Dense Visual SLAM for RGB-D cameras

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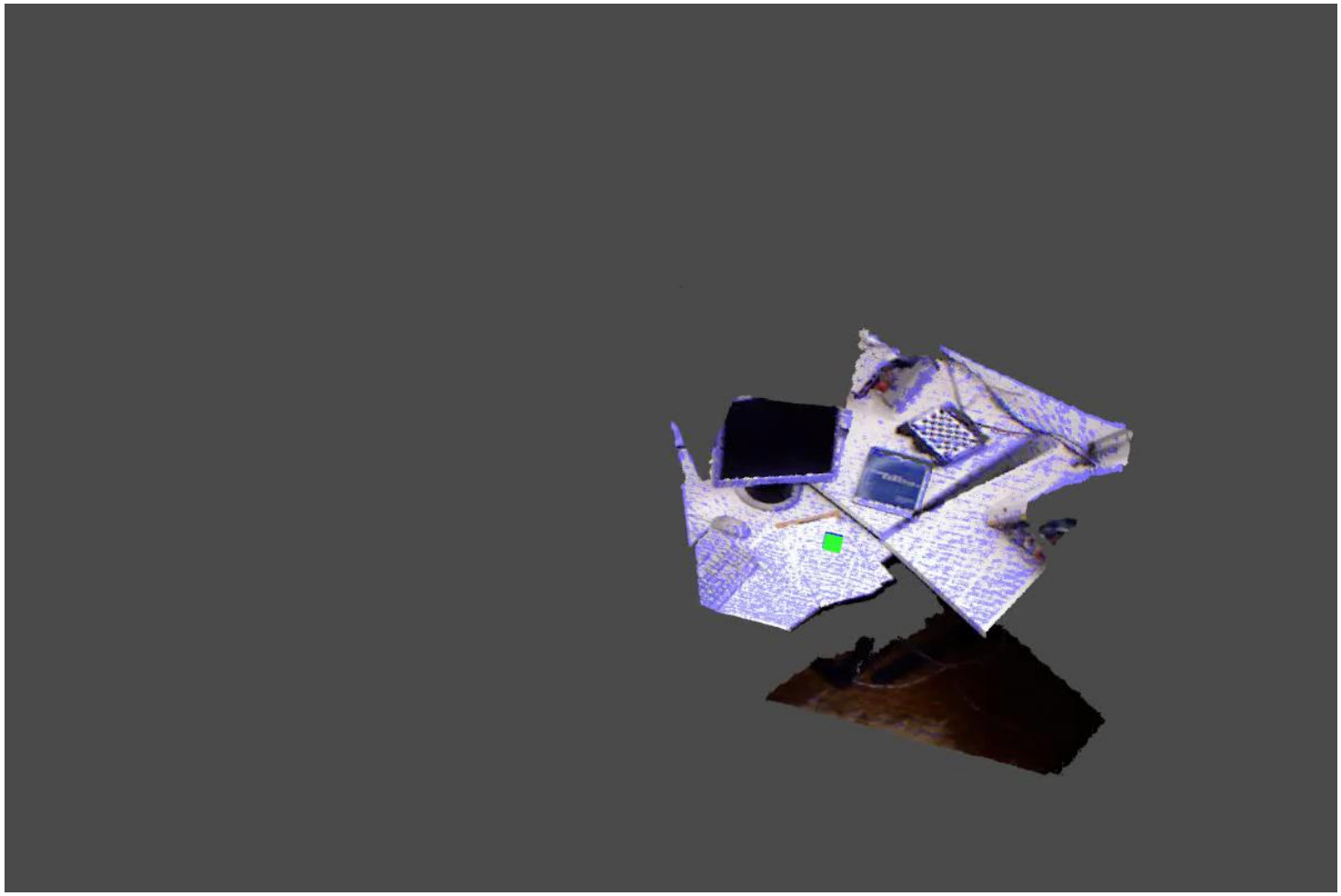
Goal

Estimate camera motion from RGB-D data

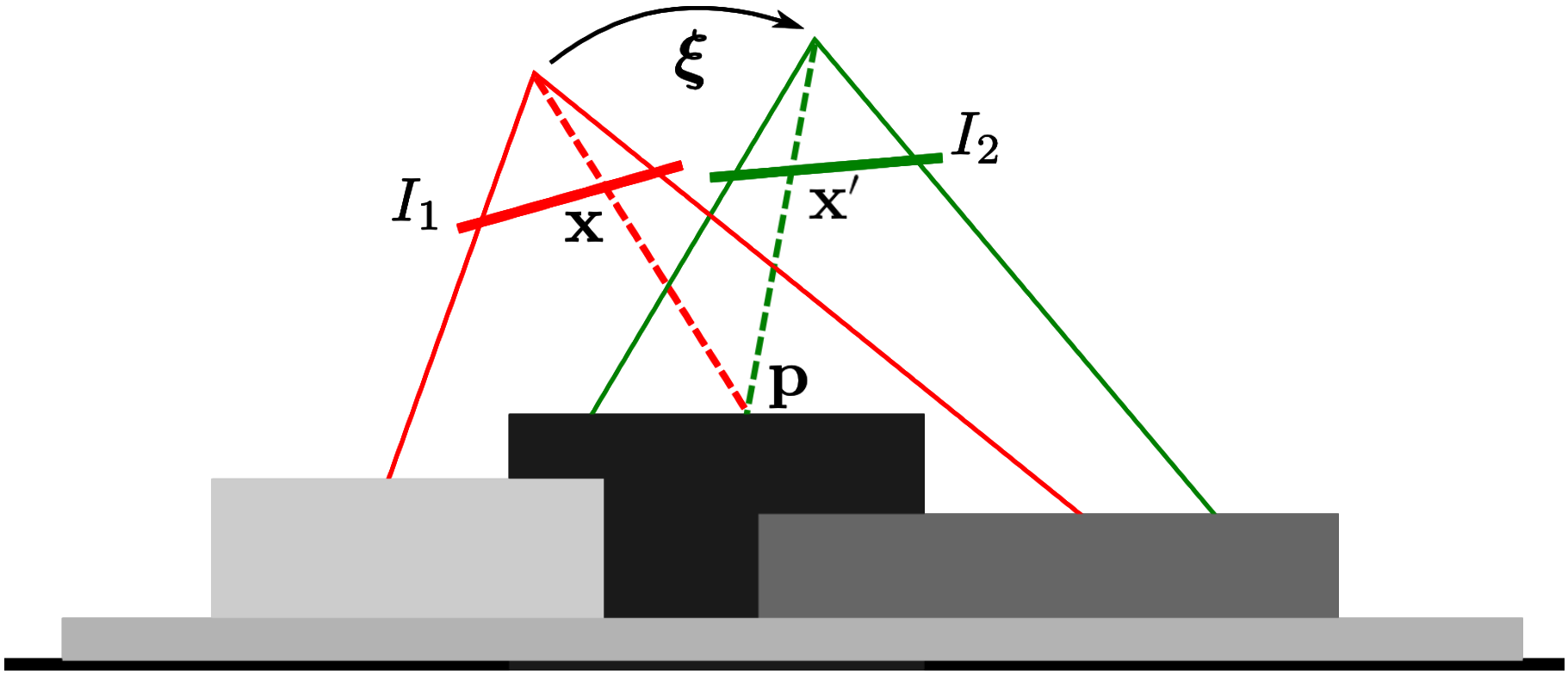


Application Domains

- Position control
- Autonomous navigation
- 3D reconstruction

Dense Visual Odometry

$$\boldsymbol{p} = \pi^{-1}(\boldsymbol{x}, Z_1(\boldsymbol{x})) \qquad \boldsymbol{p'} = T_\xi \boldsymbol{p} \qquad \boldsymbol{x'} = \pi(\boldsymbol{p'})$$



Dense Visual Odometry

- Photometric consistency

$$I_2(\boldsymbol{x'}) = I_1(\boldsymbol{x})$$

- Geometric consistency

$$Z_2(\boldsymbol{x'}) = \boldsymbol{p'}_z$$

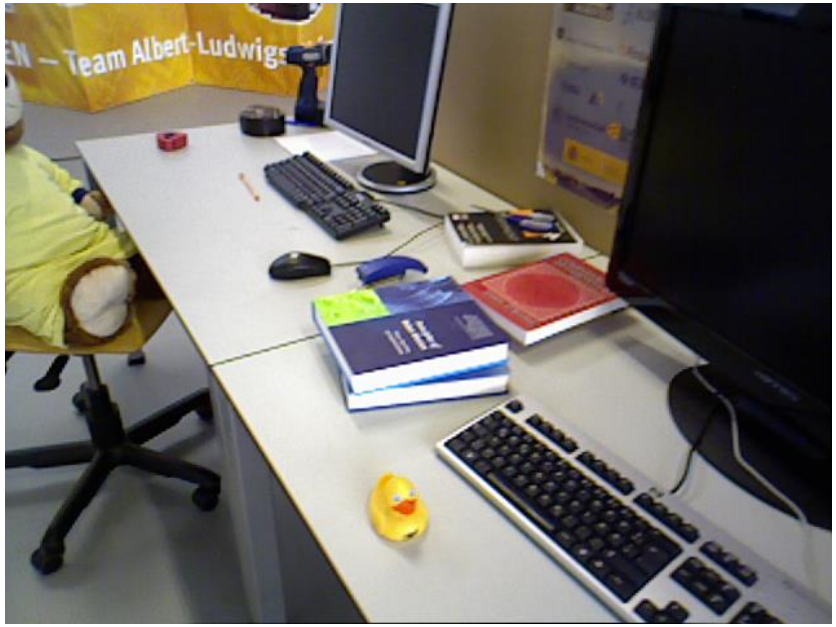
Dense Visual Odometry

- Least squares formulation

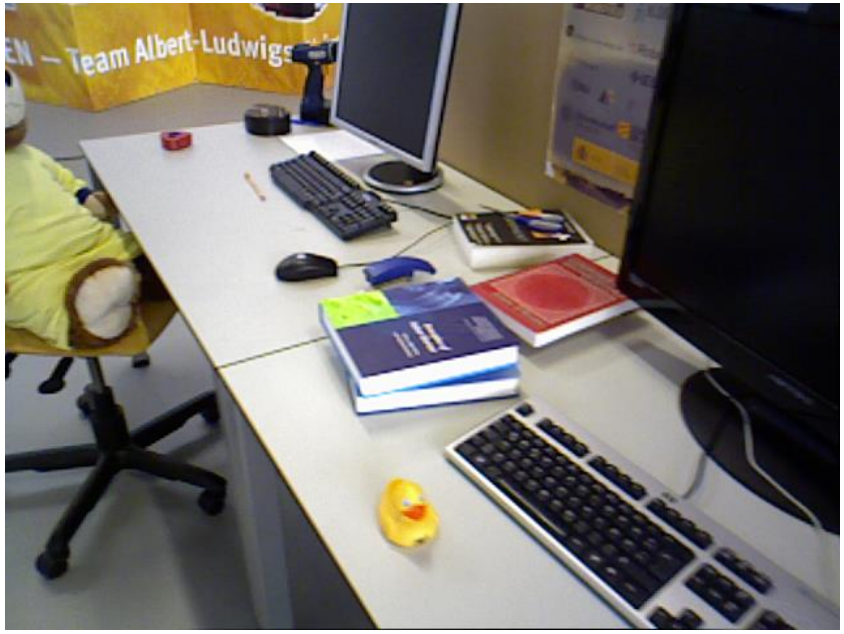
$$\mathbf{e} = \begin{pmatrix} e_I \\ e_Z \end{pmatrix} = \begin{pmatrix} I_2(\boldsymbol{x'}) - I_1(\boldsymbol{x}) \\ Z_2(\boldsymbol{x'}) - \boldsymbol{p'}_z \end{pmatrix}$$

$$\xi^* = \arg\min_{\xi} \sum_i^n \mathbf{e}_i^\top \Sigma^{-1} \mathbf{e}_i$$

Dense Visual Odometry



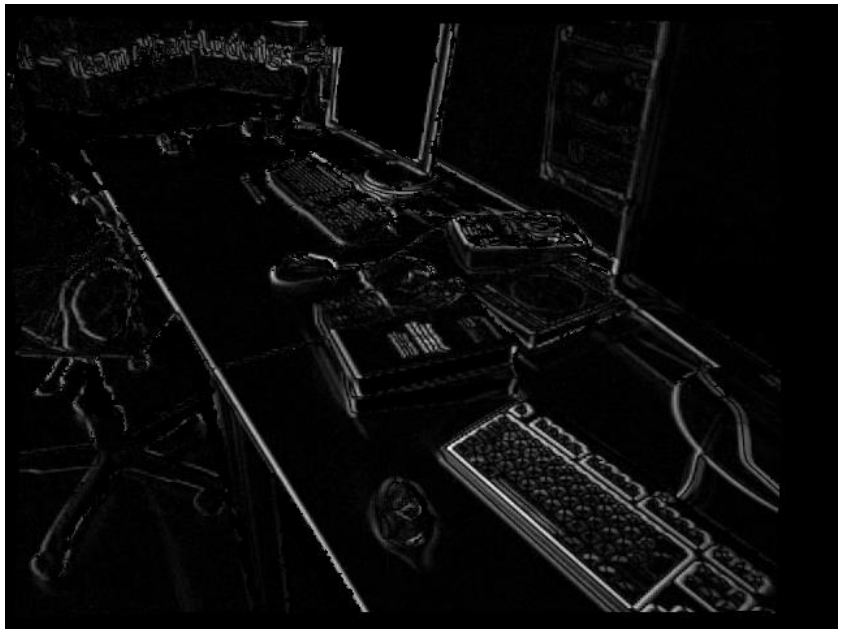
I_1



I_2

Dense Visual Odometry

Residuals before registration



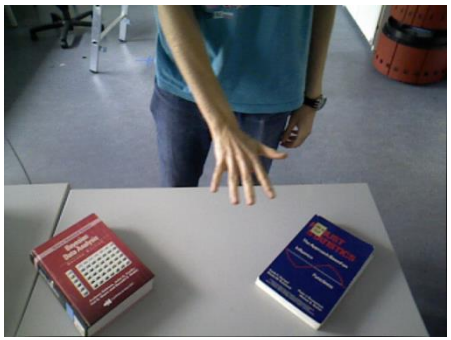
$$\left(I_2(\boldsymbol{x'}) - I_1(\boldsymbol{x})\right)^2 \quad \xi = 0$$

Residuals after registration

$$\left(I_2(\boldsymbol{x'}) - I_1(\boldsymbol{x})\right)^2 \quad \xi = \xi^*$$

Robust Dense Visual Odometry

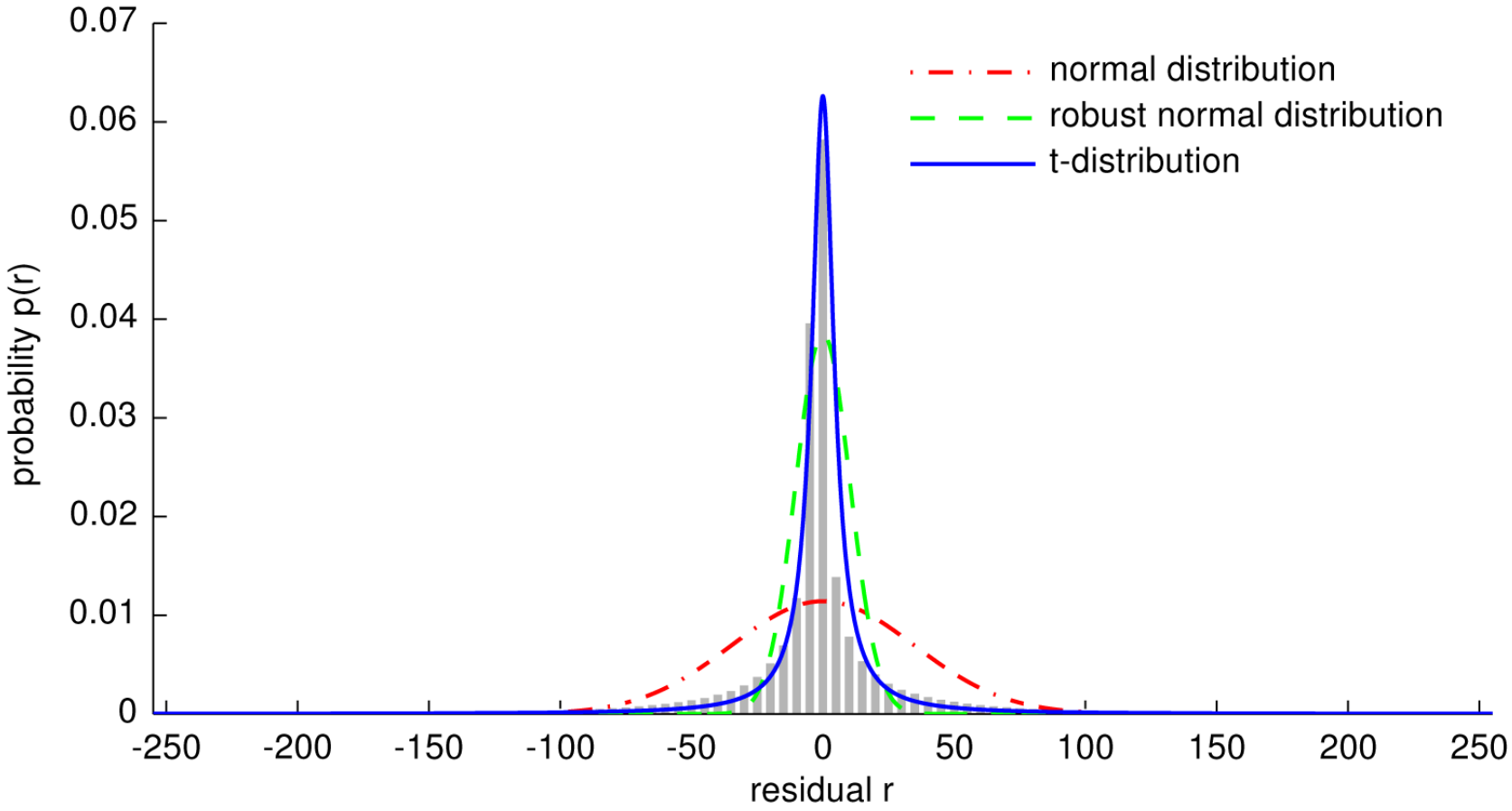
- Outliers violate consistency assumption
  - » Moving objects
  - » Non-lambertian surfaces
  - » Noise



- Problem: Quadratic term gives high influence

Robust Dense Visual Odometry

$$I_2(\boldsymbol{x'}) - I_1(\boldsymbol{x})$$



Robust Dense Visual Odometry

- Weighted least squares formulation

$$\xi^* = \arg\min_{\xi} \sum_i^n w_i \mathbf{e}_i^\mathsf{T} \Sigma^{-1} \mathbf{e}_i$$

$$w_i(\mathbf{e}_i) = \frac{\nu+1}{\nu+\mathbf{e}_i^\mathsf{T} \Sigma^{-1} \mathbf{e}_i}$$

Visual Odometry Results

Visual Odometry Results

- Frame-to-frame motion estimation
  - » Fast
  - » Highly accurate
  - » Drift 0.03 m/s
- Problem: drift accumulation (1.8 m/min)

Dense Visual SLAM

- Local drift

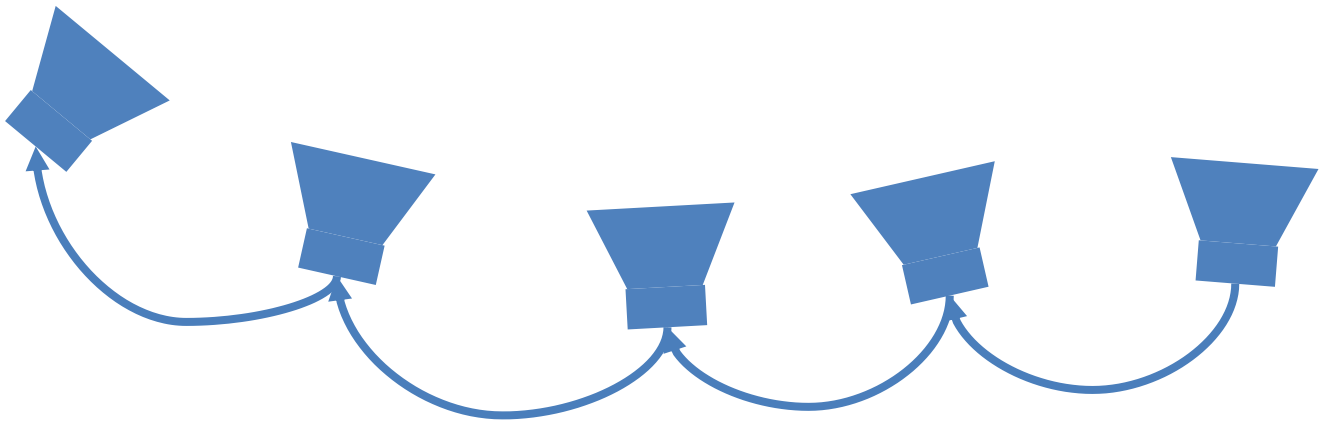
Keyframes

- Global drift

Pose graph optimization

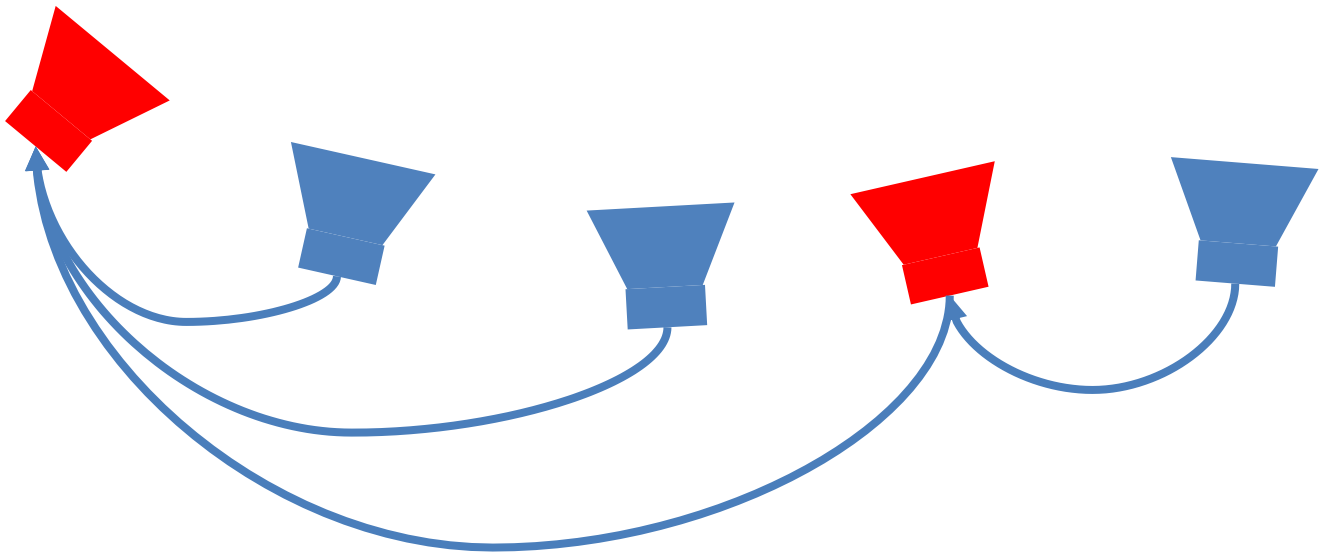
Keyframes

- Frame-to-frame



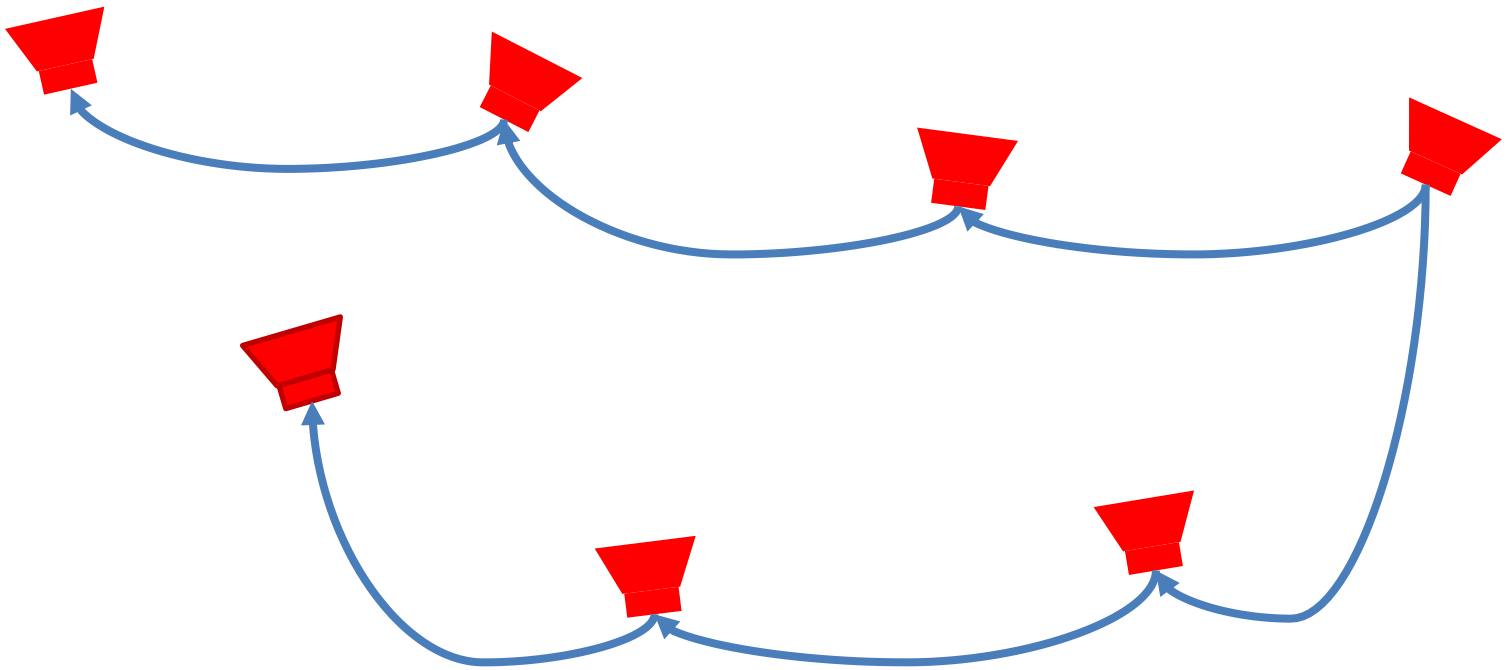
Keyframes

- Frame-to-keyframe



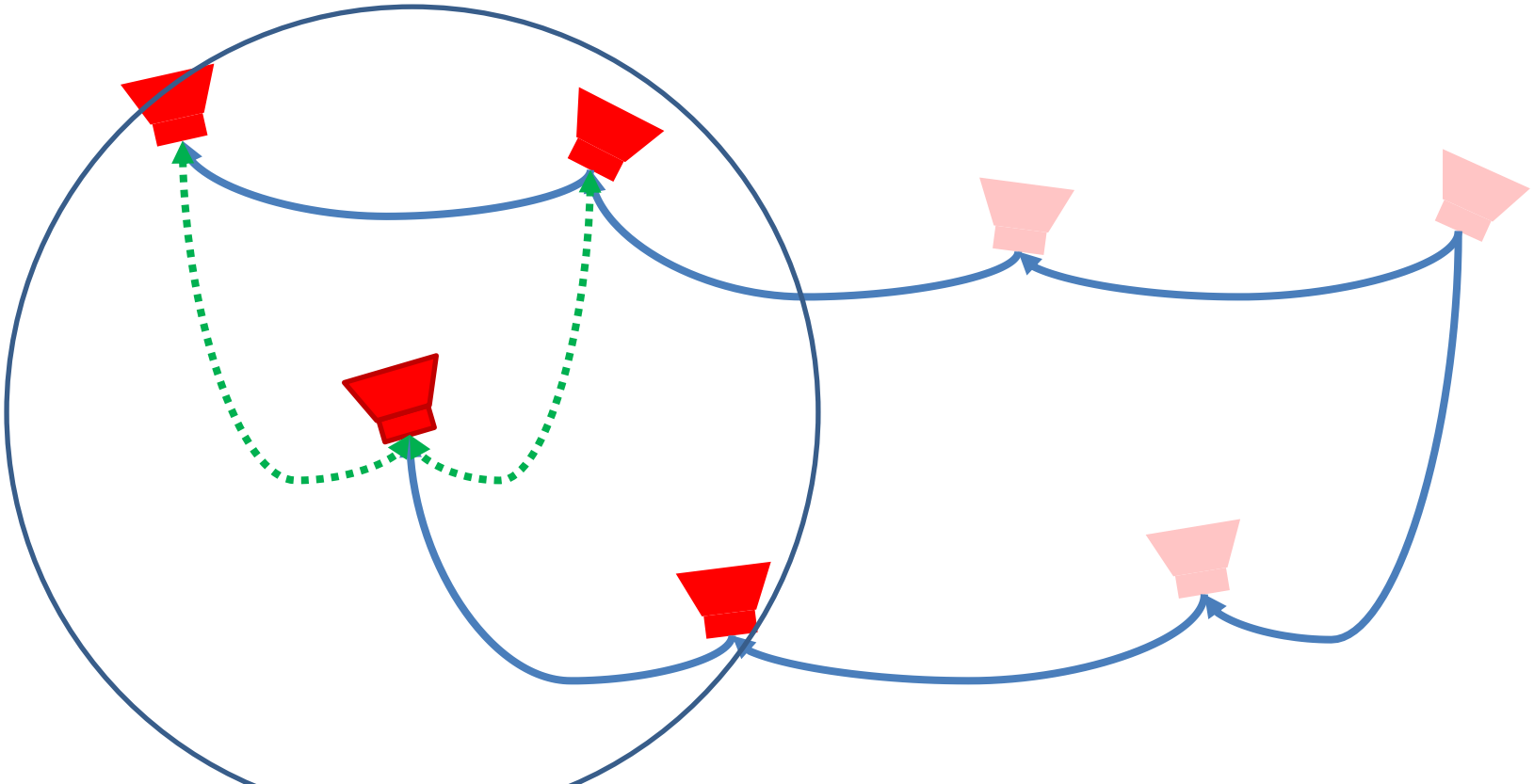
Pose Graph Optimization

- Correct global drift with loop closures



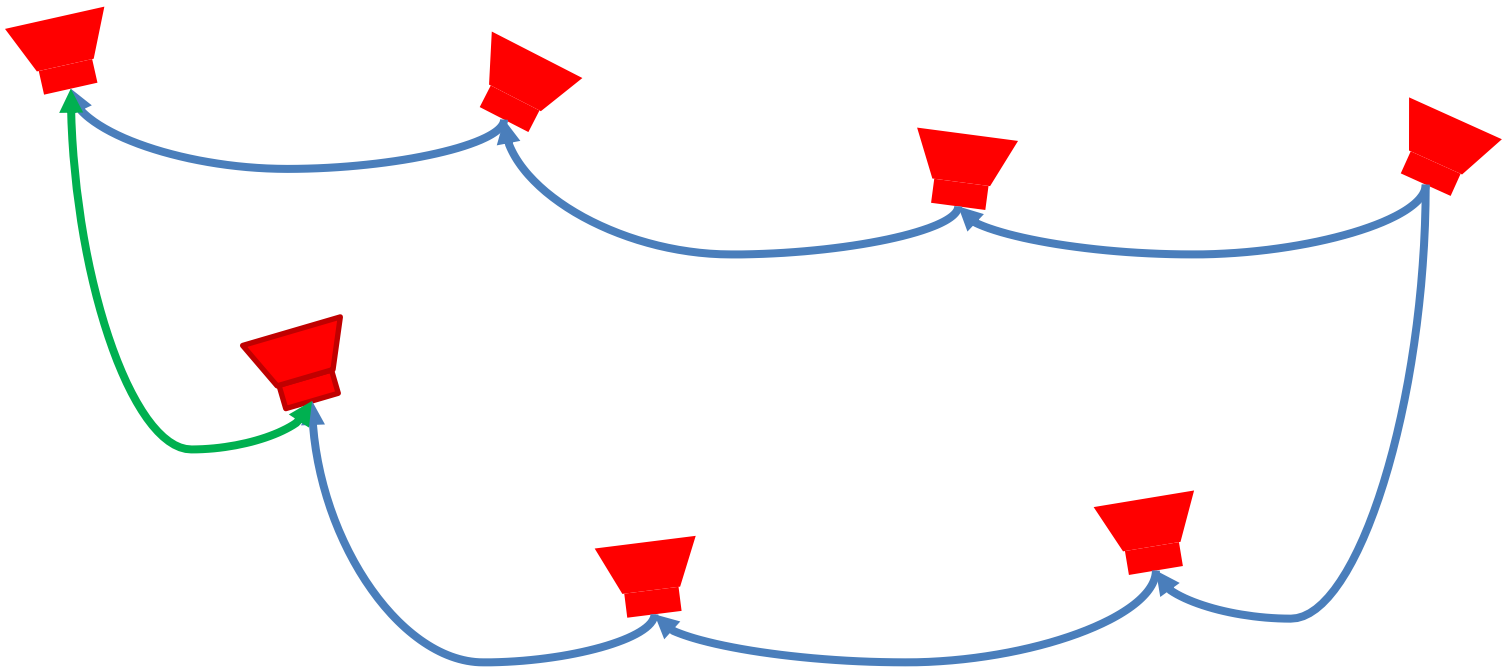
Pose Graph Optimization

- Search for loop closure candidates



Pose Graph Optimization

- Validate loop closure and update graph



Dense Visual SLAM

- How to select keyframes?
- How to validate loop closures?

Dense Visual SLAM

- Least squares yields estimate of covariance of ξ^*
- Compute entropy of parameter distribution as $H(\xi) = \ln(|\Sigma_\xi|)$
- $H(\xi)$ is a measure of uncertainty in estimate, i.e., quality

Visual SLAM Results

Master Thesis Topics

- Dense Visual SLAM for Quadrocopters
  - » Implement on AscTec Pelican
- Multi-Session Dense Visual SLAM
  - » Relocalization / place recognition
  - » Reduced pose graph
  - » Efficient map representation