Multi-body SE(3) Equivariance for Unsupervised Rigid Segmentation and Motion Estimation

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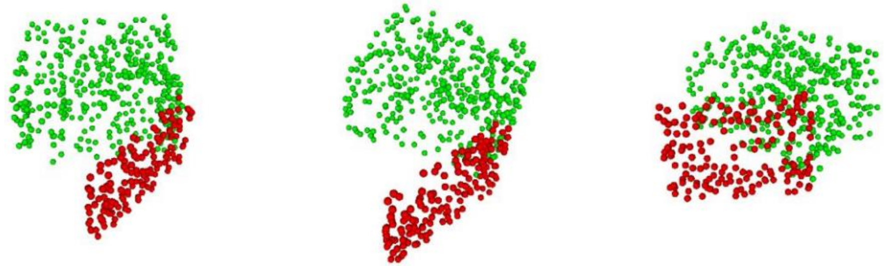
Overview

- Problem Statement
- Motivation & Main Idea
- Methodology
- Experiments
- Q & A

Problem Statement

- Unsupervised Multi-body Rigid Segmentation and Motion Estimation
  - Input
    - A set of K point cloud frames: $P = \{P_1, P_2, \dots, P_{K-1}, P_K\}$



    - Unsupervised: No training labels
    - Multi-body: Unknown multiple parts
  - Output
    - Rigid Segmentation: Moving-part rigid masks.
    - Motion Estimation: Per-part rotations and translations.

Motivation & Main Idea

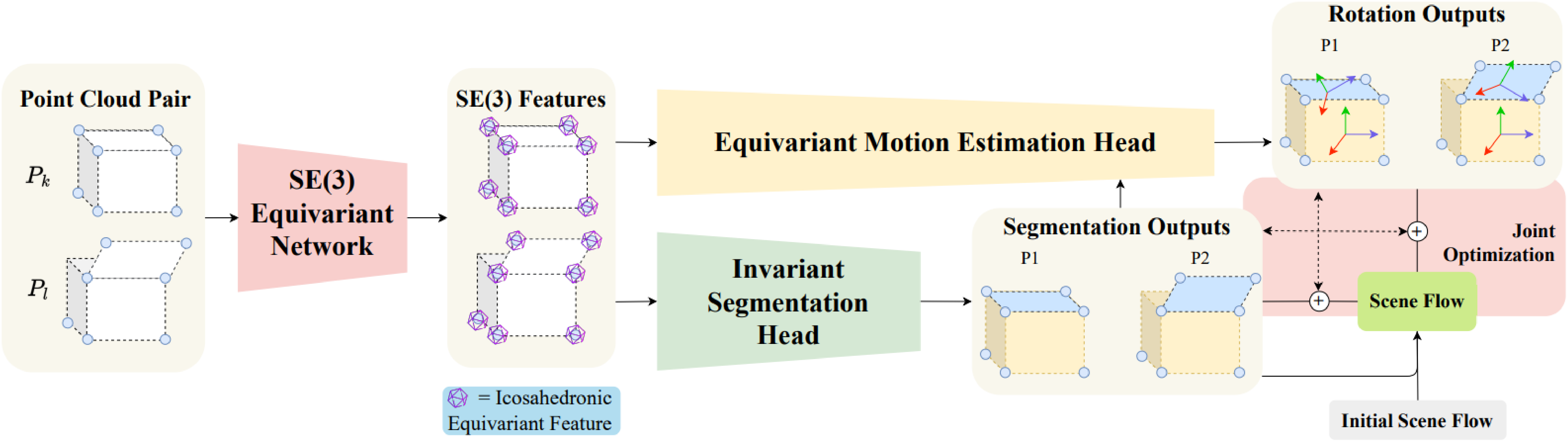
- Motivation
  - Open-set pose changes
    - SE(3)-equivariance
  - Category-agnostic about moving part
    - Matching
- Background
  - SE(3)-equivariance
- Main Idea
  - **Training Strategy:** simultaneously filter out the noisy flow predictions and refine the estimates of rigid motion by exploiting the interrelation among scene flow, segmentation mask, and rigid transformation
  - **Architecture:** Category-agnostic part-level SE(3)-equivariance

g: rigid transformation
f: features
x: a point in point clouds

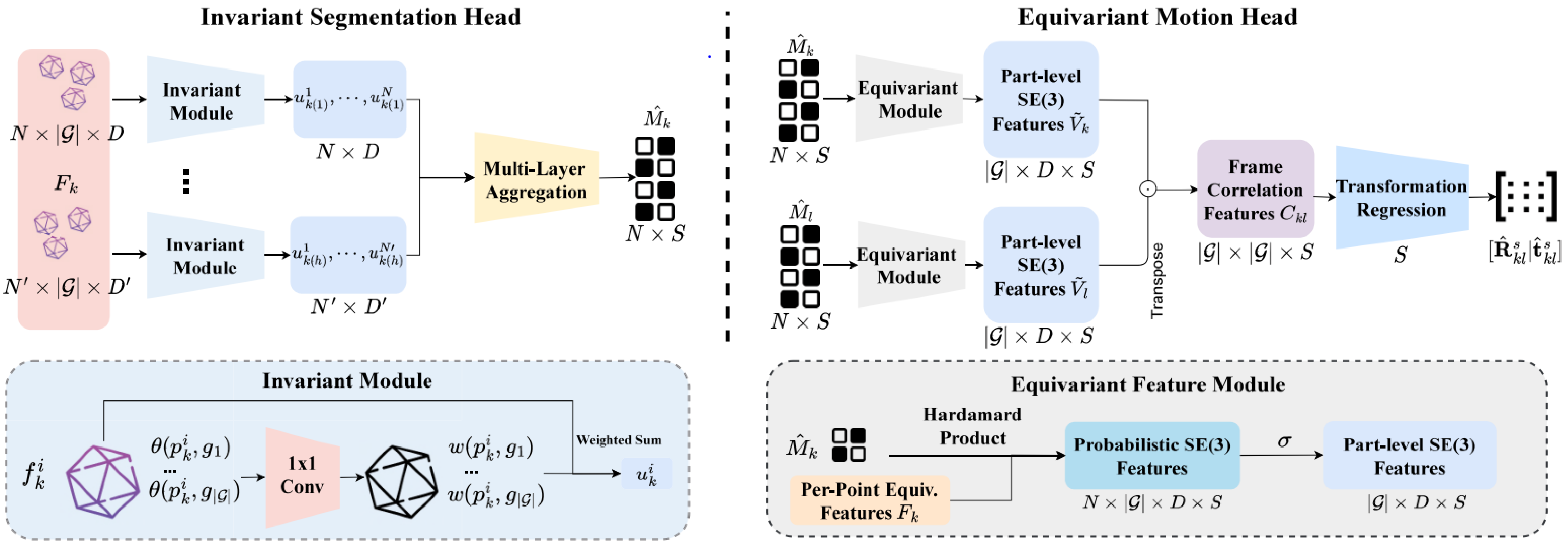
1) Rotation equivariance within the icosahedral group: $f(g \circ x) = g \circ f(x), \forall g \in \mathcal{G}$.

2) Translation invariance w.r.t. arbitrary translation t: $f(t \circ x) = f(x)$.

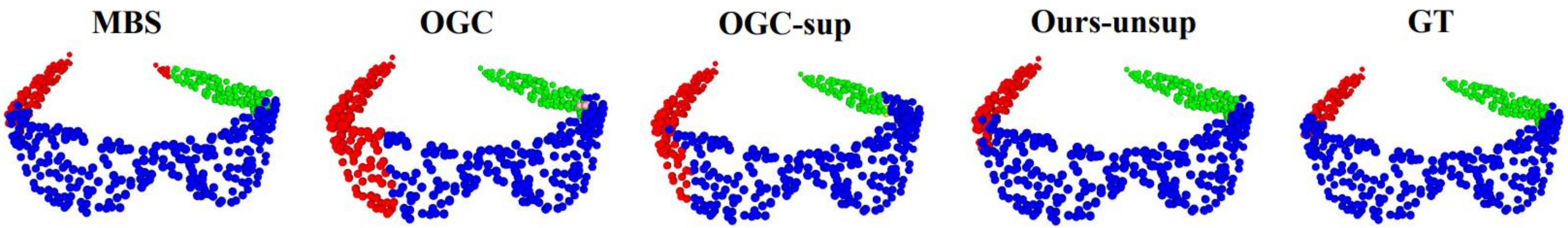
Methodology

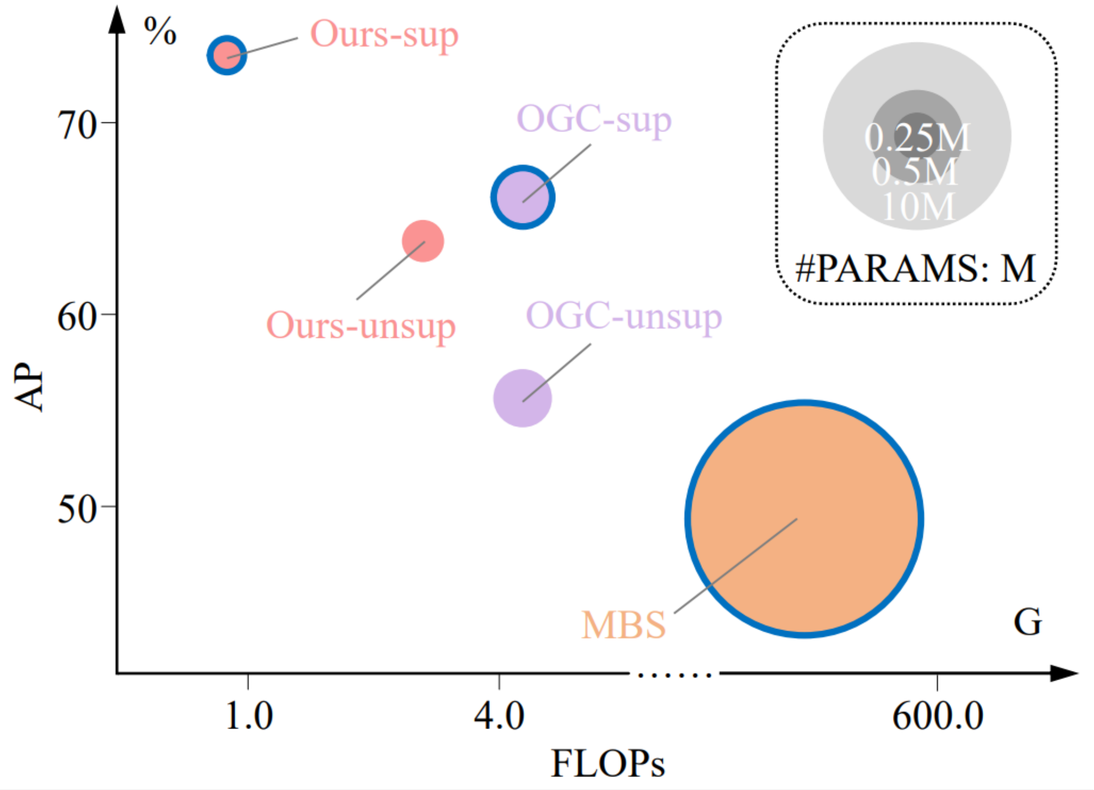


Methodology



Experiments





Experiments

Table 1: *Ablation studies on SAPIEN.*

Seg. Head		Scene Flow		Mot. Head	Metrics						
SE(3) Feat.	Point-level Flexibility	Current	Past	Consensus	AP↑	PQ↑	F1↑	Pre↑	Rec↑	mIoU↑	RI↑
					45.2	44.2	58.9	53.8	65.1	60.9	71.2
✓					51.7	50.0	65.8	64.7	67.0	61.6	72.3
✓	✓				55.3	52.8	68.3	65.9	70.0	62.3	72.7
✓	✓	✓			54.8	52.0	67.6	66.0	69.3	63.5	73.8
✓	✓	✓	✓		57.0	51.6	67.3	63.8	71.1	63.1	73.2
✓	✓	✓	✓	✓	63.8	61.3	77.3	84.2	71.3	63.7	75.4

Experiments

Table 2: *Rigid segmentation and motion estimation results on SAPIEN.* * indicates that we evaluate these metrics upon the officially released model; - means that the metric is unavailable.

		AP↑	PQ↑	F1↑	Pre↑	Rec↑	mIoU↑	RI↑	EPE3D↓
Supervised Methods	PointNet++ [55]	-	-	-	-	-	51.2	65.0	-
	MeteorNet [46]	-	-	-	-	-	45.7	60.0	-
	DeepPart [71]	-	-	-	-	-	53.0	67.0	5.95
	MBS [32]	49.4*	52.6*	67.6*	61.4*	75.2*	67.3	77.0	5.03
	OGC-sup [61]	66.1	48.7	62.0	54.6	71.7	66.8	77.1	-
	Ours-sup	**73.5**	**57.8**	**71.1**	**65.6**	**77.7**	**72.6**	**81.4**	**3.86**
Unsupervised Methods	TrajAffn [52]	6.2	14.7	22.0	16.3	34.0	45.7	60.1	-
	SSC [51]	9.5	20.4	28.2	20.9	43.5	50.6	65.9	-
	WardLinkage [66]	17.4	26.8	40.1	36.9	43.9	49.4	62.2	-
	DBSCAN [19]	6.3	13.4	20.4	13.9	37.9	34.2	51.4	-
	NPP [28]	-	-	-	-	-	51.5	66.0	21.22
	OGC [61]	55.6	50.6	65.1	65.0	65.2	60.9	73.4	-
	Ours	**63.8**	**61.3**	**77.3**	**84.2**	**71.3**	**63.7**	**75.4**	**5.47**

Experiments

Table 3: *Rigid segmentation results on OGC-DR and OGC-DRSV.*

		AP↑	PQ↑	F1↑	Pre↑	Rec↑	mIoU↑	RI↑
Supervised Methods	OGC-sup [61]	90.7 / 86.3	82.6 / 78.8	87.6 / 85.0	83.7 / 82.2	92.0 / 88.0	89.2 / 83.9	97.7 / 97.1
	Ours-sup	**92.8 / 89.3**	**86.9 / 82.6**	**91.0 / 87.9**	**88.8 / 85.5**	**93.2 / 90.4**	**91.2 / 86.6**	**98.7 / 97.9**
Unsupervised Methods	TrajAffn [52]	42.6 / 39.3	46.7 / 43.8	57.8 / 54.8	69.6 / 63.0	49.4 / 48.4	46.8 / 45.9	80.1 / 77.7
	SSC [51]	74.5 / 70.3	79.2 / 75.4	84.2 / 81.5	92.5 / 89.6	77.3 / 74.7	74.6 / 70.8	91.5 / 91.3
	WardLinkage [66]	72.3 / 69.8	74.0 / 71.6	82.5 / 80.5	**93.9 / 91.8**	73.6 / 71.7	69.9 / 67.2	94.3 / 93.3
	DBSCAN [19]	73.9 / 71.9	76.0 / 76.3	81.6 / 81.8	85.8 / 79.1	77.8 / 84.8	74.7 / 80.1	91.5 / 93.5
	OGC [61]	92.3 / 86.8	85.1 / 77.0	89.4 / 83.9	85.6 / 77.7	93.6 / 91.2	90.8 / 84.8	97.8 / 95.4
	Ours	**93.9 / 88.1**	**87.0 / 80.0**	**91.1 / 86.1**	87.0 / 80.8	**95.6 / 92.2**	**92.4 / 86.7**	**98.1 / 96.6**

Experiments

Table 4: *Rigid segmentation results on KITTI-SF.* Our model still achieves competitive results even though the data setting is inconsistent with the model's assumption.

Method Category	Method	AP↑	PQ↑	F1↑	Pre↑	Rec↑	mIoU↑	RI↑
Supervised Methods	OGC-sup [61]	62.4	52.7	65.1	63.4	67.0	67.3	95.0
	Ours-sup	**65.1**	**56.3**	**68.6**	**69.4**	**67.8**	**69.5**	**95.7**
Unsupervised Methods	TrajAffn [52]	24.0	30.2	43.2	37.6	50.8	48.1	58.5
	SSC [51]	12.5	20.4	28.4	22.8	37.6	41.5	48.9
	WardLinkage [66]	25.0	16.3	22.9	13.7	**69.8**	60.5	44.9
	DBSCAN [19]	13.4	22.8	32.6	26.7	42.0	42.6	55.3
	OGC [61]	**54.4**	42.4	52.4	47.3	58.8	**63.7**	**93.6**
	Ours	53.6	**44.4**	**55.1**	**56.3**	54.0	61.5	93.4

Experiments

Table 1: *Segmentation performance on KITTI-Det.*

Methods	**AP↑**	**PQ↑**	**F1↑**	**Pre↑**	**Rec↑**	**mIoU↑**	**RI↑**
OGC-sup [10]	51.4	41.0	49.1	43.7	56.0	66.2	91.0
Ours-sup	**52.5**	**43.3**	**51.8**	**47.5**	**57.0**	**68.0**	**92.6**
OGC-unsup [10]	40.5	30.9	37.0	30.8	**46.5**	**60.6**	86.4
Ours-unsup	**41.3**	**32.9**	**38.8**	**35.3**	43.1	60.2	**87.2**

Table 2: *Segmentation performance on SemanticKITTI.*

Sequences	**Methods**	**AP↑**	**PQ↑**	**F1↑**	**Pre↑**	**Rec↑**	**mIoU↑**	**RI↑**
00 - 10	OGC-sup [10]	53.8	41.3	48.1	40.1	60.0	68.3	90.0
	Ours-sup	**60.1**	**47.6**	**55.4**	**48.6**	**64.4**	**71.9**	**93.4**
	OGC-unsup [10]	42.6	30.2	35.3	28.2	47.3	60.3	86.0
	Ours-unsup	**46.9**	**31.6**	**36.9**	**29.0**	**50.6**	**63.2**	**88.7**
00 - 07 & 09 - 10	OGC-sup [10]	55.3	41.8	48.4	40.1	61.1	69.9	90.3
	Ours-sup	**60.5**	**48.1**	**55.6**	**48.8**	**64.7**	**73.2**	**93.8**
	OGC-unsup [10]	43.6	30.5	35.5	28.1	48.2	62.1	86.3
	Ours-unsup	**47.4**	**31.7**	**36.8**	**28.7**	**51.0**	**64.8**	**89.3**
08	OGC-sup [10]	49.4	39.2	46.6	40.0	55.8	60.3	88.3
	Ours-sup	**58.4**	**46.0**	**54.4**	**47.8**	**63.1**	**65.8**	**91.7**
	OGC-unsup [10]	38.6	29.1	34.7	28.6	44.0	51.8	84.3
	Ours-unsup	**44.2**	**31.0**	**37.3**	**30.0**	**49.1**	**55.8**	**86.1**

Q & A