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Center Focusing Network for Real-Time LiDAR Panoptic Segmentation

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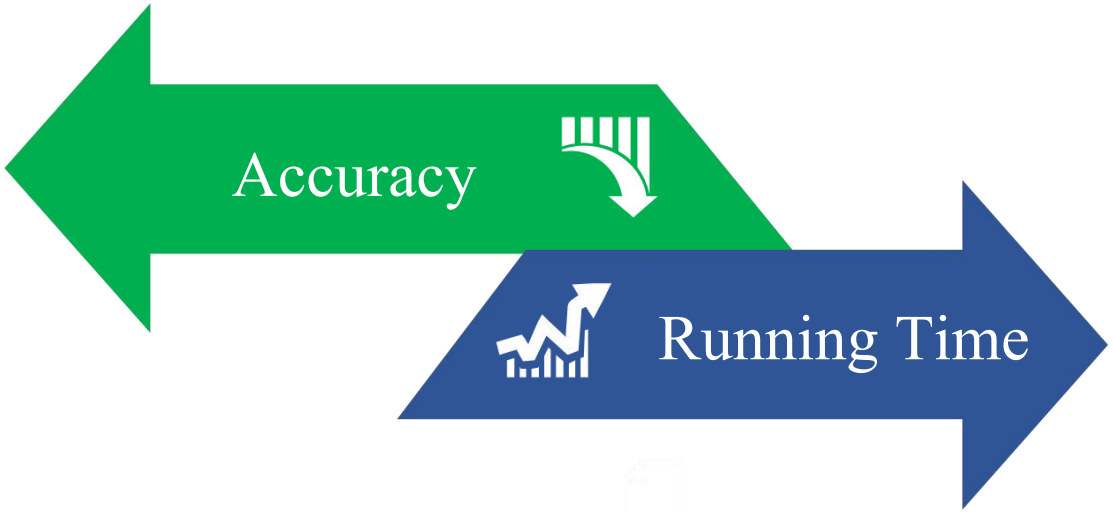
Preview

Key problems that limit the **accuracy** and **speed** of **proposal-free** LIDAR panoptic segmentation approaches

Center Encoding

Difficulty of encoding non-existent instance centers results in the errors of LiDAR instance segmentation



Center Exploiting

The costly center-based clustering algorithms slow down the overall inference speed

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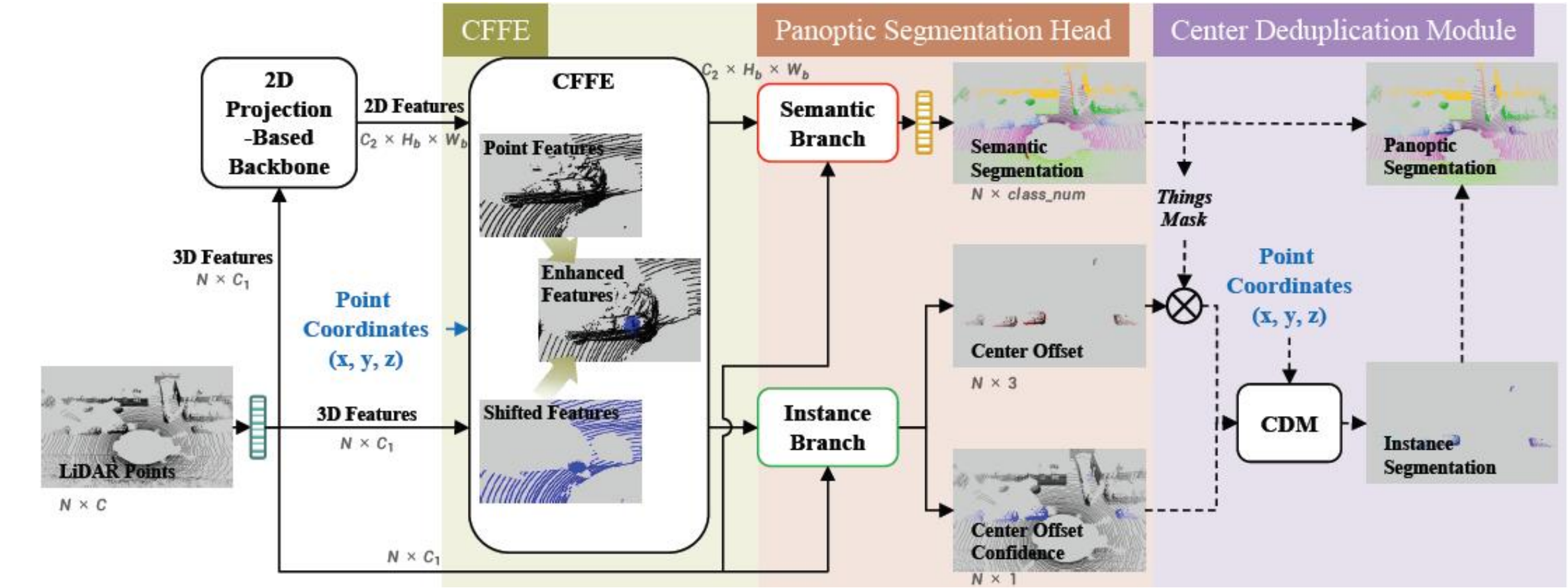
Preview



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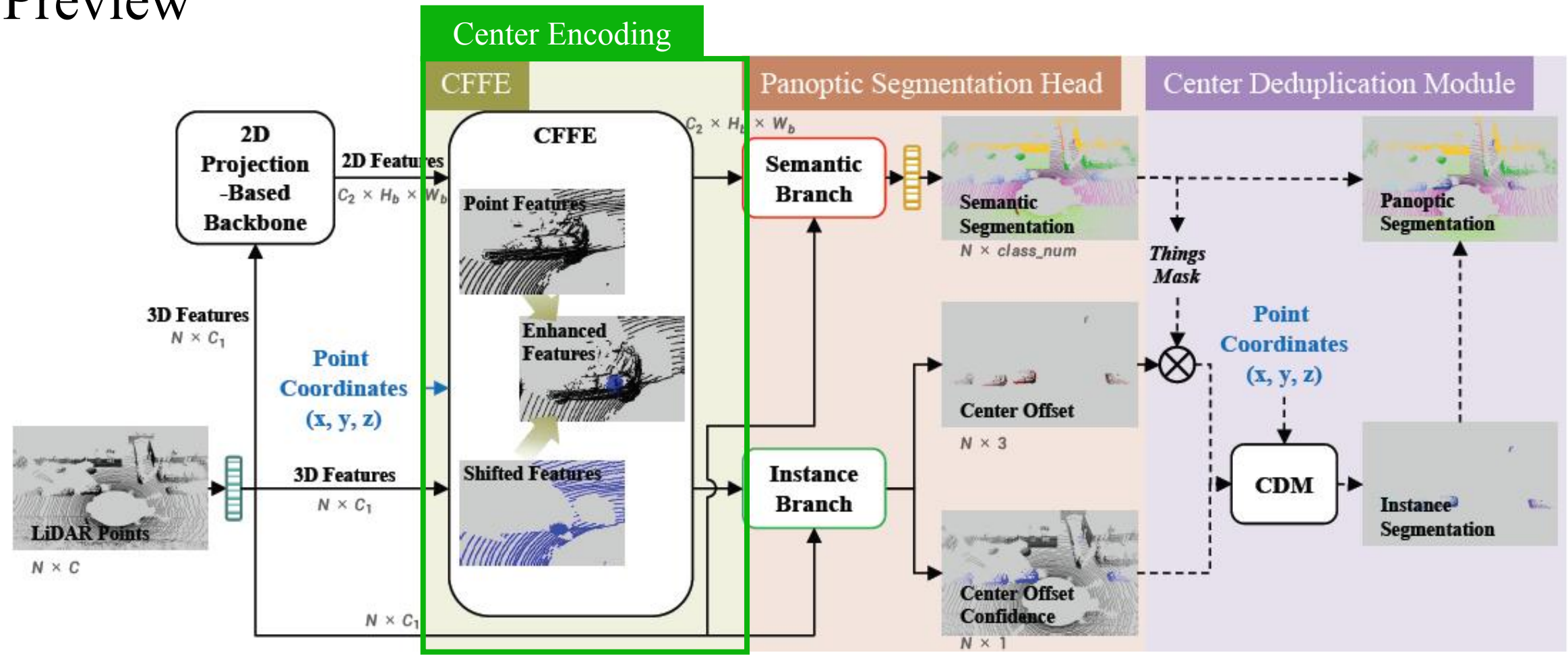
Preview



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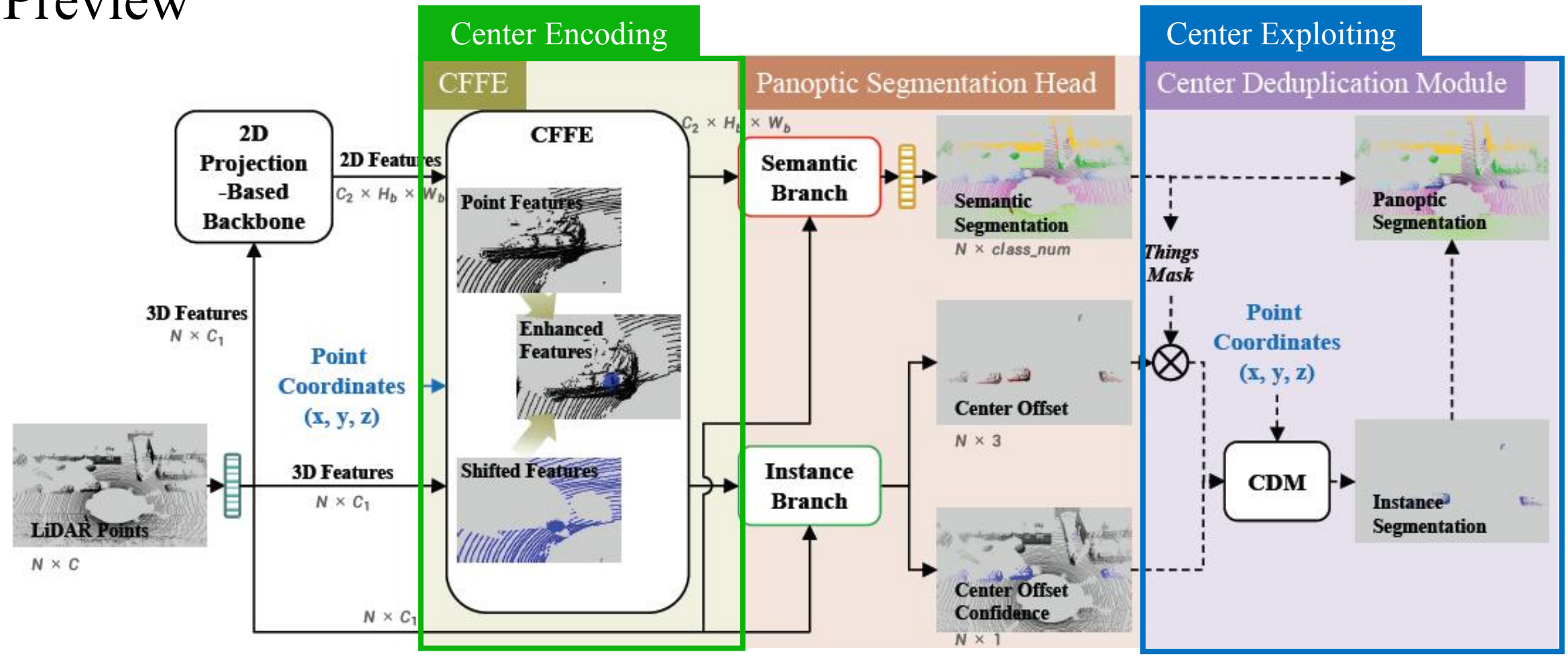
Preview



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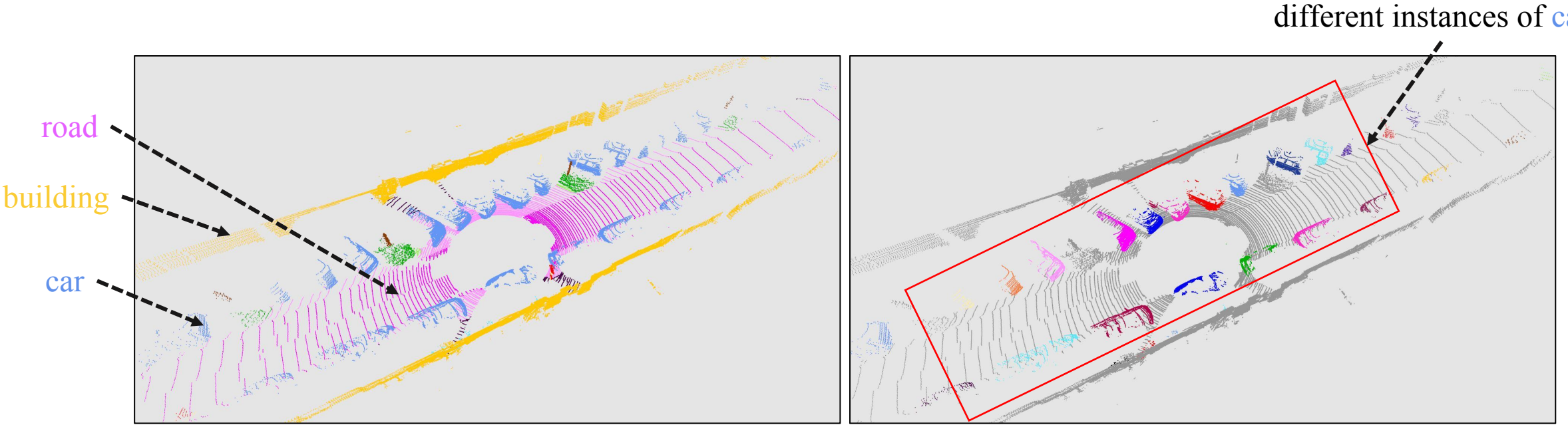
LiDAR Panoptic Segmentation

1. **LiDAR Semantic Segmentation**: for both ***Stuff*** *(e.g. road, building)* and ***Things*** *(e.g. car, pedestrian)* classes

2. **LiDAR Instance Segmentation**: only for ***Things*** *(e.g. car, pedestrian)* classes



(a) LiDAR Semantic Segmentation

(b) LiDAR Instance Segmentation

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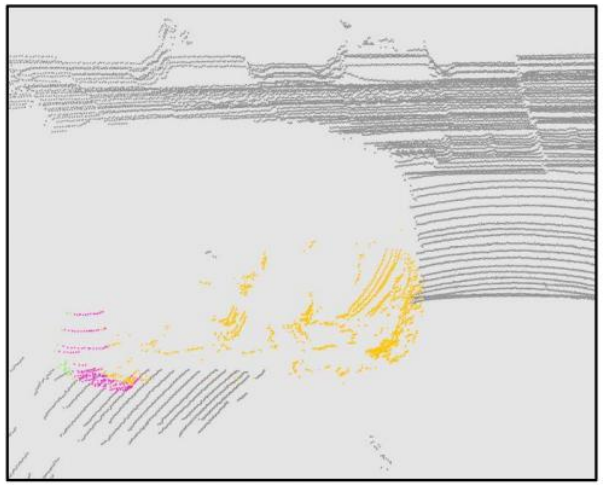
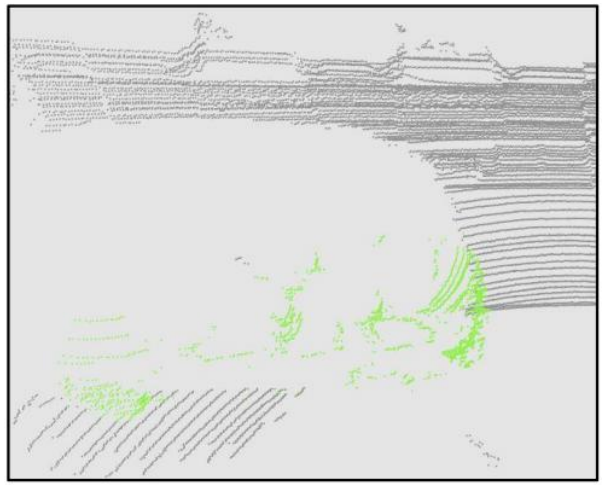
Accurate and Real-Time LiDAR Panoptic Segmentation

1. Accurate: The difficulty of modeling **non-existent instance centers** results in the errors of LiDAR instance segmentation

- LiDAR scans are surface-aggregated



(a) CFNet without CFFE



(b) CFNet with CFFE

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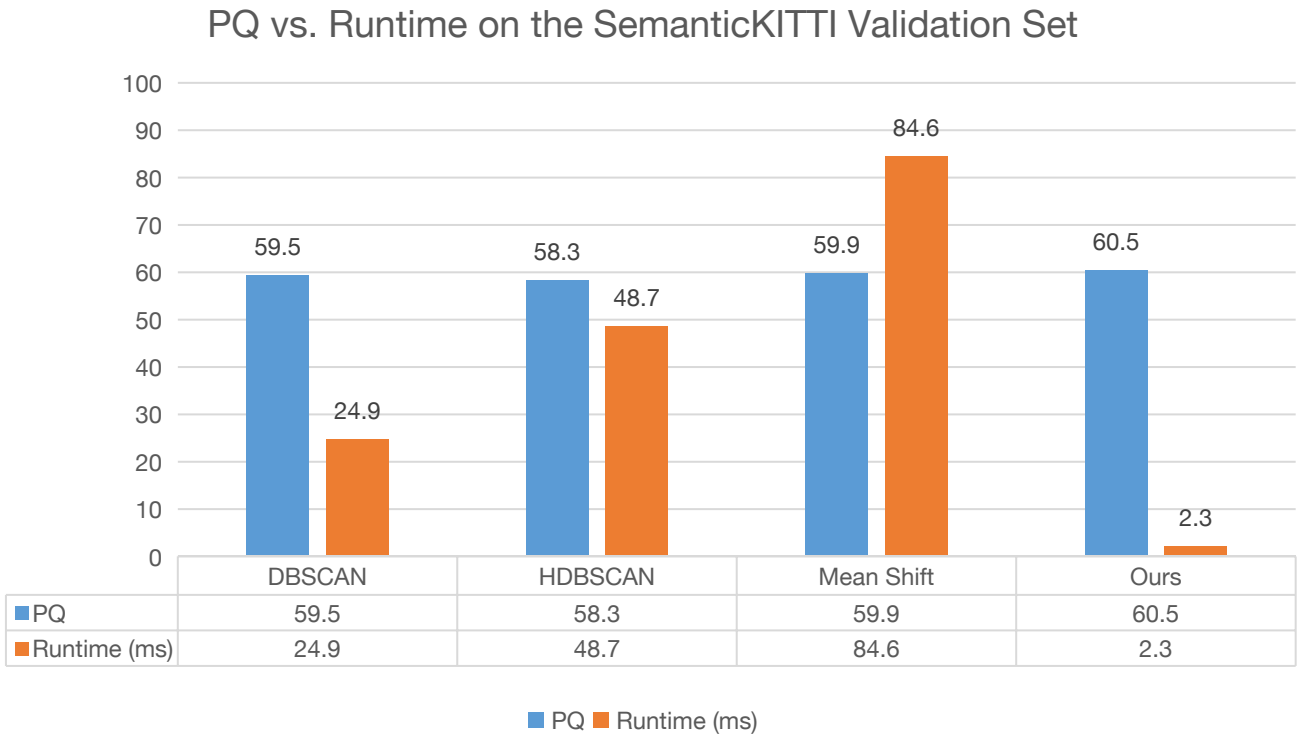
Accurate and Real-Time LiDAR Panoptic Segmentation

2. Real-Time: The costly center-based clustering algorithms slow down the overall inference speed

- These clustering algorithms follow a complicated iterative process



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Our Method—Center Focusing Network (CFNet)

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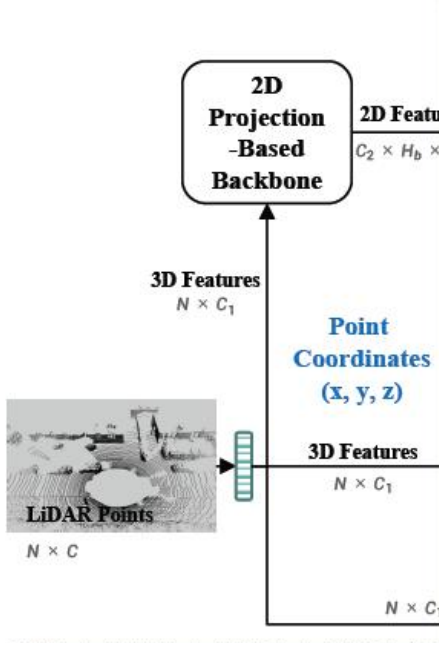
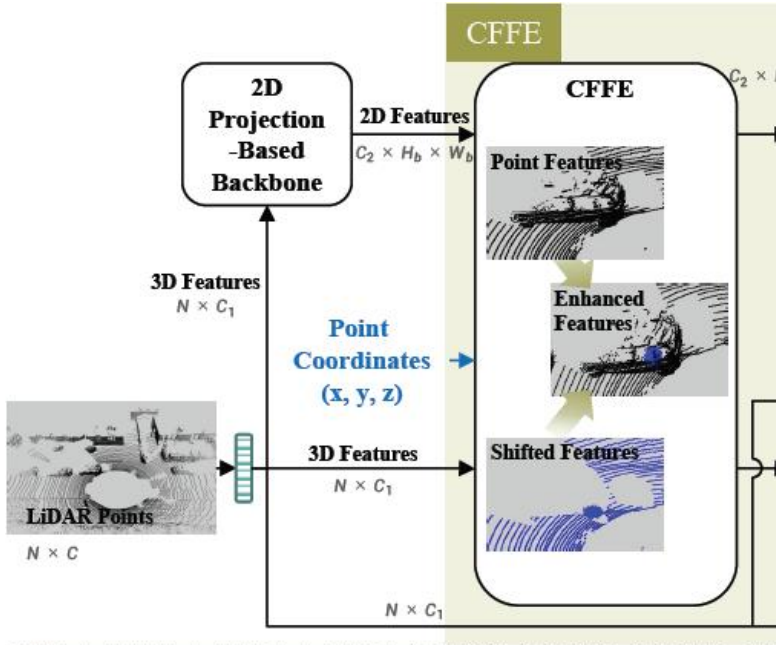


Four Step:

1. 2D projection-based backbone

Our Method—Center Focusing Network (CFNet)



Four Step:

1. 2D projection-based backbone
2. **Center focusing feature encoding (CFFE)**

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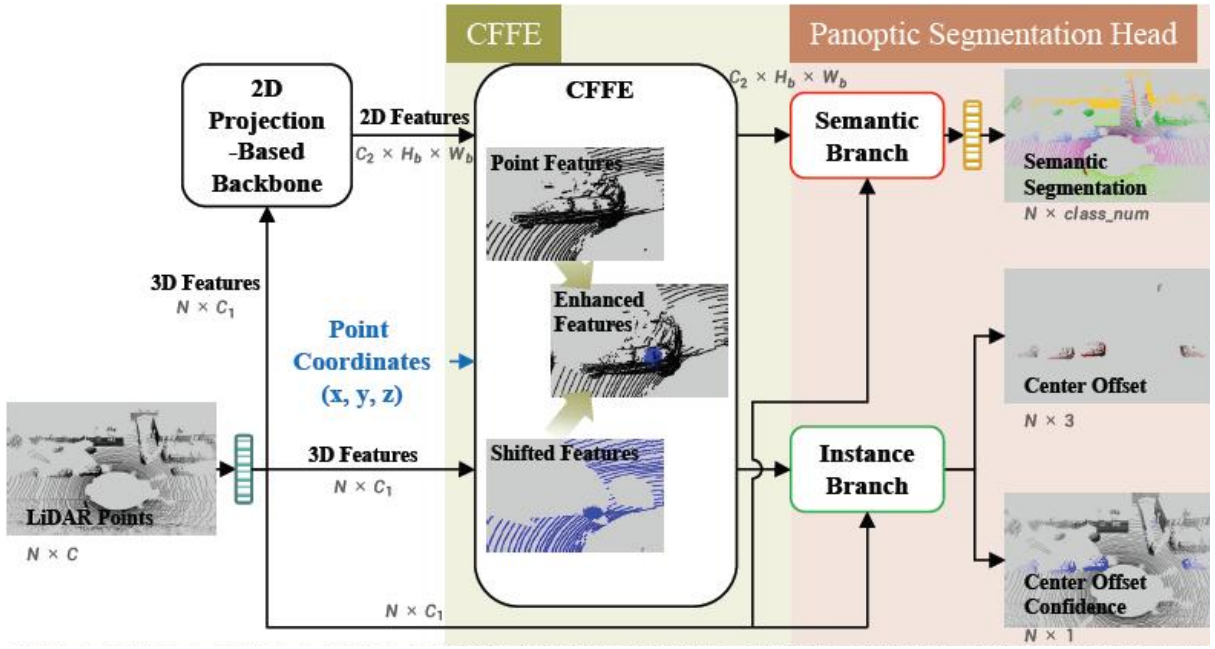
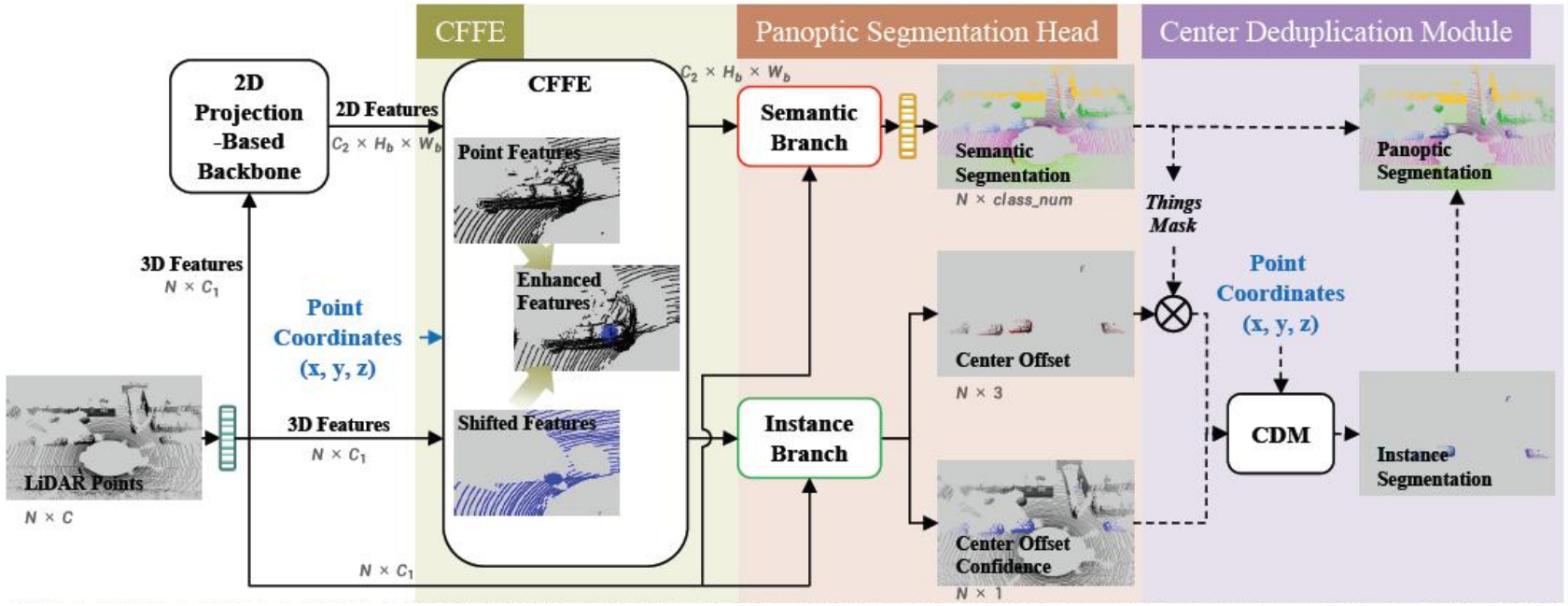
Our Method—Center Focusing Network (CFNet)



Four Step:

1. 2D projection-based backbone
2. **Center focusing feature encoding (CFFE)**
3. Panoptic segmentation head

Our Method—Center Focusing Network (CFNet)



Four Step:

1. 2D projection-based backbone
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4. **Center deduplication module (CDM)**

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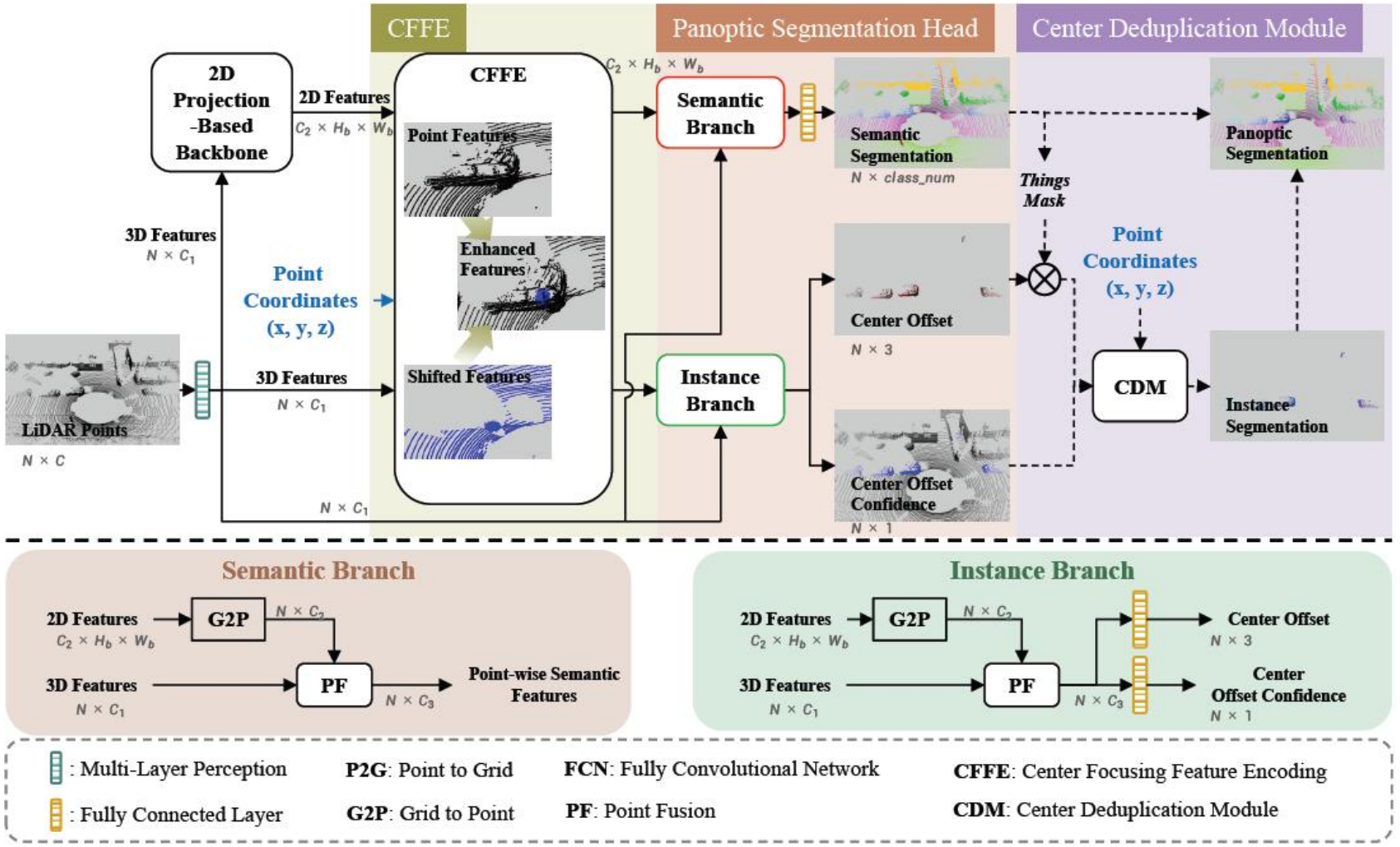


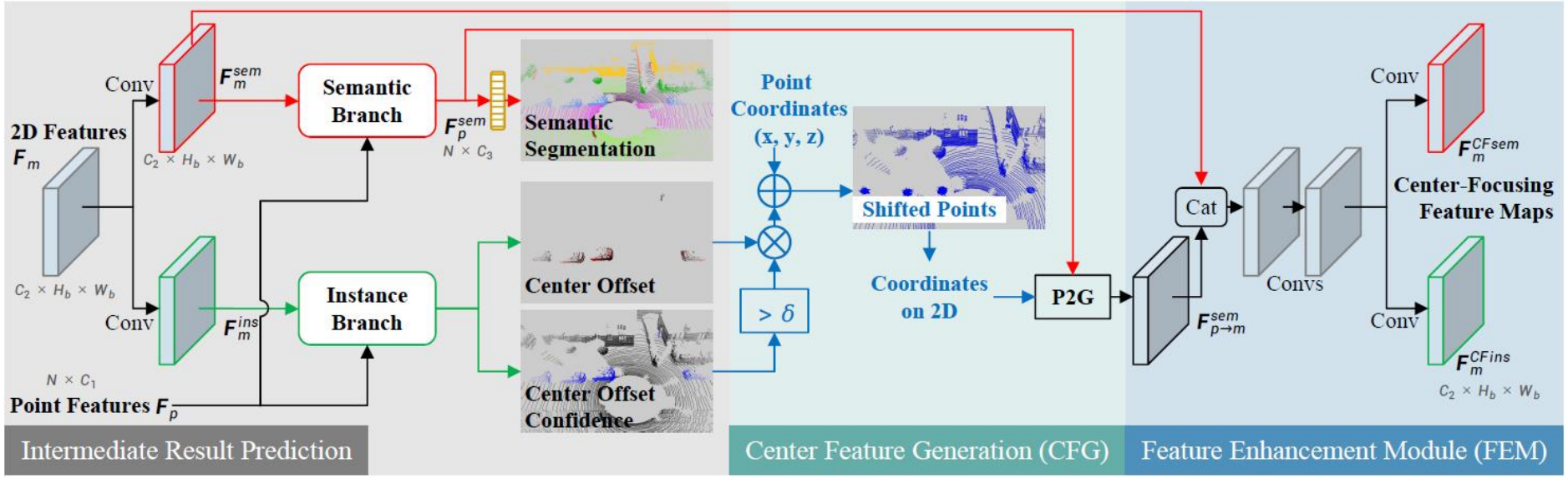
Four Step:

1. 2D projection-based backbone
2. **Center focusing feature encoding (CFFE)**
3. Panoptic segmentation head
4. **Center deduplication module (CDM)**

Our Method—Center Encoding

1. CFFE assists the model in understanding the relationships between the LiDAR points and **instance centers**

- Using the intermediate result predictions to **shift the LiDAR points and fill in the instance center points**
- Three modules: **Intermediate Result Prediction, Center Feature Generation, Feature Enhancement Module**

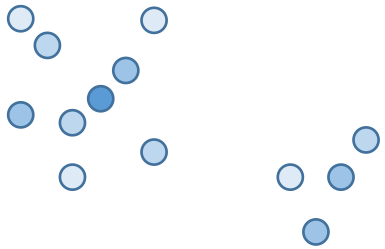


Framework of the proposed center focusing feature encoding (CFFE)

Our Method—Center Deduplication

2. Center deduplication module (CDM) efficiently **selects only one center for each instance**

- Suppressing the candidate instance centers with lower scores within a Euclidean distance threshold
- Being implemented efficiently in CUDA without iterative processing
- **Instance segmentation** is achieved by assigning the shifted ***Things*** points to the closest **deduplicated instance centers**



shifted *Things* points

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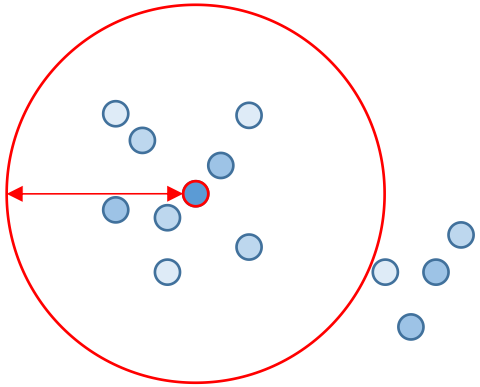

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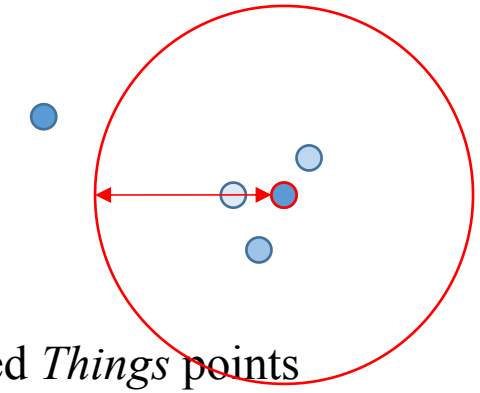

shifted *Things* points

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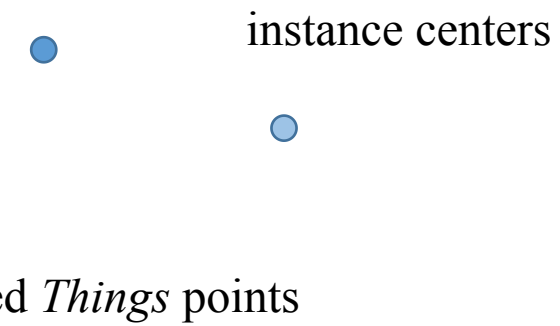
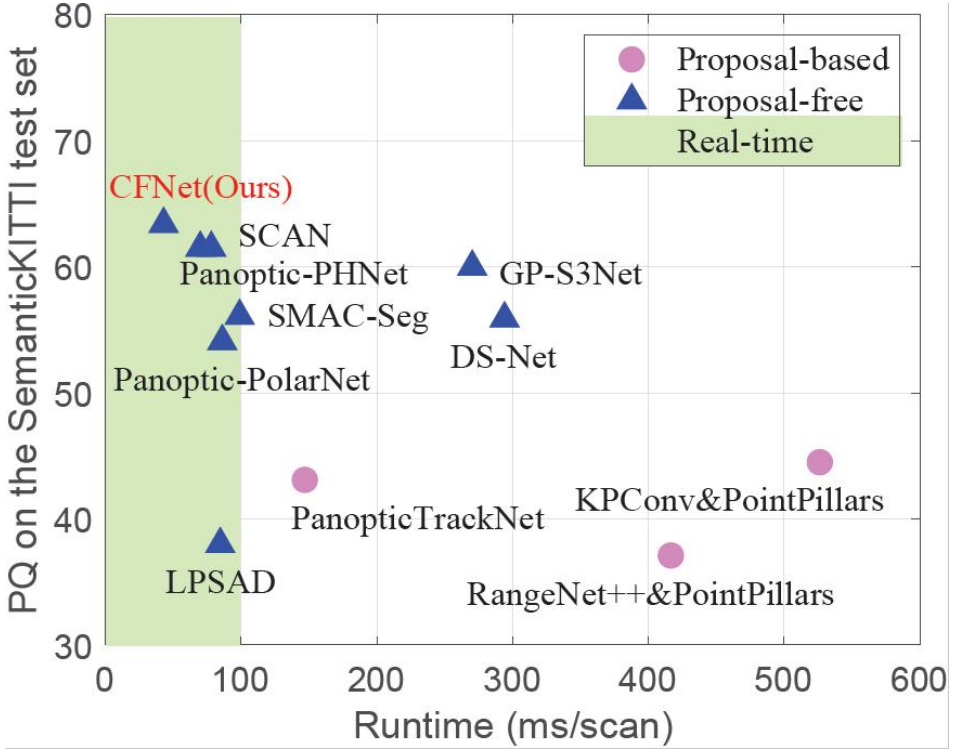


Experiment

1. Our CFNet achieves the **SOTA results with a real-time inference speed** on the SemanticKITTI leaderboard

   - Our CFNet achieves the **highest PQ of 63.4**
   - Our CFNet is **1.6 times** faster than the the current most efficient method **Panoptic-PHNet**



Experiment

2. Our CFNet achieves the **SOTA results** on the nuScenes validation set

- Our CFNet achieves the **highest PQ of 75.1**

Methods	PQ	PQ†	SQ	RQ	PQ^{Th}	SQ^{Th}	RQ^{Th}	PQ^{St}	SQ^{St}	RQ^{St}	mIoU
Proposal-based Methods											
Cylinder3D [40]&PointPillars [19]	36.0	44.5	83.3	43.0	23.3	83.7	27.0	57.2	82.7	69.6	52.3
Cylinder3D [40]&SECOND [36]	40.1	48.4	84.2	47.3	29.0	84.4	33.6	58.5	83.7	70.1	58.5
PanopticTrackNet [17]	51.4	56.2	80.2	63.3	45.8	81.4	55.9	60.4	78.3	75.5	58.0
EfficientLPS [31]	62.0	65.6	83.4	73.9	56.8	83.2	68.0	70.6	83.8	83.6	65.6
Proposal-free Methods											
LPSAD [24]	50.4	57.7	79.4	62.4	43.2	80.2	53.2	57.5	78.5	71.7	62.5
DS-Net [15]	42.5	51.0	83.6	50.3	32.5	83.1	38.3	59.2	84.4	70.3	70.7
GP-S3Net [29]	61.0	67.5	84.1	72.0	56.0	85.3	65.2	66.0	82.9	78.7	75.8
SMAC-Seg [20]	67.0	71.8	85.0	78.2	65.2	87.1	74.2	68.8	82.9	82.2	72.2
Panoptic-PolarNet [39]	63.4	67.2	83.9	75.3	59.2	84.1	70.3	70.4	83.6	83.5	66.9
SCAN [35]	65.1	68.9	85.7	75.3	60.6	85.7	70.2	72.5	85.7	83.8	77.4
Panoptic-PHNet [22]	74.7	77.7	88.2	84.2	74.0	89.0	82.5	75.9	86.8	86.9	**79.7**
CFNet [Ours] w/CPGNet [23]	**75.1**	**78.0**	**88.8**	**84.6**	**74.8**	**89.8**	**82.9**	**76.6**	**87.1**	**87.3**	79.3

Experiment—Ablation Studies

3. Effects of the CFFE

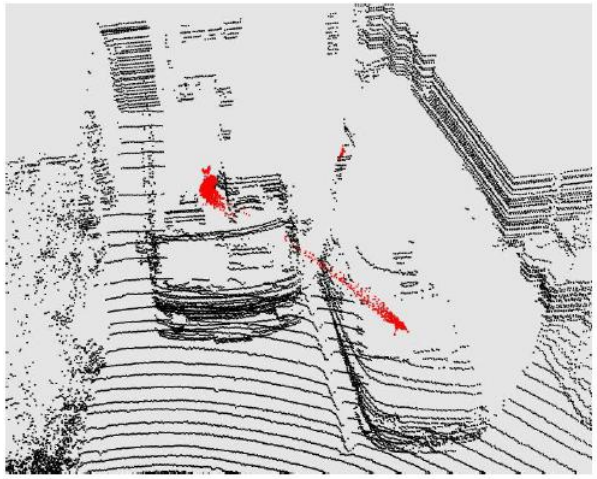
- The CFFE can improve the PQ for the backbones of PolarNet (+**1.3 PQ**) and CPGNet (+**2.2 PQ**)
- The CFFE brings acceptable latency for the backbones of PolarNet (+**6.6 ms**) and CPGNet (+**8.5 ms**)

	Backbone	CFFE		Deduplication	PQ	PQ†	PQ^{Th}	PQ^{St}	mIoU	RT(ms)
		CFG	FEM							
a	PolarNet [38]			BEV Center Heatmap [39]	59.1	64.1	65.7	54.3	64.5	65.3 + 20.9
b			✓	BEV Center Heatmap [39]	59.5	64.3	66.2	54.4	64.6	69.7 + 20.9
c		✓	✓	BEV Center Heatmap [39]	60.4	65.6	67.2	55.1	65.2	71.9 + 20.9
d		✓	✓	CDM [Ours]	**60.6**	**65.7**	**67.8**	**55.2**	**65.4**	**71.9 + 3.6**
e	CPGNet [23]			DBSCAN [11]	59.5	64.1	63.8	56.3	64.6	31.6+24.9
f				HDBSCAN [6]	58.3	62.9	60.9	56.3	64.9	31.6+48.7
g				MeanShift [9]	59.9	64.5	64.7	56.3	64.9	31.6+84.6
h				CDM [Ours]	60.5	65.6	66.1	56.5	66.3	**32.7+2.3**
i			✓	CDM [Ours]	60.8	65.9	66.3	56.9	66.5	37.4+2.3
j		✓	✓	CDM [Ours]	**62.7**	**67.5**	**70.0**	**57.3**	**67.4**	41.2+2.3

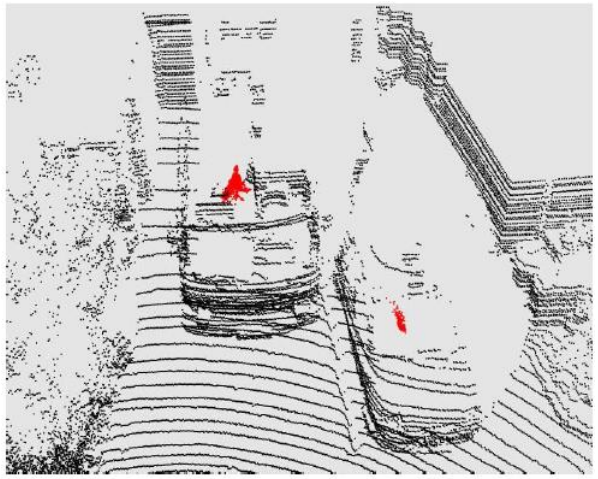
Experiment—Ablation Studies

3. Effects of the CFFE

- The CFFE makes the predicted instance centers more compact



(a) Intermediate Predictions

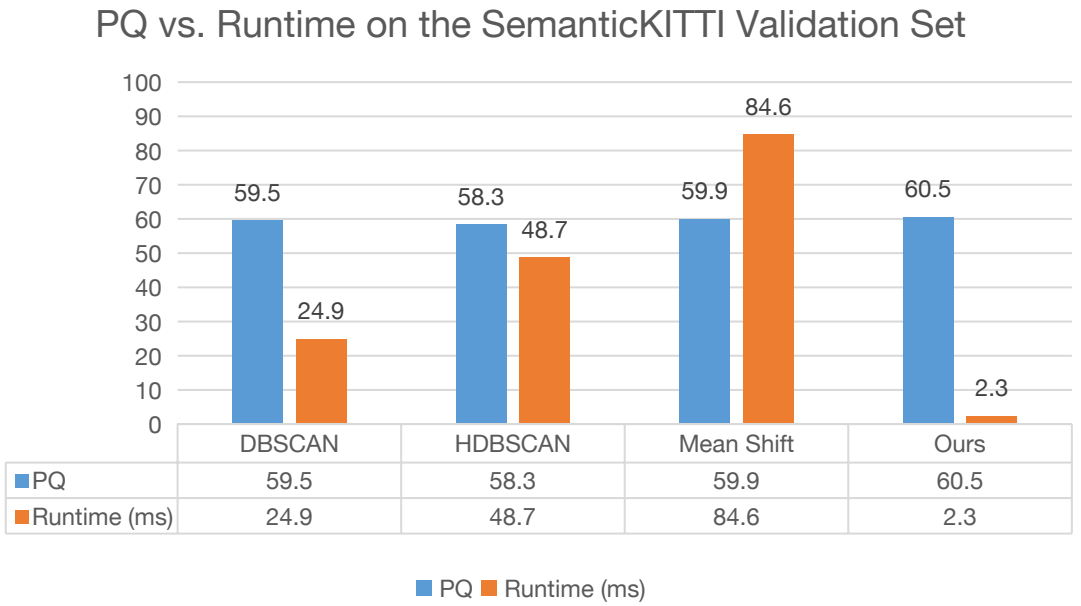


(b) Final Predictions

Experiment—Ablation Studies

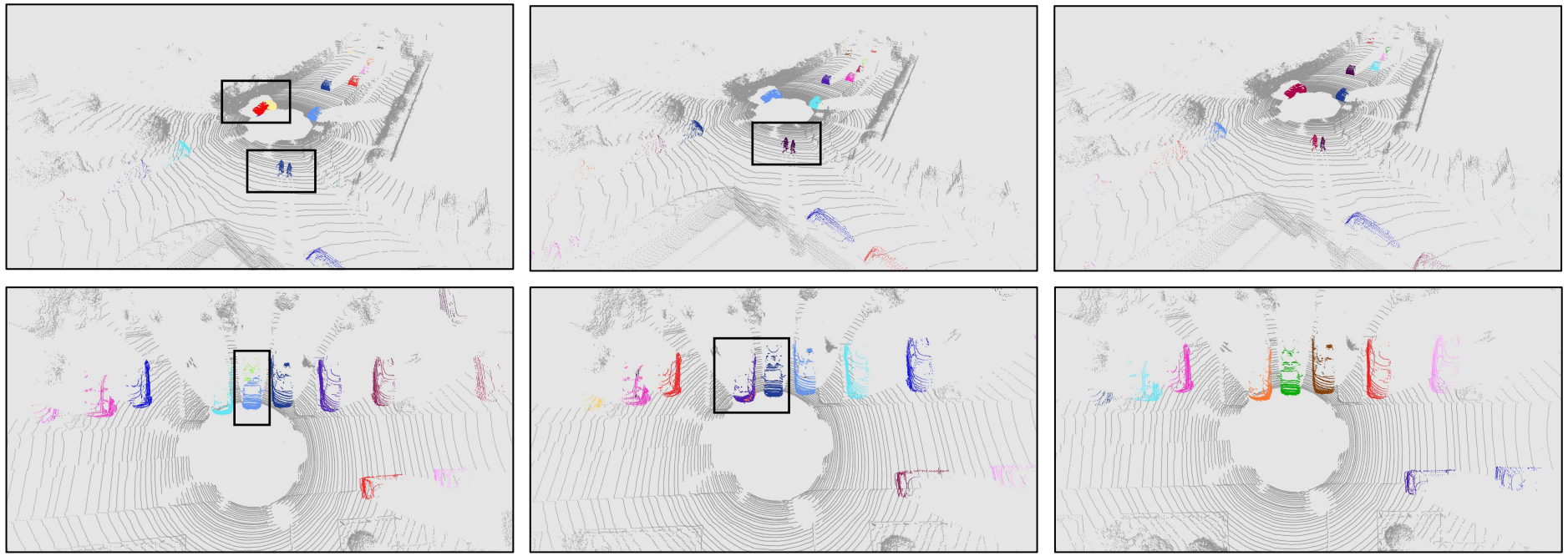
4. Effects of the CDM

- The CDM achieves the **best performance (+0.6 PQ~+2.2 PQ)**
- The CDM **significantly accelerates the inference speed**, since it is implemented efficiently in CUDA **without iterative processing**



Experiment—Ablation Studies

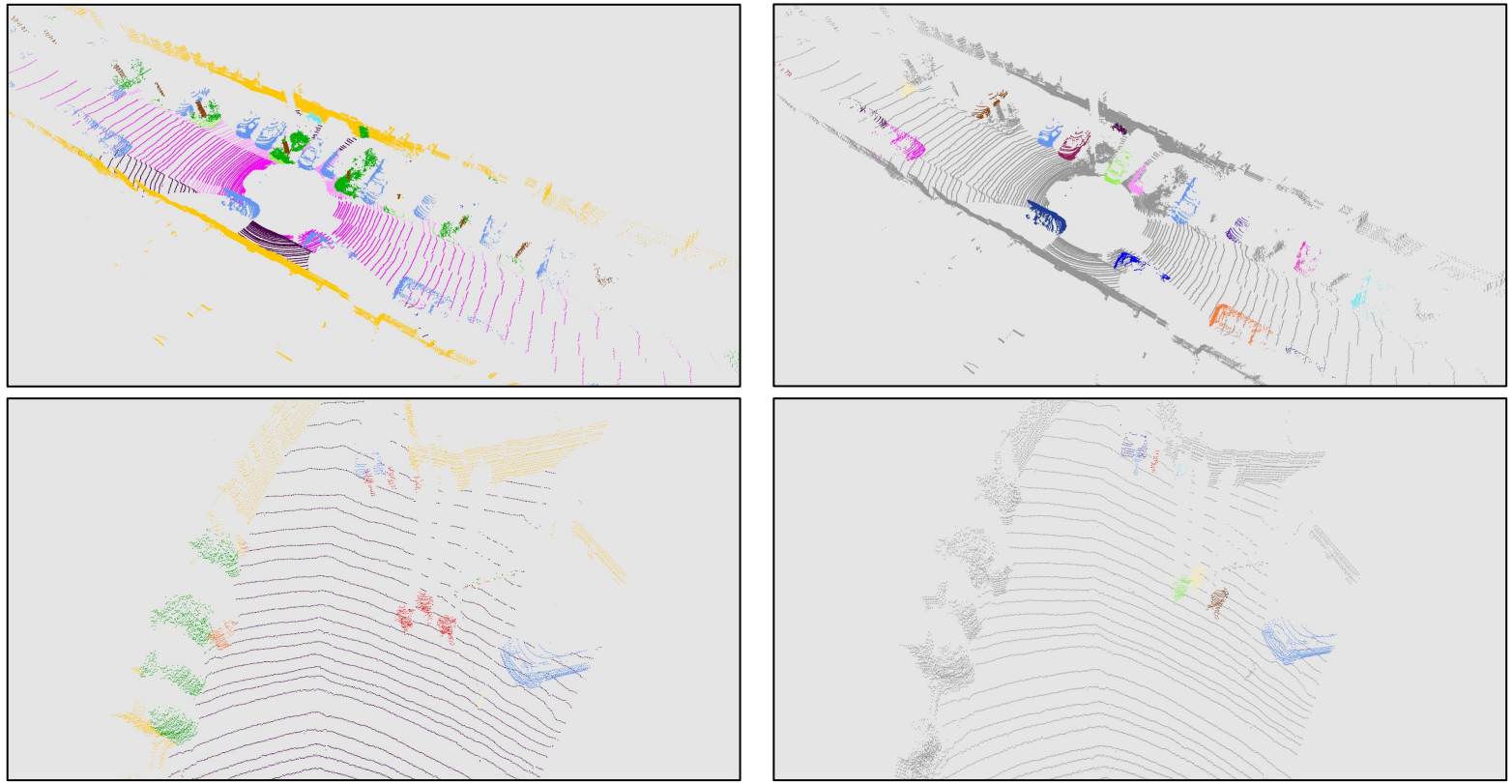
5. Comparison visualizations of instance segmentation from the Panoptic-PolarNet, DS-Net, and our CFNet



Panoptic-PolarNet DS-Net CFNet (Ours)

Experiment—Ablation Studies

6. Visualization results of our CFNet on the SemanticKITTI test set



semantic segmentation

instance segmentation

Thanks!