Remove, then Revert: Static Point cl oud Map Construction using Multiresolution Range Images

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Introduction

Paper Info

Remove, then Revert: Static Point cloud Map Construction Using Multiresolution Range Images

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KAIST

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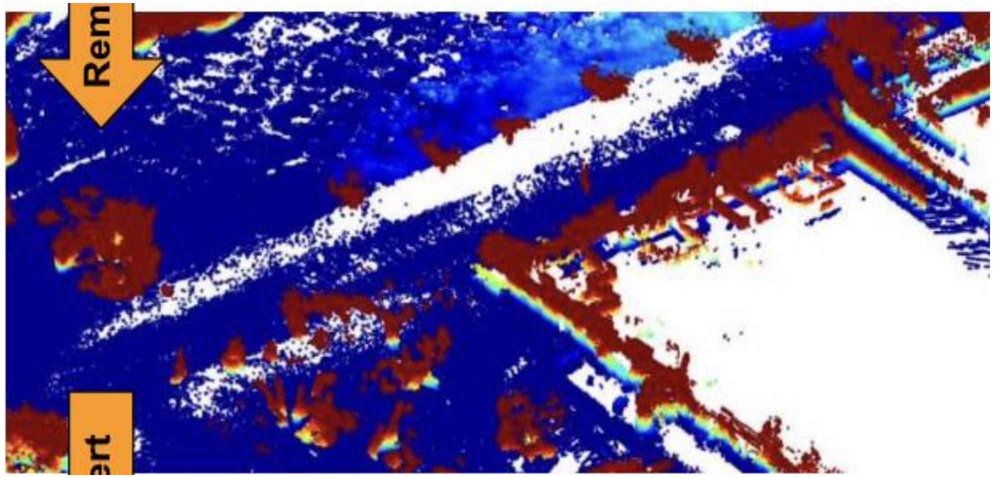

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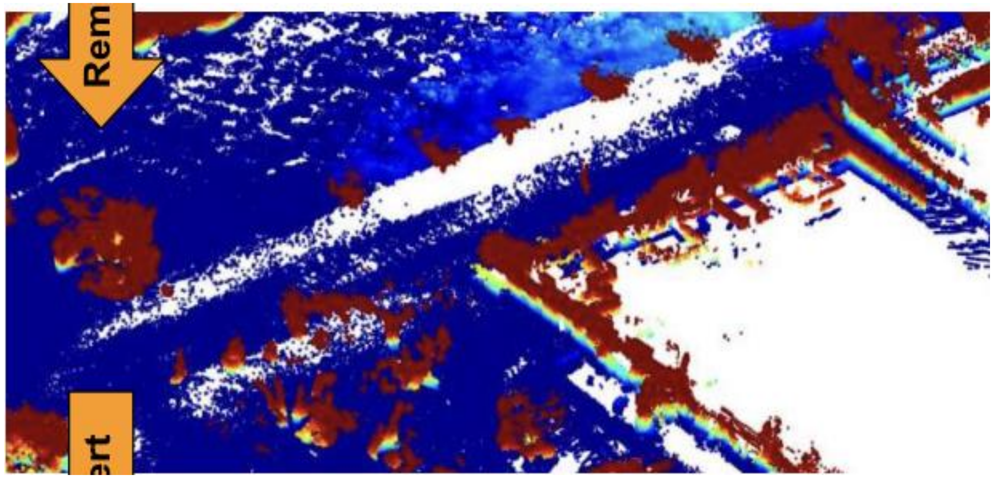

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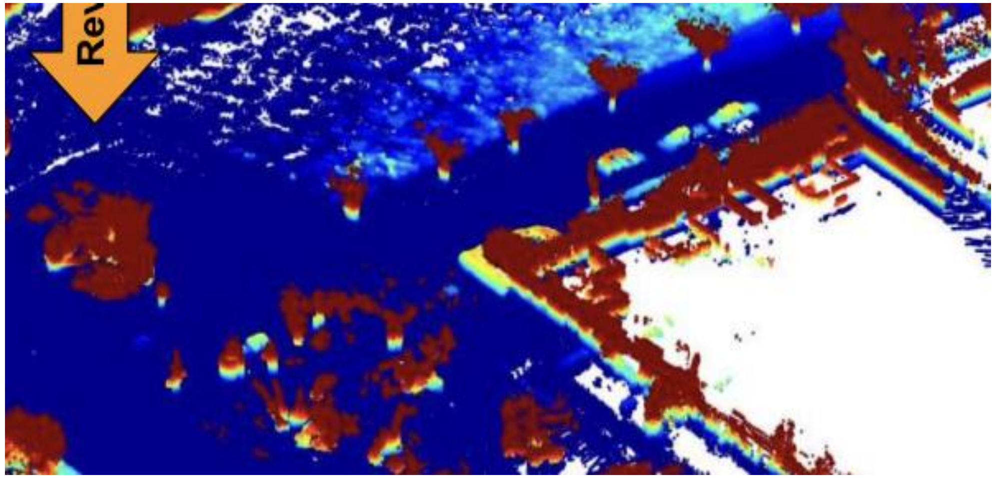

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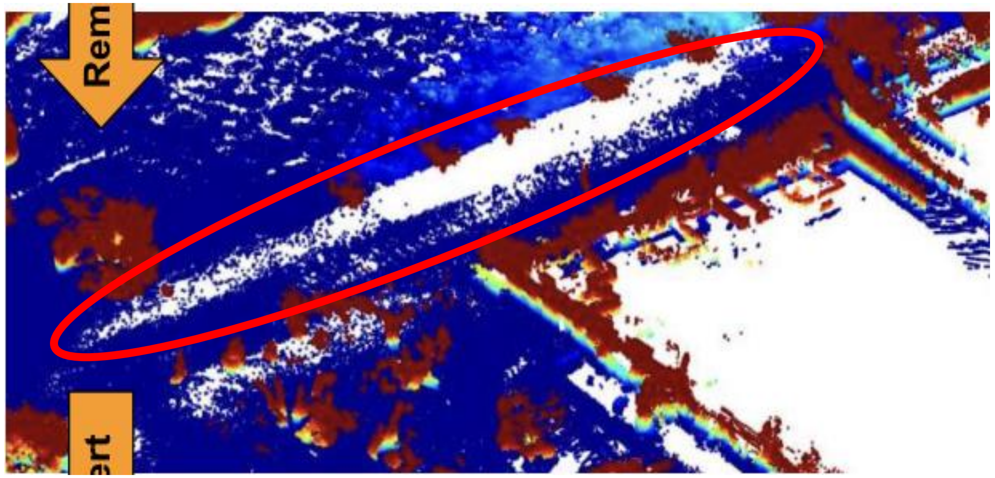

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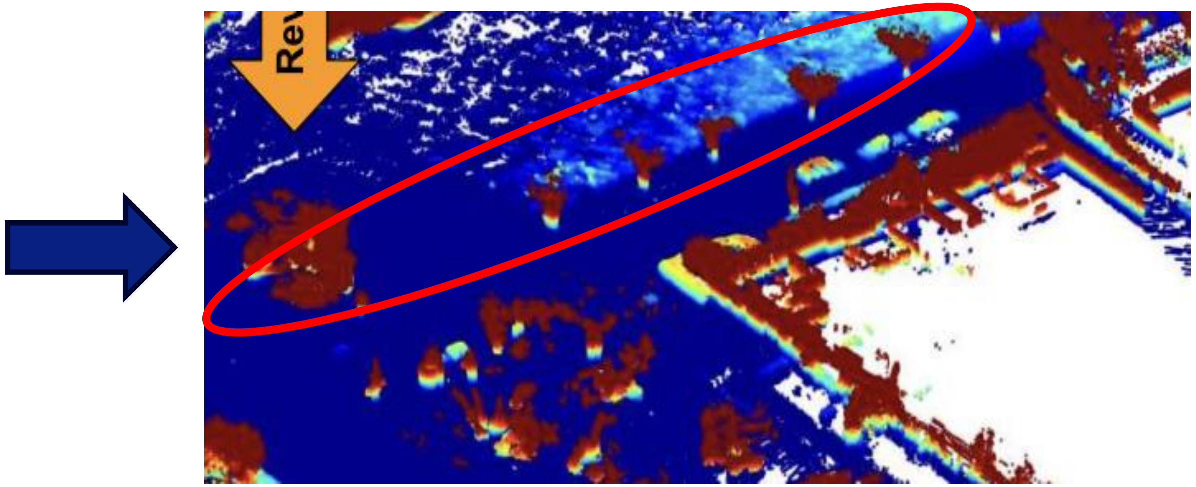

reverse falsely removed points

Related Work

A. Dynamic object removal

- **Visibility-based approaches**

A. Dynamic object removal

- **Visibility-based approaches**
  - Alleviate computational burden of conventional approaches
  - Associates a query point and a map point within a same field of view (FOV) to conclude static

A. Dynamic object removal

- **Point cloud segmentation-based approaches**

A. Dynamic object removal

- **Point cloud segmentation-based approaches**
  - Exclude segment points which are labeled as dynamic.
  - Rely on supervised labels (vulnerable to human error or unknown classes)

A. Dynamic object removal

- **Solving motion ambiguities**

A. Dynamic object removal

- **Solving motion ambiguities**
  - Undistort a LiDAR scan for dynamic object detection
  - ***Use multi-scaled range images (In this paper)***

Methodology

A. Problem definition (Notations)

- Aim: Given a point cloud map, ***remove dynamic points*** within the map to build a static map

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- Aim: Given a point cloud map, ***remove dynamic points*** within the map to build a static map
- M: global map coordinate
- Q: local sensor's coordinate
- P^Q: single scan of local sensor, P^M: submap within the global coordinate

A. Problem definition

- Compare query point cloud P_k^Q(k: index of frame) and P^M to remove dynamic objects from map points.

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set of static points

set of dynamic points

A. Problem definition

- Initially, estimate $\hat{P}^{SM}$ and $\hat{P}^{DM}$ using conventional segmentation methods
- $\hat{P}^{SM} = TP \cup FP$ and $\hat{P}^{DM} = TN \cup FN$

$\hat{P}^{SM}$	True Positive	False Positive
$\hat{P}^{DM}$	False Negative	True Negative

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- P (Positive): static status, N (Negative): dynamic status

True Positive	False Positive
False Negative	True Negative
Static	Dynamic

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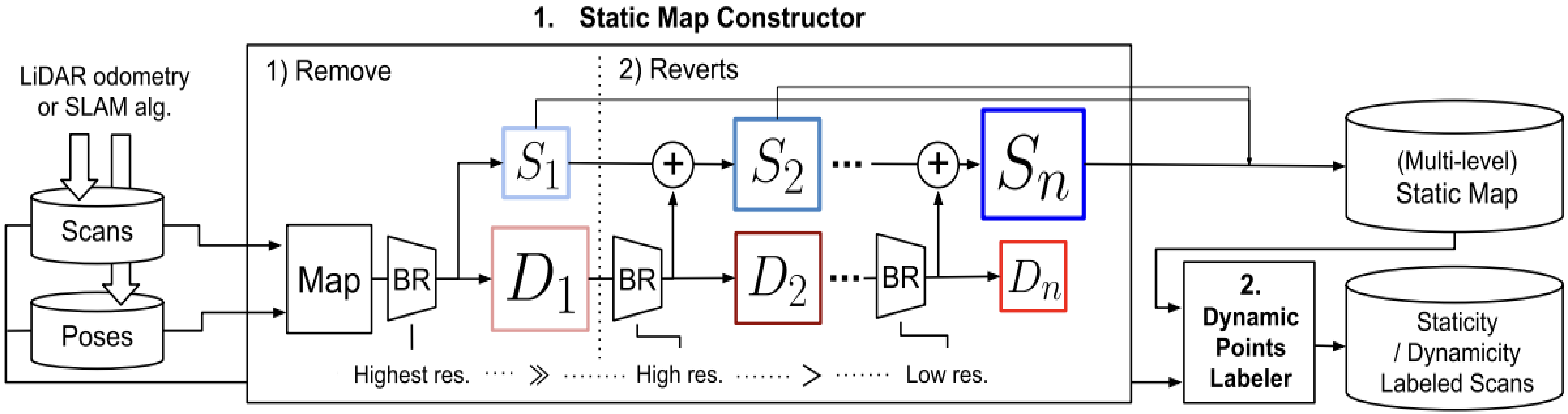

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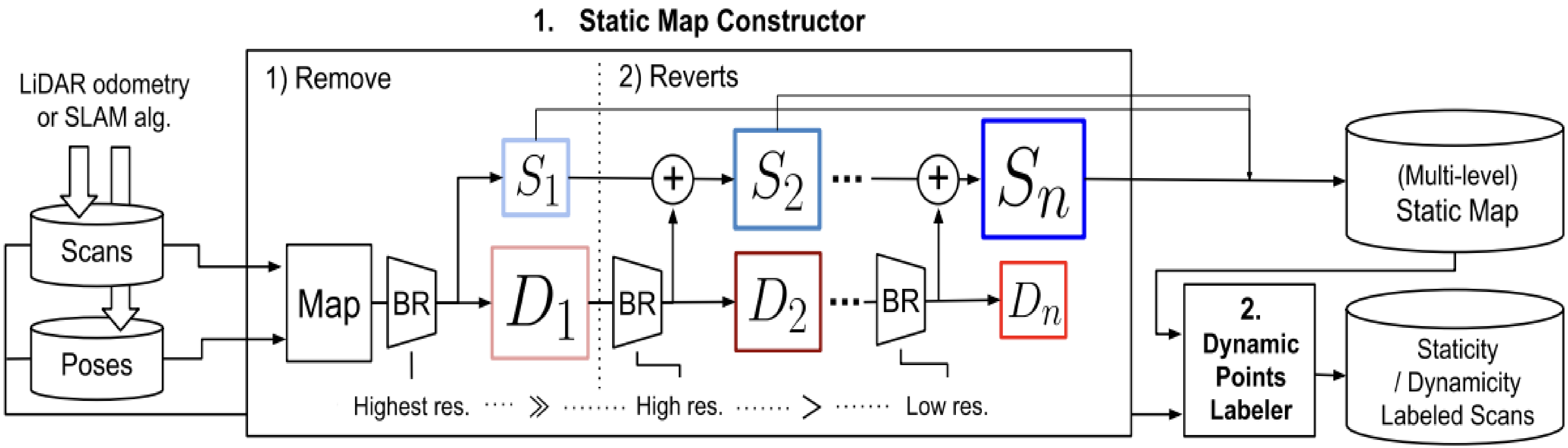
- Pipeline of the proposed static map construction method



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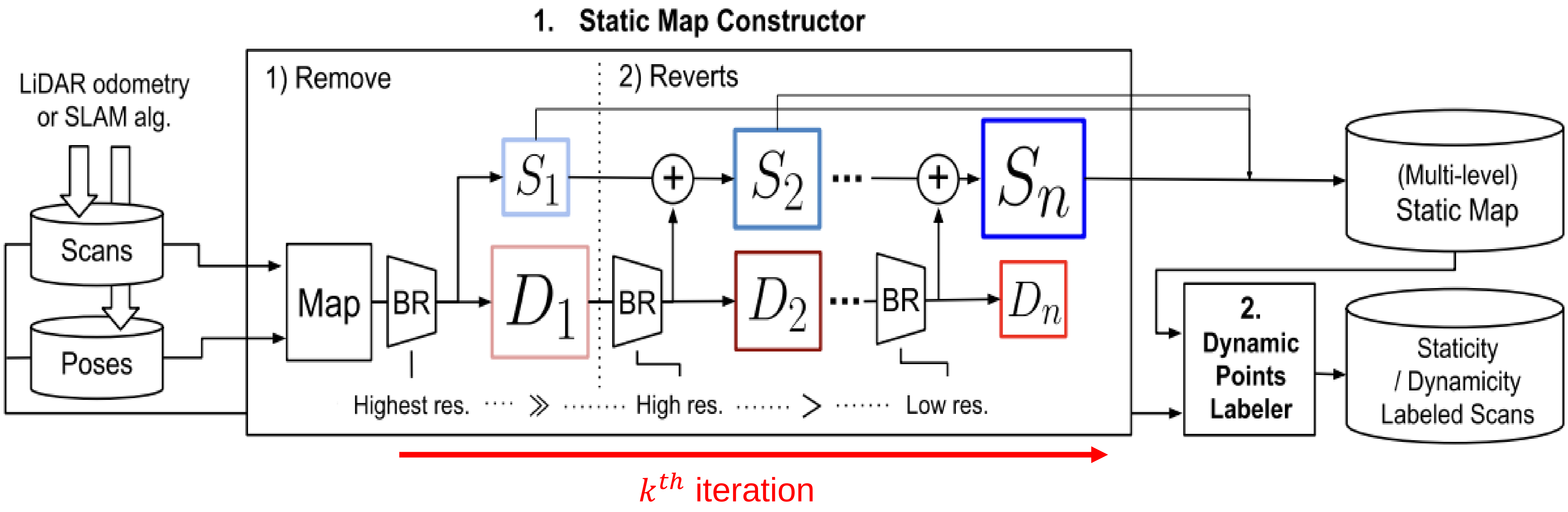

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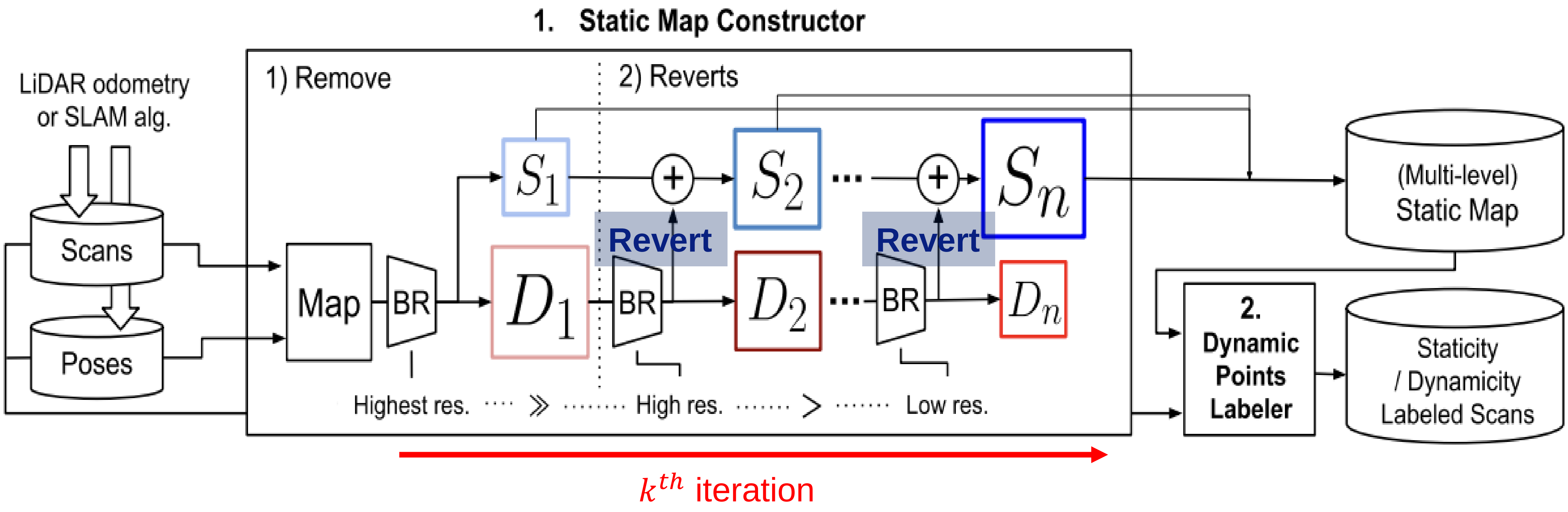

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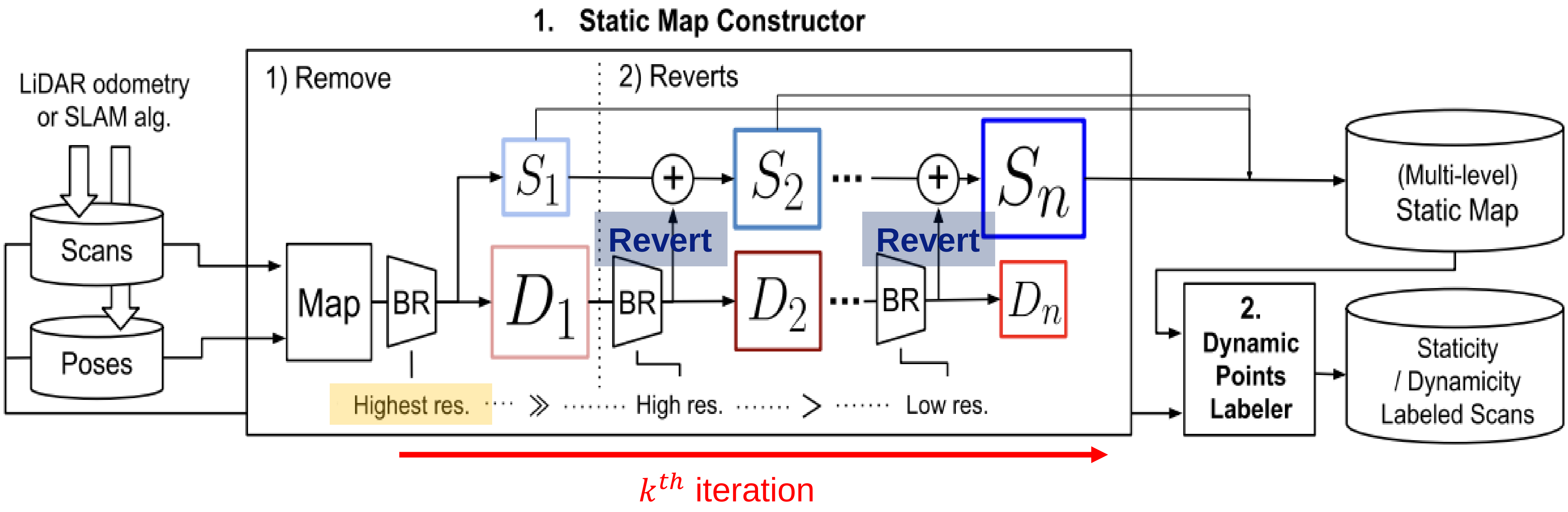

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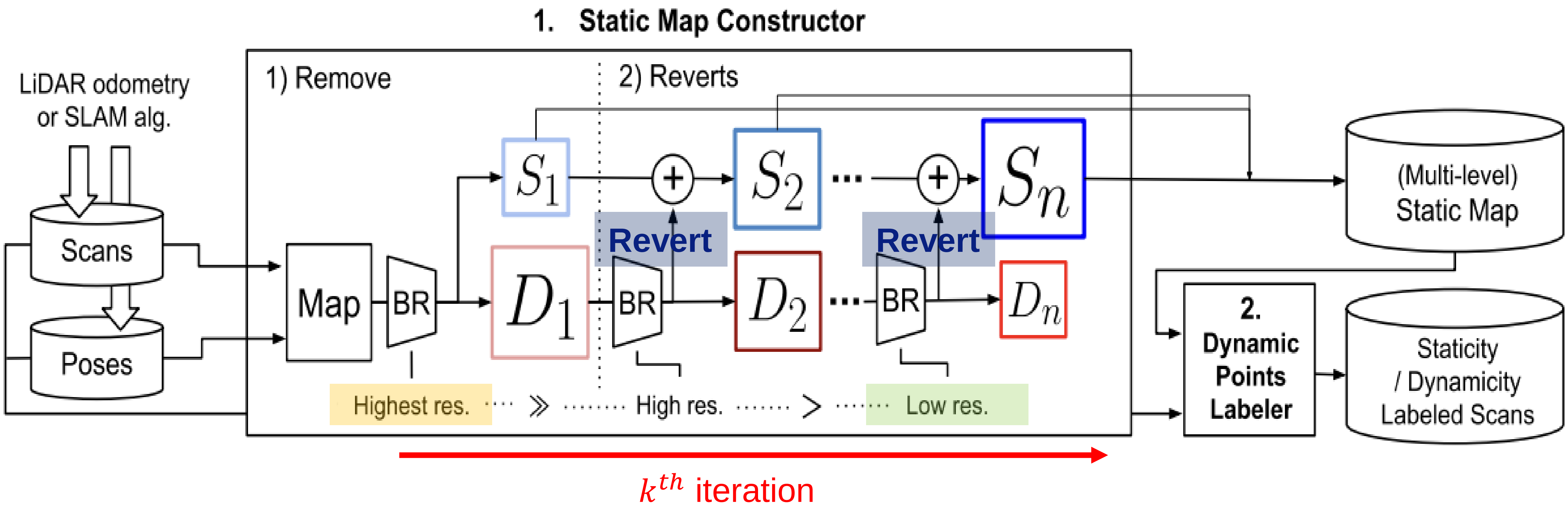

high (fine) resolution

low (coarse) resolution

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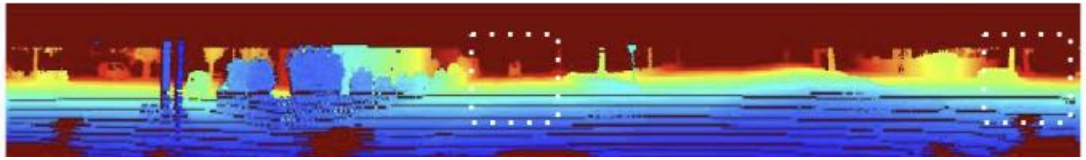

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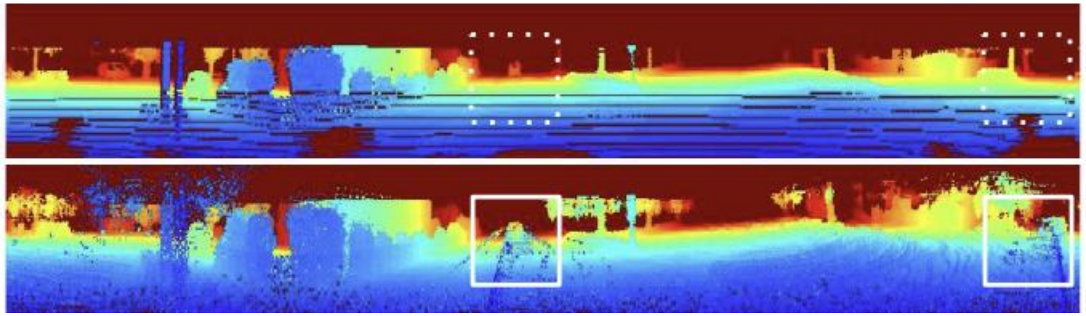

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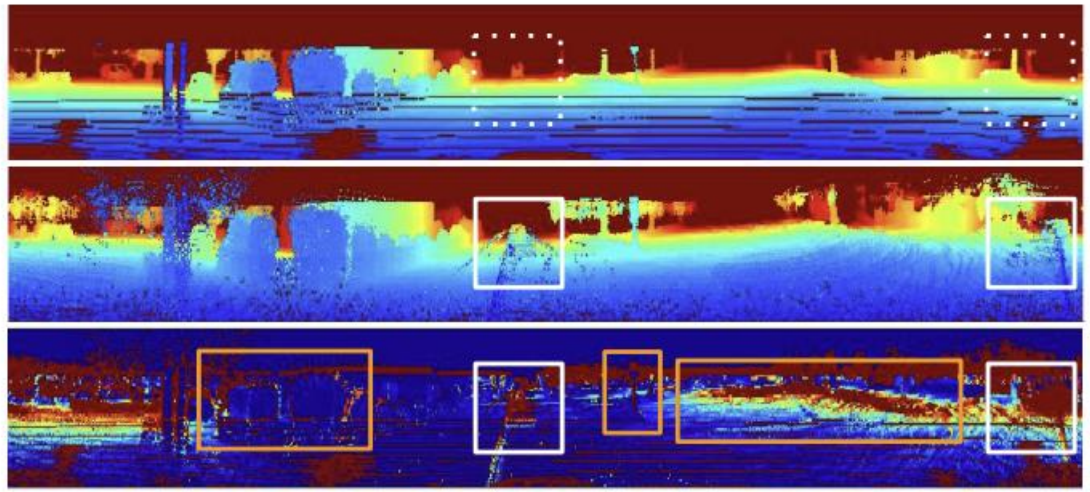
I_k^Q

I_k^M

I_k^{Diff}



High (fine) resolution range image (0.4° for a pixel)

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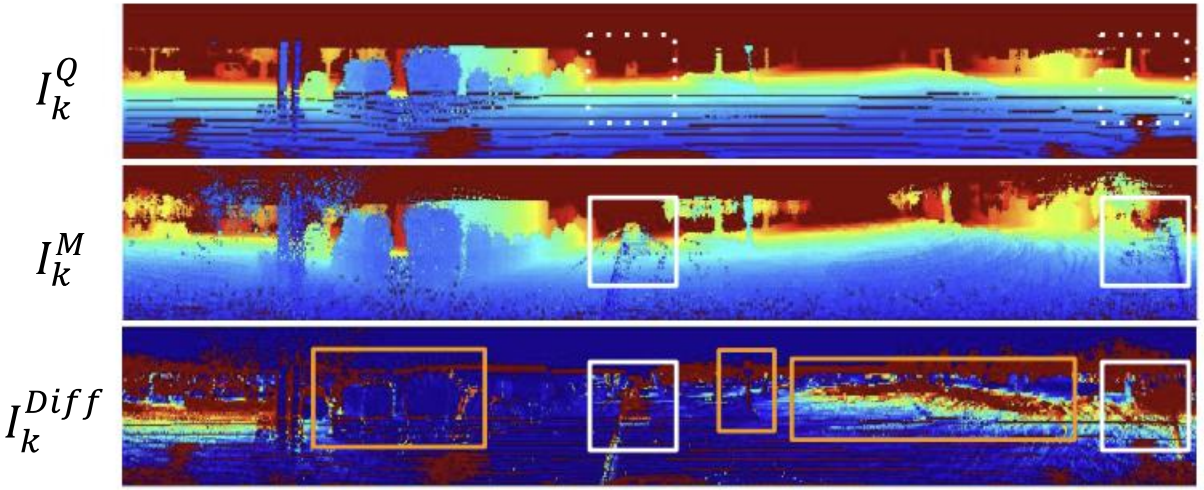

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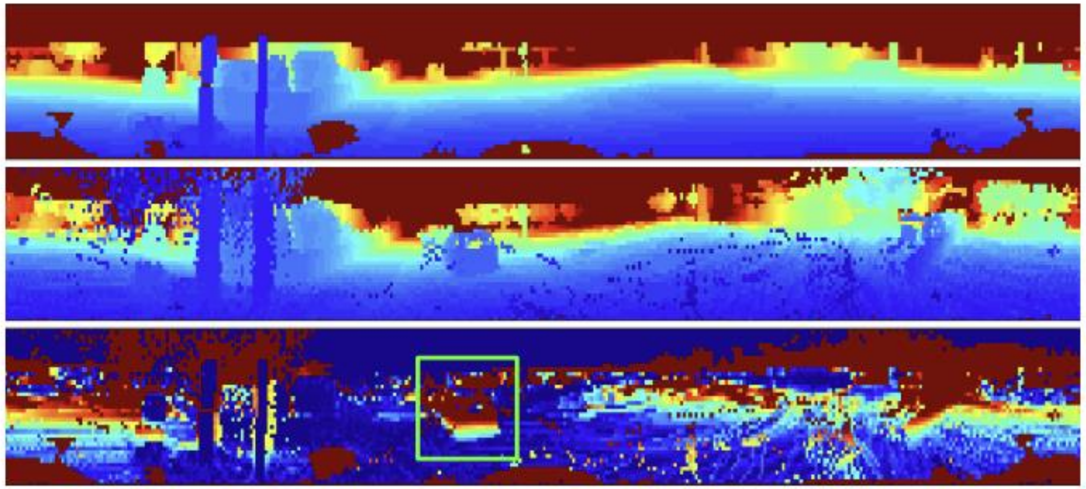

Low (coarse) resolution range image (1° for a pixel)

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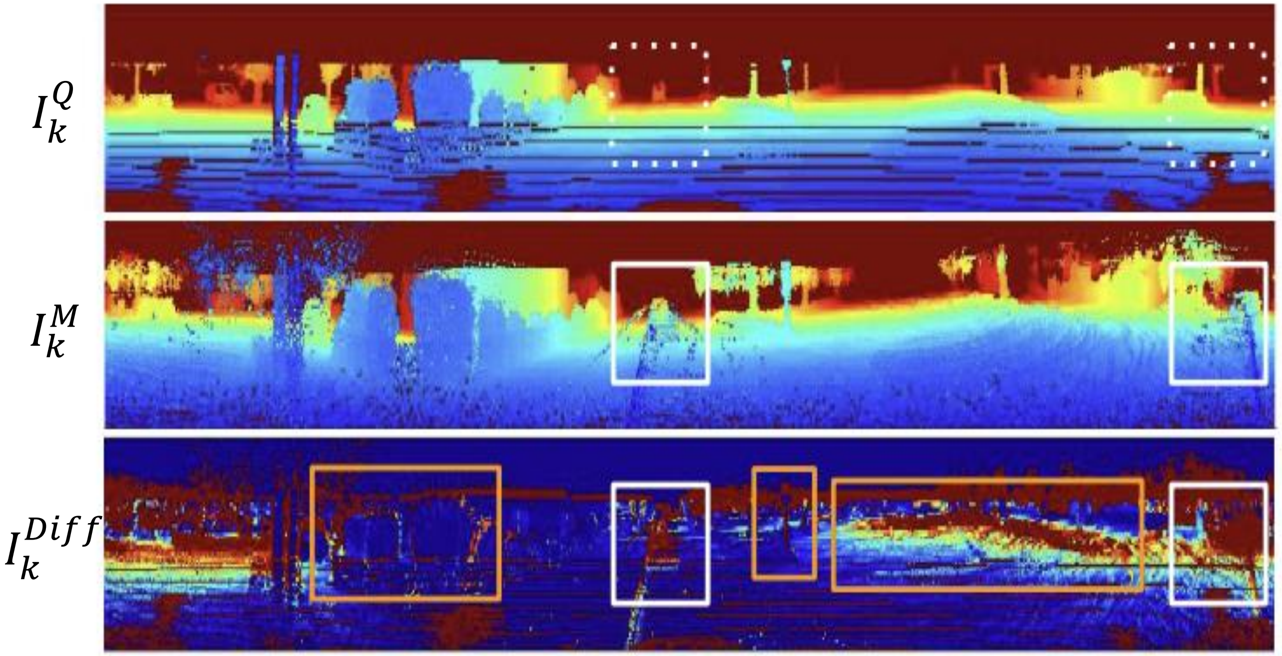
- red pixels I_k^{Diff} represent a high discrepancy between a query scan and a map



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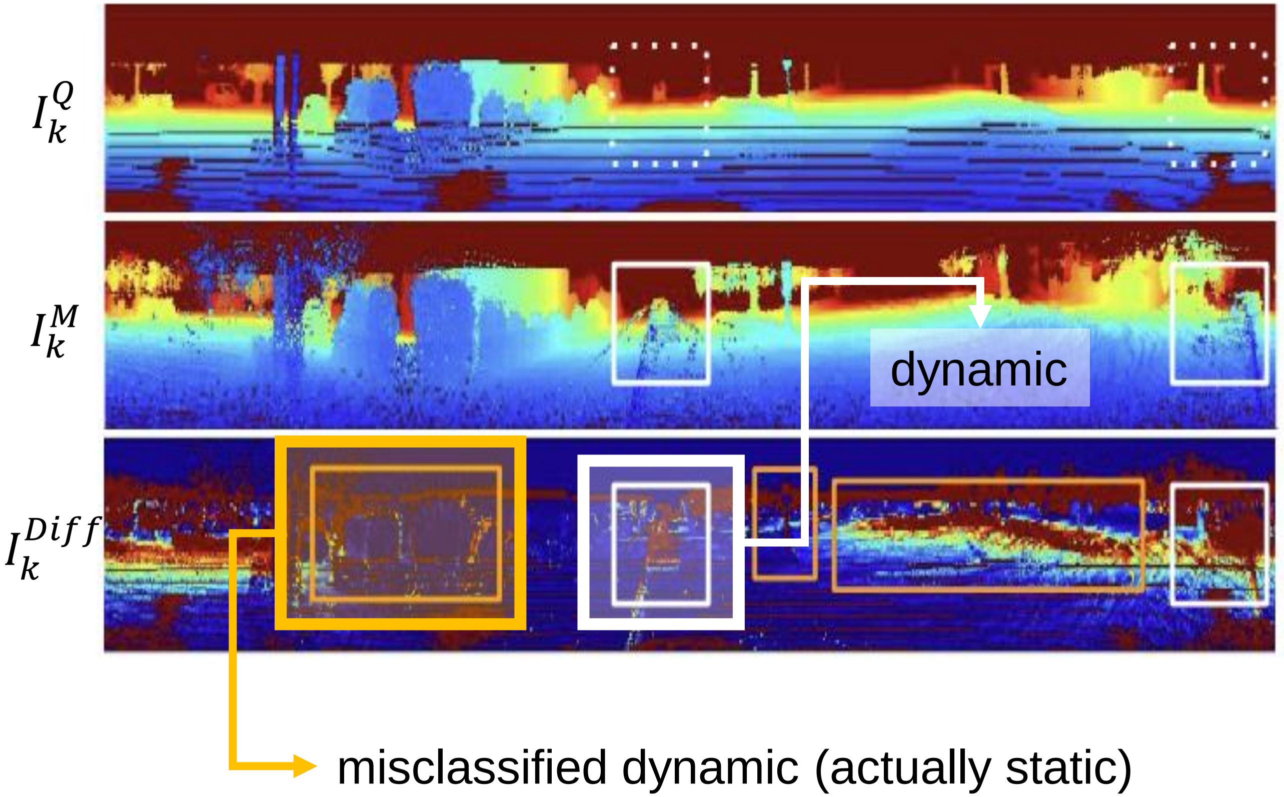

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  - Definition of dynamic map points

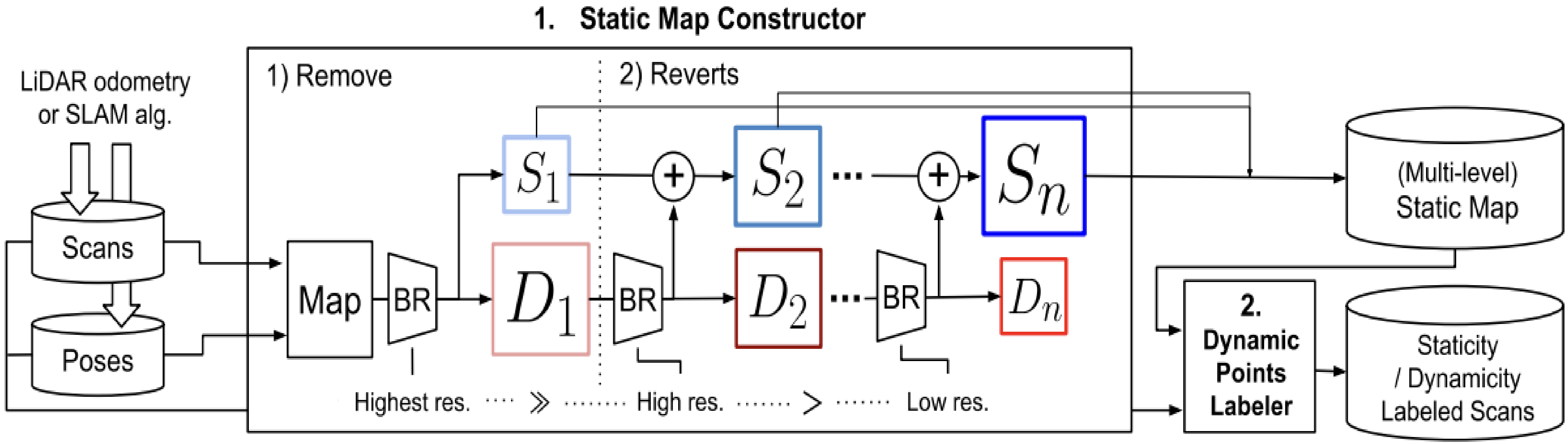
$$P_k^{DM} = \{p_{k,ij}^M \mid its\ associated\ I_{k,ij}^{Diff} > \tau_D\} \quad (4)$$

  - Definition of static map points

$$P_k^{SM} = P_k^M - P_k^{DM} \quad (5)$$

C. Batch dynamic point removal

- BR: Batch Removal



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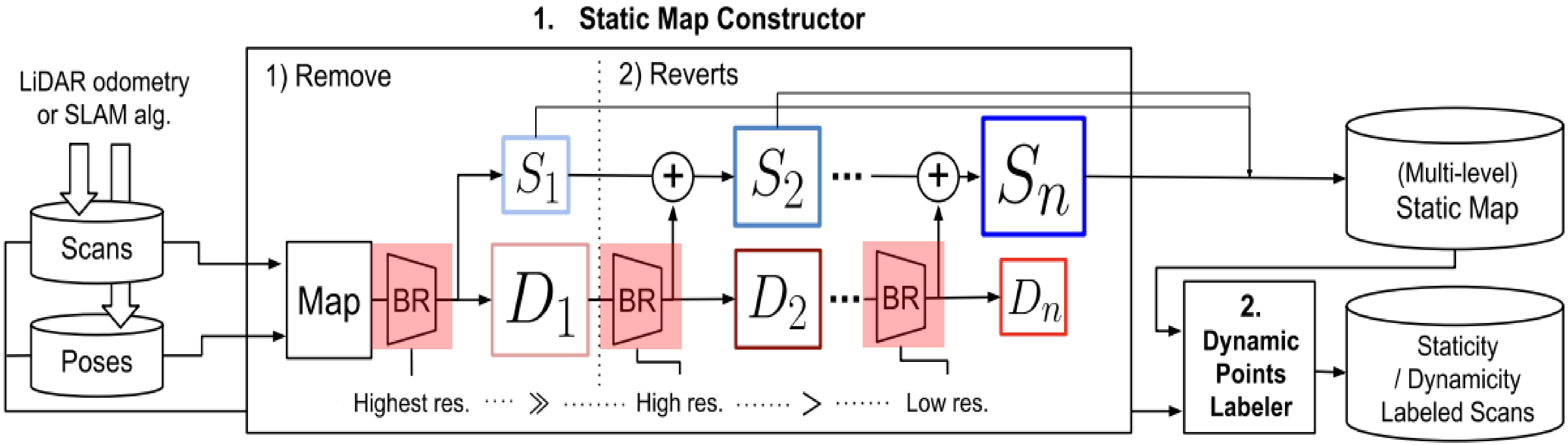

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  2. Count the total number marked as SM or DM for every single point in the map

     - n_{SM}: number of points marked as SM

     - n_{DM}: number of points marked as DM

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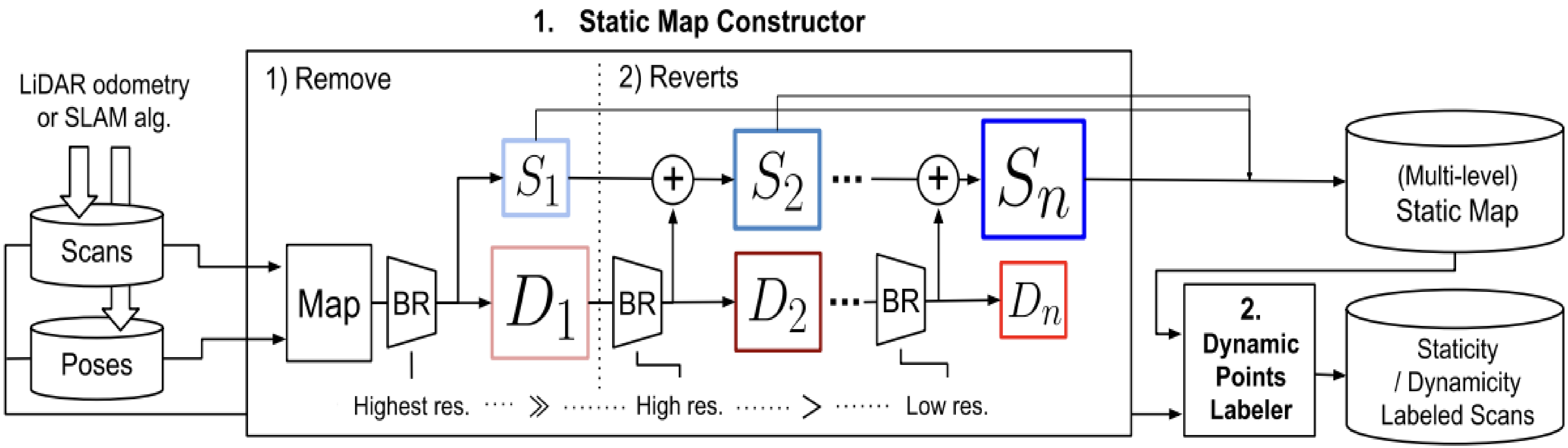
    - $P^{DM} = \{p^{M} | s(p^{M}) < \tau_{s}\}$ (7)
  - Static map is defined as the complement of P^{DM}
    - $P^{SM} = P^{M} - P^{DM}$ (8)

positive weight coefficient

negative weight coefficient

D. Removert: remove, then revert static points



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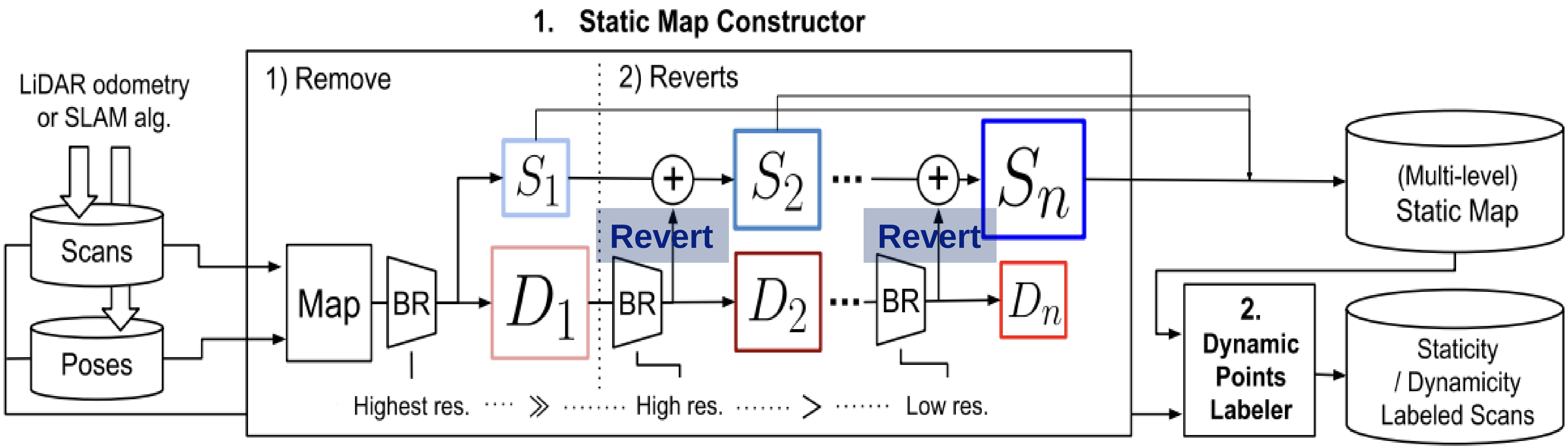

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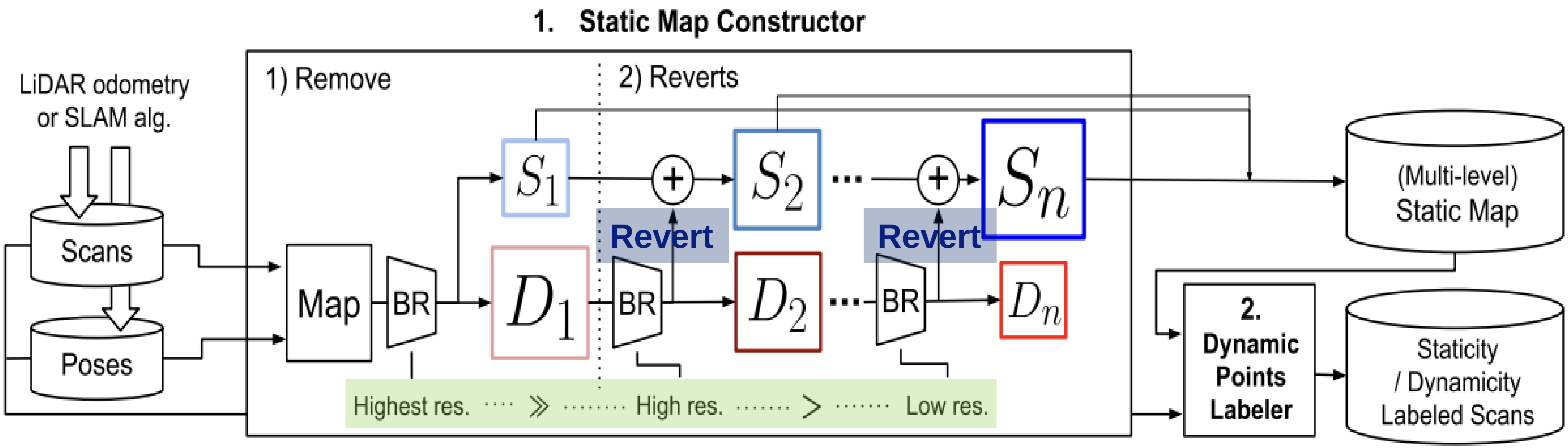

From high resolution to low resolution

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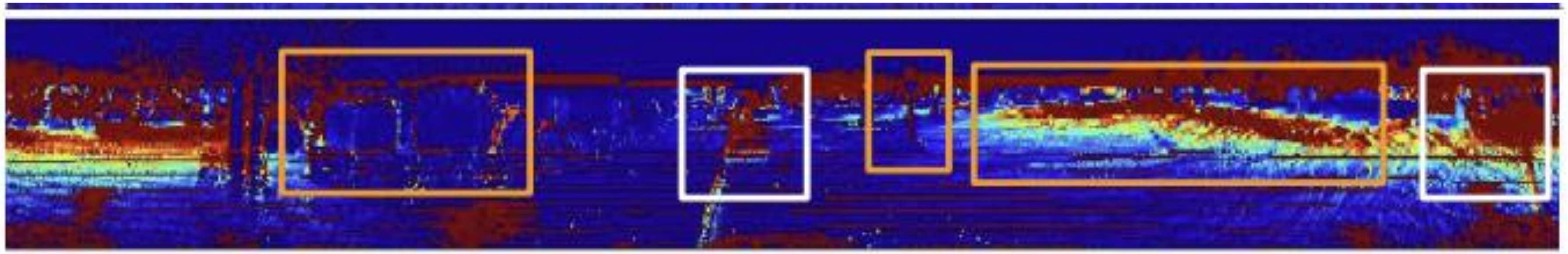

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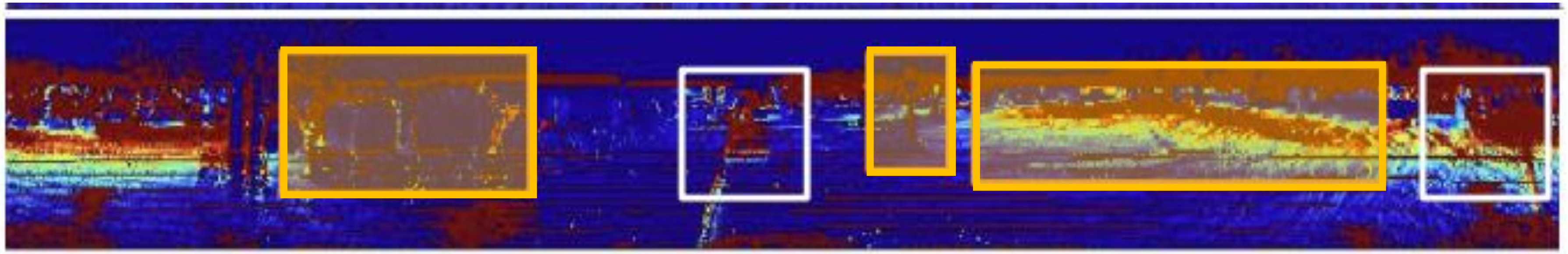

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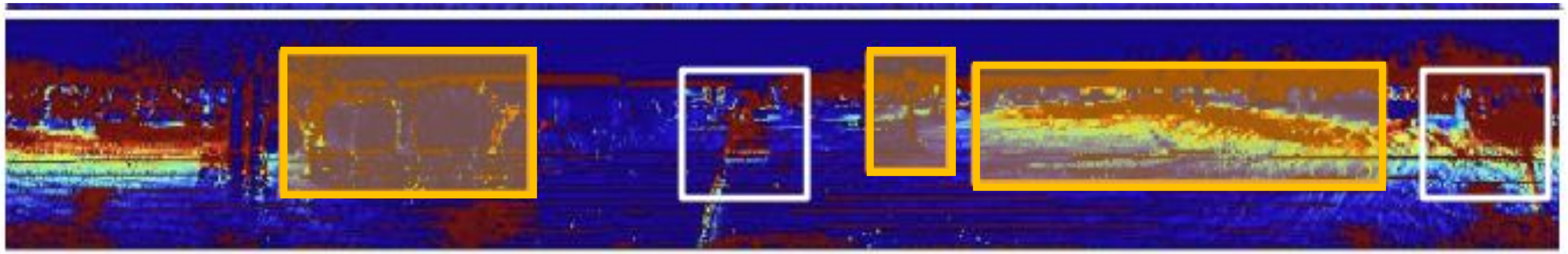

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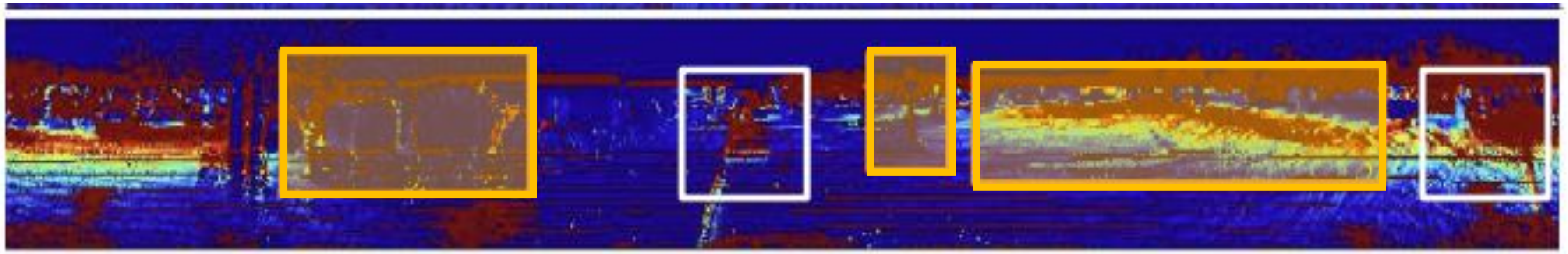
  - → Iteratively reduces the number of FN points which are actually static.



Experimental Results

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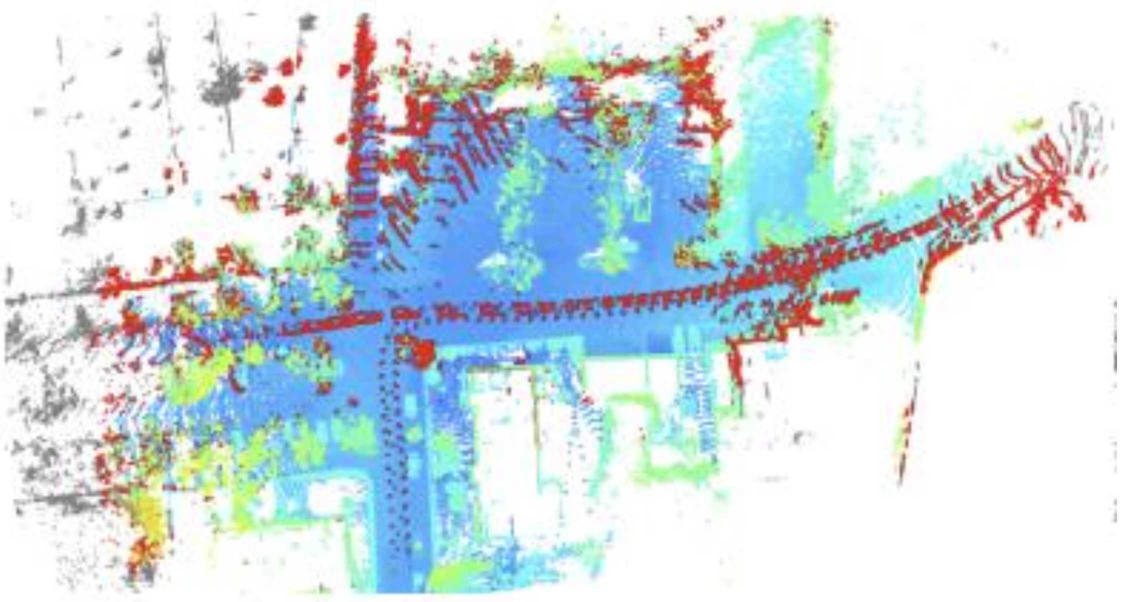

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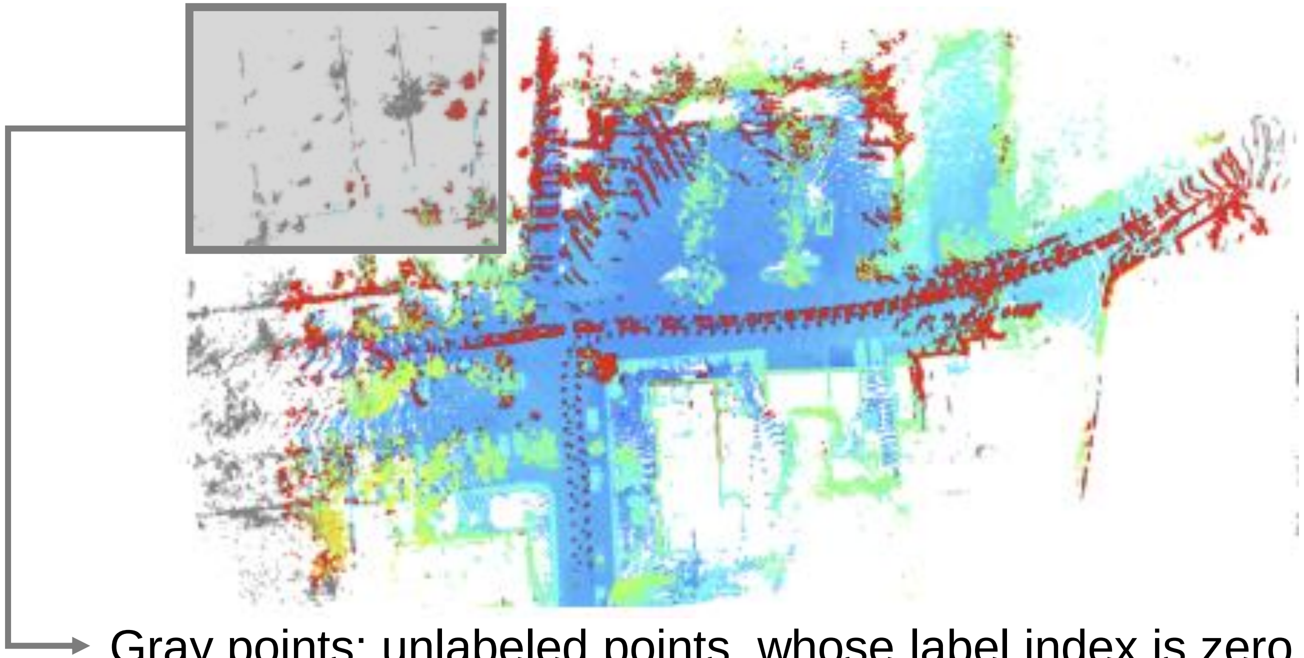

Gray points: unlabeled points, whose label index is zero

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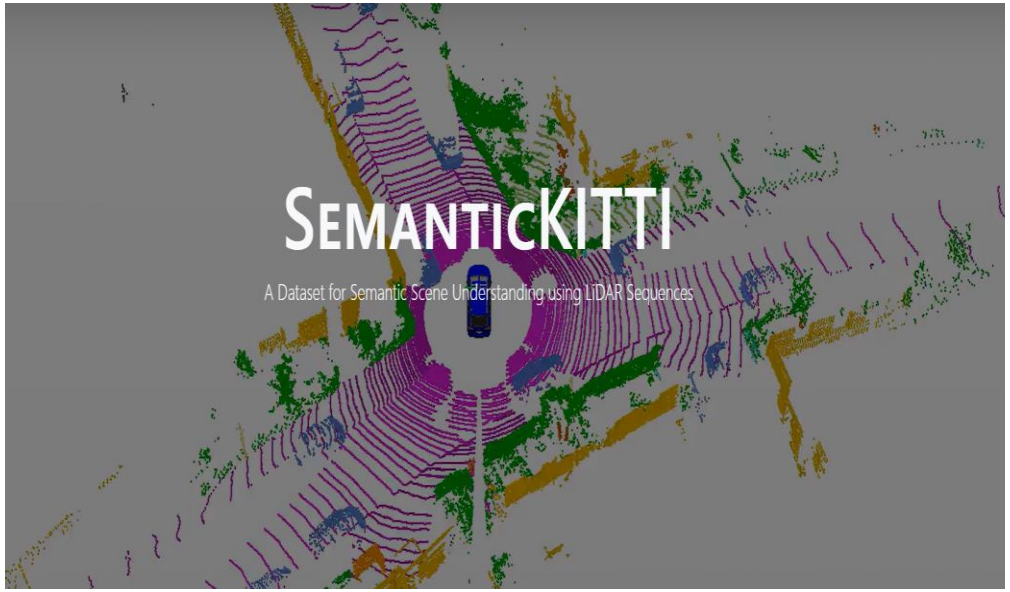

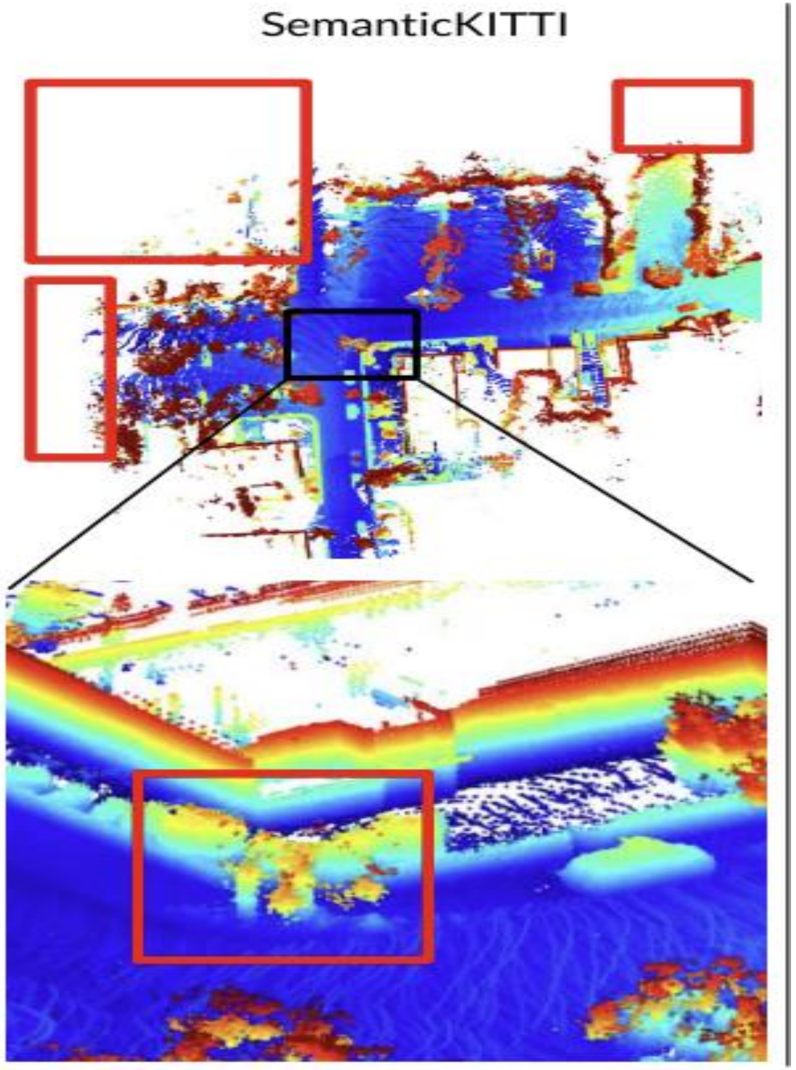

Ground truth map

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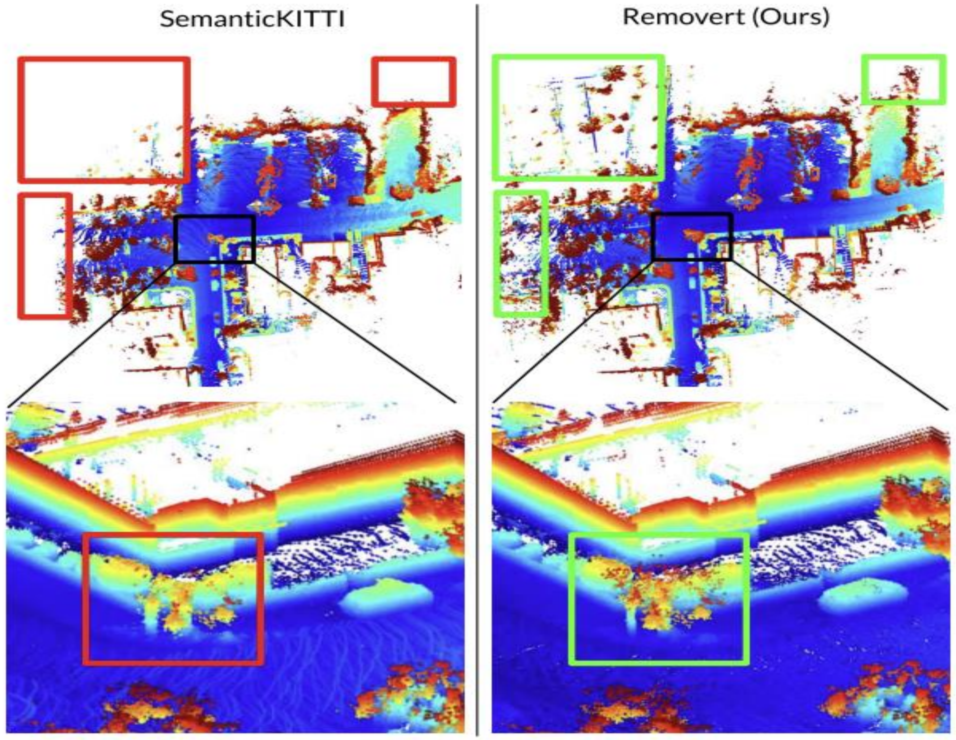

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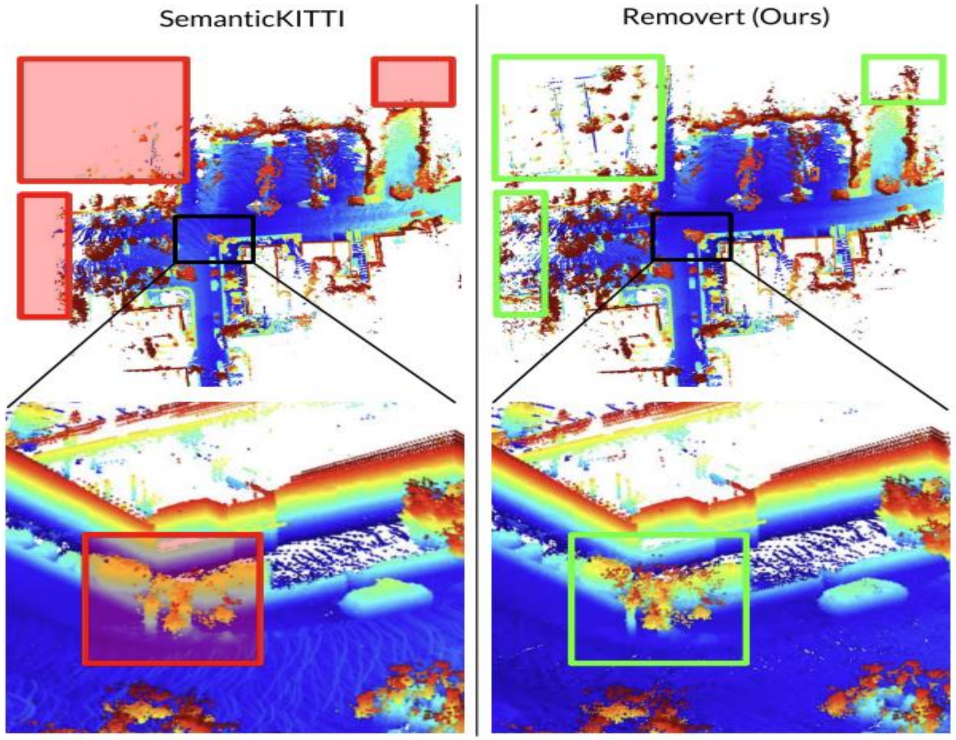

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Static map quality (Qualitative analysis)

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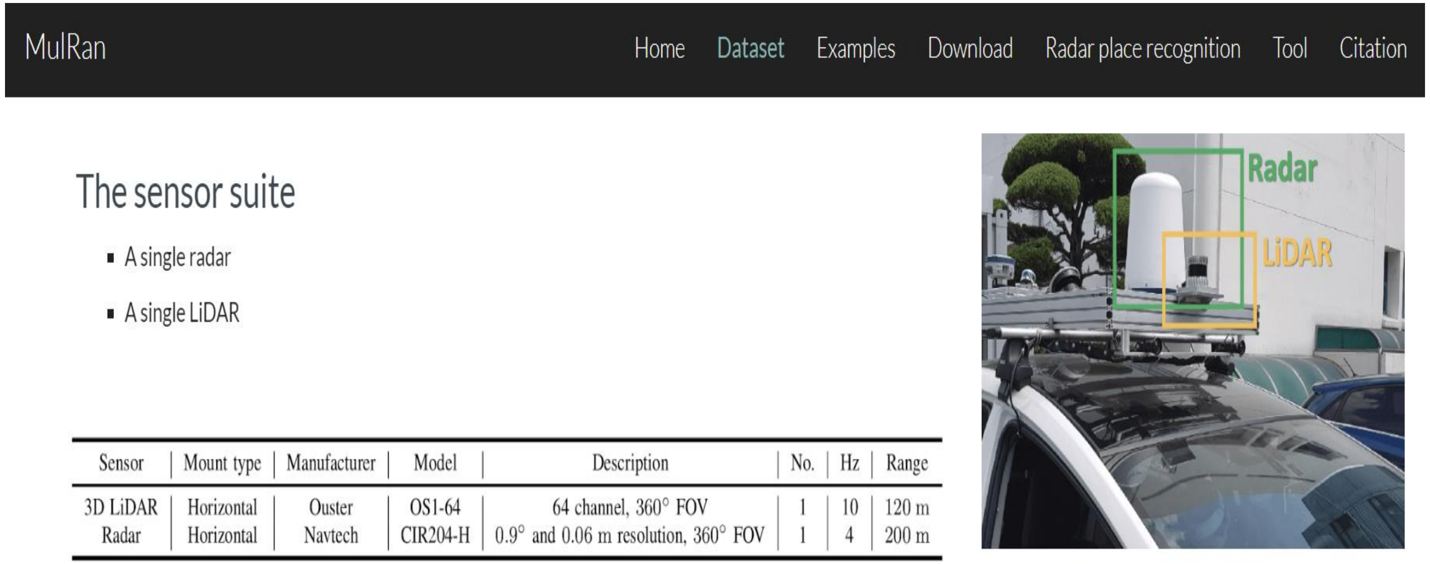


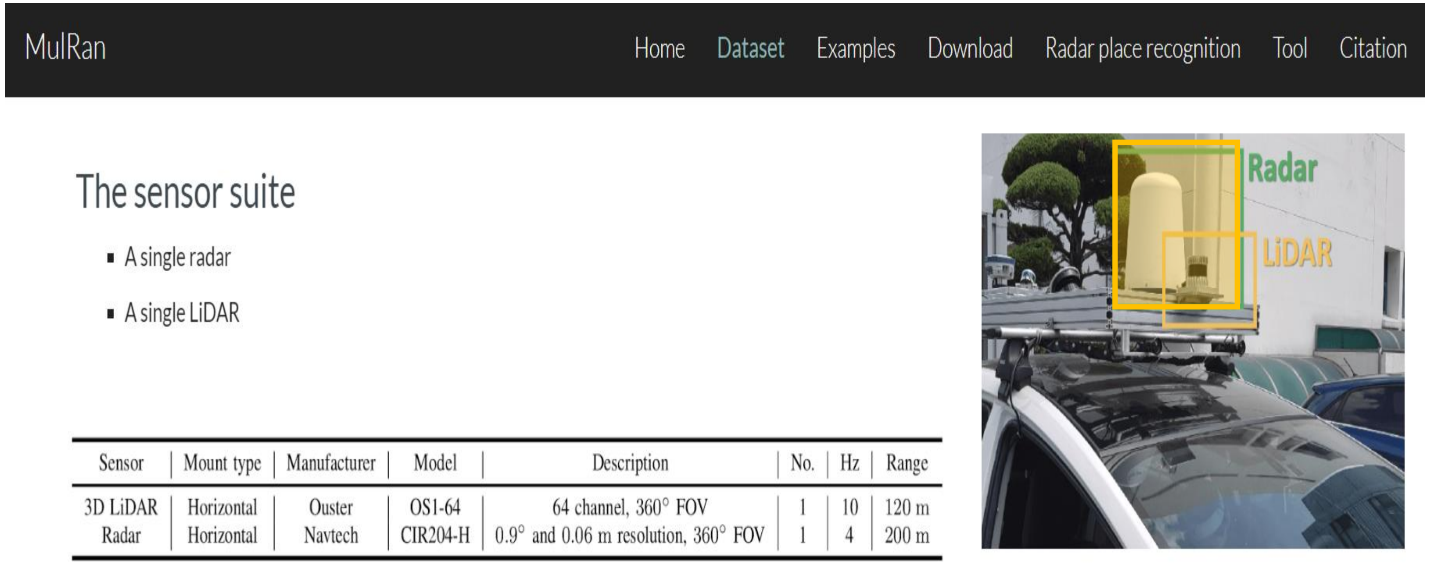
Sensor	Mount type	Manufacturer	Model	Description	No.	Hz	Range
3D LiDAR	Horizontal	Ouster	OS1-64	64 channel, 360° FOV	1	10	120 m
Radar	Horizontal	Navtech	CIR204-H	0.9° and 0.06 m resolution, 360° FOV	1	4	200 m

MulRan dataset (OS1-64)

Kitti dataset (HDL-64E)

Static map quality (Qualitative analysis)

- Validated independence of the LiDAR configuration by evaluating over the MulRan dataset which were created using Ouster (↔ Kitti dataset: Velodyne)



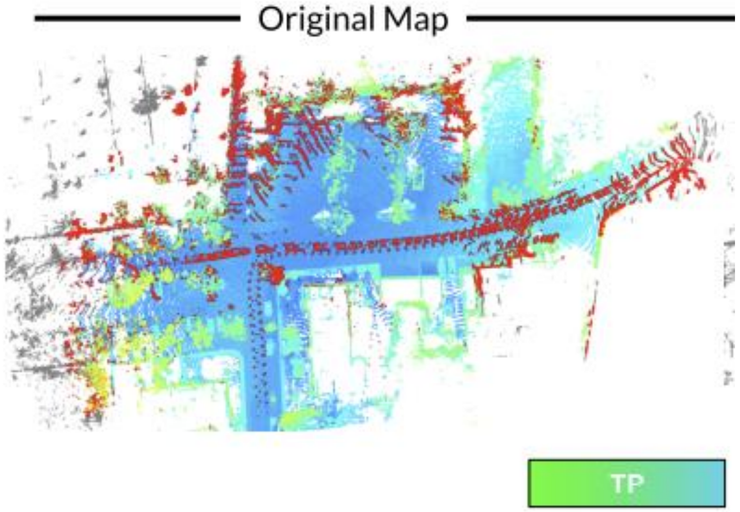
Sensor	Mount type	Manufacturer	Model	Description	No.	Hz	Range
3D LiDAR	Horizontal	Ouster	OS1-64	64 channel, 360° FOV	1	10	120 m
Radar	Horizontal	Navtech	CIR204-H	0.9° and 0.06 m resolution, 360° FOV	1	4	200 m

MulRan dataset (OS1-64)

Kitti dataset (HDL-64E)

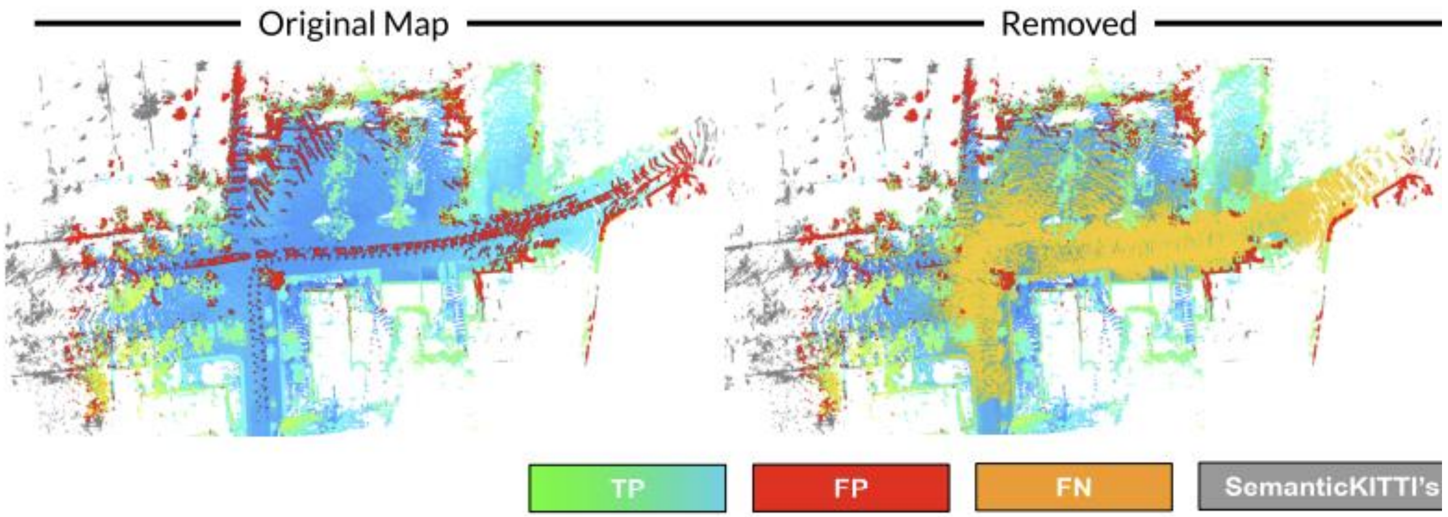
Static map quality (Quantitative analysis)

- Removert algorithm



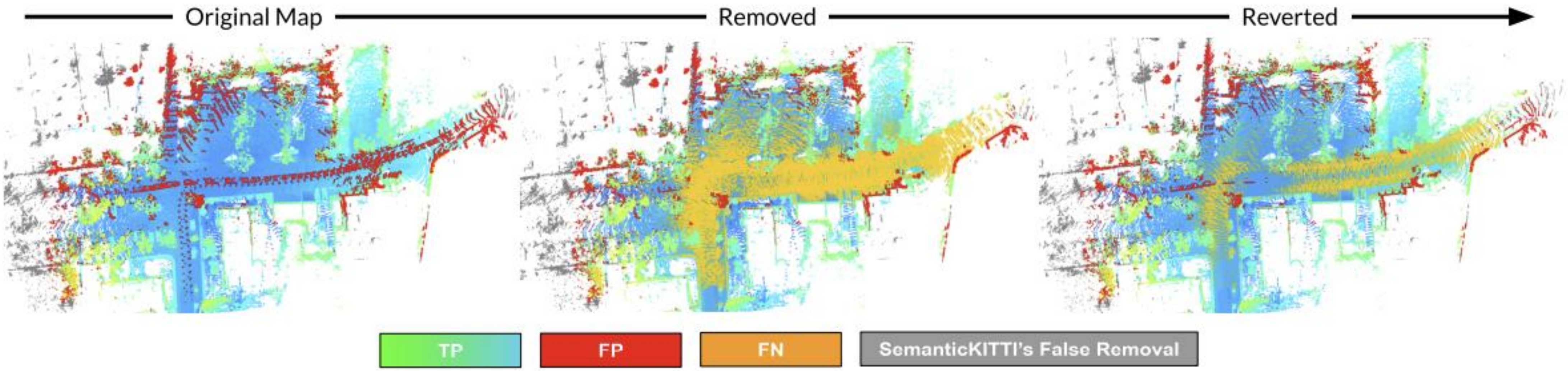
Static map quality (Quantitative analysis)

- Removert algorithm
  - 1) radically removes ambiguous points from the original noisy map



Static map quality (Quantitative analysis)

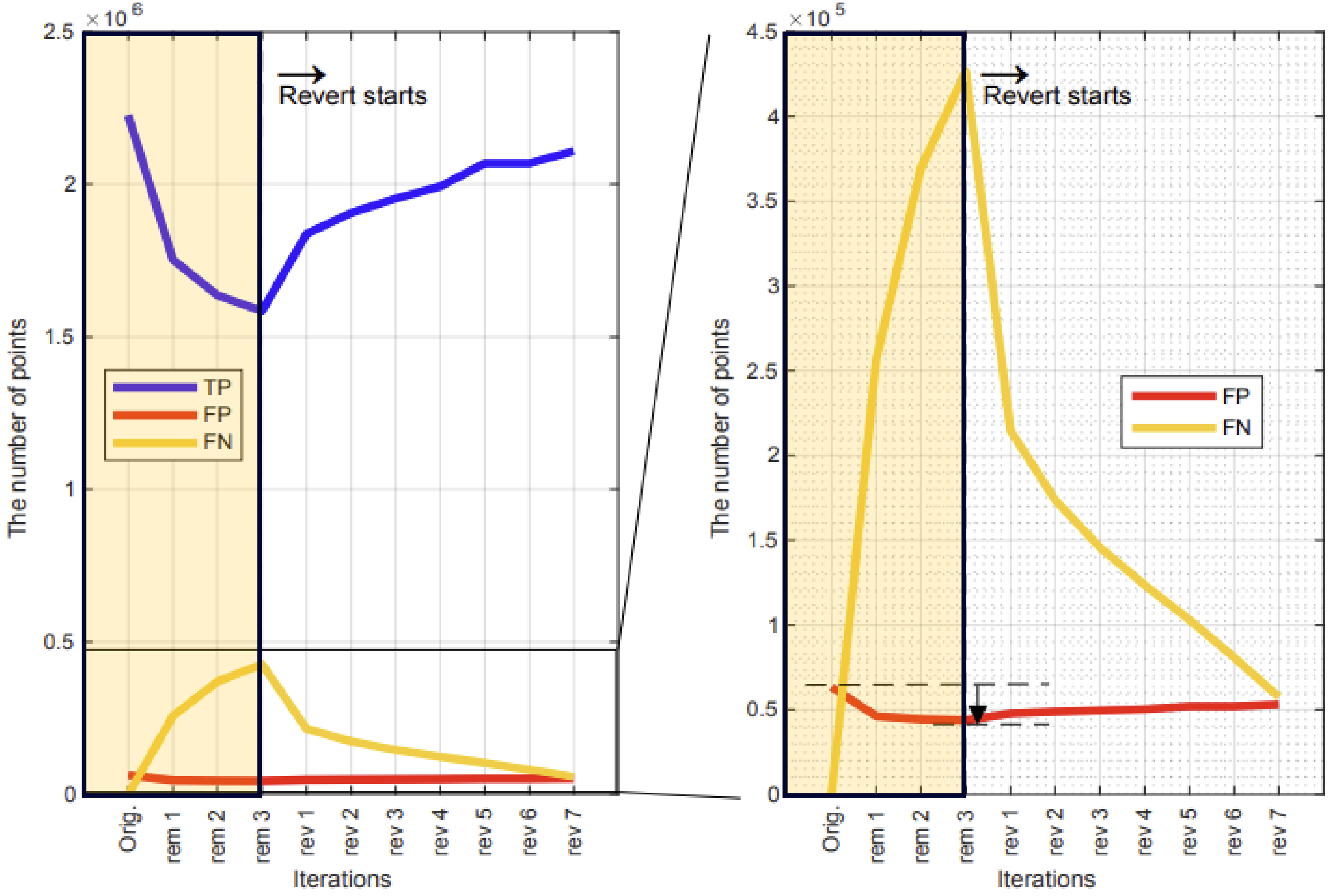
- Removert algorithm
  - 1) radically removes ambiguous points from the original noisy map
  - 2) iteratively recovers the true positive points



Static map quality (Quantitative analysis)

- history of the number of TP, FP, and FN points along the iteration

radically removes dynamic points



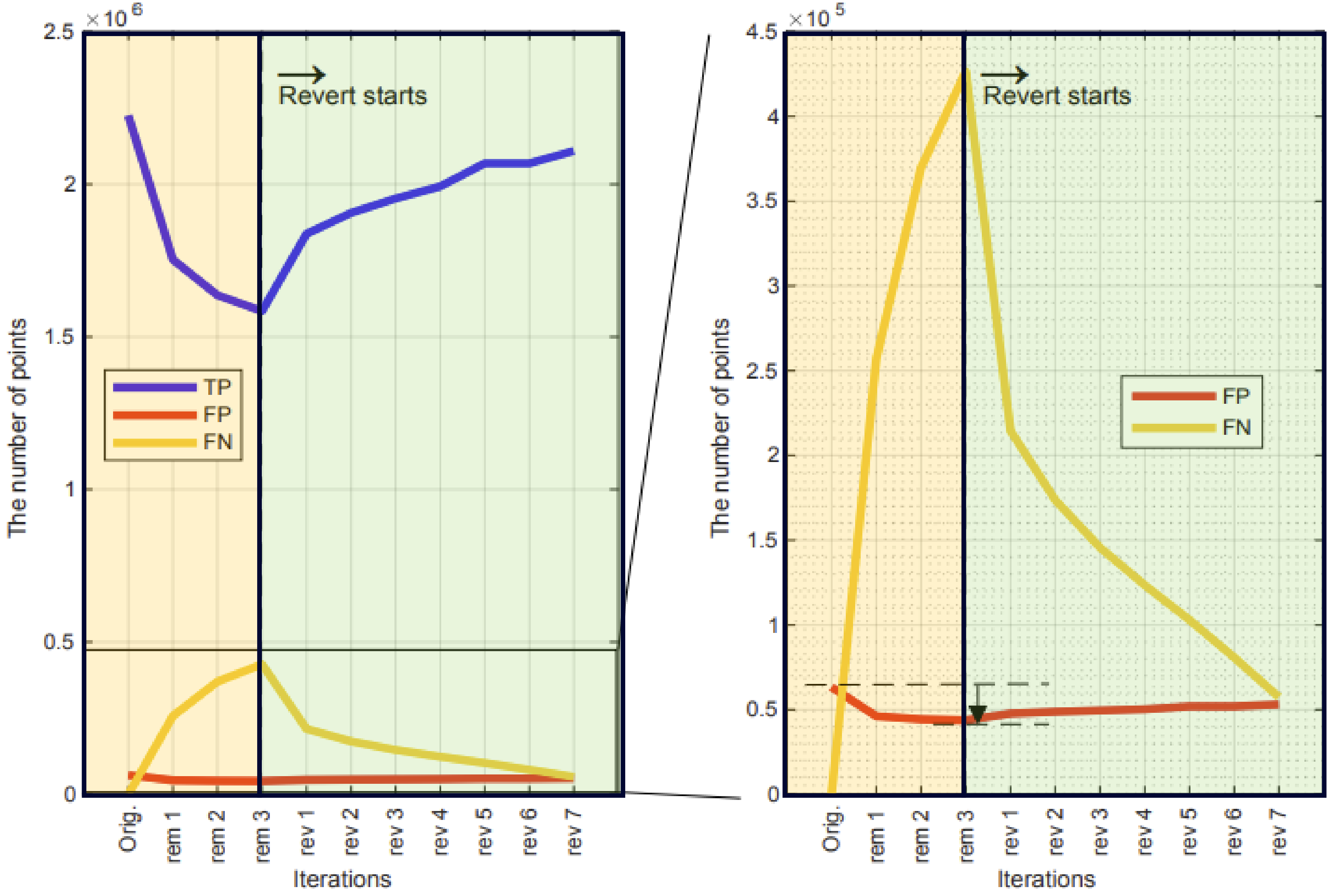
Static map quality (Quantitative analysis)

- history of the number of TP, FP, and FN points along the iteration

radically removes dynamic points

⇩

iteratively recovers static points



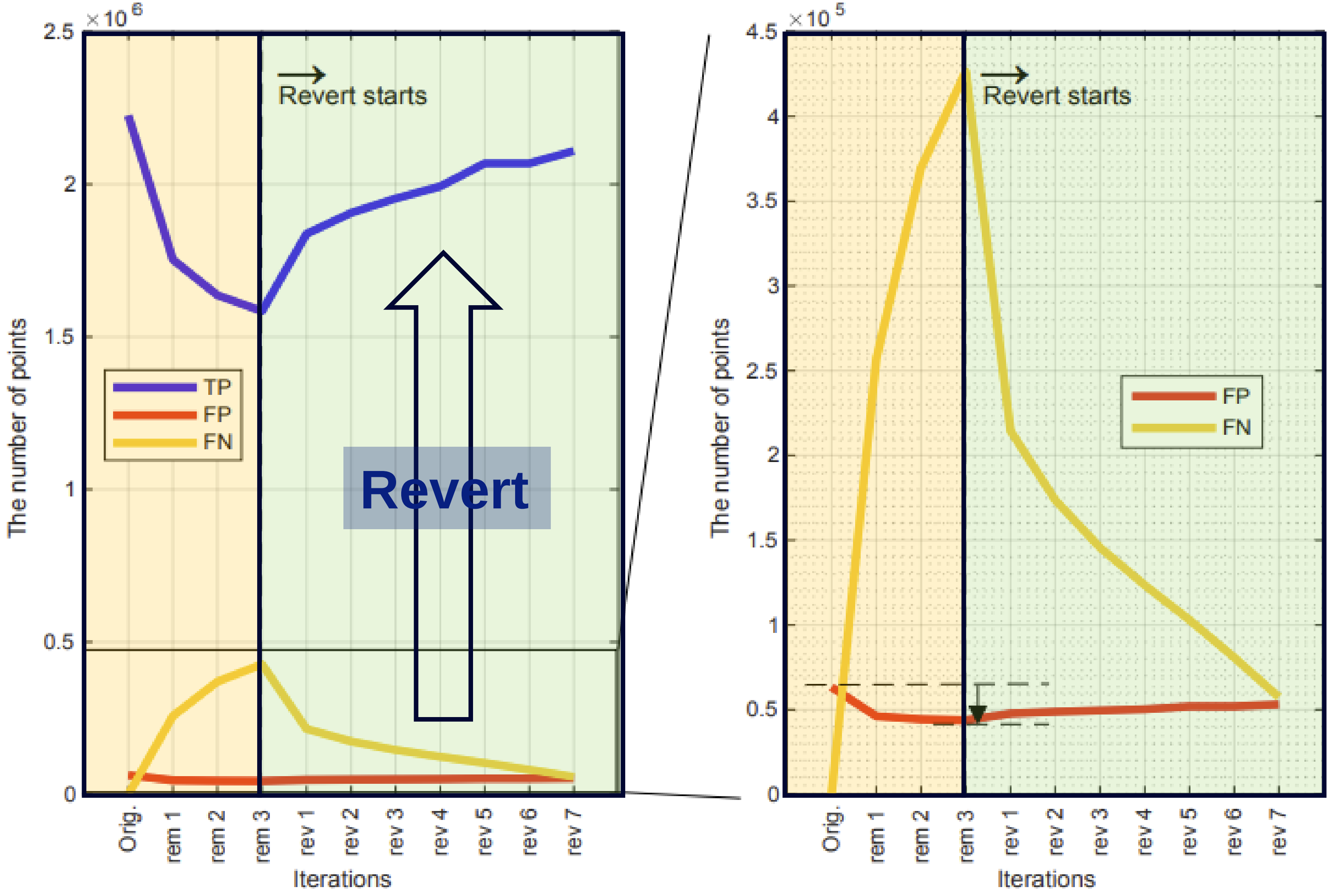
Static map quality (Quantitative analysis)

- history of the number of TP, FP, and FN points along the iteration

radically removes dynamic points

⇩

iteratively recovers static points



Conclusion

- Proposed a novel method to recover the false predictions in a dynamic map and simultaneously enhance a static map.

Conclusion

- Proposed a novel method to recover the false predictions in a dynamic map and simultaneously enhance a static map.
- Provided various qualitative and quantitative analysis using KITTI dataset by proving the capability of removing dynamic points.

Q&A

Appendix

B. Range image-based map comparison

- During the projection, they use a range image of particular resolution
  - ex) a single pixel represents 1◦ for both horizontal and vertical FOV
- They call this FOV-restricted and sampled map point cloud a "*visible map point cloud*" (P_k^M)
- A visible map point cloud P_k^M is defined as its equivalent range image $I_k^M = \left(I_{k,ij}^M\right) \in R^{m \times n}$
  - m, n: number of pixels

$$I_{k,ij}^M = \min_{p \in P_{ij}^M} r(p)$$ ($r(\cdot)$: a range of a point $p \in R^3$)

$$P_k^M = \{p_{k,ij}^M = \underset{p \in P_{ij}^M}{\operatorname{argmin}} \, r(p)\}$$