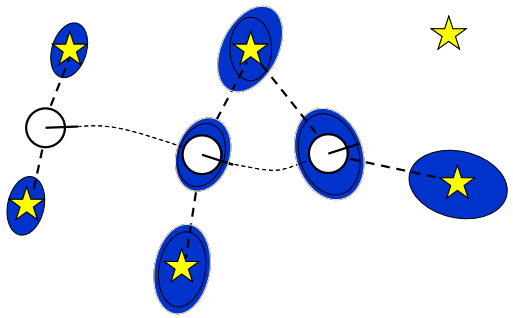
CSE-473

Mobile Robot Mapping

Mapping with Raw Odometry

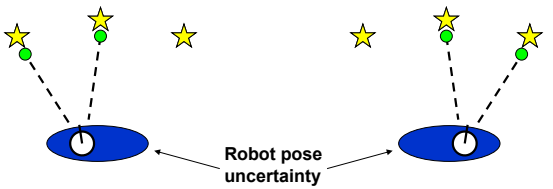
Why is SLAM a hard problem?

SLAM: robot path and map are both **unknown**



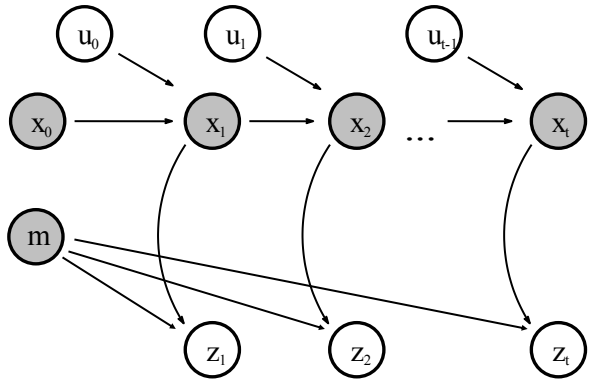
Robot path error correlates errors in the map

Why is SLAM a hard problem?



- In the real world, the mapping between observations and landmarks is unknown
- Picking wrong data associations can have catastrophic consequences
- Pose error correlates data associations

Graphical Model of Mapping



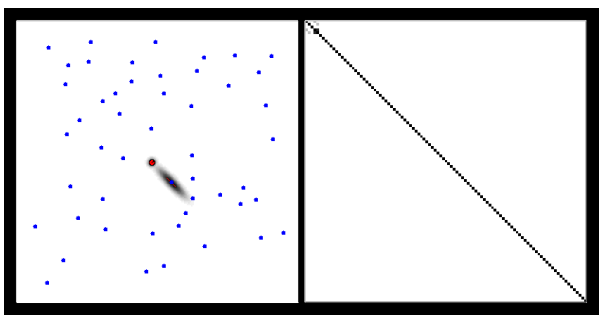
(E)KF-SLAM

- Map with N landmarks:(3+2N)-dimensional Gaussian

$$Bel(x_t, m_t) = \left\langle \begin{pmatrix} x \\ y \\ \theta \\ l_1 \\ l_2 \\ \vdots \\ l_N \end{pmatrix}, \begin{pmatrix} \sigma_x & \sigma_{xy} & \sigma_{x\theta} & \sigma_{xl_1} & \sigma_{xl_2} & \cdots & \sigma_{xl_N} \\ \sigma_{xy} & \sigma_y & \sigma_{y\theta} & \sigma_{yl_1} & \sigma_{yl_2} & \cdots & \sigma_{yl_N} \\ \sigma_{x\theta} & \sigma_{y\theta} & \sigma_\theta & \sigma_{\theta l_1} & \sigma_{\theta l_2} & \cdots & \sigma_{\theta l_N} \\ \sigma_{xl_1} & \sigma_{yl_1} & \sigma_{\theta l_1} & \sigma_{l_1} & \sigma_{l_1 l_2} & \cdots & \sigma_{l_1 l_N} \\ \sigma_{xl_2} & \sigma_{yl_2} & \sigma_{\theta l_2} & \sigma_{l_1 l_2} & \sigma_{l_2} & \cdots & \sigma_{l_2 l_N} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \sigma_{xl_N} & \sigma_{yl_N} & \sigma_{\theta l_N} & \sigma_{l_1 l_N} & \sigma_{l_2 l_N} & \cdots & \sigma_{l_N} \end{pmatrix} \right\rangle$$

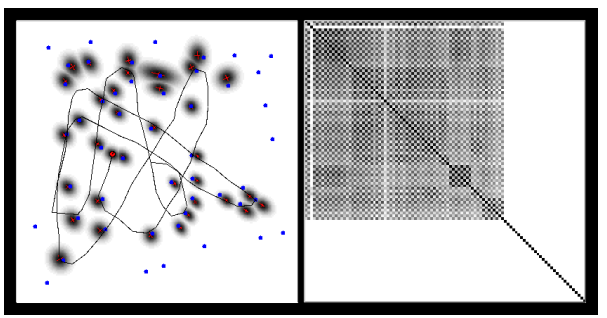
- Can handle hundreds of dimensions

EKF-SLAM



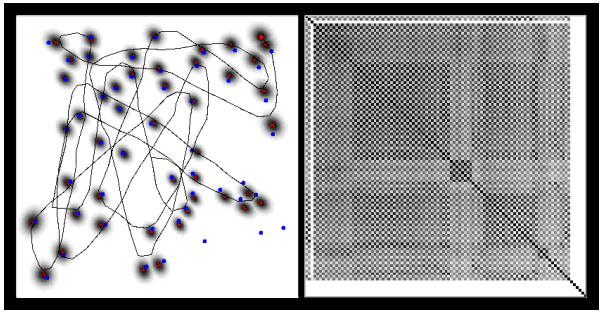
Map Correlation matrix

EKF-SLAM



Map Correlation matrix

EKF-SLAM



Map Correlation matrix

Victoria Park Data Set

[courtesy of E. Nebot]

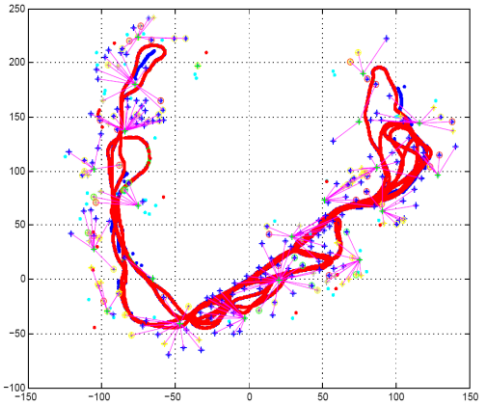
Victoria Park Data Set Vehicle

[courtesy of E. Nebot]

Data Acquisition

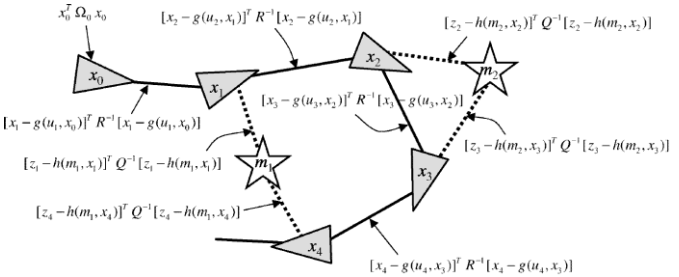
[courtesy of E. Nebot]

Estimated Trajectory



[courtesy of E. Nebot]

Graph-SLAM Idea

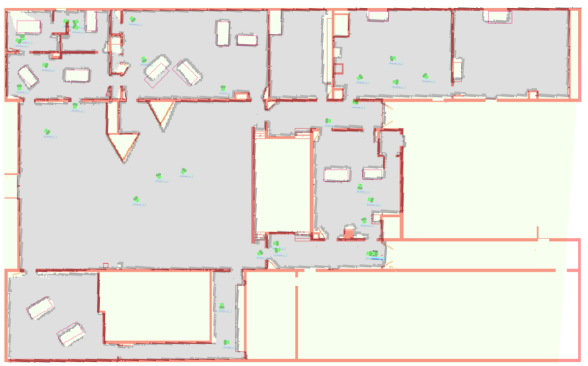


Sum of all constraints:

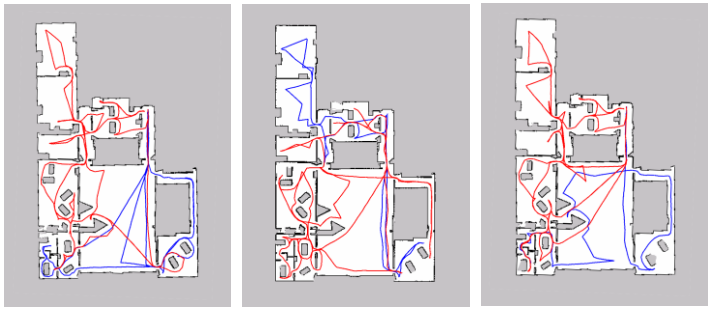
$$J_{\text{GraphSLAM}} = x_0^T \Omega_0 x_0 + \sum_t [x_t - g(u_t, x_{t-1})]^T R^{-1} [x_t - g(u_t, x_{t-1})] + \sum_t [z_t - h(m_{c_t}, x_t)]^T Q^{-1} [z_t - h(m_{c_t}, x_t)]$$

Mapping the Allen Center

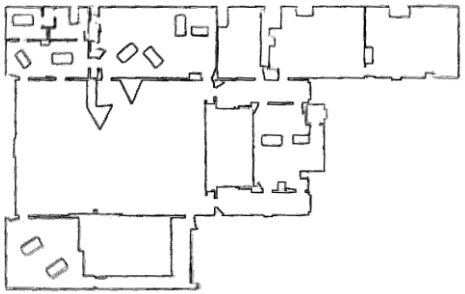
Comparison to "Ground Truth Map"



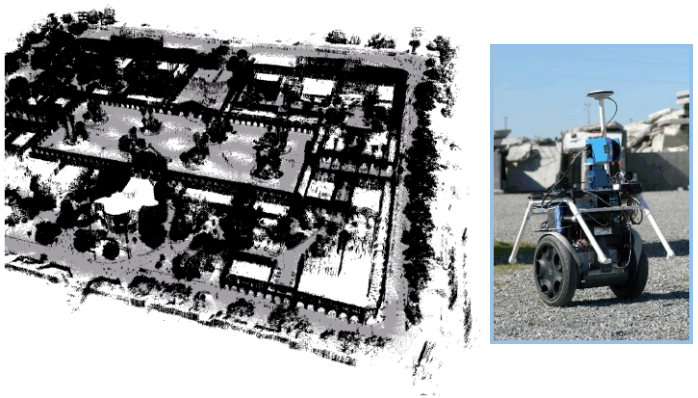
Three Mapping Runs



Three Overlayed Maps



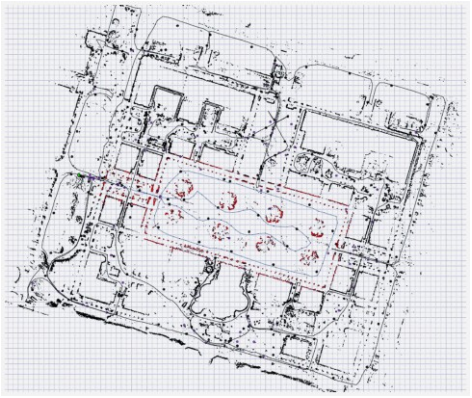
3D Outdoor Mapping



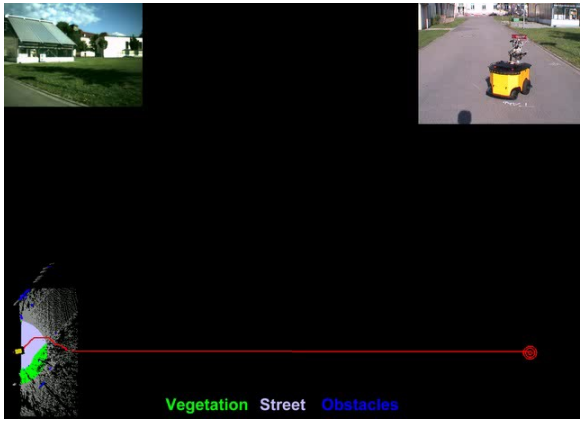
10^8 features, 10^5 poses, only few secs using cg.

Map Before Optimization

Map After Optimization



Autonomous Navigation



Courtesy of W. Burgard

Rao-Blackwellized Mapping

Compute a posterior over the map and possible trajectories of the robot :

map and trajectory

measurements

$$p(x_{1:t}, m \mid z_{1:t}, u_{0:t-}) = p(m \mid x_{1:t}, z_{1:t}, u_{0:t-})\, p(x_{1:t} \mid z_{1:t}, u_{0:t-})$$

map

robot motion

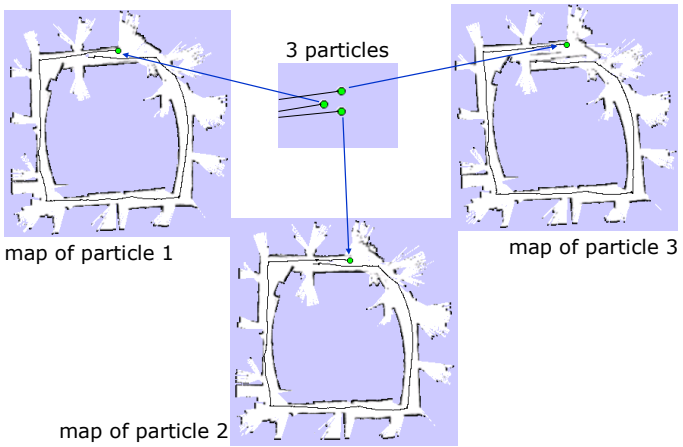
trajectory

FastSLAM

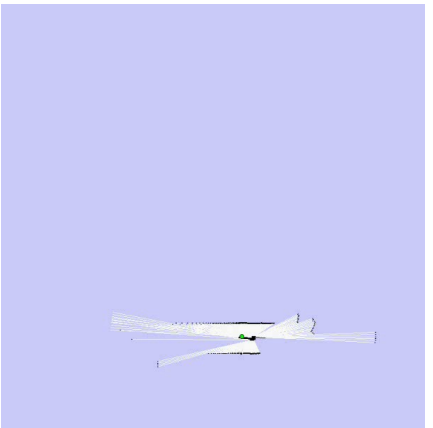
	Robot Pose	2 x 2 Kalman Filters			
Particle #1	x, y, θ	Landmark 1	Landmark 2	...	Landmark N
Particle #2	x, y, θ	Landmark 1	Landmark 2	...	Landmark N
Particle #3	x, y, θ	Landmark 1	Landmark 2	...	Landmark N
⋮					
Particle M	x, y, θ	Landmark 1	Landmark 2	...	Landmark N

[Begin courtesy of Mike Montemerlo]

Example

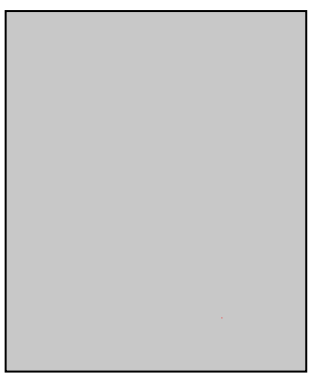


Rao-Blackwellized Mapping with Scan-Matching



Map: Intel Research Lab Seattle

Frontier Based Exploration



[Yamauchi et al. 96],
[Thrun 98]

Coordinated exploration with three robots
from unknown start locations

The robots are fully autonomous.
All computation is performed on–board.

Shown is the perspective of one robot