Cycle-Sync: Robust Global Camera Pose Estimation through Enhanced Cycle-Consistent Synchronization

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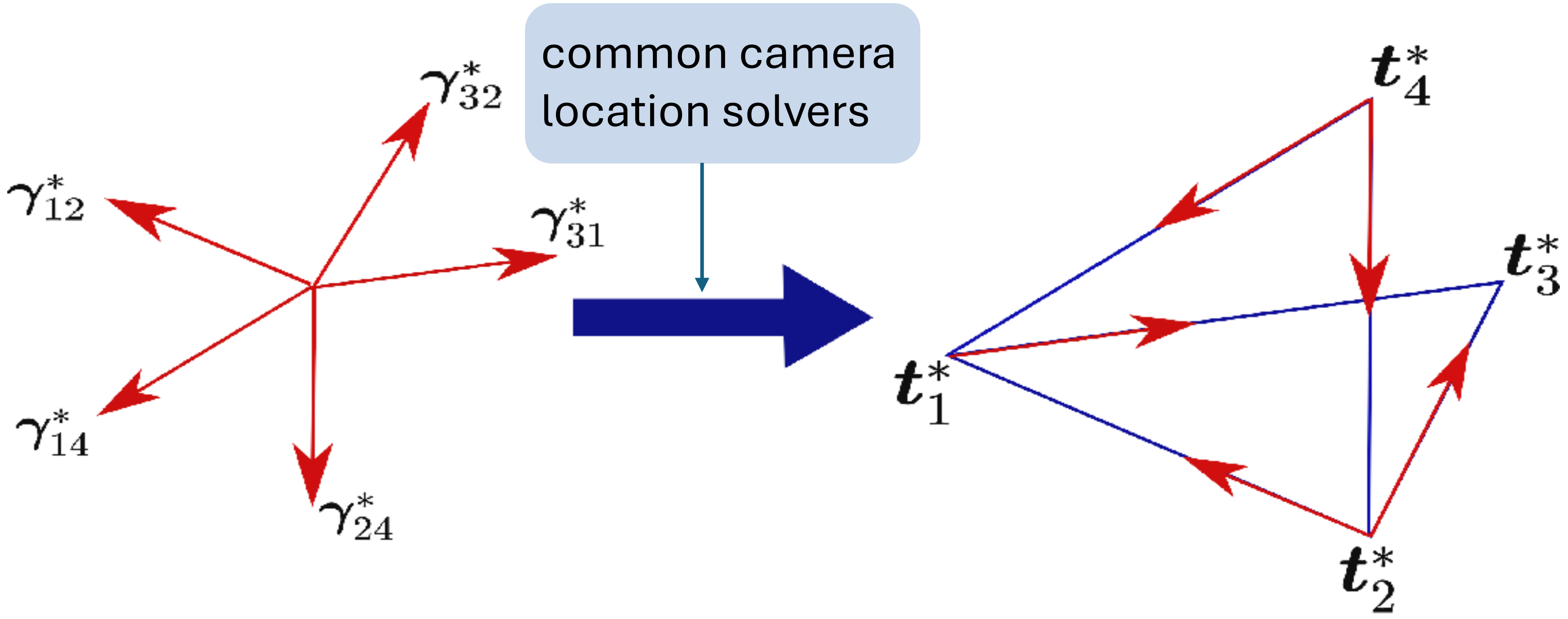
Camera Location Estimation



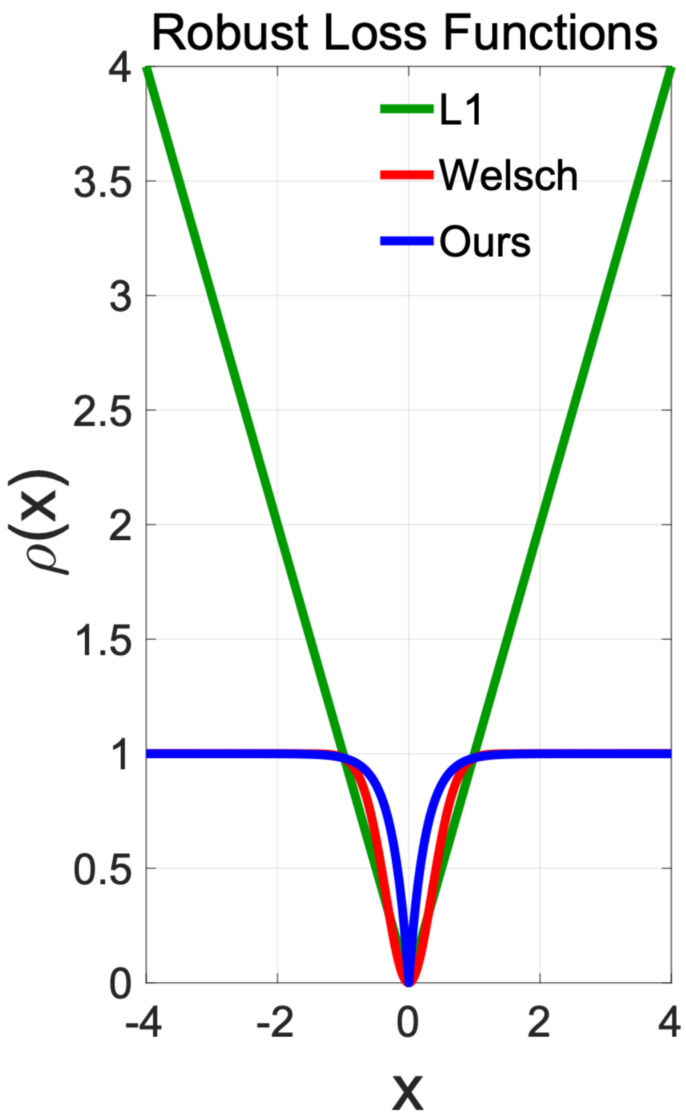
- Pairwise directions are unit vectors
- Pairwise directions can be severely corrupted

Robust Formulations

$$\min_{\{\boldsymbol{t}_i\}_{i=1}^n, \{\alpha_{ij}\}_{ij \in E}} \sum_{ij \in E} \rho(\|\boldsymbol{t}_i - \boldsymbol{t}_j - \alpha_{ij}\boldsymbol{\gamma}_{ij}\|)$$

$$\text{subject to} \quad \alpha_{ij} \geq 1, \quad \sum_i \boldsymbol{t}_i = 0,$$

Contribution 1: Improved Welsch-type Robust Loss



$$\rho(x) = 1 - e^{-a|x|}$$

- Suppress the effect of large residuals and long edges
- Non-smoothness at the origin (exact recovery is possible)

Contribution 2: Cycle-based Weight Update

- Our new robust formulation is solved by the following weighted least squares

$$\min_{\{\boldsymbol{t}_i\}_{i=1}^n, \{\alpha_{ij}\}_{ij \in E}} \sum_{ij \in E} w_{ij,t} \|\boldsymbol{t}_i - \boldsymbol{t}_j - \alpha_{ij} \boldsymbol{\gamma}_{ij}\|^2$$

- Edge weights are updated in each iteration according to our robust loss

$$w_{ij,t+1} = \rho'(h_{ij,t}) / (h_{ij,t} + \delta)$$

- $h_{ij,t}$ is the estimated corruption level of edge ij

Contribution 2: Cycle-based Weight Update

- Edge corruption level is estimated by both residual and averaged cycle inconsistency

$$h_{ij,t} = (1 - \lambda_t) r_{ij,t} + \lambda_t s_{ij,t} \qquad (\ \lambda_t \to 1\ )$$

Least squares residual

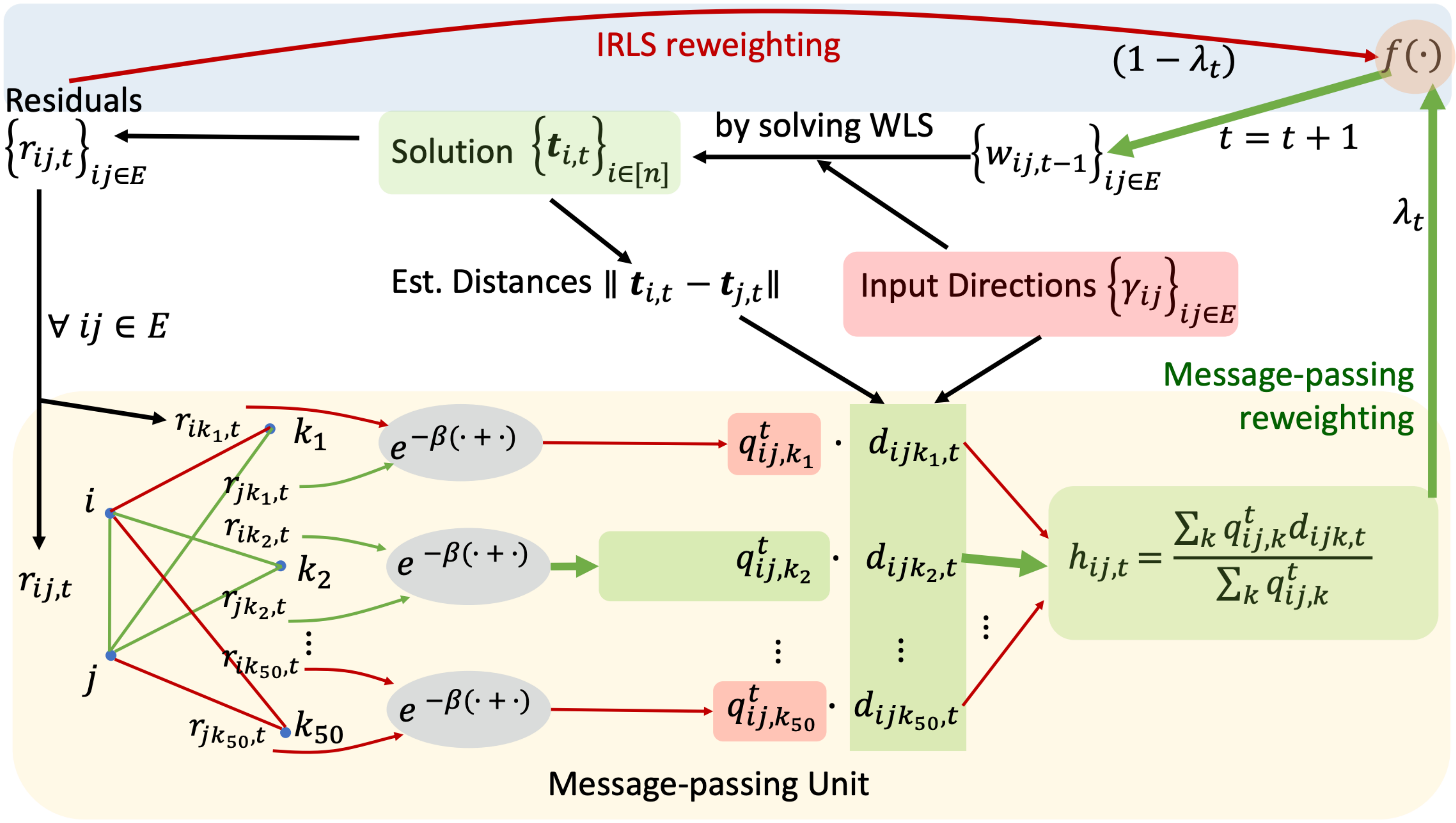
$$r_{ij,t} = \|\boldsymbol{t}_{i,t} - \boldsymbol{t}_{j,t} - \alpha_{ij,t}\boldsymbol{\gamma}_{ij}\|$$

Weighted average of cycle inconsistency

$$s_{ij,t} = \frac{1}{Z_{ij,t}} \sum_{k \in N_{ij}} e^{-\beta(r_{ik,t} + r_{jk,t})} d_{ijk,t}$$

Cycle Inconsistency: $d_{ijk,t} = \left\| \|\boldsymbol{t}_{i,t} - \boldsymbol{t}_{j,t}\|\boldsymbol{\gamma}_{ij} + \|\boldsymbol{t}_{j,t} - \boldsymbol{t}_{k,t}\|\boldsymbol{\gamma}_{jk} + \|\boldsymbol{t}_{k,t} - \boldsymbol{t}_{i,t}\|\boldsymbol{\gamma}_{ki} \right\|$

Contribution 2: Cycle-based Weight Update

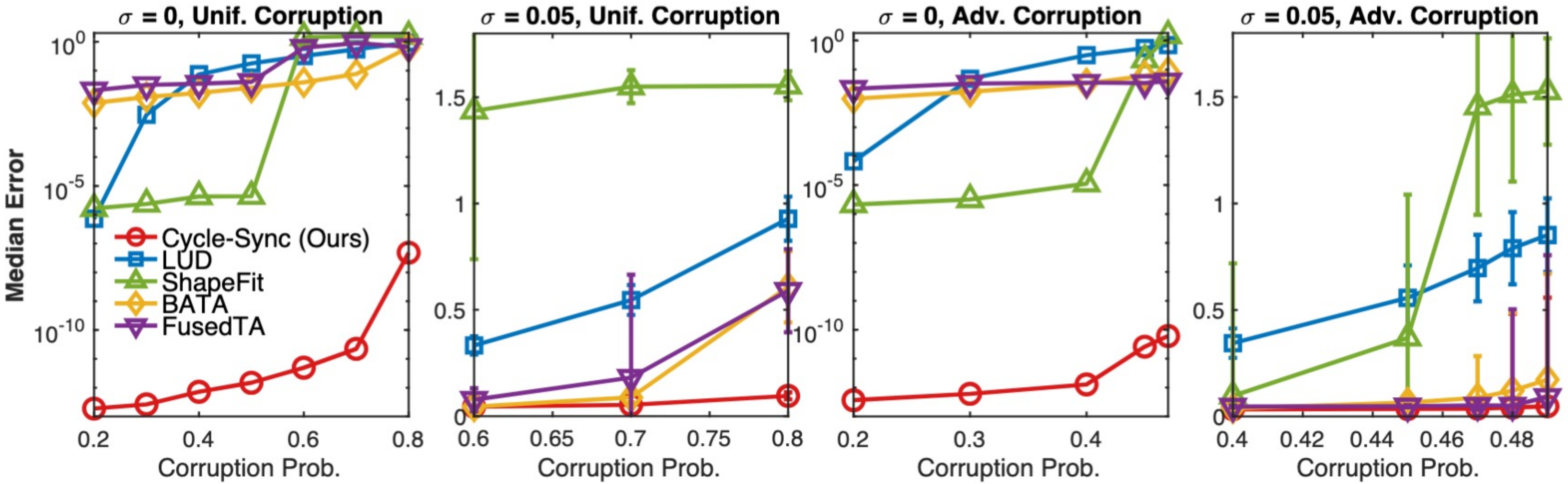


Contribution 3: Strongest Bounds for Exact Recovery

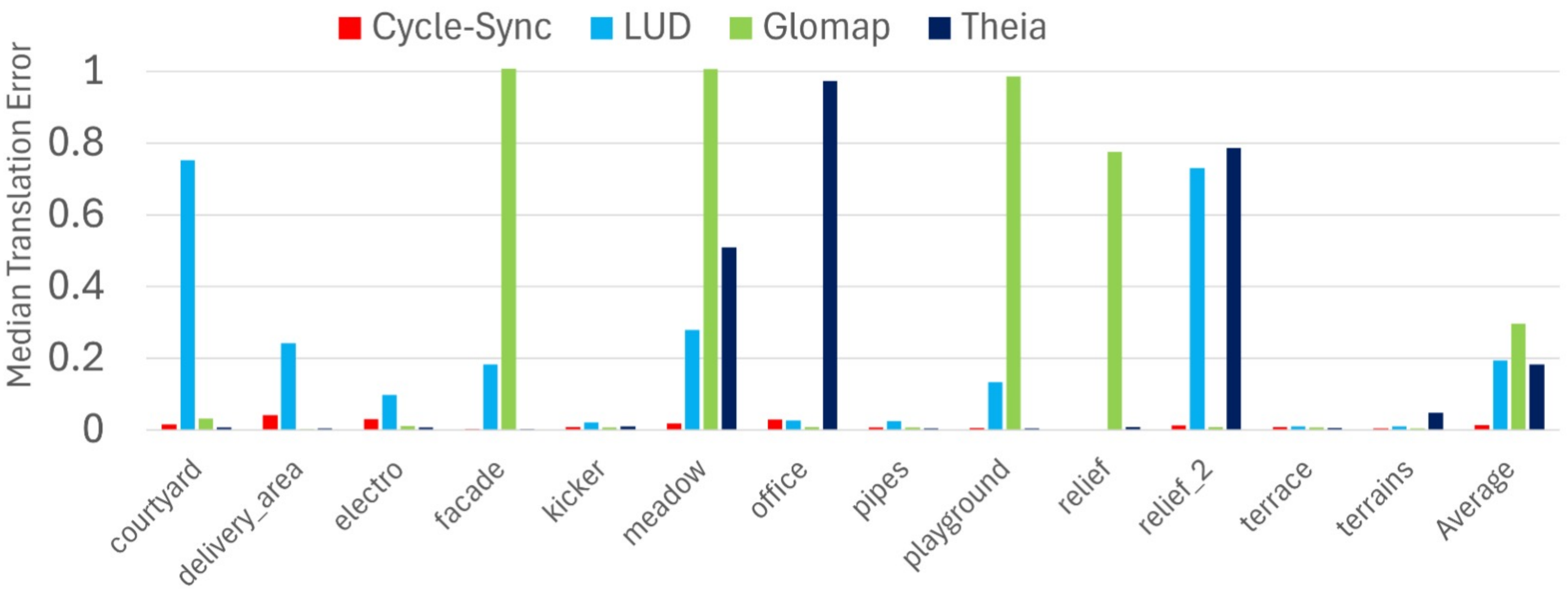
- We first prove a deterministic exact recovery theorem under adversarial corruption for the initialization stage of our method
- Next, assume Gaussian-distributed locations and Erdős–Rényi graph
- As a corollary in this special setting, we prove the phase transition bounds for exact recovery (p = prob of connection, q = prob of corruption)

Method	p	$\epsilon_b = pq$
ShapeFit	$\Omega(n^{-1/2}\log^{1/2} n)$	$O(p^5/\log^3 n)$
LUD	$\Omega(n^{-1/3}\log^{1/3} n)$	$O(p^{7/3}/\log^{9/2} n)$
Our Theory	$\Omega(n^{-1/2}\log^{1/2} n)$	$O(p/\log^{1/2} n)$

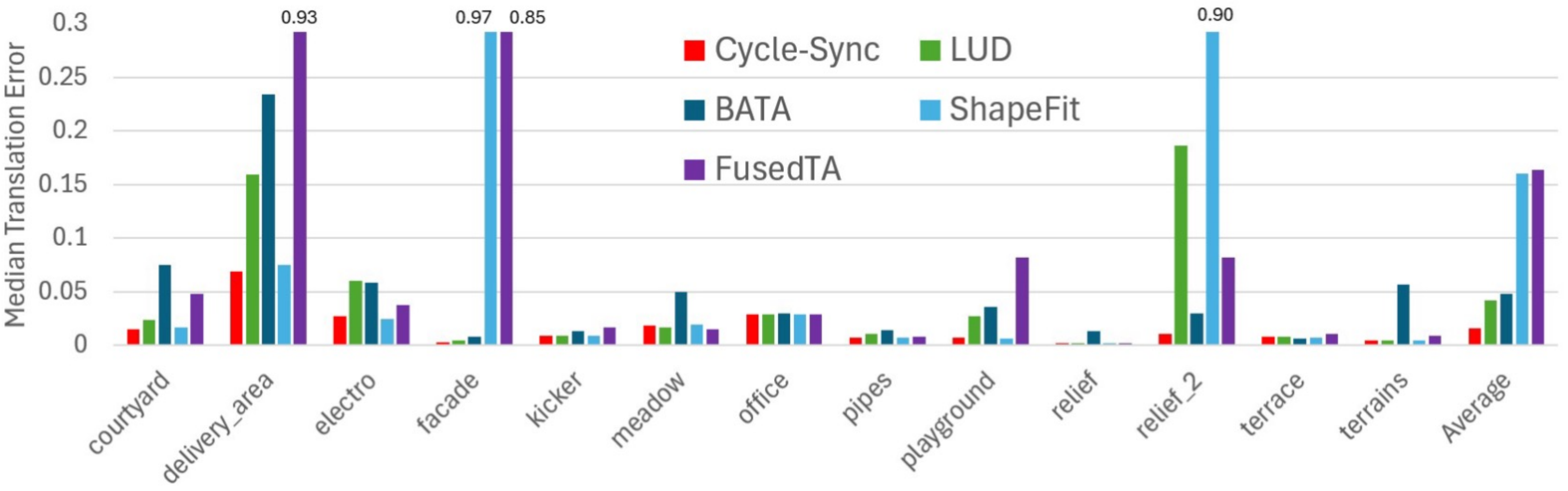
Synthetic Data: Uniform and Adversarial Corruption



Experiments on ETH3D



- No bundle adjustment for our method, unlike Glomap and Theia



- STE for direction estimation and outlier filtering for all location solvers