Sparse Bundle Adjustment for Dense Data

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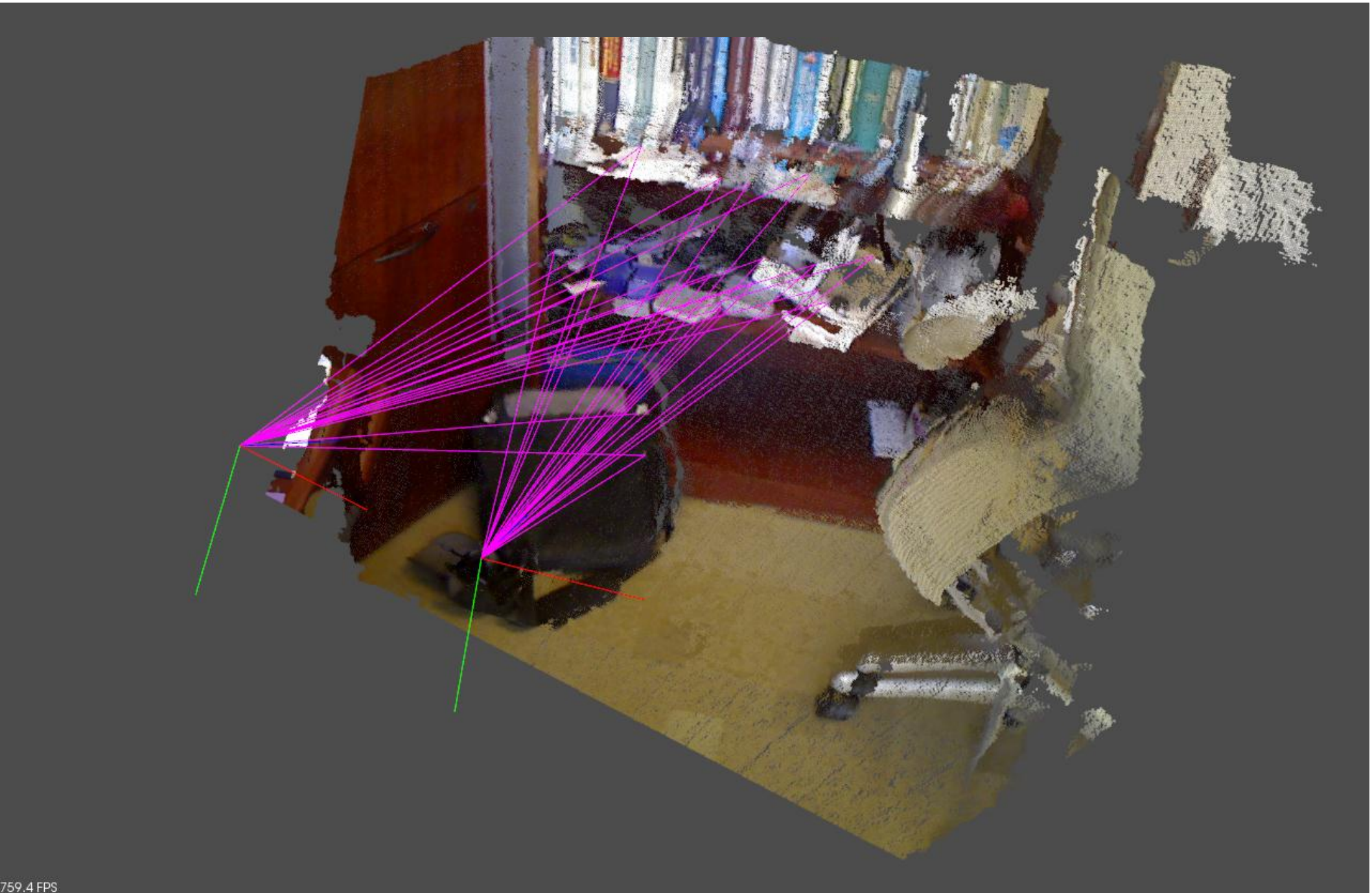
Willow Garage, Stanford CS



Bundle Adjustment

$$e_k = prj_k(p_i, q_j) - \hat{z}_k$$

Minimize sum of squared error

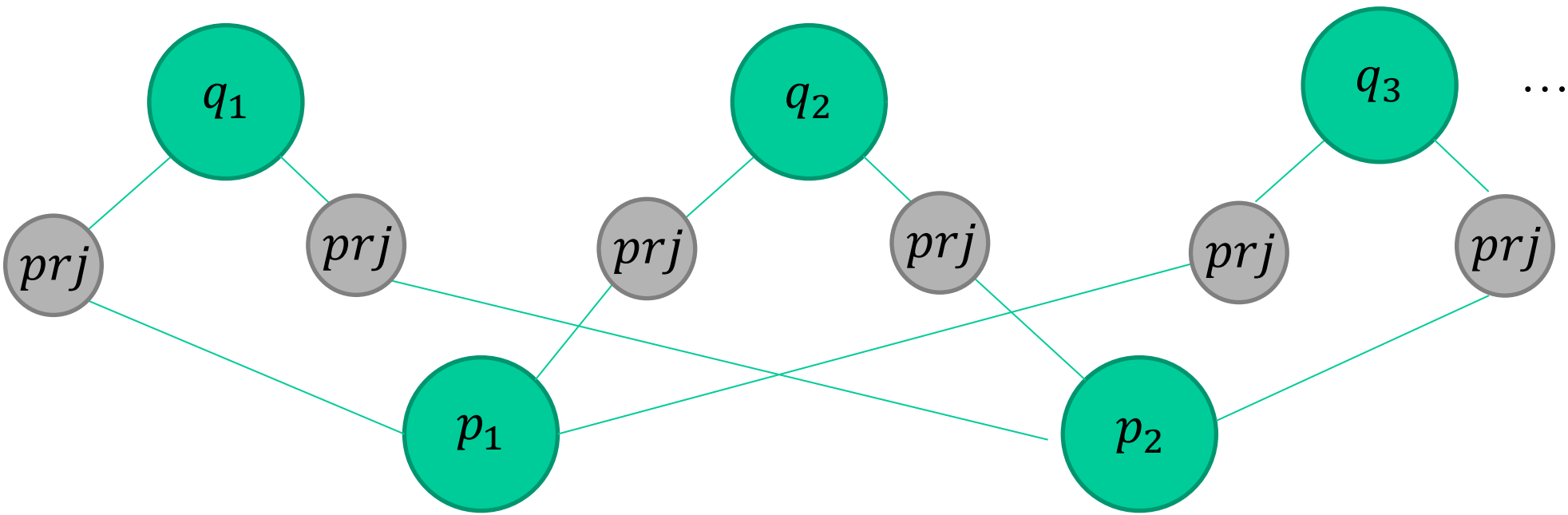


Photo tourism [Snavely, Seitz, Szeliski 2006]

Large nonlinear estimation problem: Bundle Adjustment

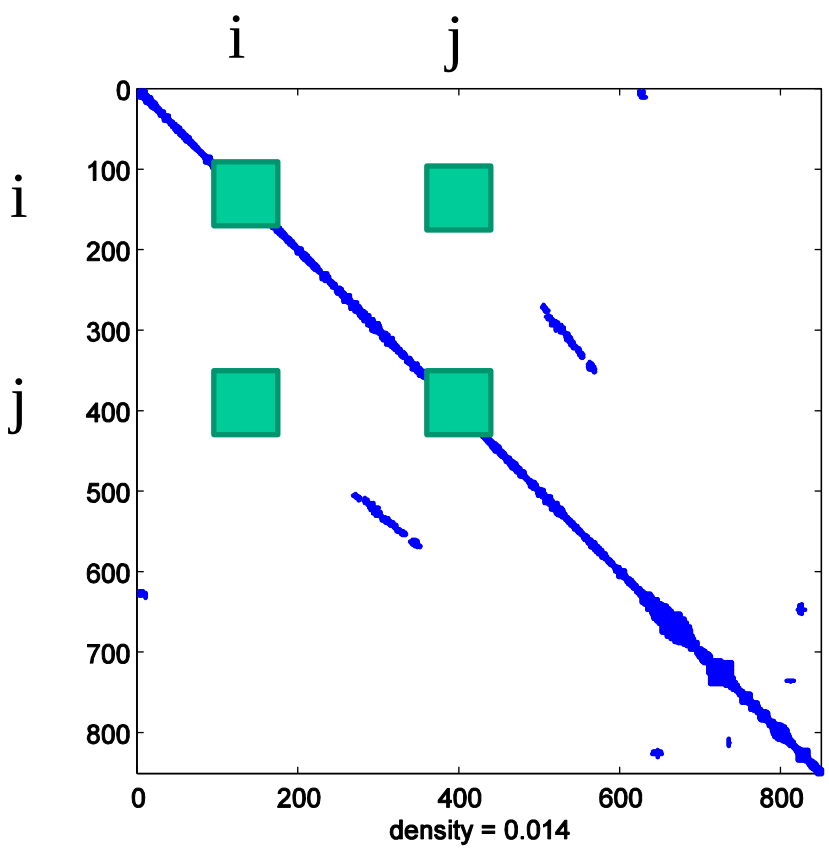
Thousands of camera poses, millions of points

Sparse Bundle Adjustment

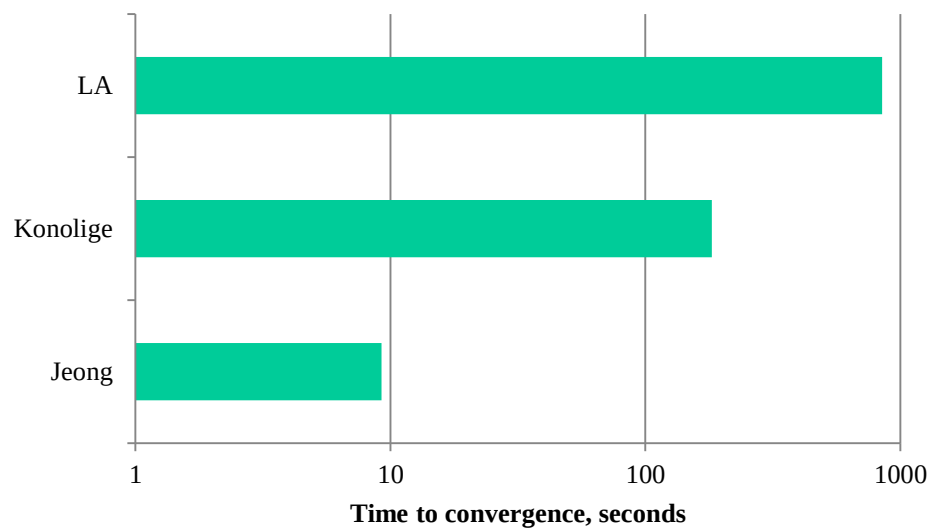
$$e_k = z_k(x_i, x_j) - \hat{z}_k$$ Error Equation

$$J_k = \frac{\partial e_k}{\partial x} | \bar{x}$$ Jacobians

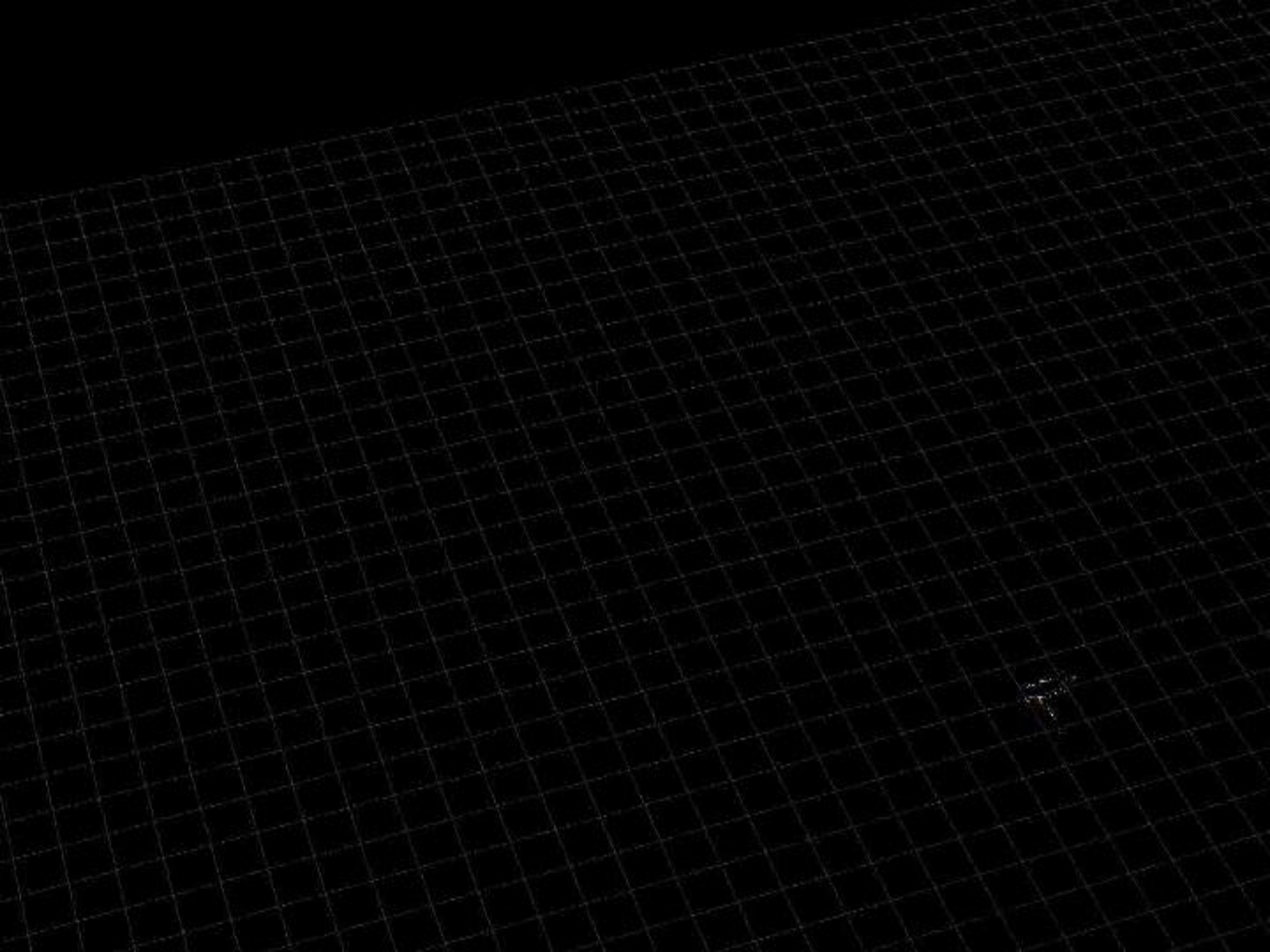
$$\boldsymbol{J^T J x = J^T e}$$ Normal Equation



Lourakis and Argyros [TR 2004]
Konolige [BMVC 2010]
Jeong et al. [CVPR 2010]

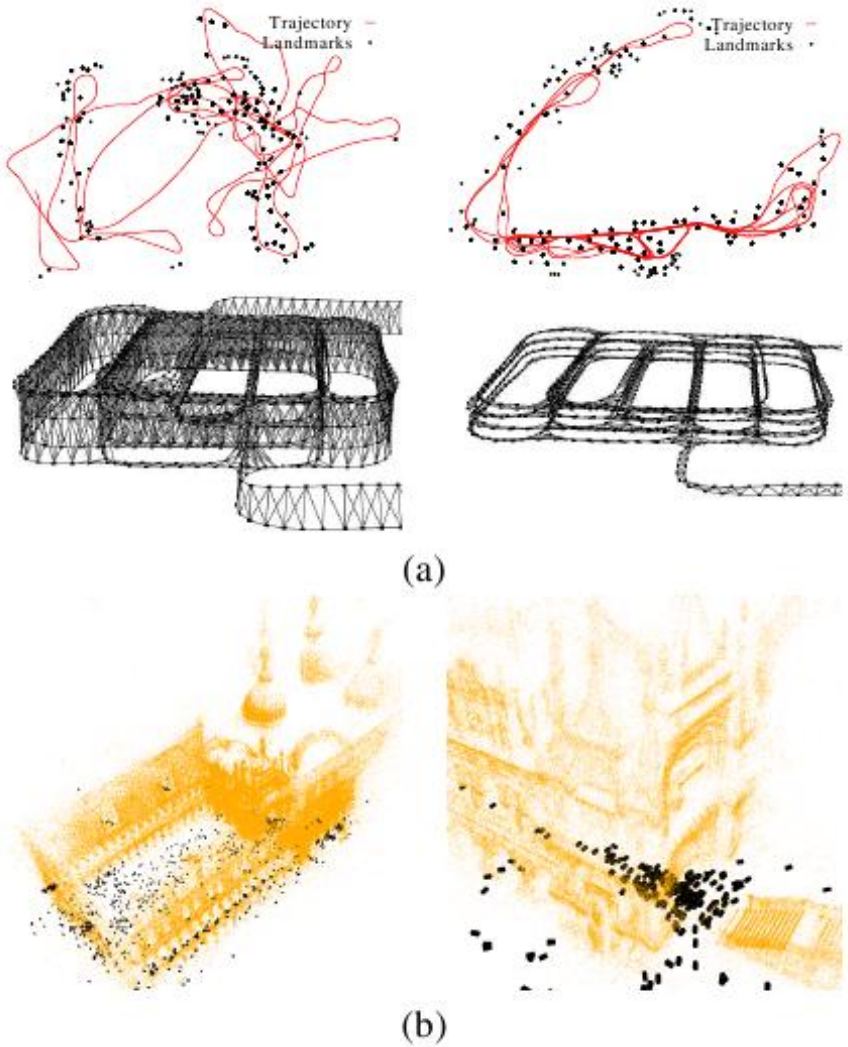


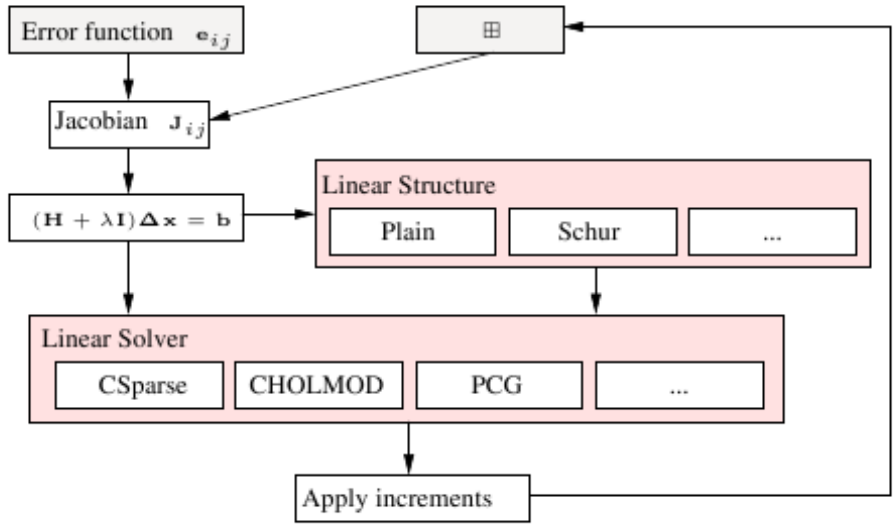
2,010,363 vars, 2,857,277 constraints



g2o: A General Framework for Graph Optimization

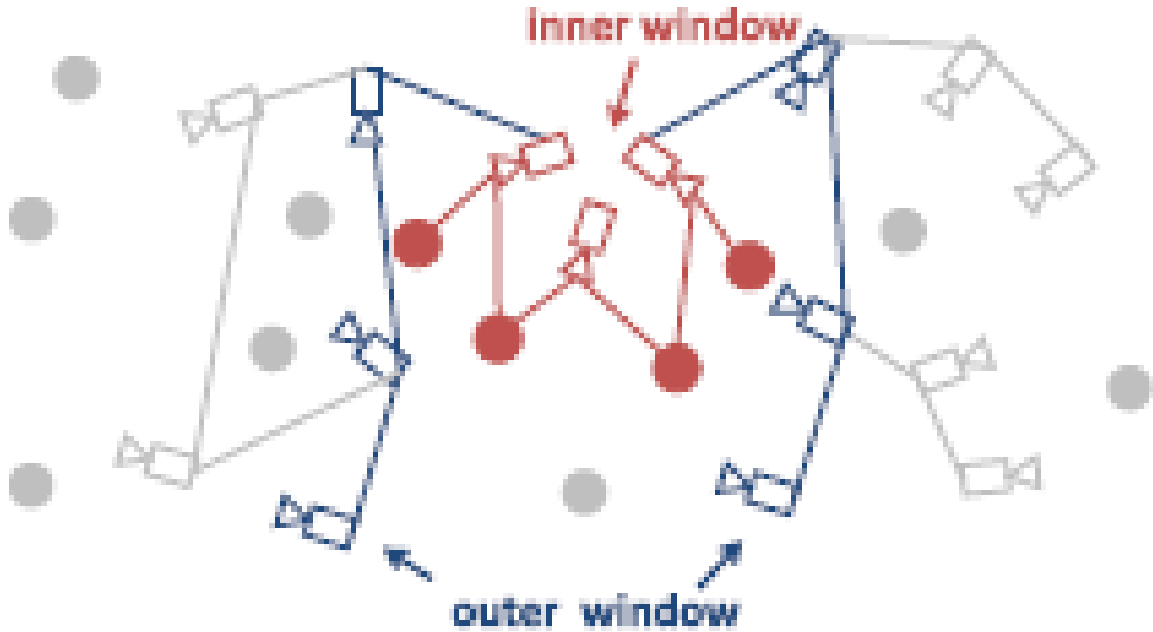
Kummerle, Grisetti, Strasdat, Konolige, Burgard [ICRA 2011]
Open Source!





Issues

- Growth of dataset
- How to incorporate ICP for dense depth
- How to set up a "surface" database



(a) Inner and outer window

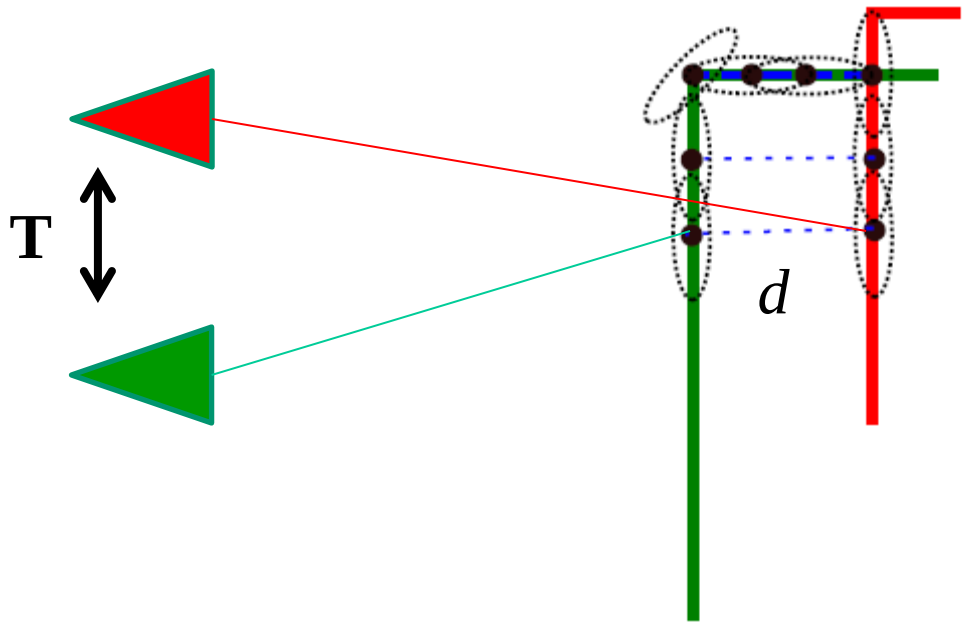
Hauke Strasdat et al., ICCV 2011

Double Window Optimisation for Constant Time Visual SLAM

Hauke Strasdat et al., ICCV 2011

Generalized ICP

[Segal et al. 2005]

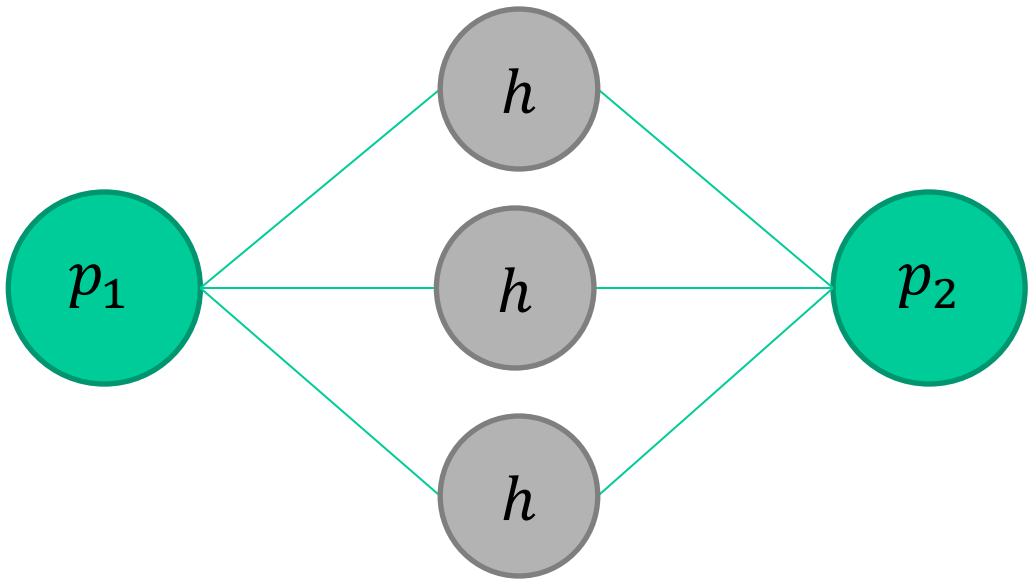


$$\mathbf{T} = \underset{\mathbf{T}}{\operatorname{argmin}} \sum_i {d_i^{(\mathbf{T})}}^T (C_i^B + \mathbf{T} C_i^A \mathbf{T}^T)^{-1} d_i^{(\mathbf{T})}$$

+ Matching of neighbors

$$e_k = h_k(p_i, p_j) - \hat{z}_k$$

…



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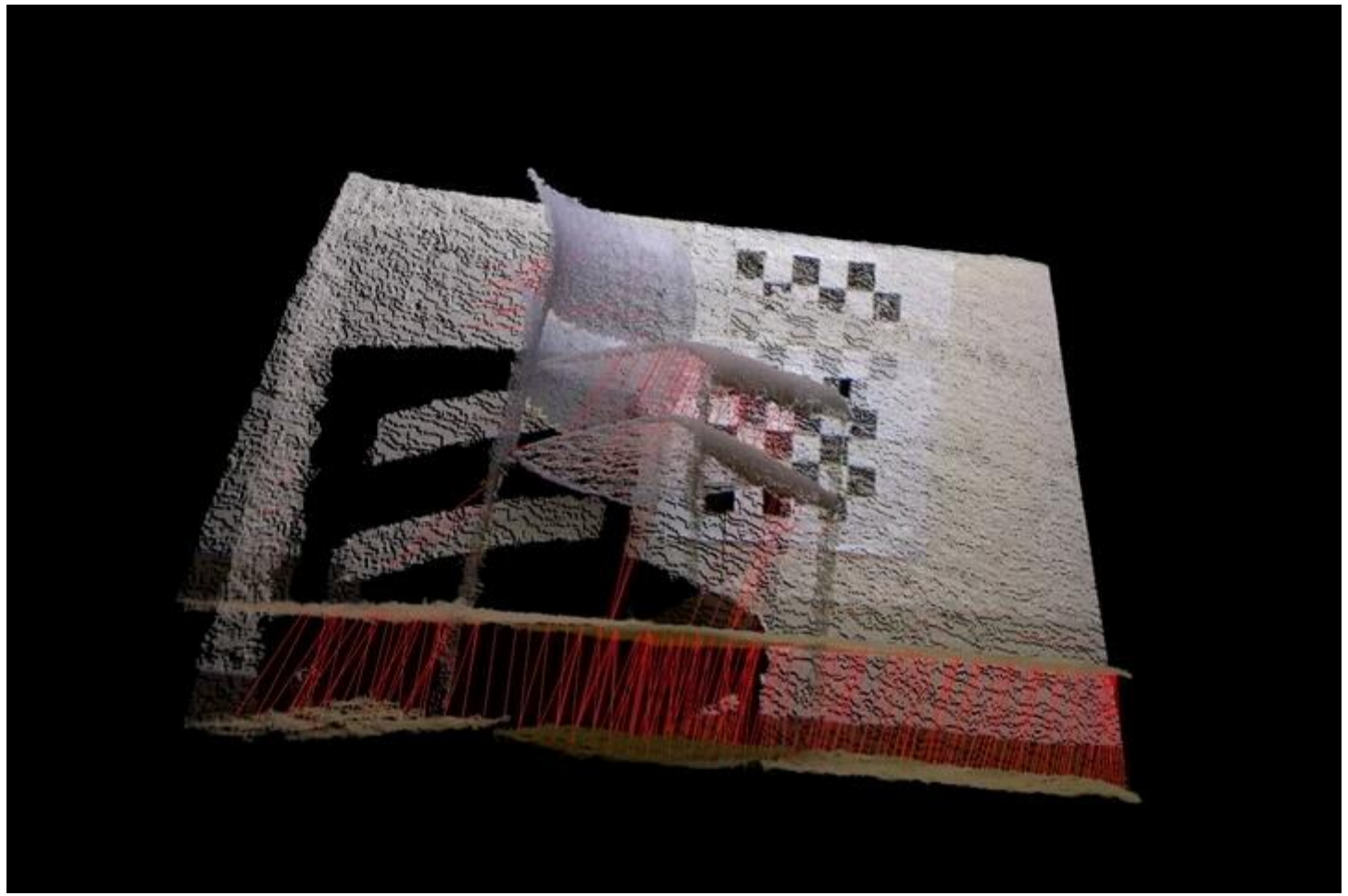
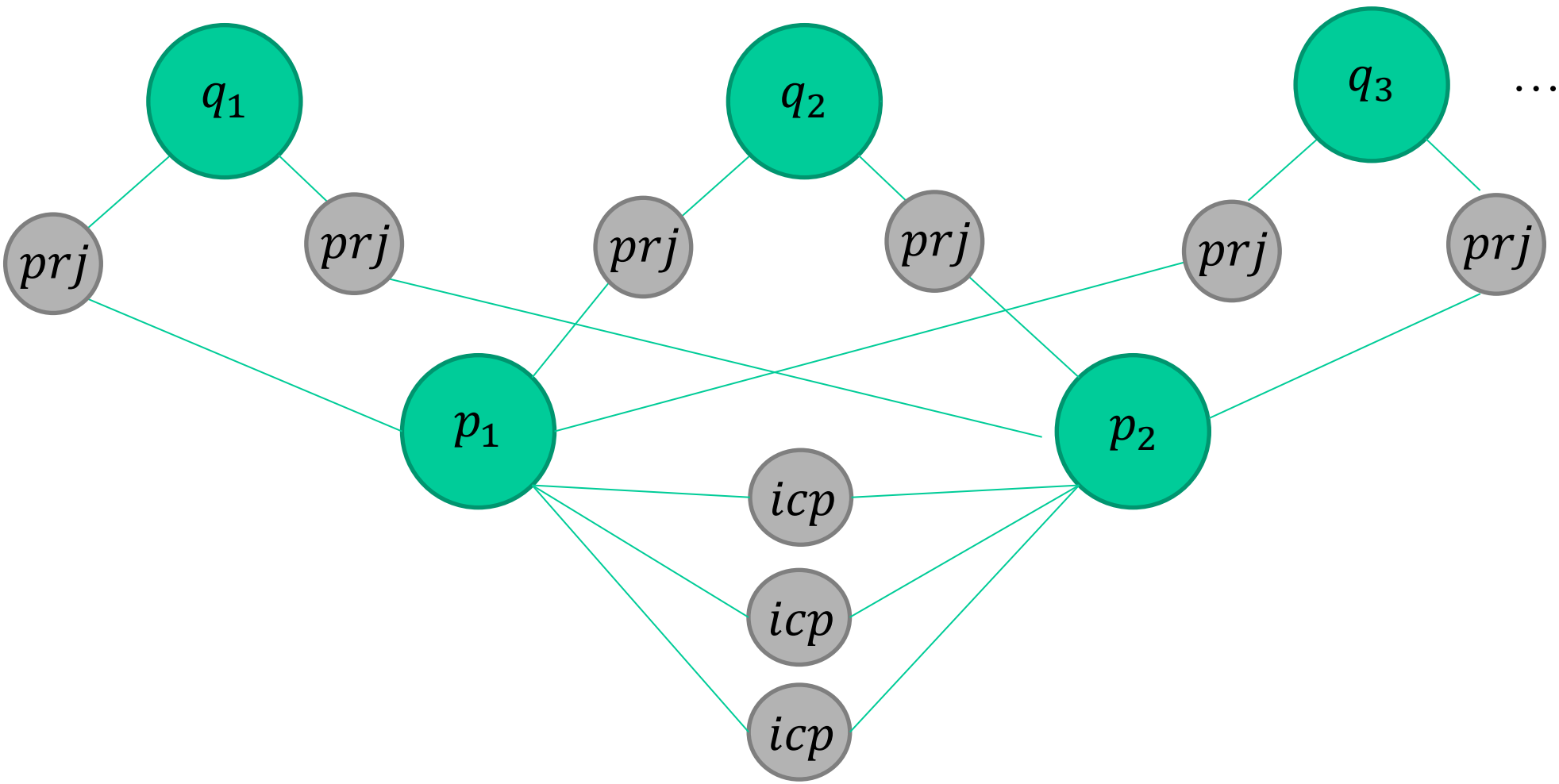


$$f(p_1, p_2, q_1, q_2, q_3, \dots) = \prod_i prj_i(p_1, q_i)\, prj_i(p_2, q_i) \prod_i icp_i(p_1, p_2)$$

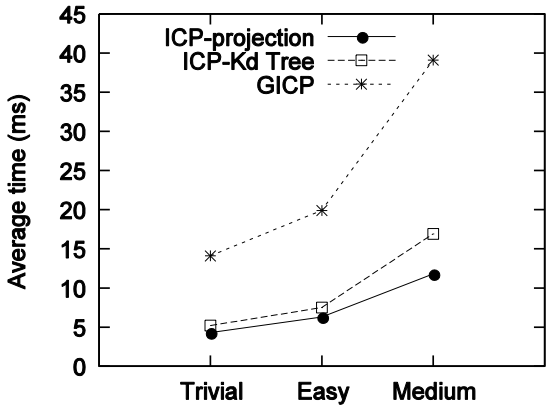


Combined ICP and Visual Features

[Fioraio and Konolige 2011]

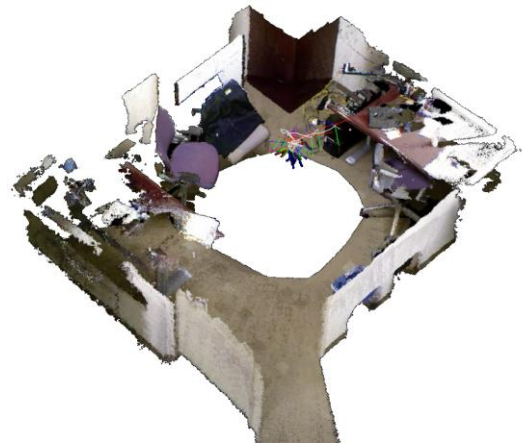
Results

Timing Performance



Based on 823 pairwise alignment tests⁎.

⁎ *GICP is an open-source implementation of plane-to-plane generalized ICP (Segal et al. "Generalized-ICP", 2009)*

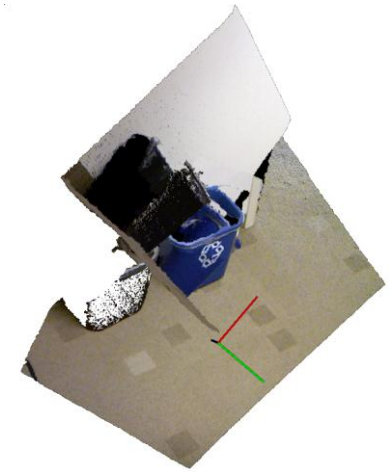


Visual Features and ICP

Plane-plane ICP

Point-plane ICP

Visual Features† only

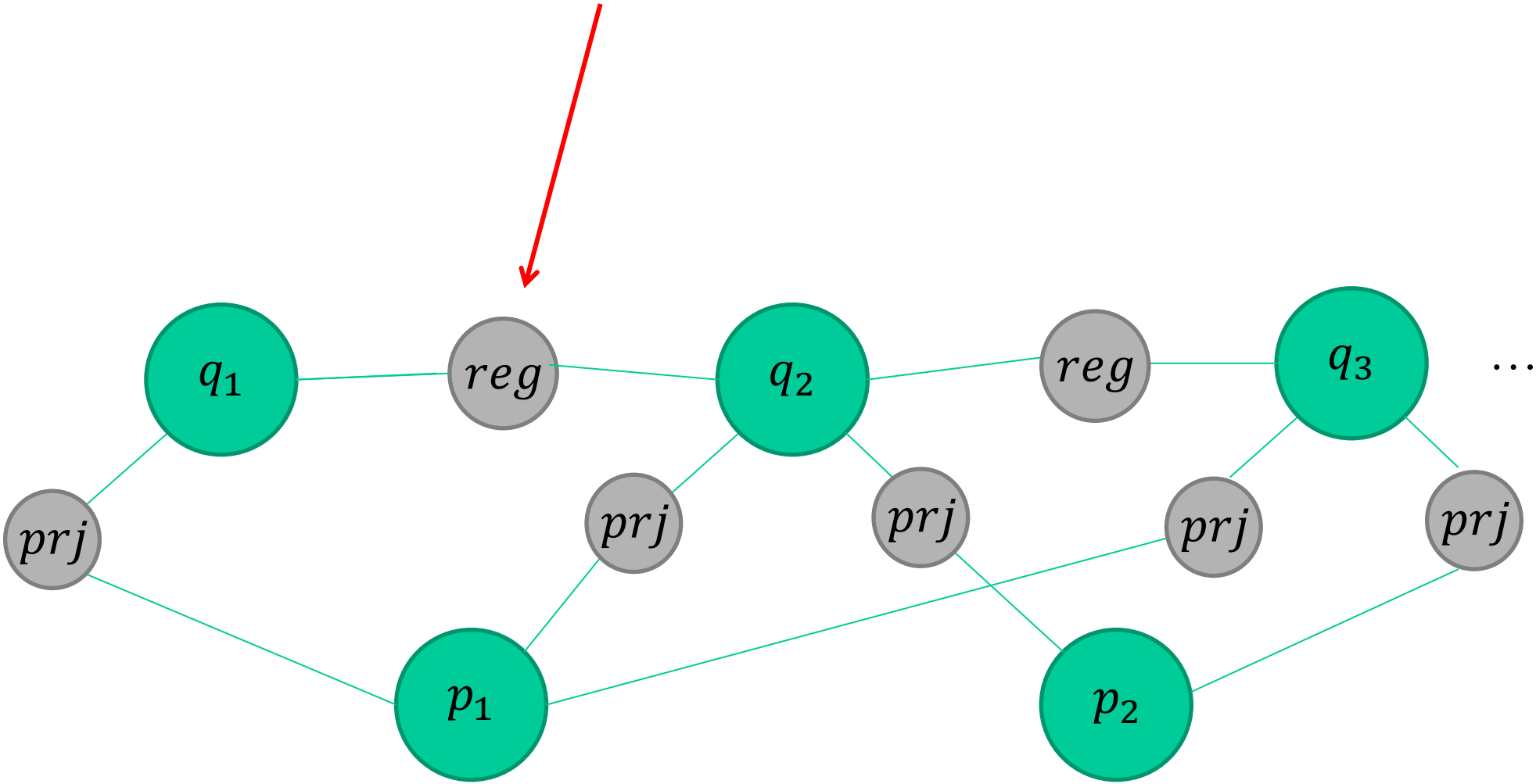


ICP & Visual Features†

† *BRIEF features from FAST keypoints.*

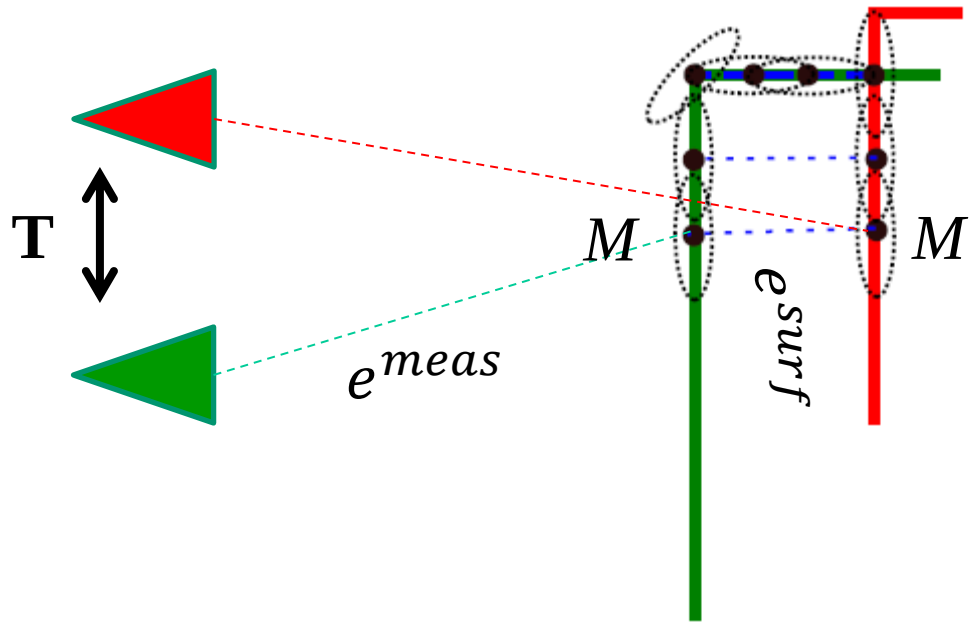
Global BA

- Incremental pairwise alignment;
- Global optimization performed with all the accumulated constraints;
- 72 nodes, 77899 edges => 346ms


q_1
reg
q_2
reg
q_3
$\ldots$
prj
prj
prj
prj
prj
p_1
p_2

Sparse Surface Adjustment

[Ruhnke et al. 2011]



$$\langle \mathbf{x}^*_{1:n}, \mathcal{M}^* \rangle = \underset{\mathbf{x}_{1:n}, \mathcal{M}}{\operatorname{argmin}} \sum_{n=1}^{N} \mathbf{e}_n^{\text{od}} + \sum_{\langle i,j \rangle} \mathbf{e}_{ij}^{\text{surf}} + \sum_{\langle n,k \rangle} \mathbf{e}_{nk}^{\text{meas}}$$

+ Matching of neighbors

Sparse Surface Adjustment Demonstration on Kinect Data

M. Ruhnke, R. Kümmerle, G. Grisetti, W.Burgard

University of Freiburg, Germany

http://www.informatik.uni-freiburg.de/~ruhnke/

Relation to Dense Methods

Dense tracking – stabilizes the front end
[ESM, Comport et al. 2010, DTAM]

Adding in visual features

Dense surface methods have difficulty with “adjustment” after loop closure

ICP bundle adjustment doesn’t make surfaces first-class objects

Sparse Surface Patch Adjustment