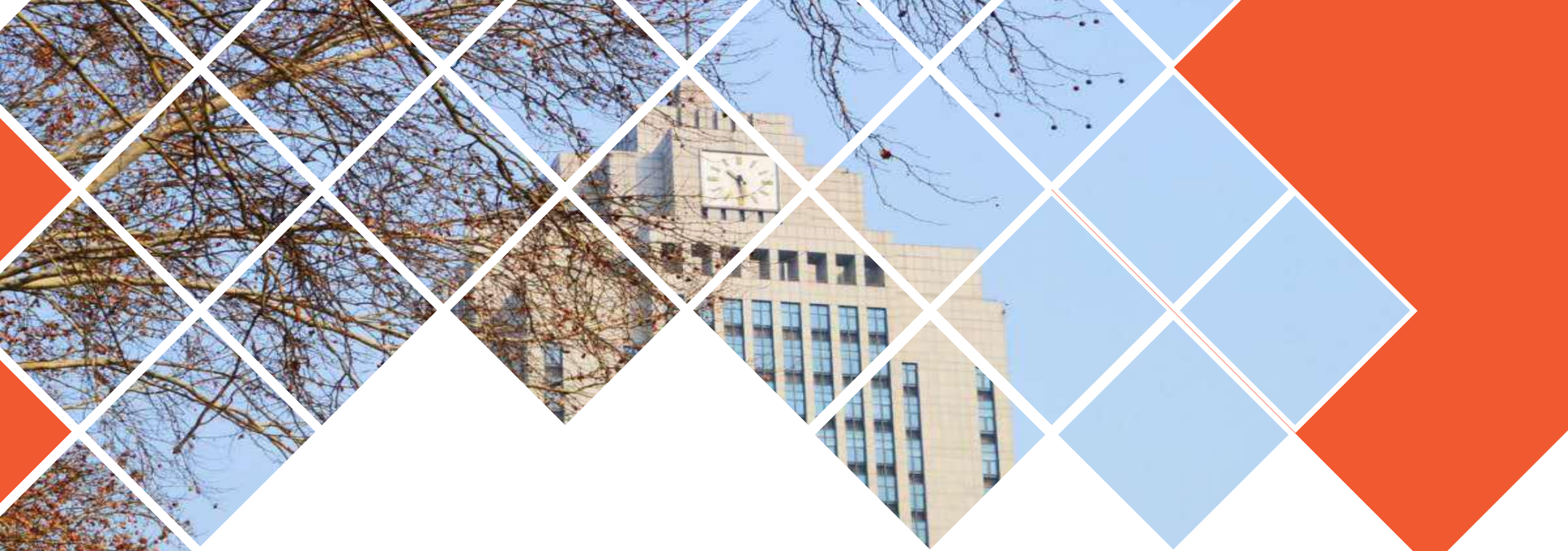


Geometry-Regularized Collapse Resistance via Consensus Enhancement for Federated Learning

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Motivation

➢ Limitations of Existing Methods

1. Parameter Constraints

- **Approach**: Constrain local parameter updates to reduce model drift
- **Limitation**: Strong constraints can limit local adaptation flexibility

2. Data Augmentation

- **Approach**: Generate or mix samples to reduce data distribution discrepancies across clients
- **Limitation**: Effectiveness depends on synthetic data quality and how well the samples approximate the global distribution

3. Parameter Constraints

- **Approach**: Transfer shared predictions or semantic representations to guide local training
- **Limitation**: Shared knowledge derived from client data can retain local biases, providing biased guidance under heterogeneity

Motivation

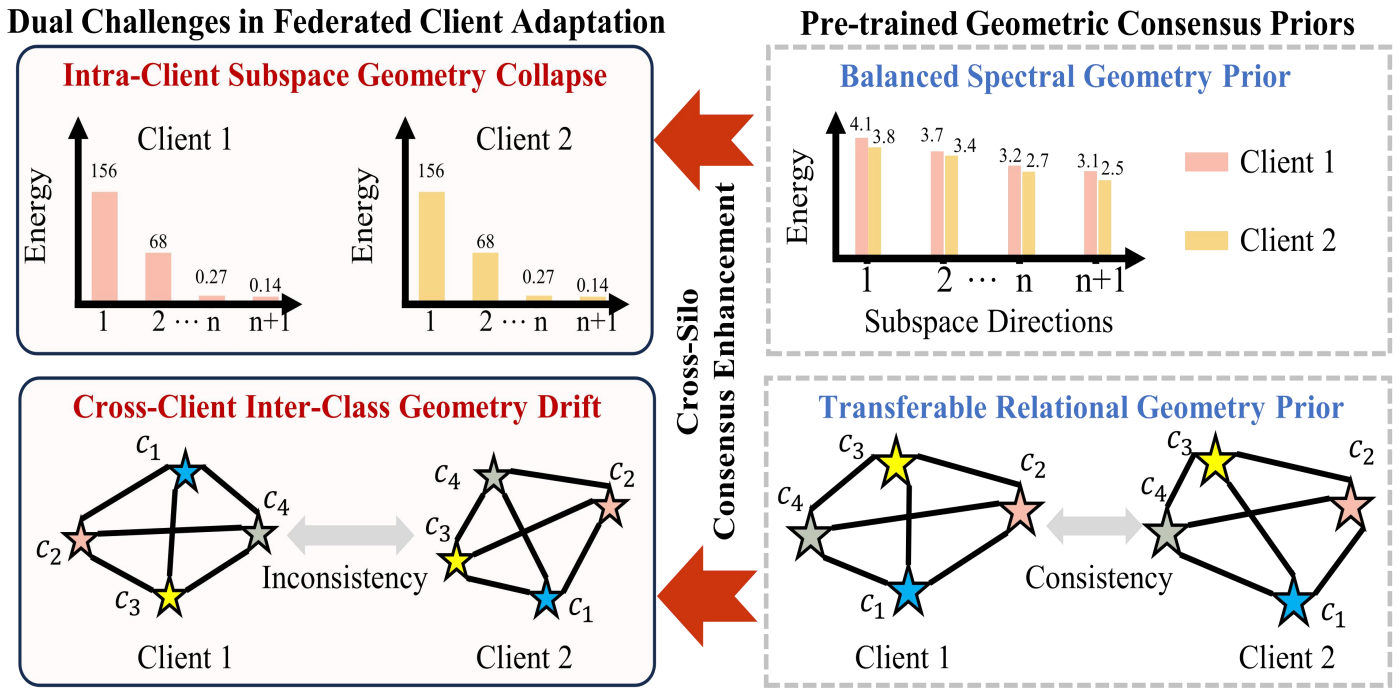
➢ Key Question

- Pretrained foundation models provide transferable prior knowledge for federated learning. **Can we extract knowledge shared across data sources from pretrained representations** and use it to guide local adaptation, thereby improving global aggregation?



- To explore this question, we examine how local adaptation changes pre-trained representations and identify two geometric challenges

Motivation



- **Intra-Client Subspace Geometry Collapse**: Local adaptation concentrates feature energy in a few dominant directions, whereas pre-trained features exhibit a relatively balanced spectral distribution.
- **Cross-Client Inter-Class Geometry Drift**: Independent local adaptation distorts inter-class relationships across clients, whereas pre-trained features provide relatively consistent relational structures.

These observations motivate RISE to preserve pre-trained geometric consensus during local adaptation.

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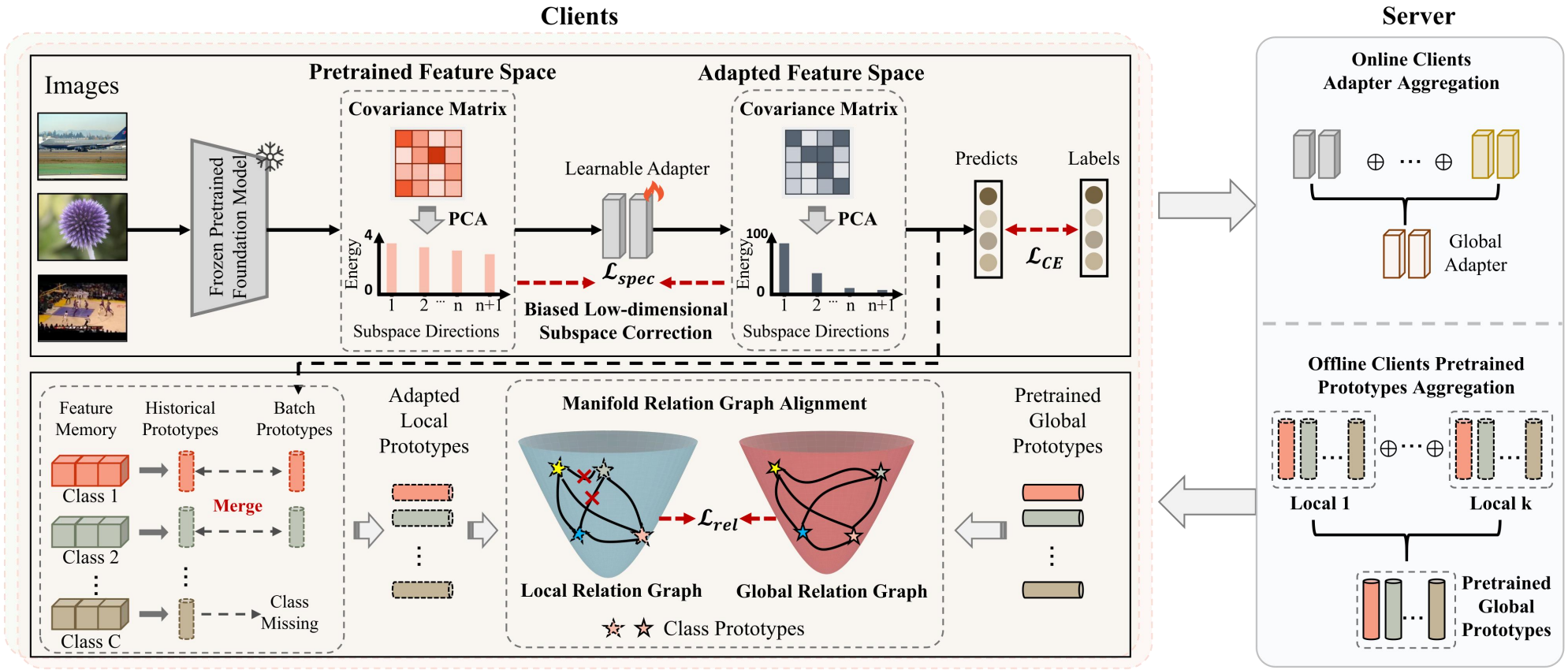
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Method



We propose RISE, a cross-source consistency enhancement method that preserves pre-trained geometric consensus priors to mitigate adaptation-induced biases that hinder alignment and aggregation under heterogeneous federated settings

Method

Biased Low-dimensional Subspace Correction (BLSC)

- Compute covariance matrices from centered pre-trained and adapted features, and extract their top-K eigenvalues to characterize the principal spectral energy distributions
- Regularize the adapted spectrum toward the pre-trained reference to prevent excessive energy concentration in a few dominant directions and mitigate biased subspace collapse

$$\mathcal{L}_{\text{eng}} = \frac{1}{K} \left\| \Lambda^{\text{pre}} - \Lambda^{\text{adp}} \right\|_2^2$$

Manifold Relation Graph Alignment (MRGA)

- Aggregate pre-trained class prototypes across data sources and map them into hyperbolic space to construct a global reference graph of inter-class relationships
- Combine current-batch prototypes with historical feature memory to obtain more stable local class prototypes under missing or sparsely sampled classes
- Align local and reference pairwise hyperbolic distances to preserve transferable inter-class geometry and reduce structural drift across data sources

$$\mathcal{L}_{\text{rel}} = \frac{1}{\tau |\mathcal{C}^{\text{cur}}|^2} \left\| D^{\text{cur}} - D^{\text{pre}} \right\|_F^2$$



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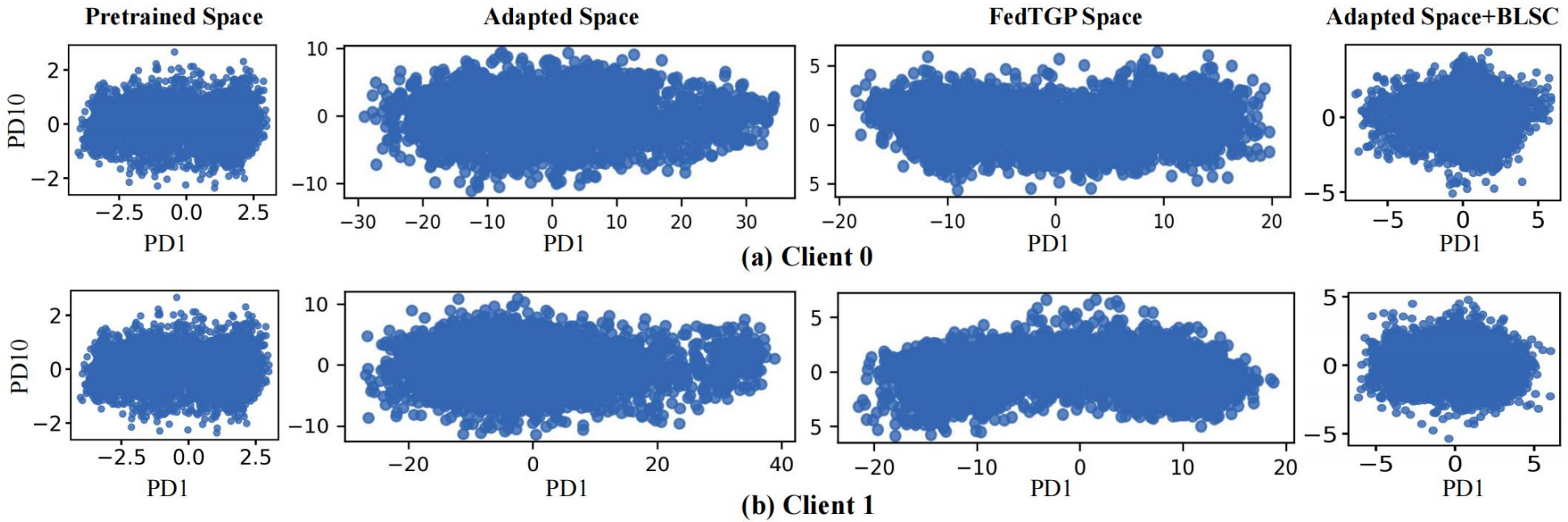
➢ Performance Comparison

Method	Caltech101		FGVCAircraft		DTD		StanfordCars		Flowers102		UCF101		Office-Home		PACS	
	CLIP	Qwen3-VL	CLIP	Qwen3-VL	CLIP	Qwen3-VL	CLIP	Qwen3-VL	CLIP	Qwen3-VL	CLIP	Qwen3-VL	CLIP	Qwen3-VL	CLIP	Qwen3-VL
MOON	95.30	98.10	54.86	61.79	71.66	81.51	82.55	86.98	95.92	99.63	83.07	86.70	81.45	90.69	96.09	98.31
FedETF	95.33	98.10	54.87	62.00	73.10	82.09	82.78	87.58	97.49	**99.75**	84.29	86.95	82.02	91.75	96.10	98.44
FedSOL	94.97	97.99	53.49	61.50	71.99	82.15	80.55	86.18	95.89	99.63	82.75	86.74	81.17	90.40	95.91	98.26
FedTGP	95.80	98.30	55.08	62.70	72.82	82.16	83.45	88.87	96.82	99.08	83.85	86.94	82.08	91.46	96.29	98.30
FedFSA	95.34	97.60	55.91	62.20	72.63	81.20	83.45	87.67	96.16	99.38	83.45	87.01	82.04	91.43	96.46	98.31
Client2Vec	95.34	98.22	54.54	62.00	72.69	82.21	82.56	87.05	96.69	99.63	83.58	87.07	81.51	90.83	96.25	98.19
GGEUR	95.79	98.24	55.92	62.43	73.64	82.17	83.38	88.27	96.82	99.68	84.23	87.15	82.23	91.77	96.45	98.37
FedPM	95.68	98.17	55.28	61.65	72.87	81.97	83.36	88.41	96.77	99.63	83.13	86.91	81.88	91.23	96.12	98.35
RISE	**96.33**	**98.53**	**57.42**	**64.44**	**74.30**	**83.00**	**85.43**	**90.60**	**98.14**	99.63	**85.45**	**88.10**	**83.61**	**92.78**	**96.97**	**98.82**

- Under heterogeneous federated settings, we evaluate RISE on six single-domain and two multi-domain datasets using CLIP and Qwen3-VL as frozen backbones. RISE achieves the best accuracy in 15 out of 16 settings, with particularly strong results on FGVCAircraft, StanfordCars, and Office-Home, **demonstrating the effectiveness of the cross-silo consensus preservation mechanism.**

Experiments

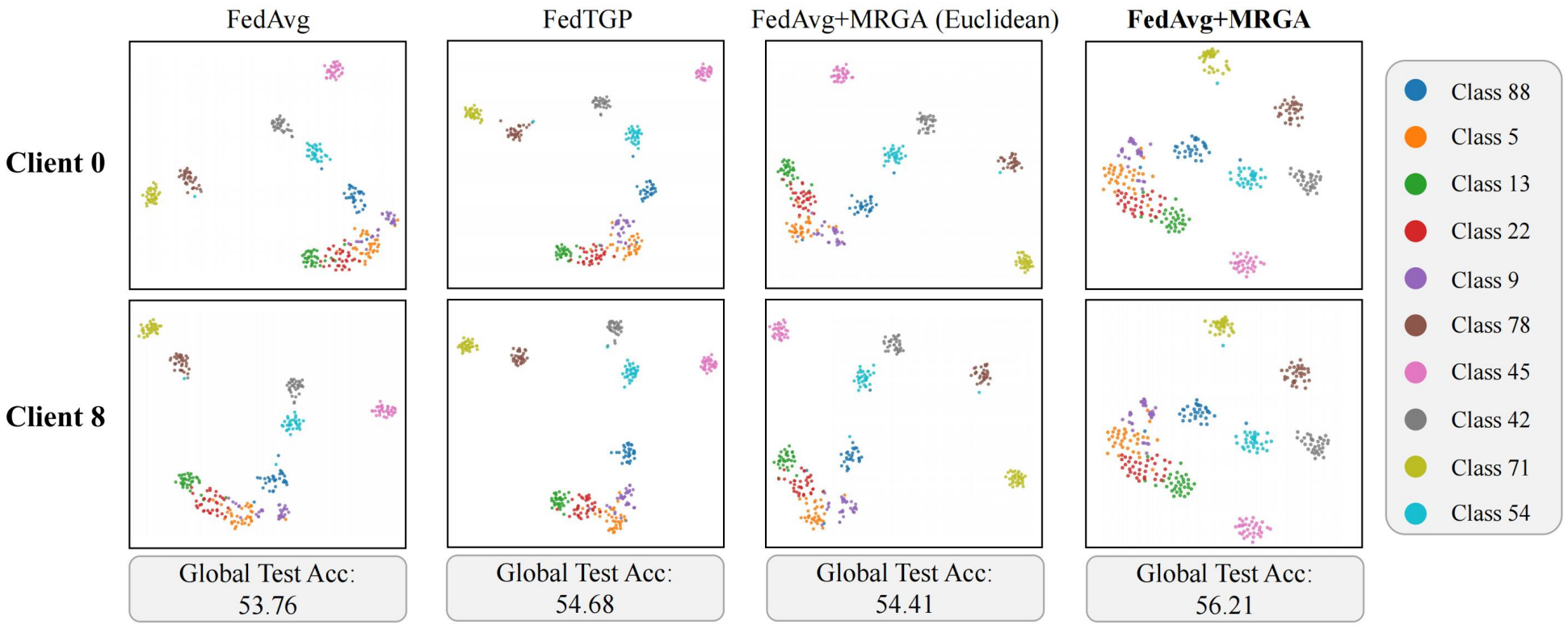
➢ BLSC Mitigates Subspace Collapse



- PCA projections of two clients on FGVCAircraft show that local adaptation excessively stretches features along the first principal direction (PD1). While FedTGP only partially alleviates this distortion, BLSC substantially reduces PD1-dominant stretching and restores a more balanced spectral energy distribution, mitigating biased subspace collapse.

Experiments

➢ MRGA Preserves Inter-Class Geometry



- On FGVCAircraft, hyperbolic MRGA produces more consistent inter-class layouts across the two clients than FedAvg, FedTGP, and Euclidean MRGA. It also achieves the highest global test accuracy among the compared methods, improving from 54.41% to 56.21% over the Euclidean variant.

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➢ Conclusion

- RISE mitigates the degradation of pre-trained consensus knowledge during local adaptation, improving cross-source representation consistency and global model generalization.

➢ Limitations and Future Work

- Performance may depend on the quality and domain relevance of the foundation model, and geometric regularization introduces additional computational overhead.

- Future work will explore efficient spectral approximation and prototype sampling to reduce local training costs.



THANKS!

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