Practical Course: Vision Based Navigation

Projects

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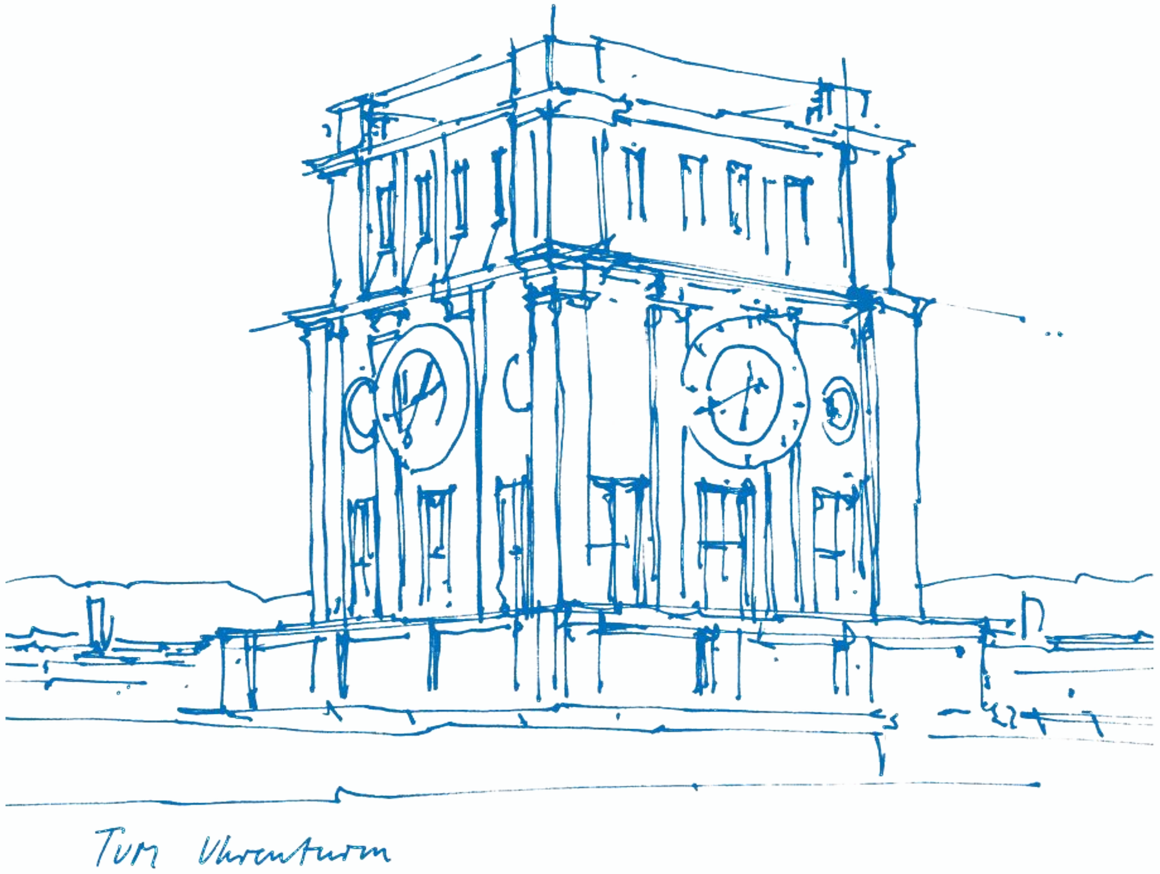
Prof. Dr. Daniel Cremers



Version: 29.11.2021

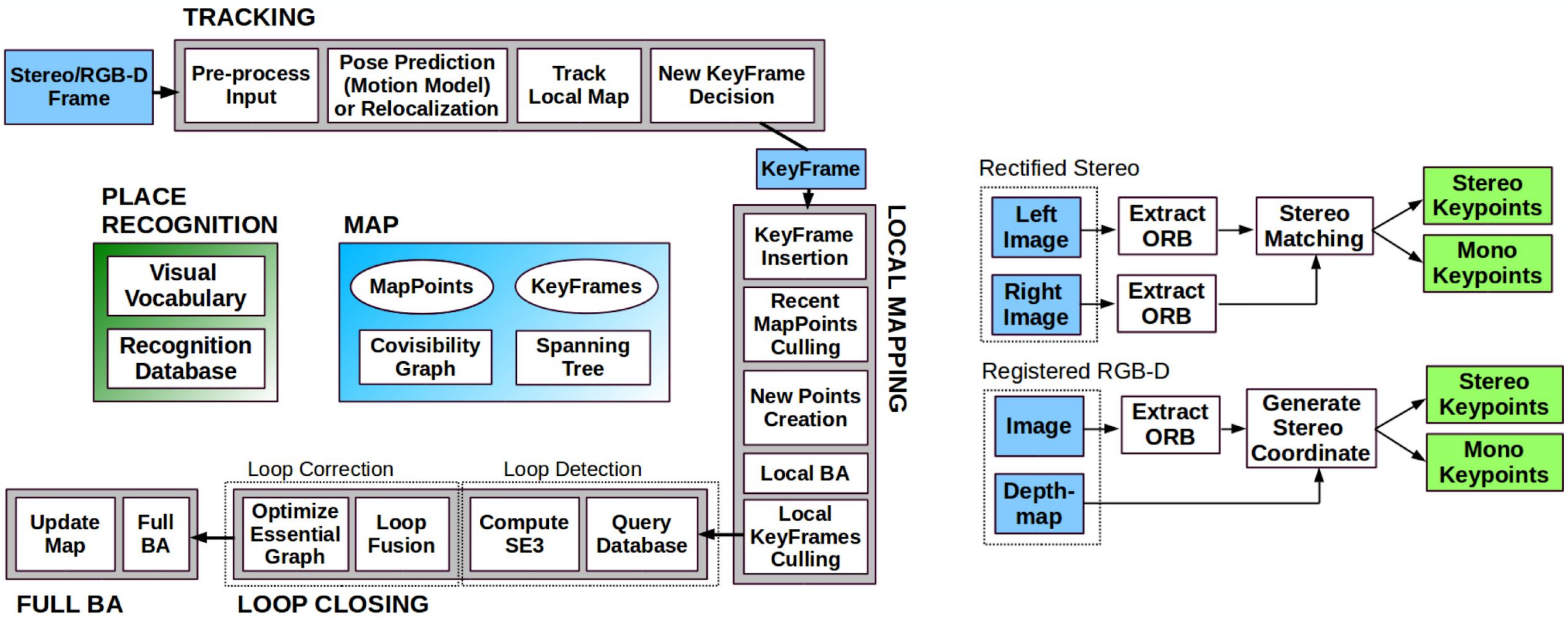
Project Phase

- Start after sheet 5 is complete. For the remainder of the lecture period.
- Work on open-ended project (1-2 people).
- Mandatory weekly meeting with tutors to discuss progress and next steps.
  - fixed 30 min time slot
  - preferably Mondays 2pm-6pm (first come first served)
- Project goal is to be determined:
  - Choose from list of suggested projects or suggest your own.
  - “Advanced” topics have more uncertain scope / solution. More independent work required.
  - At most 2 groups should work on the same project (first come first served).

- Present project outcome in talk and Q&A session (15min per group)
- Written report on project outcome (10-12 pages, single column, single-spaced lines, 11 pt)

- Important dates:
  - Fix groups, project topic, and time for weekly meeting: 06.12.2021 (sheet 5 deadline)
  - First meeting on 13.12.2021 (**dates:** 20.12, 10.01, 17.01, 24.01)
  - Project presentations: 31.01.2021 2:00pm
  - Project report due: 31.03.2021

1. SLAM



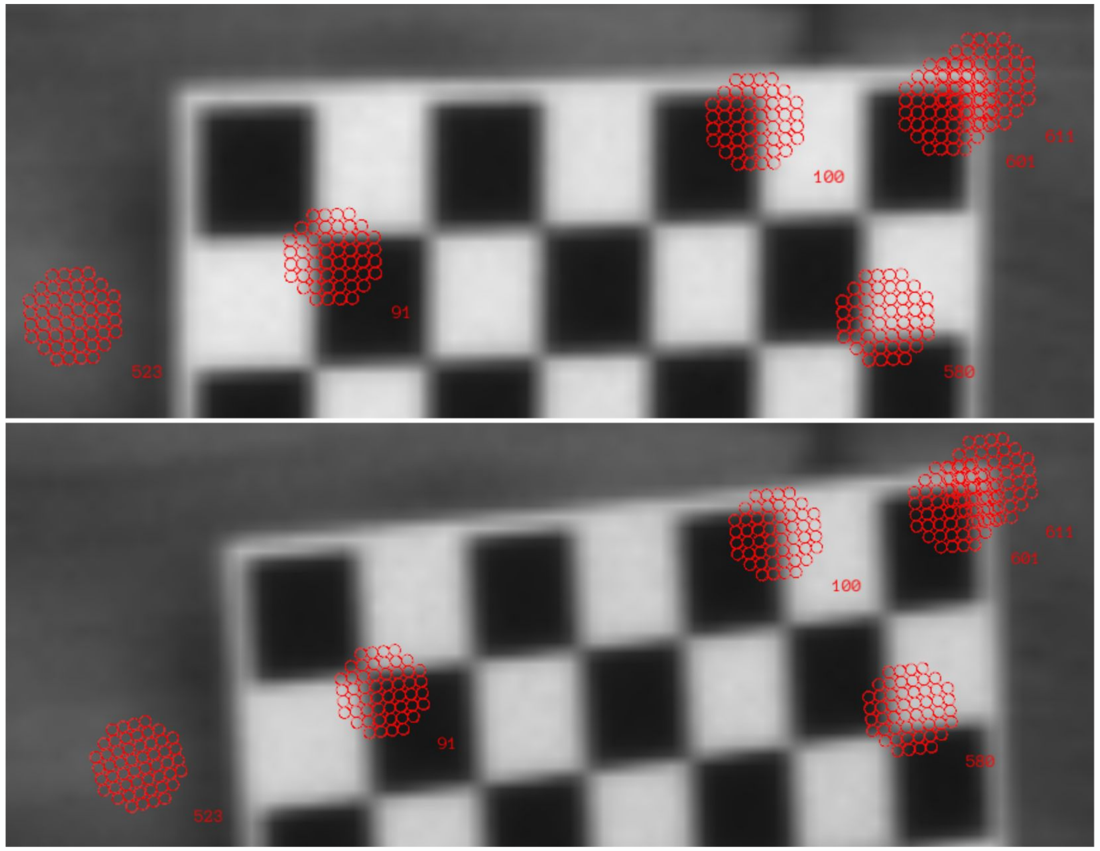
(a) System Threads and Modules.

(b) Input pre-processing

- ORB_SLAM: http://webdiis.unizar.es/~raulmur/MurMontielTardosTRO15.pdf
- ORB_SLAM2: https://arxiv.org/abs/1610.06475
- Map management
- Reusing Keyframes
- Spanning tree for pose-graph optimization

2. Indirect Visual Odometry with Optical Flow

- Sparse optical flow as alternative to feature matching
- Extend odometry application
- Compare runtime, accuracy, …
- Possible extensions:
  - patch similarity norms
  - Keyframing, local optimization
  - Different image warping strategies
  - Implement Gauss-Newton (or LM) manually

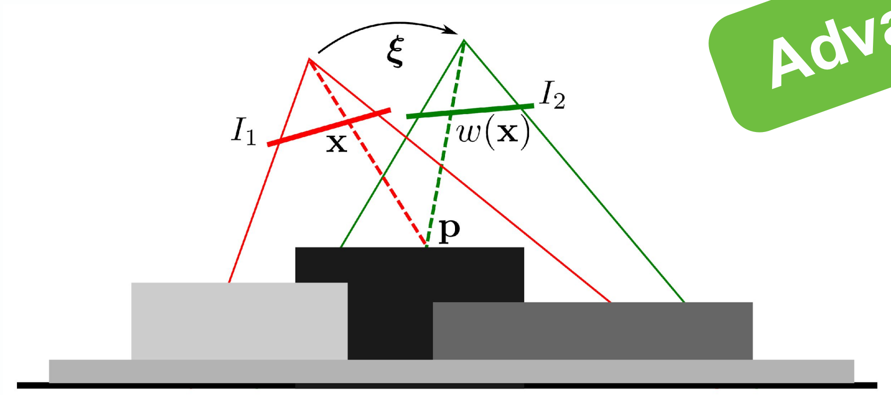


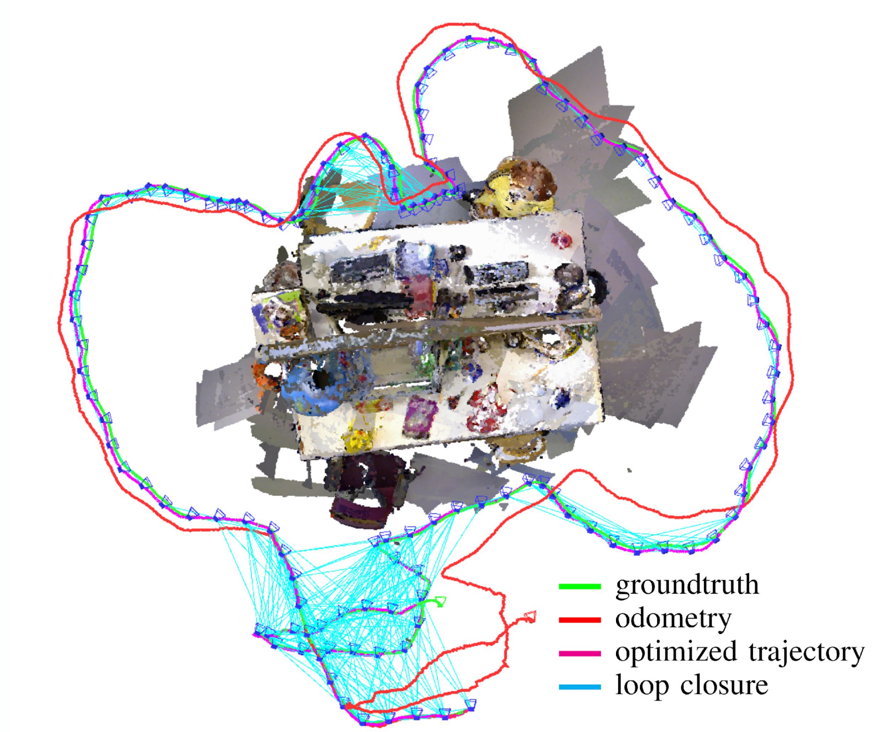
- Visual-Inertial Mapping with Non-Linear Factor Recovery (V. Usenko, N. Demmel, D. Schubert, J. Stueckler and D. Cremers), In arXiv:1904.06504, 2019. https://arxiv.org/pdf/1904.06504
- Equivalence and efficiency of image alignment algorithms (Baker, Simon, and Iain Matthews), In IEEE Computer Society Conference on Computer Vision and Pattern Recognition. Vol. 1. IEEE Computer Society; 1999, 2001. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.70.20&rep=rep1&type=pdf

3. Direct Visual Odometry for RGB-D Images

Advanced

- Work with RGB-D data
- Estimate the relative pose via Direct Image Alignment
- Implement Gauss-Newton (or LM) manually
- Frame-to-frame or frame-to-keyframe
- Different image warping strategies
- coarse-to-fine to improve convergence
- robust-norm to handle outliers





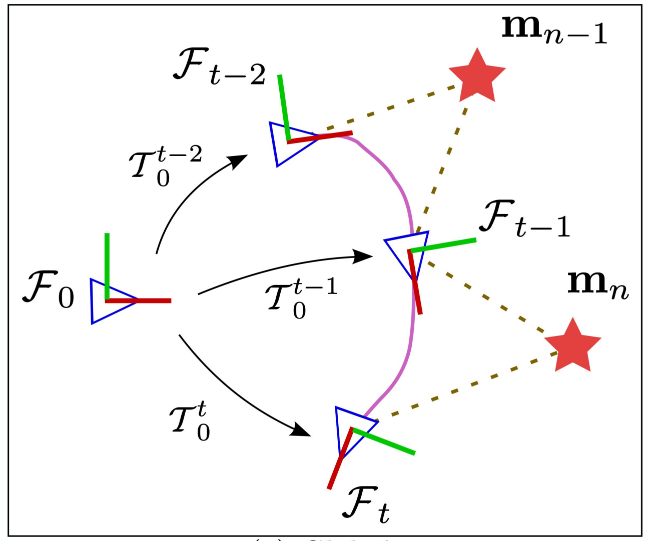
- Robust Odometry Estimation for RGB-D Cameras (C. Kerl, J. Sturm and D. Cremers), In International Conference on Robotics and Automation (ICRA), 2013.

https://vision.in.tum.de/_media/spezial/bib/kerl13icra.pdf

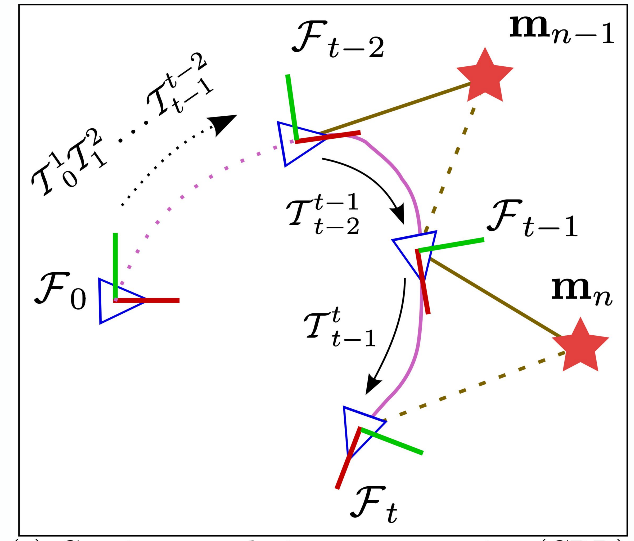
- Equivalence and efficiency of image alignment algorithms (Baker, Simon, and Iain Matthews), In IEEE Computer Society Conference on Computer Vision and Pattern Recognition. Vol. 1. IEEE Computer Society; 1999, 2001.

http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.70.20&rep=rep1&type=pdf

4. Relative Map Formulation for SLAM

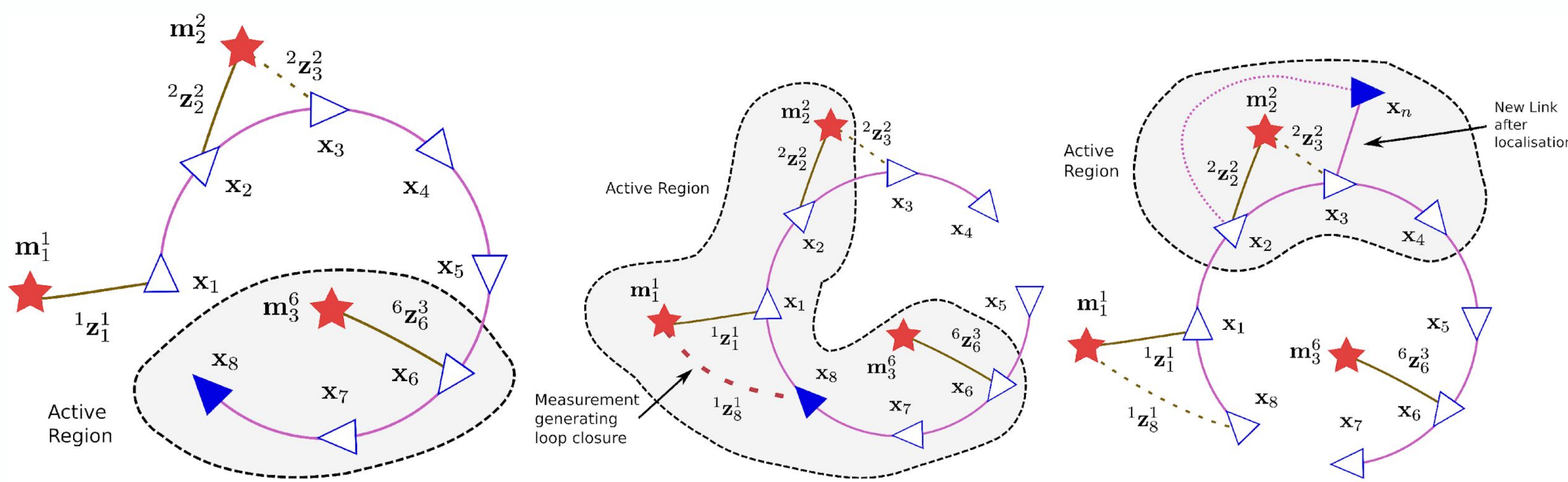


(a) Global



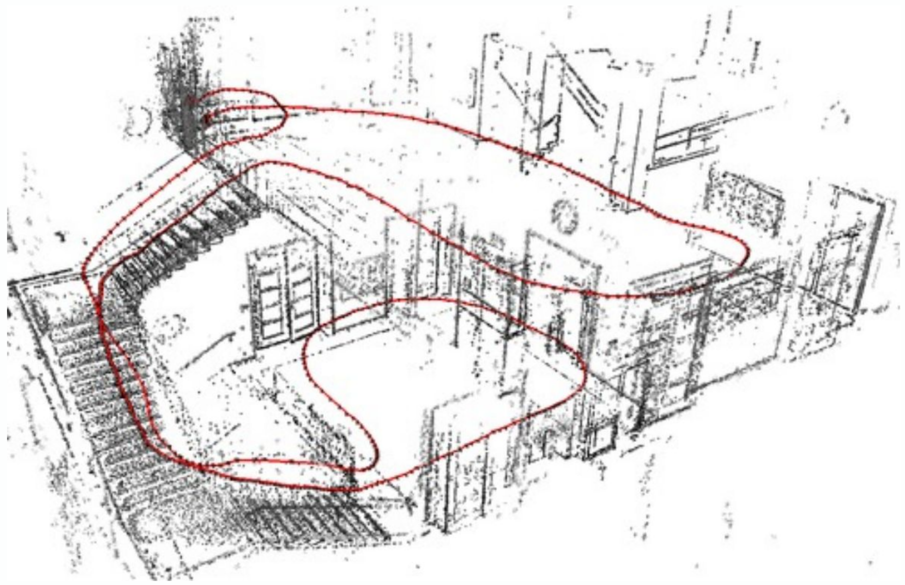
(e) Continuous relative representation (CRR)

- Change the map formulation to the relative one
  - Parameters are relative poses between keyframes
  - All points are defined relative to some frame
- Extend either SfM or Odometry application
- Paper: http://www.robots.ox.ac.uk/~mobile/Papers/2010IJCV_mei.pdf



(a) (b) (c)

5. Photometric Bundle Adjustment

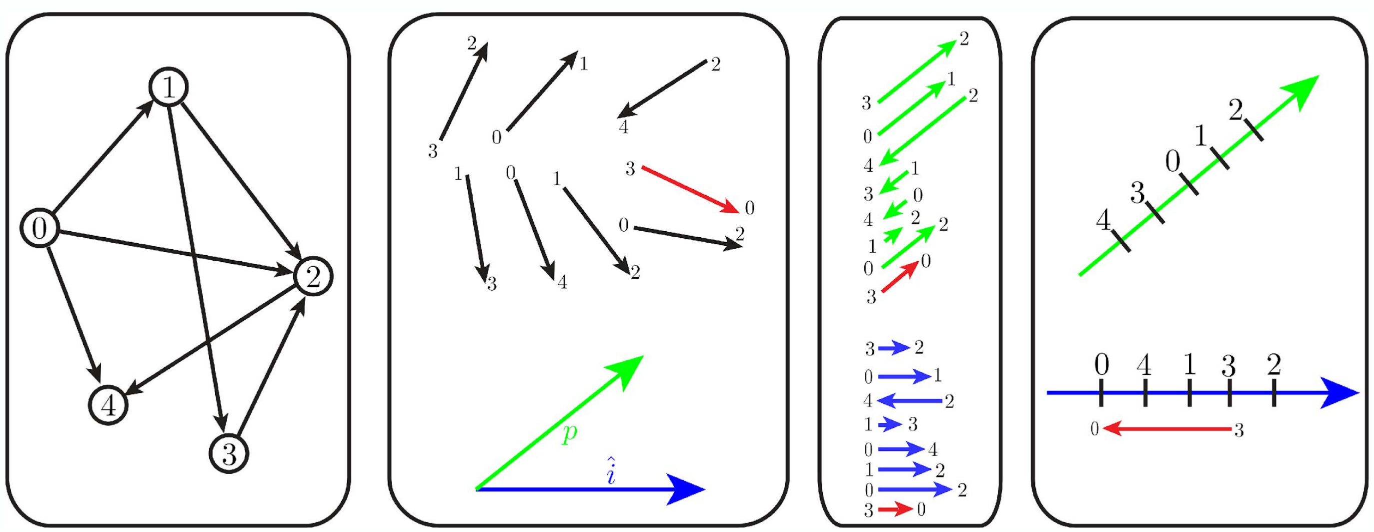


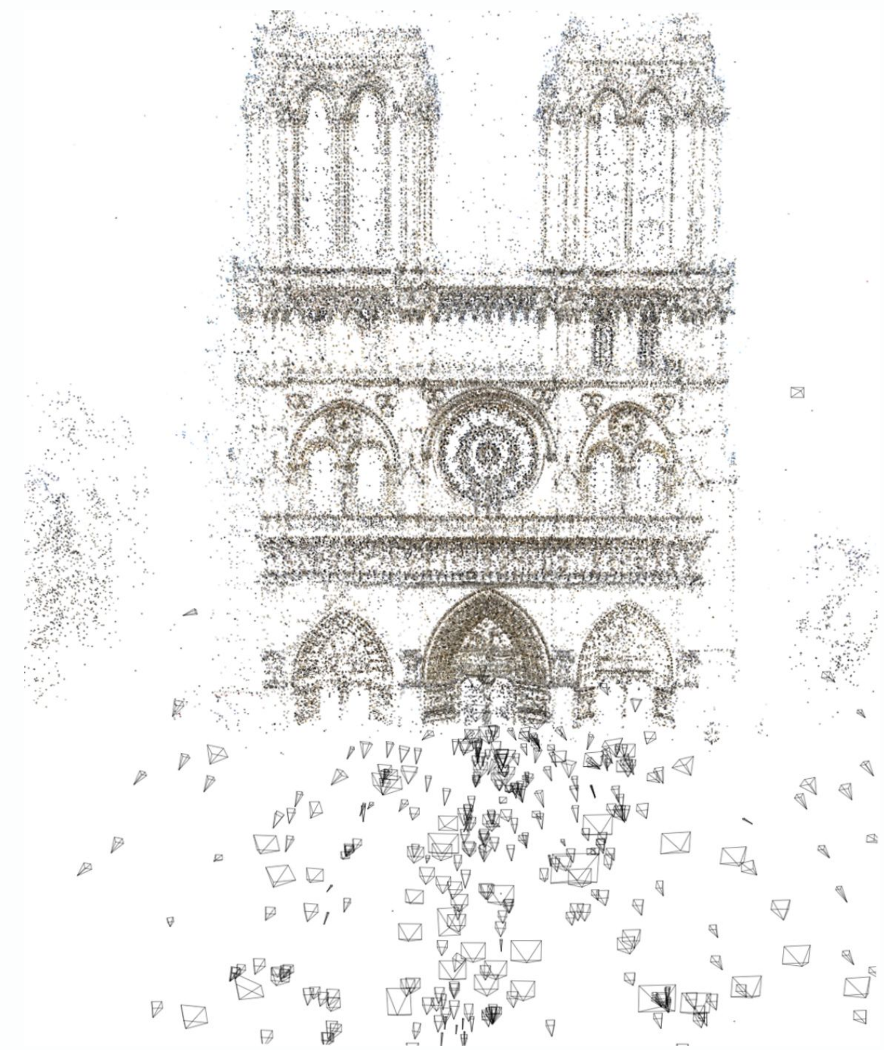
$$E_{\mathbf{p}j} := \sum_{\mathbf{p} \in \mathcal{N}_{\mathbf{p}}} w_{\mathbf{p}} \left\| \left(I_j[\mathbf{p}'] - b_j\right) - \frac{t_j e^{a_j}}{t_i e^{a_i}} \left(I_i[\mathbf{p}] - b_i\right) \right\|_{\gamma}$$

- Photometric Bundle adjustment in SFM
  - Error metric similar to DSO (https://arxiv.org/pdf/1607.02565.pdf)
  - Initialize and optimize additional (non-feature) points
  - Possibly use vignetting and response

6. Global SfM with Motion Averaging

- Goal: Implement global SfM pipeline using Motion Averaging
(as opposed to the incremental pipeline from sheet 4)
- Approach:
  - Estimate relative rotation between pairs of cameras
  - Solve for global camera orientations
  - Given the global orientations, estimate global translations
  - Triangulate structure





- Chatterjee, Avishek, and Venu Madhav Govindu. "Efficient and robust large-scale rotation averaging." Proceedings of the IEEE International Conference on Computer Vision. 2013.

https://www.cv-foundation.org/openaccess/content_iccv_2013/papers/Chatterjee_Efficient_and_Robust_2013_ICCV_paper.pdf

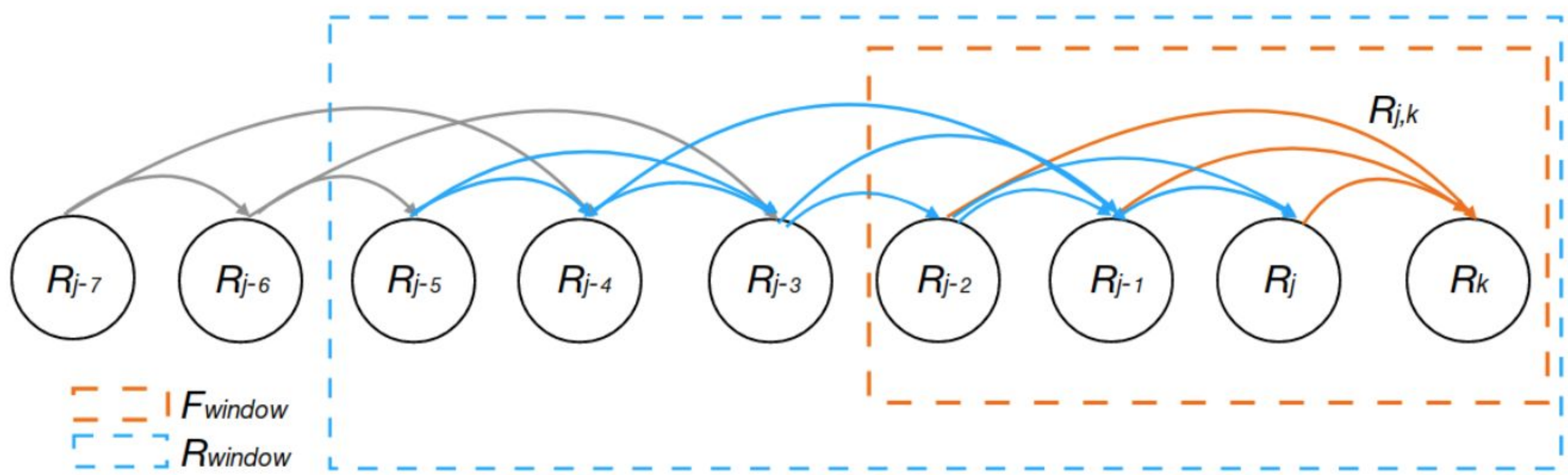
- Wilson, Kyle, and Noah Snavely. "Robust global translations with 1dsfm." European Conference on Computer Vision. Springer, Cham, 2014.

https://research.cs.cornell.edu/1dsfm/docs/1DSfM_ECCV14.pdf

- Zhu, Siyu, et al. "Very large-scale global sfm by distributed motion averaging." Proceedings of the IEEE Conference on Computer Vision

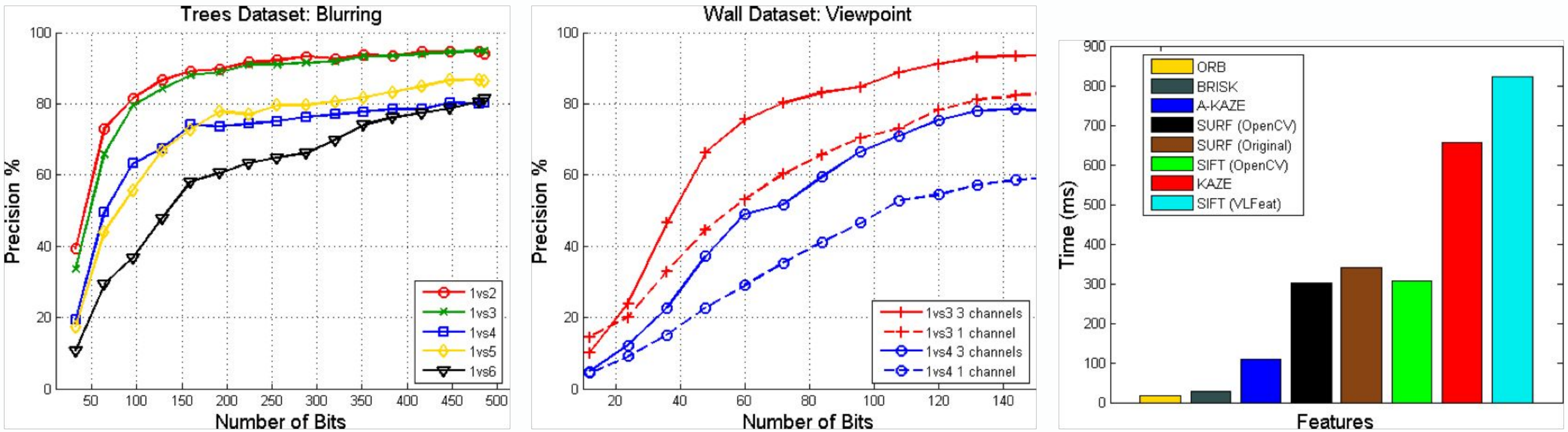
7. Rotation-only SLAM

Advanced



- Chng et al, “Monocular Rotational Odometry with Incremental Rotation Averaging and Loop Closure”, 2020
  - paper: https://arxiv.org/pdf/2010.01872.pdf
- Incremental rotation averaging
- Global optimization with “pose graph optimization” (but only rotations)
- Handle pure-rotation case for monocular camera
- Once rotations are estimated: “Known rotation” SLAM or SfM
- Possible extensions: S. LeeHun and J. Civera. “Rotation-Only Bundle Adjustment”, 2020 (https://arxiv.org/pdf/2011.11724.pdf)

8. Advanced Matching and Keypoint Evaluation

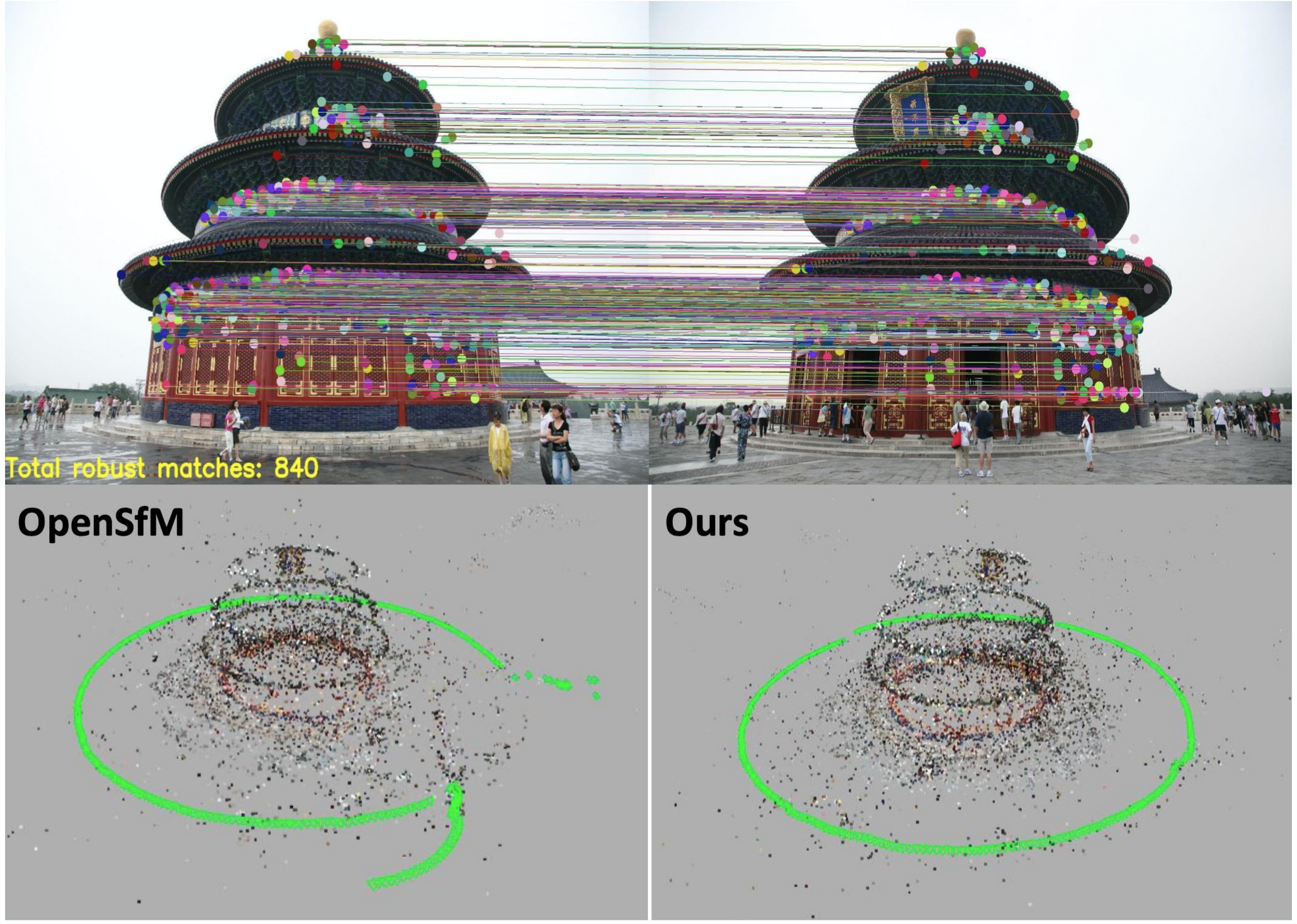


Alcantarilla, Pablo F., and T. Solutions. "Fast explicit diffusion for accelerated features in nonlinear scale spaces." *IEEE Trans. Patt. Anal. Mach. Intell* 34.7 (2011): 1281-1298.

- Keypoints evaluation:
  - ORB, AKAZE, SIFT, BRISK
  - Computation time / matching statistics
- Cascade Hashing for descriptor matching:
  - http://www.nlpr.ia.ac.cn/jcheng/papers/CameraReady-CasHash.pdf

9. Improving SfM with Reliable Resectioning

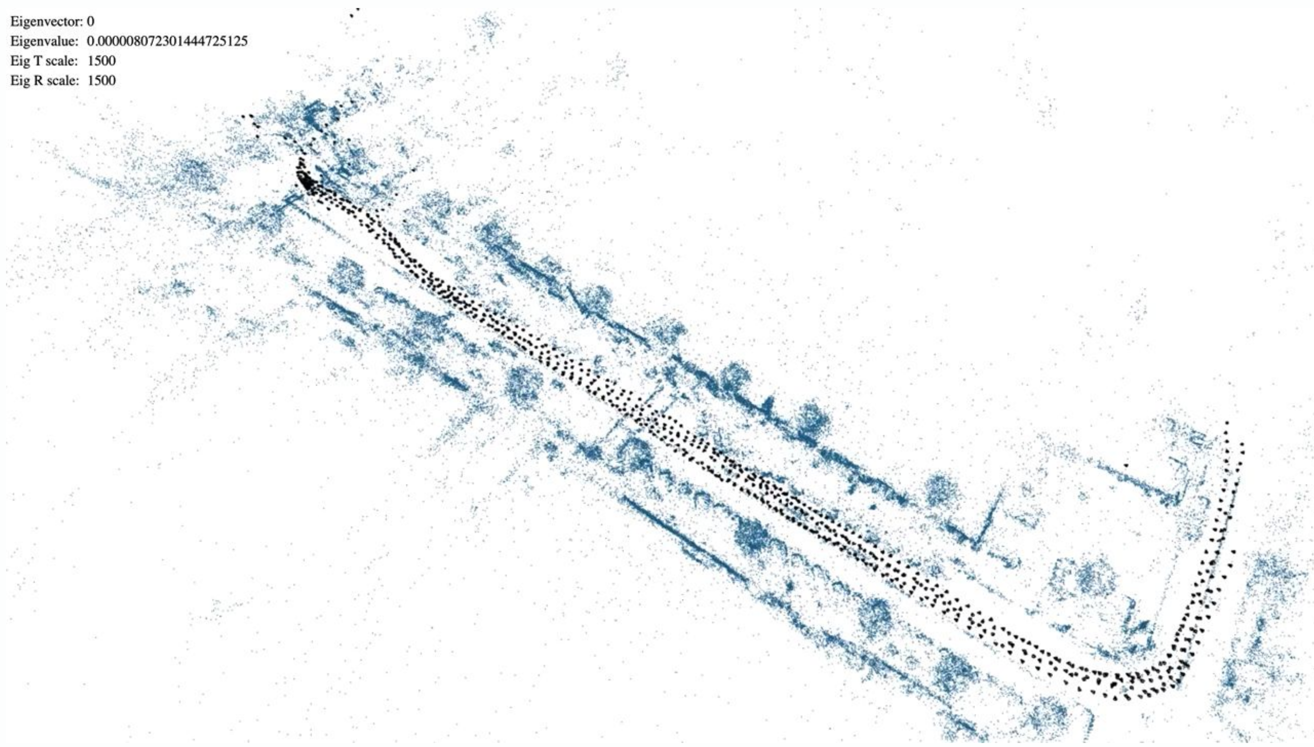
Advanced

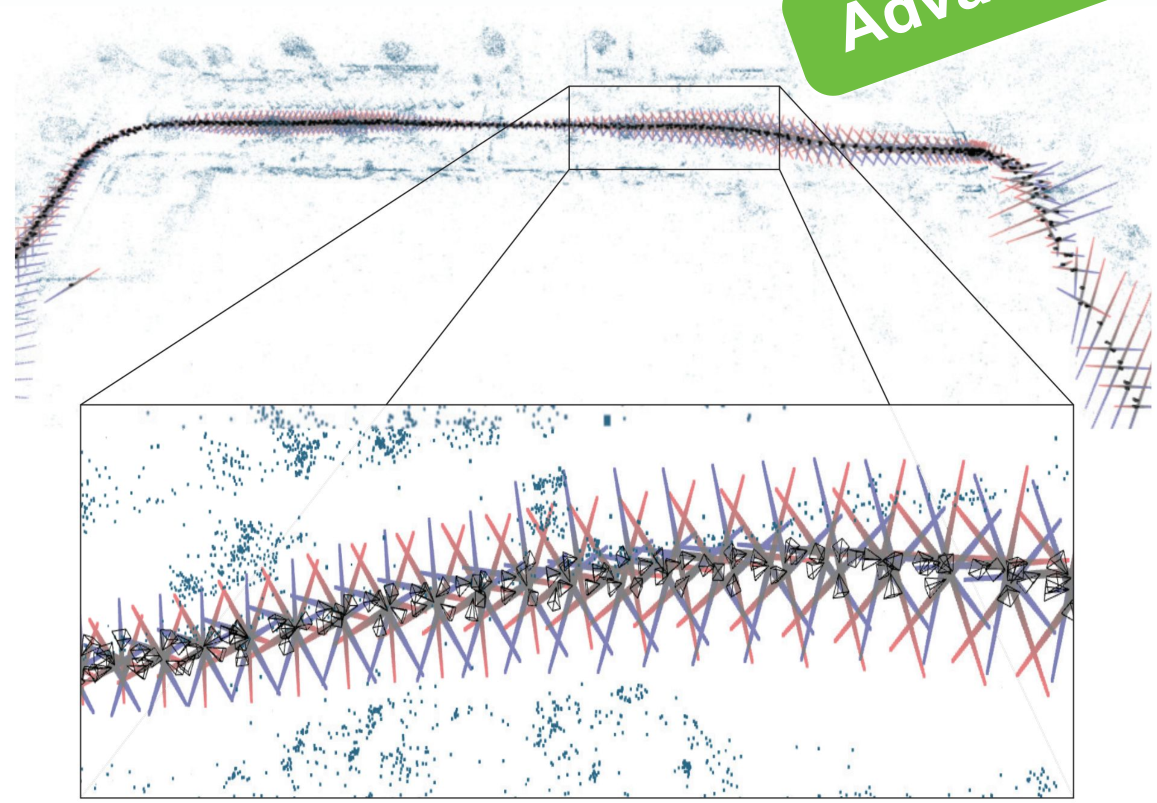


- R. Kataria et al., 3DV 2020
  - paper & code: https://github.com/rajkataria/ReliableResectioning
  - video: https://slideslive.com/embed/presentation/38941065
- Implement ideas from paper in our SfM pipeline:
  - Adjust order of adding cameras (weight shorter tracks higher)
  - Initialise pose only with reliable matches; then find more matches by projection

10. Visualizing Spectral BA Uncertainty

Advanced



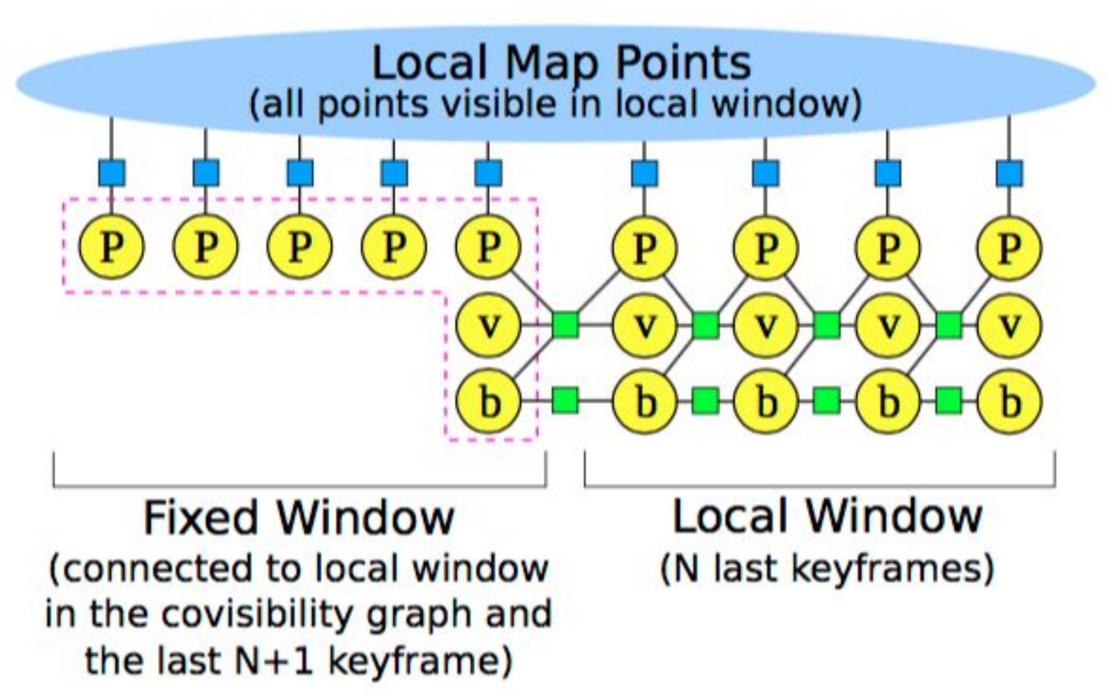


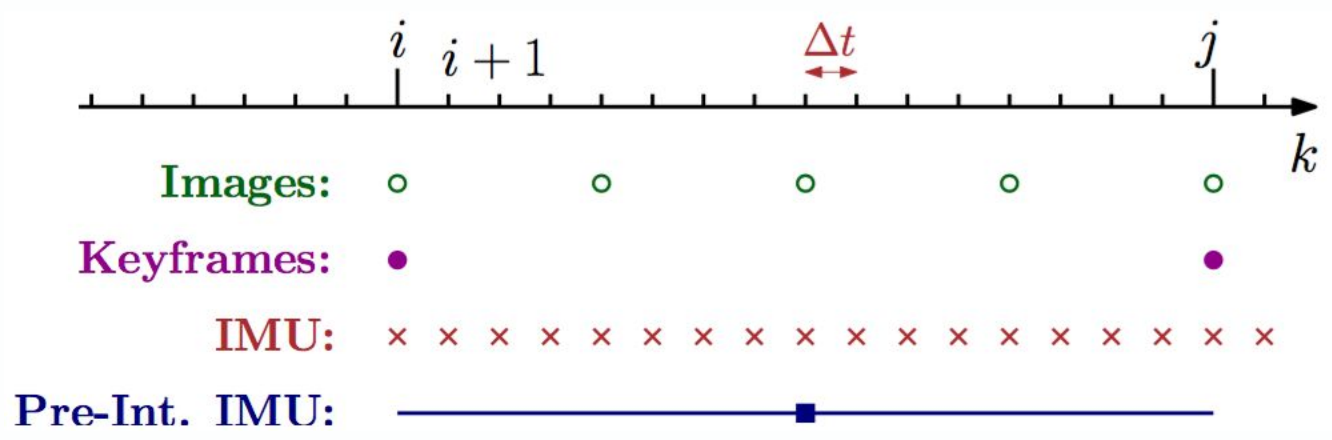
- K. Wilson and S. Wehrwein, 3DV 2020
  - https://facultyweb.cs.wwu.edu/~wehrwes/files/sfmflex.pdf
  - video: https://slideslive.com/embed/presentation/38941084
- Implement pose uncertainty visualisation in our SfM application
  - static (ellipses)
  - animated
- Investigate relative scaling of units (rotation vs translation)
- public implementation for reference: https://wilsonkl.github.io/sfmflex-release/

11. Visual-Inertial Tracking using Preintegrated Factors

Advanced

- Use camera + IMU for stability and scale observability
- Estimate IMU biases and velocity
- Preintegrate measurements between image frames





- Theory: Forster et al., "On-manifold preintegration for real-time visual-inertial odometry", 2016
http://rpg.ifi.uzh.ch/docs/TRO16_forster.pdf
- Library with preintegrated factors: gtsam.org
- Example system with preintegrated factors: visual-inertial ORB-SLAM
https://arxiv.org/pdf/1610.05949.pdf