

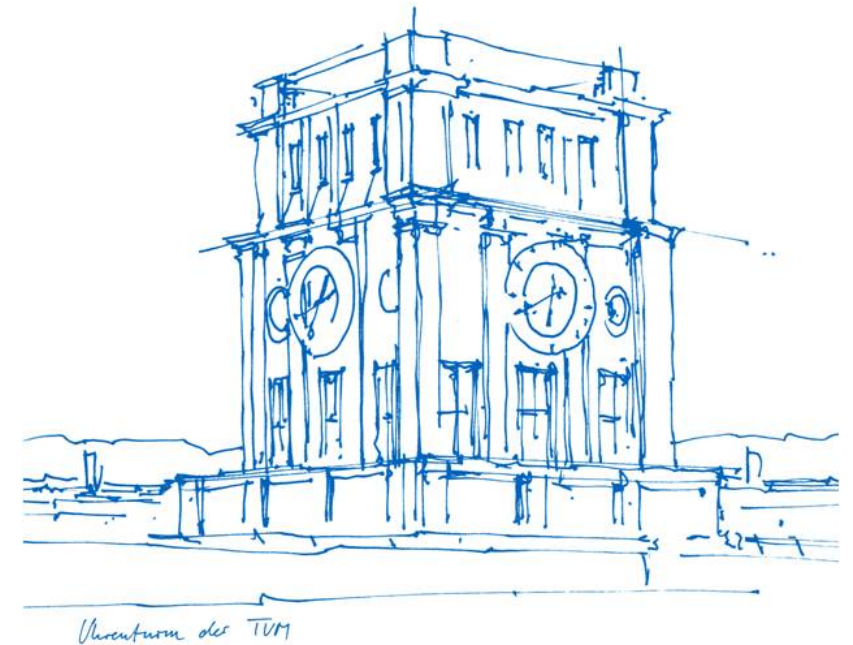
Local Tracking and Mapping for Direct Visual SLAM

Pablo Rodríguez Palafox

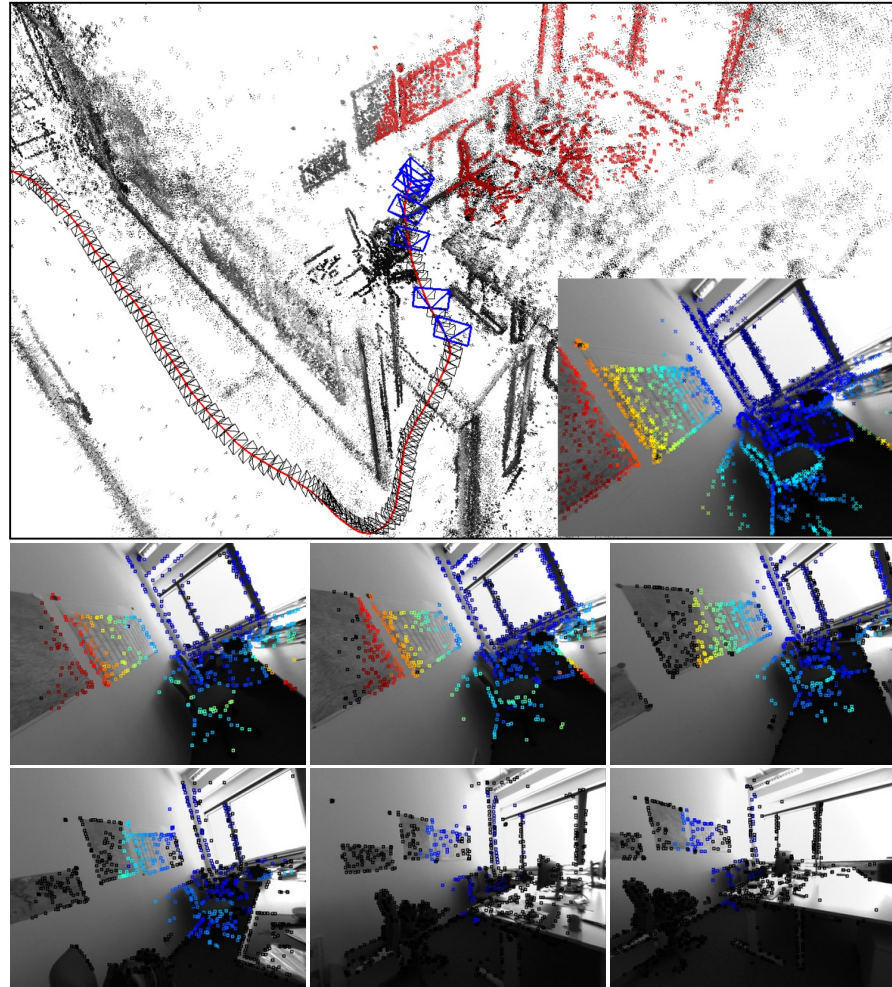
Technical University of Munich

Chair of Helicopter Technology & Computer Vision Group

Garching, October 11, 2019



Problem Statement



Direct Sparse Odometry, Engel et al.

Problem Statement

When doing **marginalization** of keyframes / points in VO,

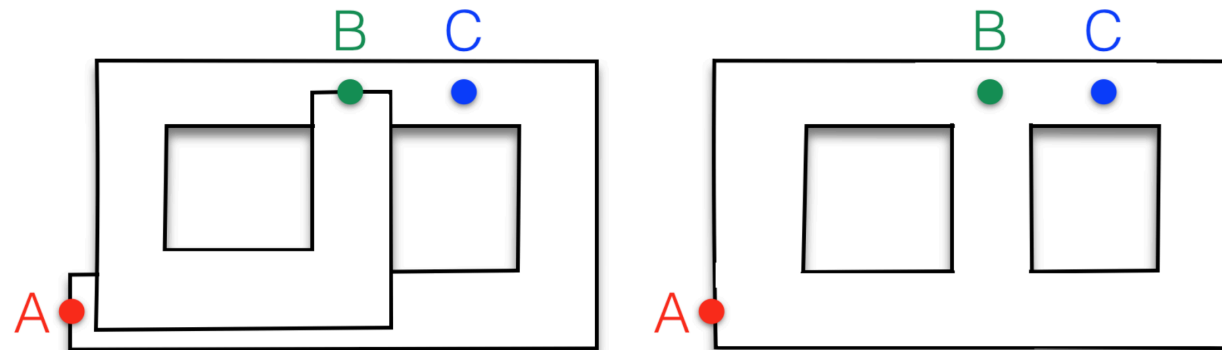
reusing map points

(when revisiting already mapped areas)

is not possible.

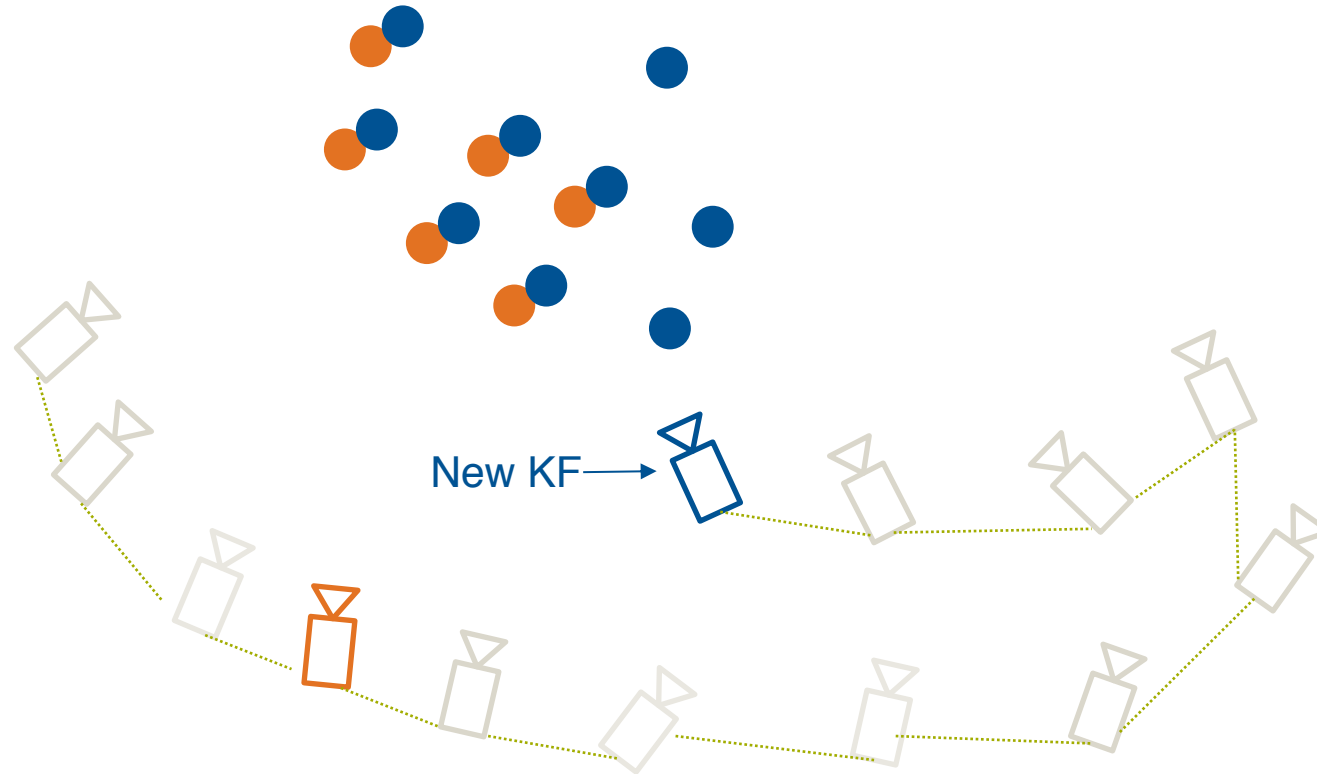
Problem Statement

Odometry → SLAM



Past, Present, and Future of Simultaneous Localization And Mapping: Towards the Robust-Perception Age, [Cadena et al.](#)

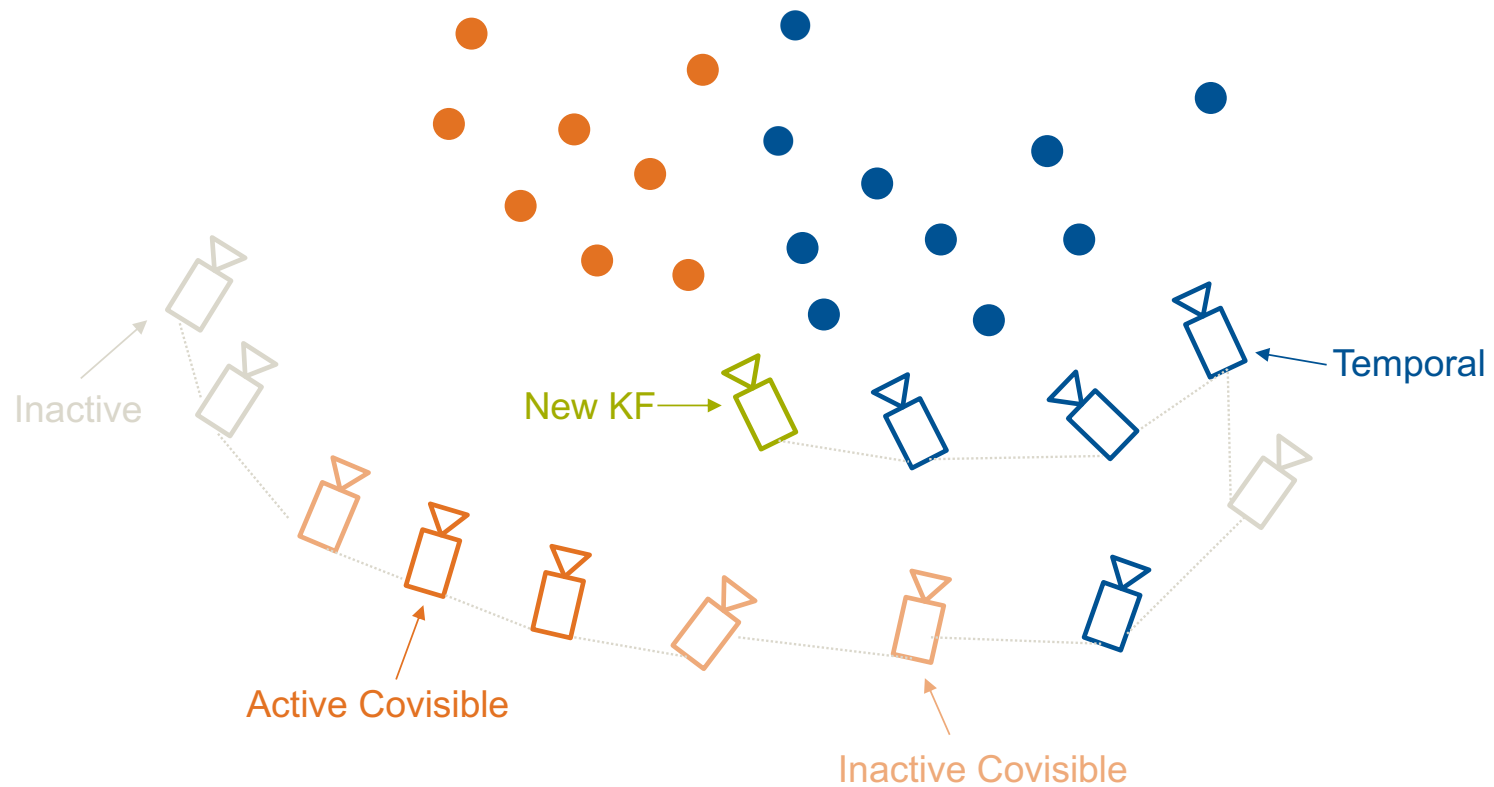
Problem Statement



Problem Statement

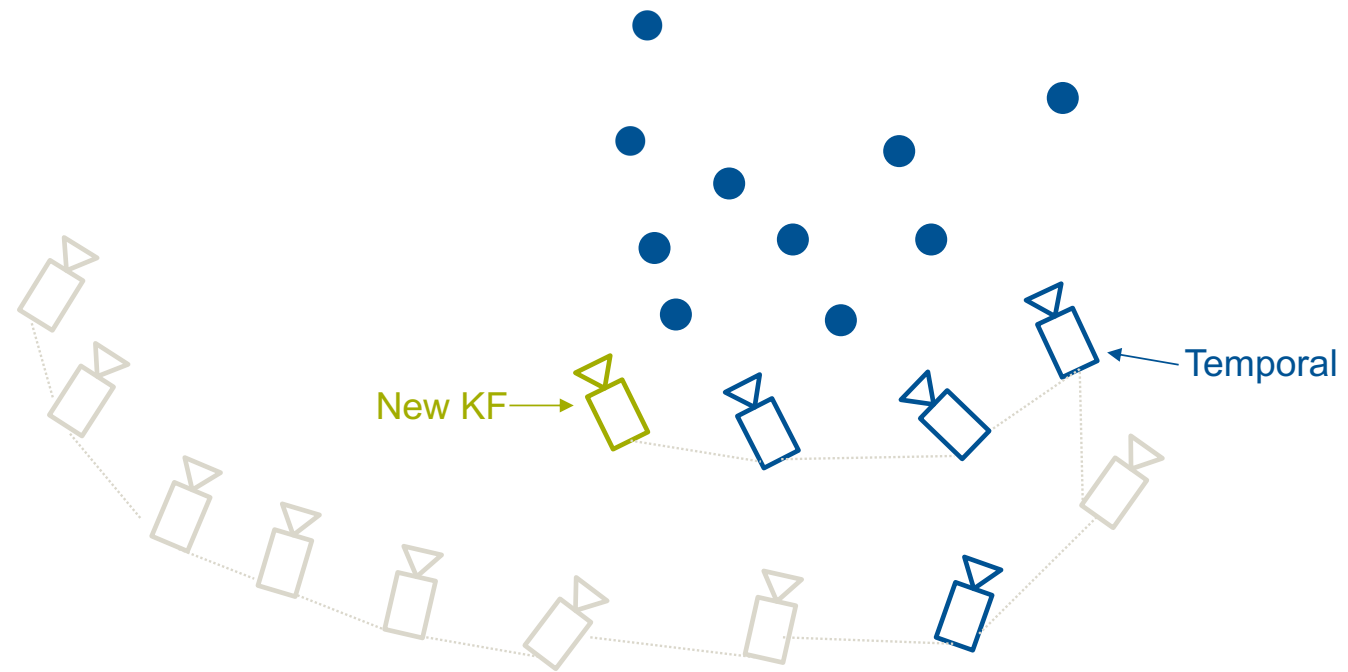


Approach

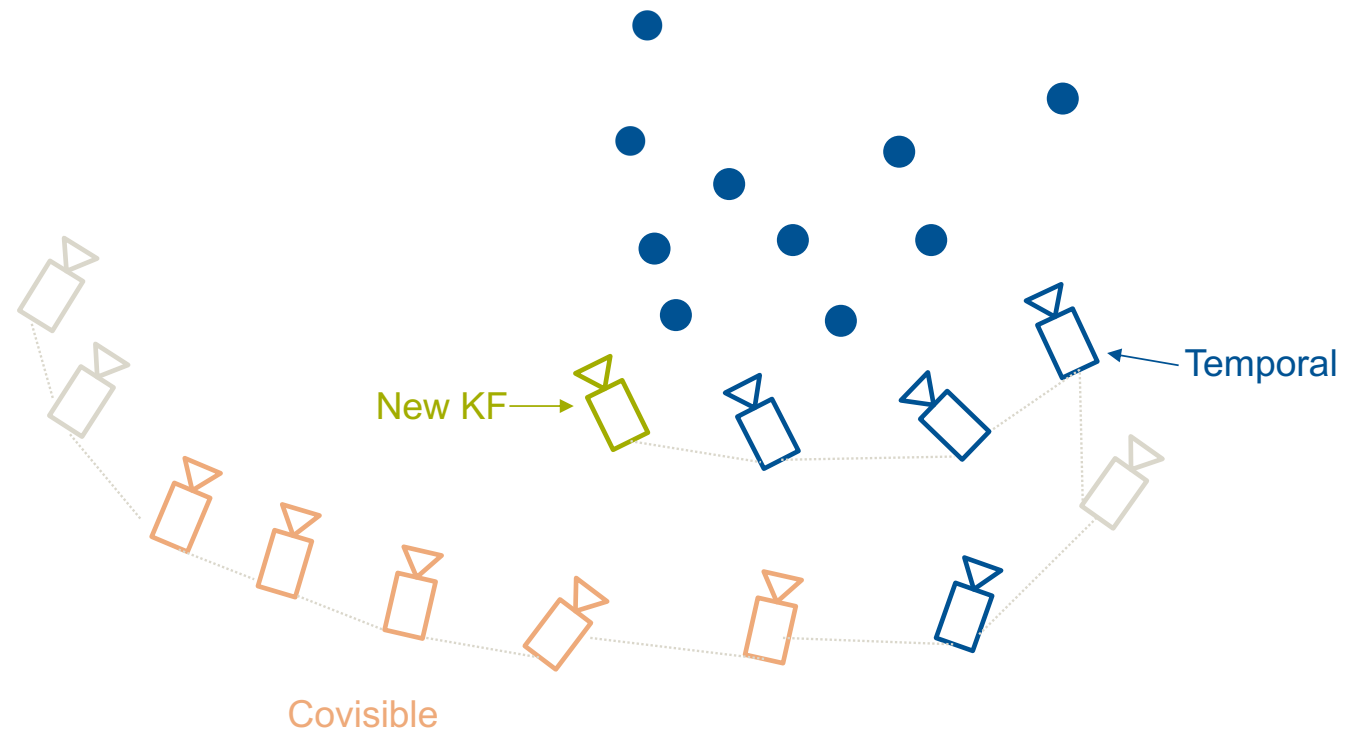


Original idea from: *Direct Sparse Mapping*, [Zubizarreta et al.](#)

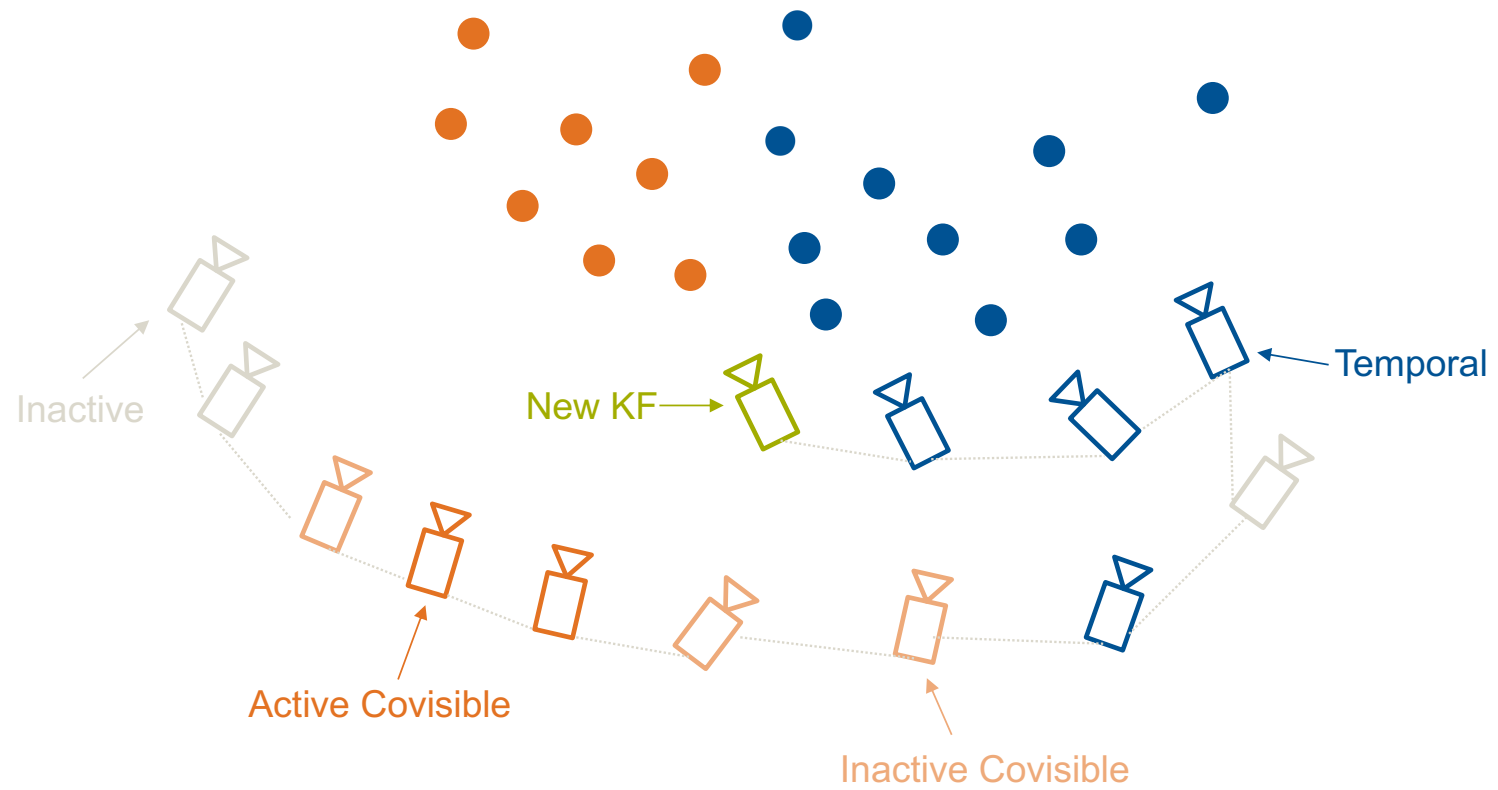
Approach



Approach

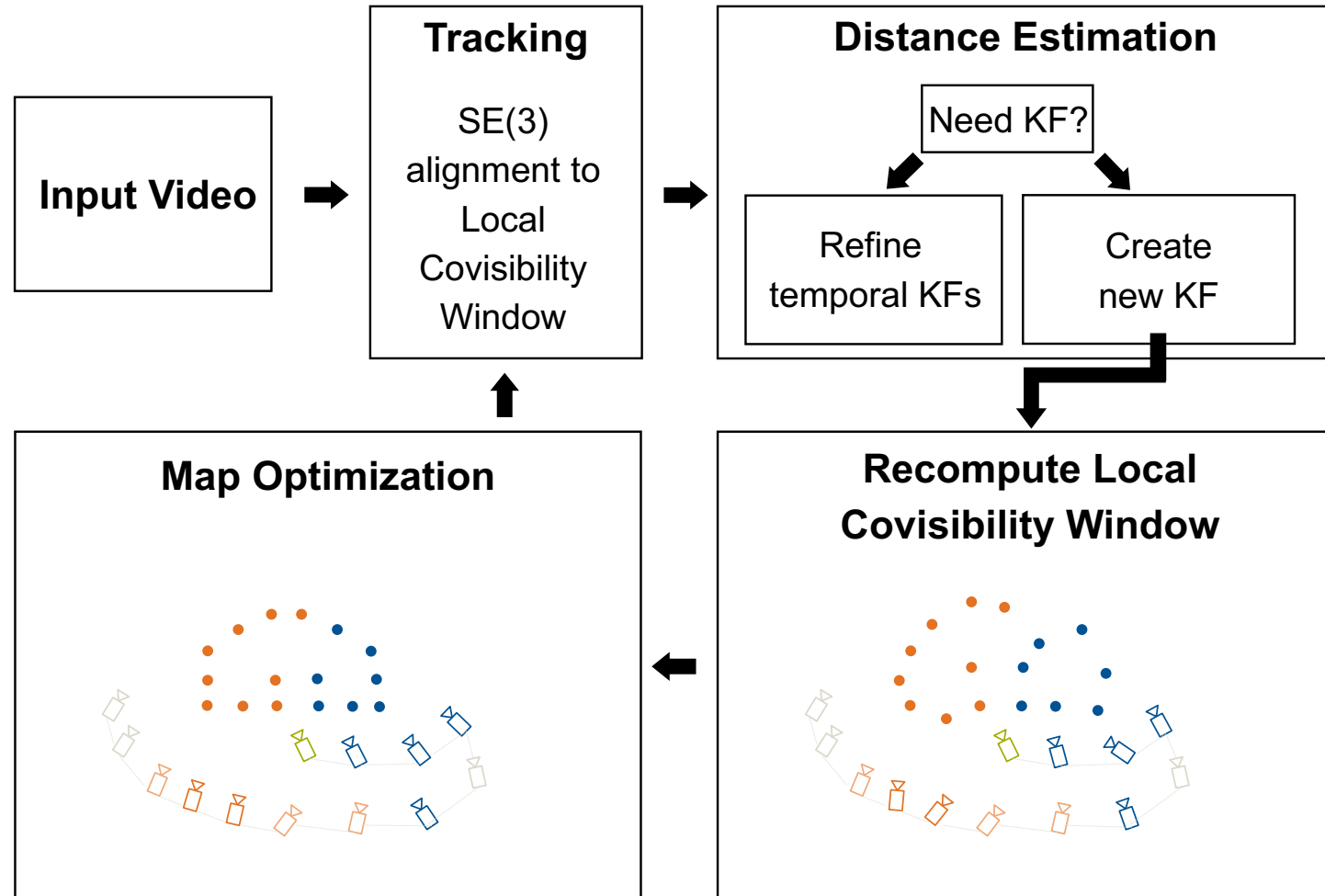


Approach



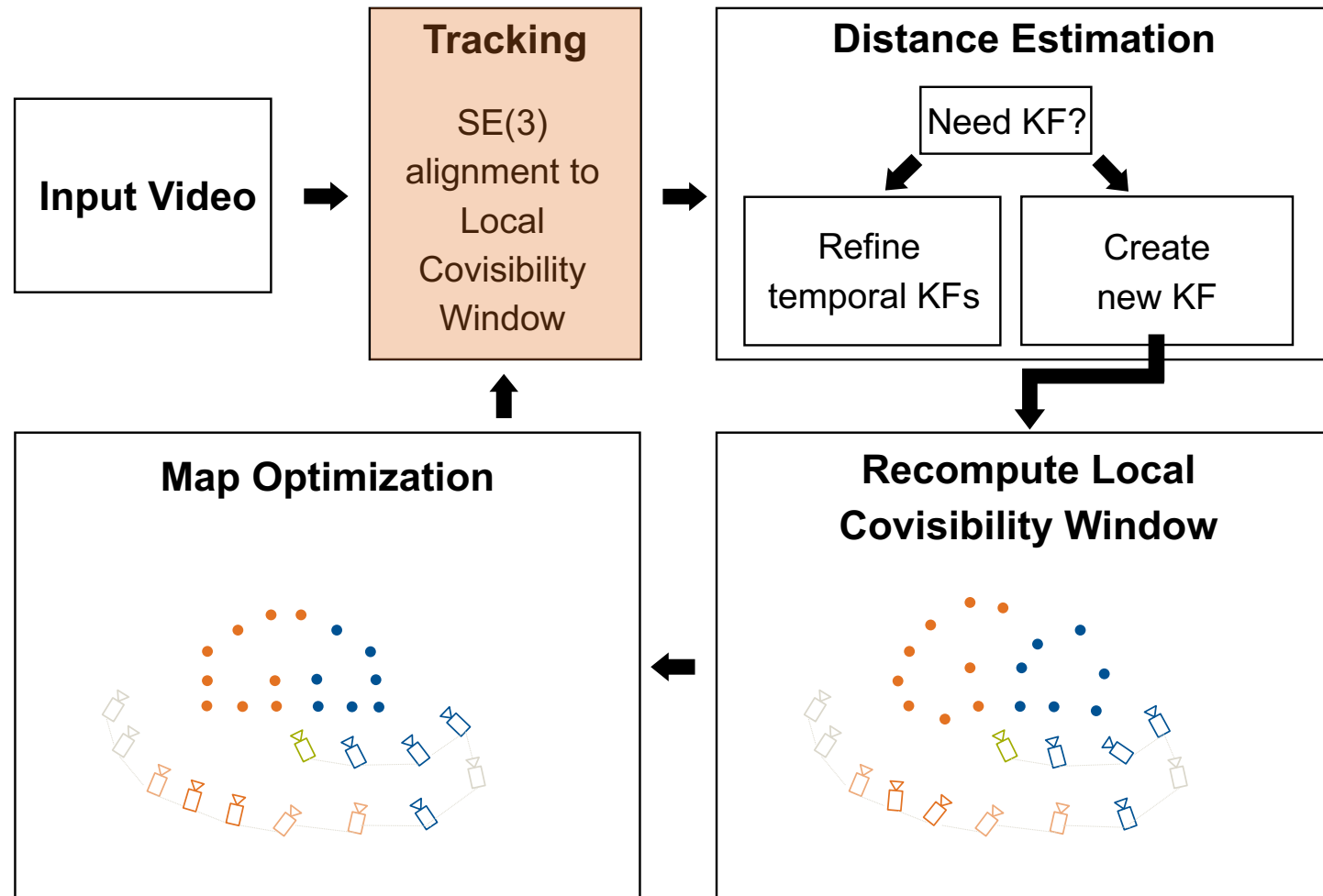
Approach

Overview



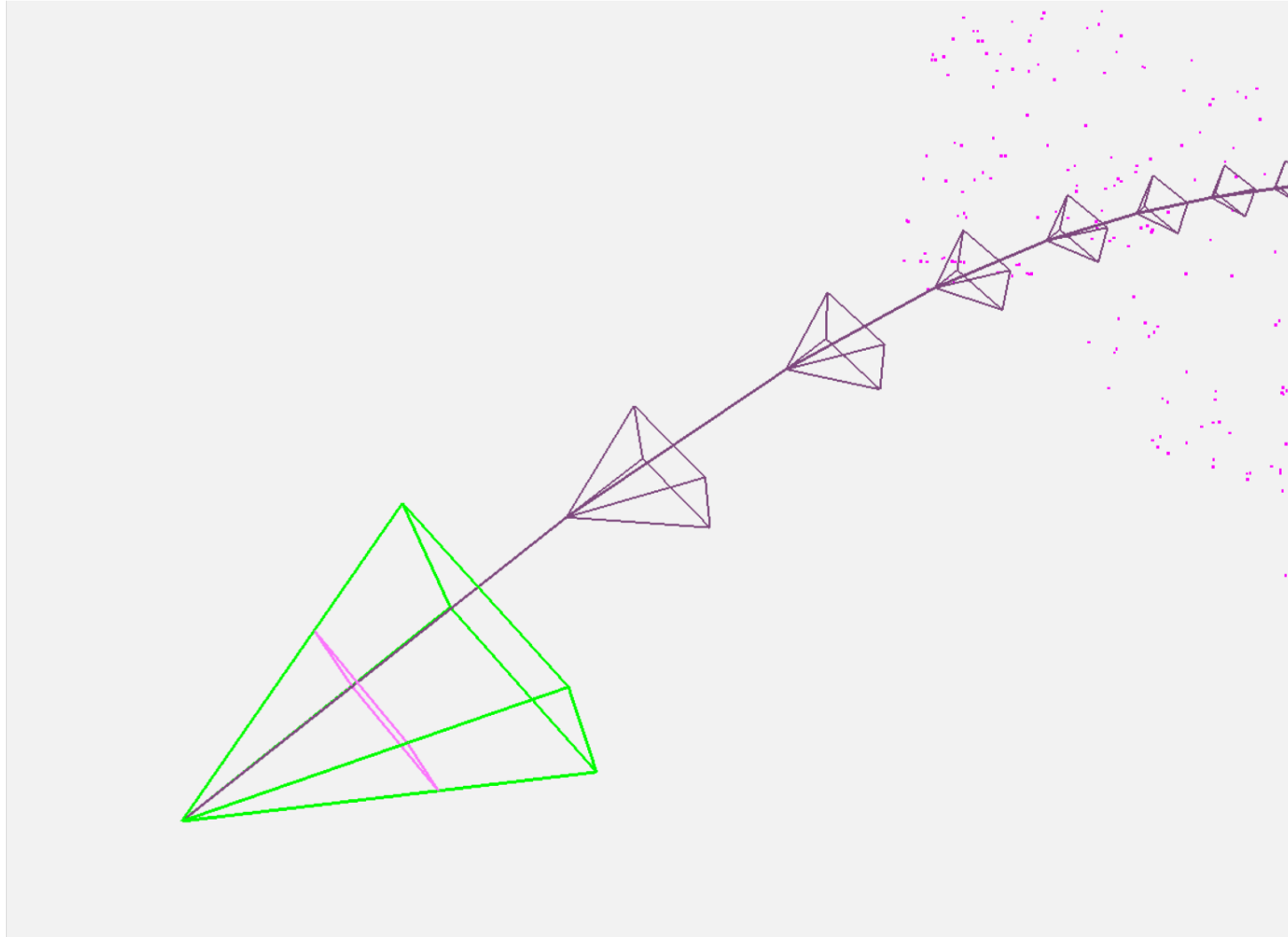
Approach

Overview



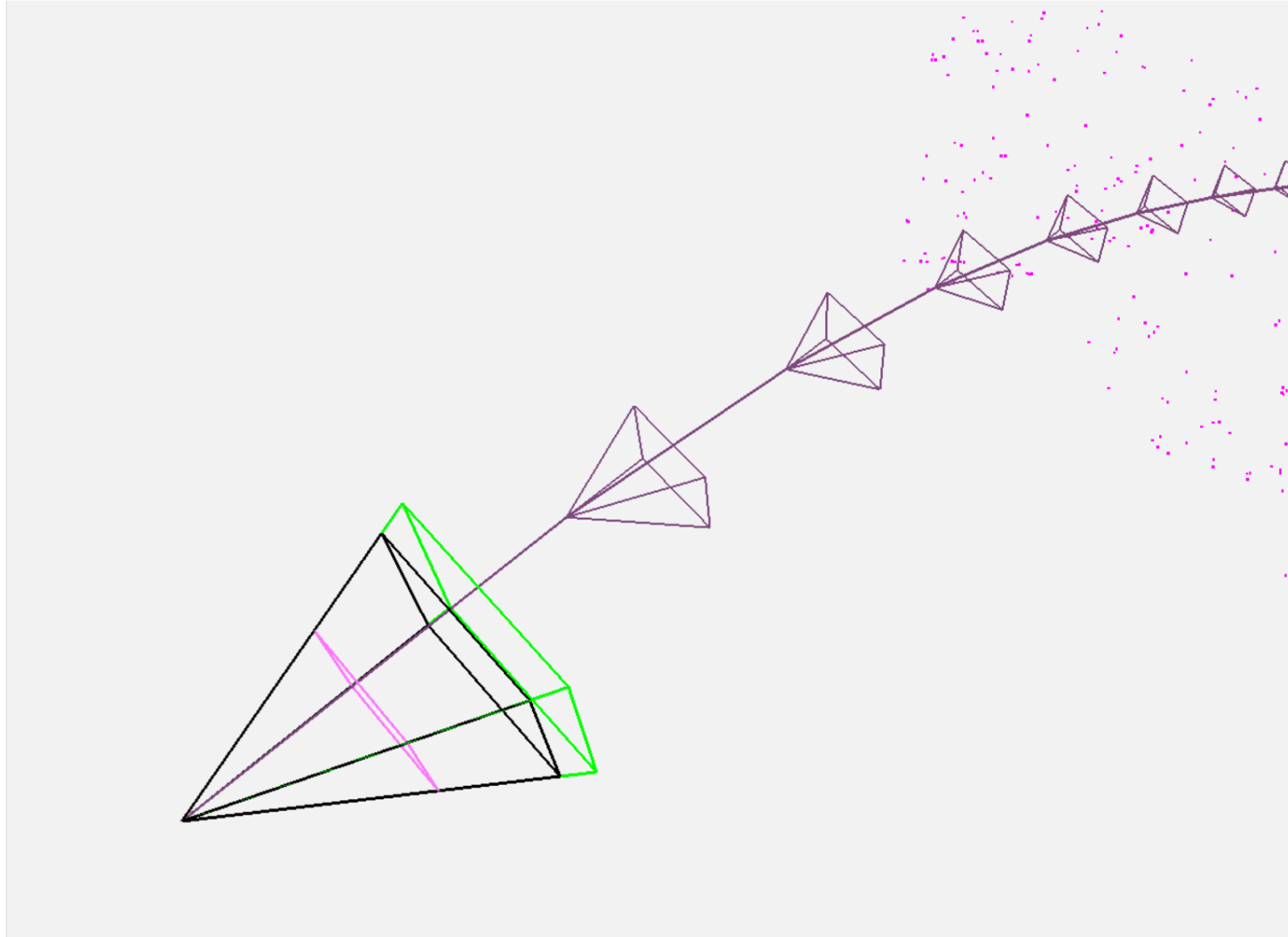
Approach

Tracking



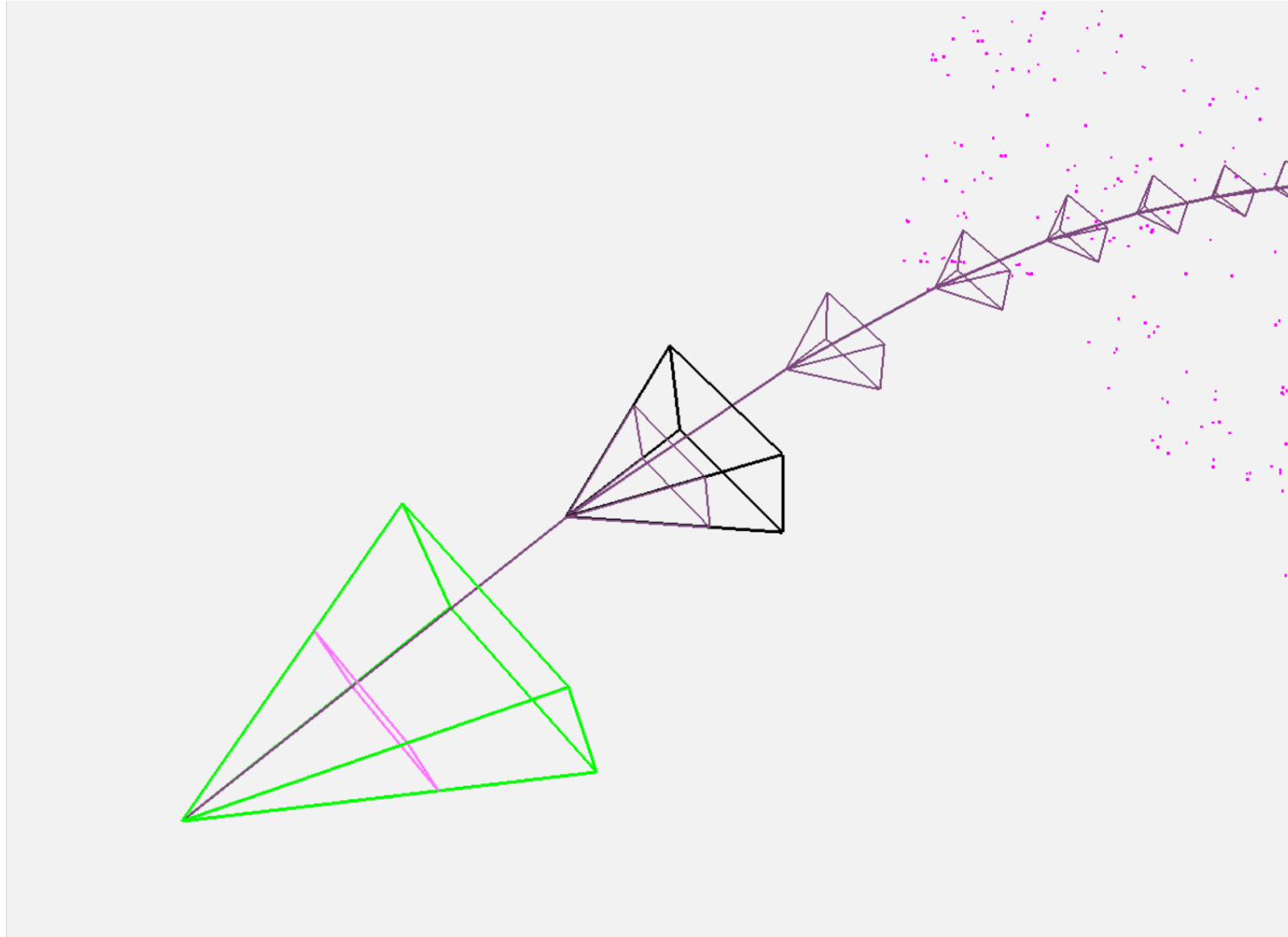
Approach

Tracking



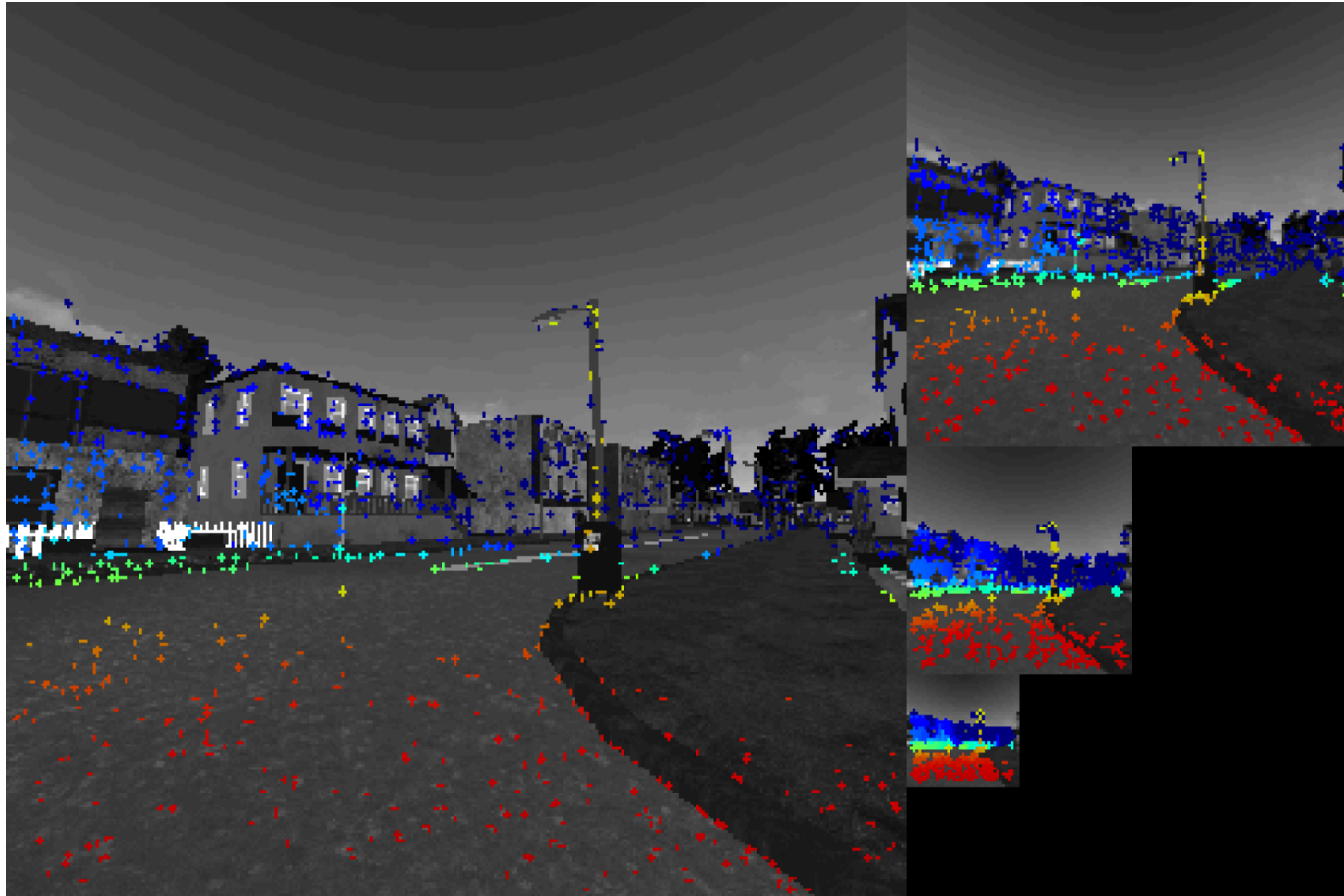
Approach

Tracking



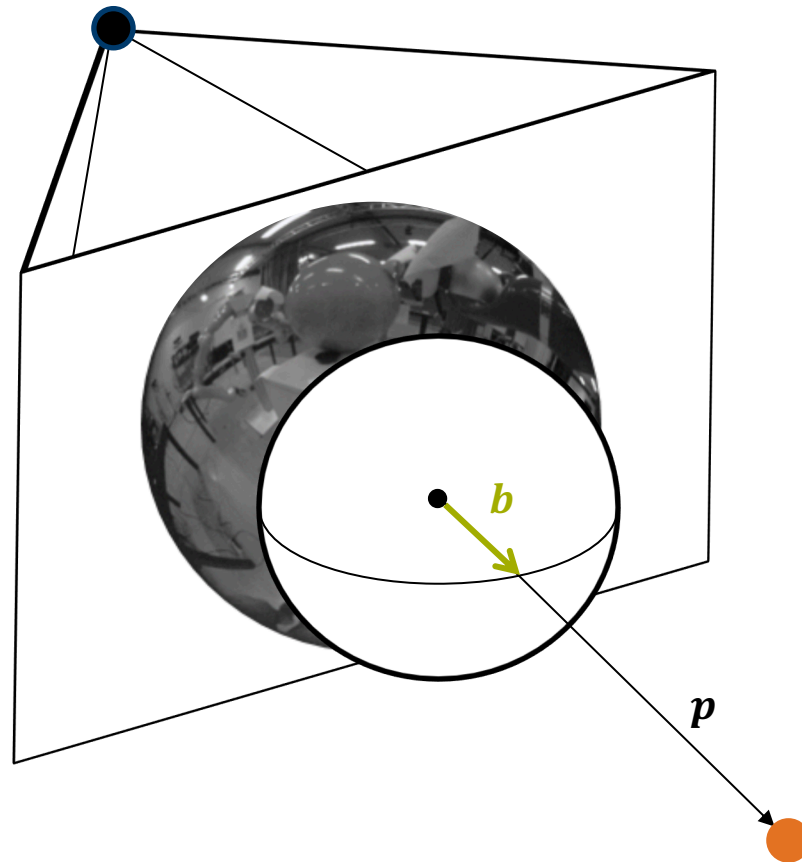
Approach

Building the Image Pyramids



Approach

(Inverse Distance Formulation)



$d_p :=$ Inverse distance

$$d_p = \frac{1}{\|p\|}$$

$$p = \|p\| b = \frac{b}{d_p}$$

Approach

Tracking

Direct Image Alignment

Forward Additive

$$r_i(\mathbf{T} \oplus \boldsymbol{\xi}) = I_t(w(\mathbf{T} \oplus \boldsymbol{\xi}, \mathbf{u})) - I_h(\mathbf{u})$$

Inverse Compositional

$$r_i(\boldsymbol{\xi}) = I_h(w(\mathbf{I} \oplus \boldsymbol{\xi}, \mathbf{u})) - I_t(w(\mathbf{T}, \mathbf{u}))$$

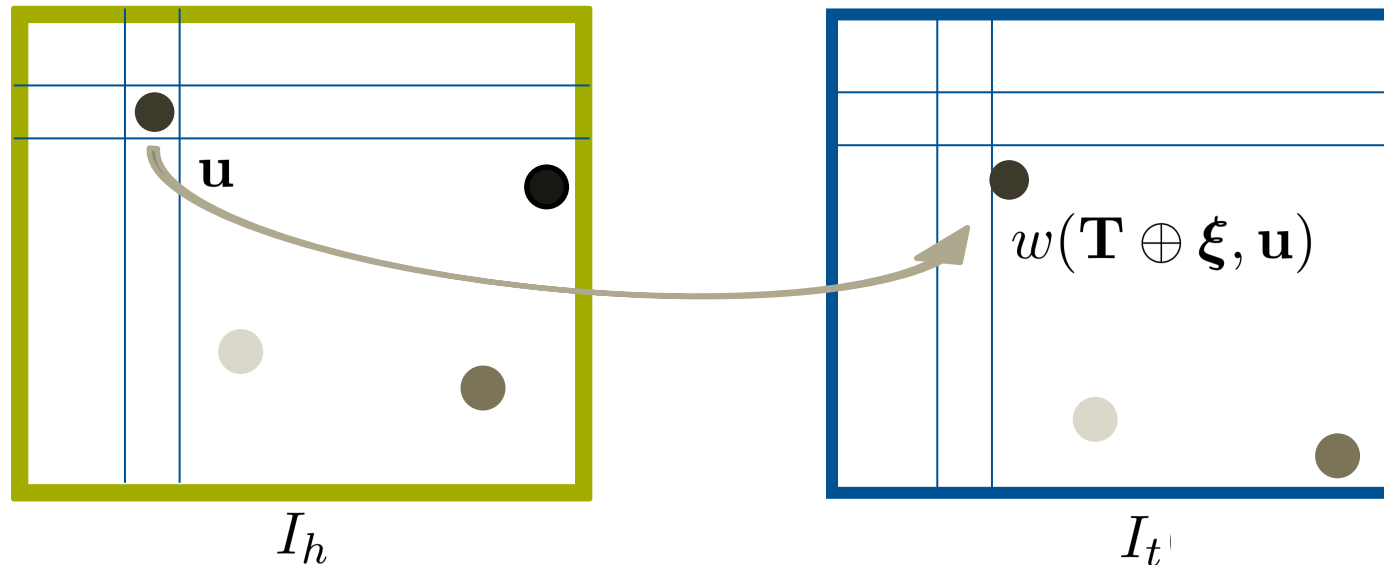
Approach

Tracking

Direct Image Alignment

Forward Additive

$$r_i(\mathbf{T} \oplus \boldsymbol{\xi}) = I_t(w(\mathbf{T} \oplus \boldsymbol{\xi}, \mathbf{u})) - I_h(\mathbf{u})$$



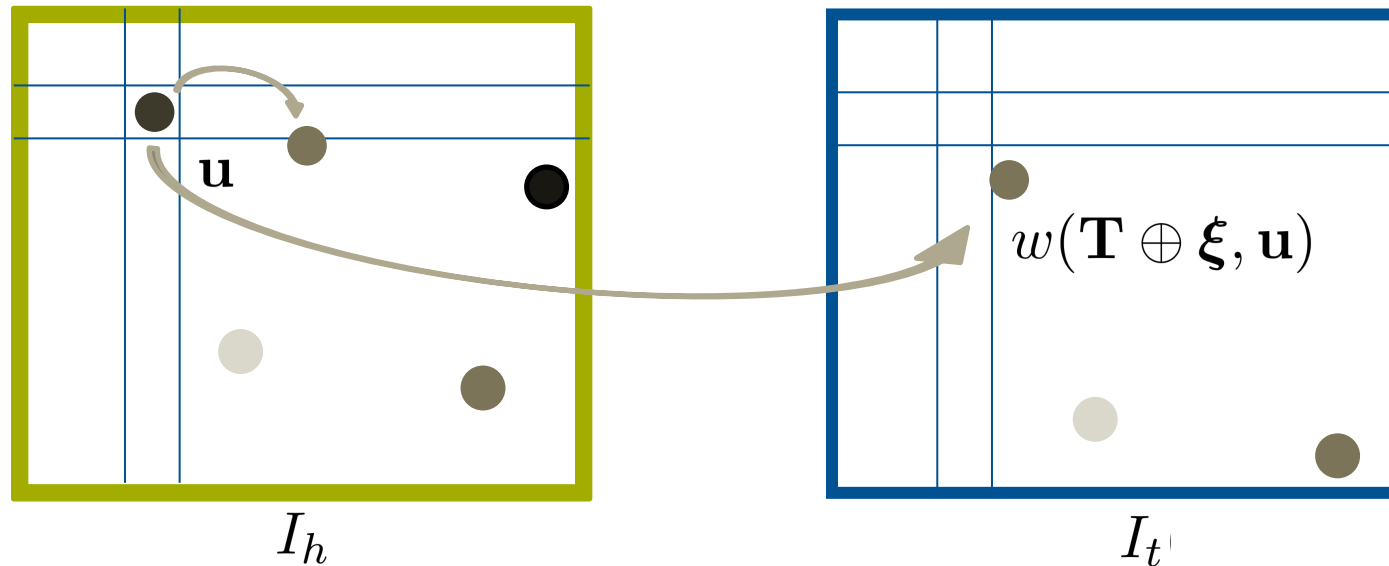
Approach

Tracking

Direct Image Alignment

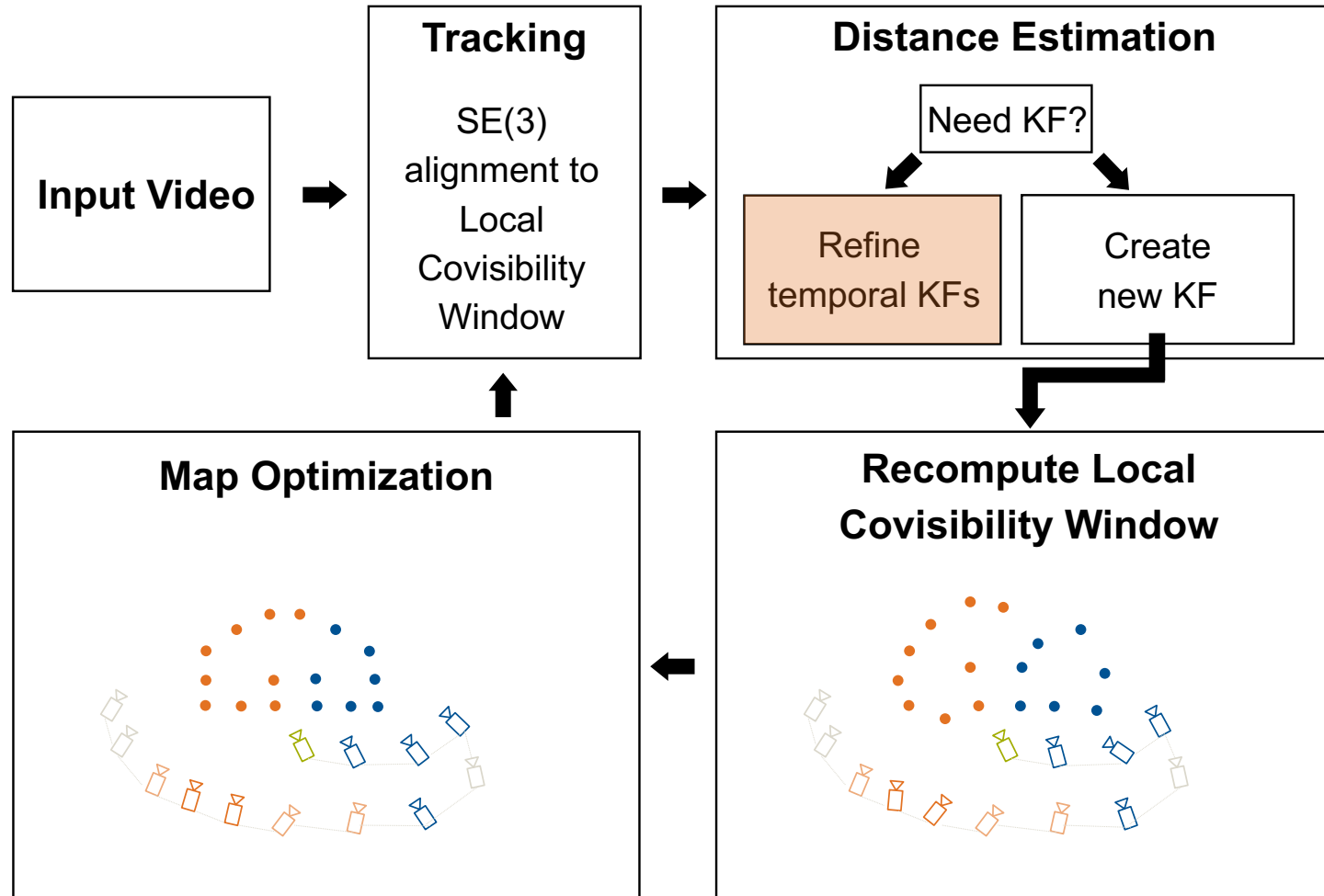
Inverse Compositional

$$r_i(\xi) = I_h(w(\mathbf{I} \oplus \xi, \mathbf{u})) - I_t(w(\mathbf{T}, \mathbf{u}))$$



Approach

Overview



Approach

Candidate Point Tracking

Epipolar Curve Search

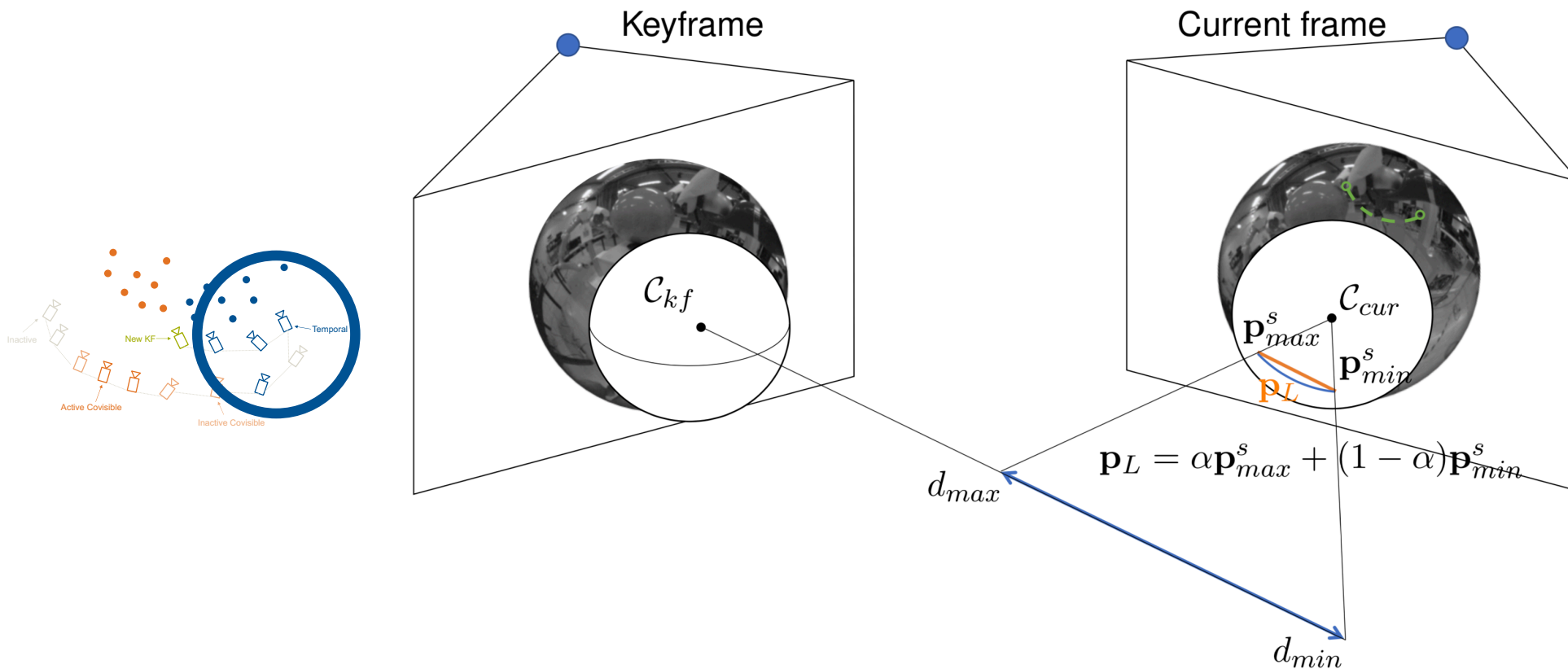
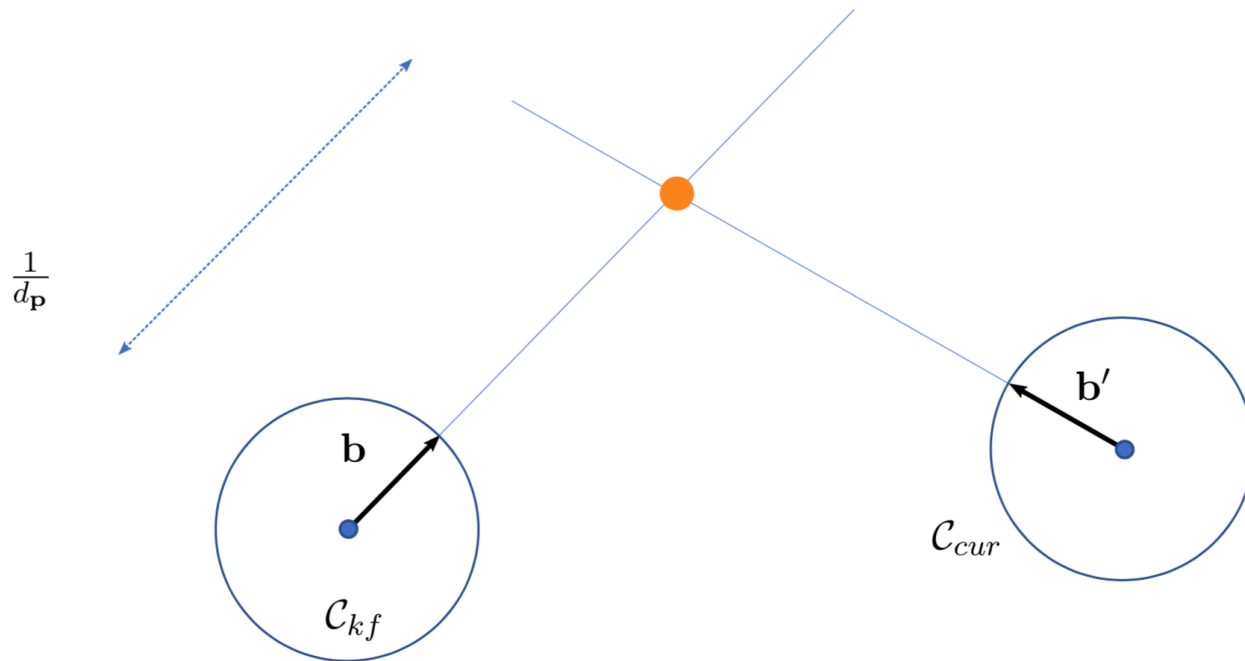


Figure based on that presented in OmniDSO

Approach

Candidate Point Tracking

Epipolar Curve Search



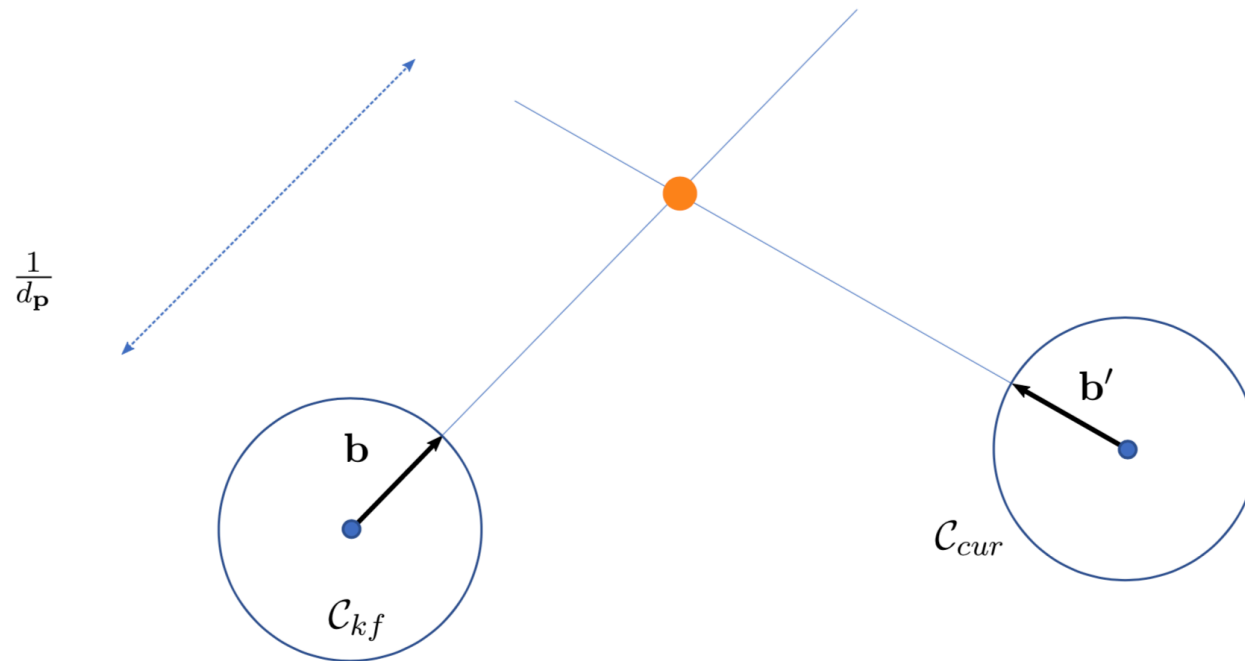
$$\begin{aligned} \mathbf{p}' &= \mathbf{R}\mathbf{p} + \mathbf{t} \\ &= \mathbf{R} \frac{\mathbf{b}}{d_p} + \mathbf{t} \end{aligned}$$

$$\mathbf{b}' = \frac{\mathbf{p}'}{\|\mathbf{p}'\|} = \frac{\mathbf{R} \frac{\mathbf{b}}{d_p} + \mathbf{t}}{\left\| \mathbf{R} \frac{\mathbf{b}}{d_p} + \mathbf{t} \right\|}$$

Approach

Candidate Point Tracking

Epipolar Curve Search



$$p' = R p + t$$

$$= R \frac{\mathbf{b}}{d_p} + t$$

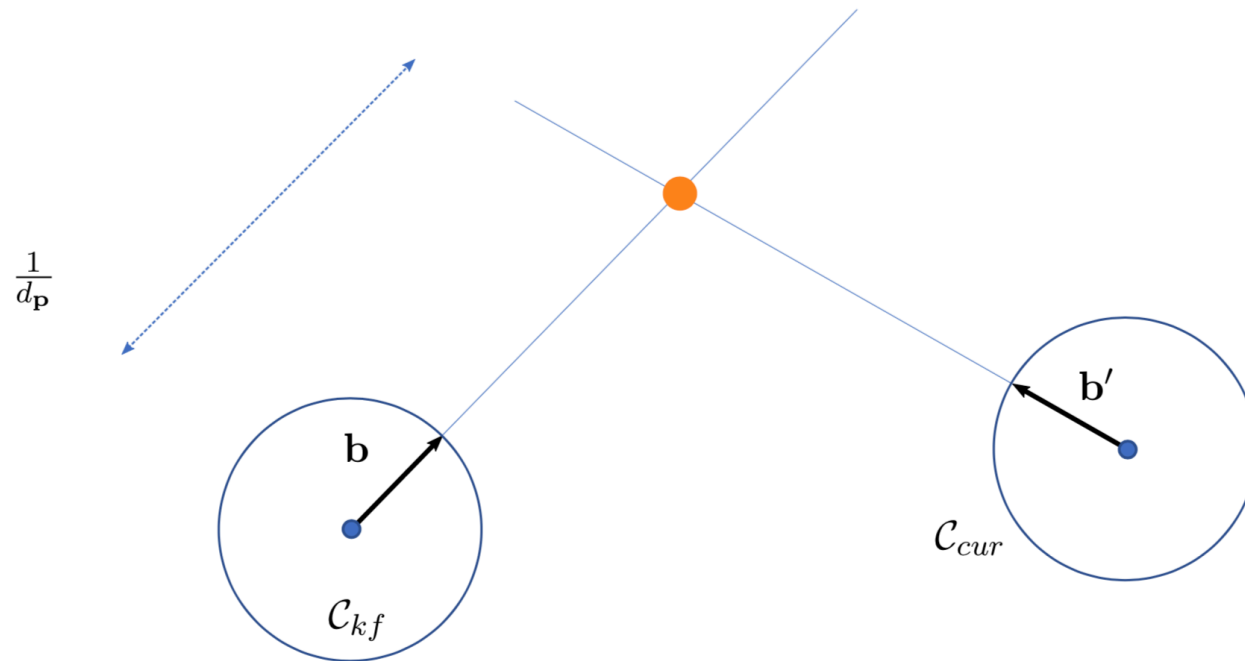
$$b'_x = \frac{p'_x}{\|\mathbf{p}'\|} = \frac{\frac{\mathbf{r}_0 \cdot \mathbf{b}}{d_p} + t_x}{\|\mathbf{p}'\|}$$

$$b'_y = \frac{p'_y}{\|\mathbf{p}'\|} = \frac{\frac{\mathbf{r}_1 \cdot \mathbf{b}}{d_p} + t_y}{\|\mathbf{p}'\|}$$

Approach

Candidate Point Tracking

Epipolar Curve Search



$$\begin{aligned}
 \mathbf{p}' &= \mathbf{R}\mathbf{p} + \mathbf{t} \\
 &= \mathbf{R} \frac{\mathbf{b}}{d_{\mathbf{p}}} + \mathbf{t}
 \end{aligned}$$

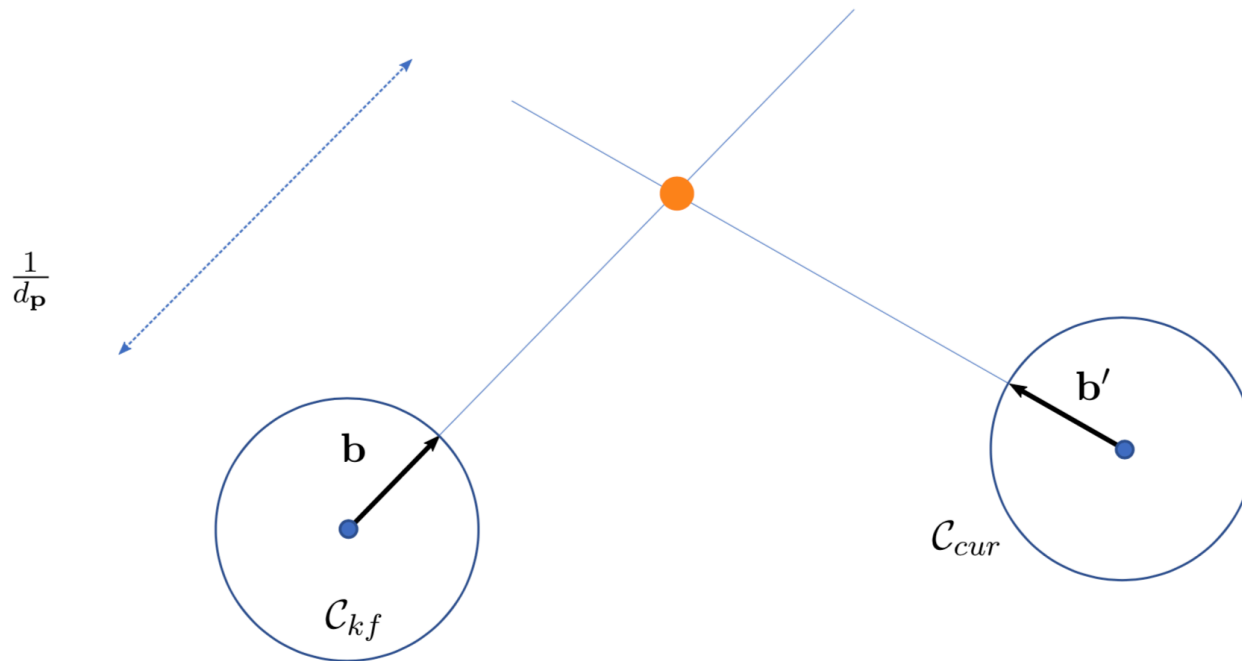
$$b'_x = \frac{p'_x}{\|\mathbf{p}'\|} = \frac{\frac{\mathbf{r}_0 \cdot \mathbf{b}}{d_{\mathbf{p}}} + t_x}{\|\mathbf{p}'\|} \qquad b'_y = \frac{p'_y}{\|\mathbf{p}'\|} = \frac{\frac{\mathbf{r}_1 \cdot \mathbf{b}}{d_{\mathbf{p}}} + t_y}{\|\mathbf{p}'\|}$$

$$\frac{b'_x}{b'_y} = \frac{\frac{\mathbf{r}_0 \cdot \mathbf{b}}{d_{\mathbf{p}}} + t_x}{\frac{\mathbf{r}_1 \cdot \mathbf{b}}{d_{\mathbf{p}}} + t_y}$$

Approach

Candidate Point Tracking

Epipolar Curve Search

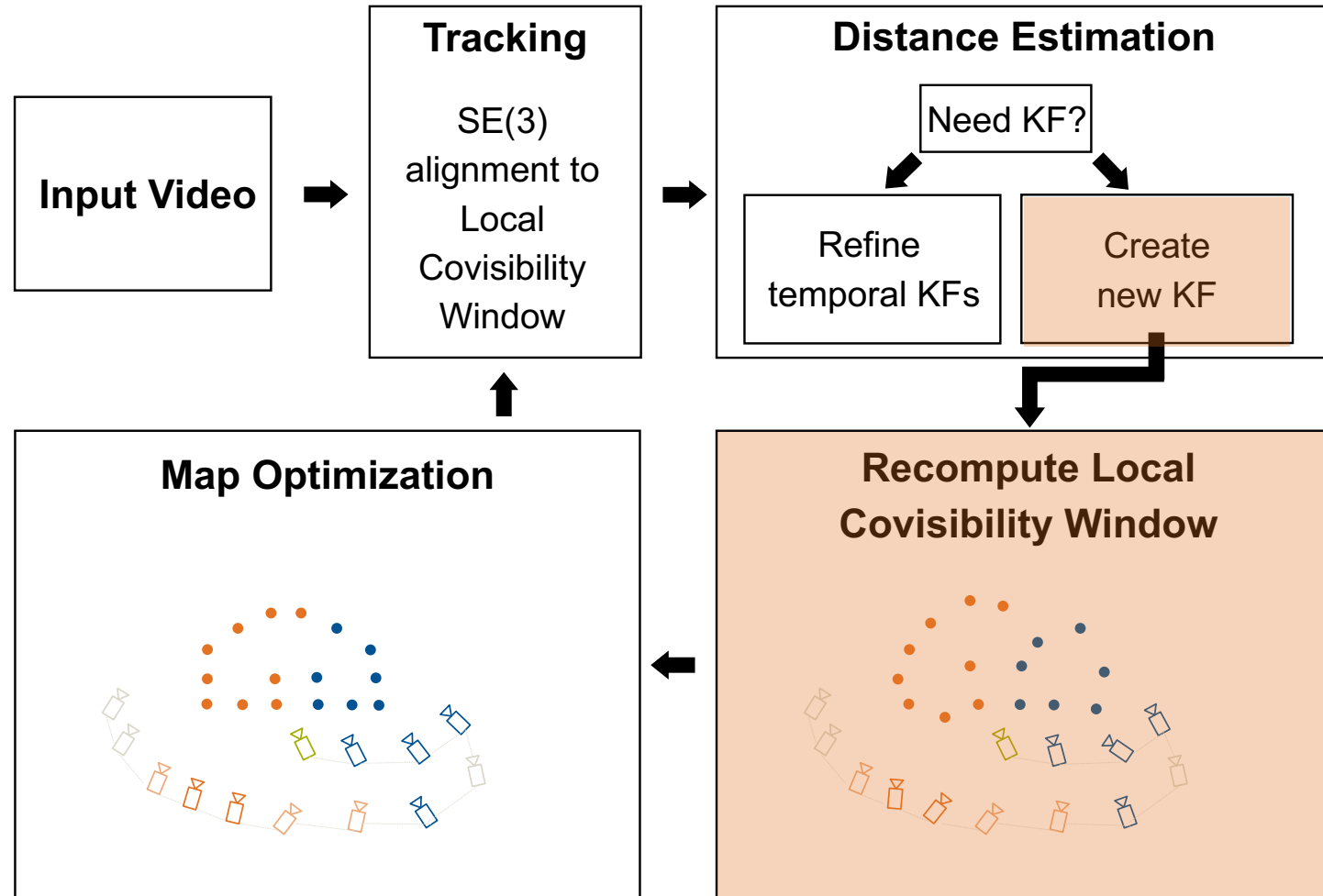


$$\begin{aligned}
 \mathbf{p}' &= \mathbf{R}\mathbf{p} + \mathbf{t} \\
 &= \mathbf{R} \frac{\mathbf{b}}{d_p} + \mathbf{t}
 \end{aligned}$$

$$d_p = \frac{b'_y \mathbf{r}_0 \cdot \mathbf{b} - b'_x \mathbf{r}_1 \cdot \mathbf{b}}{b'_x t_y - b'_y t_x}$$

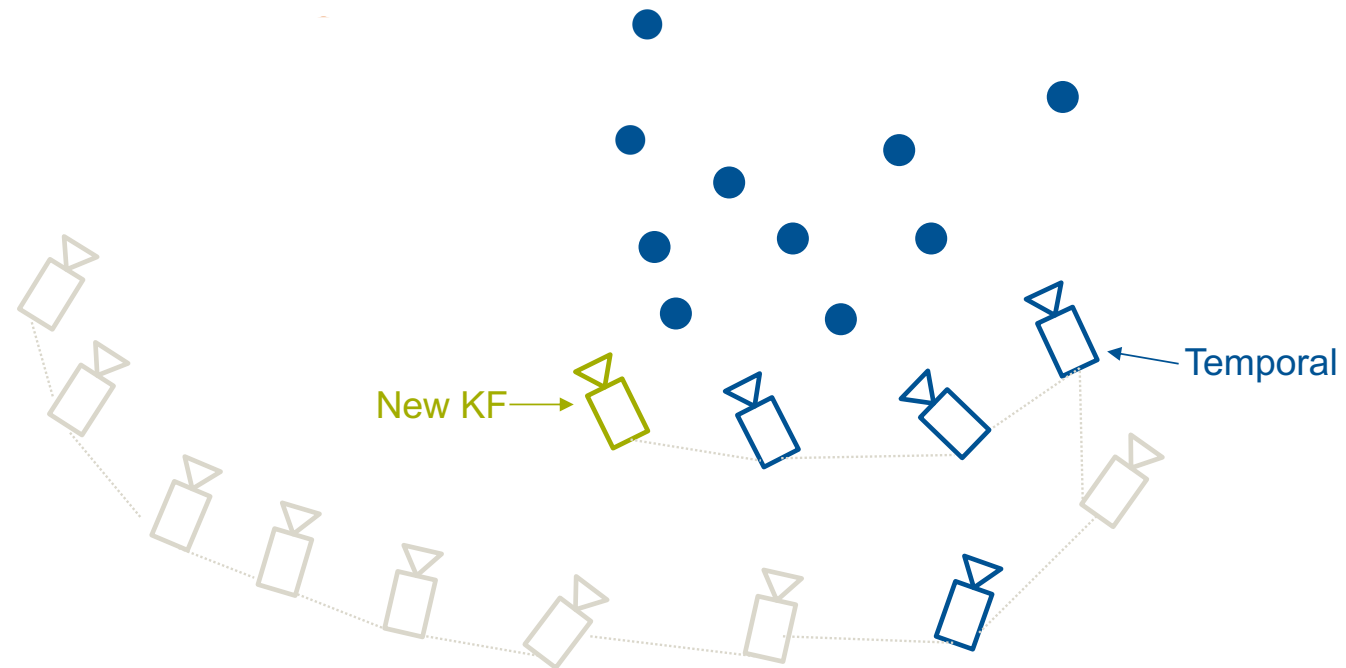
Approach

Overview



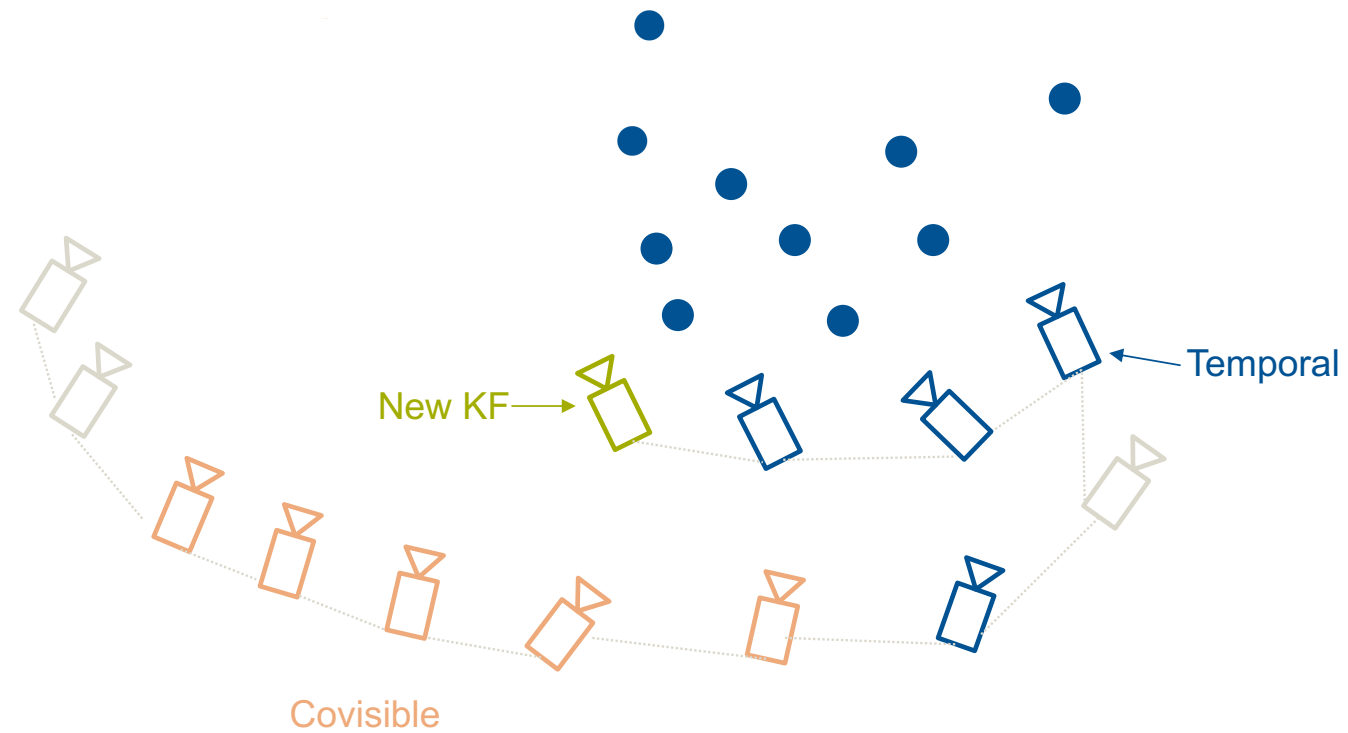
Approach

Recomputing Local Covisibility Window



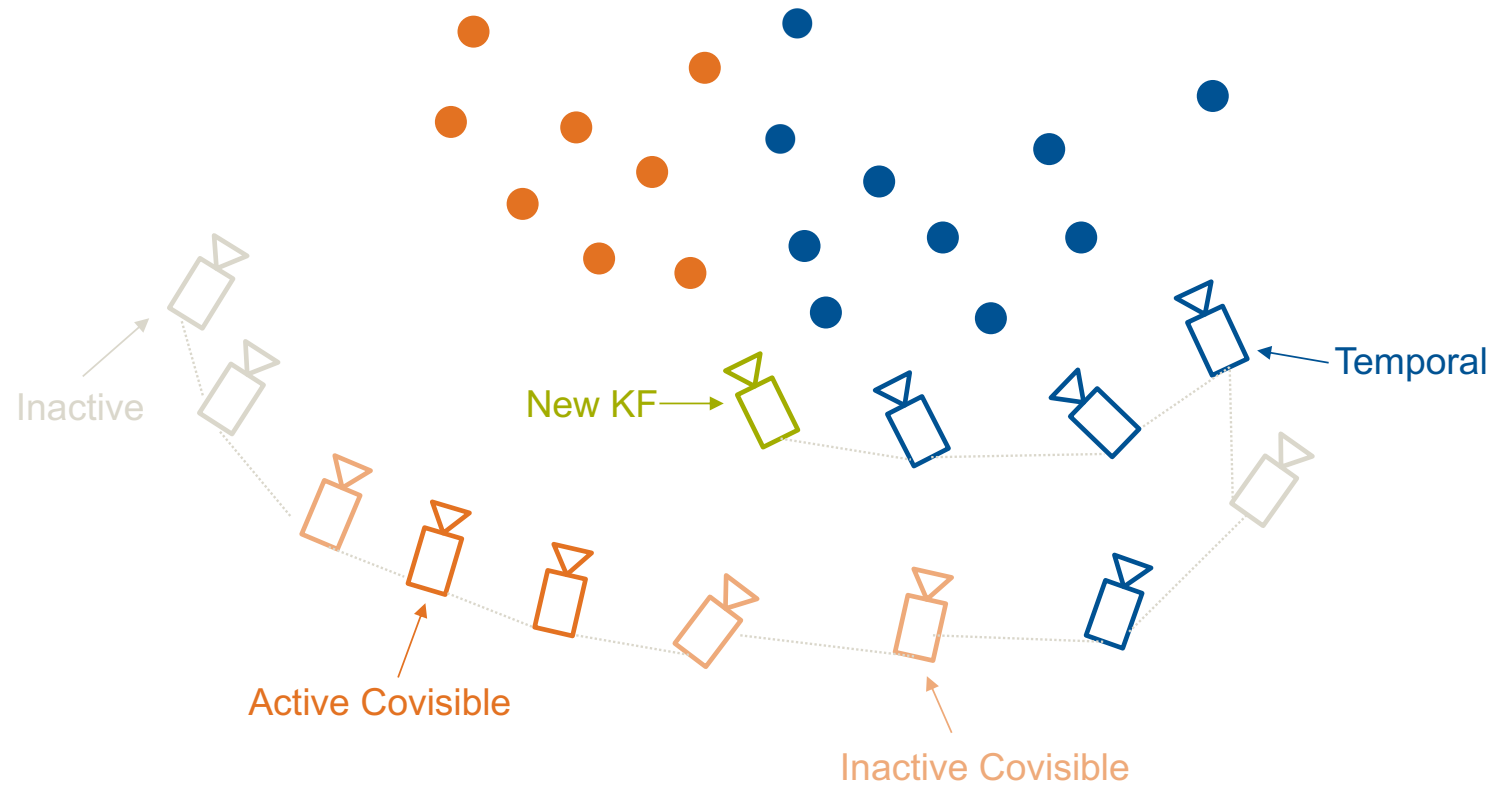
Approach

Recomputing Local Covisibility Window



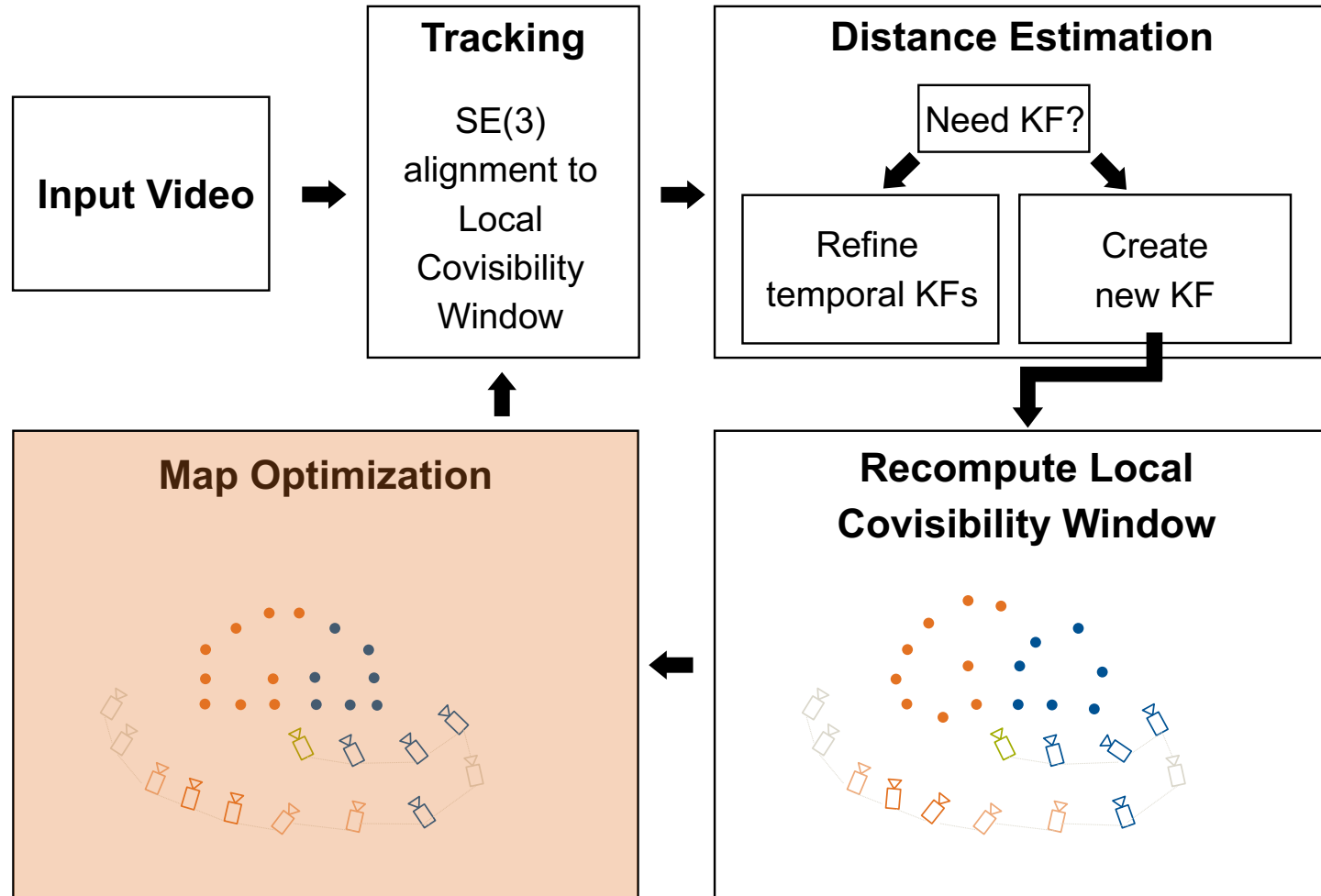
Approach

Recomputing Local Covisibility Window



Approach

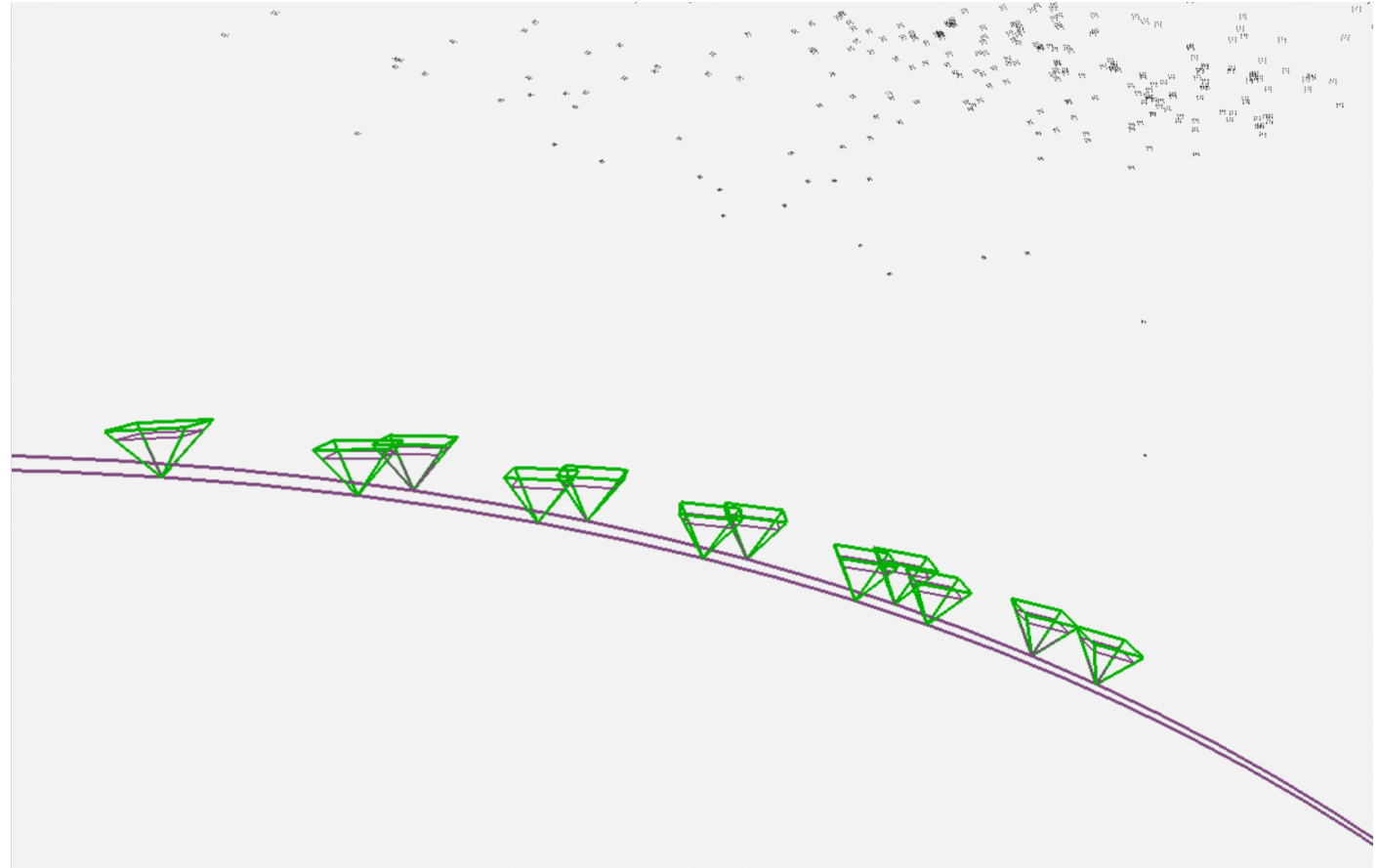
Overview



Approach

Photometric Bundle Adjustment

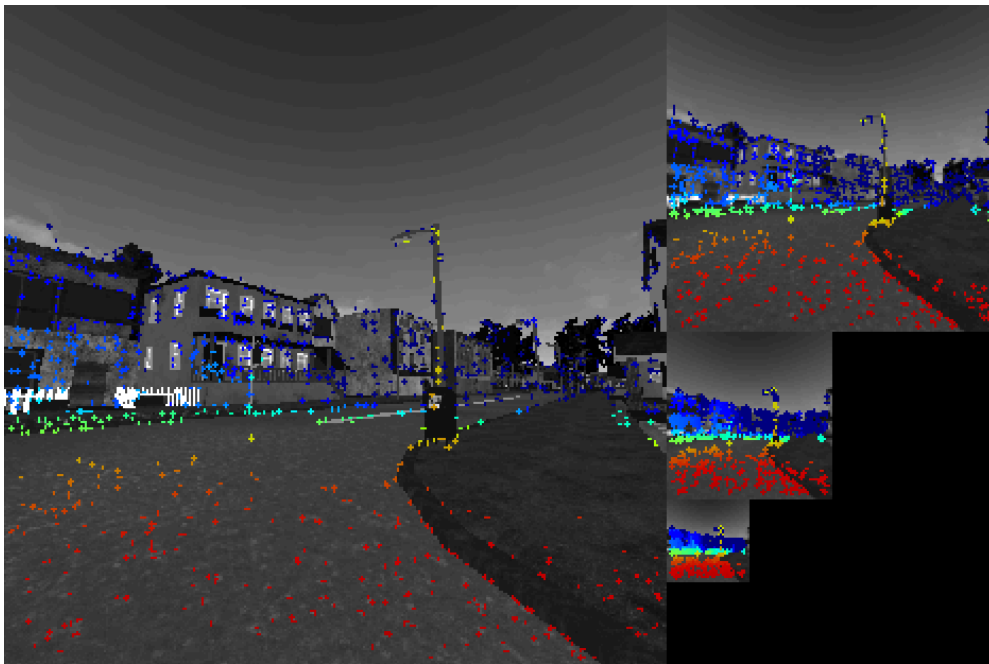
- Ceres
(w/o coarse-to-fine)
- Manual Solver
(w/ and w/o coarse-to-fine)



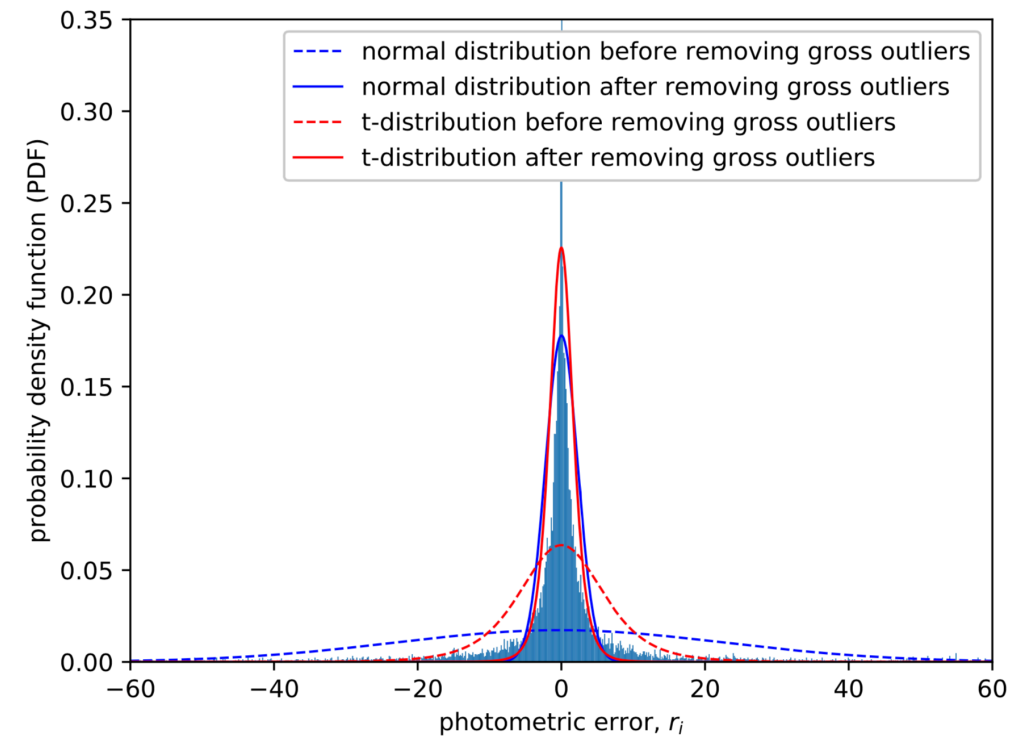
Approach

Robustification

Coarse-to-Fine



Residual Distribution

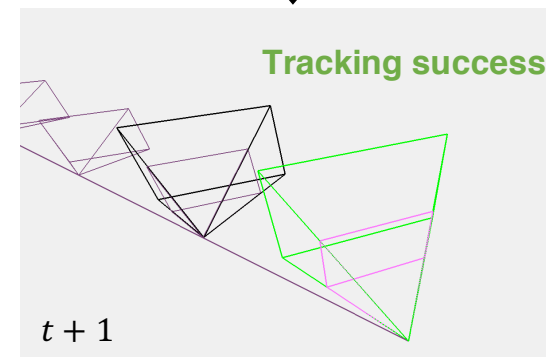
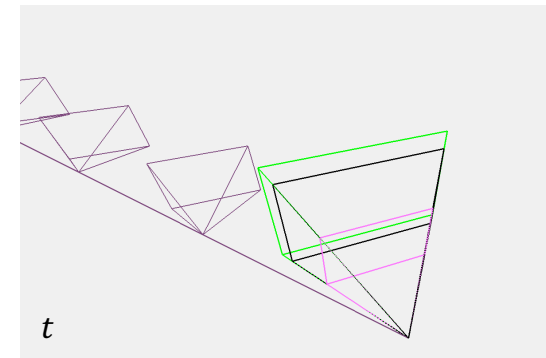
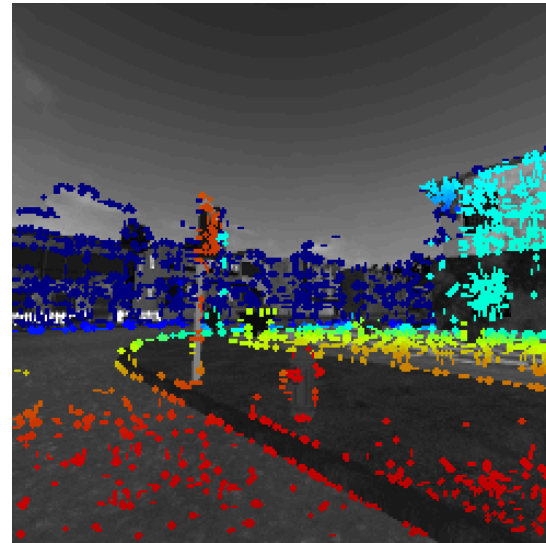


Results

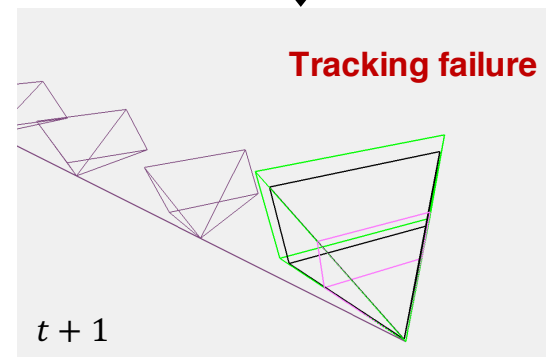
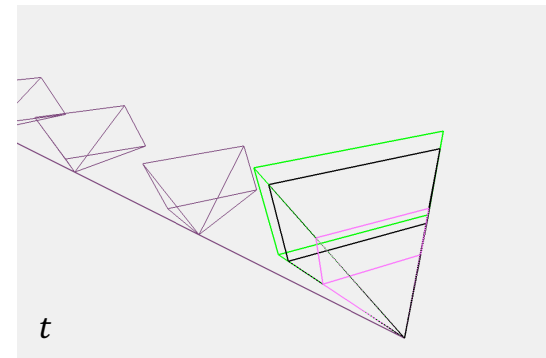
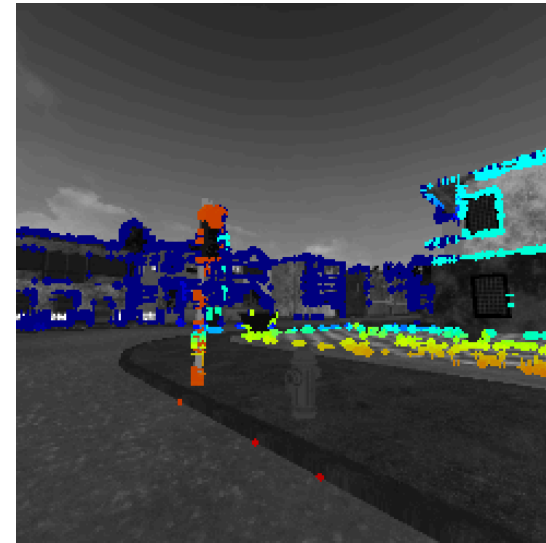
Results

Influence of
Candidate Point
Selection on Tracking

Setting A

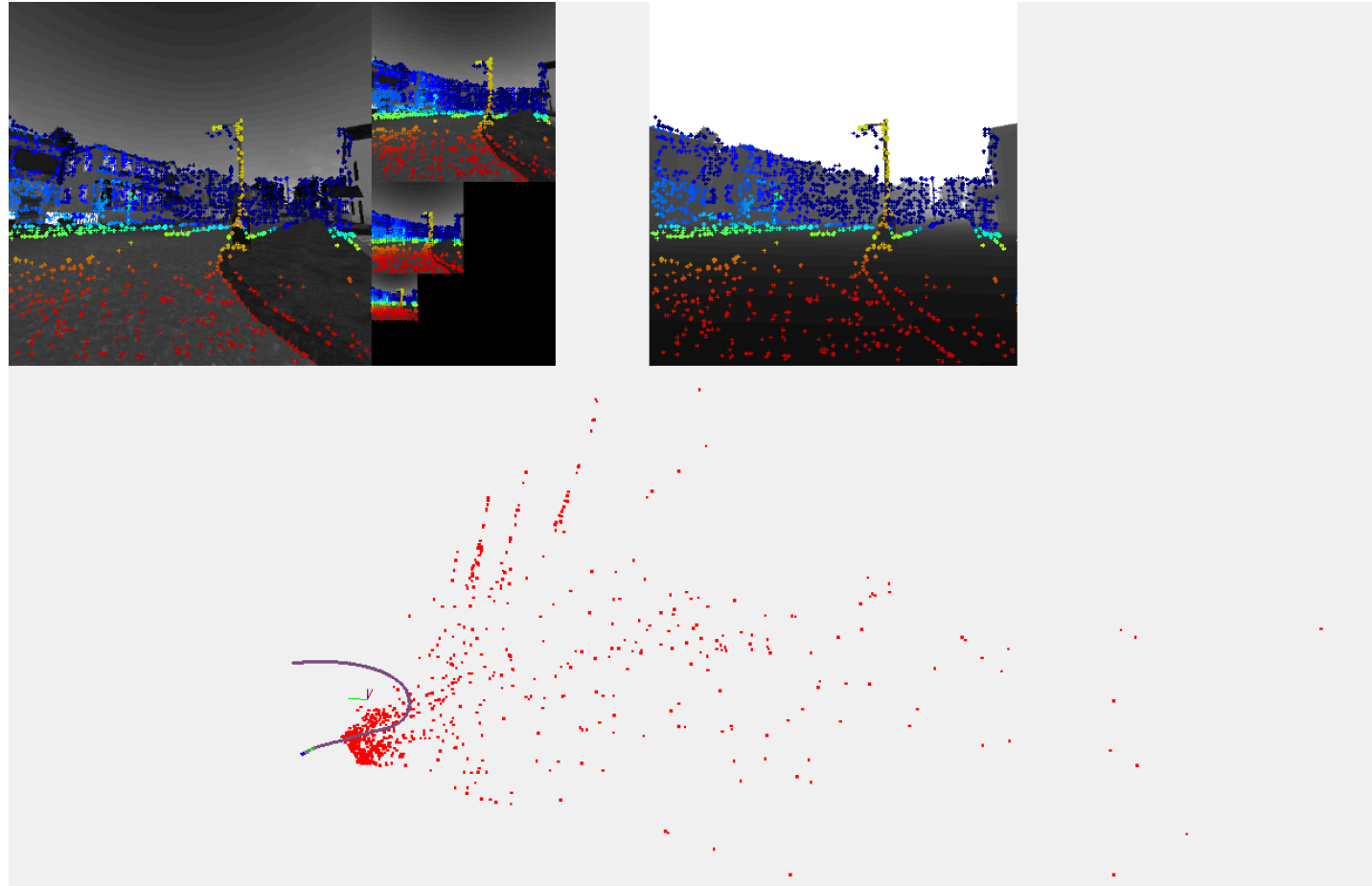


Setting B



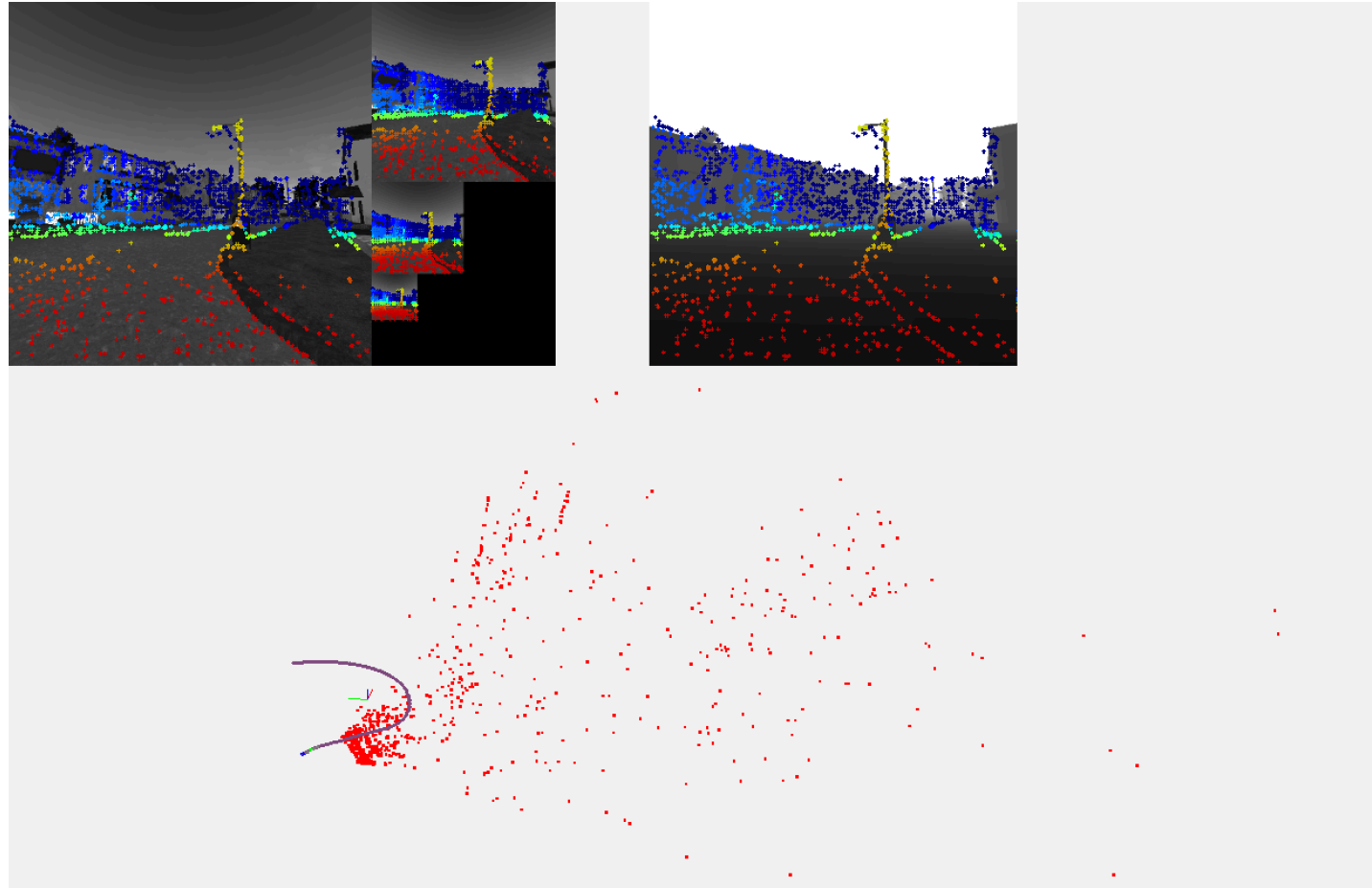
Results

Candidate Point Tracking



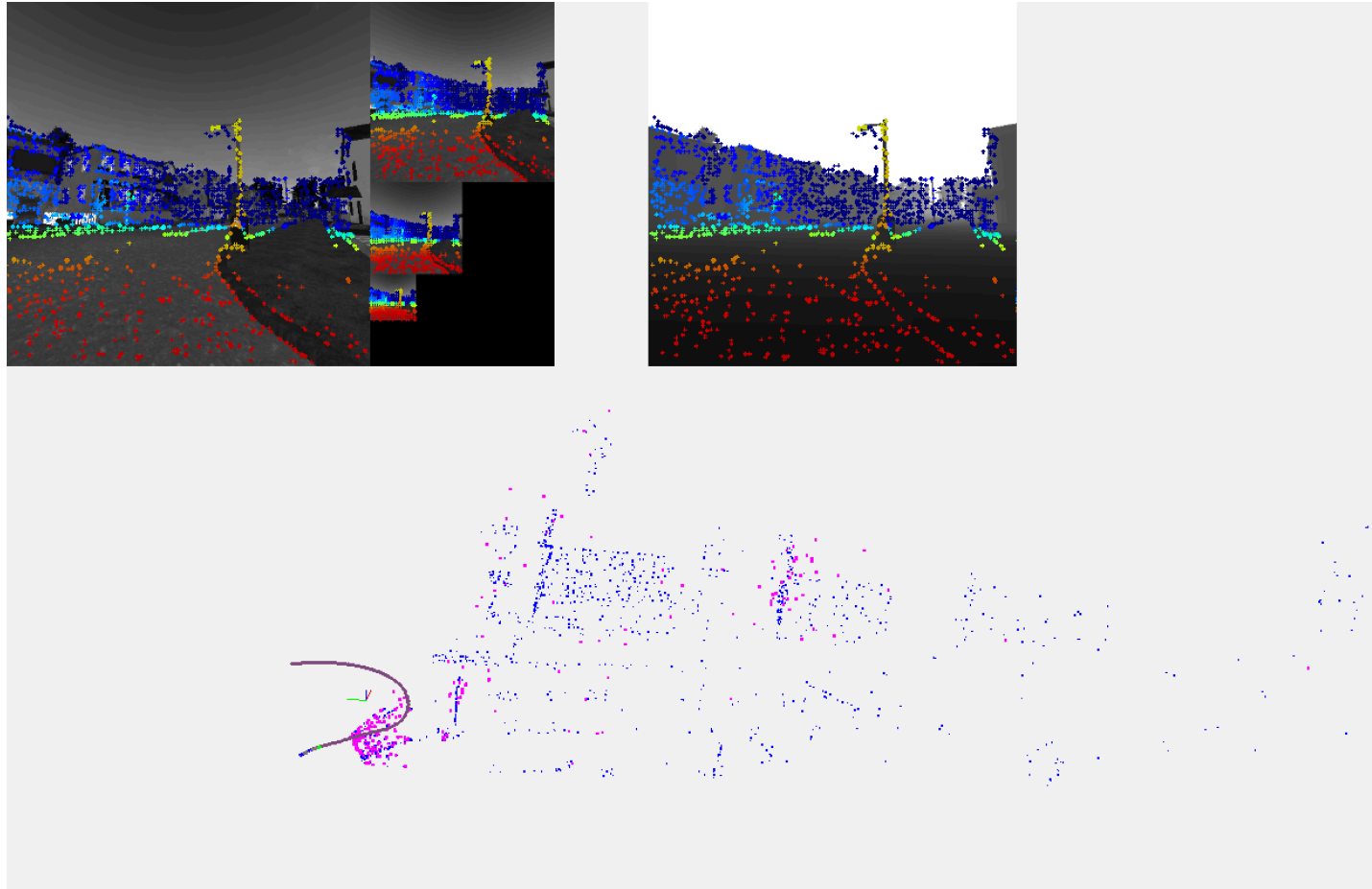
Results

Candidate Point Tracking



Results

Candidate Point Tracking

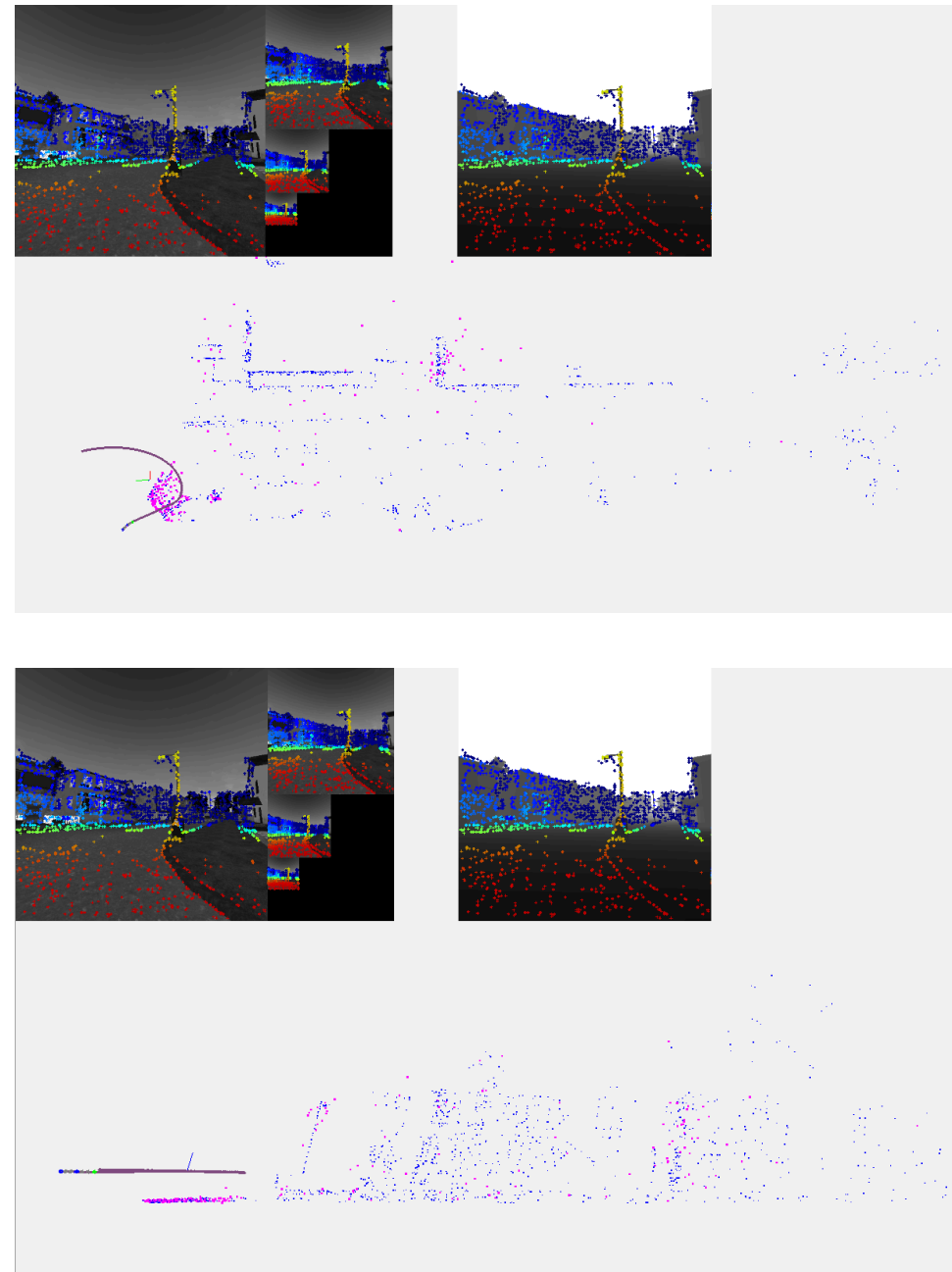
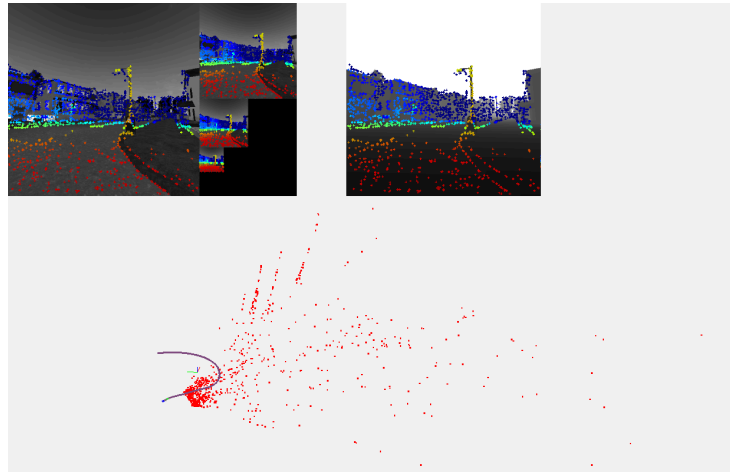


Upgraded to Landmarks

Results

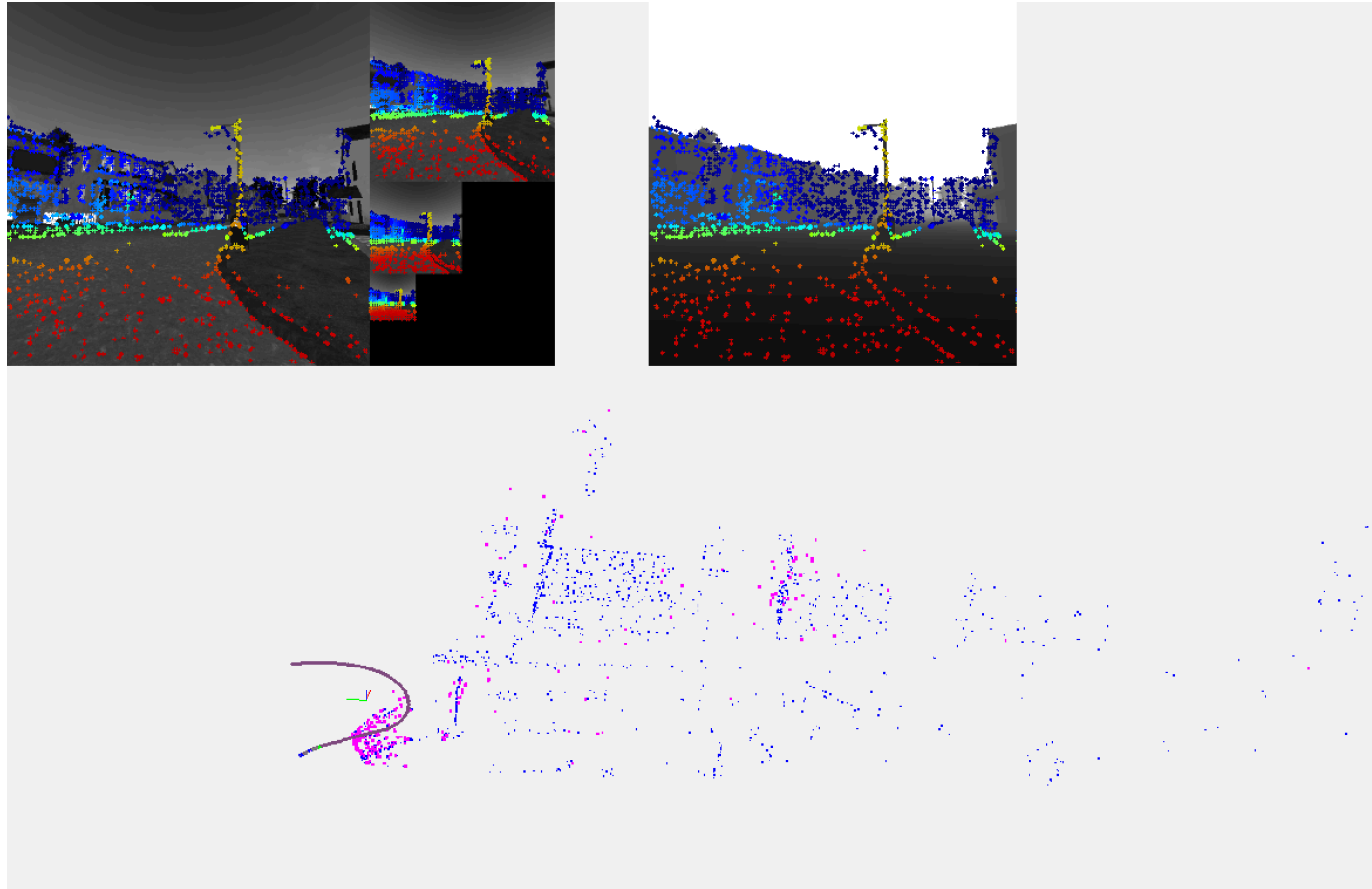
Candidate

Point Tracking



Results

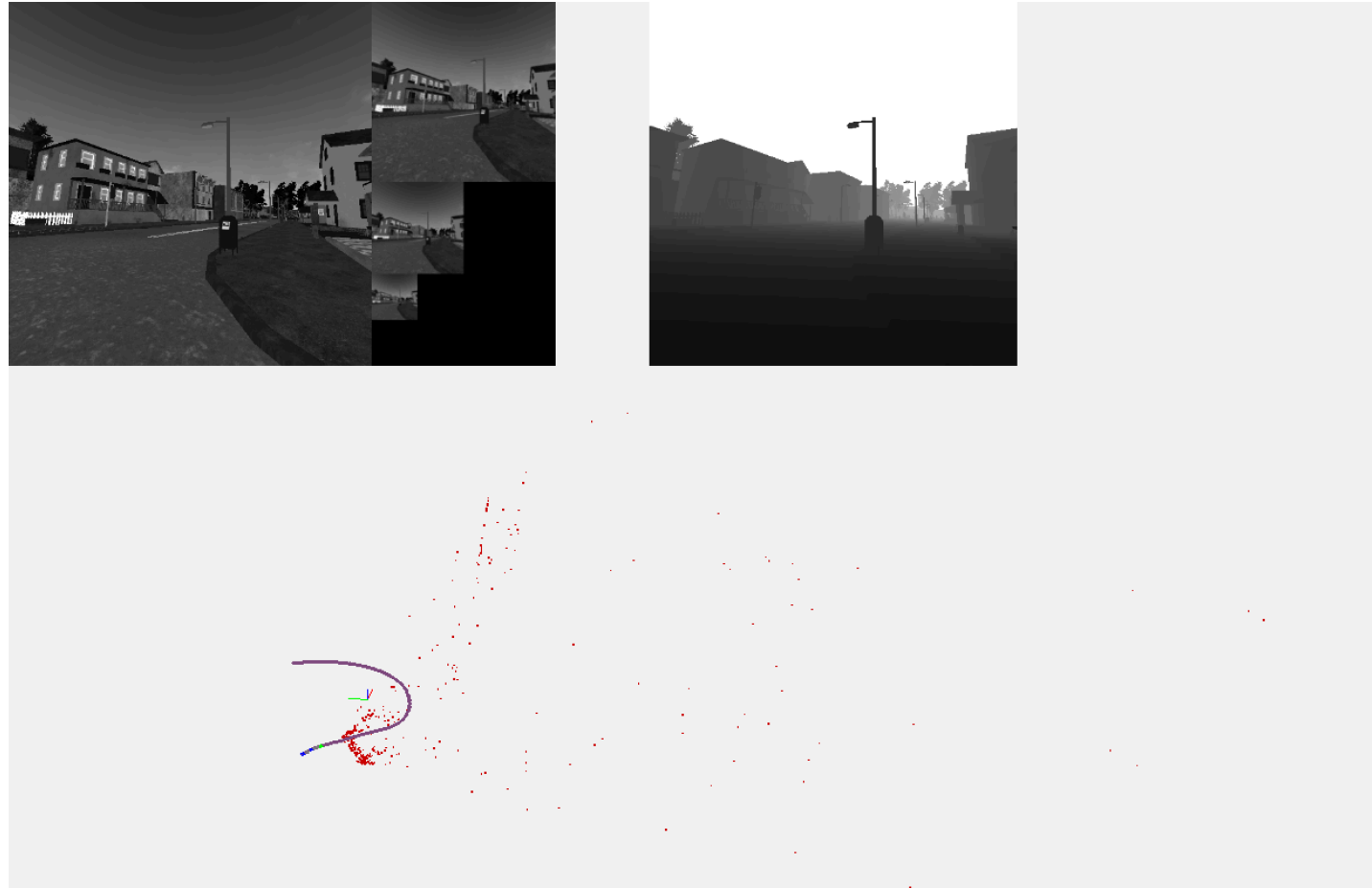
Candidate Point Tracking



Upgraded to Landmarks

Results

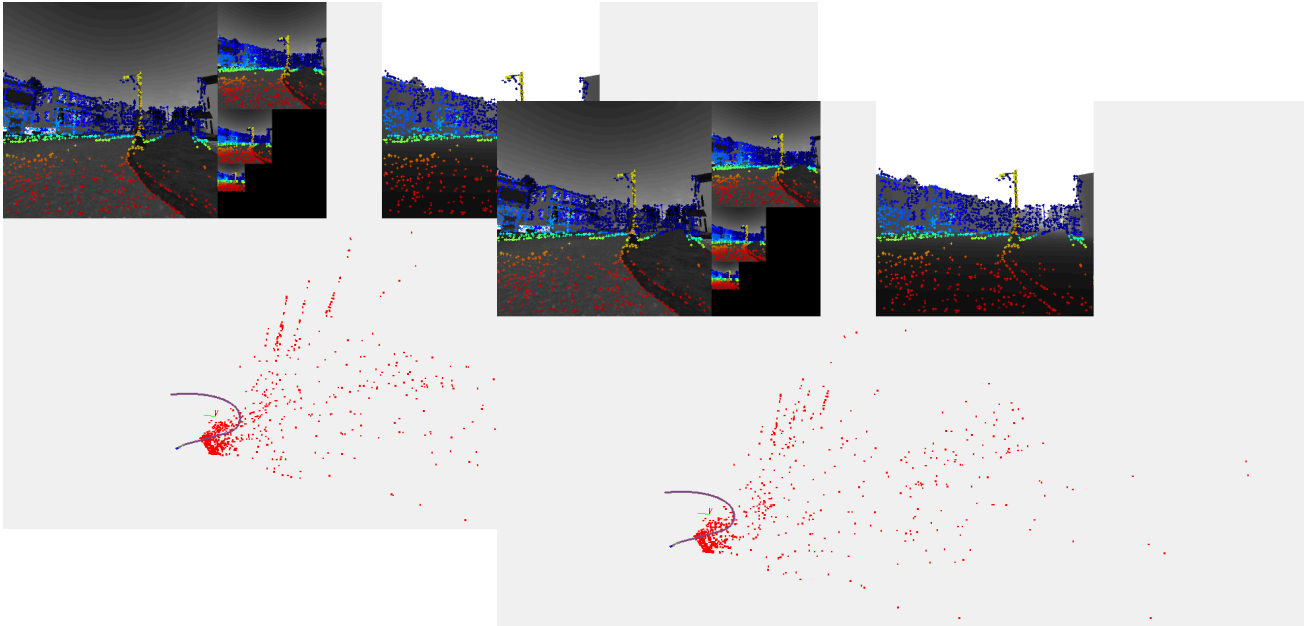
Candidate Point Tracking



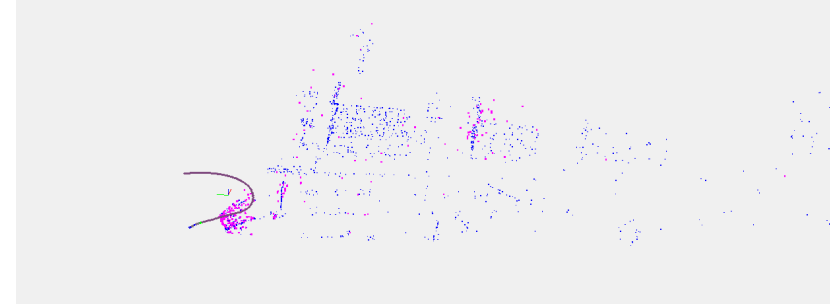
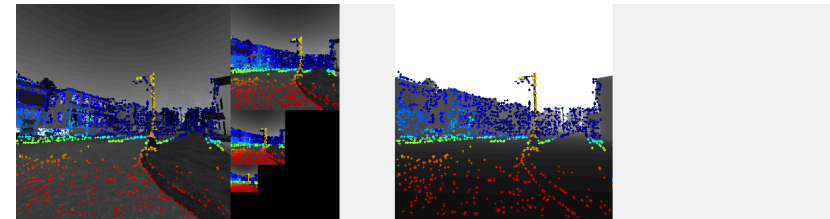
Remaining as Candidate Points

Results

Candidate Point Tracking



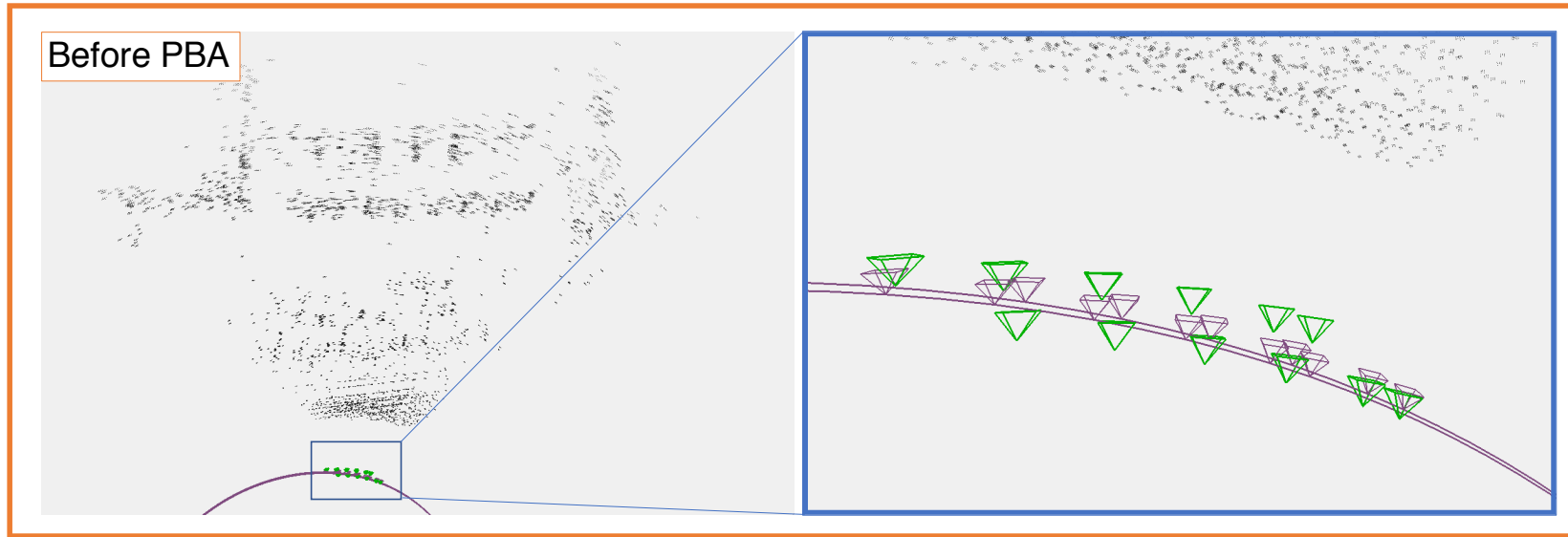
Remaining as Candidate Points



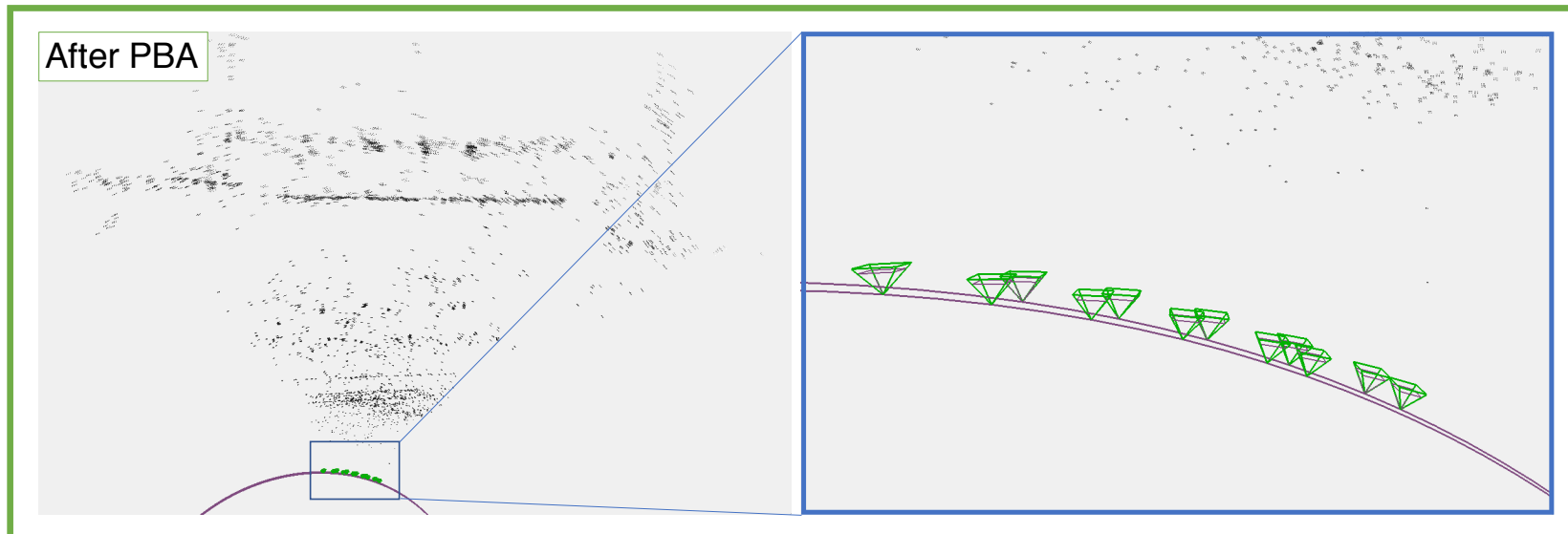
Upgraded to Landmarks

Results

Photometric
Bundle
Adjustment



PBA (Photometric Bundle Adjustment)



Results

Photometric Bundle Adjustment

Max Number of Iterations per Level: **10**

Solver Type		Metric						
		ATE (m)	Runtime (s)	Total	Iterations			
					3	2	1	0
Manual	w/o pyrs	0.00131	0.43	10	-	-	-	10
Ceres	w/o pyrs	0.03761	2.05	10	-	-	-	10
Manual	w/ pyrs	0.00054	2.42	29	7	3	10	9
Ceres	w/ pyrs	-	-	-	-	-	-	-

Results

Full System

show_extra_options

keyframe 59

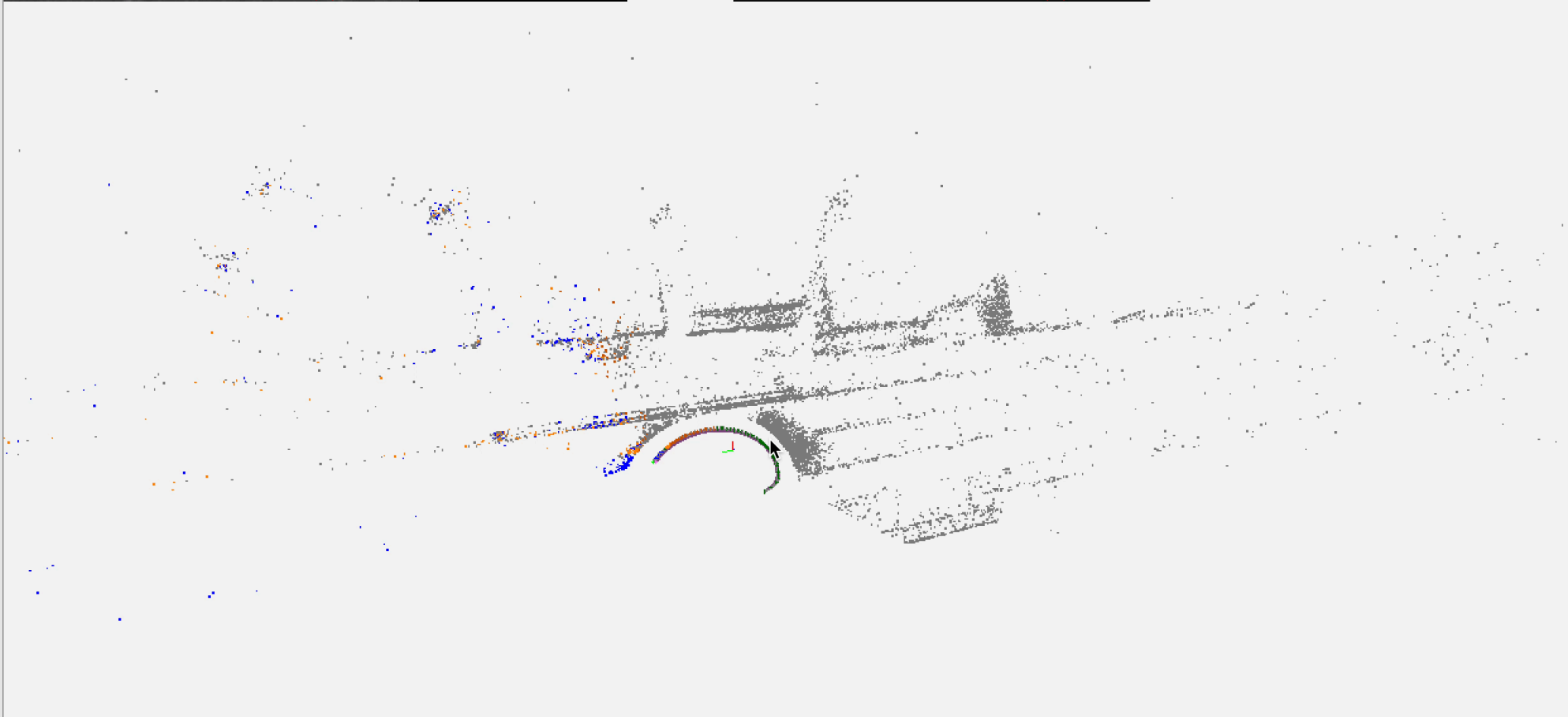
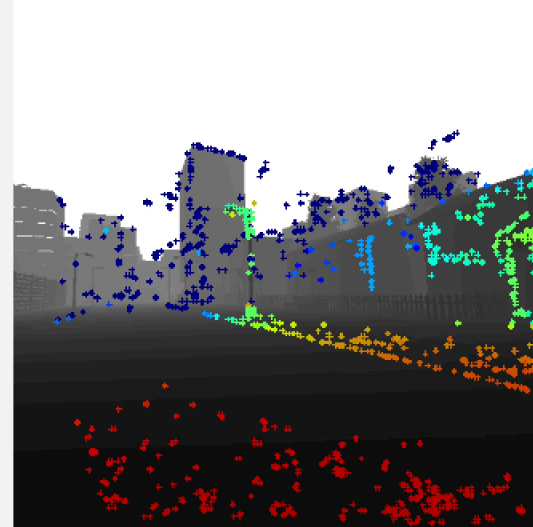
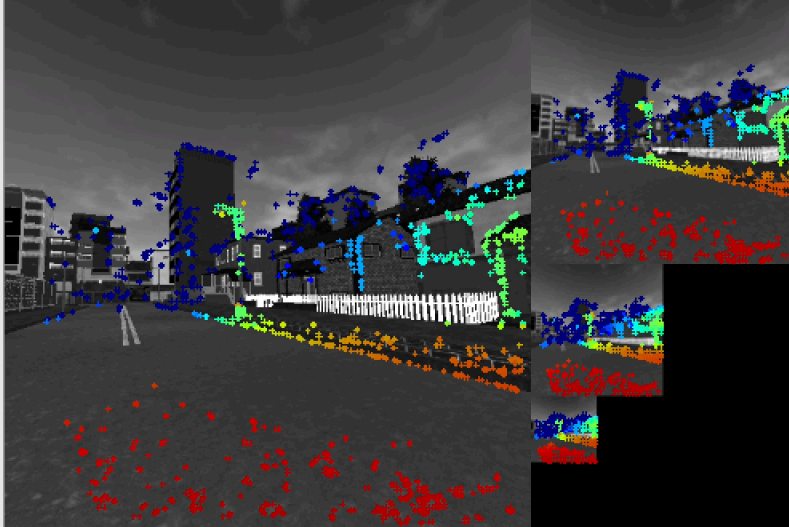
continue_next

next_step

unload_maps

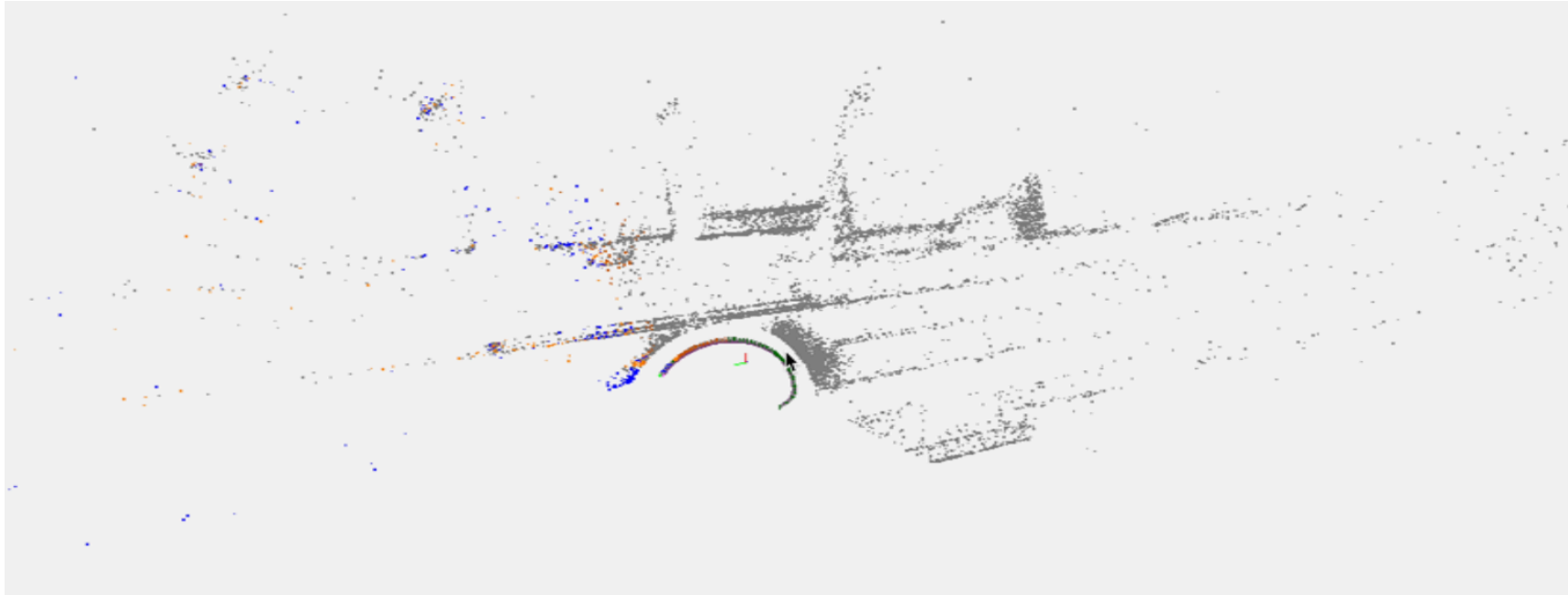
load_photo_map

save_observation_graph



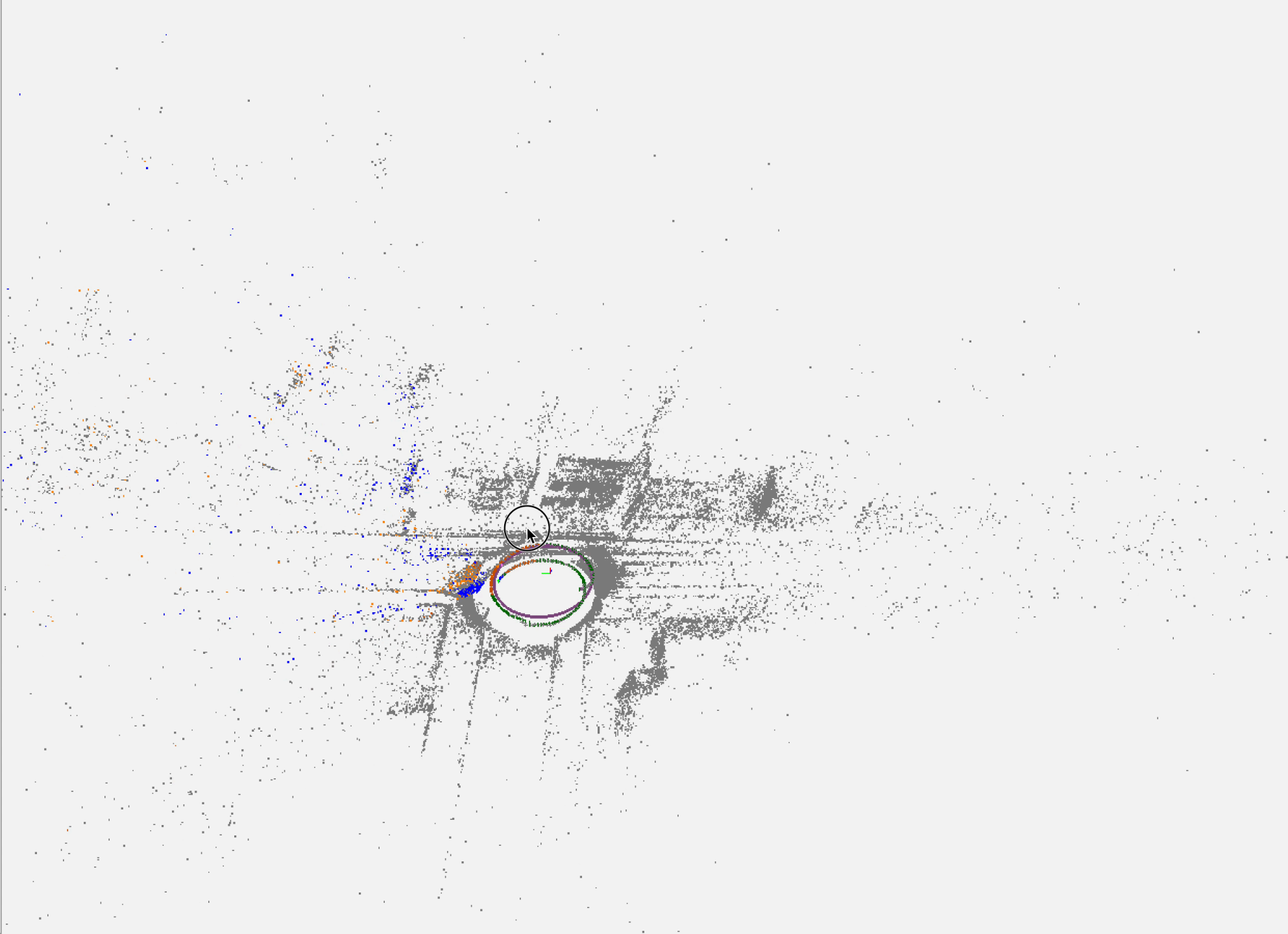
Results

Full System



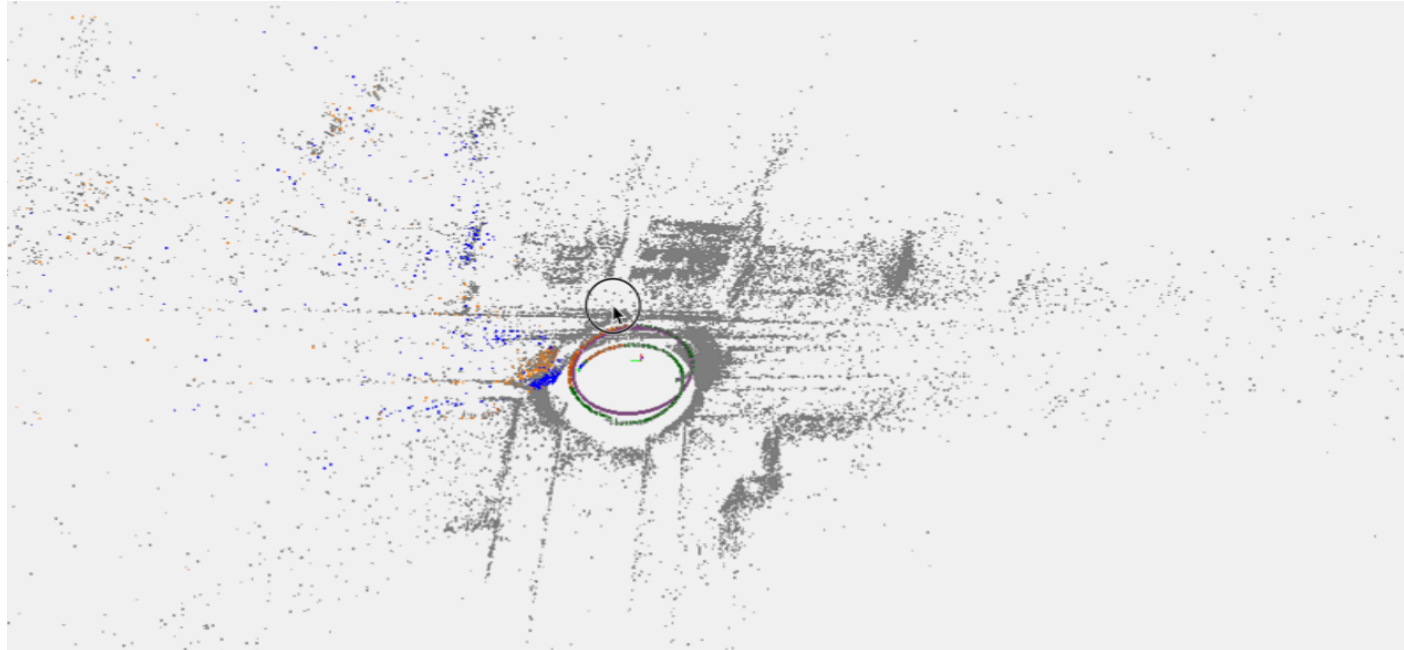
RMSE ATE: **0.00589** m

- show_extra_options
- keyframe 197**
- continue_next
- next_step
- unload_maps
- load_photo_map
- save_observation_graph



Results

Full System



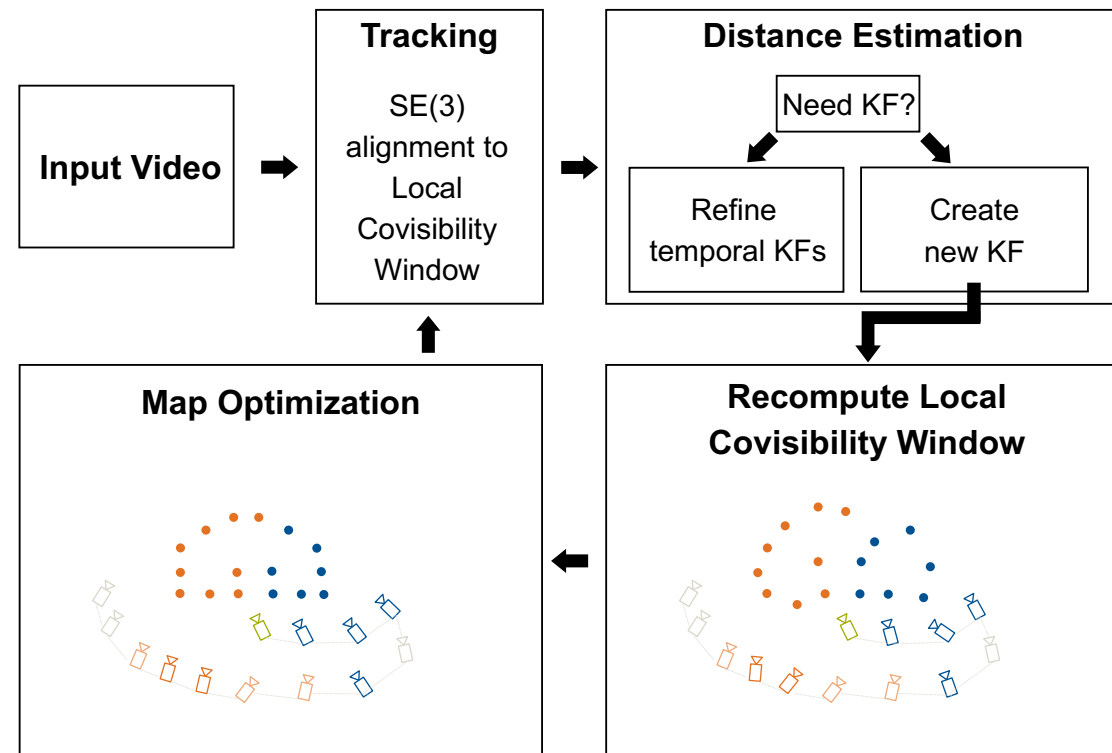
RMSE ATE: **1.05** m

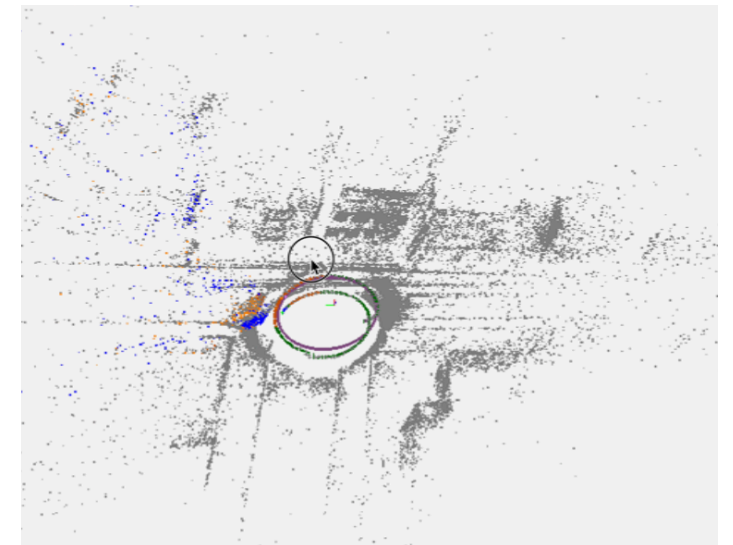
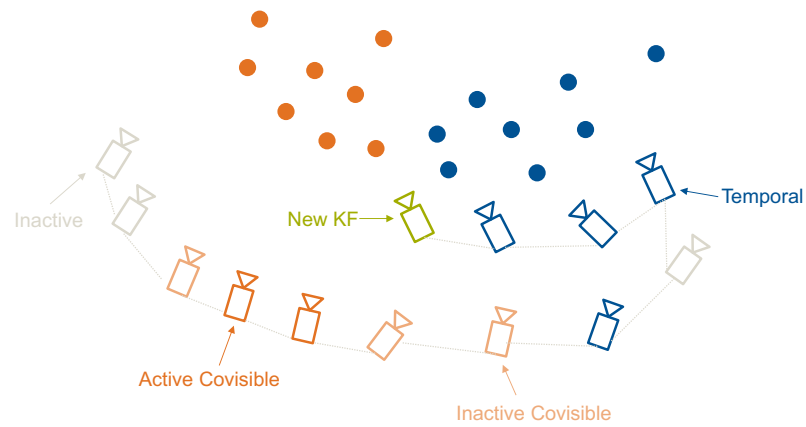
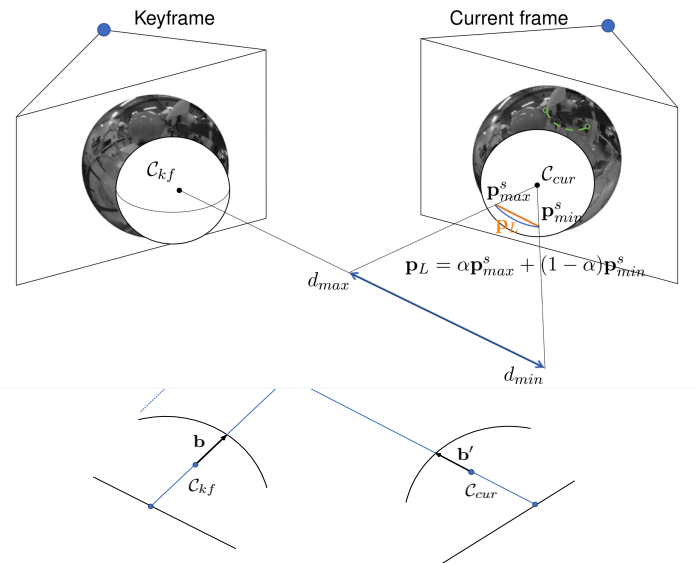
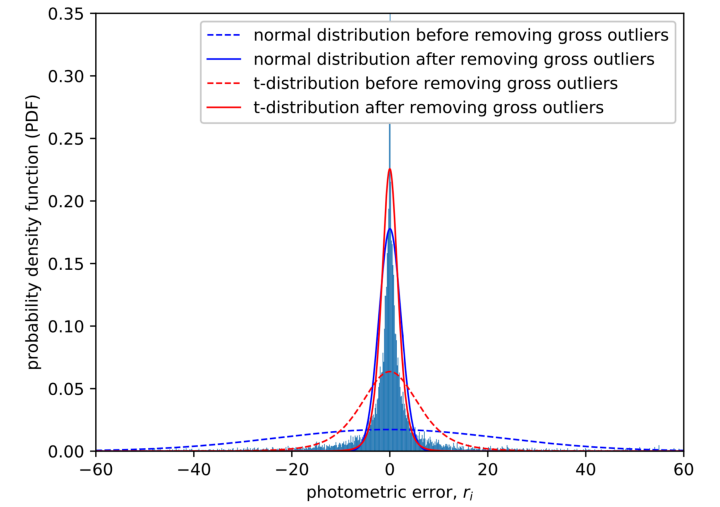
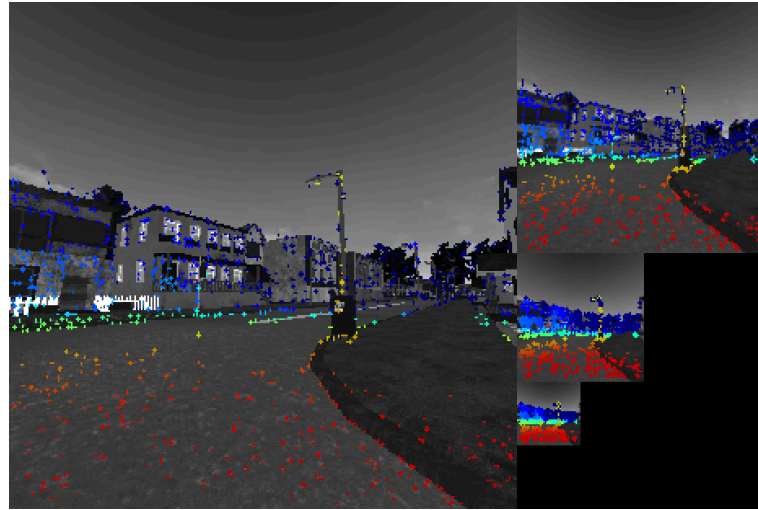
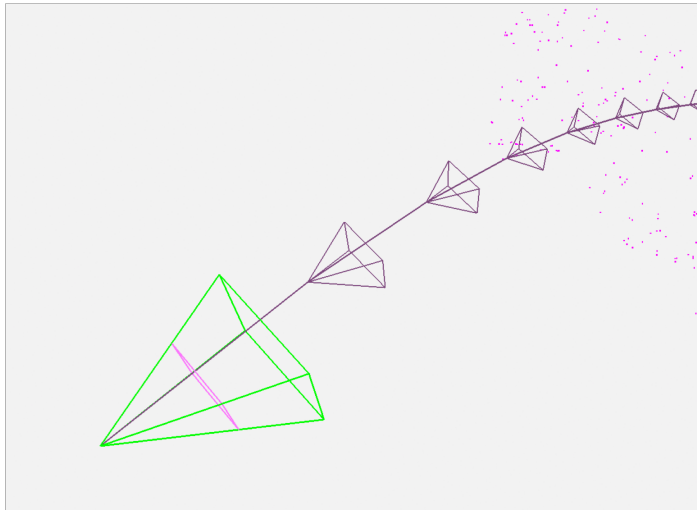
Conclusion

Direct **SLAM**

+

Modular & flexible **framework** for future development





Future Work

- Refine system and find good balance for user-defined parameters
- Pose-graph optimization to close larger loops:
 - Double-window optimization (accurate pose-point & soft pose-pose)
- Test the system on real datasets (e.g., EuRoC)

Thank you very much
for your attention.

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pablo.rodriiguez-palafox@tum.de

