BA-BFL: Barycentric Aggregation for Bayesian Federated Learning

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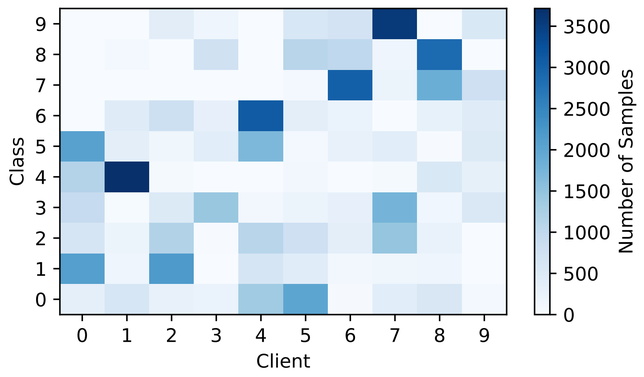
Introduction & Motivations

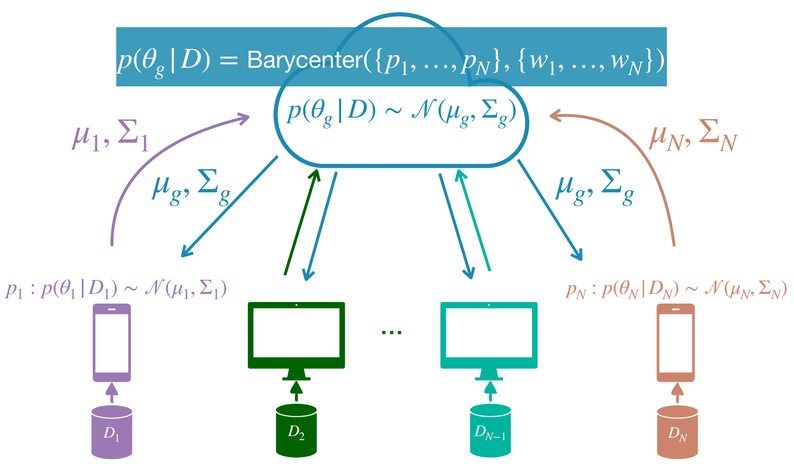
Federated Learning (FL) is a privacy-preserving decentralized learning paradigm consisting in 2 phases:

- **Learning Phase**: Each client trains its local model.
- **Aggregation Phase**: Local models are combined into a global model.

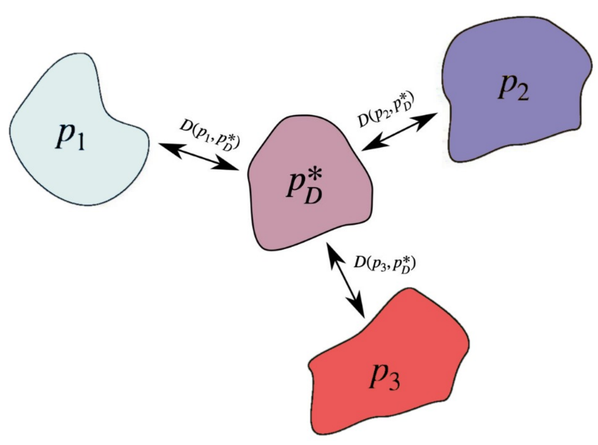
FL faces some challenges, like statistical heterogeneity, algorithmic fairness and uncertainty quantification.



Main Contributions



The BA-BFL Framework.



Closed form solutions for:

- **Reverse KL Barycenter of Gaussians**
- **Wasserstein-2 Barycenter of Independent Gaussians**

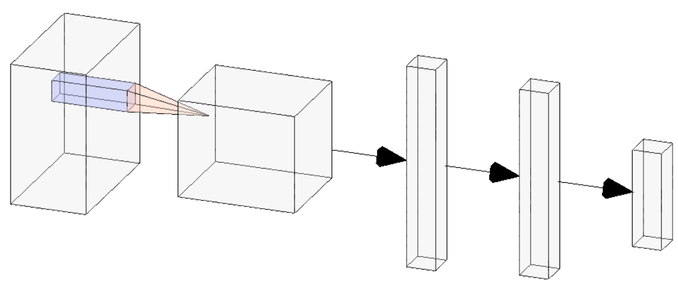
A Unifying Framework:

Deterministic Arithmetic Average Aggregations *FedAvg, FedProx, PropFair, GiFair, FedLaw* → **WB / RKLB with variance → 0**

Multiplicative Aggregations of Posteriors *FedPA, FOLA, FedEP, FedIvon* → **RKLB**

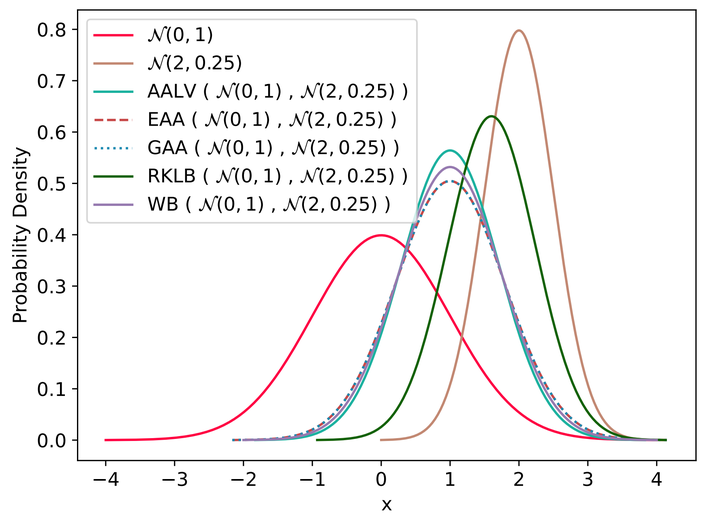
$$\Sigma_{RKL} = \left(\sum_{k=1}^N w_k \Sigma_k^{-1}\right)^{-1}, \quad \mu_{RKL} = \Sigma_{RKL} \sum_{k=1}^N w_k \Sigma_k^{-1} \mu_k.$$
$$\Sigma_{W_2^2} = \left(\sum_{k=1}^N w_k \Sigma_k^{\frac{1}{2}}\right)^2, \quad \mu_{W_2^2} = \sum_{k=1}^N w_k \mu_k.$$

Comparison to Statistical Aggregation Methods in a Heterogeneous Setting



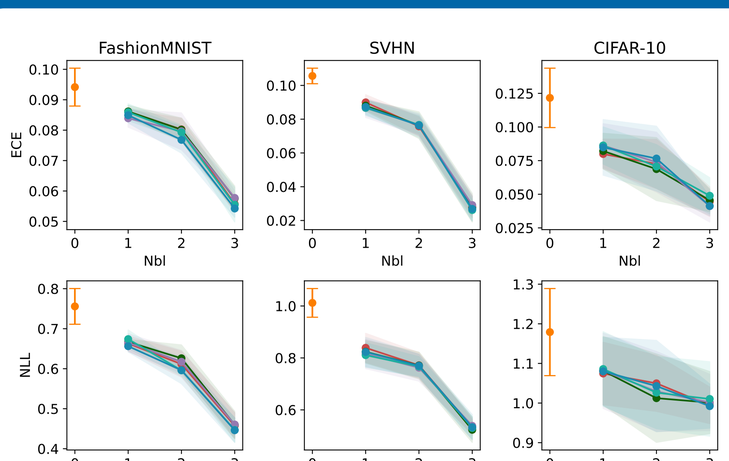
- The models' architecture consists of two convolutional layers and three fully connected layers.
- The last $n = 0, 1, 2, 3$ layers are implemented as Bayesian fully connected layers following the HBDL approach.
- The remaining layers are deterministic.

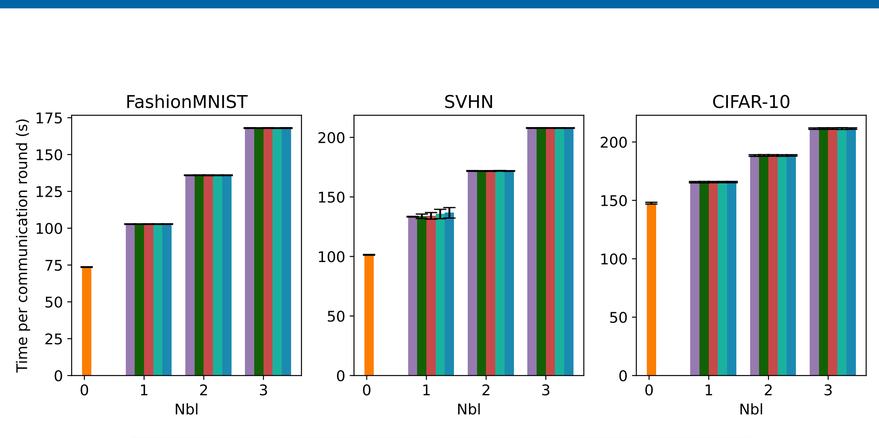
Nbl	Algorithm	FashionMNIST	SVHN	CIFAR-10
0	**FedAvg**	87.88 ± 0.79	86.06 ± 0.45	61.63 ± 3.11
1	**AALV**	88.22 ± 0.34	86.52 ± 0.29	63.42 ± 3.02
	EAA	88.07 ± 0.22	86.24 ± 0.20	63.69 ± 2.47
	GAA	88.15 ± 0.31	86.36 ± 0.28	63.66 ± 2.22
	RKLB	88.07 ± 0.36	86.26 ± 0.26	63.37 ± 2.62
	WB	$\mathbf{88.34 \pm 0.30}$	$\mathbf{86.55 \pm 0.37}$	63.91 ± 2.64
2	**AALV**	87.62 ± 0.45	85.46 ± 0.10	65.03 ± 2.92
	EAA	87.53 ± 0.57	85.64 ± 0.33	64.02 ± 1.99
	GAA	87.82 ± 0.64	85.54 ± 0.44	64.59 ± 3.51
	RKLB	87.59 ± 0.57	85.57 ± 0.45	$\mathbf{65.20 \pm 3.99}$
	WB	87.69 ± 0.74	85.57 ± 0.51	64.74 ± 3.29
3	**AALV**	88.07 ± 0.58	86.15 ± 0.80	63.71 ± 3.63
	EAA	87.81 ± 0.54	86.04 ± 0.62	64.45 ± 1.79
	GAA	88.02 ± 0.55	86.27 ± 1.02	64.40 ± 2.30
	RKLB	87.77 ± 0.80	86.53 ± 1.03	64.55 ± 2.97
	WB	87.54 ± 0.54	85.99 ± 0.68	64.30 ± 2.55

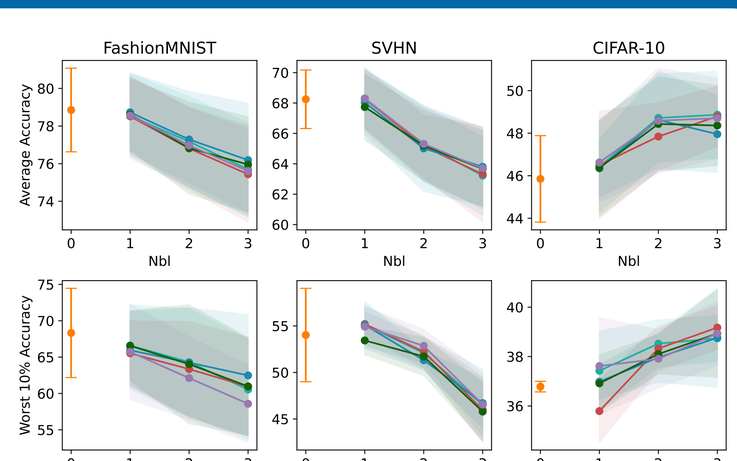


Comparison of statistical and barycentric aggregations using univariate Gaussian distributions.

Effect of Bayesian Layers on Uncertainty Quantification, Model Calibration, Time-Effectiveness & Fairness







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