HyperSfM

An HyperGraph approach for Hierarchical Structure From Motion

Reading Group

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10/2/23

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Introduction

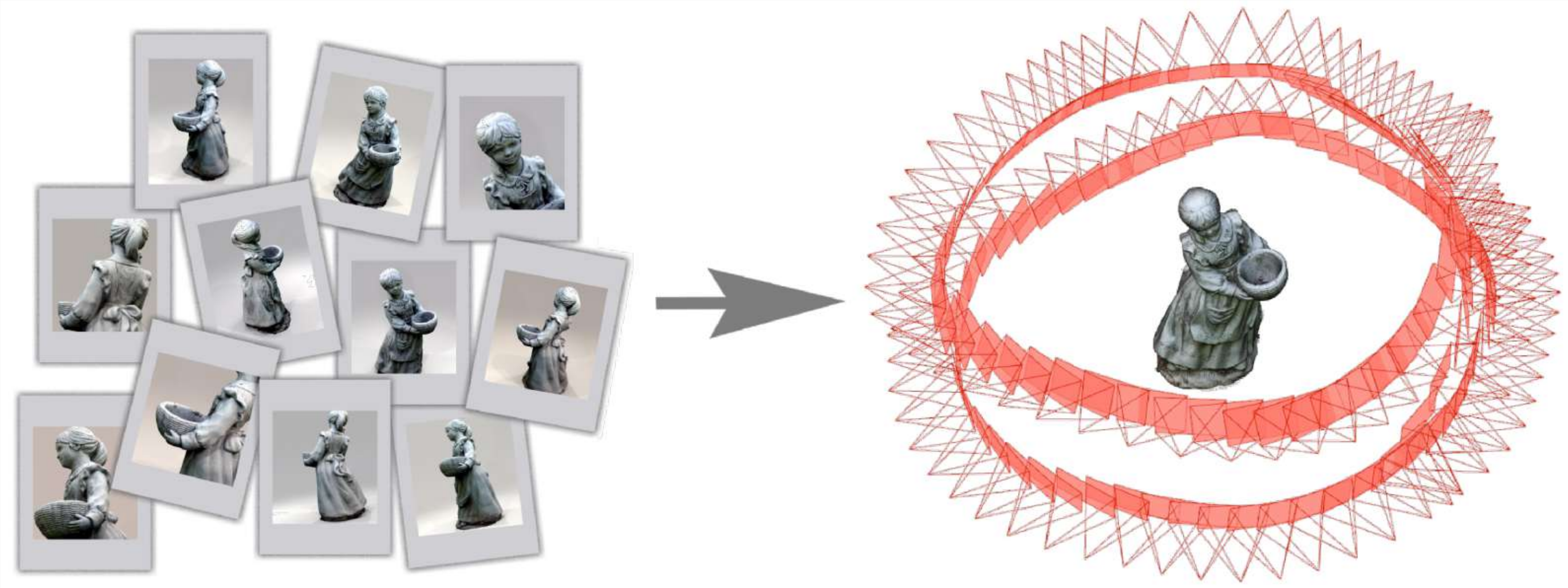


Figure 1: 3D reconstruction using Structure from Motion. From (Bianco, Ciocca, and Marelli 2018)

Papers

- Hyper SFM (Ni and Dellaert 2012).
- Out-of-Core Bundle Adjustment for Large-Scale 3D Reconstruction (Ni, Steedly, and Dellaert 2007)

Goals

- Large Scale SFM (Structure From Motion).
  - Divide and Conquer approach.
- Avoid degeneracies between submap.
- Handle initialization issue of bundle adjustment.

Structure from Motion

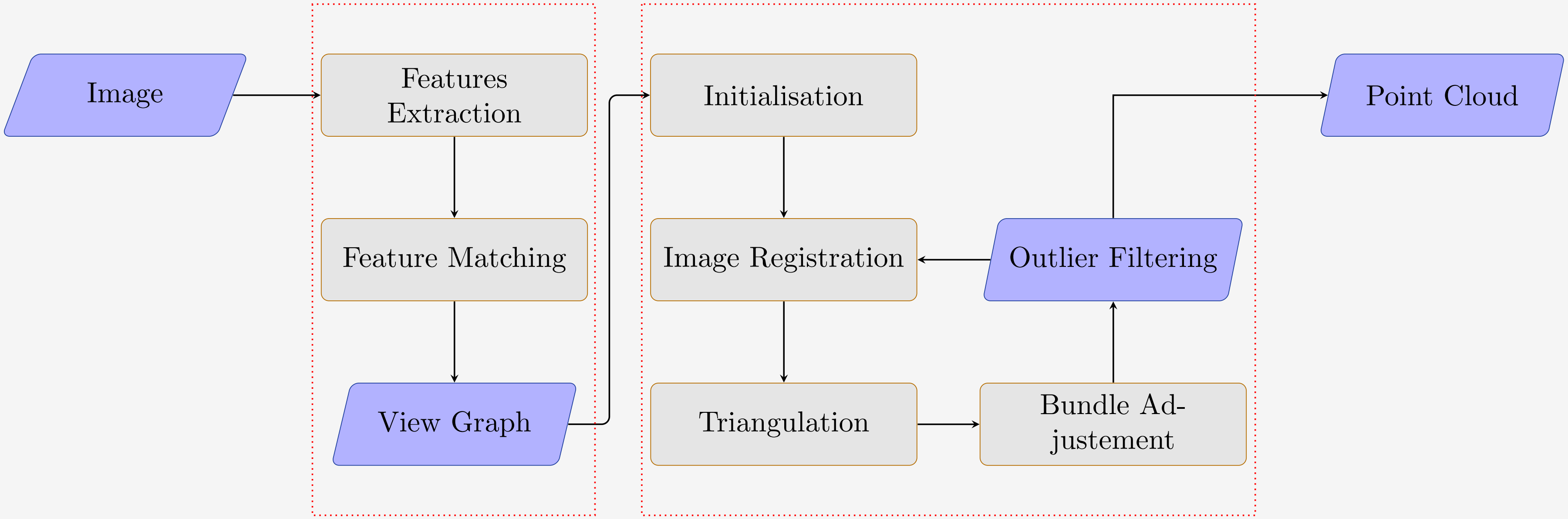


Figure 2: Execution steps for a *Structure From Motion* pipeline.

- Incremental

Add image per image incrementally to the Bundle Adjustment. And a final global Bundle Adjustment.

- Hierarchical

Divide the SfM problem in smaller problems. Resolve each in parallel then merge the results. Finish with a Bundle Adjustment.

- Global

Add all the image at once and do a Global Bundle Adjustment.

Structure from Motion

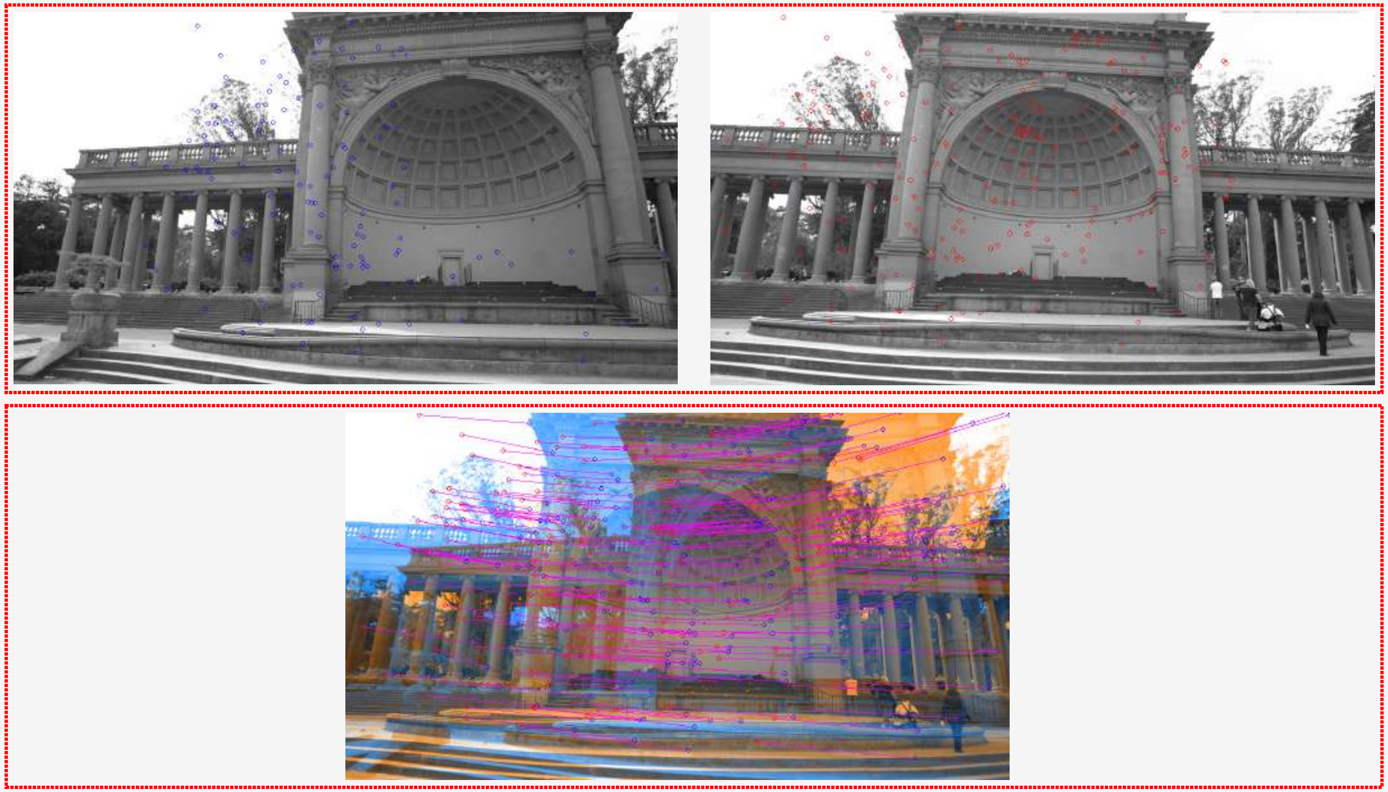
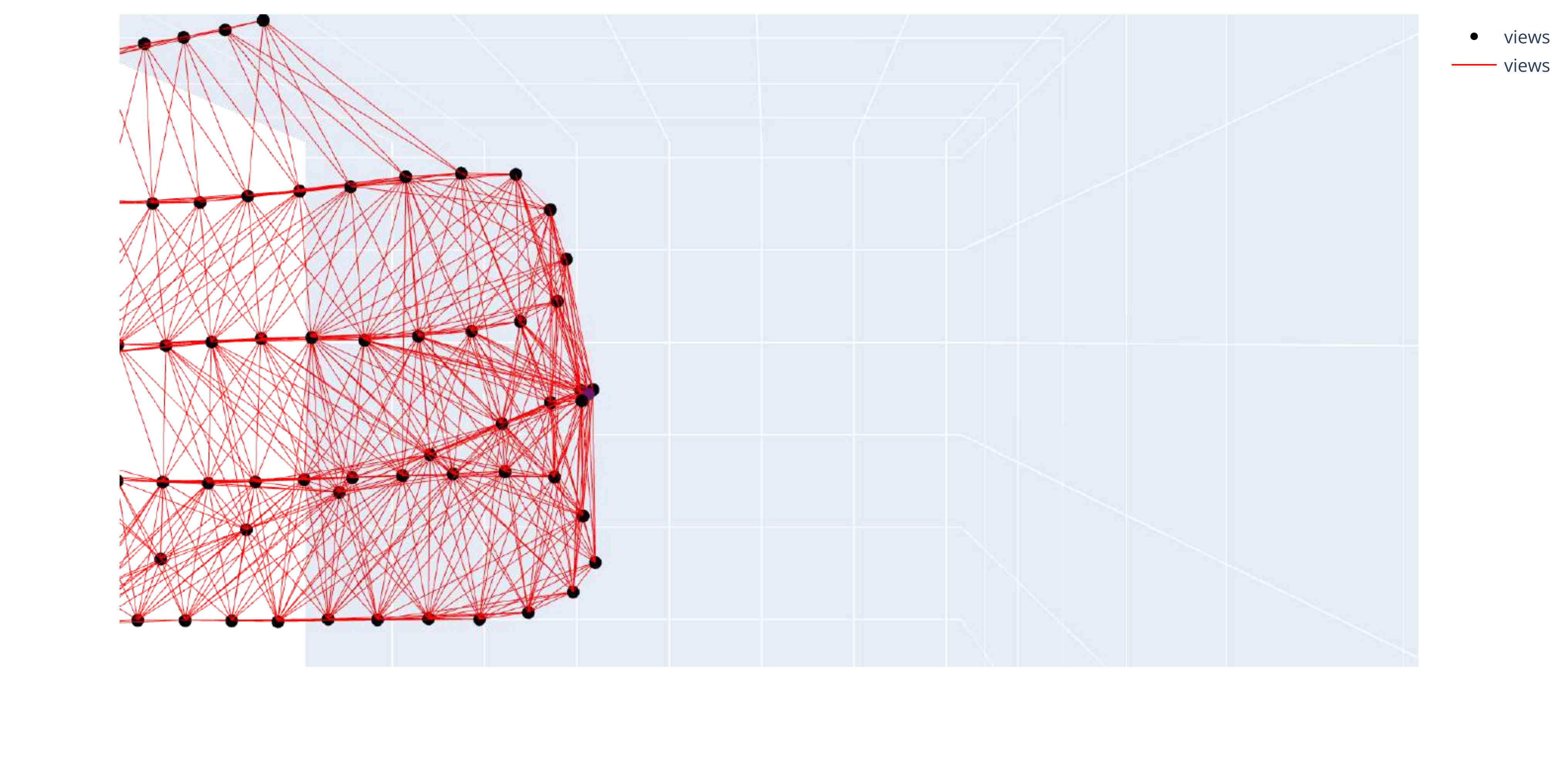


Figure 3: Detection and Matching of Feature Points pairwise. From Temple dataset (Knapitsch et al. 2017).

Structure from Motion

View Graph



Structure from Motion

Bundle Adjustment

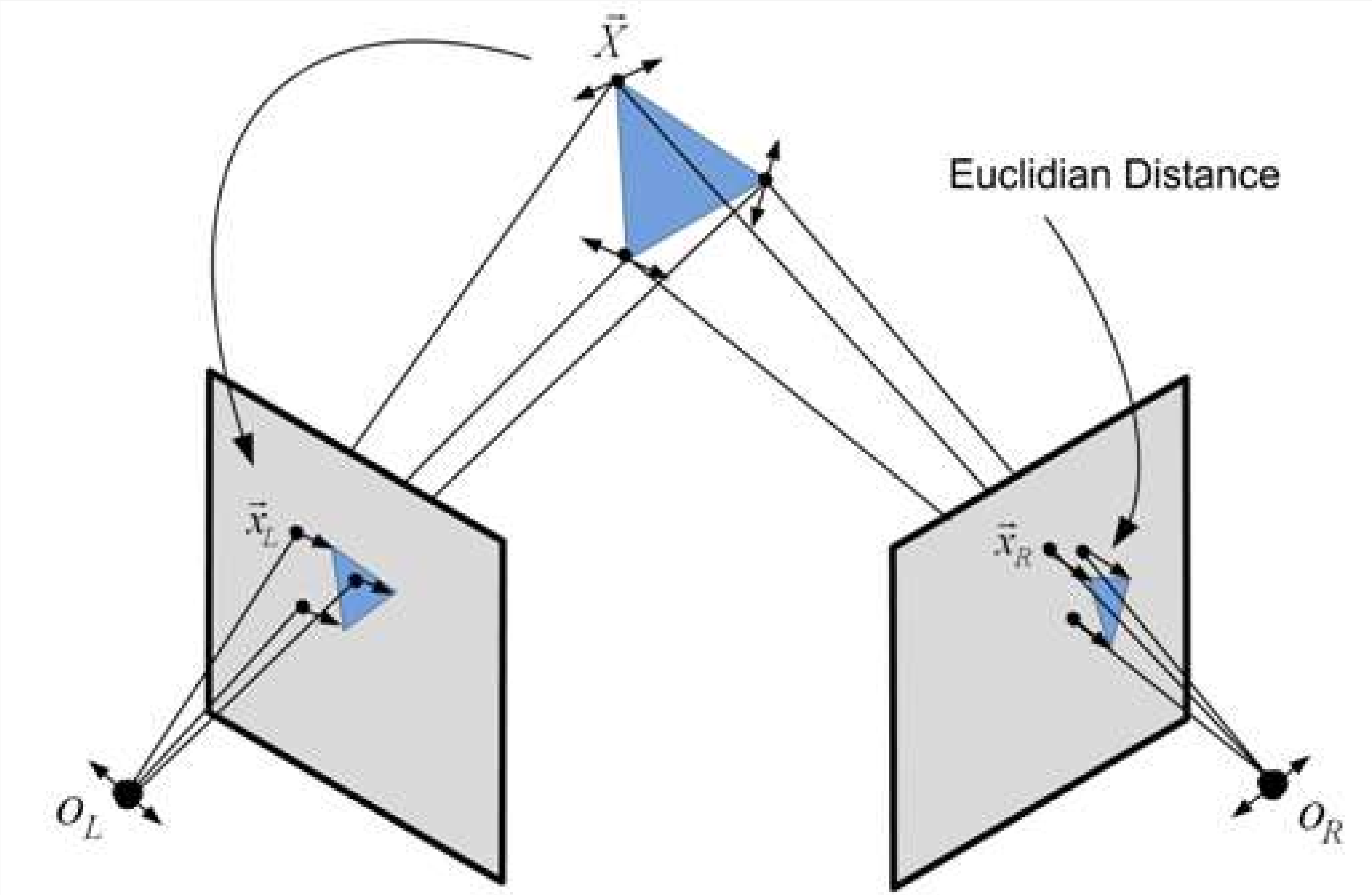


Figure 4: Example of bundle adjustement. Image from (Martos 2011)

HyperSfM Approach

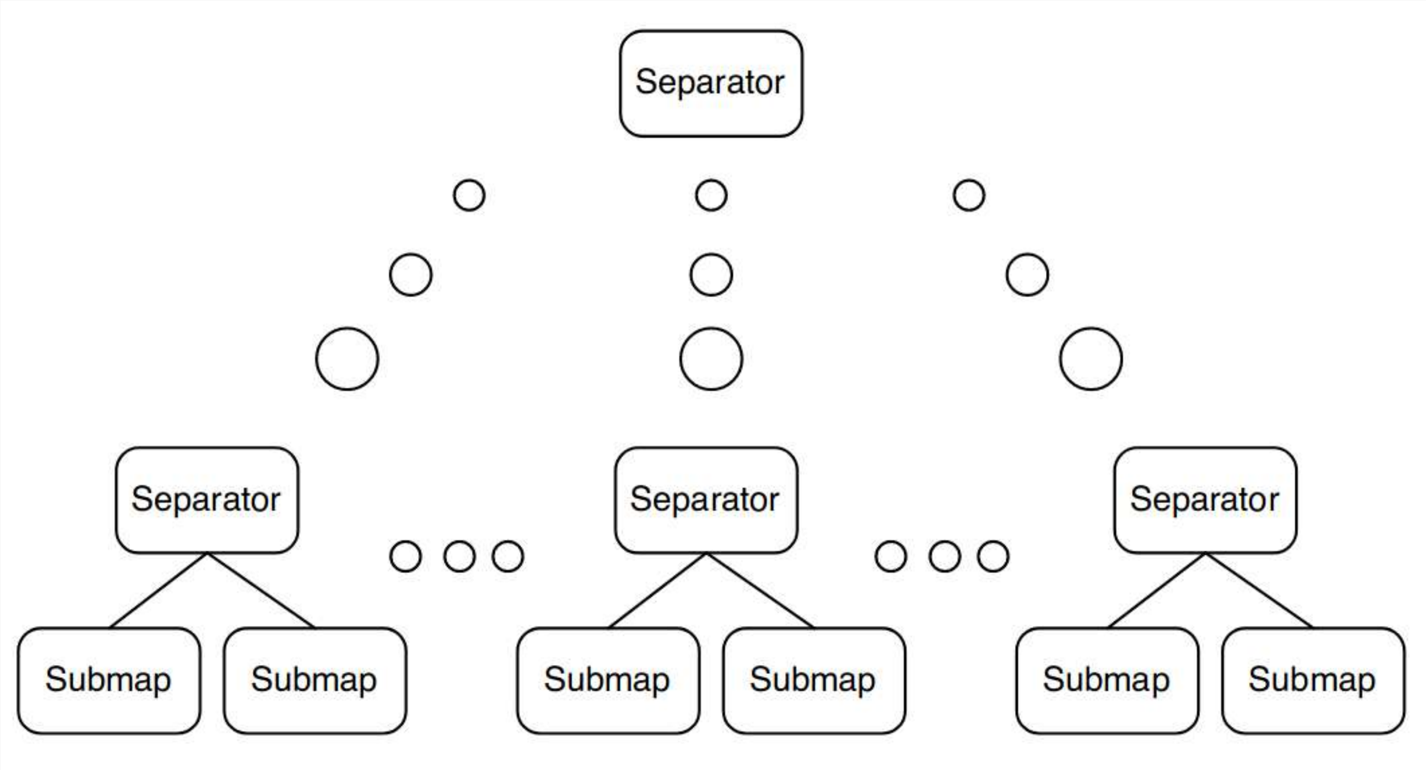
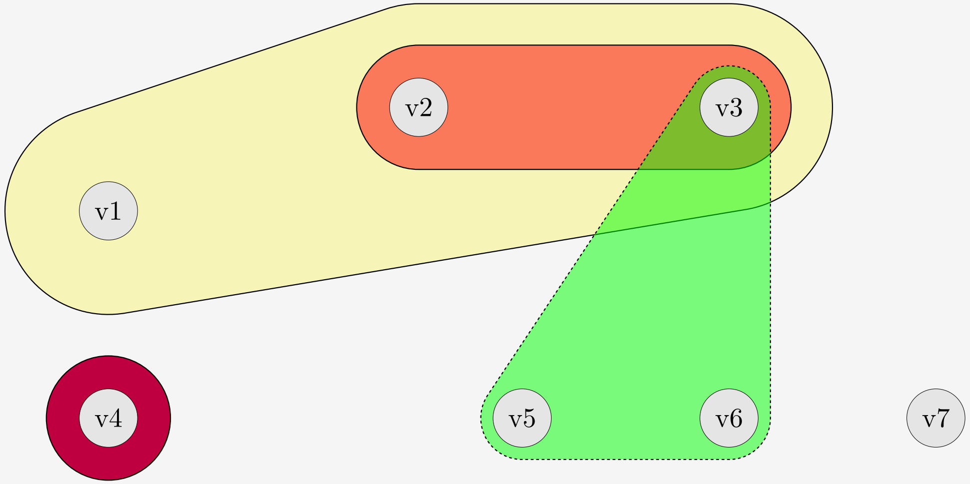


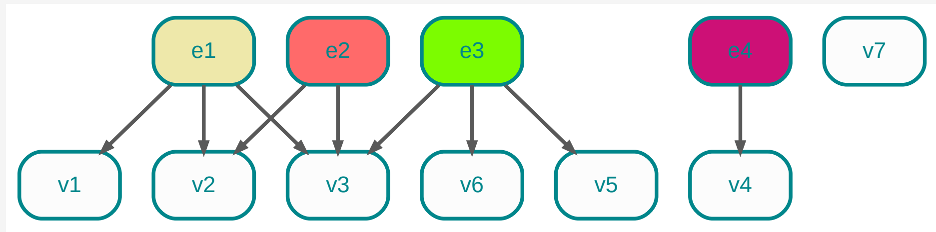
Figure 5: By partitioning the hypergraphs and finding vertex separators in the visibility graph, the original SfM problem can be partitioned recursively.

Dividing the original SfM problem is equivalent to partitioning the corresponding visibility graph.

HyperGraph



(a) Example of HyperGraph structure.



(b) Example of Bipartite Graph structure

Figure 6: HyperGraph topography comparison.

Problem Specification

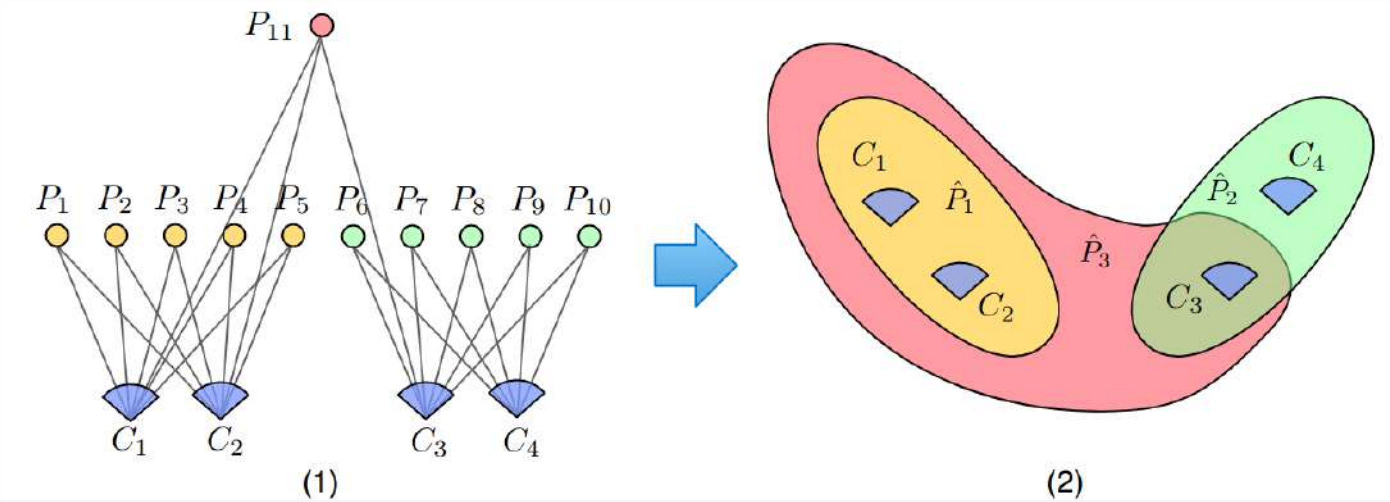


Figure 7: The visibility graph of an exemplar SfM problem on the left is converted to the corresponding hypergraph representation on the right.

The view graph :

$G_{SfM} = (C, P, E)$

- Vertice : Camera C
- Vertice : 3D Point P
- Edge e_{ij} for P_j visible in C_i at measurement z_k

The *hypergraph*:

$\mathcal{H}_{cam} = (C, P)$

- Vertice : Camera C
- Edge : Set of 3D Points P

HyperSfM Steps

1. A hierarchical partitioning based on hypergraphs.
2. A refinement step that deals with degeneracies.
3. A bottom up optimization step that merges submaps.

HyperGraph Partition

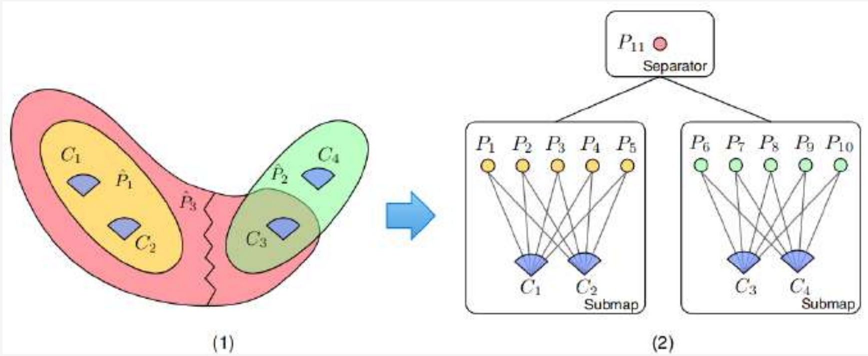


Figure 8: Partitioning a hypergraph for a SfM problem.

Using the graphcut method from (Karypis and Kumar 1998). Select the smallest set *edge-separator* of *hyperedges*

$$\hat{\varepsilon}_S = \{\varepsilon..\}$$

The graphcut satisfy two constraint for each submap:

- At least n Camera
- Viewing at least m Points

With $n = 2$ and $m = 5$.

HyperGraph Partition - GraphCut

The graphcut from (Karypis and Kumar 1998) proceed in 3 steps :

HyperGraph refinement

- The refinement phase check in each submap if each Camera and 3D Point have enough constraint in their partition.
- If a Camera or a Point is not enough constrained, it is moved inside the upper separator.

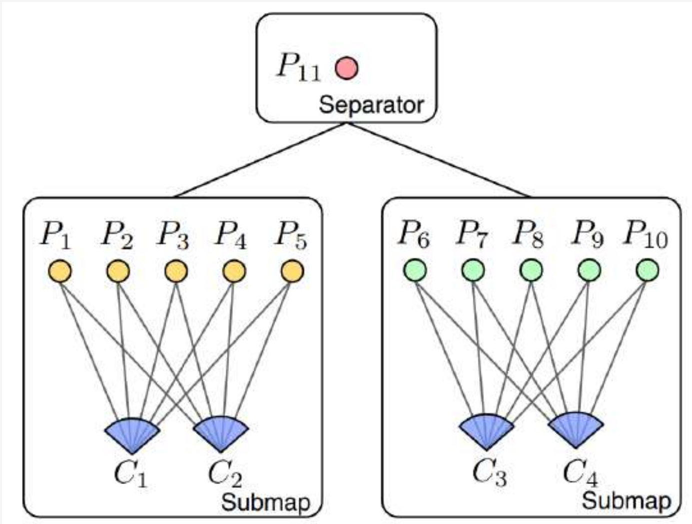


Figure 9: Example of a partition

HyperGraph refinement

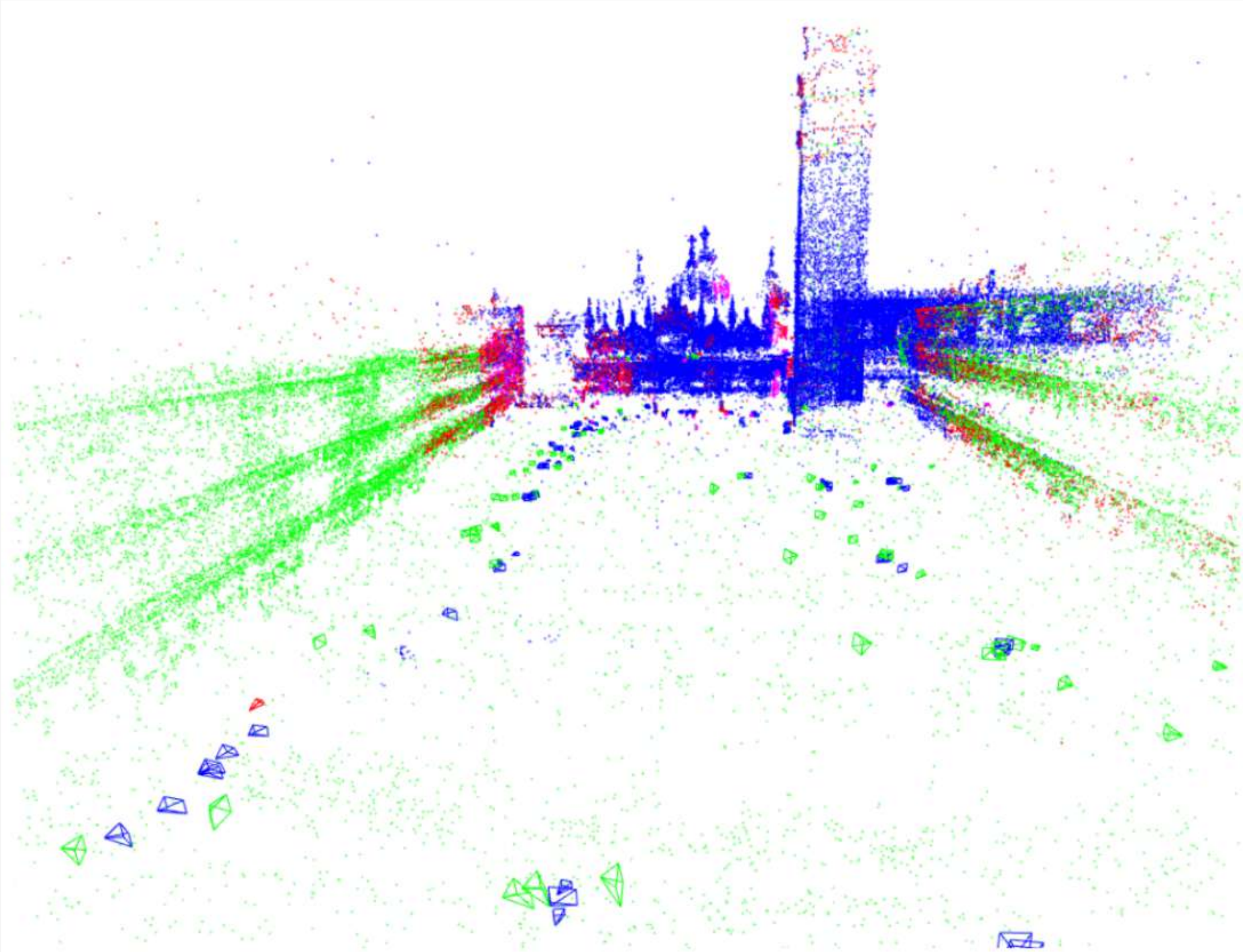


Figure 10: Example of camera refinement from result data

Bottom-Up Optimization

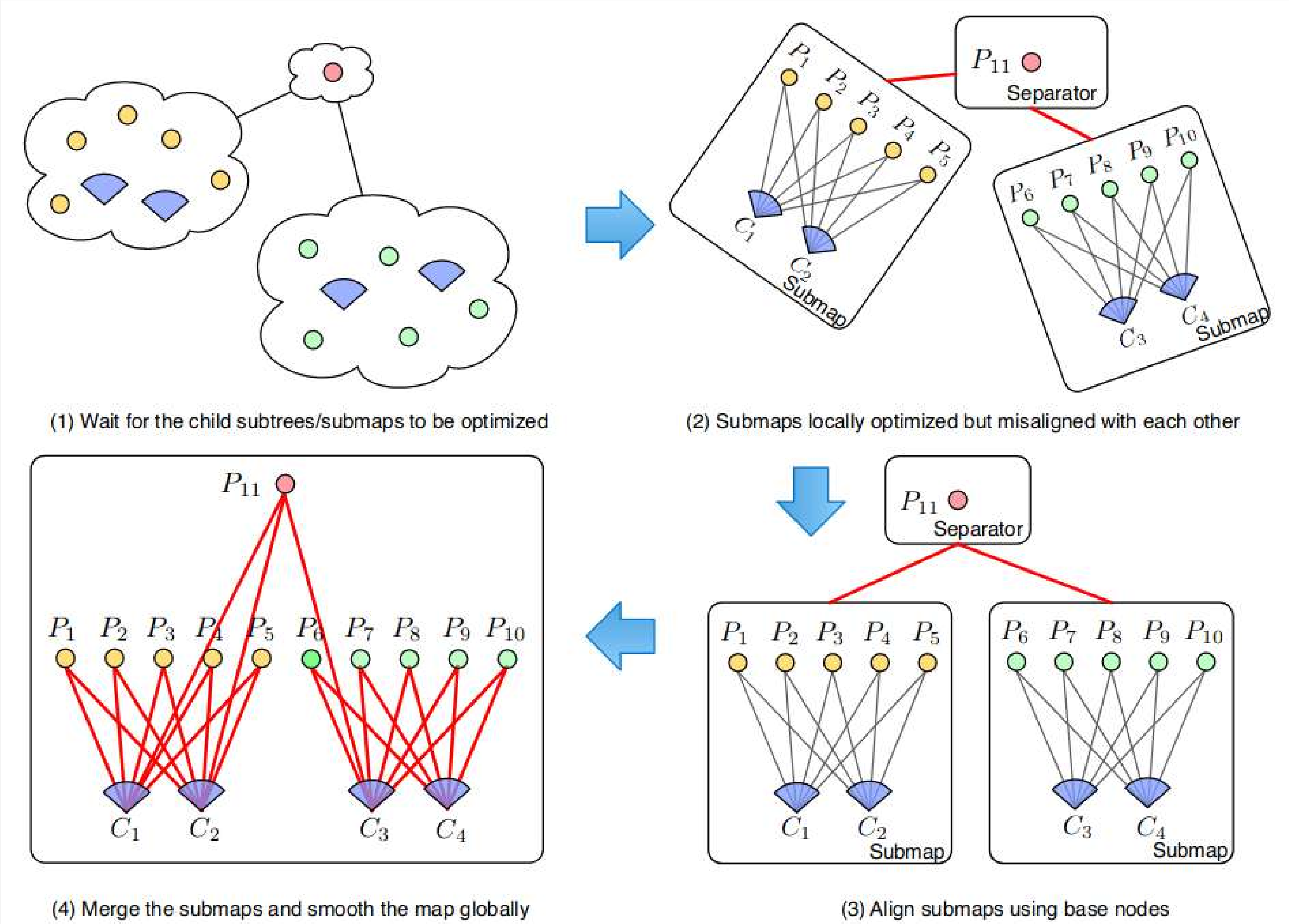


Figure 11: The bottom-up optimization is carried out recursively.

Bottom-Up Optimization

Local Optimization

- Initialize submap in a local coordinate system from a base node camera which is connected to the separator.

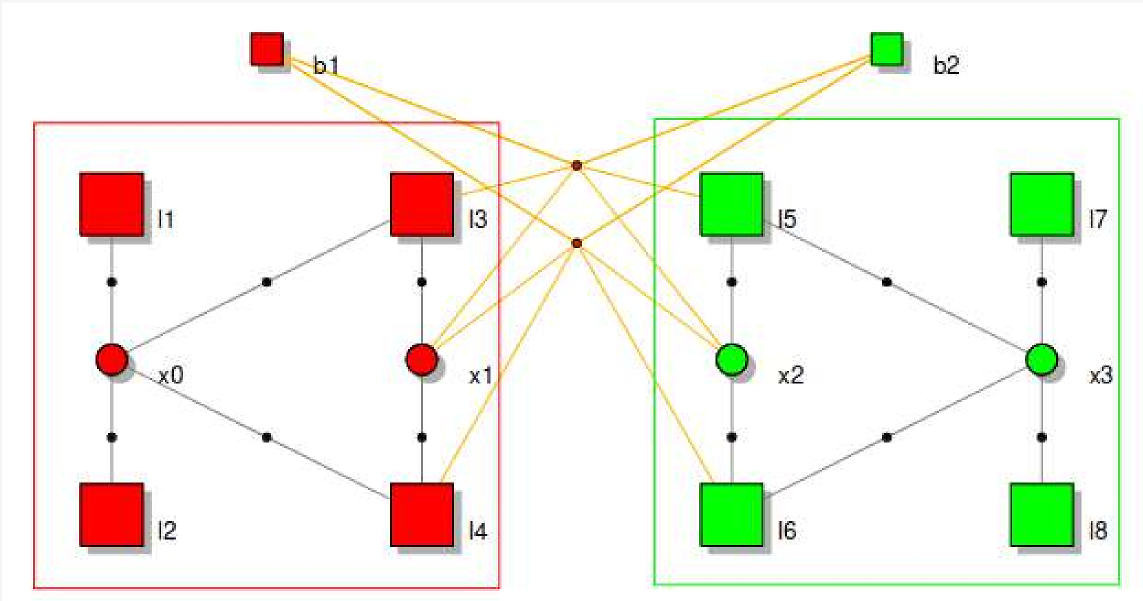
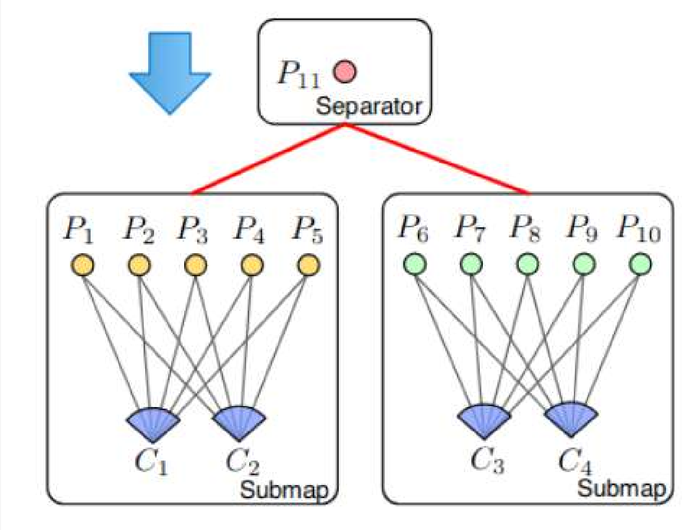


Figure 12: Two submap and their base nodes b_1 and b_2

Bottom-Up Optimization

Align submaps

- Using the base nodes relations with the separator to align submaps
- 6DoF transformation between the submap and its separator.



(3) Align submaps using base nodes

Bottom-Up Optimization

Global Smoothing

- Simultaneous smoothing and mapping (SAM) (Dellaert and Kaess 2006)
    - Bundle Adjustement simplified by previous steps
- Each submap doesn't need to converge as it is the initialization of the next iteration.

Results

Table 1: The partitioning results for five datasets.

	$\|P_S\|/\|G_{SfM}\|$	**Nr. Submap**	**Time (sec.)**
Brown House	2.48%	2	0.57
Old House	1.61%	3	1.28
Grand Canal	0.99%	2	3.12
San Marco	12.5%	3	3.71
St. Peters	4.00%	2	5.10

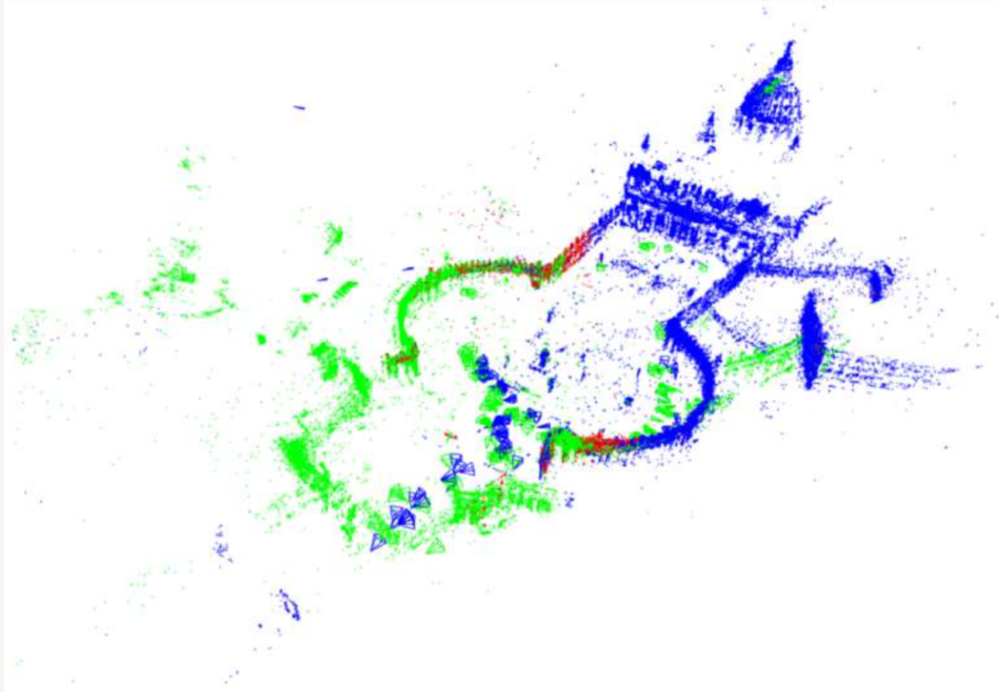
Results

Table 2: The timing results for five datasets.

	Cameras	BA (sec.)	HyperSfM (sec.)
Brown House	61	725	456
Old House	178	1279	789
Grand Canal	270	3237	1553
San Marco	237	N/A	1465
St. Peters	285	N/A	1823

Results

(a) St. Peters Dataset



(b) St. Peters Dataset Partition

Figure 14: Example on St. Peters Dataset.

References

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Thanks

Questions ?

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