# Experimental Analysis of Dynamic Covariance Scaling for Robust Map Optimization Under Bad Initial Estimates

**Pratik Agarwal[1], Giorgio Grisetti[3], Gian Diego Tipaldi[1], Luciano Spinello[1], Wolfram Burgard[1] and Cyrill Stachniss[1,2]**

[1]University of Freiburg, Germany
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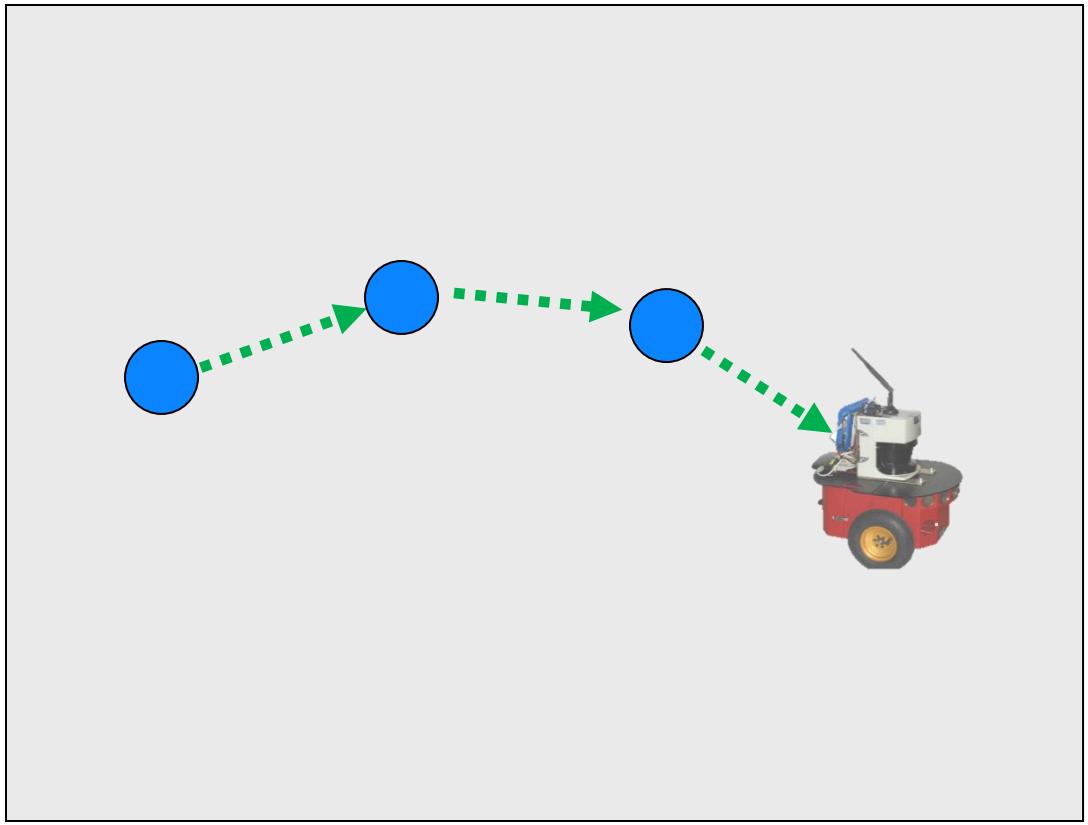
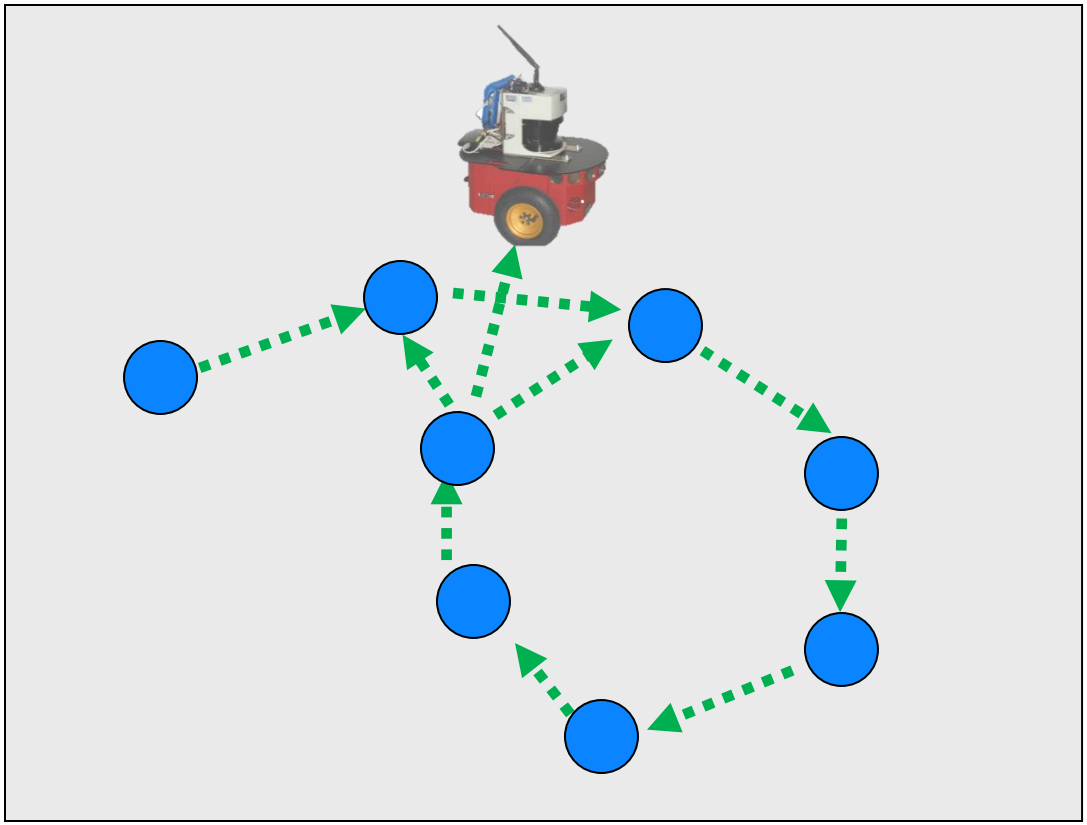
# Graph-Based SLAM



Robot pose

Constraint

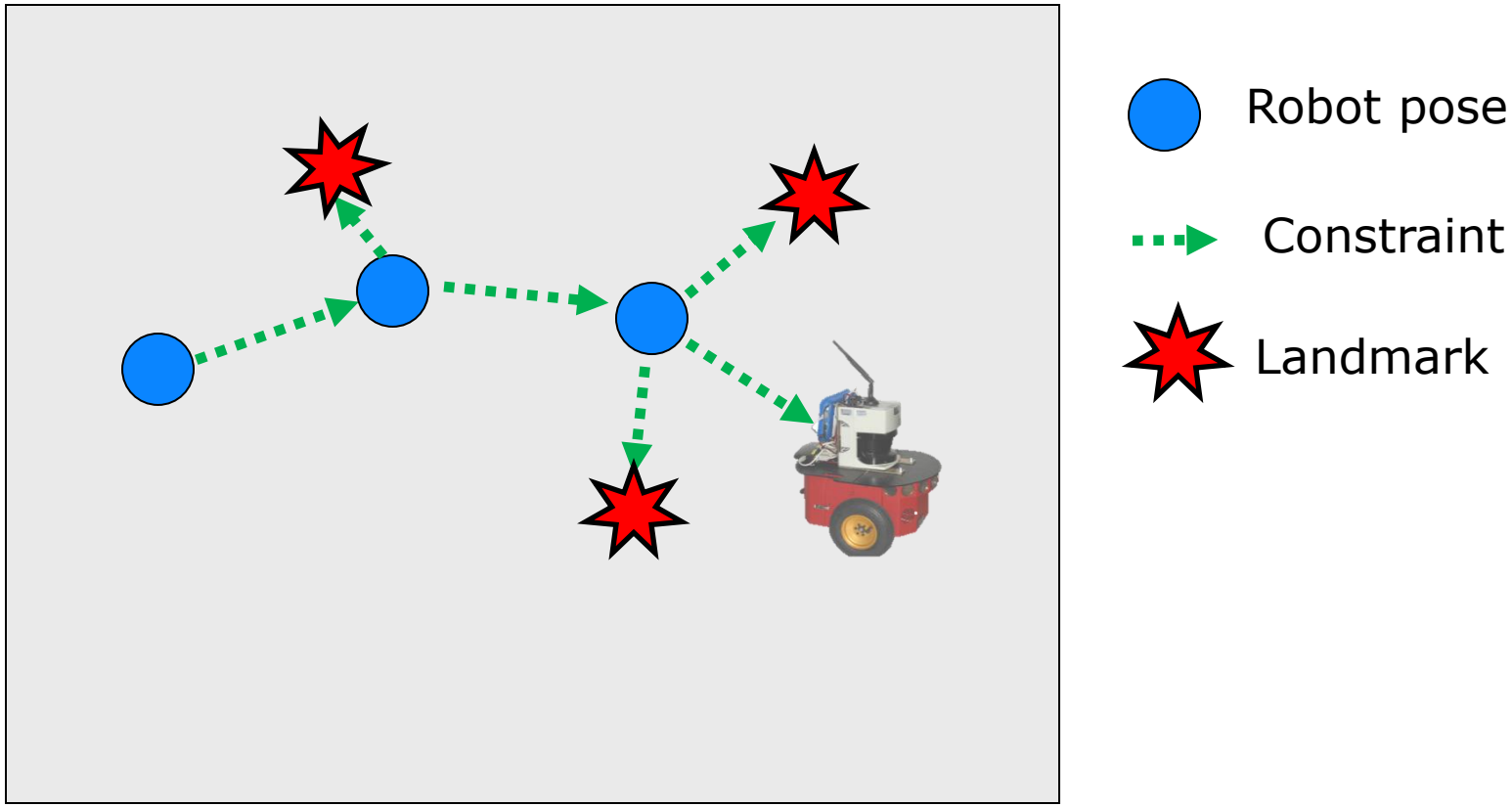
# Graph-Based SLAM



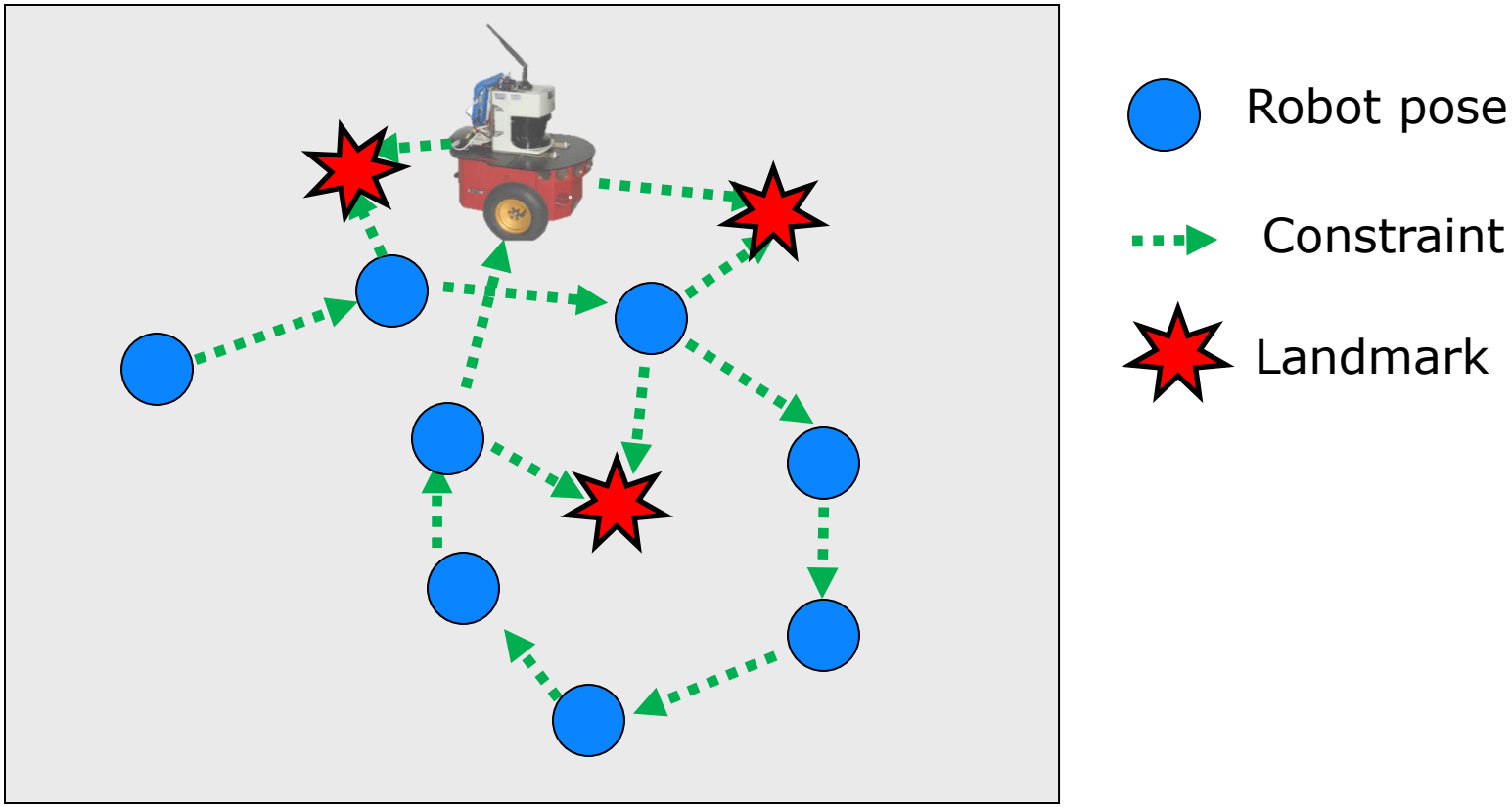
Robot pose

Constraint

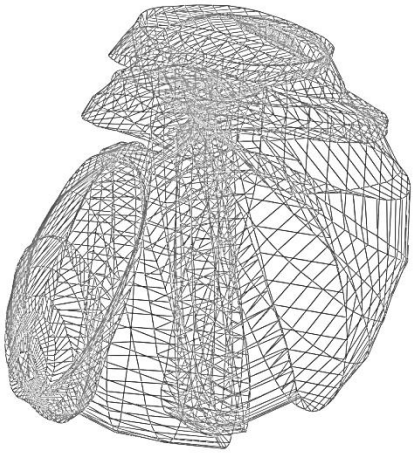
# Graph-Based SLAM



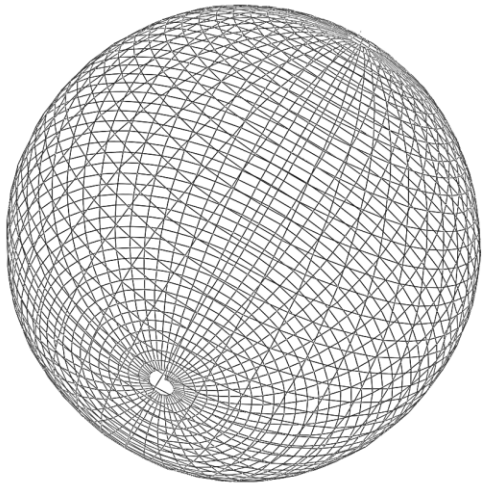
# Graph-Based SLAM



# Graph-SLAM Pipeline



**Front end**



**Back end**

# SLAM Back End Depends on the Initial Guess

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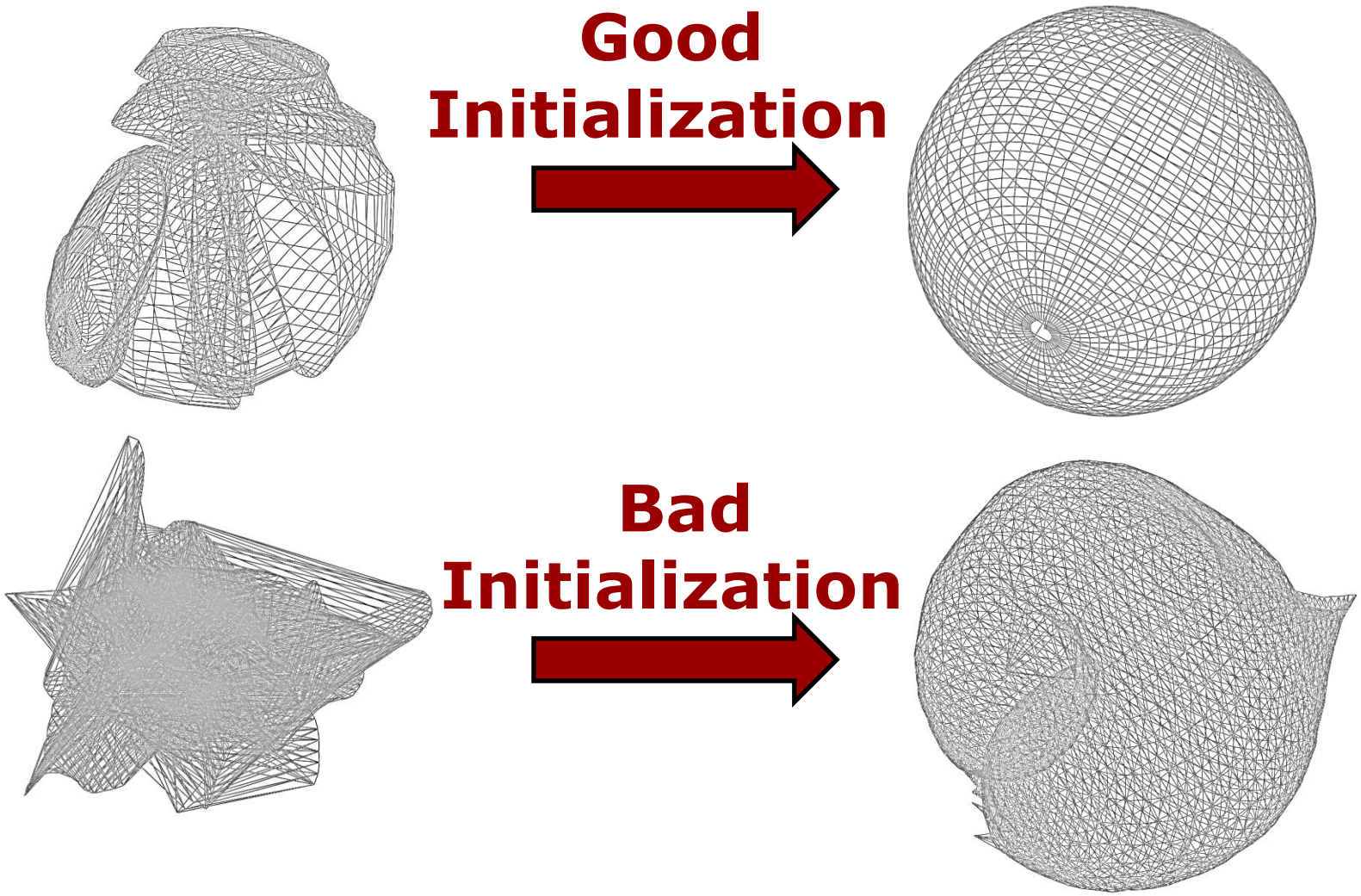

# Typical Assumptions in Graph-SLAM

- **No outliers**

- **Initial guess** close to correct solution

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  Outliers violate Gaussian assumption

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  Bad initialization violates linear approximation

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  Outliers violate Gaussian assumption

- **Initial guess** close to correct solution

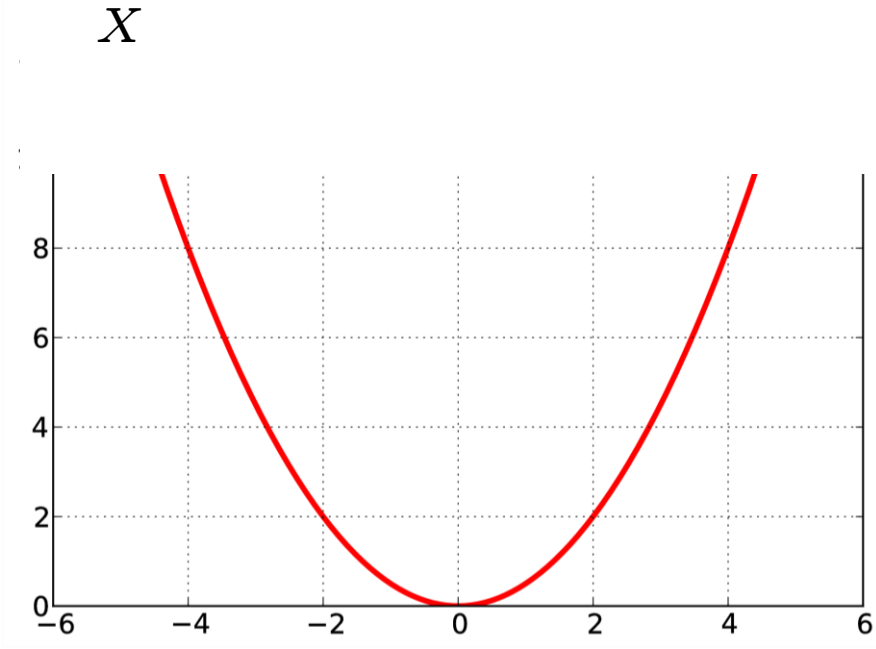
  Bad initialization violates linear approximation

**DCS** addresses **both problems**

# Standard least squares

$$X^* = \arg\min_X \sum_{ij} \mathbf{e}_{ij}(X)^T \quad {}_{ij}\mathbf{e}_{ij}(X)$$

$$X^* = \arg\min_X \sum r^2$$

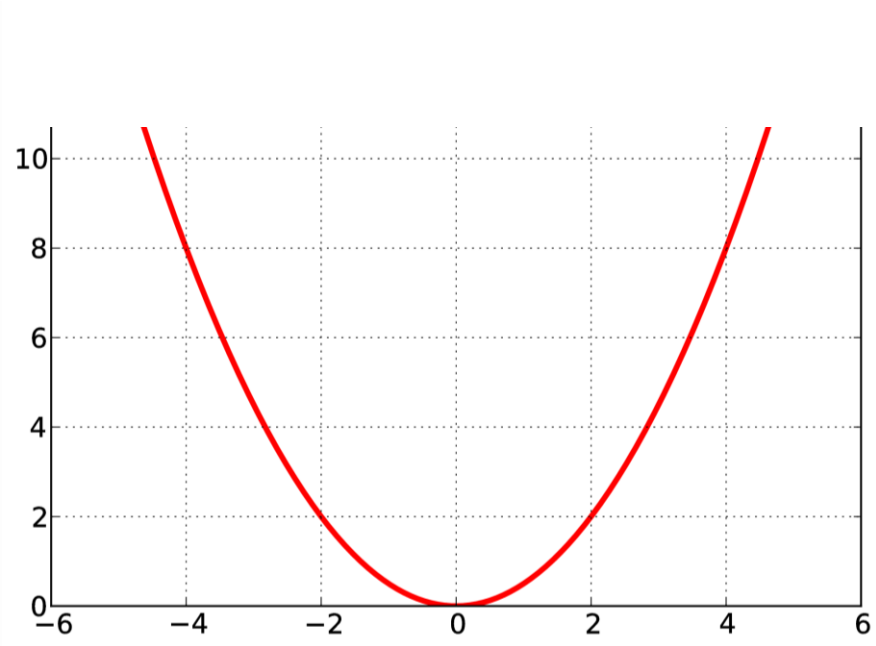


# Robust M-Estimation

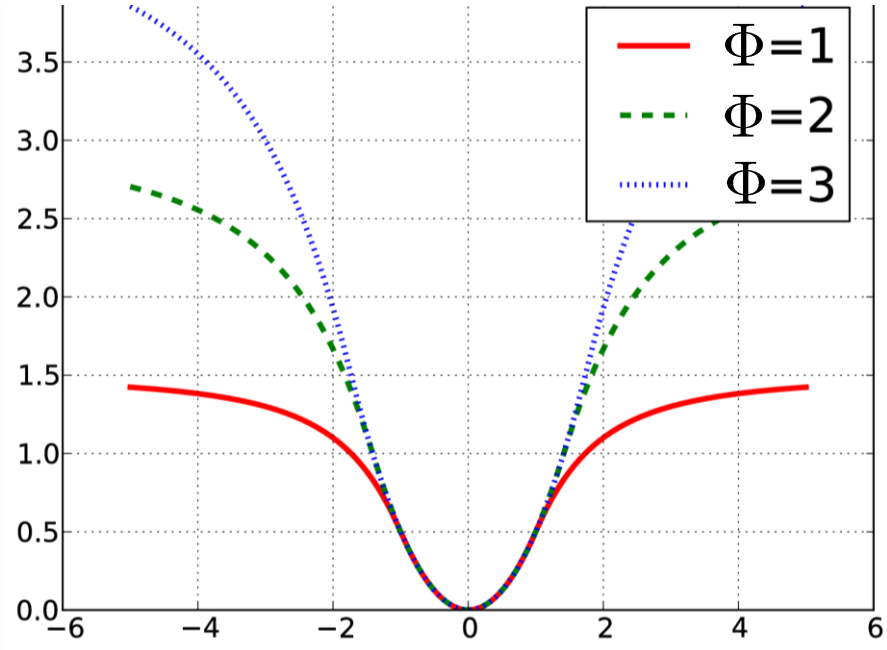
$$X^* = \arg\min_X \sum r^2$$

$$X^* = \arg\min_X \sum \rho(r^2)$$

# DCS vs Standard Squared Error

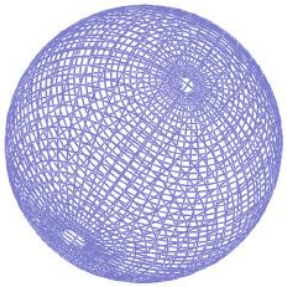
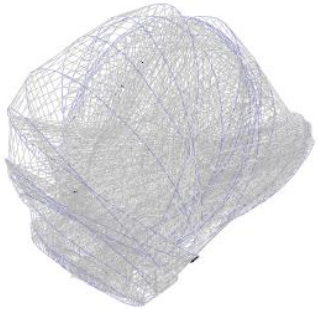
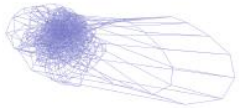
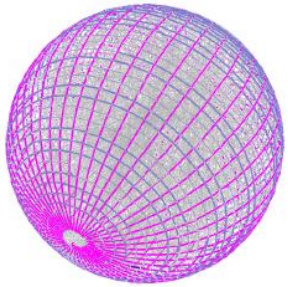
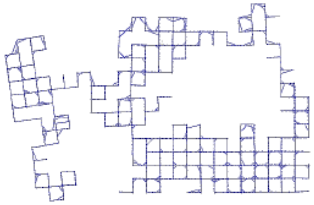
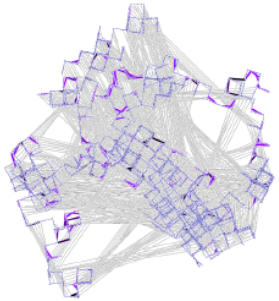
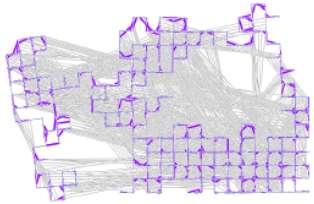



Squared



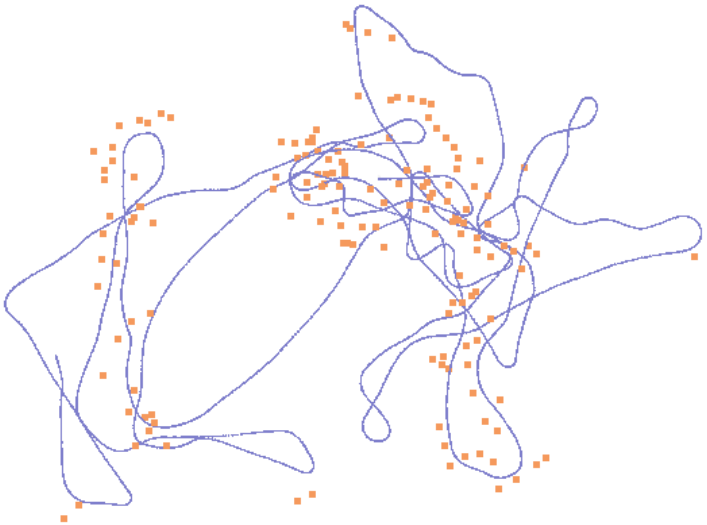

DCS

# Robust SLAM with Our Method

| | Ground Truth | Initialization | Gauss Newton | **Our Method** |
|---|---|---|---|---|
| Sphere2500 (1000 Outiers) |  |  |  |  |
| Manhattan3500 (1000 Outiers) |  |  |  |  |

ICRA’ 13

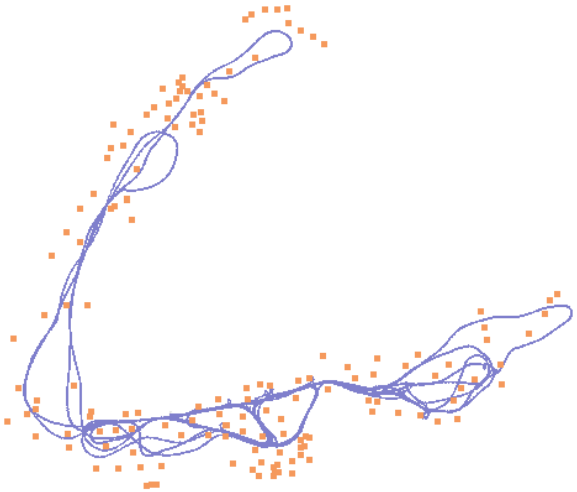
# Robust SLAM with Our Method



Victoria Park
Odometry Initialization

**Dynamic Covariance Scaling**

Gauss Newton

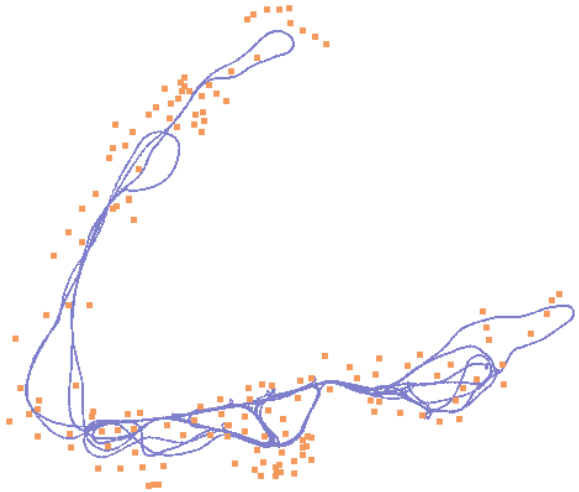


Courtesy E. Nebot

# Robust SLAM with Our Method

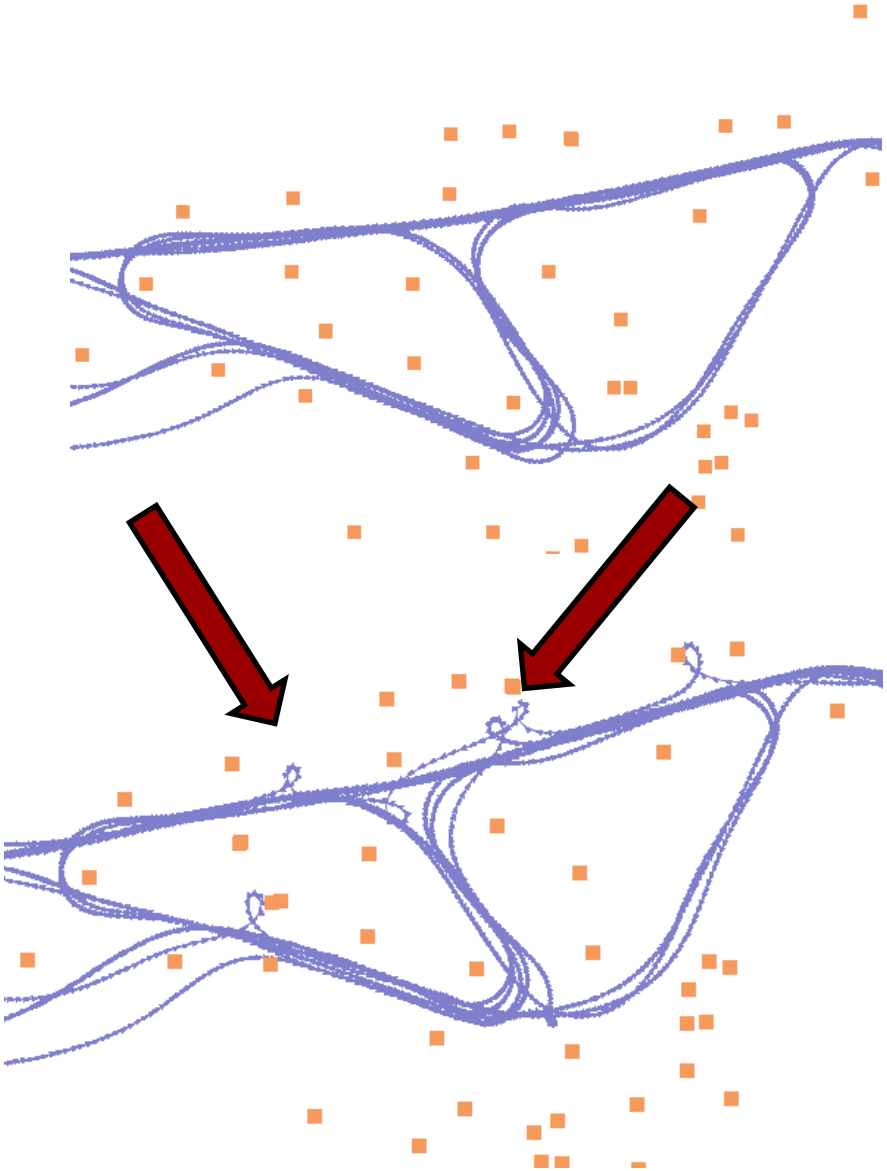
**Dynamic Covariance Scaling**

Gauss Newton

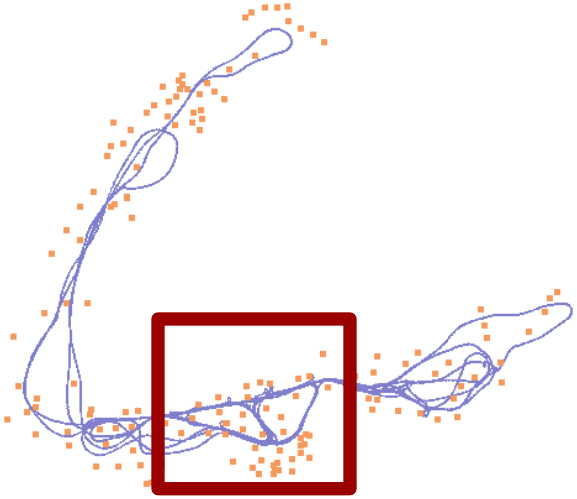


# Robust SLAM with Our Method

**Dynamic Covariance Scaling**

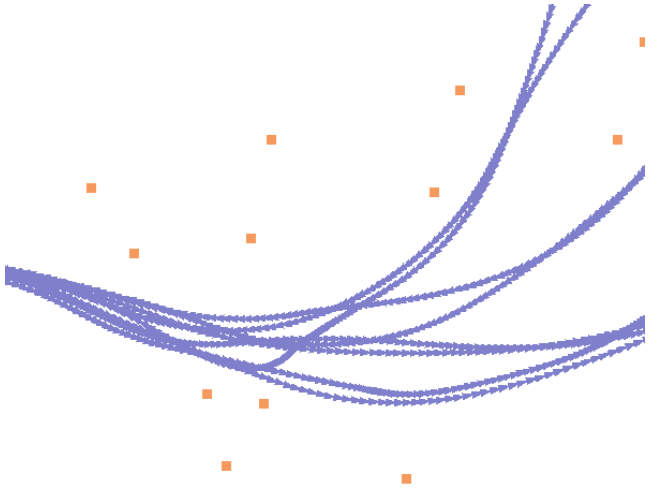


Gauss Newton

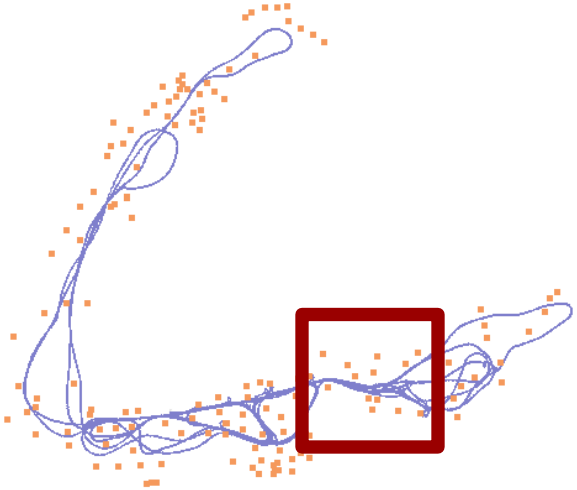


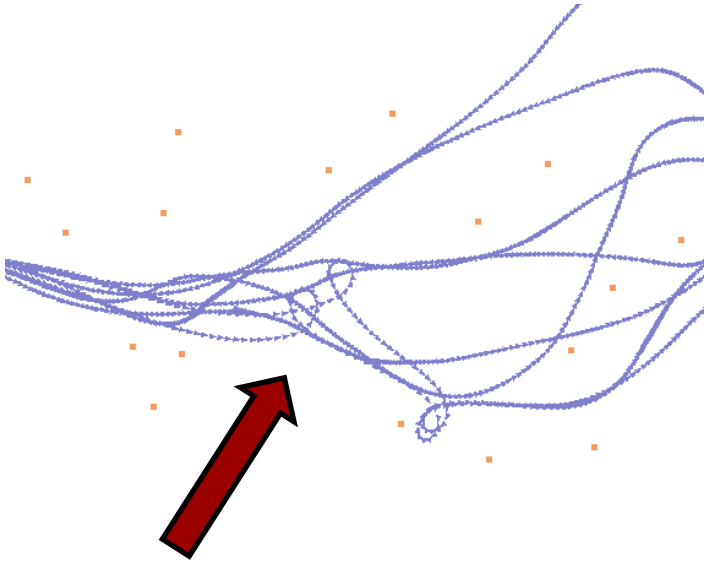
# Robust SLAM with Our Method

**Dynamic Covariance Scaling**

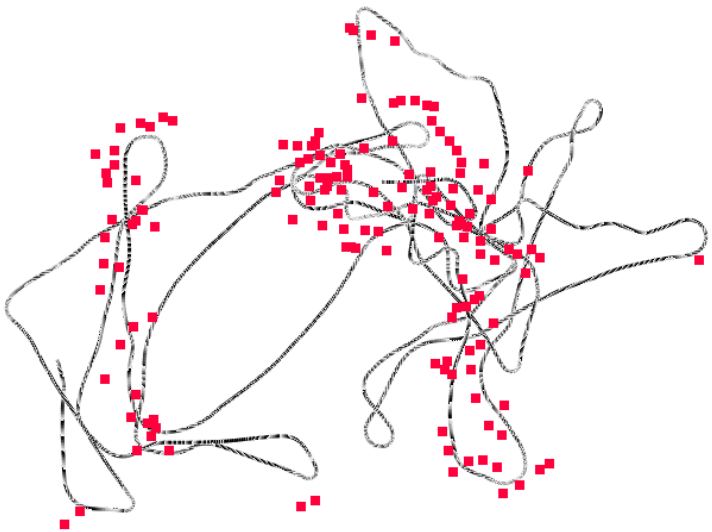


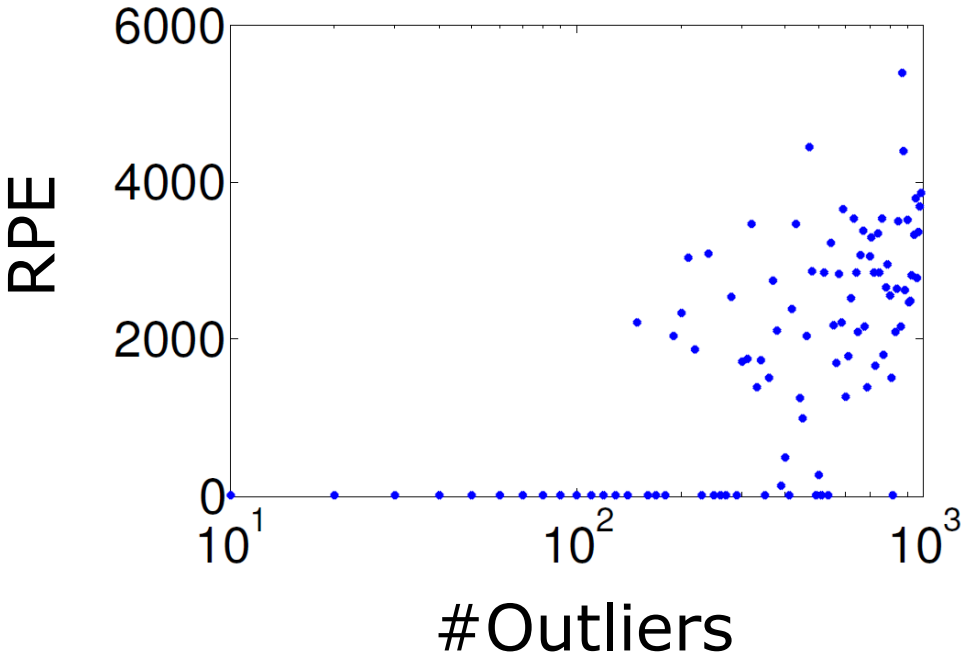
Gauss Newton





# Dynamic Covariance Scaling with Outliers in Victoria Park

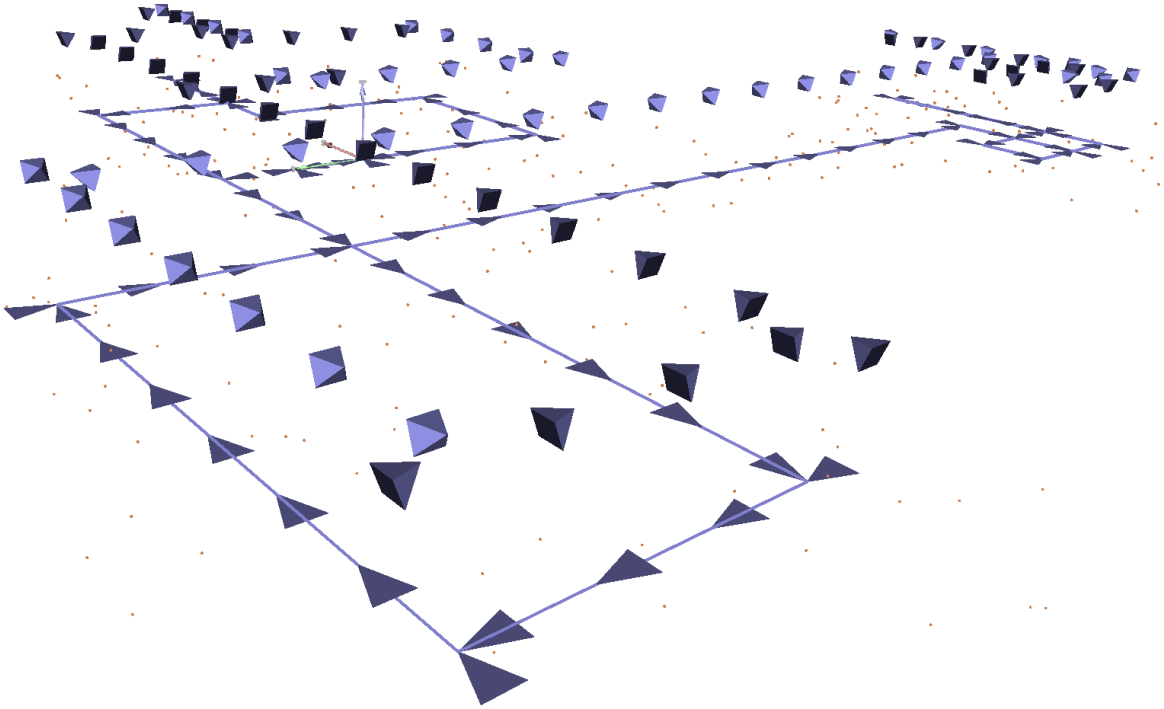




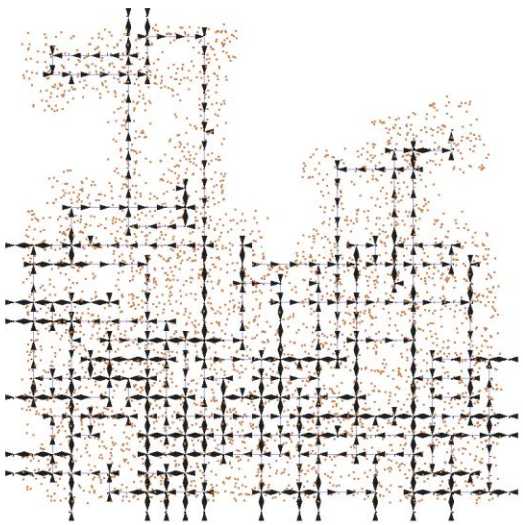

- DCS recovers correct solution
- GN fails to converge to the correct solution even for **outlier-free case**

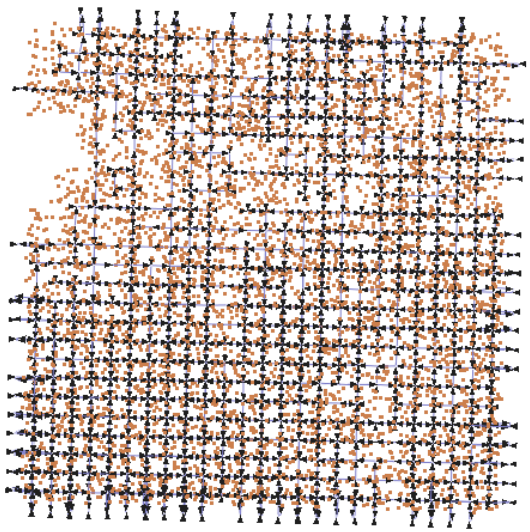
# Robust Visual SLAM with Our Method

- 3D grid worlds of different sizes
- Robot perceives point landmarks



# Robust Visual SLAM with Our Method





~1000 camera poses
~4000 features
~20K constraints

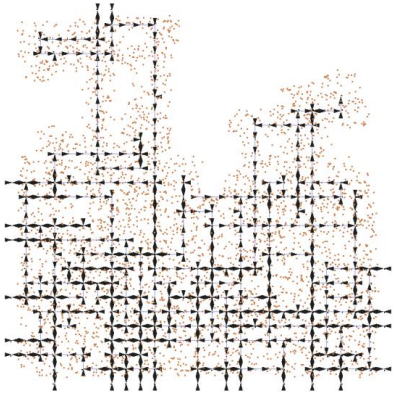
~5000 camera poses
~5000 features
~100K constraints

IROS' 12

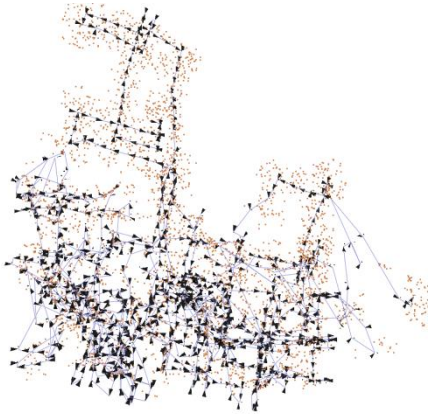
# Robust Visual SLAM with DCS

Simulated Stereo
(Bad initial guess)

Ground Truth



Initialization (Odometry)



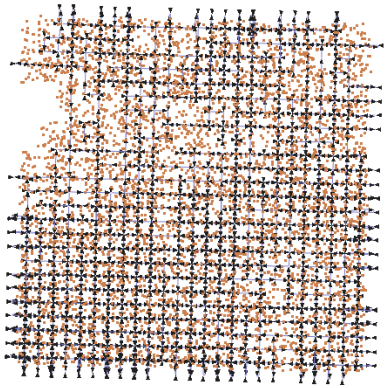
Levenberg-Marquardt
(100 iterations)

**Our Method**
**(15 iterations)**

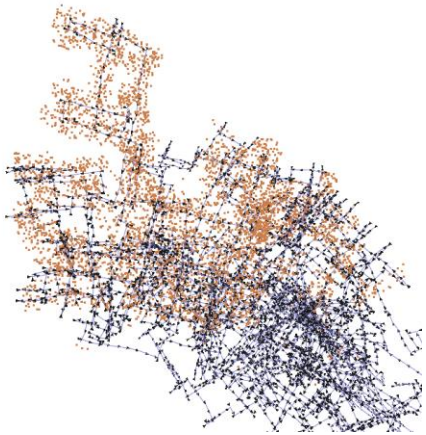
# Robust Visual SLAM with DCS

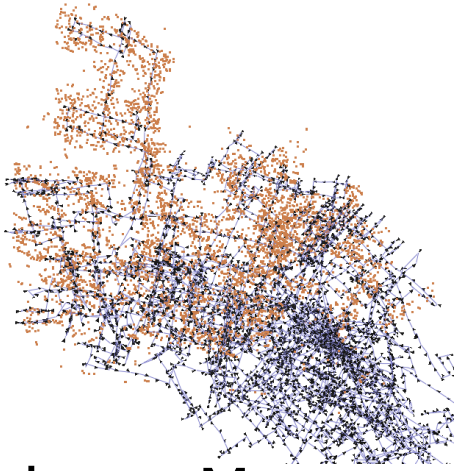
Simulated Stereo
(Bad initial guess)

Ground Truth

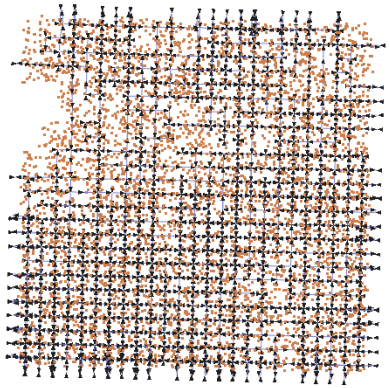


Initialization (Odometry)



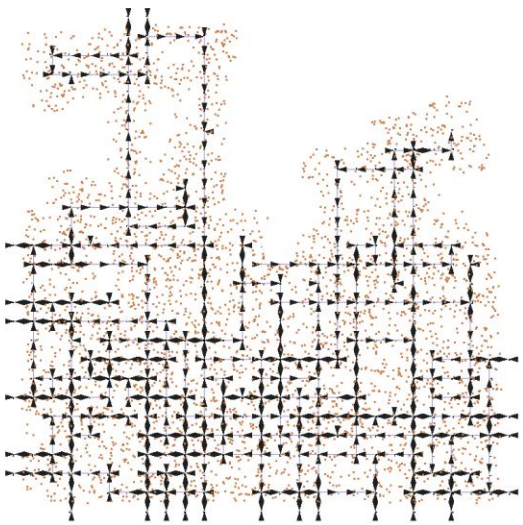


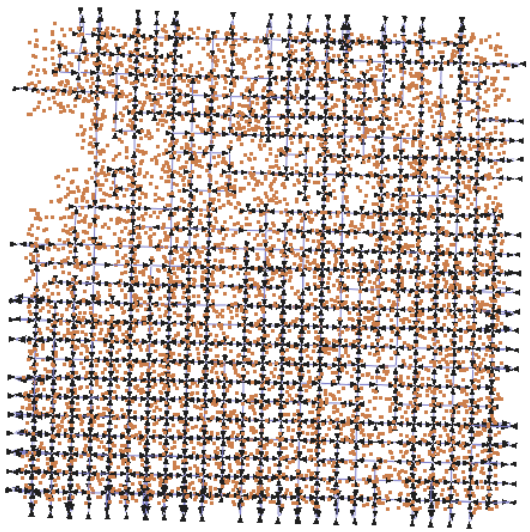
Levenberg-Marquardt
(150 iterations)



**Our Method**
**(15 iterations)**

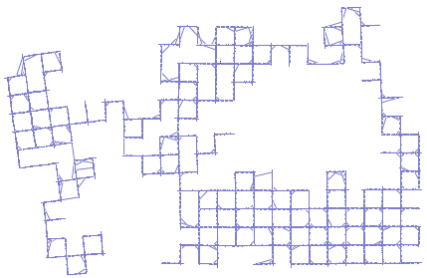
# Robust Visual SLAM with DCS



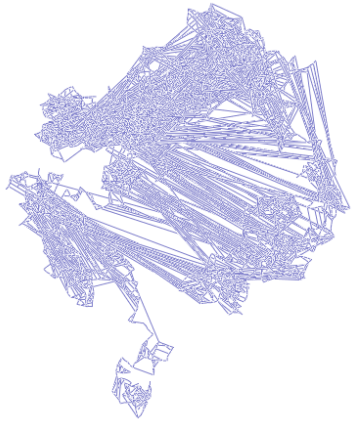


- DCS recovers correct solution in the presence of up to **25% outliers**
- LM fails to converge to the correct solution even for **outlier-free cases**

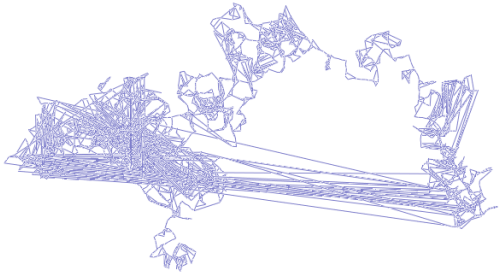
# Increased Noise Manhattan3500



Ground Truth



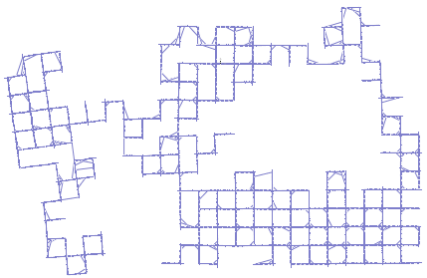
Odometry Initialization



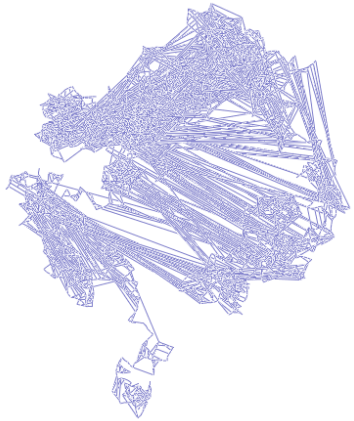
Spanning Tree Initialization

Courtesy Edwin Olson
Reprocessed by Carlone & Censi, TRO’14

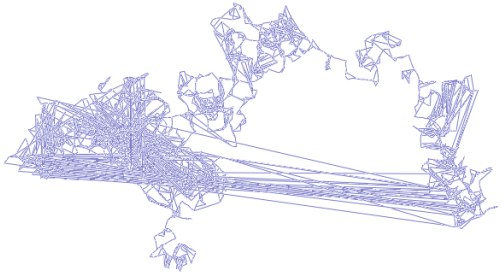
# Increased Noise Manhattan3500



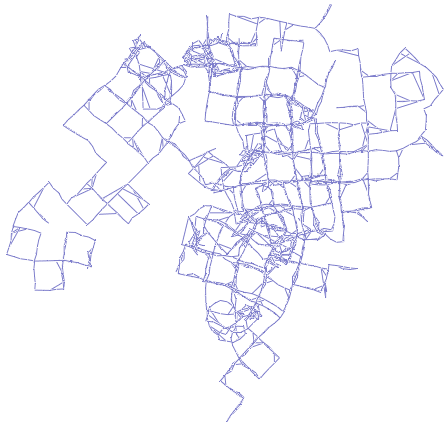
Ground Truth

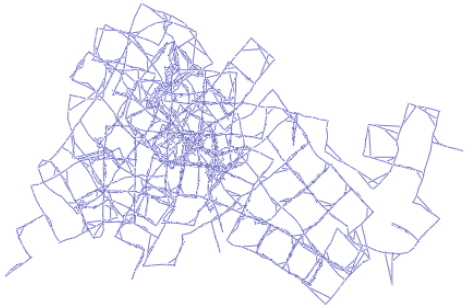


Odometry Initialization



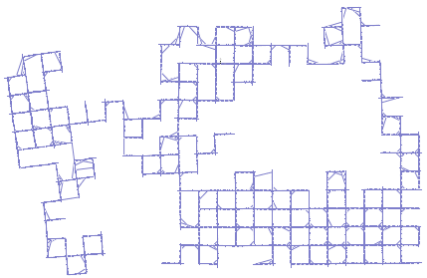
Spanning Tree Initialization



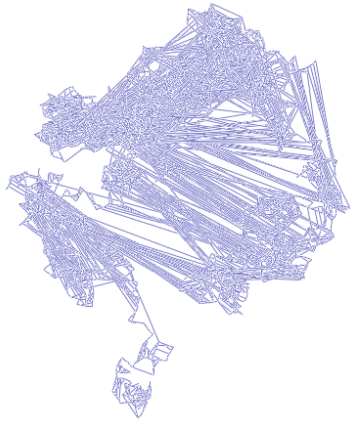


Gauss-Newton

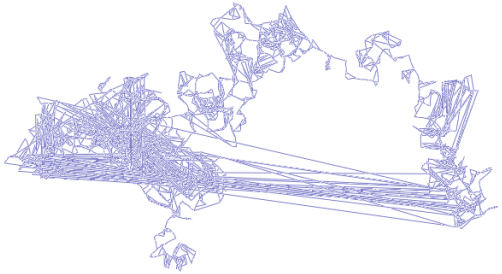
# Increased Noise Manhattan3500



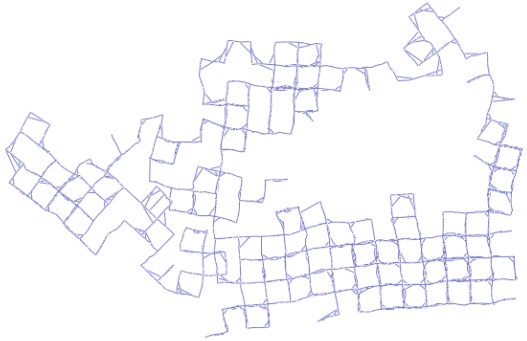
Ground Truth



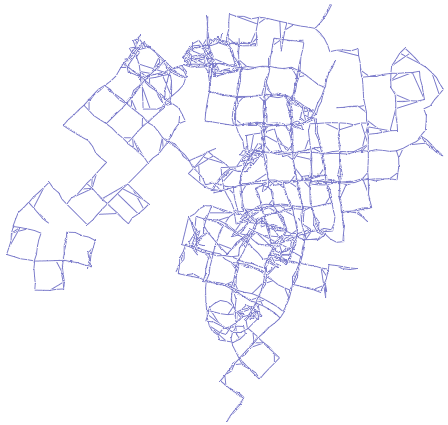
Odometry Initialization

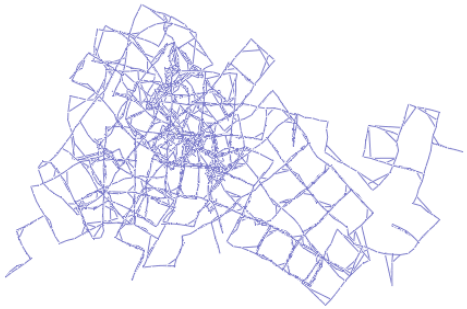


Spanning Tree Initialization



Carlone & Censi TRO'14





Gauss-Newton

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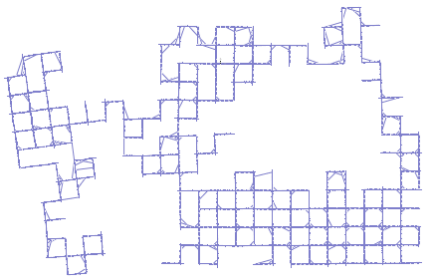

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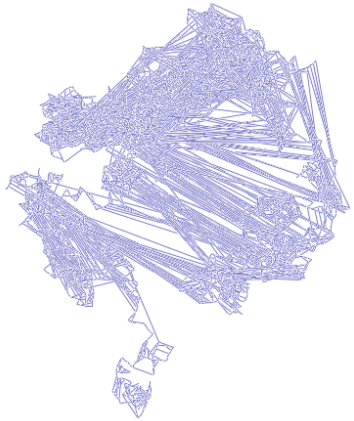
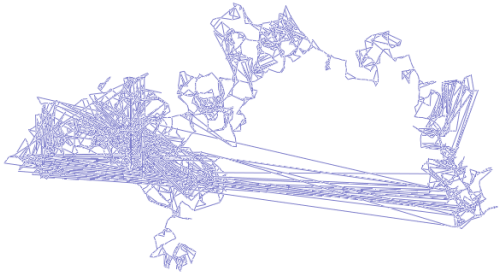
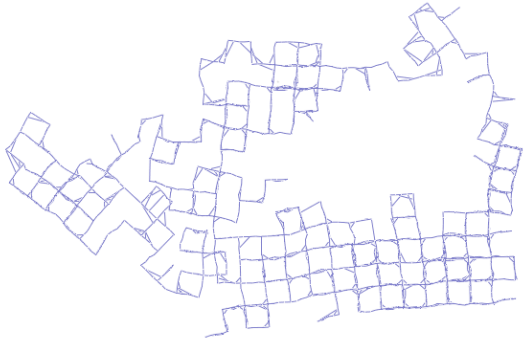


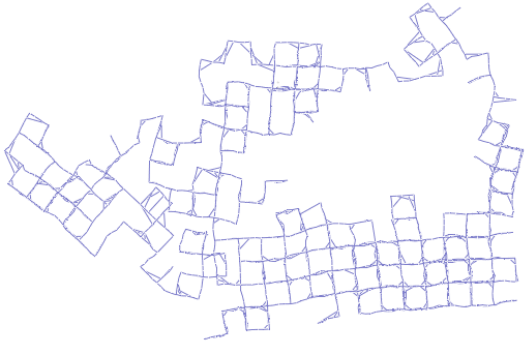
Odometry Initialization

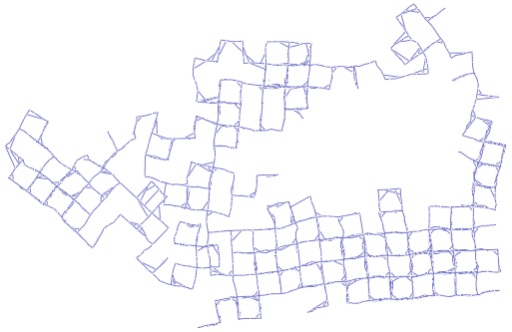


Spanning Tree Initialization



Carlone & Censi TRO'14

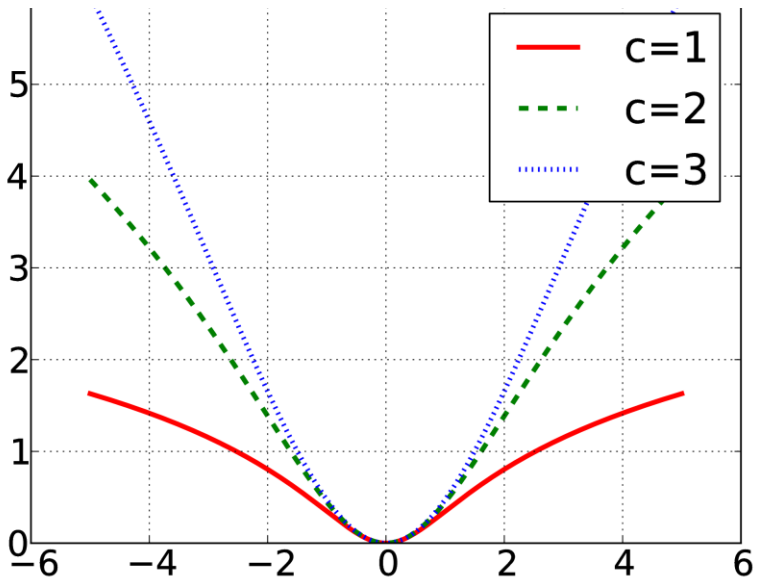




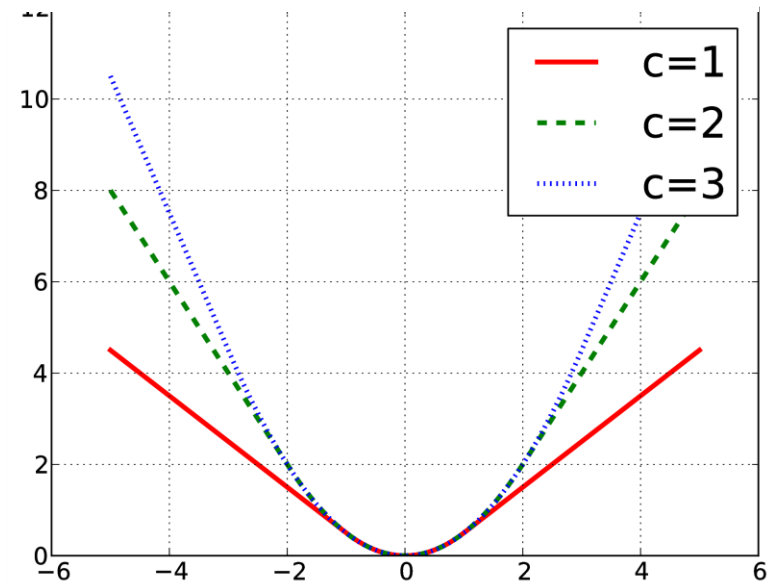
**Our Method DCS**

# Comparison to M-estimators

How do other M-estimators perform?



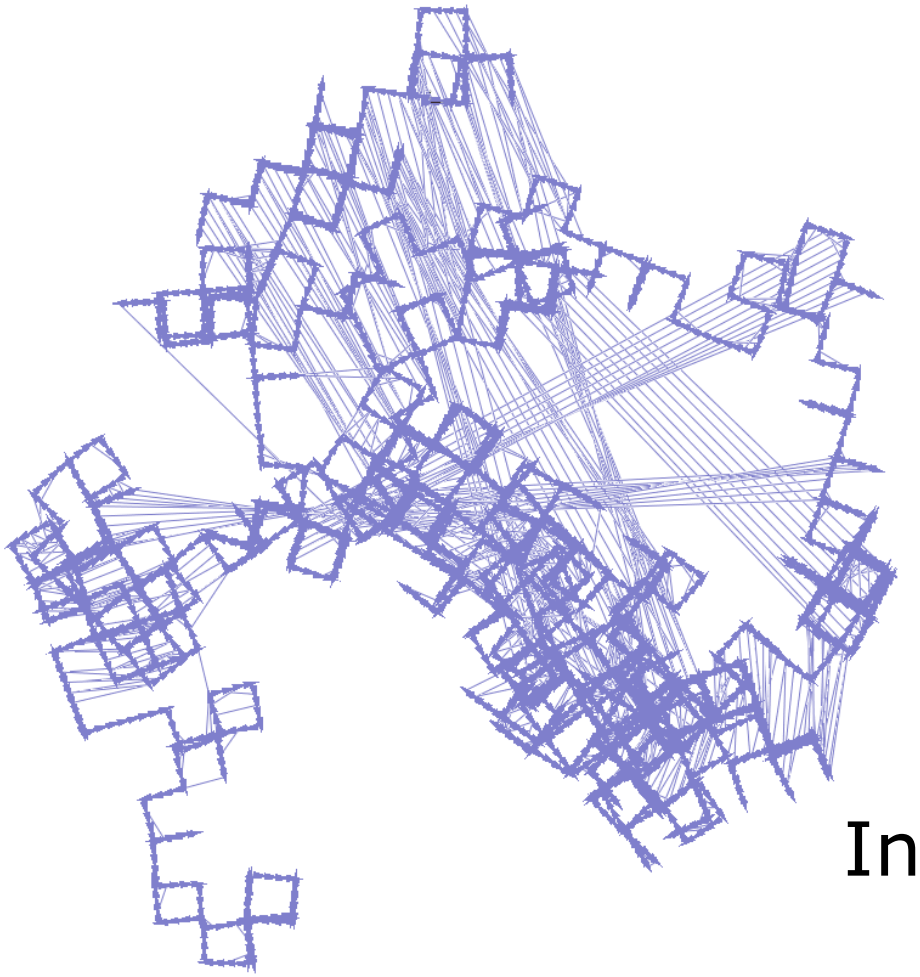

Cauchy




Huber

# Comparison to M-estimators

Compare against **Cauchy** and **Huber**



Manhattan3500

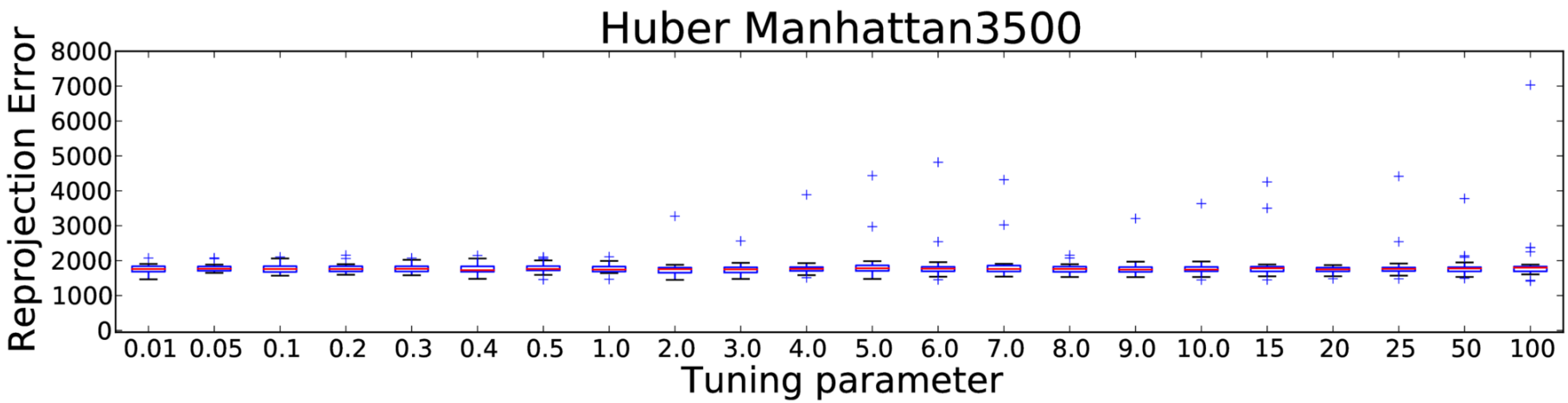
**100 outliers**

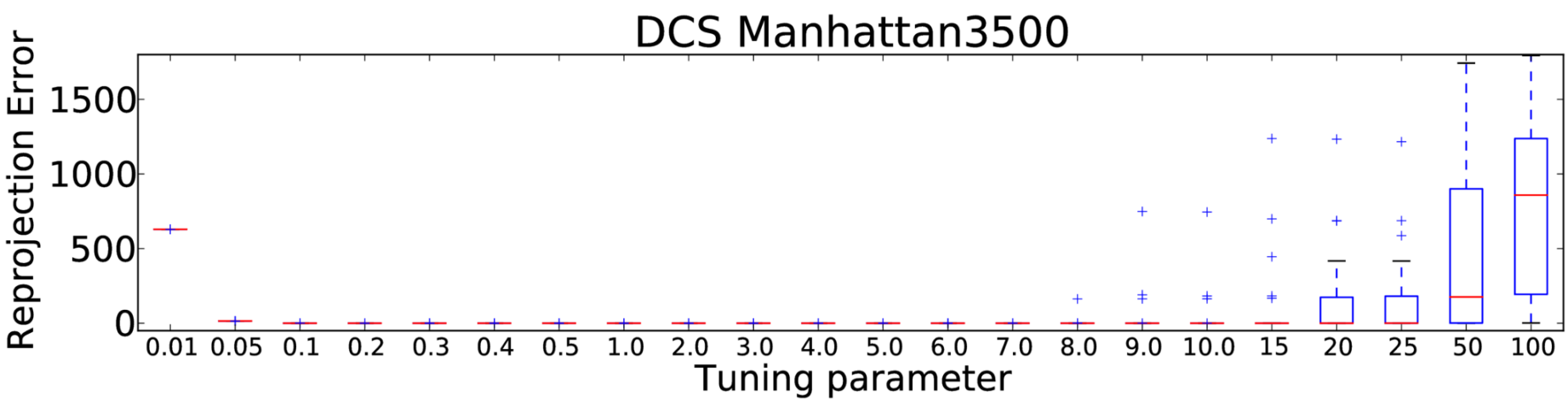
**groups of 10**

25 instances

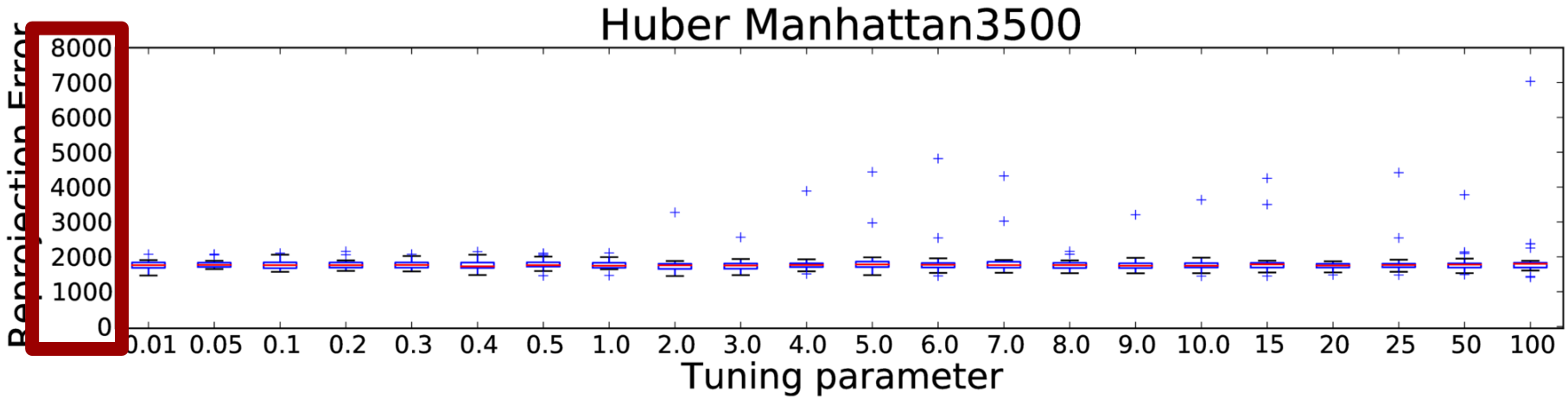
Initialization with odometry

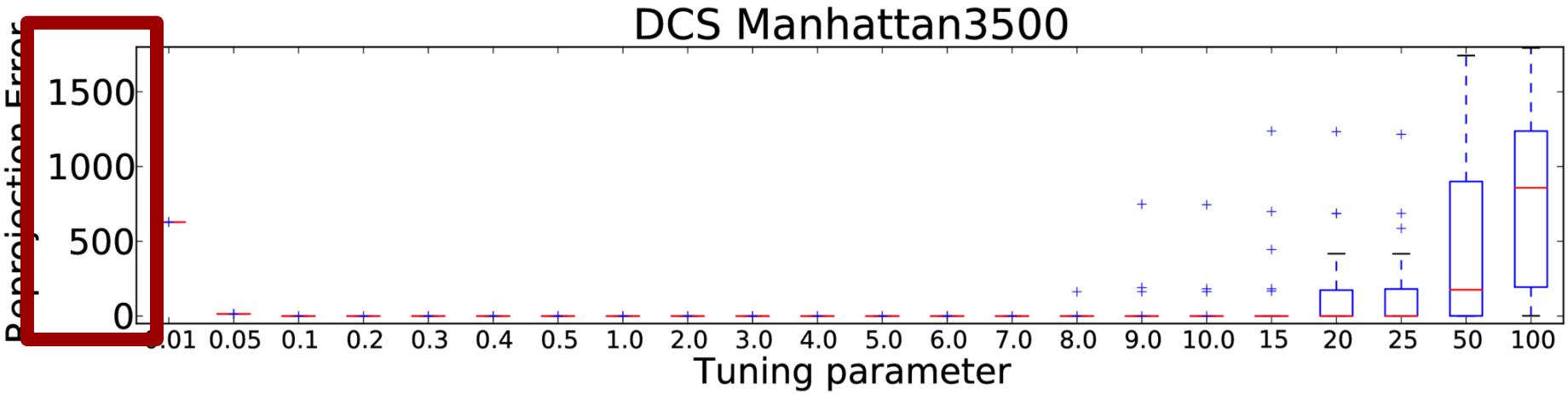
# Comparison to Huber



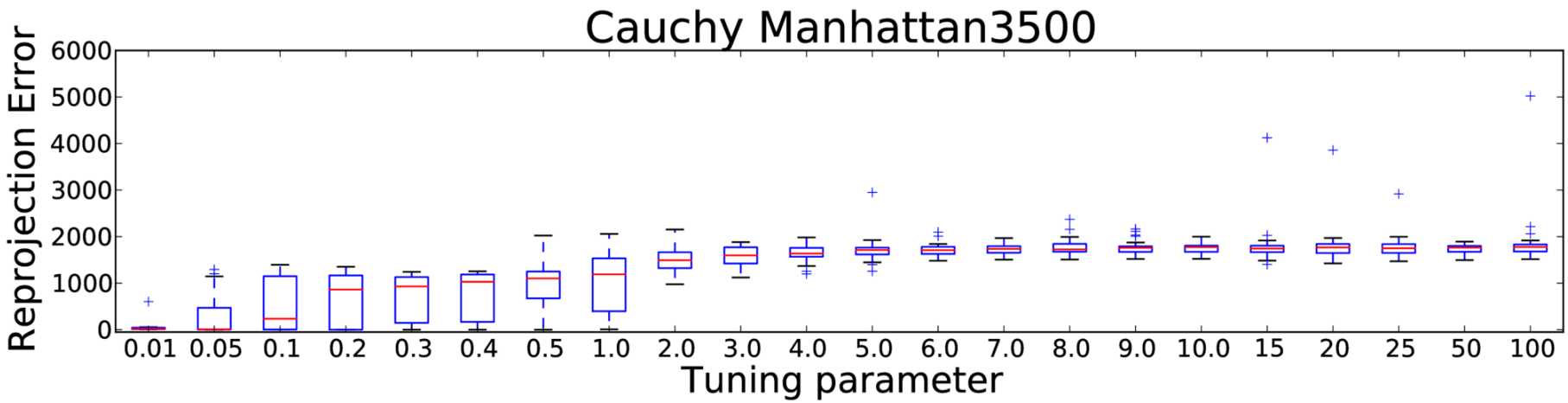



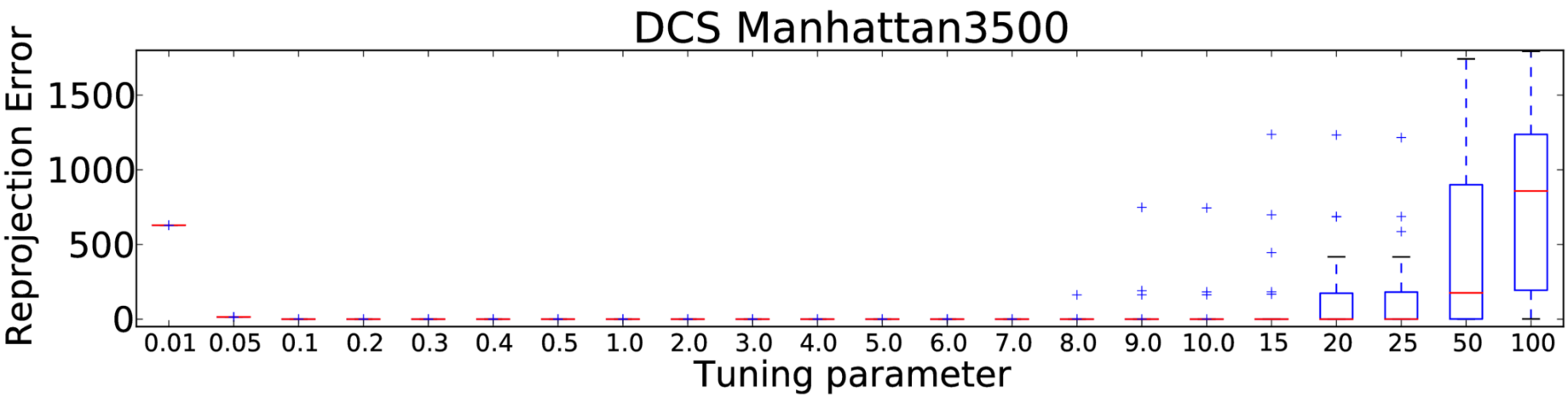
# Comparison to Huber



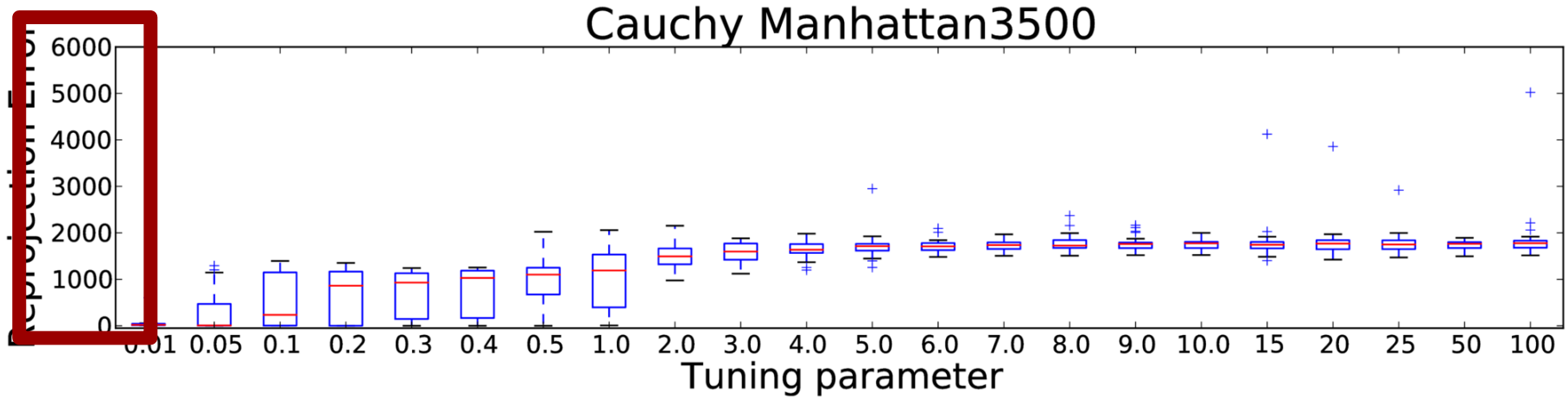



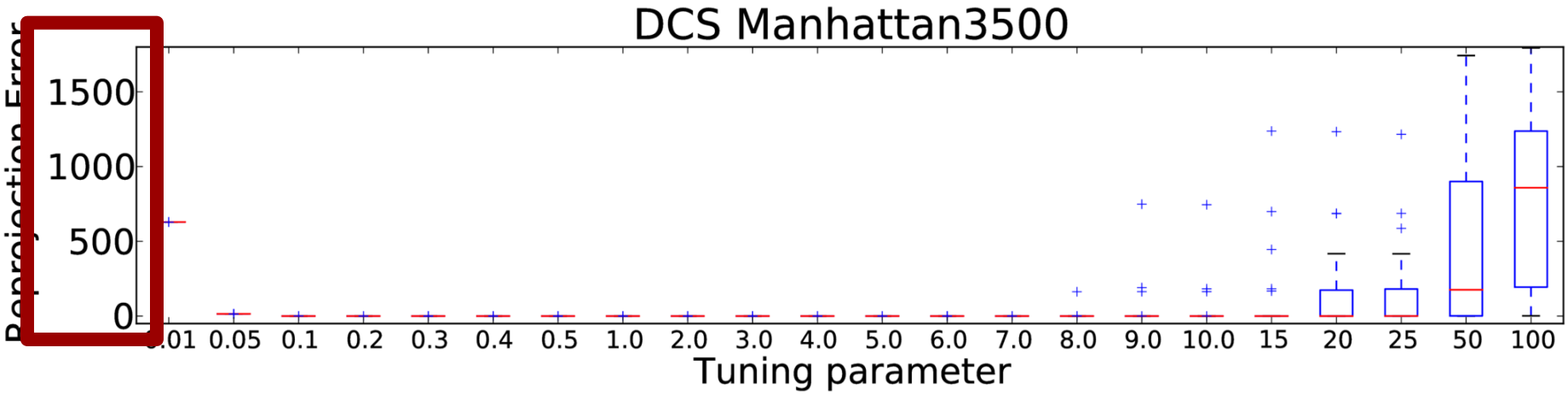
# Comparison to Cauchy



# Comparison to Cauchy



# Conclusion

- Good kernel for 2D & 3D SLAM
- Robust to **initialization & outliers**
- Outperforms **Huber and Cauchy** on evaluated scenarios
- Integrated in current **g2o** release

# Thank you for your attention!