Exploiting Unlabeled Data, Cheaper Labels and Efficient Annotation for 3D Point Cloud Deep Learning

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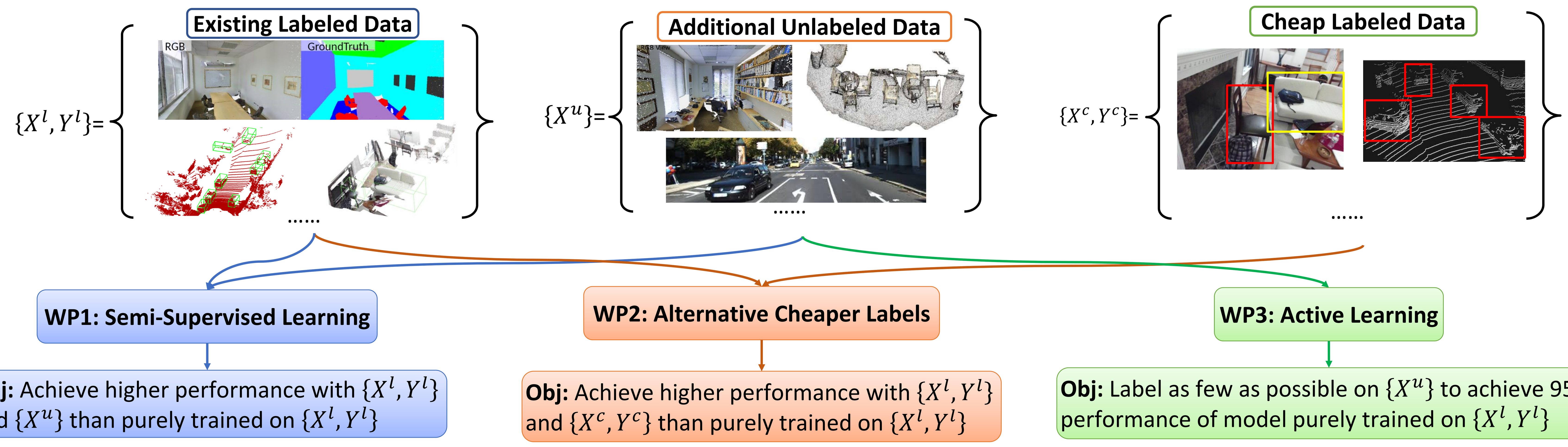
Background

Environment sensing is key to the safety of autonomous driving and robotics. 3D point cloud deep learning[1] is the state-of-the-art techniques, however, requires substantial amount of labeled data. We aim to exploit unlabeled data, cheaper labels and efficient annotation to improve the efficacy of 3D point cloud deep learning.

Key Challenges to Address

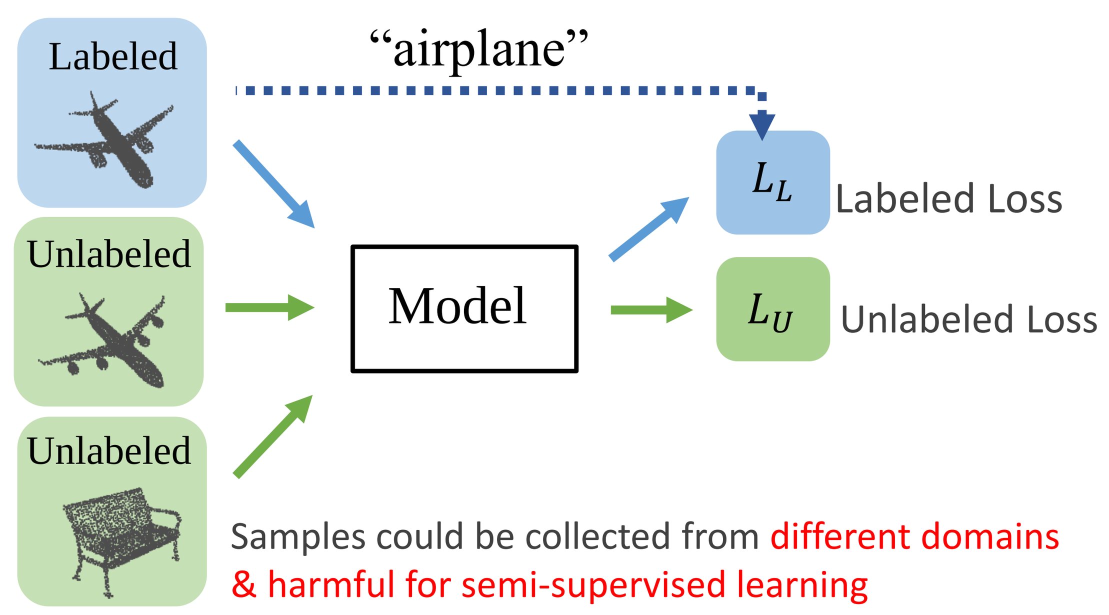
- ❑ Unlabeled data is abundant but hard to be used for training
- ❑ Cheap labeled data is easier to acquire but gives less precise supervision
- ❑ Annotation budget is precious and should be used wisely

Our Solution



WP1: Semi-Supervised Learning [2-3]

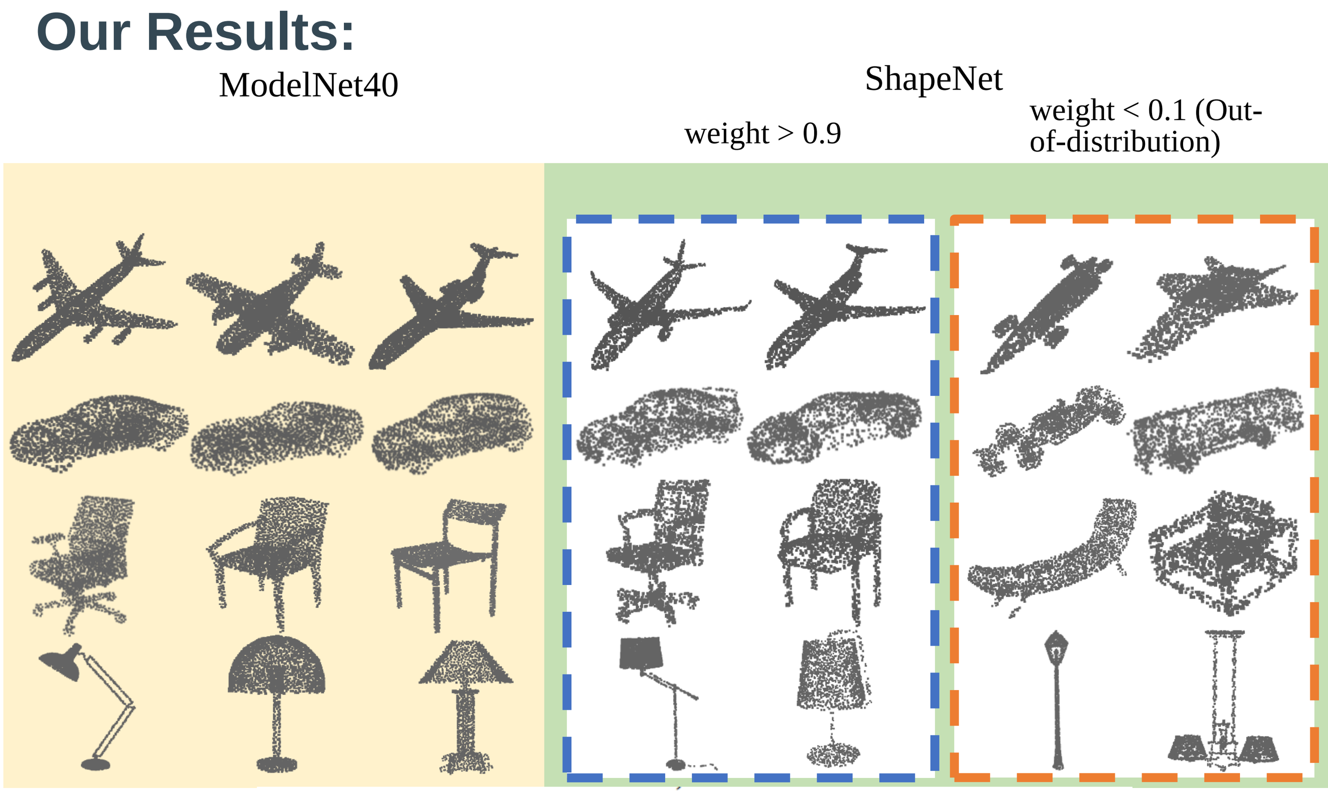
We develop the first open-set semi-supervised 3D point cloud semantic segmentation approach to exploit large uncurated unlabeled data.



Our Contributions:

- ❑ Formulate open-set semi-supervised learning as a bi-level optimization problem.
- ❑ A weight predictor network is introduced to estimate per-sample weights for unlabeled data.
- ❑ To address the instability issue of bi-level optimization, we introduce three regularization terms to further stabilize meta optimization loop.

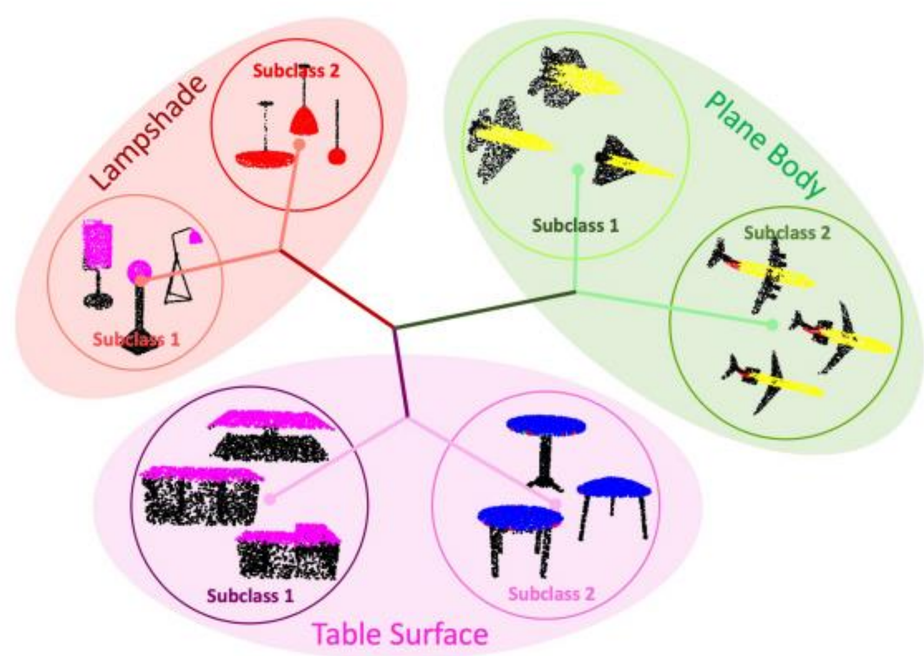
Our Results:



Data	Methods	1%	5%
$\{\mathcal{L}\}$	SO-Net[12]	64.0	69.0
	PointCapsNet[36]	67.0	70.0
	JointSSL[1]	71.9	77.4
	Multi-task[9]	68.2	77.7
$\{\mathcal{L},\mathcal{N}\}$	PCont[31]	74.0	79.9
$\{\mathcal{L},\mathcal{C}\}$	ACD[7]	75.7	79.7
$\{\mathcal{L},\mathcal{M}\}$	ReBO	76.2	80.1
$\{\mathcal{L},\mathcal{U},\mathcal{M}\}$	ReBO	**76.9**	**80.3**

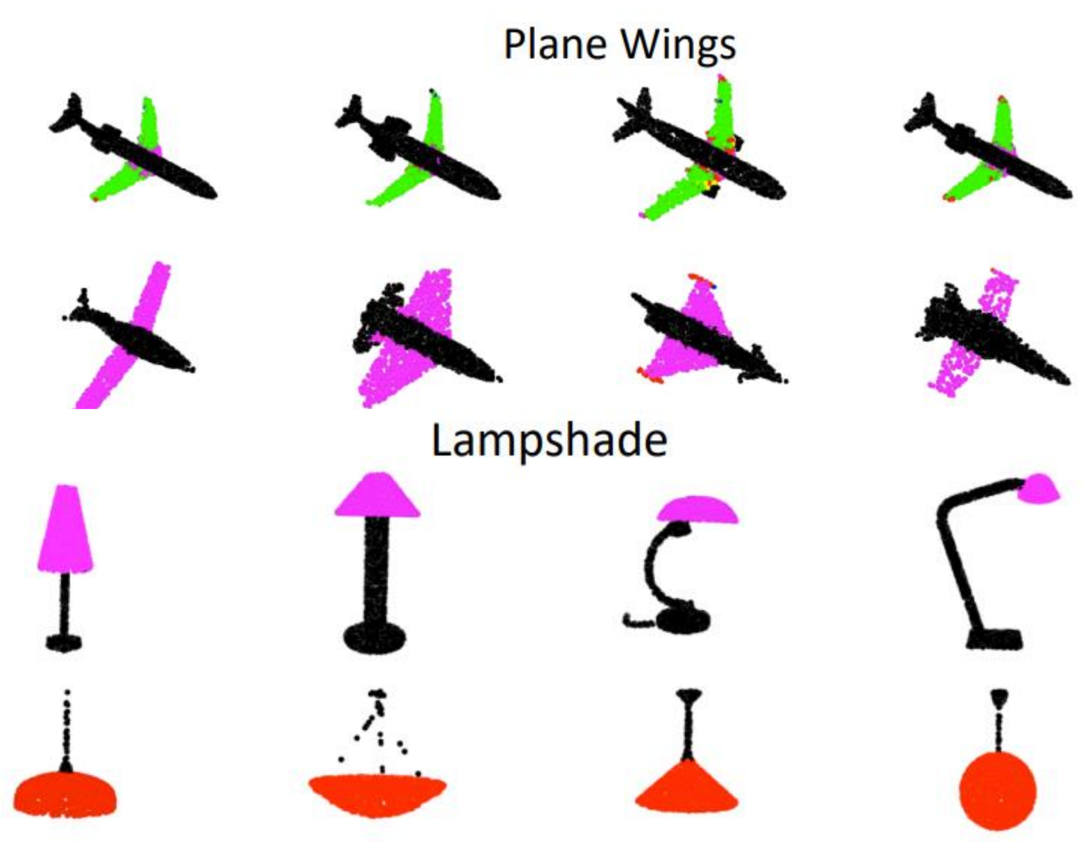
WP2: Alternative Cheaper Labels [4]

We developed weakly supervised 3D point cloud segmentation approach by introducing multi-prototype learning.



Our Contributions:

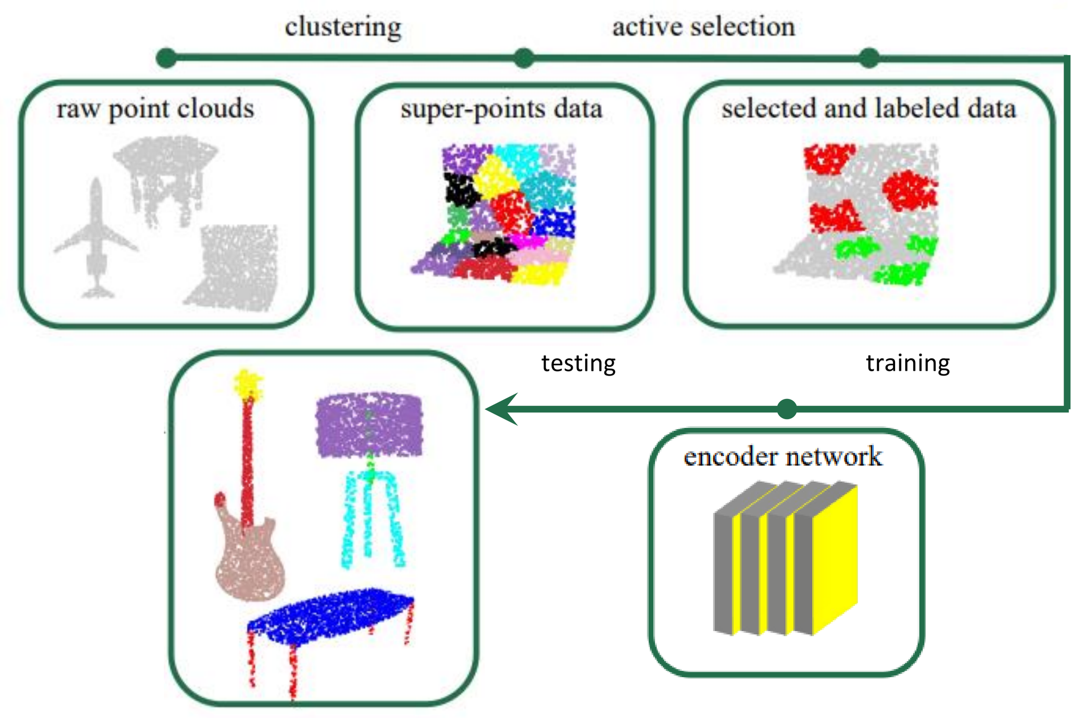
- ❑ Observing the clear sub-class structures in 3D point cloud data, we propose a multi-prototype classifier
- ❑ We propose a subclass averaging constraint to exploit both labeled and unlabeled data to supervise prototypes learning.
- ❑ We discover subclasses within each semantic category without any additional supervision.



Method	Annotation	SampAvg(%)	CatAvg(%)
DGCNN	1pt	72.6	72.2
DGCNN	10%	84.5	81.5
DGCNN	100%	85.1	82.3
DGCNN + MulPro	1pt	79.4	77.8
DGCNN + MulPro	10%	85.3	82.0
DGCNN + MulPro	100%	85.5	82.4

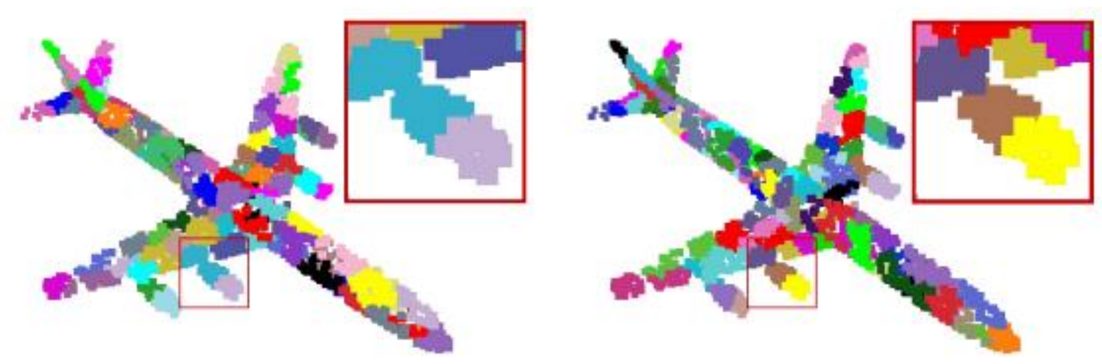
WP3: Active Learning [5-6]

We developed one of the first active learning approach to 3D point cloud segmentation.

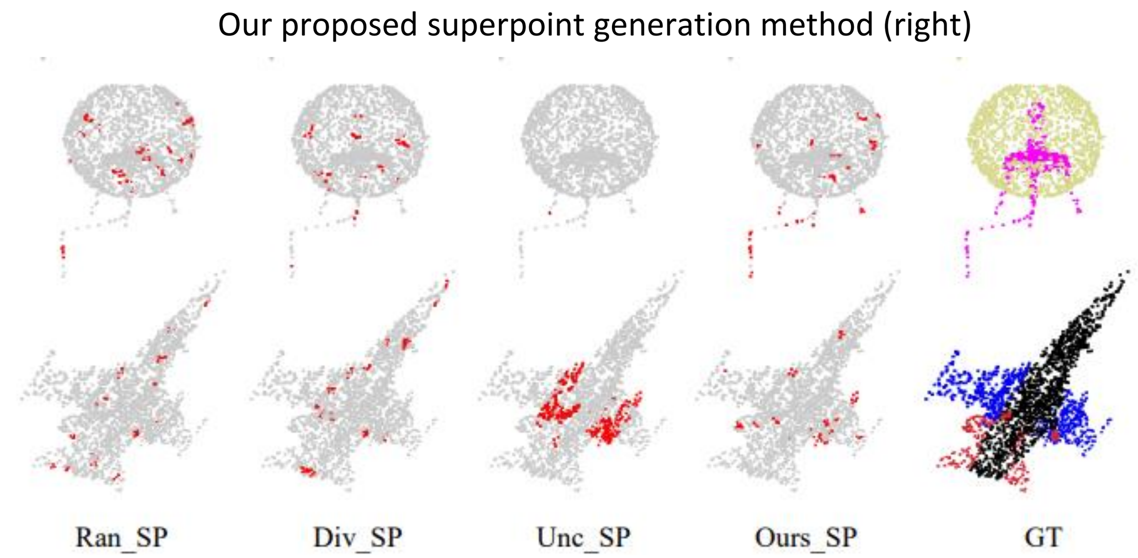


Our Contributions:

- ❑ We demonstrate that active learning is effective for label-efficient 3D point cloud segmentation.
- ❑ We investigate the effectiveness of point-level, instance-level, polygon-level and superpoint-level selection schemes using realistic, click-based annotation cost.
- ❑ We propose to combine uncertainty and feature diversity for active selection.



Our proposed superpoint generation method (right)



Comparing selected superpoints for annotation

Methods	mIoU (%)	#Clicks	#Points
SONet [46]	64.0	$\sim 250k$	$\sim 250k$
3DCNet [47]	67.0	$\sim 250k$	$\sim 250k$
MUS [48]	68.2	$\sim 250k$	$\sim 250k$
PTCT(HC) [7]	74.0	$\sim 250k$	$\sim 250k$
PTCT(PINCE) [7]	73.1	$\sim 250k$	$\sim 250k$
PCWS [4]	74.4	$\sim 200k$	$\sim 200k$
Ours	79.9	$200k$	$\sim 710k$

References (* corresponding author; # equal contribution)

[1] Qi, C. R., Su, H., Mo, K., & Guibas, L. J. (2017). Pointnet: Deep learning on point sets for 3d classification and segmentation. In *Proceedings of the IEEE conference on computer vision and pattern recognition* (pp. 652-660).
[2] Shi, X., **Xu, X.***, Zhang, W., Zhu, X., Foo, C. S., & Jia, K. (2022, August). Open-set semi-supervised learning for 3d point cloud understanding. In *2022 26th International Conference on Pattern Recognition (ICPR)* (pp. 5045-5051). IEEE.
[3] Deng, S.#, **Xu, X.**#, Wu, C., Chen, K., & Jia, K. (2021). 3d affordancenet: A benchmark for visual object affordance understanding. In *proceedings of the IEEE/CVF conference on computer vision and pattern recognition* (pp. 1778-1787).
[4] Su, Y., **Xu, X.***, & Jia, K. (2023). Weakly Supervised 3D Point Cloud Segmentation via Multi-Prototype Learning. *IEEE Transactions on Circuits and Systems for Video Technology*.
[5] Liang, Z., **Xu, X.***, Deng, S., Cai, L., Jiang, T., & Jia, K. (2024). Exploring diversity-based active learning for 3d object detection in autonomous driving. *Submitted to IEEE Transactions on Intelligent Transportation Systems.*
[6] Shi, X.#, **Xu, X.#***, Chen, K., Cai, L., Foo, C. S., & Jia, K. (2024). Label-efficient point cloud semantic segmentation: An active learning approach. *Submitted to World Scientific Annual Review of Artificial Intelligence.*