Toward Online Probabilistic Path Replanning

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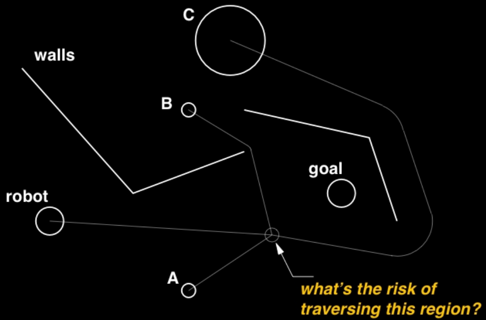
Outline

- Algorithm Overview
- SLIP and ECKF
- Co-Occurrence Estimation
- E* Weighted Region Planner
- PNF: Integrating It All
- Conclusion and Outlook

Problem Statement



world "hard" to model

- closely sensor-based
- unknown trajectories

"don't think, act!"

- worst-case risk
- local collision avoidance

Comparison with "Known-Trajectory" Approaches

- very cluttered dynamic environments
- frequent changes to environment model
- static objects = environment topology
- hardly predictable movement = risky regions
- use "worst-case" scenarios

$\Rightarrow$ **Probabilistic Navigation Function**

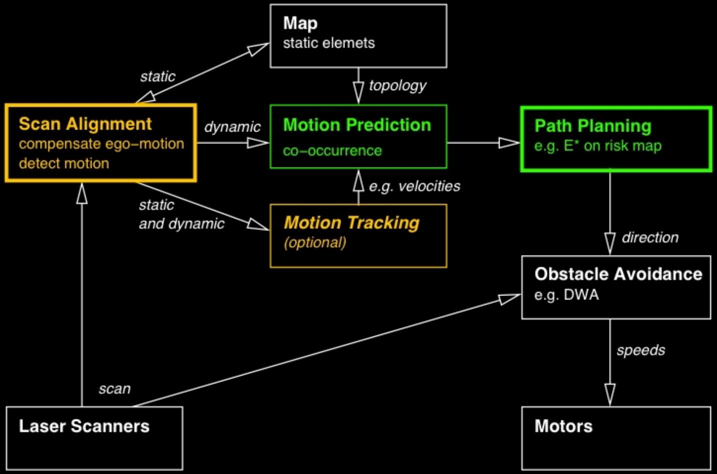
Requirements for PNF

- static object positions
- dynamic object positions, shapes, and speeds
  - *sensor* based
  - circular shapes for simplicity
  - estimated or assumed *max* speed
- estimation of co-occurrence probability
- weighted region planner

High-Level Steps

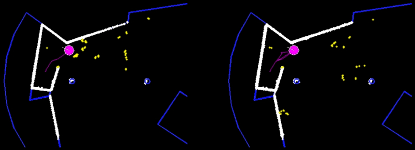
Input: Laser scanner data
1: SLIP/ECKF $\Rightarrow$ extract and track motion
2: Determine co-occurrence risk
3: E* $\Rightarrow$ navigation function
Output: Direction for reactive obstacle avoidance

PNF Architecture



SLIP and ECKF

align scans



robustly detect and track motion

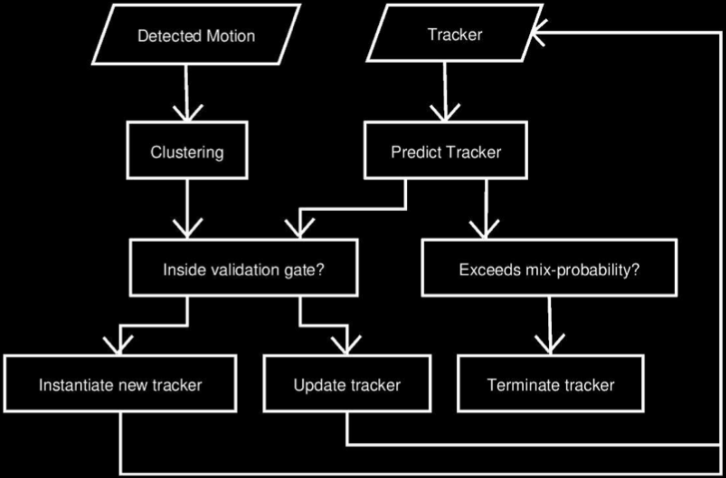
Motion Tracking: Challenge and Approach

robust tracking despite occlusion and uncertainty

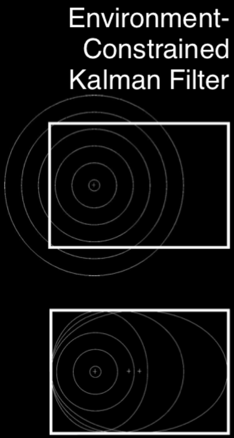
- compensate ego-motion
  - ICP variant called *SLIP*
  - probabilistic distance metric
- constrained object motion
  - multi-object Kalman filter called *ECKF*
  - topology via particle-filtering

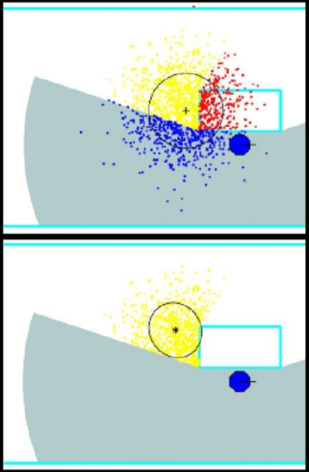
[Jensen, 2005]

Motion Tracking Flow Diagram

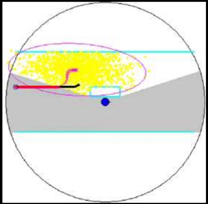


Motion Tracking: Environment Constraints



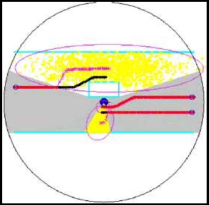


Motion Tracking: Videos

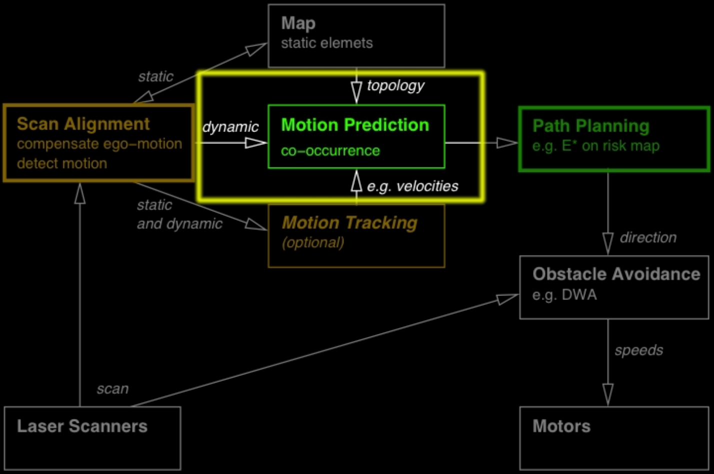


`1obj_ECKF_series.wmv`
environment-constrained particles

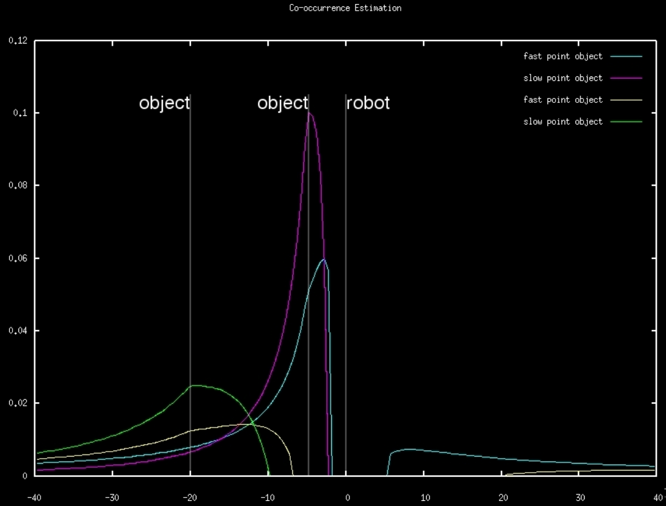
`3obj_ECKF_series.wmv`
tracking robustly through occlusions



Co-Occurrence Estimation



1D Co-Occurrence Estimation



1D Case Computations

assumptions

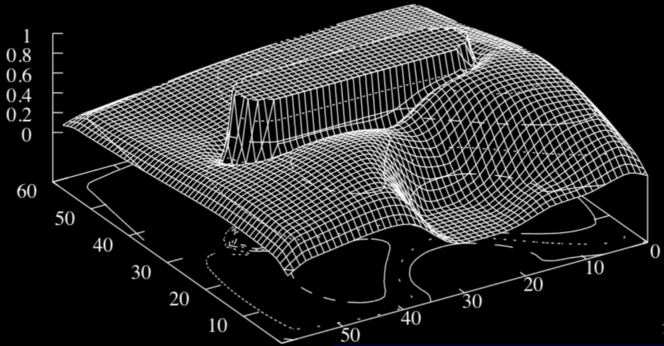
- point object and robot
- object speed v_i
- discretized process, $N = \lceil \lambda_r / \delta \rceil$
- can change direction at each step

$$\text{if } (v_1, v_2) \in [-v_i, 0) \times [0, v_i) \text{ where } v_{1,2} = \frac{v_r (\lambda_i \mp \delta)}{2\lambda_r}$$

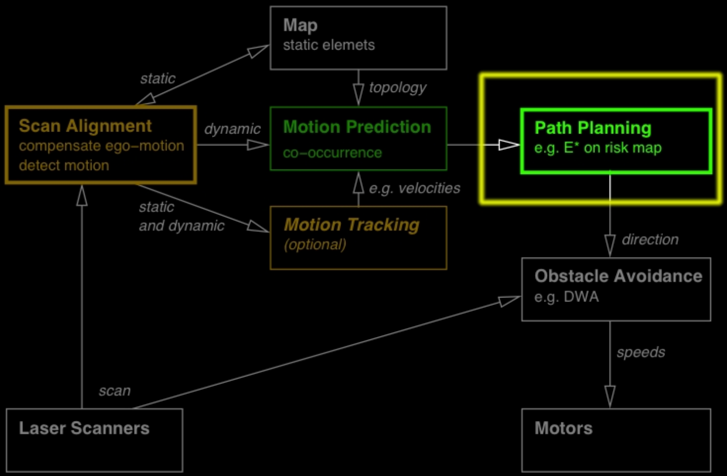
$$p_{c,m} = \frac{v_2 - v_1}{v_i} - \frac{N-1}{2Nv_i^2}\left(v_2^2 + 2v_1^2\right)$$

More Realistic Setting

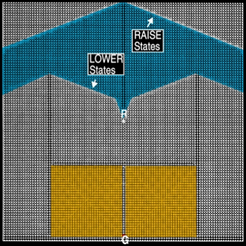
- N-dimensional *(currently 2D)*
- non-point objects and robot, *(currently circles)*
- λ is topologically correct distance
- *reduce λ by object and robot radii* (future work)

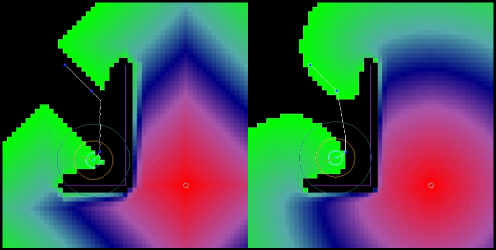


E* Weighted Region Planner



Interpolated Weighted Path Replanning





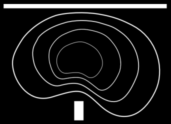
D* [Stentz, 1995]

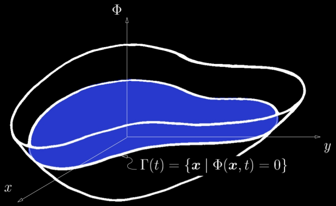
- *edge* costs
- local cost changes

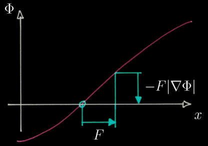
E* [Philippsen, 2004]

- *cell* costs
- less "local" cost changes
- smooth distance measure

Level Set Method Interpolation







$$\begin{cases} \Gamma(t): & \text{closed } (N-1)\text{D surface} \\ \Phi(\vec{x}, t): & \mathbb{R}^N \to \mathbb{R} \\ t_0: & \Phi(\vec{x}, t=0) = \pm d(\vec{x}, \Gamma(t=0)) \\ \Rightarrow & \Gamma(t) = \{\vec{x} \mid \Phi(\vec{x}, t) = 0\} \end{cases}$$

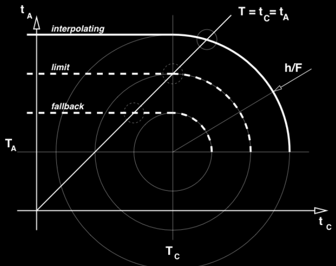
...solve:

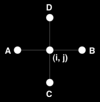
$$\frac{\partial \Phi}{\partial t} + F|\nabla\Phi| = 0$$

Solving the LSM Equations

1st order *upwind* gradient, “Fast Marching” $\Rightarrow$

$$\sum_{i=1}^{\mathcal{N}} \left(\max(D^{-x_i} T_\iota, 0)^2 + \min(D^{+x_i} T_\iota, 0)^2 \right) = \frac{1}{F_\iota^2}$$

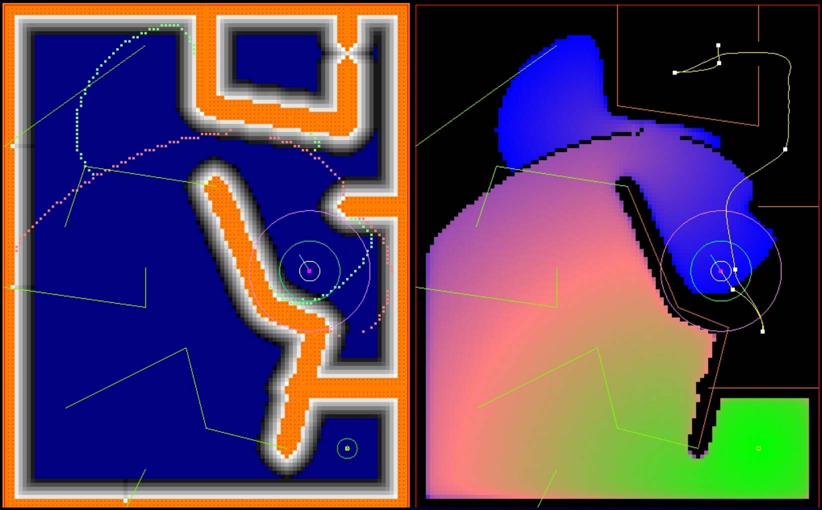




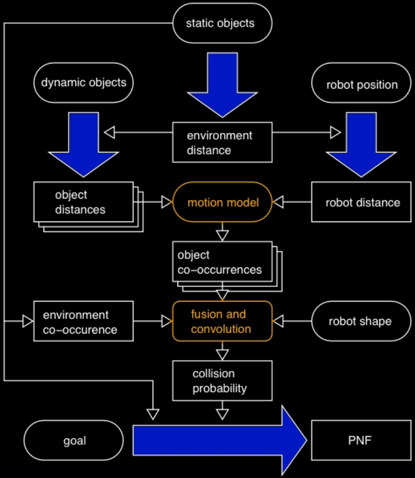
$$(T - T_A)^2 + (T - T_C)^2 = h^2/F^2$$

$$\Leftrightarrow \begin{cases} T = t_A = t_C \\ (t_A - T_A)^2 + (t_C - T_C)^2 = h^2/F^2 \end{cases}$$

E* Demonstration

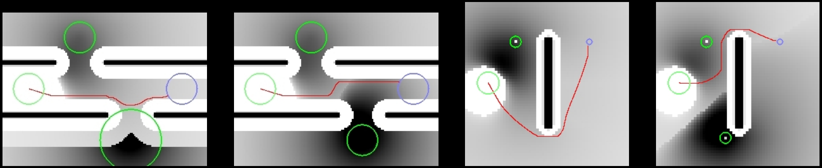


PNF Flow Diagram

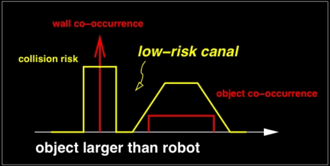


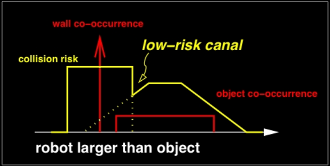
- static objects
  ⇒ topology
- dynamic objects
  ⇒ co-occurrence
- integration ⇒ risk map
- E^* ⇒ gradient descent

PNF Demonstration



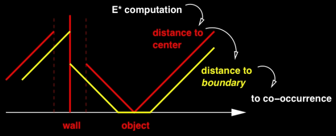
"Fusion and Convolution" Quirks

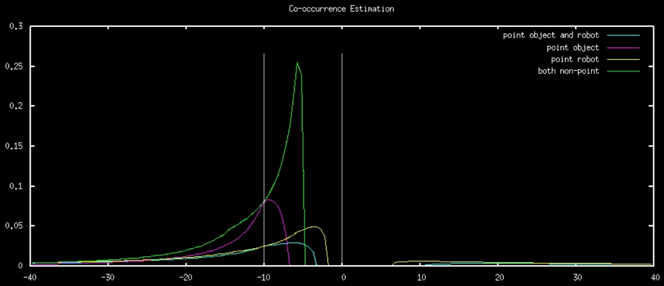




- low-cost "canals" at obstacle boundaries
- strong tendency to "hug walls"
- related problem at grid boundary

Distance-Correction Step





$\Rightarrow$ fuse co-occurrences along robot boundary after λ correction

Conclusion and Outlook

approach

- weighted regions on grid
- sensor-based world model
- trade-off risk vs. distance

future work

- resurrect SLIP/ECKF
- implement new $\mathcal{W} \rightarrow \mathcal{C}$ transform
- real-world tests
- reusability

`http://estar.sourceforge.net/`