Let Images Give You More: Point Cloud Cross-Modal Training for Shape Analysis

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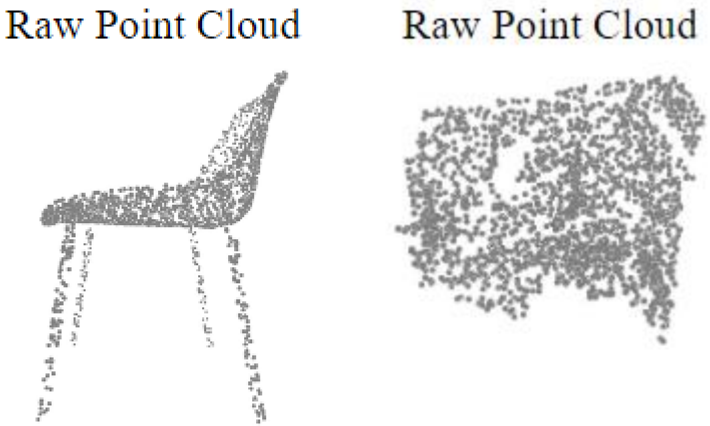
Motivation

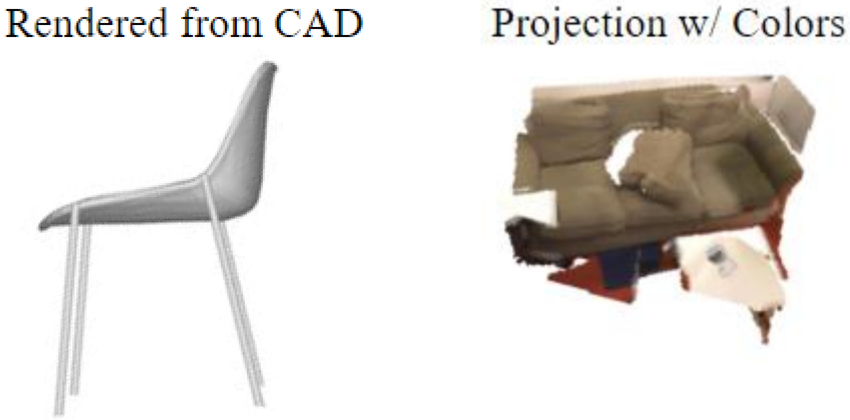
3D point cloud:
Partial and geometric information.
Only sparse and textureless features.

2D image:
Rich color and fine-grained texture.
Ambiguous in depth and shape sensing.



Two problems

Or one?



Motivation

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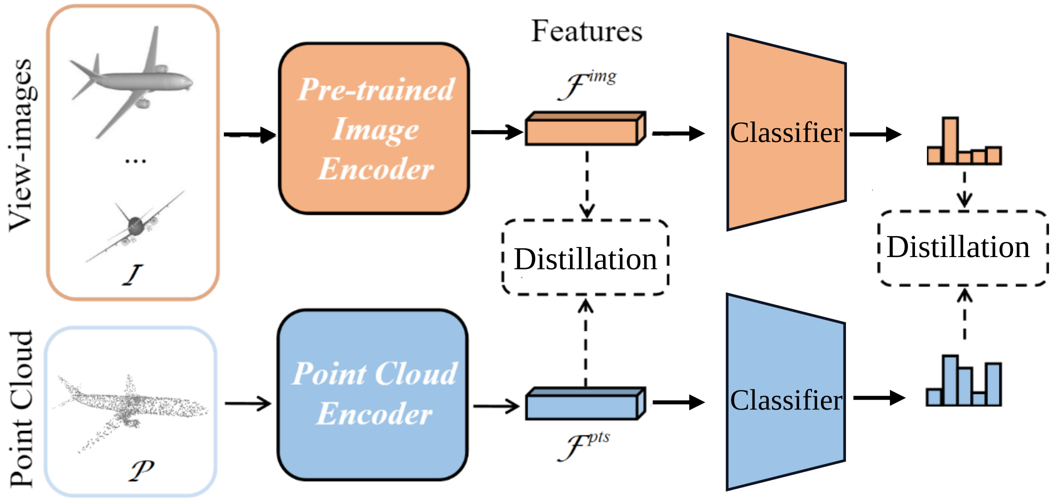
Could we use the rich information hidden in 2D images to boost 3D point cloud shape analysis?

Motivation

Knowledge distillation:
Takes extra image inputs **only in training phases**.
Not computation-intensive during inference.
Don't need paired-images during inference.

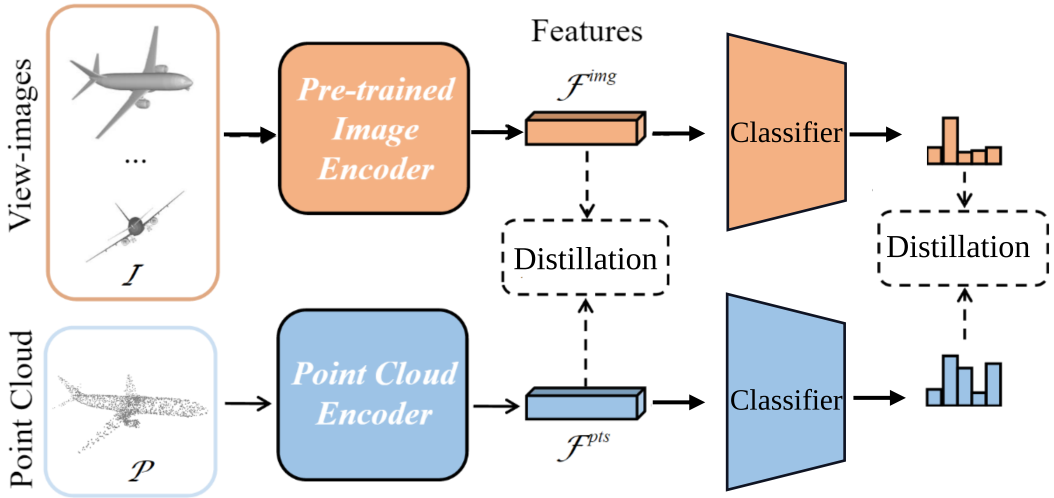


Motivation

Our cross-modality setting:

3D and 2D data contain different information.

Encoders are quite different.



Motivation

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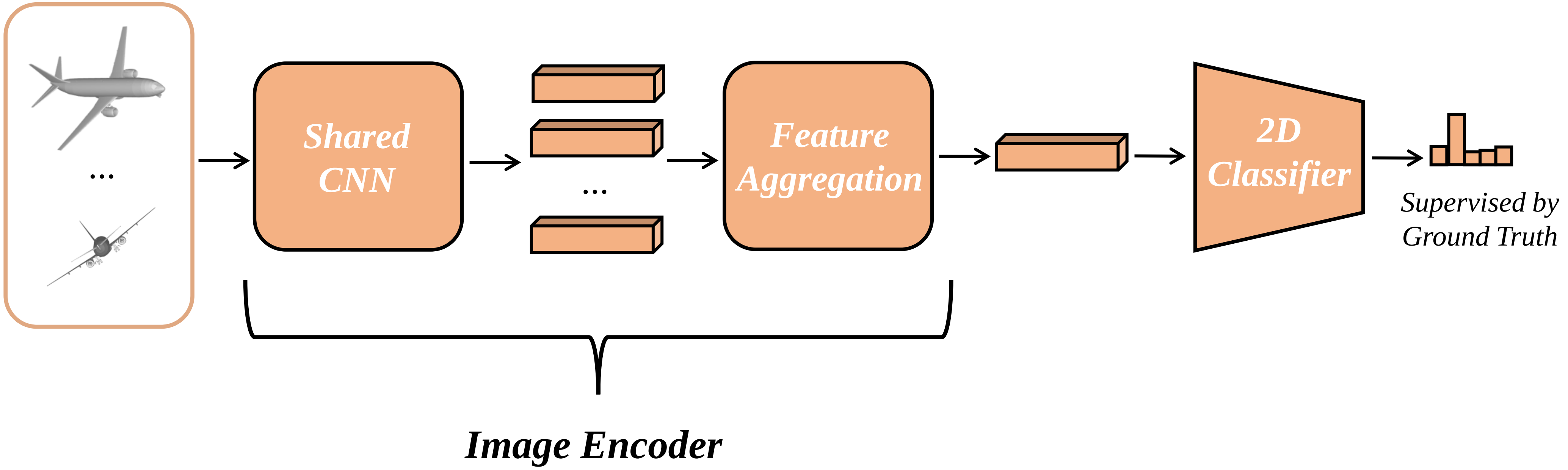
New cross-modal knowledge distillation methods are needed!

PointCMT

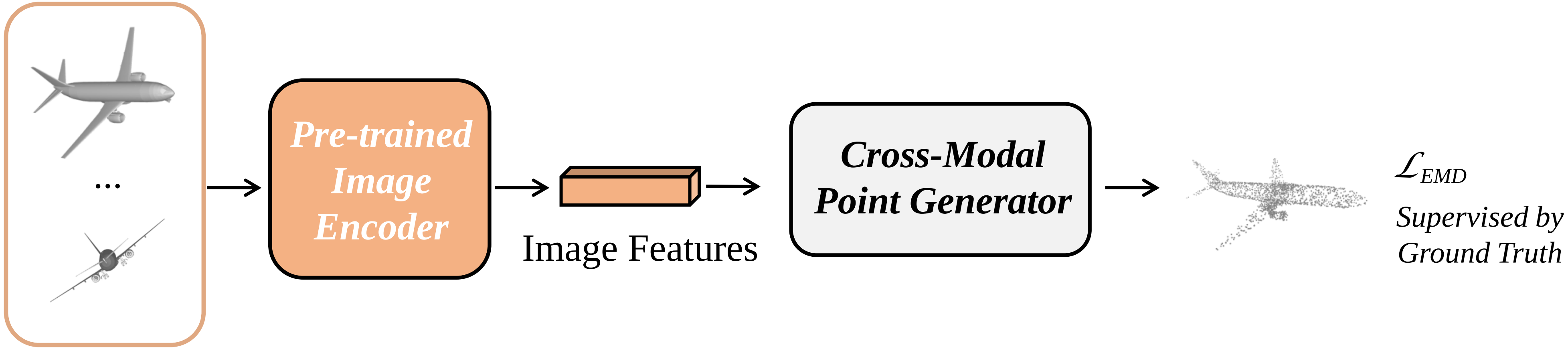
Obtaining image encoder:

$$\mathcal{F}^{img} = \mathcal{A}\{\text{CNN}(\mathcal{I}_v)\}_{v=1}^{V}.$$



PointCMT

Training cross-modal point generator (CMPG):



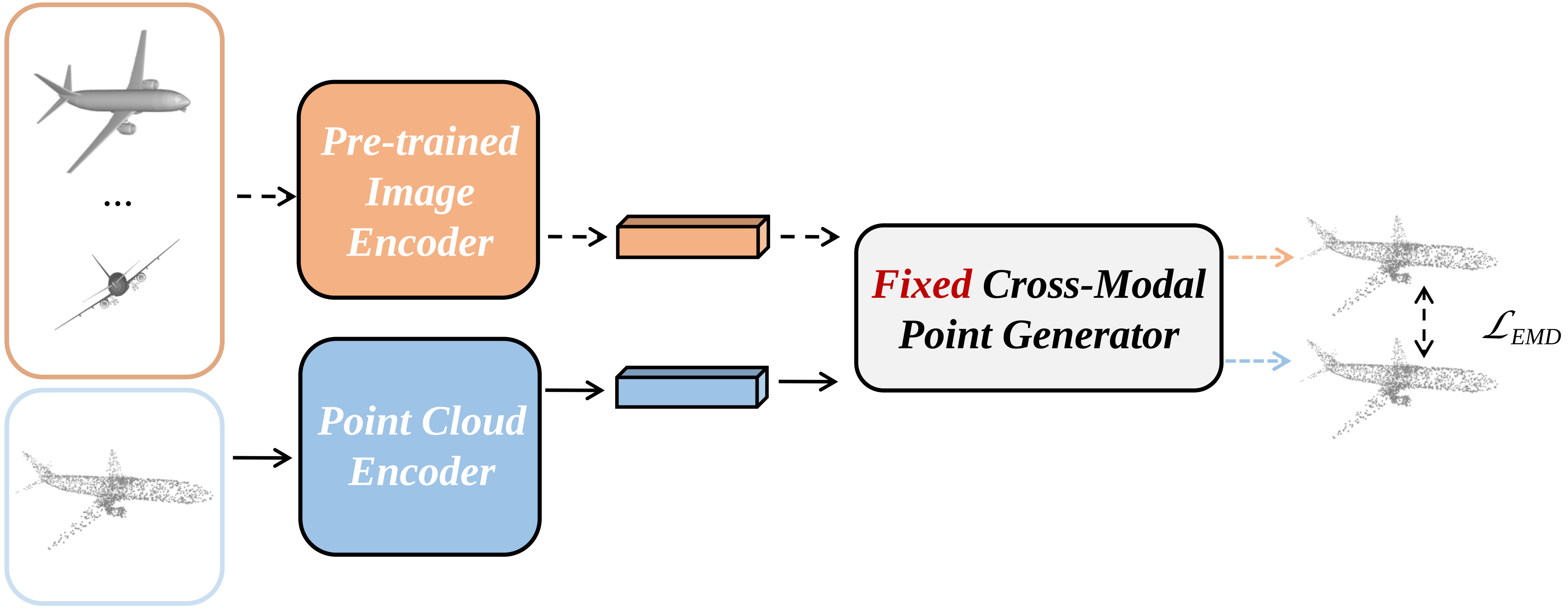
$$\mathcal{L}_{\text{EMD}}(\mathcal{P}, \hat{\mathcal{P}}^{img}) = \min_{\phi} \sum_{p \in \mathcal{P}} ||p - \phi(p)||$$

Compared with traditional L_2 loss, the EMD distance is natural for solving an assignment problem for permutation-invariant point sets!

PointCMT

Feature Enhancement Loss:

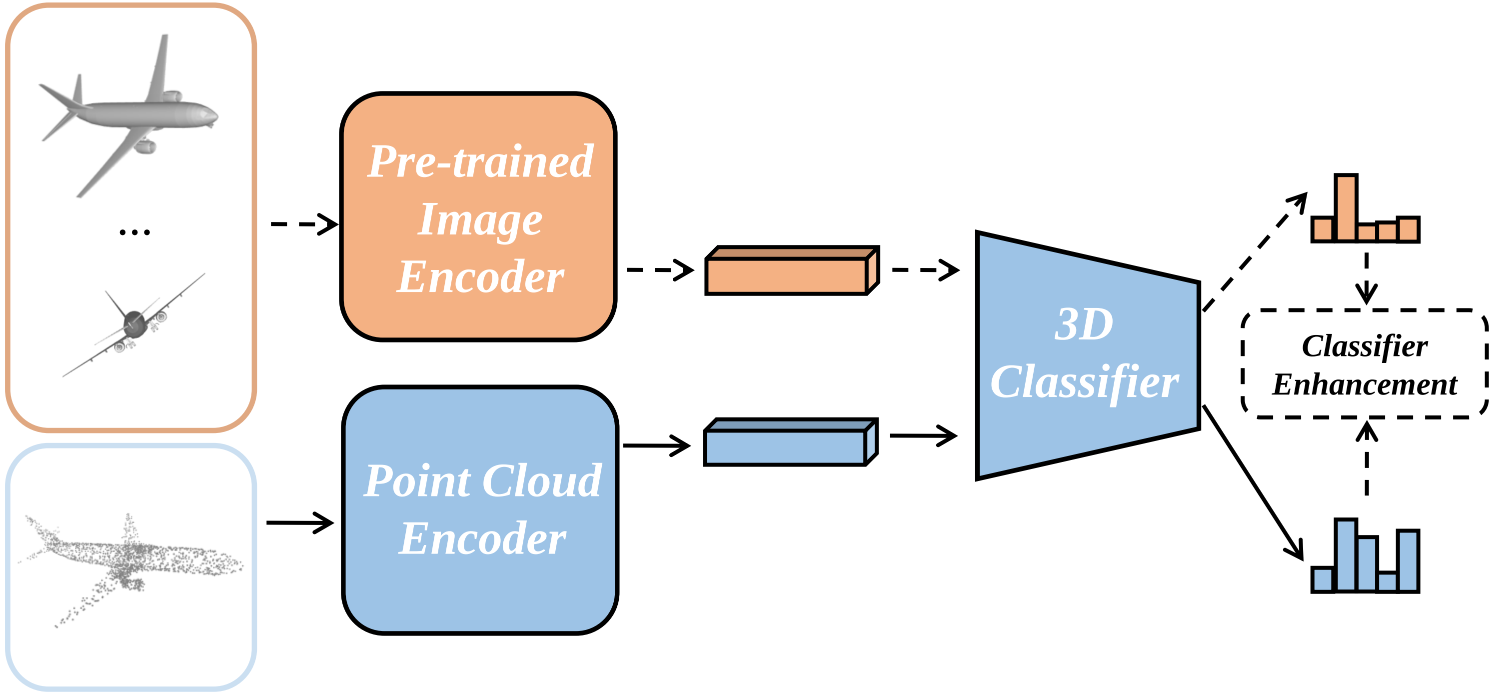
$$\mathcal{L}_{\text{Feature}} = \mathcal{L}_{\text{EMD}}(\hat{\mathcal{P}}^{pts}, \hat{\mathcal{P}}^{img}) = \min_{\phi} \sum_{p \in \hat{\mathcal{P}}^{pts}} ||p - \phi(p)||$$



PointCMT

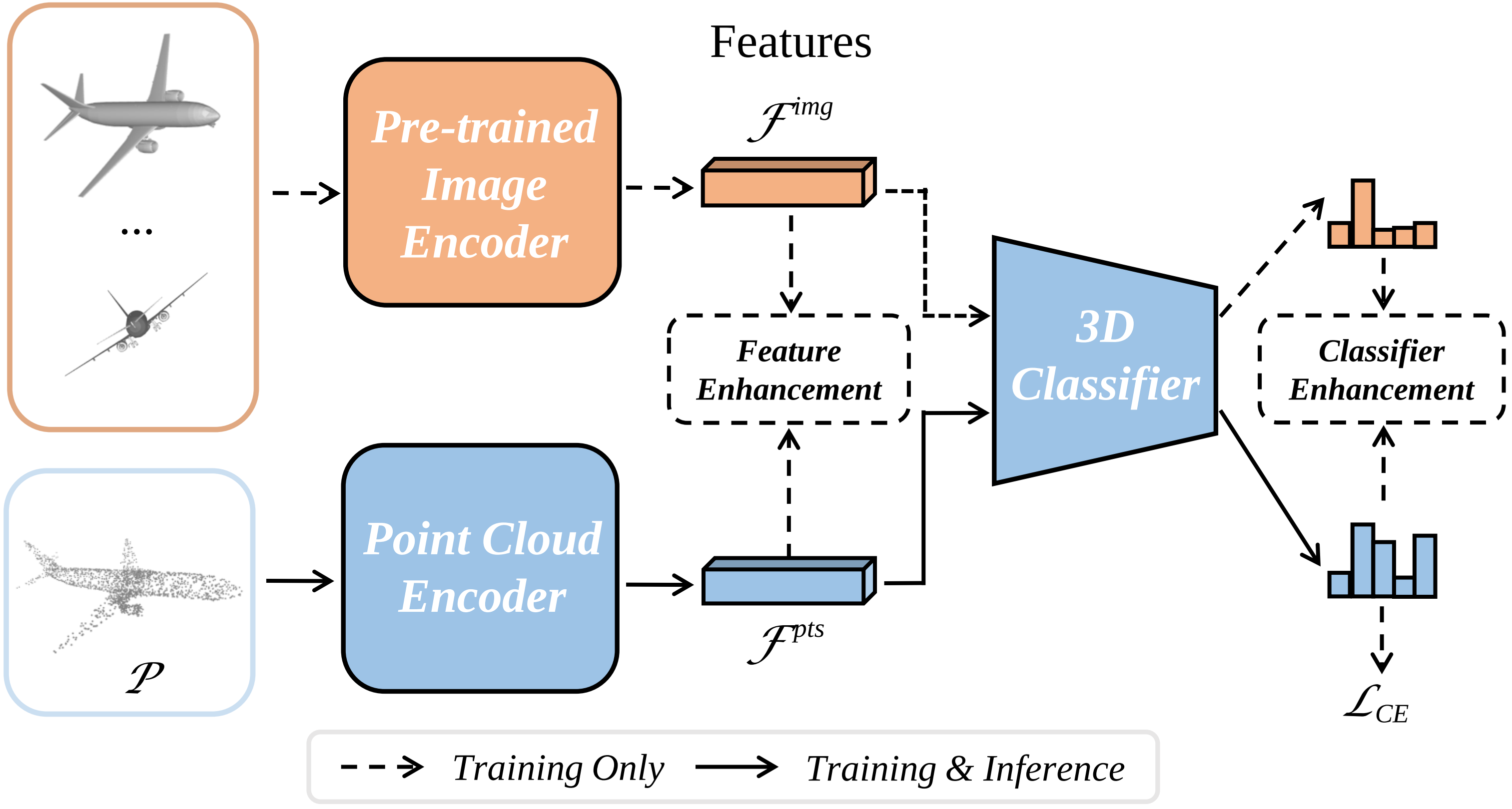
Classifier Enhancement Loss:

$$\mathcal{L}_{\text{Classifier}} = \mathcal{D}_{KL}(\text{Cls}^{pts}(\mathcal{F}^{img})||\text{Cls}^{pts}(\mathcal{F}^{pts}))$$



PointCMT

The whole framework of PointCMT:



Experiment

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Classification results on ModelNet40 dataset

Method	Input	#Points	mAcc(%)	OA(%)	Speed	Param.
PointNet [33]	pnt	1k	86.0	89.2	-	3.47M
PointNet++ [34]	pnt, nor	5k	-	91.9	-	1.47M
PointCNN [25]	pnt	1k	88.0	92.5	-	-
PointConv [47]	pnt, nor	1k	-	92.5	$80^{\dagger}$	18.6M
KPConv [39]	pnt	7k	-	92.9	$10^{\dagger}$	15.2M
PointASNL [54]	pnt, nor	1k	-	93.2	-	-
PosPool [29]	pnt	5k	-	93.2	-	-
Point Transformer [60]	pnt	1k	90.6	93.7	-	-
GBNet [36]	pnt	1k	91.0	93.8	$112^{\dagger}$	8.4M
GDANet [51]	pnt	1k	-	93.8	$14^{\dagger}$	0.9M
SimpleView [12]	pnt	1k	-	93.9	2208	1.64M
CurveNet [49]	pnt	1k	-	94.2	$15^{\dagger}$	2.0M
PointMLP [31]	pnt	1k	**91.4**	**94.5**	139	12.6M
DGCNN [43] (baseline)	pnt	1k	90.2	92.9	518	1.68M
RS-CNN [27] (baseline)	pnt	1k	89.3	92.9	2174	1.17M
PointNet++ [34] (baseline)	pnt	1k	90.1	93.4*	300	1.62M
DGCNN **w/** PointCMT	pnt	1k	90.8 (+0.6)	93.5 (+0.6)	518	1.68M
RS-CNN **w/** PointCMT	pnt	1k	90.1 (+0.8)	93.8 (+0.9)	2174	1.17M
PointNet++ **w/** PointCMT	pnt	1k	<u>91.2</u> (+1.1)	<u>94.4</u> (+1.0)	300	1.62M

Experiment

Classification results on ScanObjectNN dataset:

Method	OBJ_ONLY mAcc(%)	OBJ_ONLY OA(%)	PB_T50_RS mAcc(%)	PB_T50_RS OA(%)
3DmFV [3]	-	73.8	58.1	63.0
PointNet [33]	-	79.2	63.4	68.2
SpiderCNN [52]	-	79.5	69.8	73.7
PointNet++ [34]	-	84.3	75.4	77.9
DGCNN [43]	-	86.2	73.6	78.1
PointCNN [25]	-	85.5	75.1	78.5
DRNet [35]	-	-	78.0	80.3
GBNet [36]	-	-	77.8	80.5
SimpleView [12]	86.2	89.0	-	80.8
PRANet [4]	-	-	79.1	82.1
MVTN [15]	-	-	-	82.8
PointNet++ [34] (baseline)	85.4±0.2	87.4±0.1	75.5±0.3	79.2±0.2
PointMLP [31] (baseline)	89.1±0.3	92.2±0.3	83.9±0.5	85.4±0.3
PointNet++ w/ PointCMT	89.0±0.3 (+3.7)	91.6±0.2 (+4.3)	79.9±0.3 (+4.4)	83.1±0.2 (+3.9)
PointMLP w/ PointCMT	**91.8±0.2** (+2.6)	**93.2±0.3** (+1.0)	**84.4±0.4** (+0.4)	**86.4±0.3** (+1.0)

Experiment

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Ablation study on ModelNet40 and ScanObjetNN dataset:

Model	FE	CE	ModelNet40	OBJ_ONLY	PB_T50_RS
PointNet++	✗	✗	93.4	87.5	79.4
	✓	✗	93.8 (+0.4)	89.2 (+1.7)	82.5 (+3.1)
	✗	✓	94.0 (+0.6)	91.3 (+3.8)	82.3 (+2.9)
	✓	✓	94.4 (+1.0)	91.8 (+4.3)	83.3 (+3.9)

Comparison with Knowledge Distillation Methods:

Method	ModelNet40	PB_T50_RS
Baseline	93.4	79.4
Hinton *et al.* [17]	93.1 (-0.3)	81.8 (+2.4)
Huang *et al.* [21]	93.6 (+0.2)	82.0 (+2.6)
Yang *et al.* [55]	93.9 (+0.5)	81.1 (+1.7)
PointCMT (ours)	**94.4** (+1.0)	**83.3** (+3.9)

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Thanks for watching!

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