

Distribution Alignment for One-Shot Federated Learning via Optimal Transport

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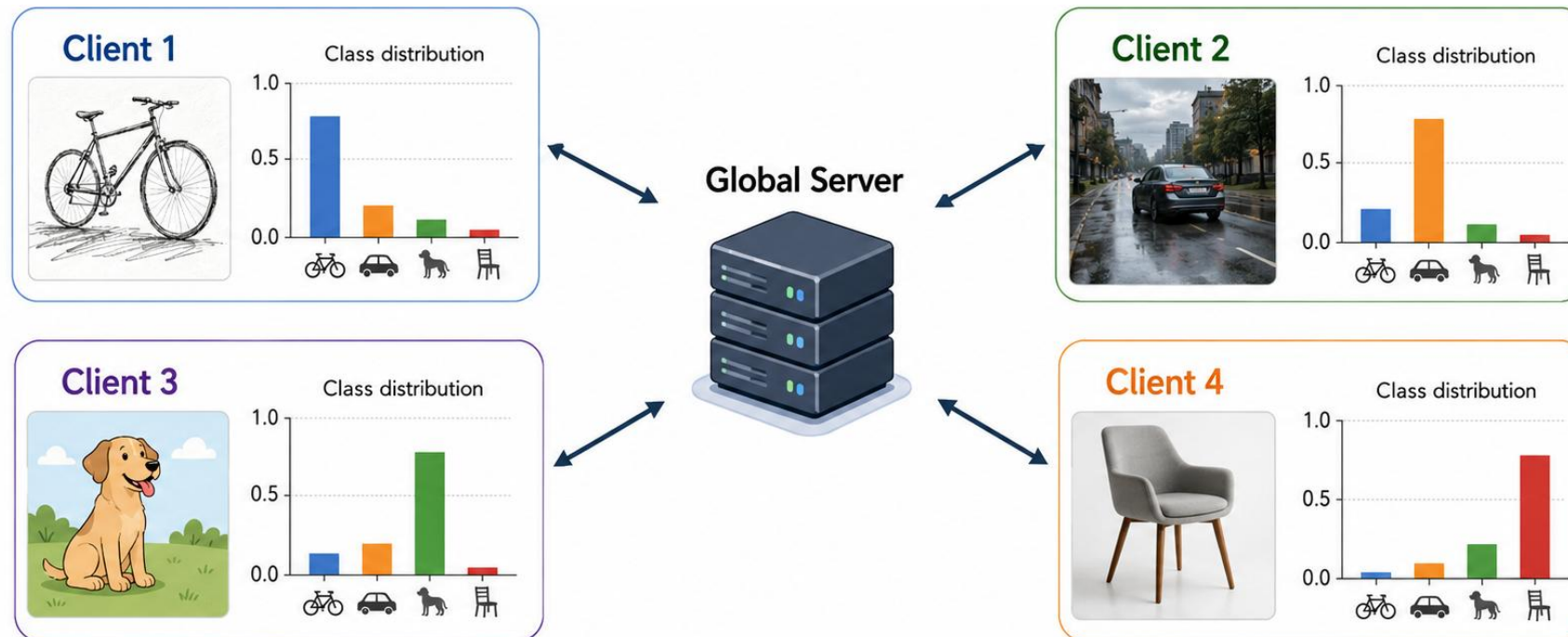
Federated Learning under Heterogeneity

Federated Learning (FL) trains a shared model across K distributed clients without centralizing raw data

However, client data are **heterogeneous**:

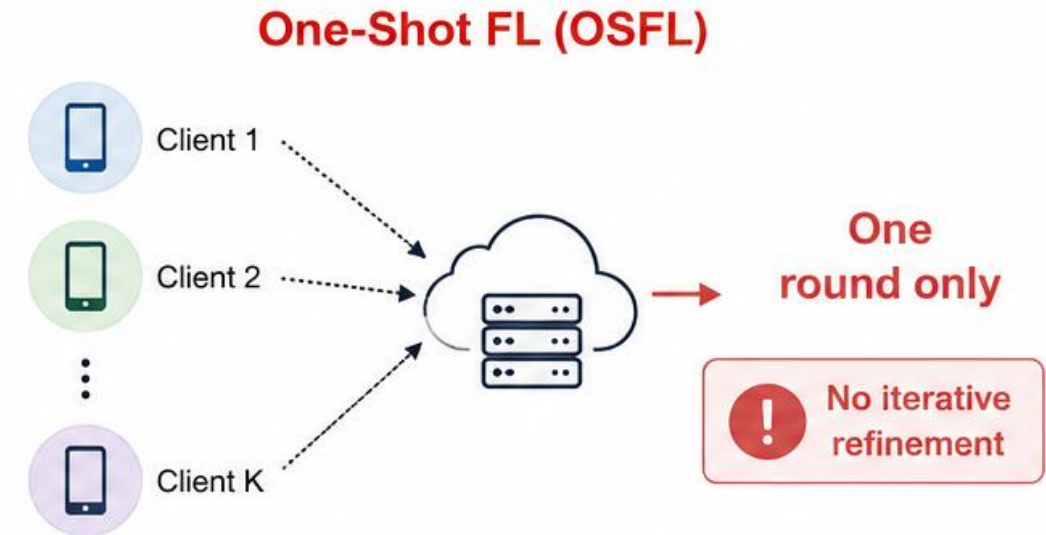
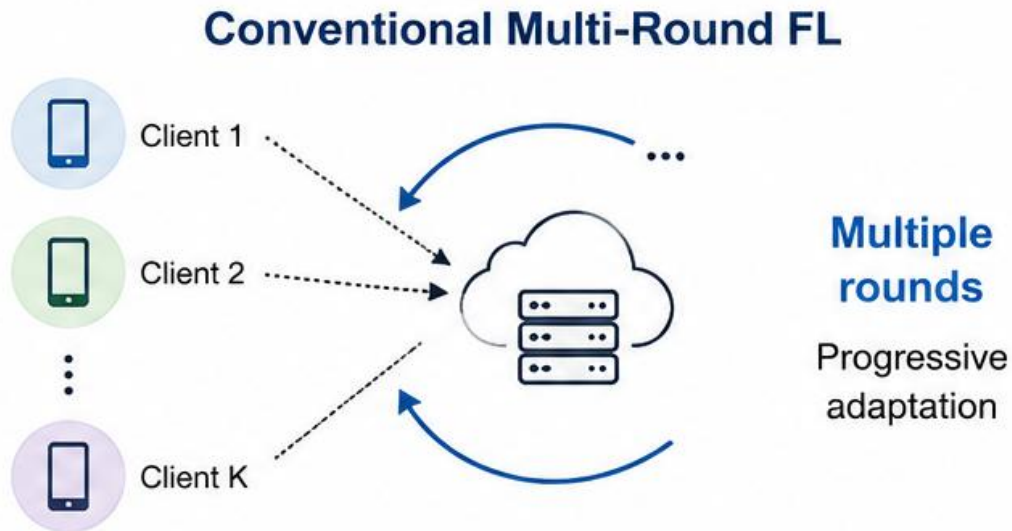
- Different input distributions $P_k(x)$ (*Domain shift*)
- Different label distributions $P_k(y)$ (*Label shift*)

Misaligned class-posterior decision functions and divergent local feature representations across clients



One-shot Federated Learning under Heterogeneity

- In conventional multi-round FL, inconsistencies are progressively mitigated through iterative client-server optimization
- One-Shot Federated Learning (OSFL) restricts clients to a single communication round with the server
→ No iterative learning and amplified impact of distribution mismatch.



One-shot Federated Learning Approaches

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Existing OSFL Strategies



Distillation

Often needs auxiliary data
or server-side optimization



Generation-based

Powerful, but
computationally heavy



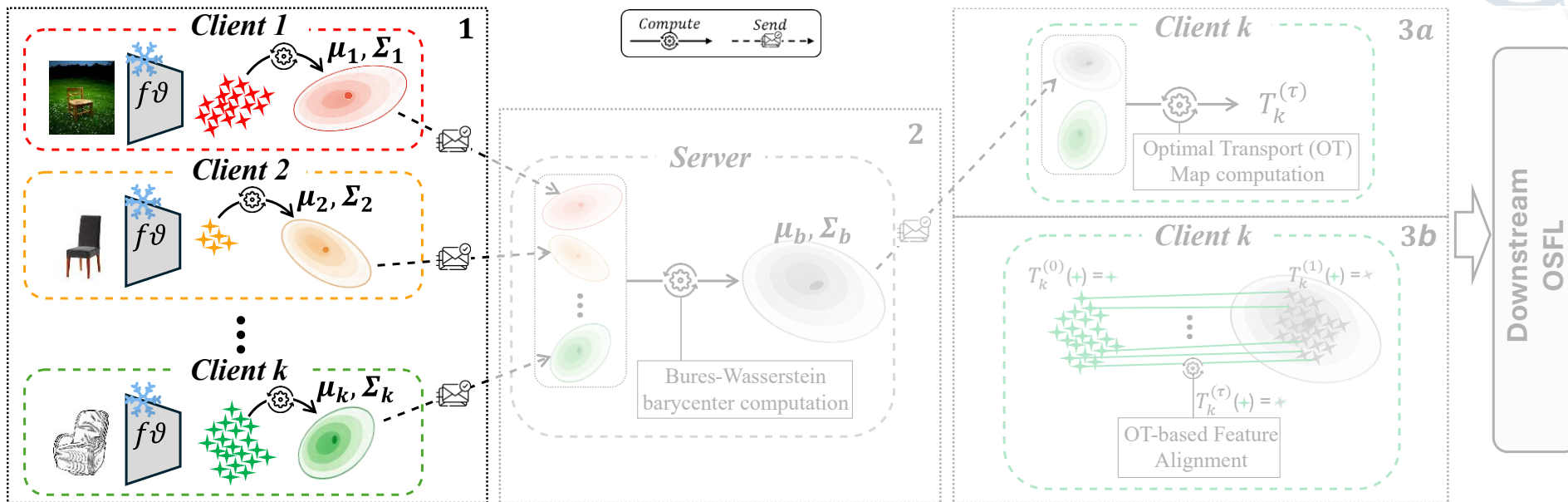
Statistics / Feature-sharing

Lightweight, but assume feature
summaries are comparable

Discrepancies from compound domain and label shift remain largely uncorrected in the one-shot setting

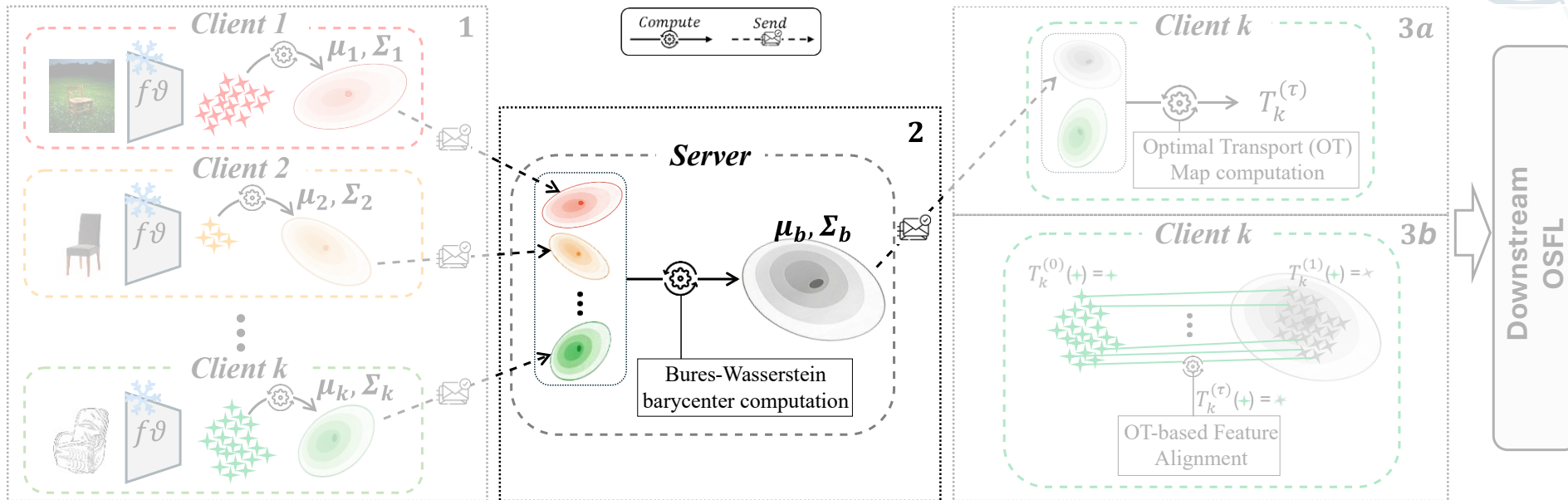
SLOT-Align: Geometry-Aware Feature Alignment

- Our **SLOT-Align** is a Single-Round, Learning-free Optimal Transport Alignment acting as a preprocessing step:
 - Clients use a shared frozen encoder to extract $z = f_{\vartheta}(x)$ and send compact statistics μ_k, Σ_k
 - Server aggregates summaries into a global reference distribution μ_b, Σ_b via Bures–Wasserstein barycenter
 - Clients align local features toward the global reference using closed-form geodesic optimal transport maps:
 $z' = T_k^{(\tau)}(z)$



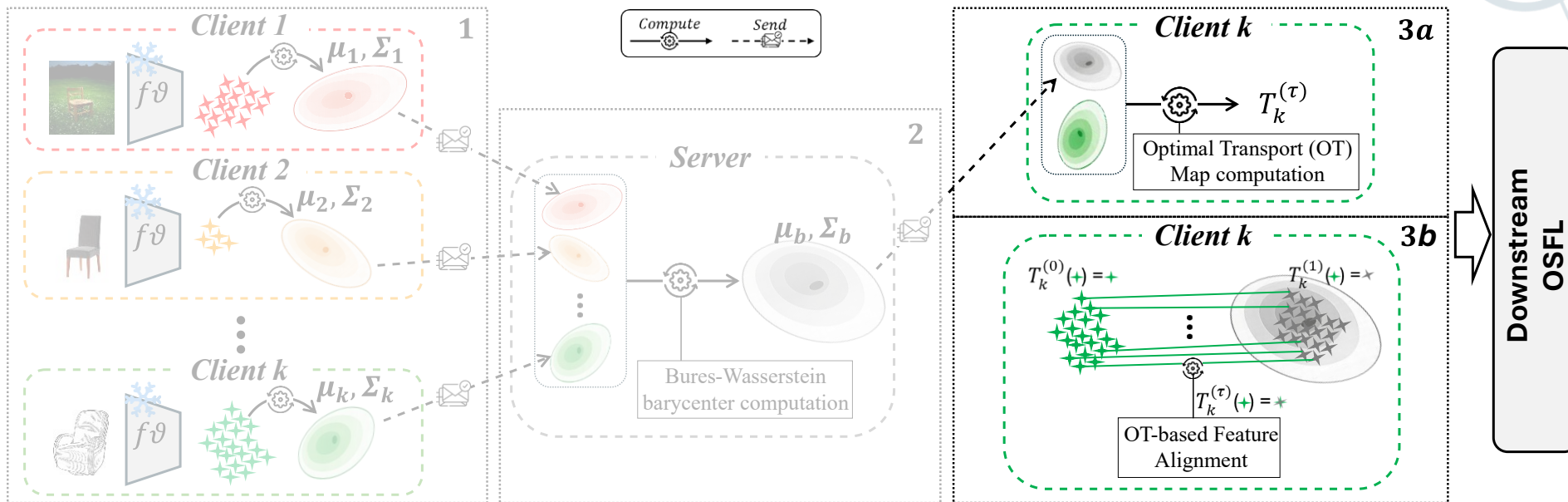
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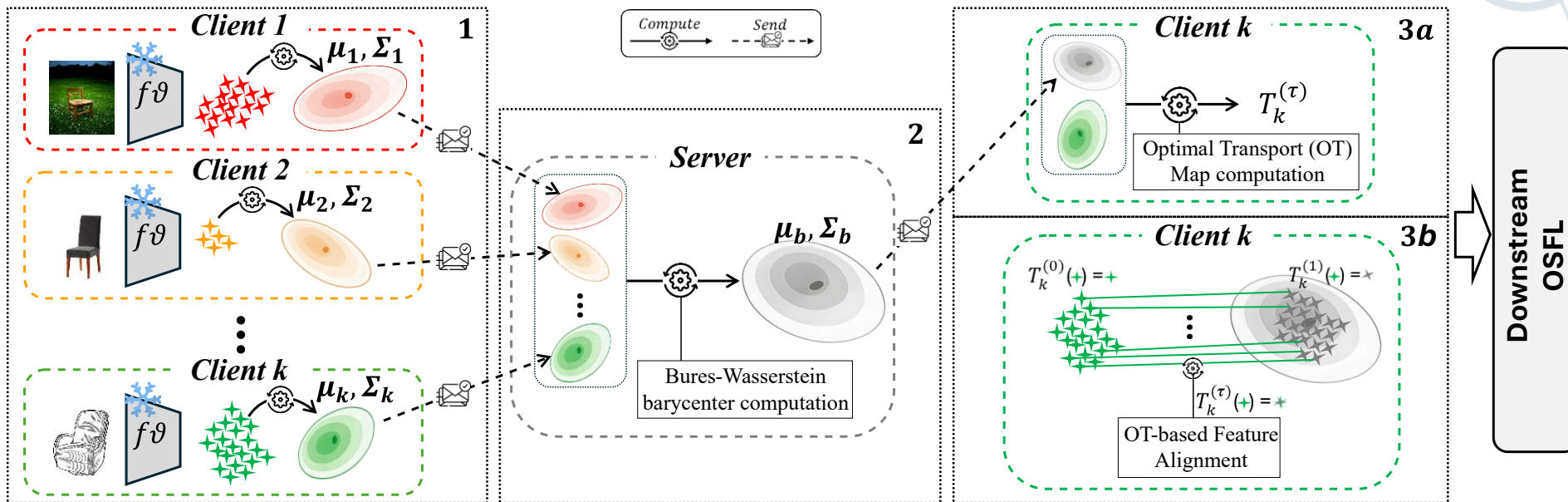
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Aligned features are used by any downstream OSFL method relying on frozen encoder

SLOT-Align: Results

- SLOT-Align was evaluated across Office-Home, Digits, and DomainNet benchmarks under domain shift compounded by label shift ($\alpha = 0.1$)
- The framework consistently improves the macro-averaged accuracy of existing OSFL baselines. Improvements remains under stronger label skew, different frozen backbones, and finer client partitions.

Method	Office-Home						Digits						DomainNet							
	A	C	P	R	mean	std	Mnist	Usps	Svhn	Synth	mean	std	Cl	In	Pa	Qu	Re	Sk	mean	std
O-FedAvg	66.09	55.45	69.22	66.01	64.19	5.21	76.36	73.98	49.99	58.45	64.70	10.93	56.93	24.55	43.34	17.56	53.09	40.69	37.69	12.53
+SLOT	67.57	67.51	78.95	74.16	72.05 (+7.86)	4.81	85.61	76.97	56.03	71.84	72.61 (+7.91)	10.77	49.90	27.73	45.16	20.03	54.56	43.91	40.26 (+2.57)	12.18
FedCGS	80.52	74.58	94.74	87.61	84.37	7.56	82.18	81.46	53.29	51.55	67.12	14.72	66.67	31.74	58.16	20.66	73.08	58.11	51.40	18.82
+SLOT	80.66	75.95	94.89	88.69	85.05 (+0.68)	7.28	84.05	73.44	63.05	59.9	70.11 (+2.99)	9.48	70.00	40.59	63.02	28.54	75.42	62.21	56.63 (+5.23)	16.59
FedPFT	67.99	61.25	85.51	82.01	74.19	9.94	84.74	82.23	61.60	64.85	73.36	10.23	62.85	29.13	54.71	23.54	65.86	52.13	48.04	16.10
+SLOT	75.99	72.06	89.64	85.24	80.74 (+6.55)	7.02	86.87	83.19	62.75	69.18	75.50 (+2.14)	9.89	65.54	34.83	57.45	26.73	68.37	56.48	51.57 (+3.53)	15.46

SLOT-Align improves consistency across heterogeneous clients, while remaining highly communication-efficient (transmits only ~264 KB per client for a 512-dimensional feature space)

Conclusion and Future Work

SLOT-Align:

- Frames OSFL as a distribution alignment problem in the 2-Wasserstein space
- It harmonizes client feature distributions via an exchange of compact statistics
- Is learning-free and plug-in for downstream OSFL pipelines based on frozen encoders

Future directions

- Richer distribution proxies beyond Gaussian moments
- Client-adaptive alignment hyperparameter τ





ICML

International Conference
On Machine Learning

Thank you!

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Project page: github.com/daniebera/SLOT-Align

