NEURAL INFORMATION PROCESSING SYSTEMS

UNIVERSITÉ Concordia UNIVERSITY

GINA CODY SCHOOL OF ENGINEERING AND COMPUTER SCIENCE

GeoCurv-TTT: Geometry-Aware Deformation Restoration for 3D Test-Time Training

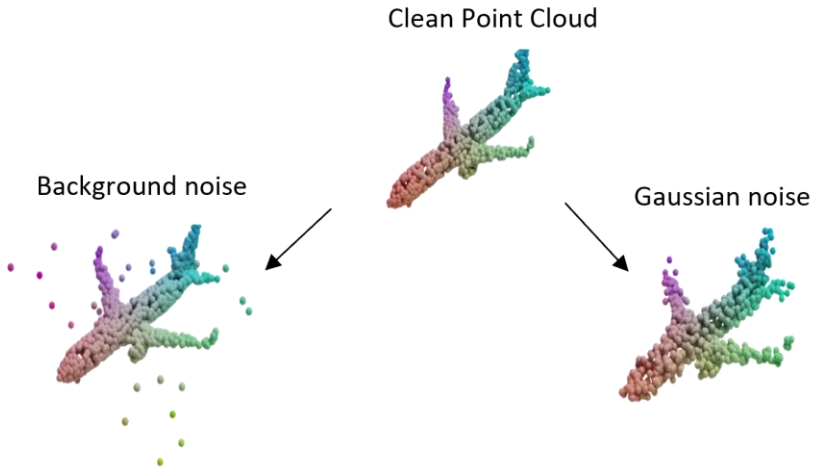
Sina Ghofrani Majelan, M. Omair Ahmad, M.N.S. Swamy

Concordia University, Montreal, QC, Canada

{s_ghofra, omair, swamy}@ece.concordia.ca

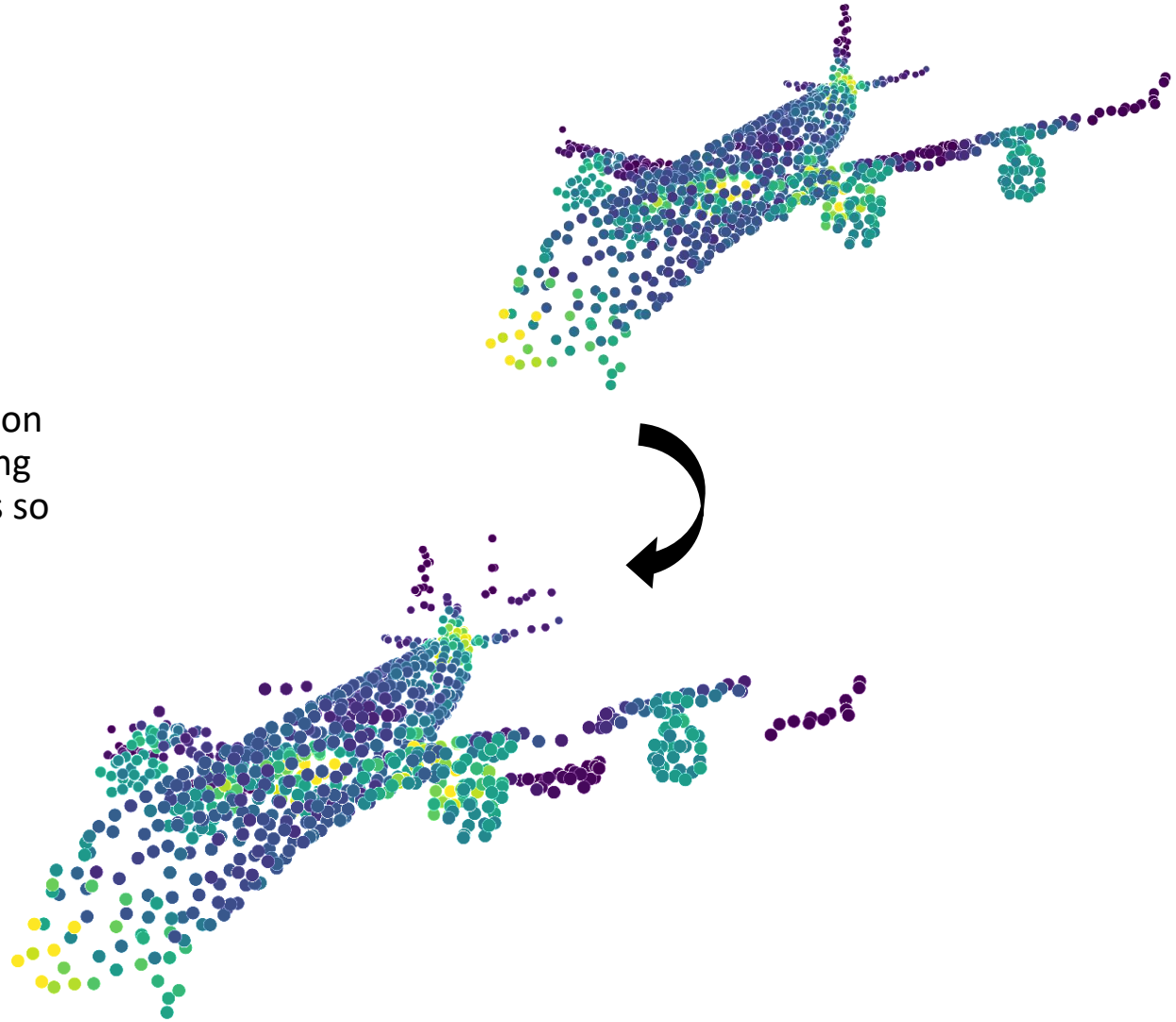
• Problem Statement

- What is TTT?
  - Test-Time Training (TTT) is a domain adaptation paradigm that realigns representations by using unlabeled test data to adapt a pre-trained model directly to the distribution of the test data during inference.

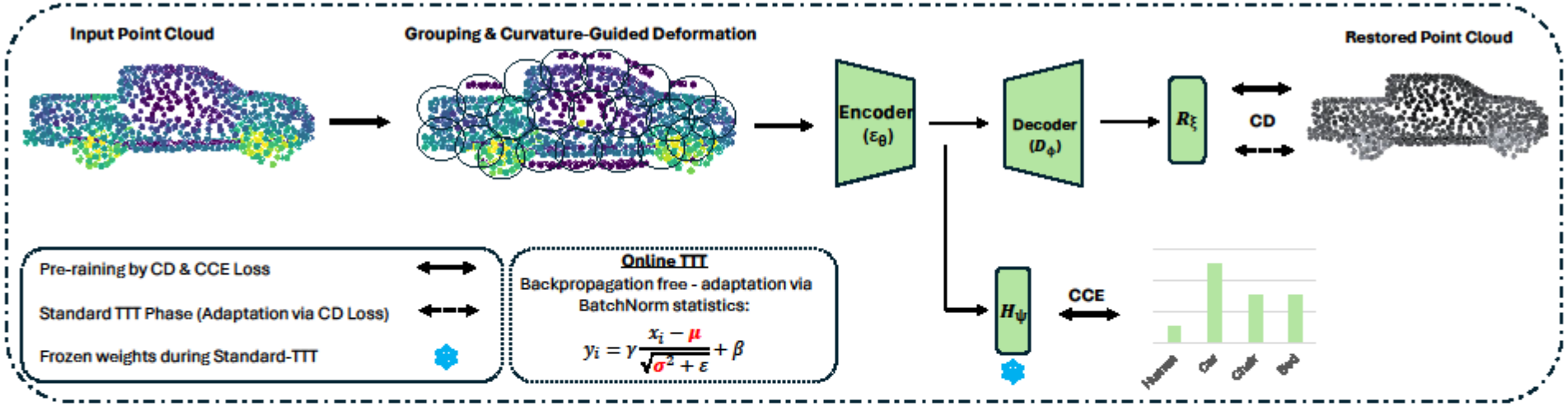


• Motivation

- What is the goal?
  - We propose a curvature-guided deformation restoration task to effectively capture global structure by preserving stable anchors, while deforming low-curvature regions so the model learns fine local surface details through restoration.



- **GeoCurvTTT**



Pre-training

$$\mathcal{L}_{res} = \sum_{i=1}^{G} d_{CD}(\hat{\mathcal{G}}_i, \mathcal{G}_i), \qquad \hat{\mathcal{G}} = \mathcal{R}_\xi(\mathcal{D}_\phi(\mathcal{E}_\theta(\tilde{\mathcal{G}}, C), C)).$$

$$\mathcal{L}_{cls} = \mathcal{L}_{CE}(\mathcal{H}_\psi(\mathcal{E}_\theta(\tilde{\mathcal{G}}, C)), y),$$

$$\mathcal{L}_{total} = \mathcal{L}_{res} + \mathcal{L}_{cls}.$$

Standard TTT

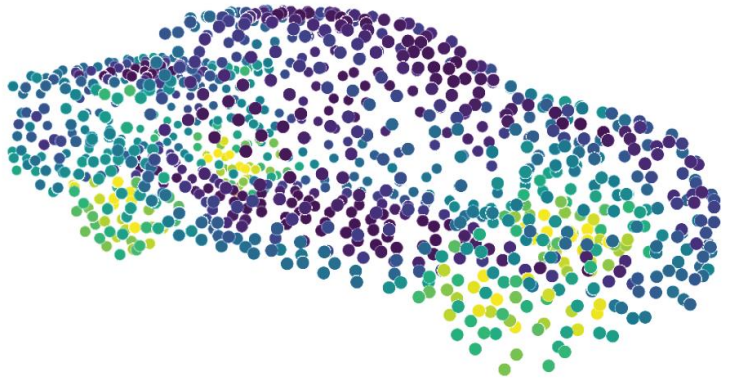
$$\theta_{adapted} = \arg\min_\theta \sum_{i=1}^{G} d_{CD}(\hat{\mathcal{G}}_{t,i}, \mathcal{G}_{t,i}), \qquad \hat{\mathcal{G}}_t = \mathcal{R}_\xi(\mathcal{D}_\phi(\mathcal{E}_\theta(\tilde{\mathcal{G}}_t, C_t), C_t)).$$

- **Main Results**

	Corruptions:	uni	gaus	backg	impul	ups	rbf	rbfinv	den-	den+	shear	rot	cut	distr	ocls	lidar	Mean
ModelNet-40C	MATE-S* [1]	66.9	58.8	12.3	61.3	73.3	64.1	65.9	74.3	81.1	70.9	36.8	68.8	66.2	38.7	29.5	57.9
	SMART-PC-S* [2]	82.4	80.1	12.0	67.1	84.5	76.0	78.6	67.3	72.9	73.3	43.9	72.6	73.5	37.4	24.8	63.1
	GeoCurv-TTT-S	79.9	75.8	17.9	54.1	84.6	79.7	80.7	63.8	76.4	81.8	54.1	58.4	80.3	37.6	21.7	63.2
	MATE-O* [1]	81.9	77.1	21.7	74.7	83.8	74.3	75.9	81.8	85.4	75.2	51.2	74.4	74.5	54.5	45.2	68.8
	SMART-PC-O*† [2]	85.0	83.2	31.6	77.6	85.9	79.2	80.8	77.8	79.3	77.8	60.3	60.3	76.8	45.2	40.4	70.8
	GeoCurv-TTT-O†	83.6	81.2	31.8	73.3	85.1	80.4	82.6	80.2	82.9	82.9	67.8	77.3	81.2	47.0	50.1	72.5
ShapeNet-C	MATE-S* [1]	74.6	69.5	4.2	59.6	75.4	74.4	75.0	86.2	83.5	78.2	56.3	85.7	75.7	11.3	6.8	61.1
	SMART-PC-S* [2]	80.8	78.9	8.9	60.4	81.8	81.1	81.7	84.8	78.4	80.8	63.7	84.9	79.8	11.5	8.8	64.4
	GeoCurv-TTT-S	81.6	76.8	5.3	53.4	81.7	83.1	83.3	87.5	81.5	83.2	66.1	87.3	82.0	12.9	10.0	65.1
	MATE-O* [1]	75.0	69.2	17.1	68.9	75.3	73.9	74.7	85.5	81.5	76.7	55.3	84.8	72.2	10.8	11.5	62.2
	SMART-PC-O*† [2]	80.4	78.7	21.0	72.7	80.9	80.9	80.6	82.5	78.3	80.9	70.1	82.5	79.0	10.5	9.7	65.9
	GeoCurv-TTT-O†	81.1	78.2	9.6	68.1	81.7	82.3	81.9	85.7	81.4	82.2	69.0	85.2	81.0	11.5	11.2	66.1
ScanObj-C	MATE-S* [1]	26.5	30.5	14.6	23.4	26.9	39.9	43.7	72.5	62.3	45.3	34.8	72.8	44.8	7.6	8.6	36.9
	SMART-PC-S* [2]	27.5	39.1	19.3	21.5	29.8	44.2	48.9	68.3	60.2	49.4	45.4	70.1	49.1	8.4	12.2	39.6
	GeoCurv-TTT-S	34.8	39.8	15.5	19.5	37.2	47.7	48.6	71.5	64.4	51.3	42.6	72.9	50.1	8.0	11.1	41.0
	MATE-O* [1]	33.2	47.5	10.5	30.3	31.5	44.6	47.5	72.3	70.2	47.2	38.6	72.5	50.1	7.9	10.8	41.0
	SMART-PC-O*† [2]	39.4	54.6	19.6	40.1	40.3	54.4	55.9	73.3	69.5	55.1	50.1	74.9	57.8	6.9	7.9	46.7
	GeoCurv-TTT-O†	40.8	51.7	16.1	38.6	39.6	54.3	58.4	74.1	68.9	56.8	49.4	70.4	61.0	8.1	11.2	46.7

- **Efficiency Analysis**

Solver	T_{ref}(s)	T_{ours}(s)	Speedup	Eig. err.	Cos.	Angle Diff(°)
`symeig`	0.6342	0.0020	317.1×	5.81×10^{-10}	1.0000	0.0357
`linalg.eigh`	0.1922	0.0020	96.1×	5.96×10^{-10}	1.0000	0.0303



Metric	GeoCurv-TTT	SMART-PC [3]
FLOPs (G)	2.9	2.9 (same)
GPU Mem Alloc (MB)	4463.9	9095.7 (103.8%)
Wall-Time (ms)	49.3	62.2 (26.2%)







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Thank you!