all particles have a weight of zero, the robot has been kidnapped $\Rightarrow$ localisation failure
- Global localisation process is restarted

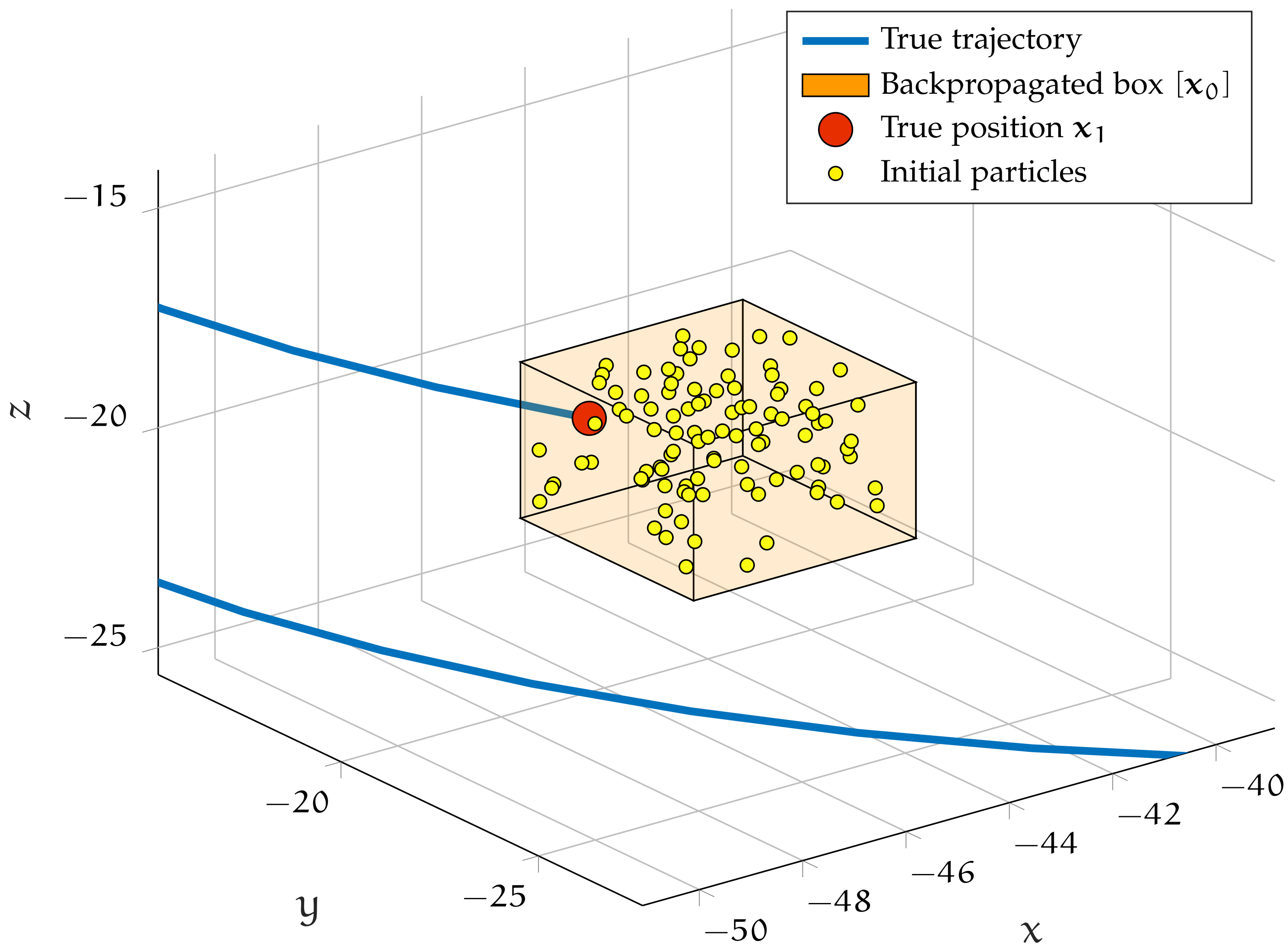
Novel Hybrid Algorithms – Bounded-error estimation



Novel Hybrid Algorithms – Backward propagation

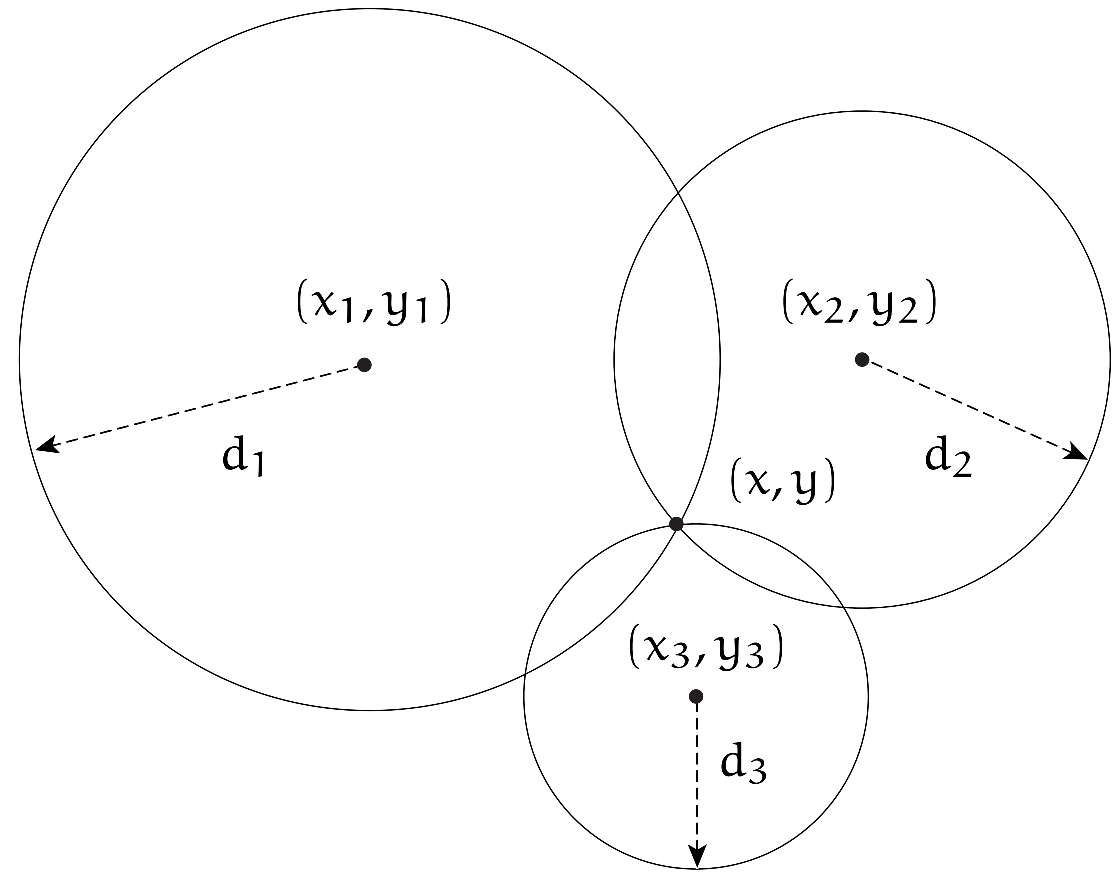


Novel Hybrid Algorithms – Sample from Initial Distribution



Constraints

- Lateration
- Euclidean distance
- Inflate measurement model

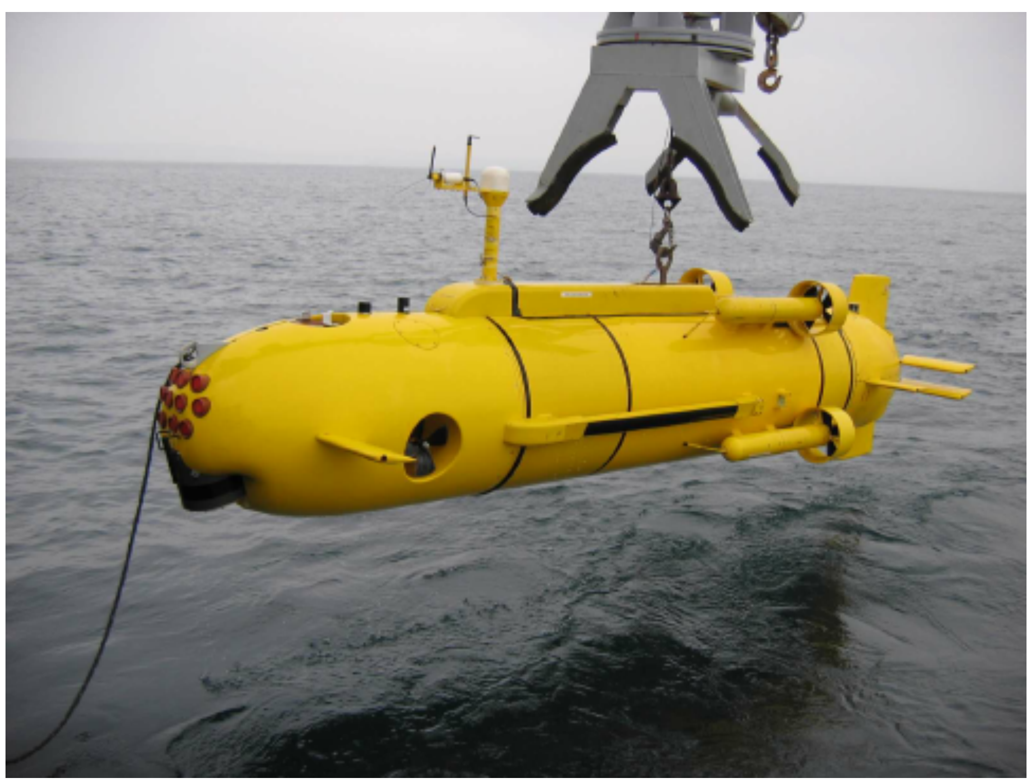


$$
\begin{aligned}
[\mathbf{z}_k] &= \begin{bmatrix} [d_{1,k} - \xi\sigma_d, d_{1,k} + \xi\sigma_d] \\ [d_{2,k} - \xi\sigma_d, d_{2,k} + \xi\sigma_d] \\ \vdots \\ [d_{n_z,k} - \xi\sigma_d, d_{n_z,k} + \xi\sigma_d] \end{bmatrix} \\
&= [\mathbf{h}_k]([\mathbf{x}_k], 0) \\
&= \begin{bmatrix} \sqrt{([x_k] - x_1)^2 + ([y_k] - y_1)^2 + ([z_k] - z_1)^2} \\ \sqrt{([x_k] - x_2)^2 + ([y_k] - y_2)^2 + ([z_k] - z_2)^2} \\ \vdots \\ \sqrt{([x_k] - x_{n_z})^2 + ([y_k] - y_{n_z})^2 + ([z_k] - z_{n_z})^2} \end{bmatrix}
\end{aligned}
$$

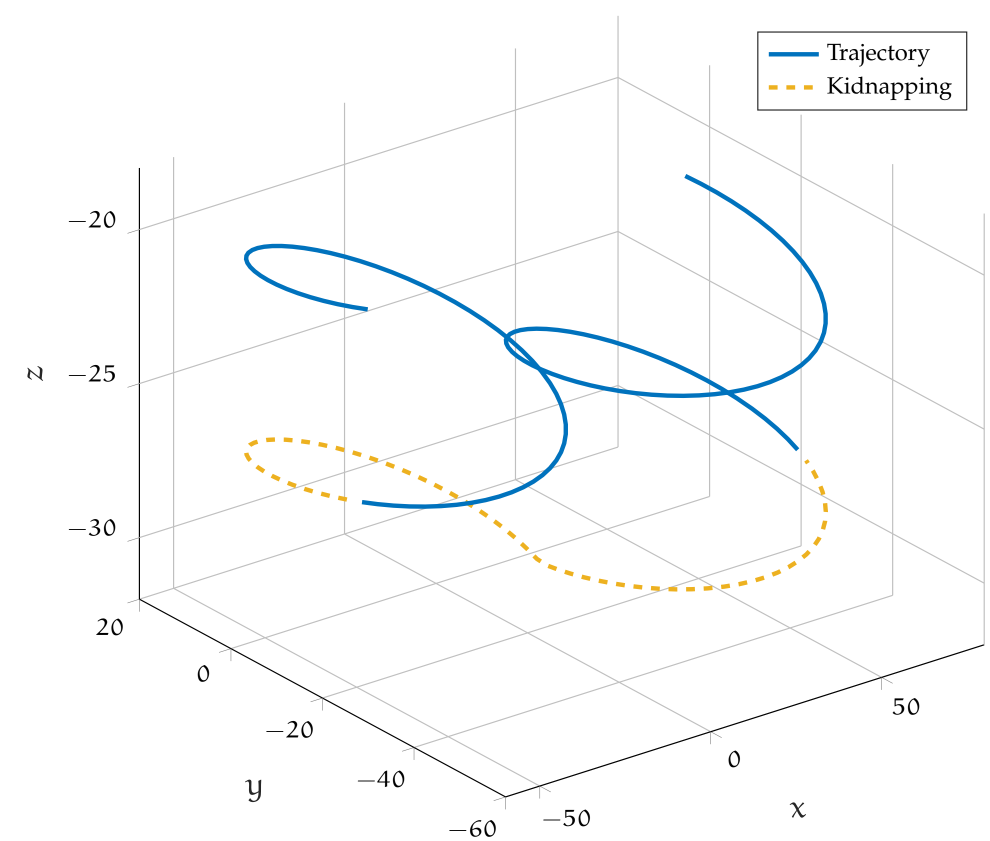
Experiments

- Existing simulations from an autonomous underwater robot generated by the MORSE Simulator

- Added landmarks and computed distance measurements

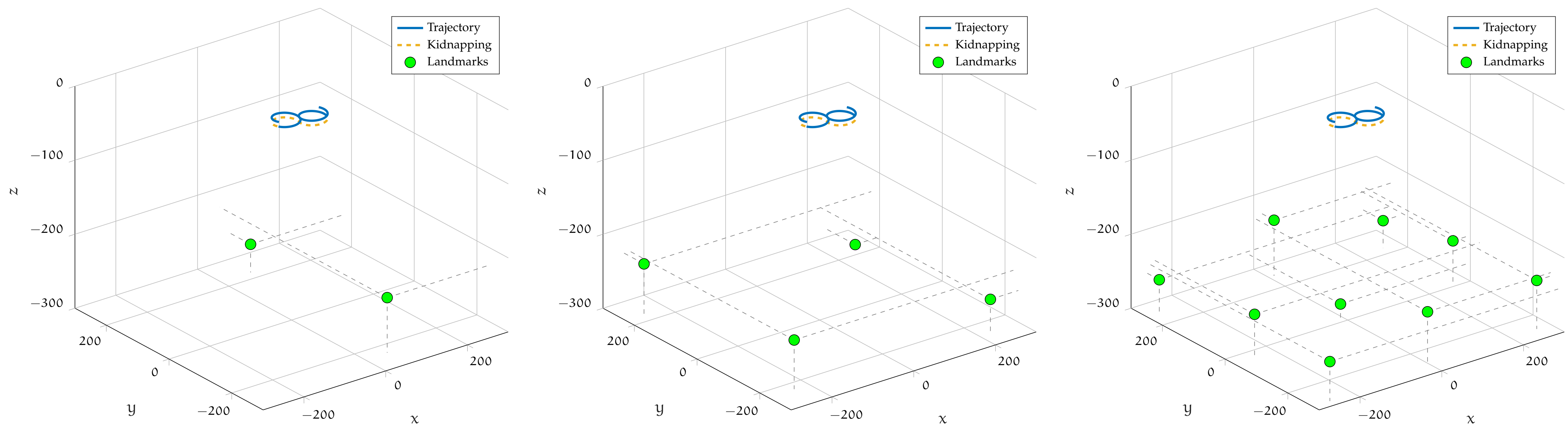


UAV *Redermor*, source: Groupe d’Etude Sous-Marine de l’Atlantique

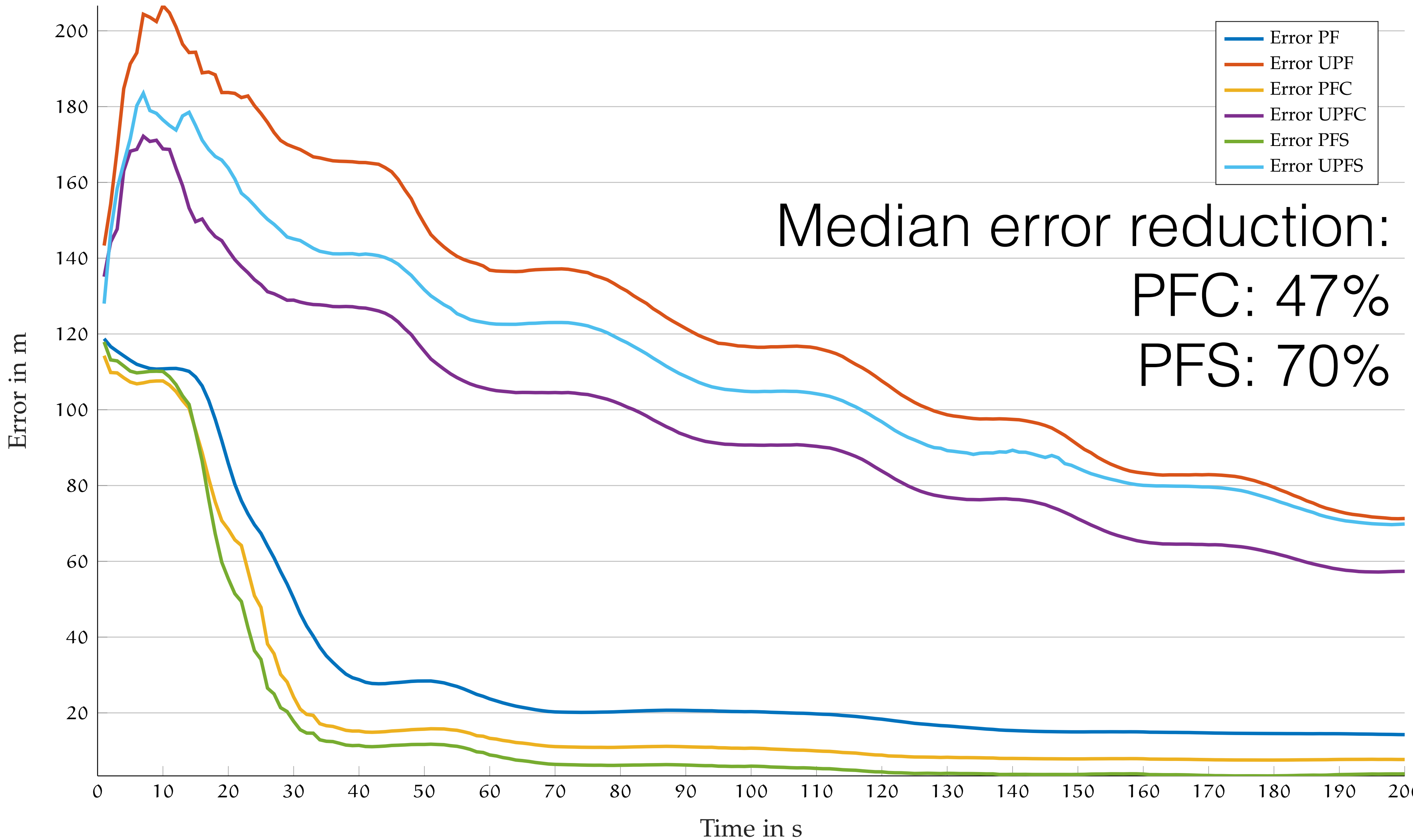


Experiments

- Three scenarios with two, four and nine landmarks on the seabed, with and without kidnapping, 100 runs
- 10 000 particles for the bootstrap particle filters
- 100 particles for the unscented particle filters



Results – 2 Landmarks – Wake-up Robot Problem

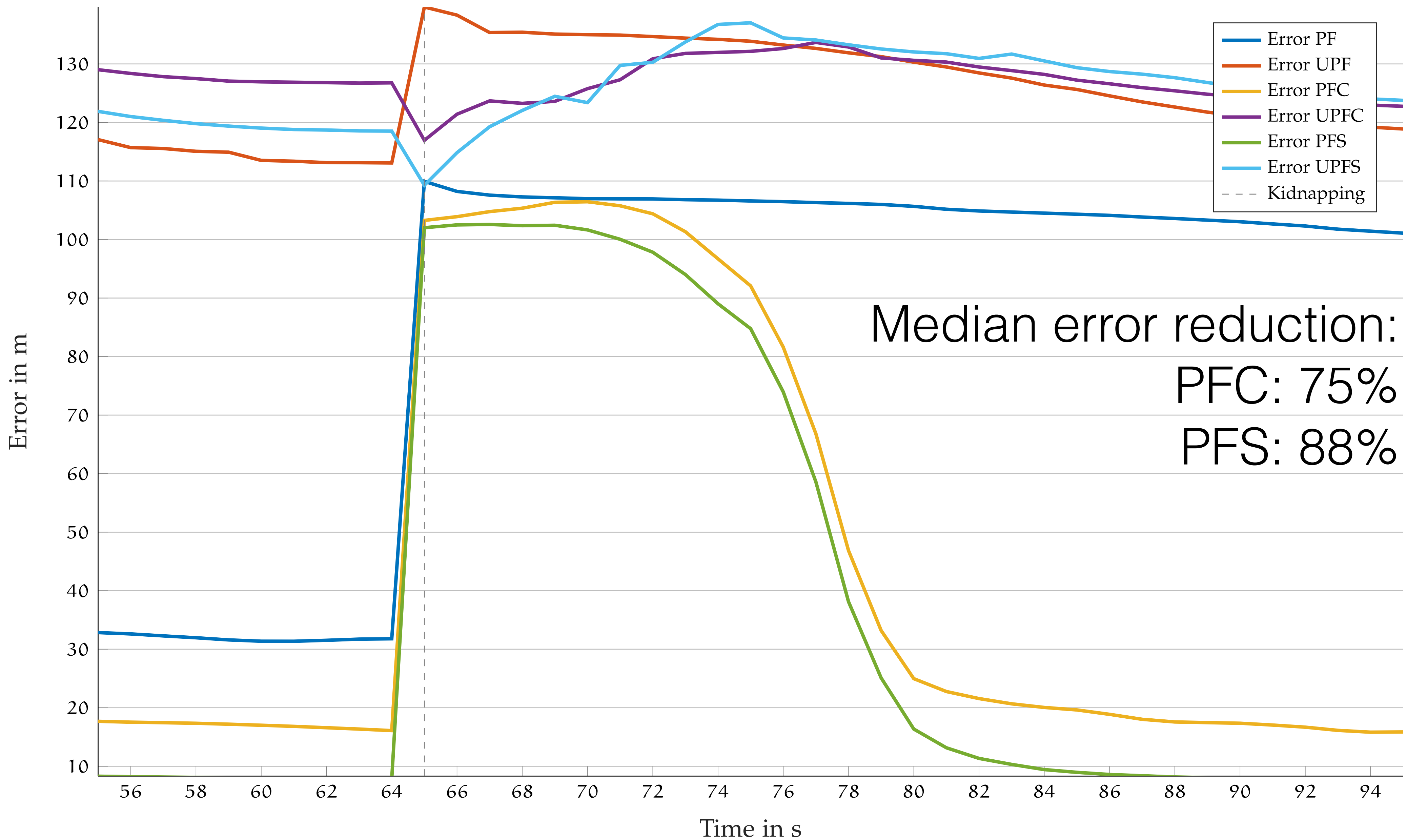


Median error reduction:

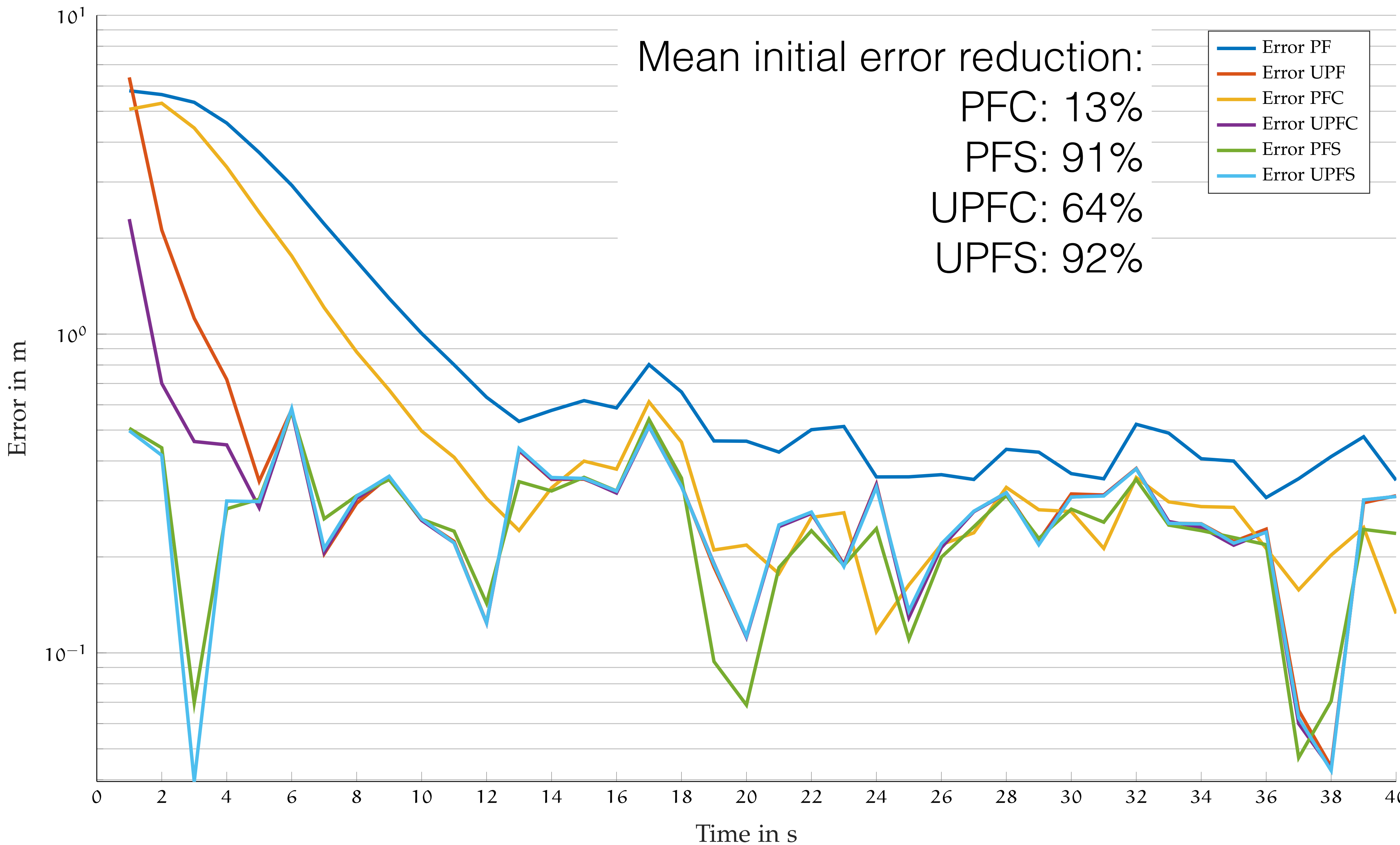
PFC: 47%

PFS: 70%

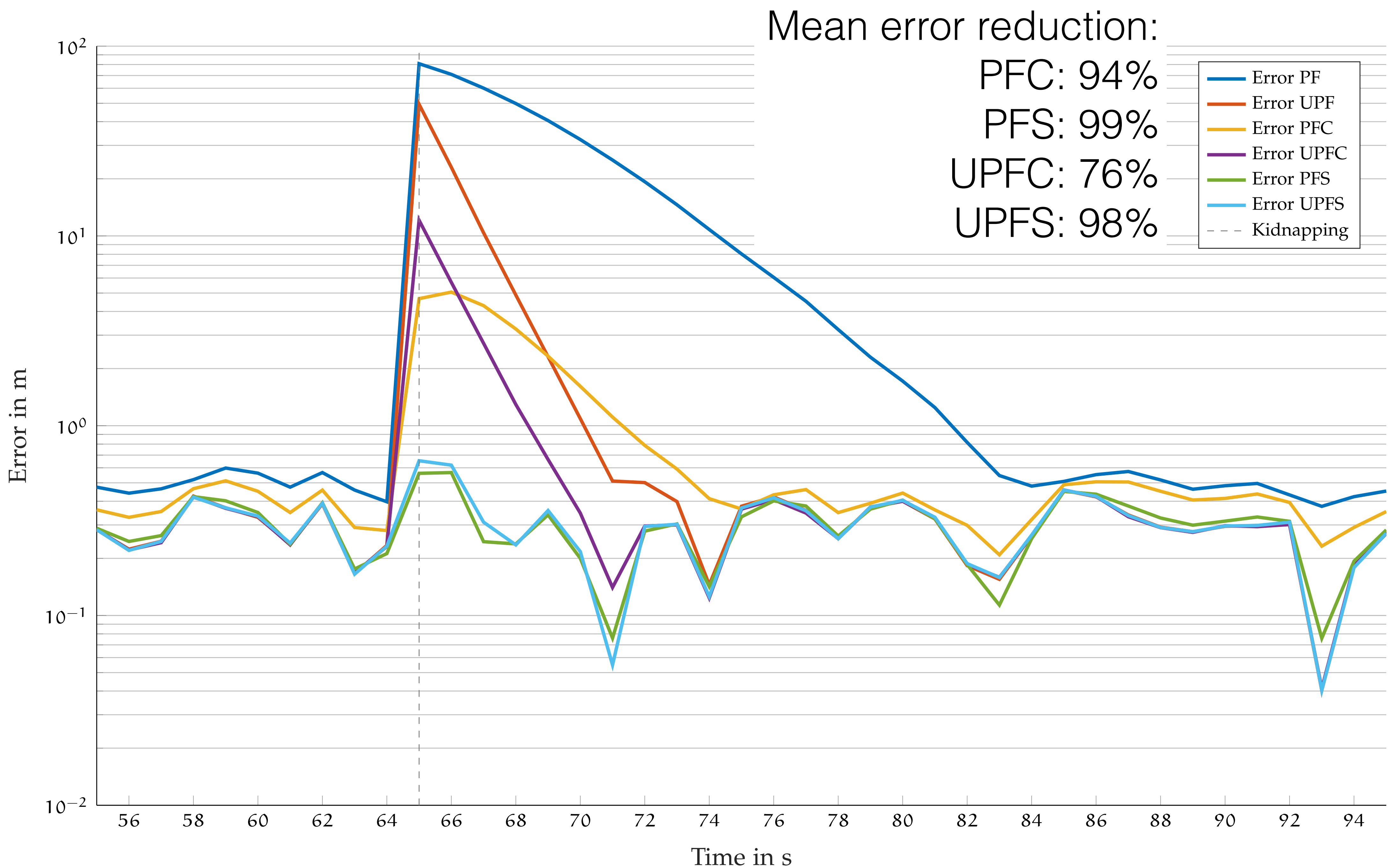
Results – 2 Landmarks – Kidnapped Robot Problem



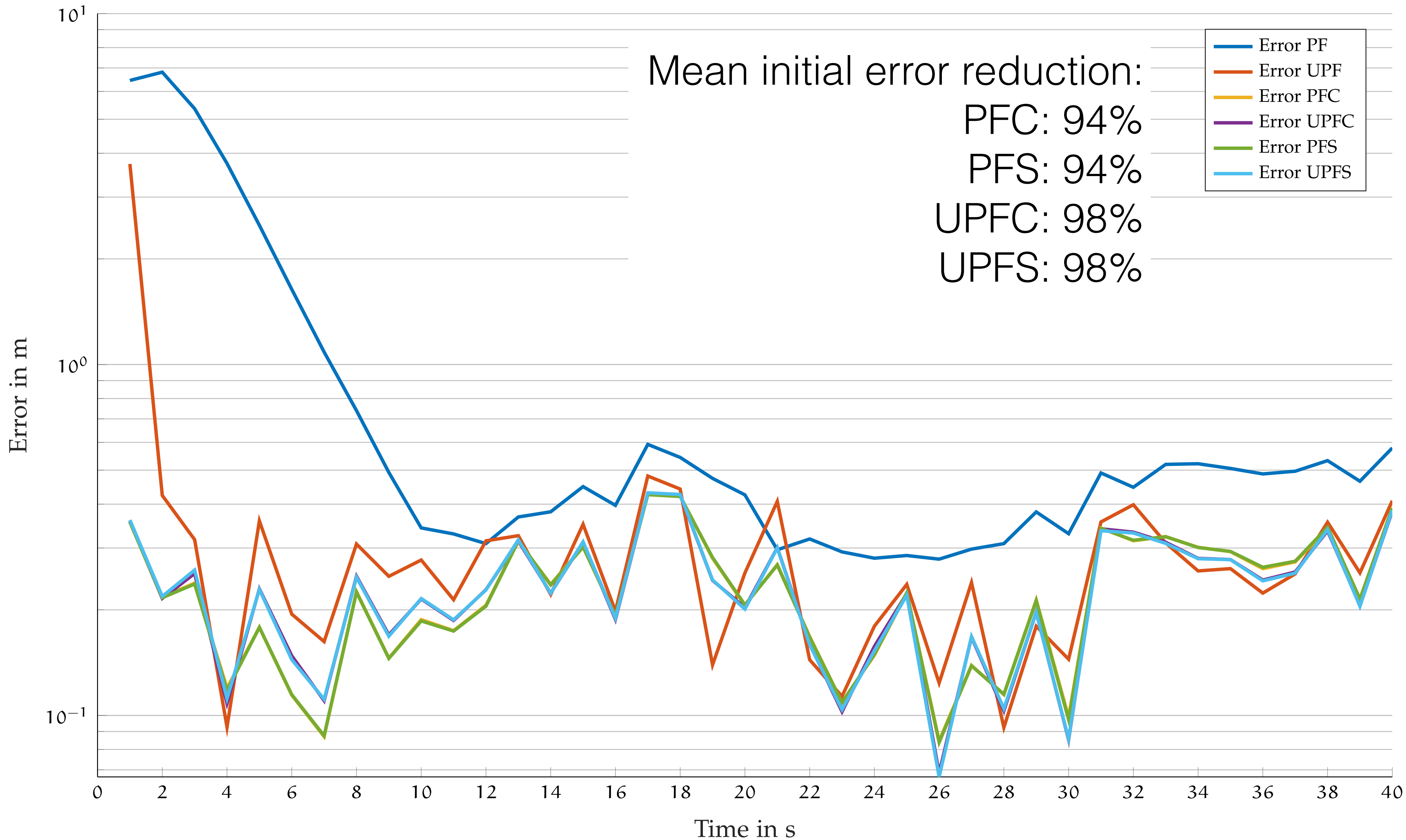
Results – 4 Landmarks – Wake-up Robot Problem



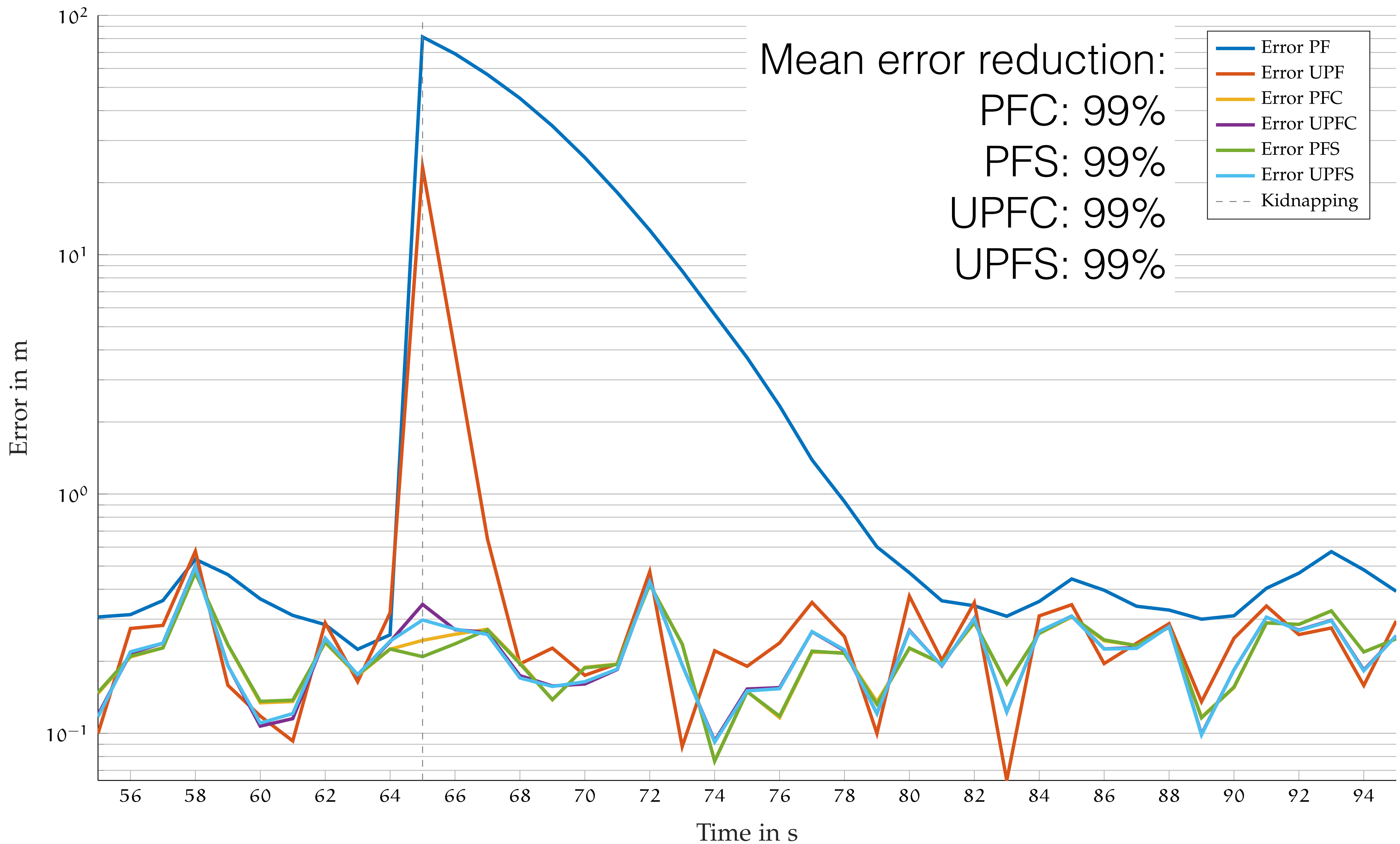
Results – 4 Landmarks – Kidnapped Robot Problem



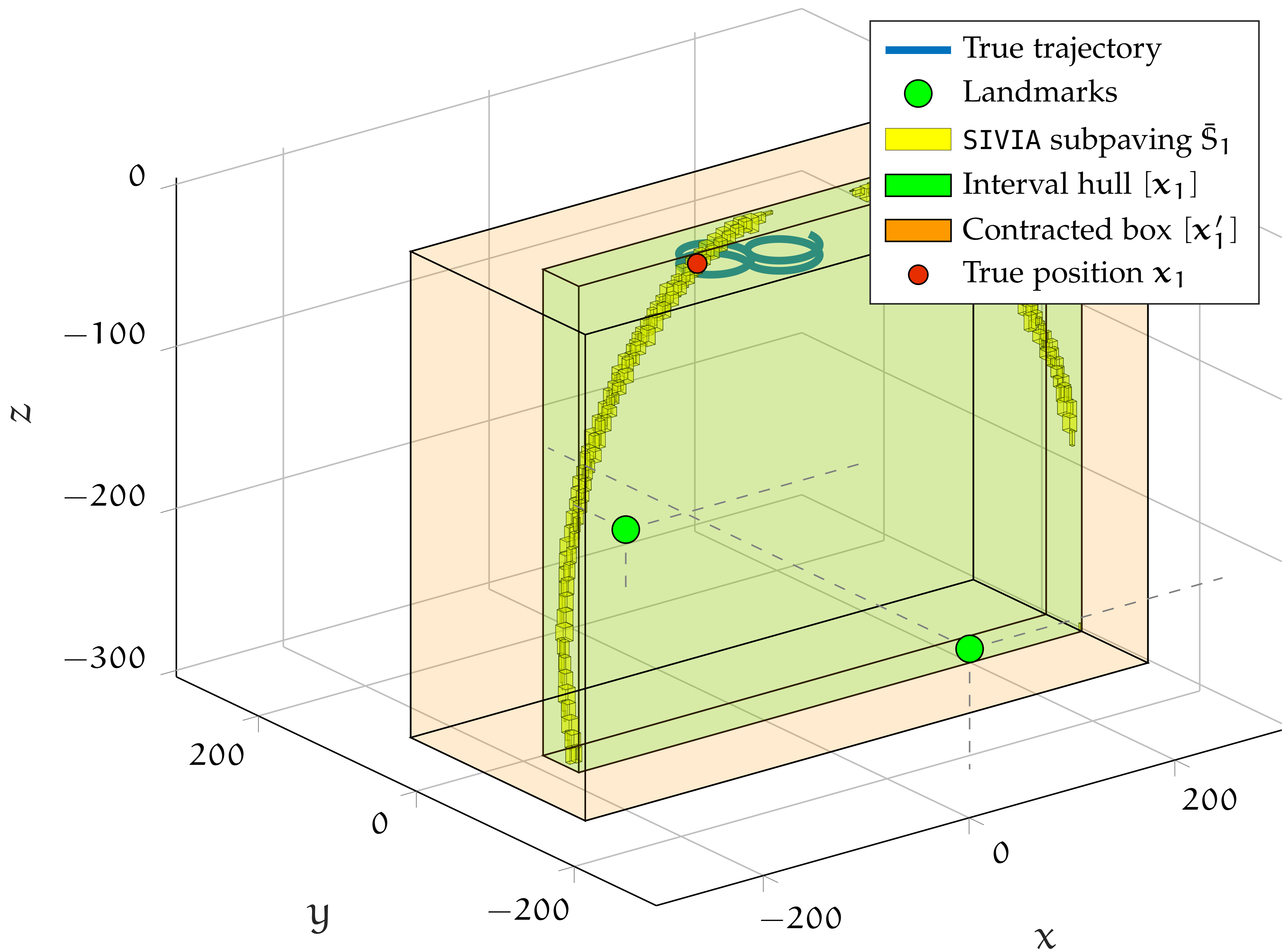
Results – 9 Landmarks – Wake-up Robot Problem



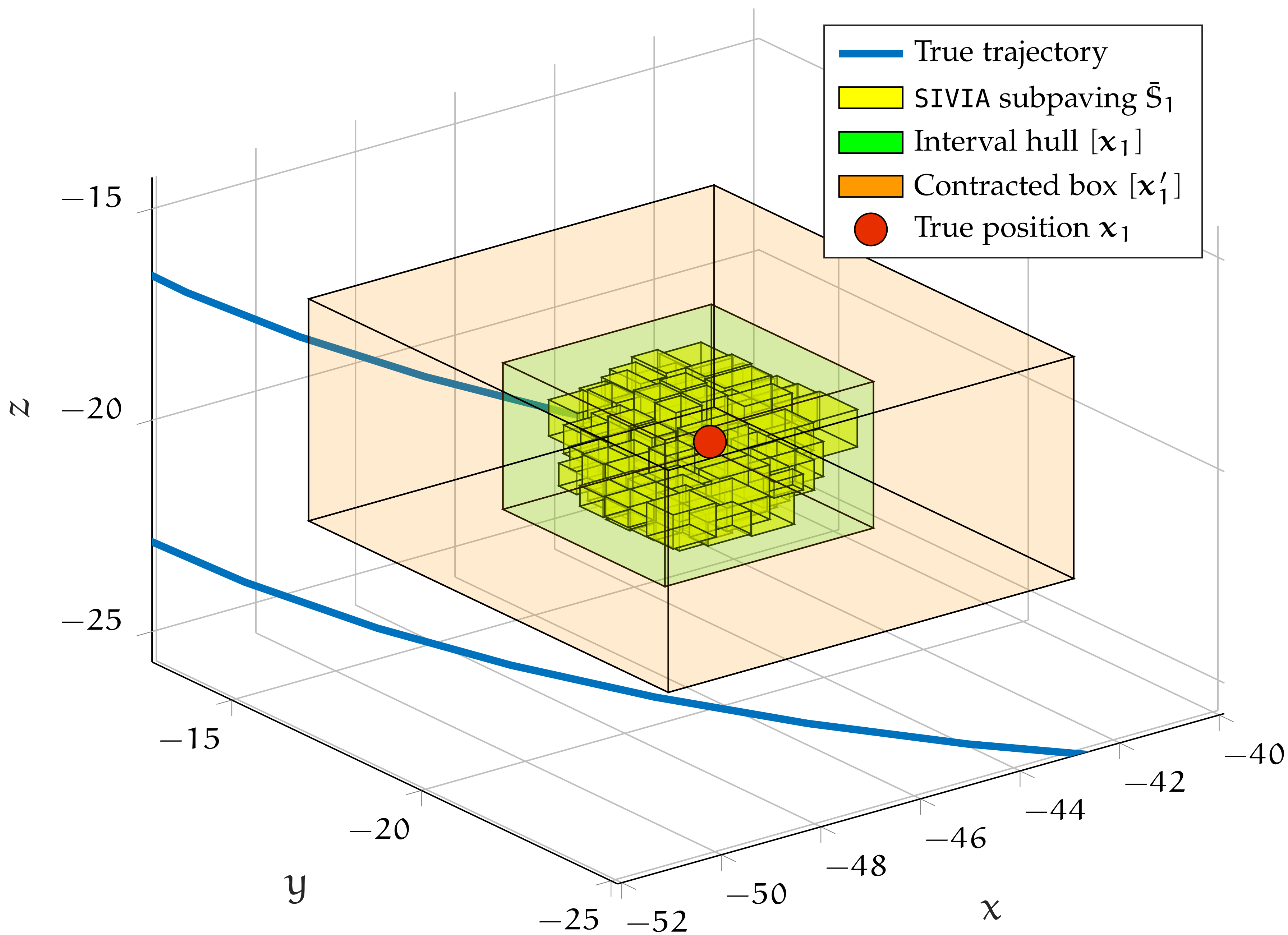
Results – 9 Landmarks – Kidnapped Robot Problem



Results – 2 Landmarks – HC4 vs. SIVIA



Results – 9 Landmarks – HC4 vs. SIVIA



Conclusion

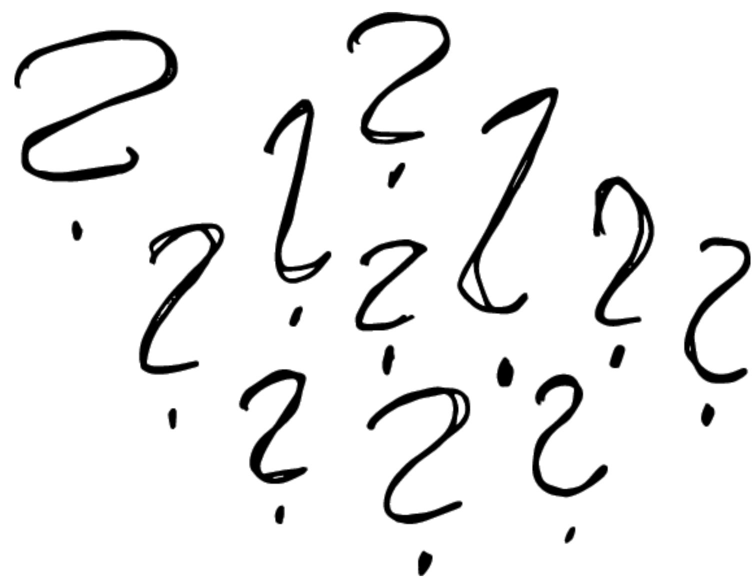
- All four new hybrid filters are generally able to solve the wake-up and kidnapped robot problem more accurately than the conventional filters
- Improvement of up to 88% in the median estimation error
- Mean initial estimation error reduced by up to 94%
- Mean error after kidnapping is reduced by up to 99%
- Improvement is particularly pronounced when 4 or 9 landmarks are present
- With 4 landmarks UPFC better than PFC at 100 times fewer particles.
- Instead of 200 bounded-error estimations 1 + 1 per kidnapping for the estimated scenarios sufficient
- The four novel filters are applicable to any landmark-based localisation scenario

Future Work

- Dynamically replace the particle filter by a Kalman filter when:
  - One subpaving results from the bounded-error estimation
  - The volume of the confined region is smaller than some threshold
  - Particle variance is smaller than some threshold ⇒ filter converged
  - Tracking ⇒ uni-modal Gaussian distribution appropriate
- Dynamically vary measurement noise covariance of unscented Kalman filter to influence the impact of the UKF on the proposal distribution ⇒

  keep benefits of UPF when more than 2 landmarks are available but do bootstrap filtering when only 2 landmarks are available

Questions?



References

[27] Renata Neuland, Jeremy Nicola, Renan Maffei, Luc Jaulin, Edson Prestes and Mariana Kolberg. „Hybridization of Monte Carlo and Set-membership Methods for the Global Localization of Underwater Robots“. In: *International Conference on Intelligent Robots and Systems*. Sept. 2014.

[28] Renata Neuland, Renan Maffei, Luc Jaulin, Edson Prestes and Mariana Kolberg. „Improving the Precision of AUVs Localization in a Hybrid Interval-Probabilistic Approach Using a Set-Inversion Strategy“. In: *Unmanned Systems* 02 (Oct. 2014), pp. 361–375.

[106] Luc Jaulin, Michel Legris and Frédéric Dabe. „GESMI, un logiciel pour l'aide à localisation de mines sous-marines“. In: *JIME* (2006).