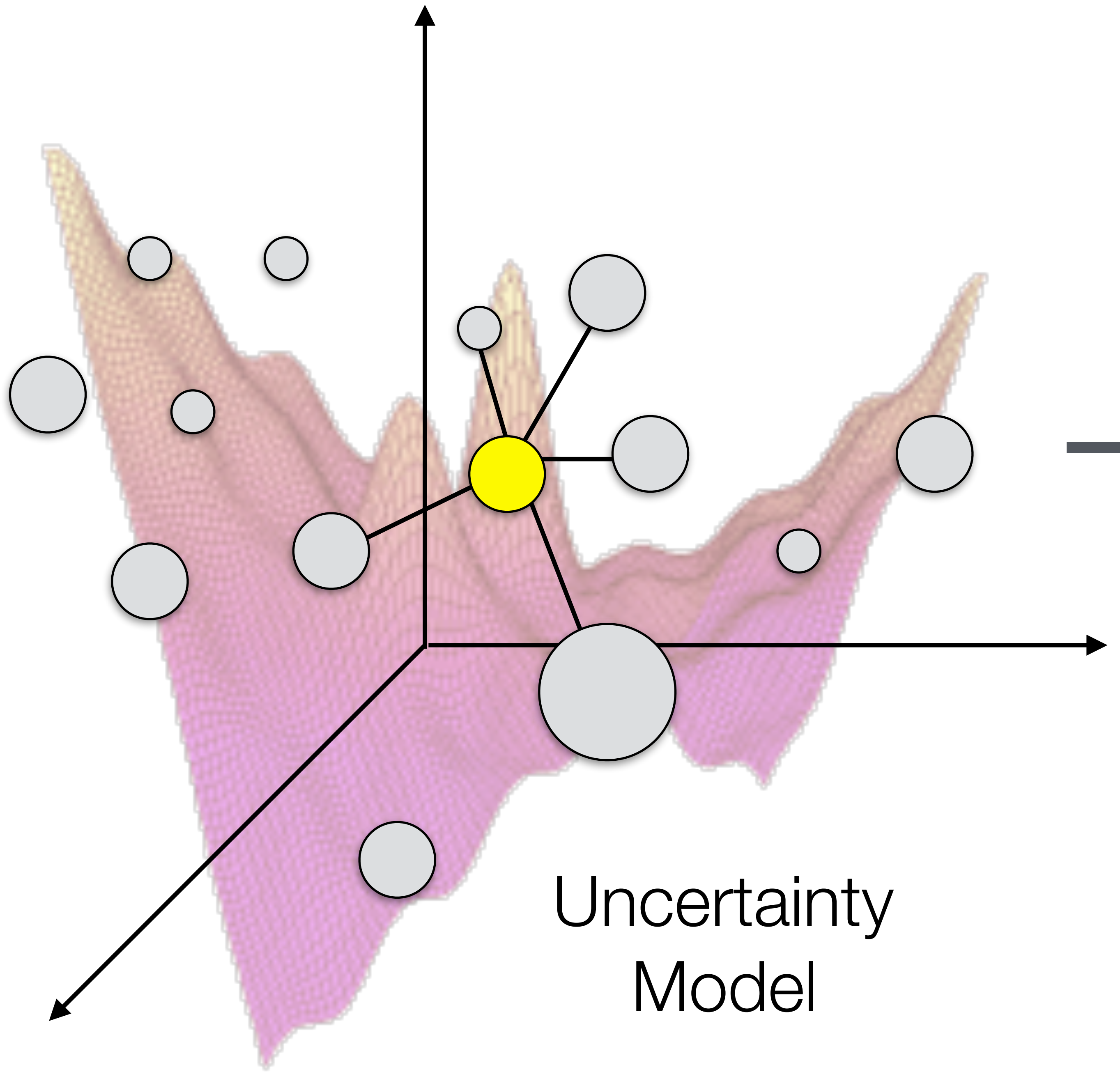
# **PROBE-GK:** Predictive Robust Estimation using Generalized Kernels

Valentin Peretroukhin, William Vega-Brown, Nicholas Roy, and Jonathan Kelly

*Visual-Based Navigation | ICRA 2016 | Stockholm, Sweden*

Sensor Data



Uncertainty Model

$$\min \sum_i (\nu_i + 1) \log \left(1 + \boldsymbol{e}_i^{\top} \boldsymbol{\Psi}_i^{-1} \boldsymbol{e}_i\right)$$

**Predictively Robust**
Cost

Institute for Aerospace Studies
UNIVERSITY OF TORONTO

MIT CSAIL

icra STOCKHOLM 2016 SWEDEN
ICRA 2016 IEEE INTERNATIONAL CONFERENCE ON ROBOTICS AND AUTOMATION

# **Motivation** | Sensor uncertainty is hard to model

Example: **visual odometry** through urban environments.

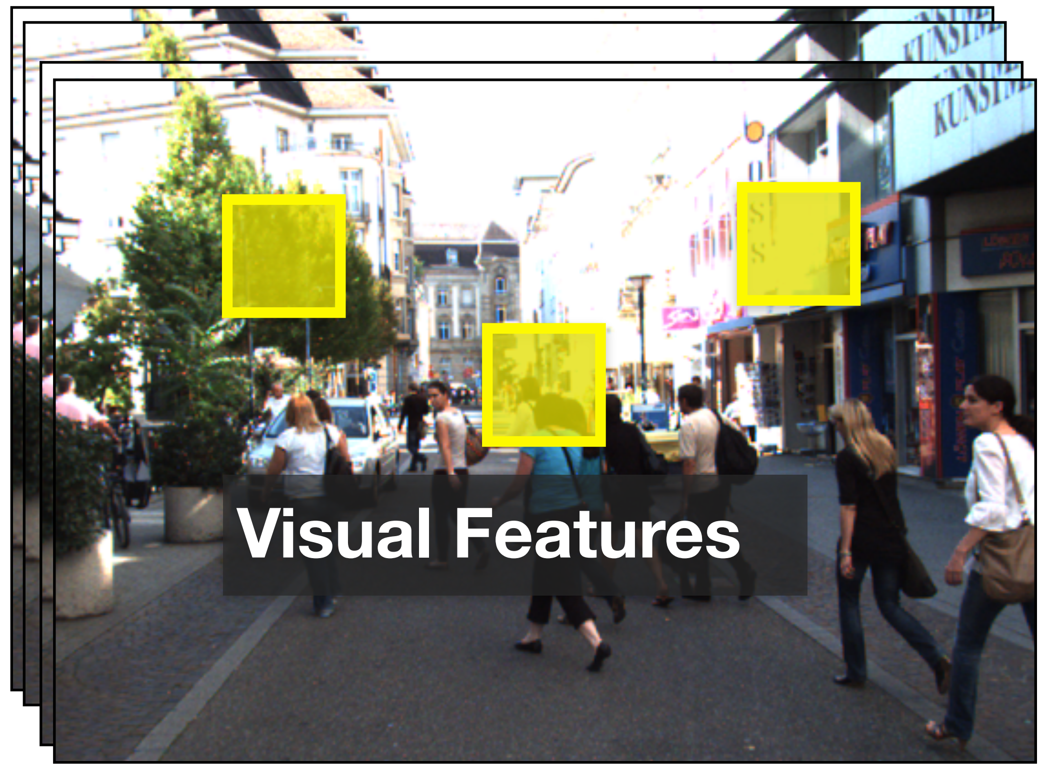

*KITTI Urban Driving Dataset. Sequence 2011_09_29_drive_0071*

Different regions in image space may contain less **useful information** than others.

A. Geiger, P. Lenz, C. Stiller, and R. Urtasun, "Vision meets robotics: The KITTI dataset," *IJRR, 2013.*

# **Application** | Visual Odometry

## Traditional Approach




→

Estimation errors: $\mathbf{e}_i$

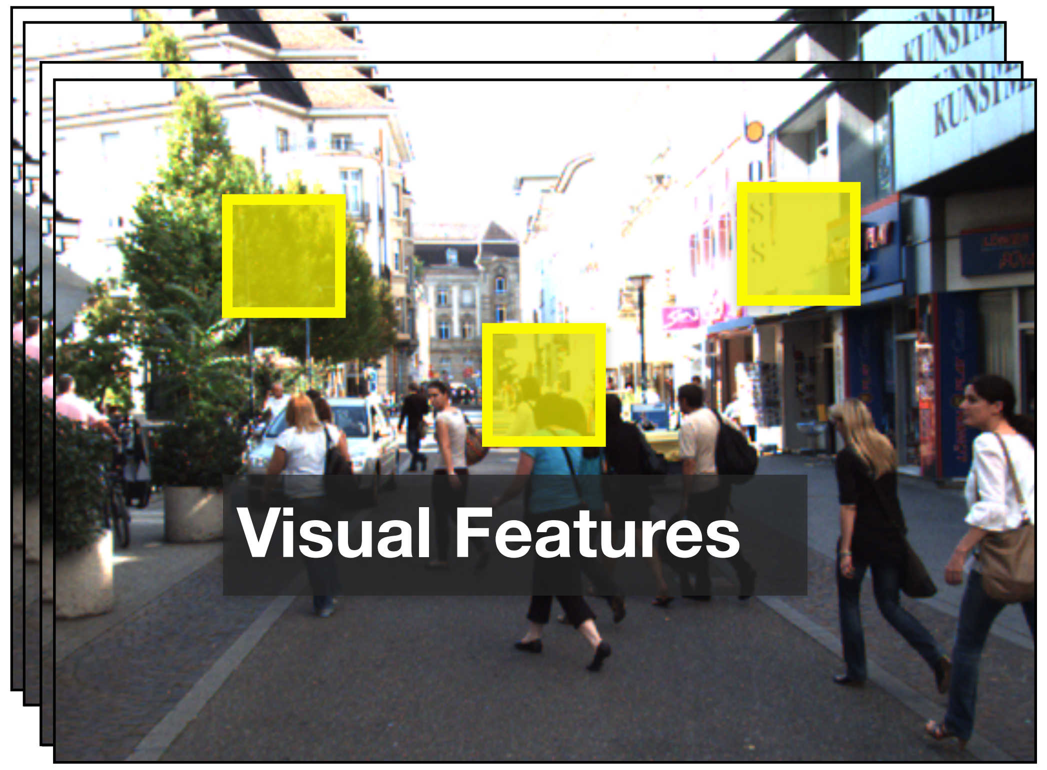
Stationary **point** uncertainty: $\mathbf{R}$

→

MAP Estimator:

$$\underset{\mathcal{T} \in \mathrm{SE}(3)}{\arg\min} \sum_{i=1}^{N} \boldsymbol{e}_i{}^{\top} \mathbf{R}^{-1} \boldsymbol{e}_i$$

## **PROBE**-GK




→

Estimation Errors: $\mathbf{e}_i$

**Bayesian,** kernel based covariance probability

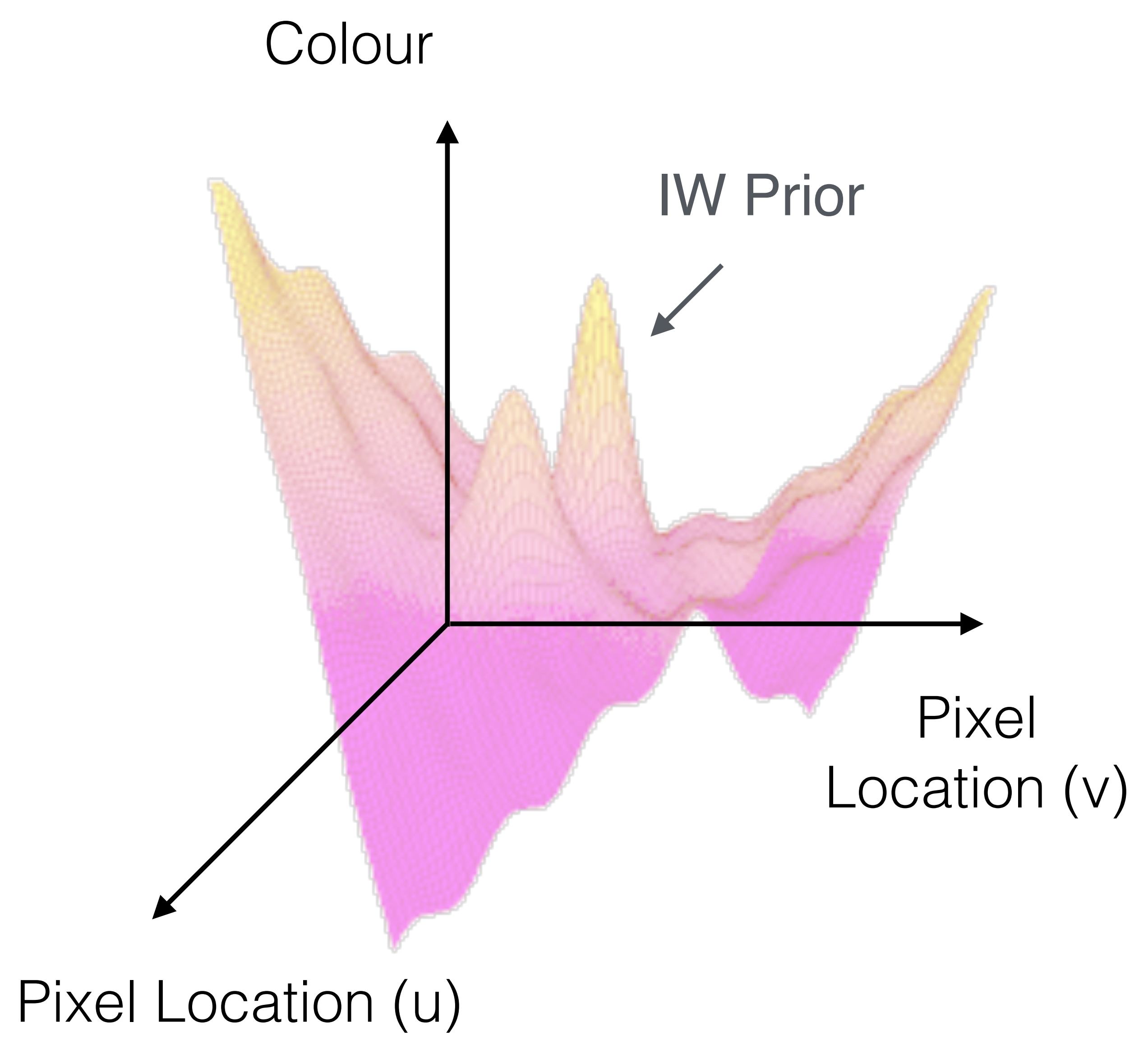
$$p\left(\mathbf{R}_i\right) = \mathrm{IW}\left(\mathbf{R}; \boldsymbol{\Psi}_i, \nu_i\right)$$

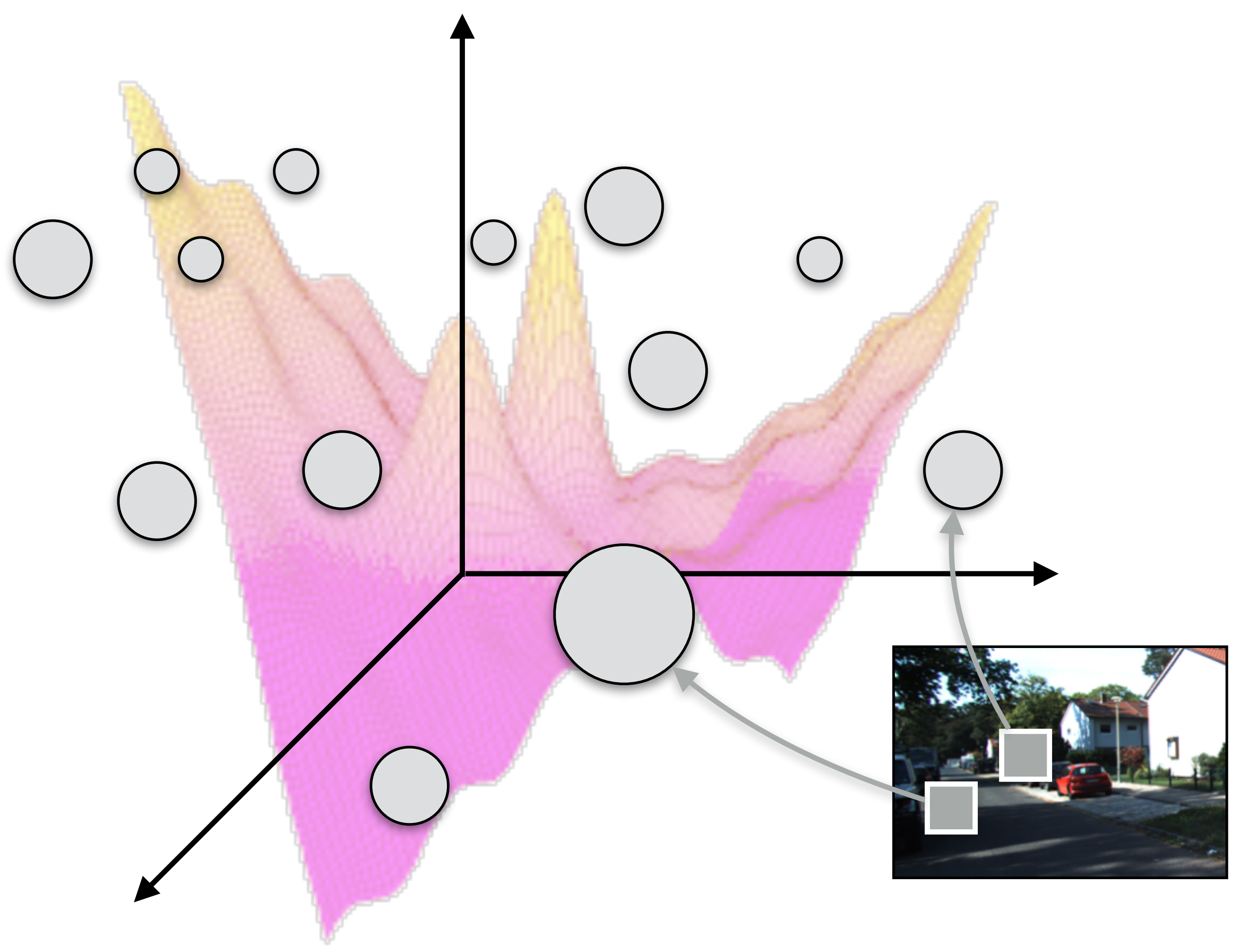
→

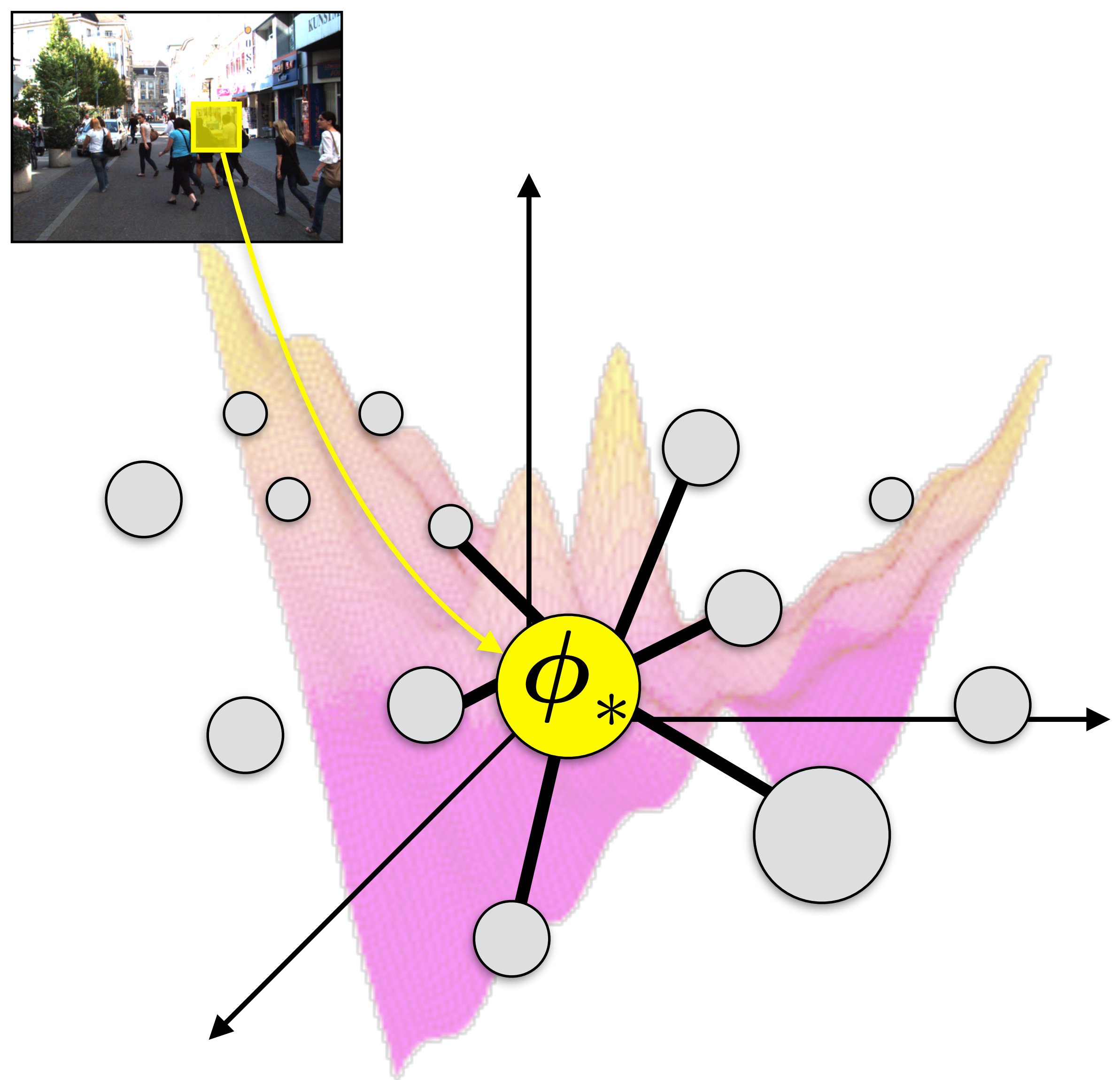
Predictively Robust Estimator:

$$\underset{\mathcal{T} \in \mathrm{SE}(3)}{\arg\min} \sum_{i=1}^{N} (\nu_i + 1) \log\left(1 + \boldsymbol{e}_i{}^{\top} \boldsymbol{\Psi}_i^{-1} \boldsymbol{e}_i\right)$$

# **Model of Uncertainty** | Bayesian Predictive Model for Covariance






1. **Define**:
   Inverse-Wishart prior on covariance matrices at all locations within prediction space.

2. **Train**:
   Populate space with training data (empirical errors). Ground truth not required.

3. **Test**:
   a) Compute Inverse-Wishart posterior using technique of Generalized Kernels.

   b) Marginalize out the covariance, transform likelihood into robust cost.

*Predictively* Robust Cost

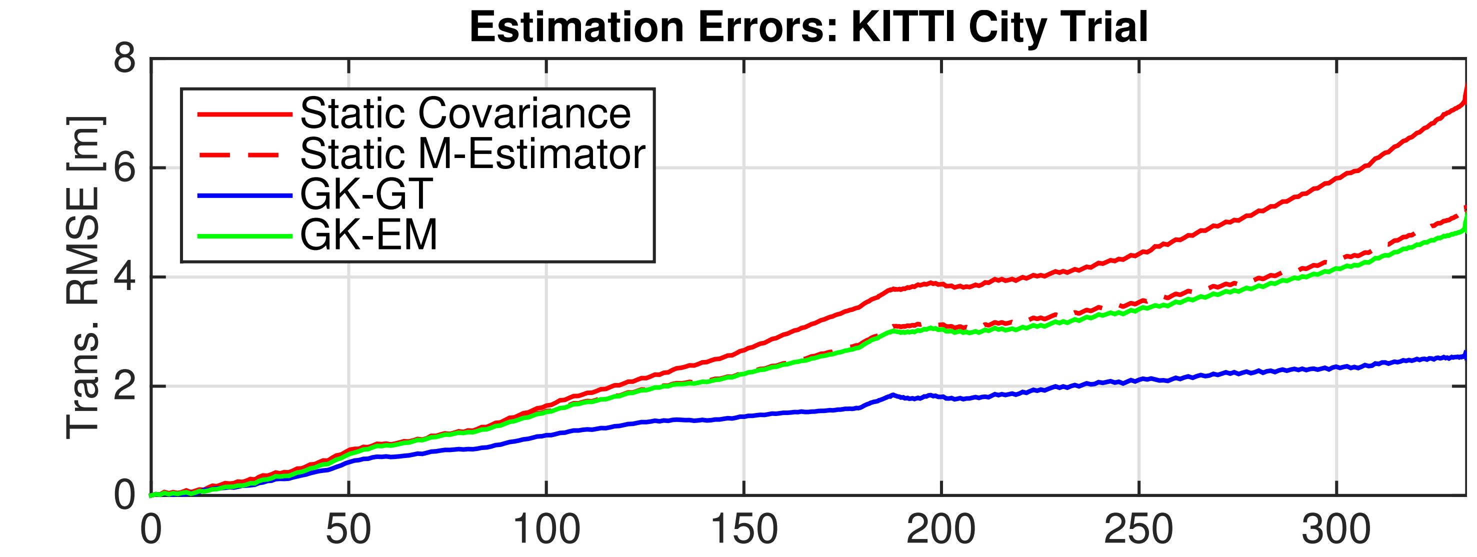
$$\operatorname*{arg\,min}_{\mathcal{T}\in \mathrm{SE}(3)} \sum_{i=1}^{N} (\nu_i + 1) \log \left(1 + \boldsymbol{e}_i{}^{\top} \boldsymbol{\Psi}_i^{-1} \boldsymbol{e}_i\right)$$

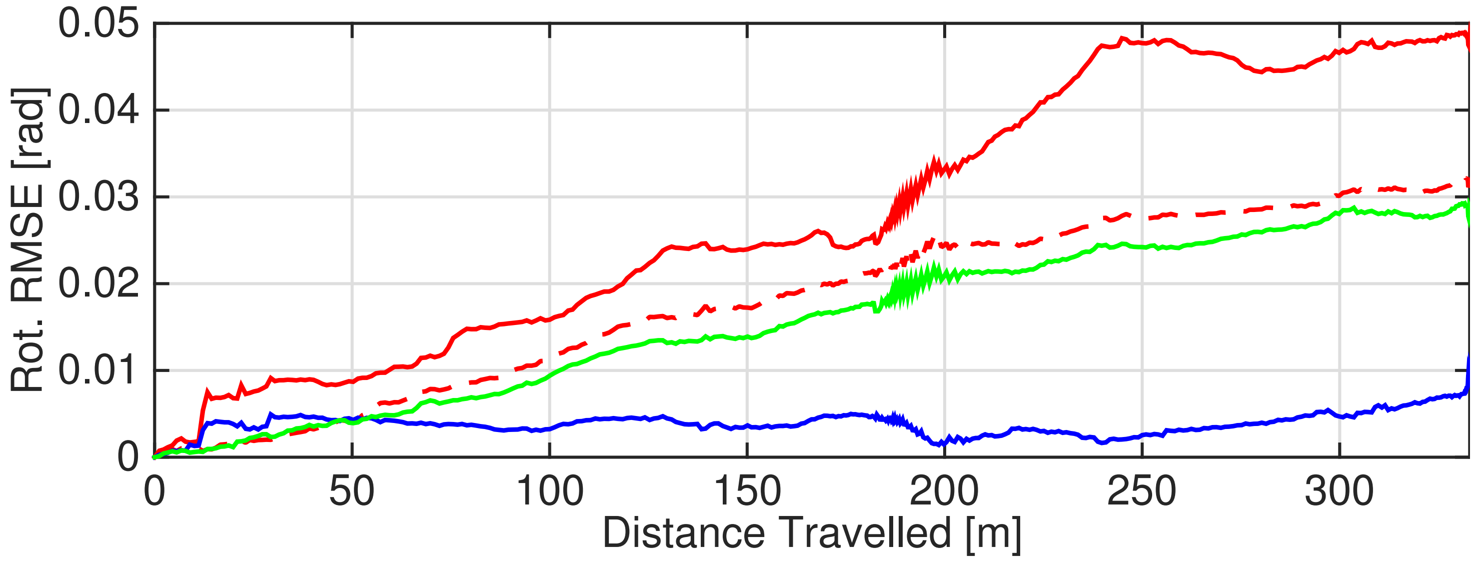
# Visual Odometry Results | Training and Evaluation

We use use PROBE-GK to improve **stereo visual odometry**

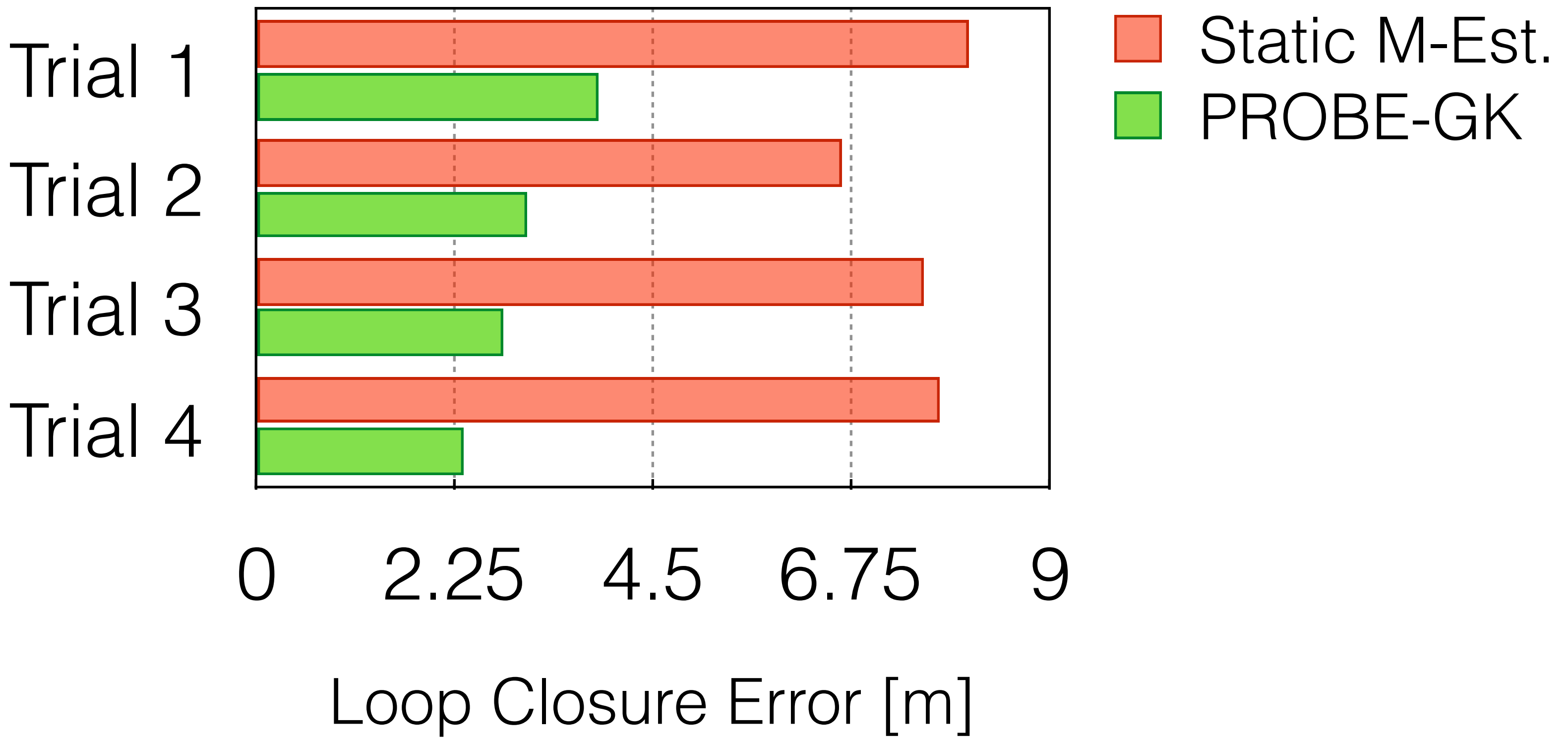
Train and test on separate trials from two datasets

## **KITTI** Data


## **MarsDome** Data

# Thank you!

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