

Federated Learning and Its Extension With Large Pre-trained Generators

- **Name:** Jianqing Zhang
- **Age:** 26
- **Ph.D.:** Shanghai Jiao Tong University
- **M.S.:** Shanghai Jiao Tong University
- **Collaborations:**
 - Tsinghua University
 - Queen's University Belfast
 - Louisiana State University

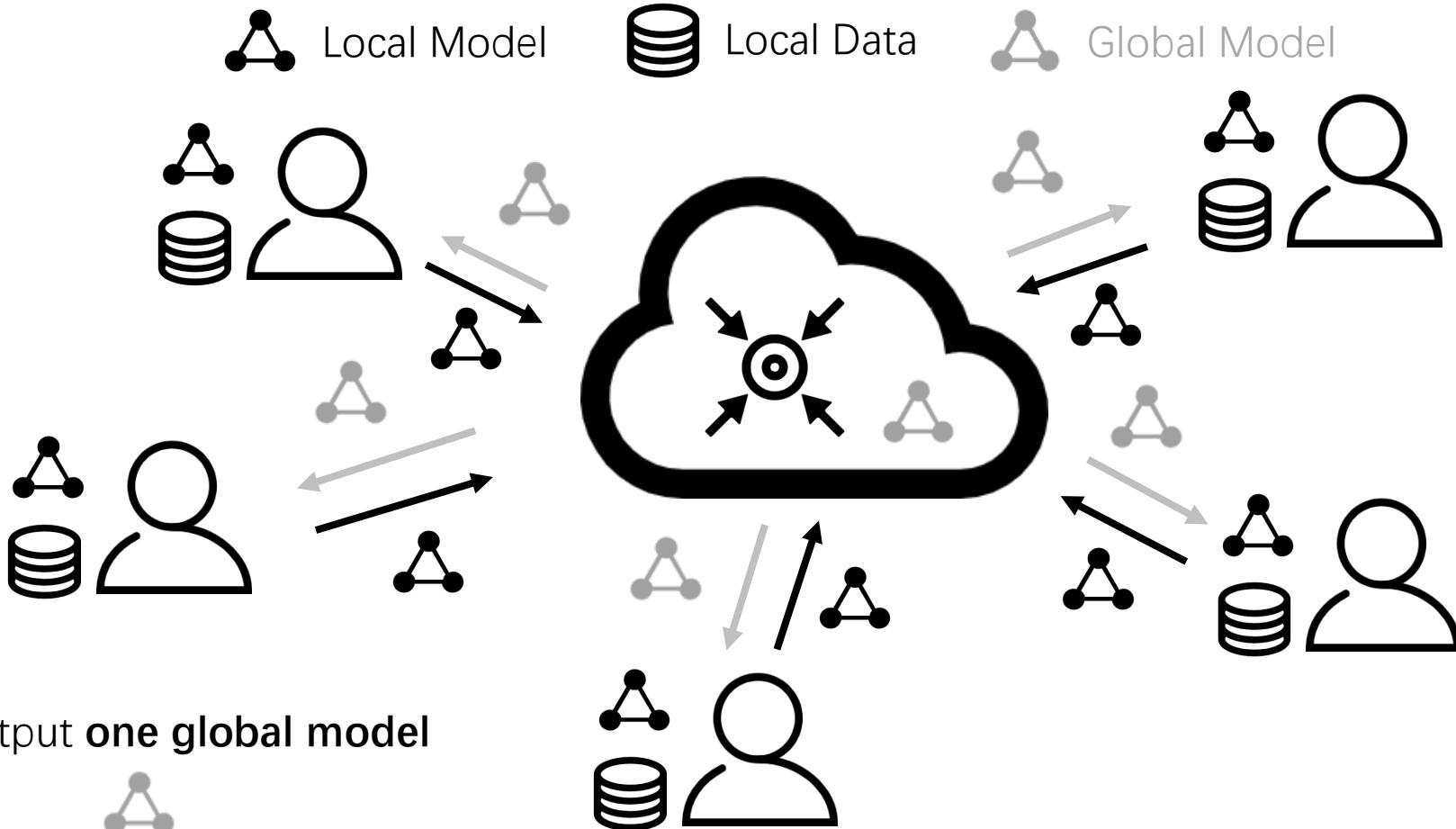


Content

- **Research interests**
 - Federated learning, transfer learning, recommender systems
- **Projects**
 - PFLlib (1000+ stars, 200+ forks), HtFL, FL-IoT, etc.
- **Featured publications (first author)**
 - Stage ① [personalized federated learning]:
 - AAAI'23, KDD'23, ICCV'23, NeurIPS'23, PFLlib'paper
 - Stage ② [heterogeneous federated learning]:
 - AAAI'24, CVPR'24

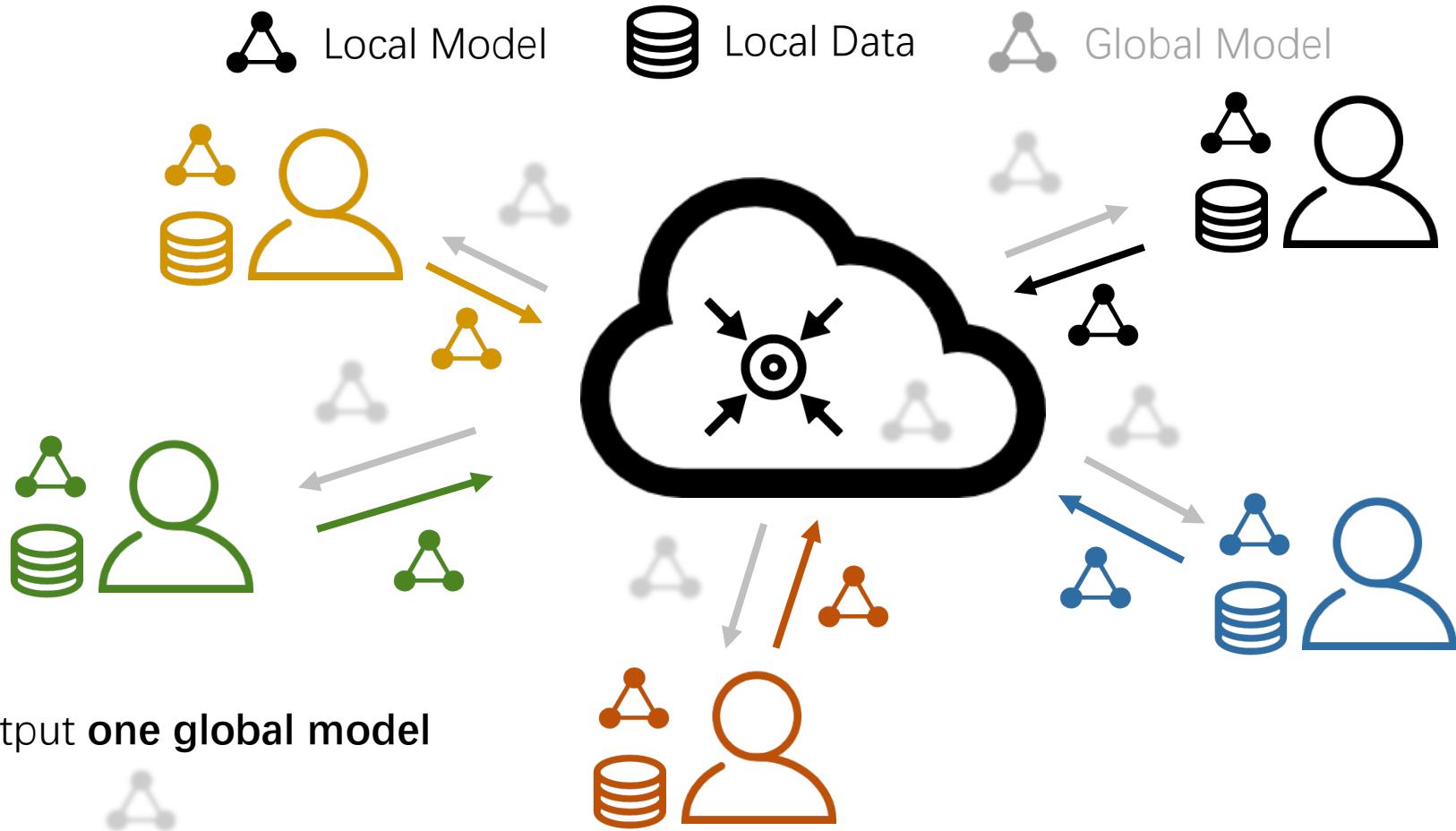
Federated Learning (FL)

- A **collaborative-learning** and **privacy-preserving** technique
- Learn an AI model among clients by **only sharing models** with the server.



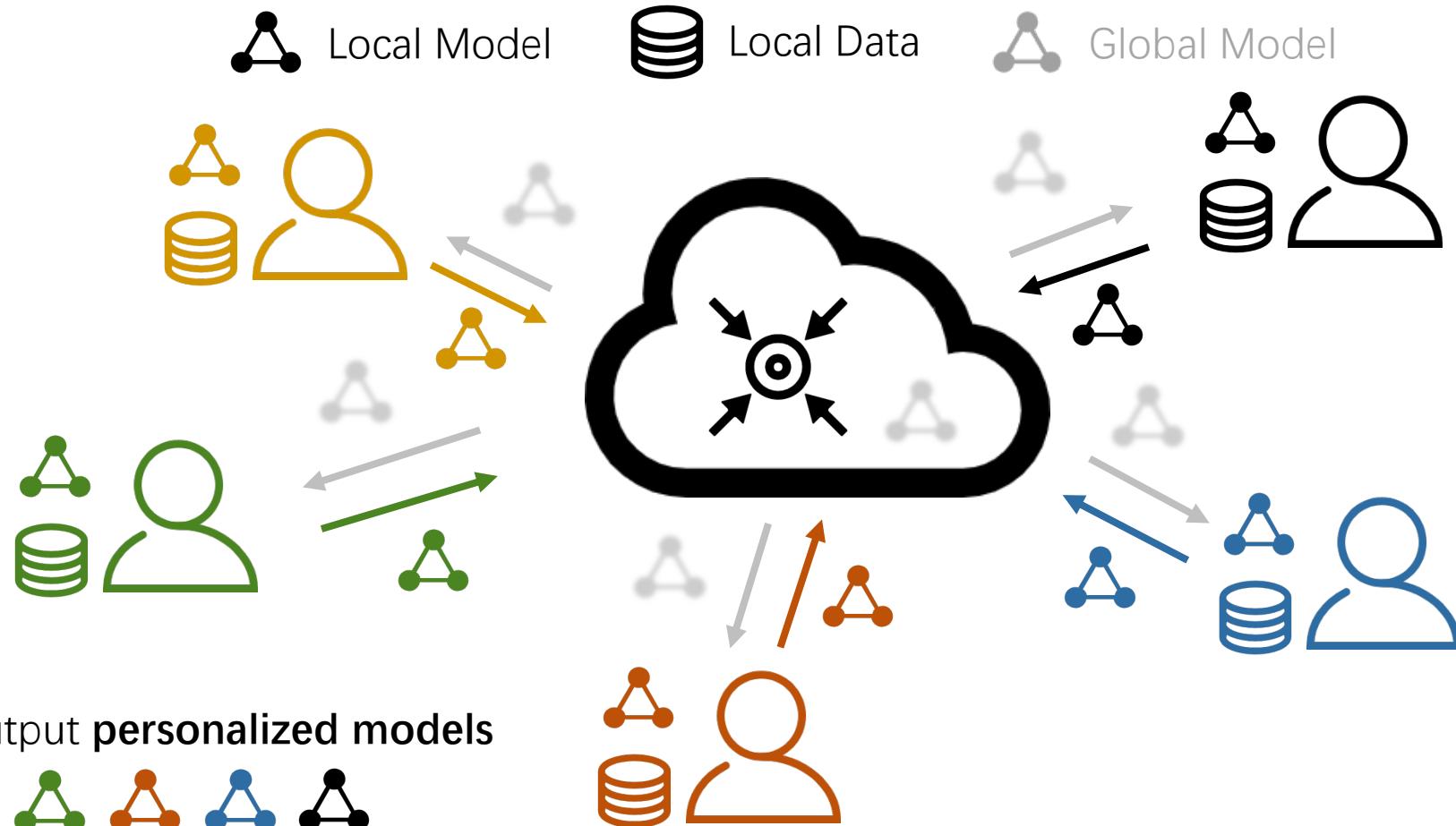
① Data Heterogeneity Issue in FL

- Data is **generated by different clients** and forbidden to be manipulated
- Each client has **personalized preferences**



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① PFLlib: Personalized FL (pFL) Algorithm Library

- Beginner-friendly
- Comprehensive (34 pFLs)
- Popular (1000+ stars)
- ...

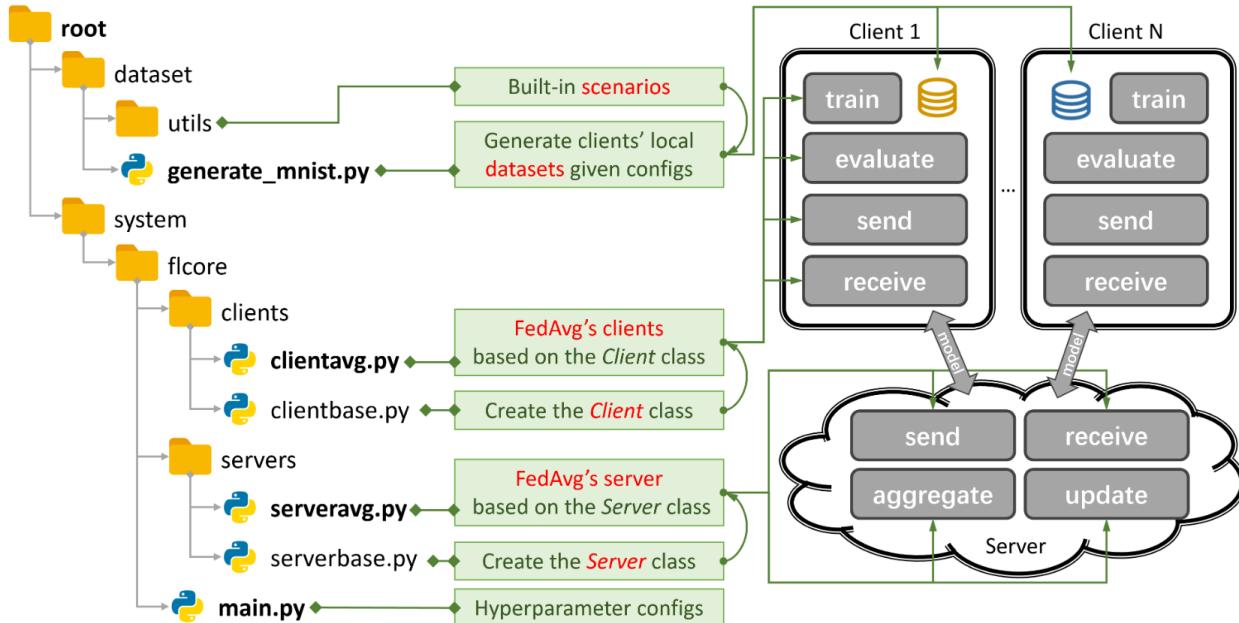
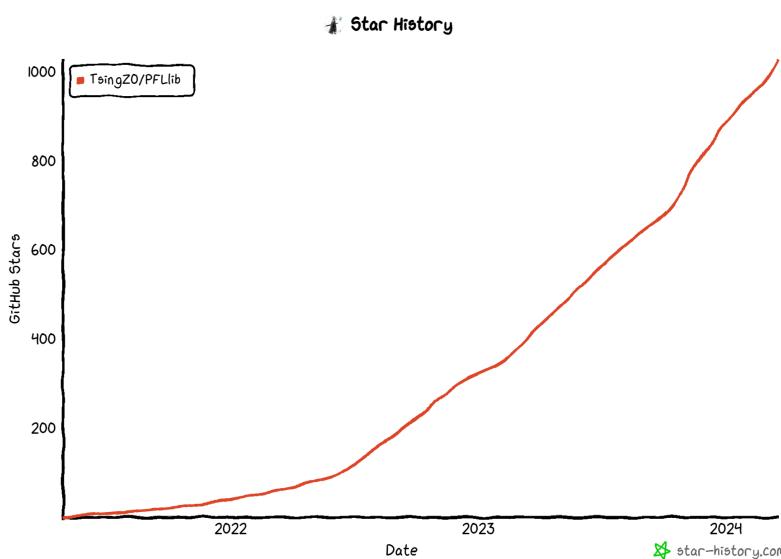


Figure 1: An Example for FedAvg. You can create a scenario using `generate_DATA.py` and run an algorithm using `main.py`, `clientNAME.py`, and `serverNAME.py`.

We expose this user-friendly algorithm library (with an integrated evaluation platform) for beginners who intend to start federated learning (FL) study.

- 34 traditional FL ([tFL](#)) or personalized FL ([pFL](#)) algorithms, 3 scenarios, and 20 datasets.
- Some experimental results are available [here](#).
- Refer to [this guide](#) to learn how to use it.
- This library can simulate scenarios using the 4-layer CNN on Cifar100 for 500 clients on one NVIDIA GeForce RTX 3090 GPU card with only 5.08GB GPU memory cost.

① Featured publications

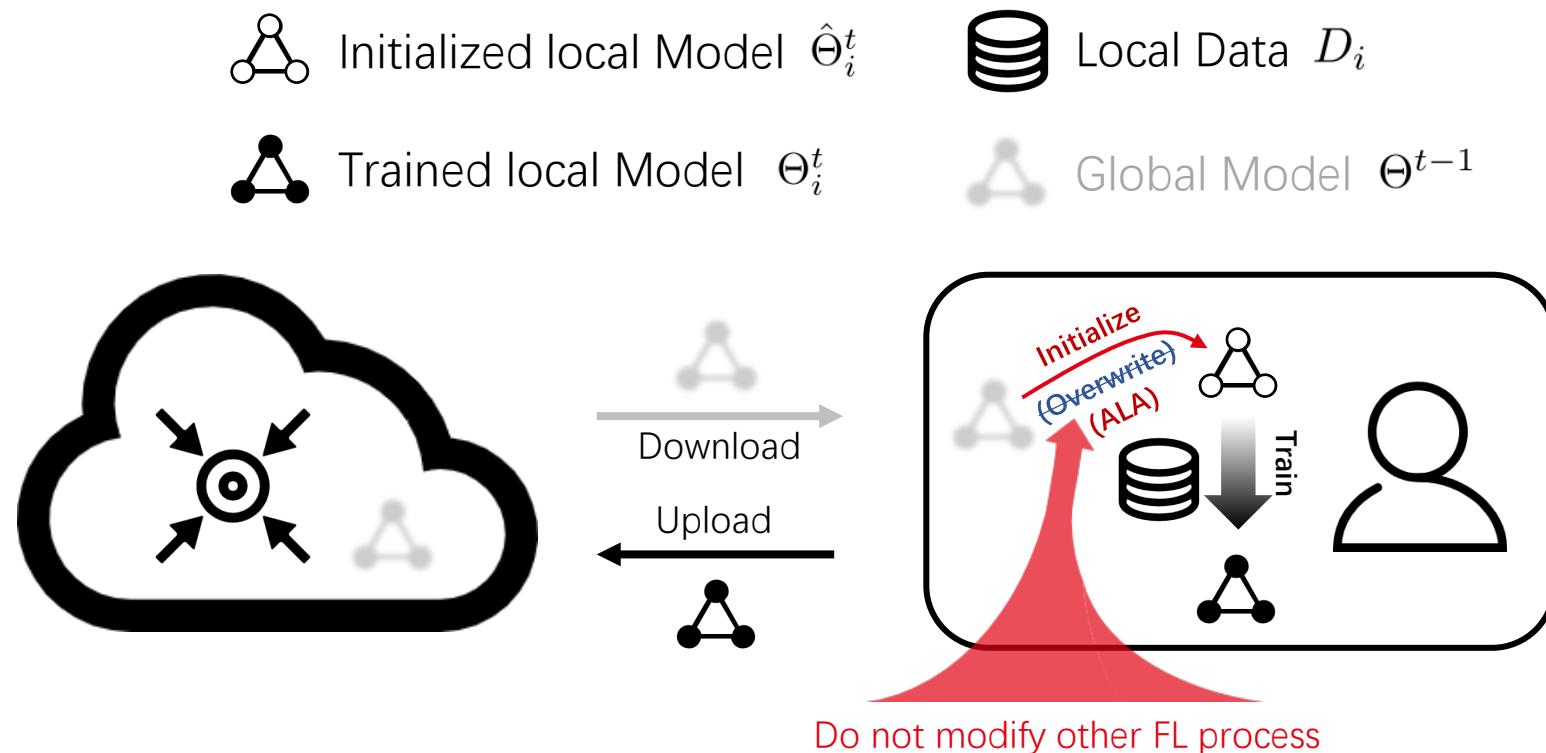
- [AAAI'23] FedALA: Adaptive Local Aggregation for Personalized Federated Learning.
- [KDD'23] FedCP: Separating Feature Information for Personalized Federated Learning via Conditional Policy.
- [ICCV'23] GPFL: Simultaneously Learning Generic and Personalized Feature Information for Personalized Federated Learning.
- [NeurIPS'23] Eliminating Domain Bias for Federated Learning in Representation Space.
- How can we consider both generalization and personalization?

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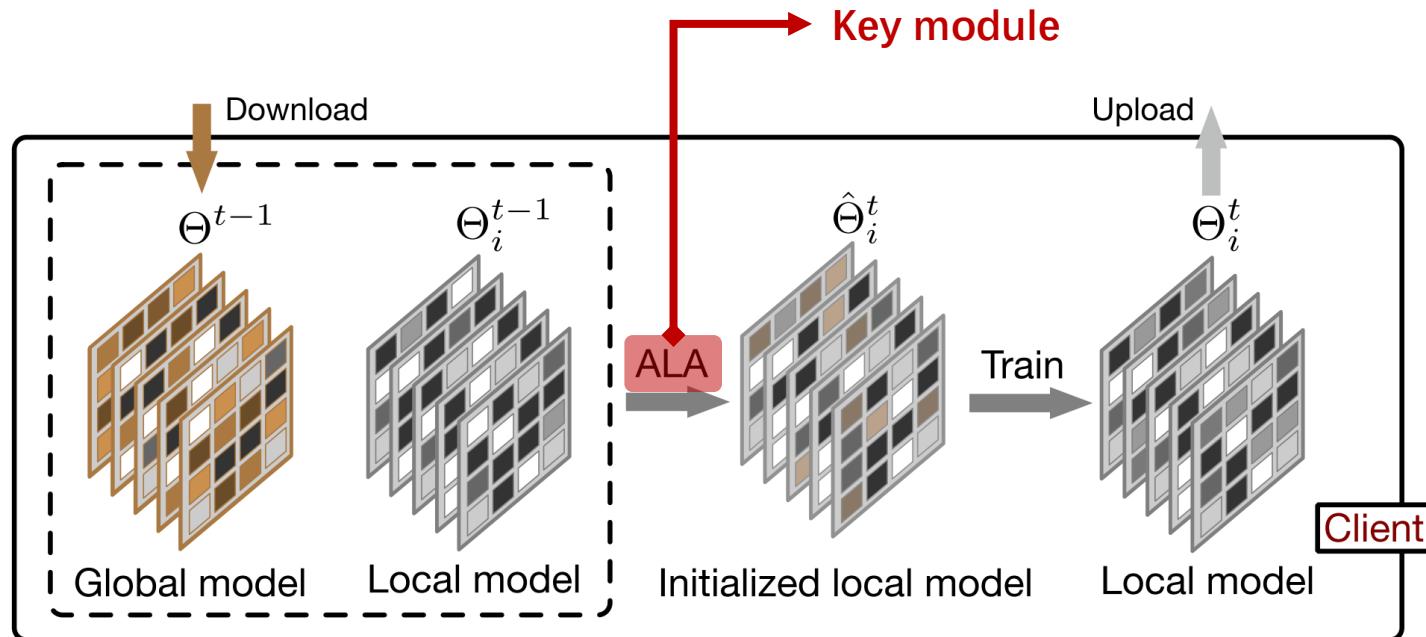
Motivation of FedALA

- Original workflow in FL
 - Both the **desired** and **undesired** information exist in the global model, resulting in **poor generalization ability**



FedALA

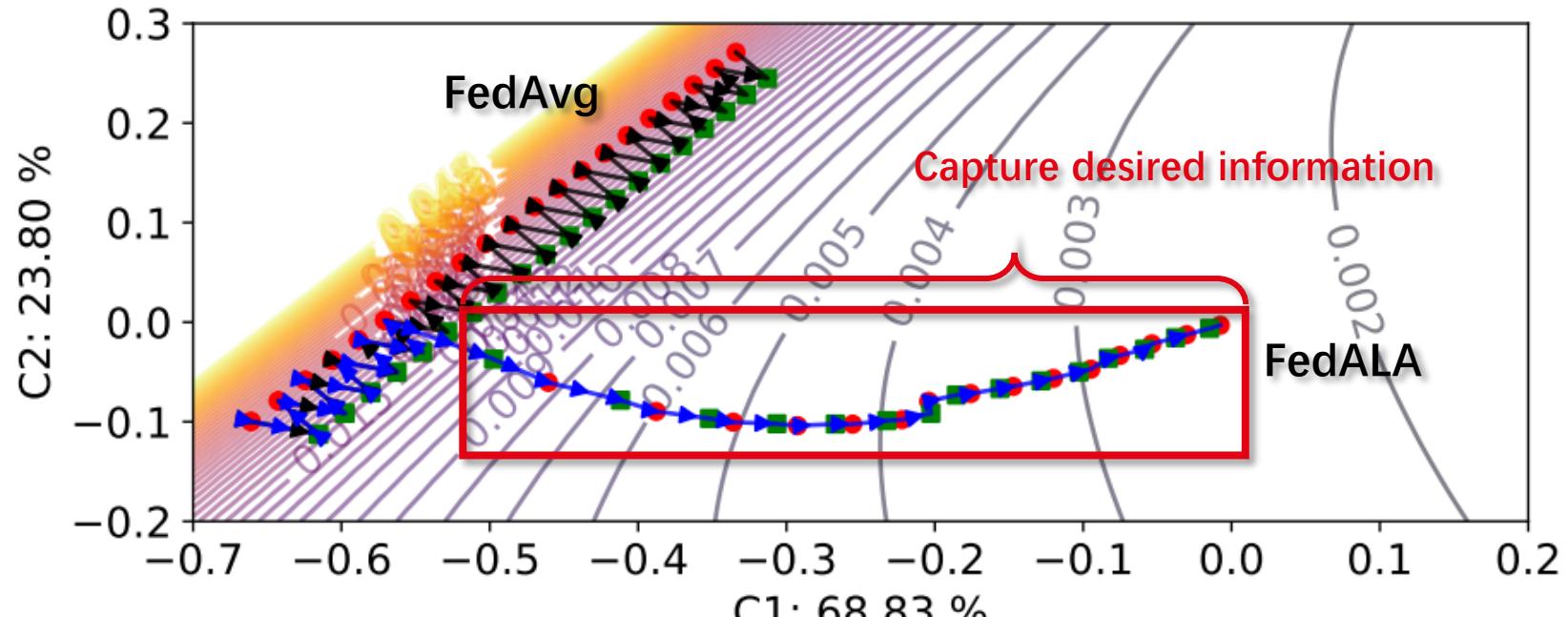
- Extract each client's desired information from the global model that facilitates local training
- Adaptively aggregate the information in the global and local model for initialization



Workflow on the client in one iteration

FedALA

- Learning trajectory on one client: **FedAvg** vs. **FedALA**
- Activate ALA in the subsequent iterations



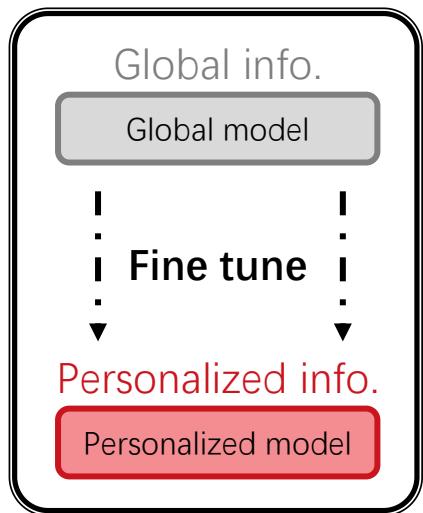
2D visualization of local learning trajectory

① Featured publications

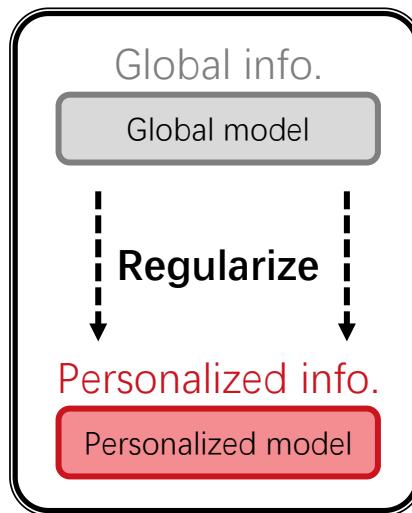
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Existing pFL

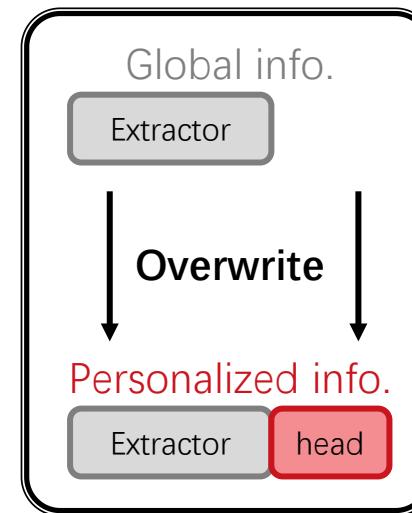
- **Consensus:** reasonably utilizing global and personalized information is the key for pFL.
 - meta-learning-based (Per-FedAvg), regularization-based (Ditto), and personalized-head-based (FedRep) pFL.



Per-FedAvg[1]



Ditto[2]



FedRep[3]

- They only focus on model parameters, but **ignore the source of information: data.**

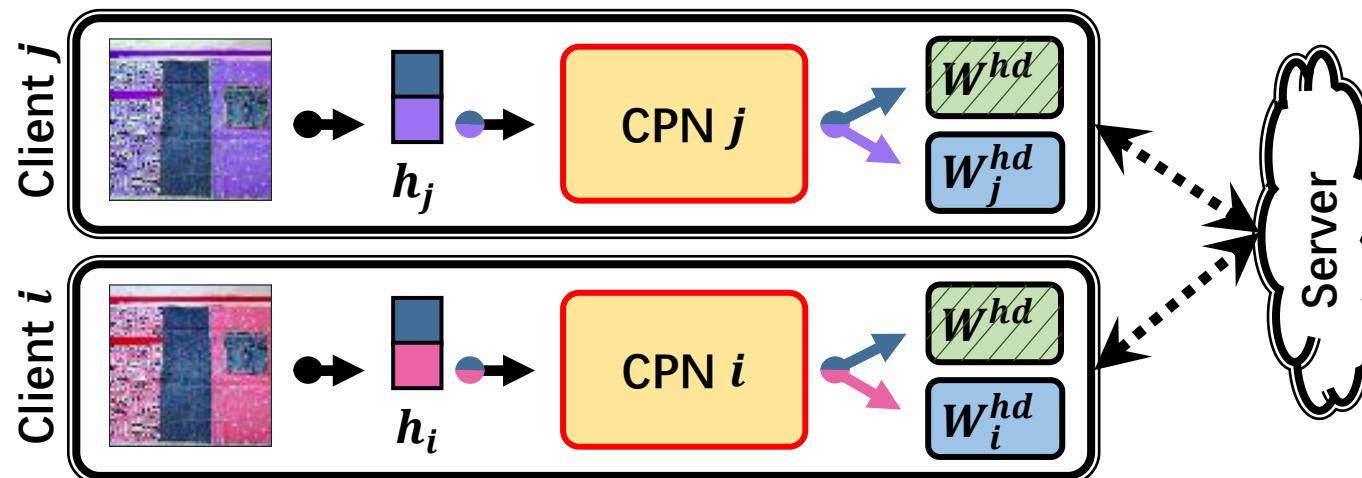
[1] Fallah A, Mokhtari A, Ozdaglar A. Personalized federated learning with theoretical guarantees: A model-agnostic meta-learning approach. NeurIPS, 2020.

[2] Li T, Hu S, Beirami A, et al. Ditto: Fair and robust federated learning through personalization. ICML, 2021.

[3] Collins L, Hassani H, Mokhtari A, et al. utilizing shared representations for personalized federated learning. ICML, 2021.

FedCP

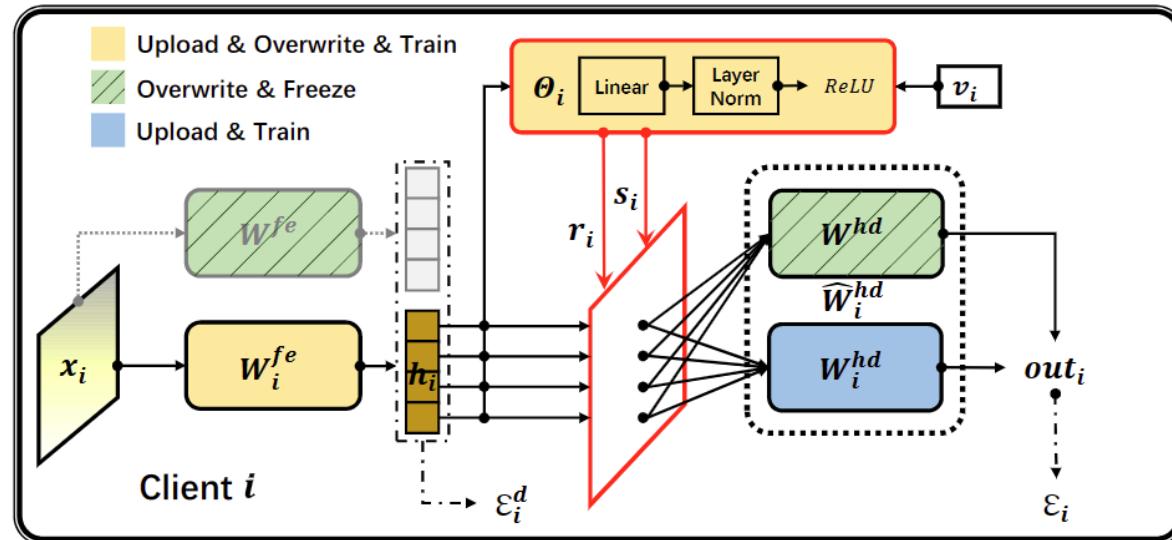
- We separate feature information via an *auxiliary Conditional Policy Network (CPN)*.
 - Generate *sample-specific policy*
 - *End-to-end training* together with the client model
 - *Lightweight* (e.g., 4.67% parameters of ResNet-18)



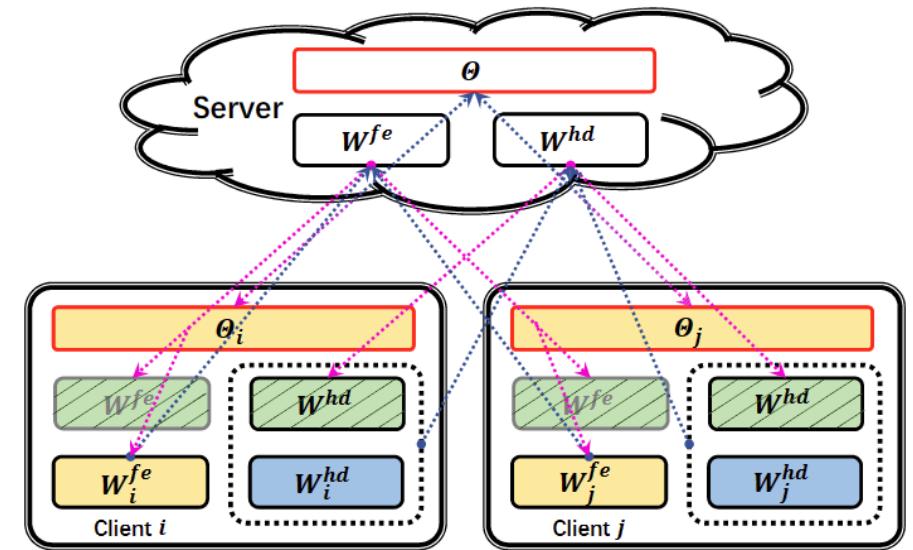
- We utilize *global and personalized information* via global and personalized heads.

FedCP

- Architecture



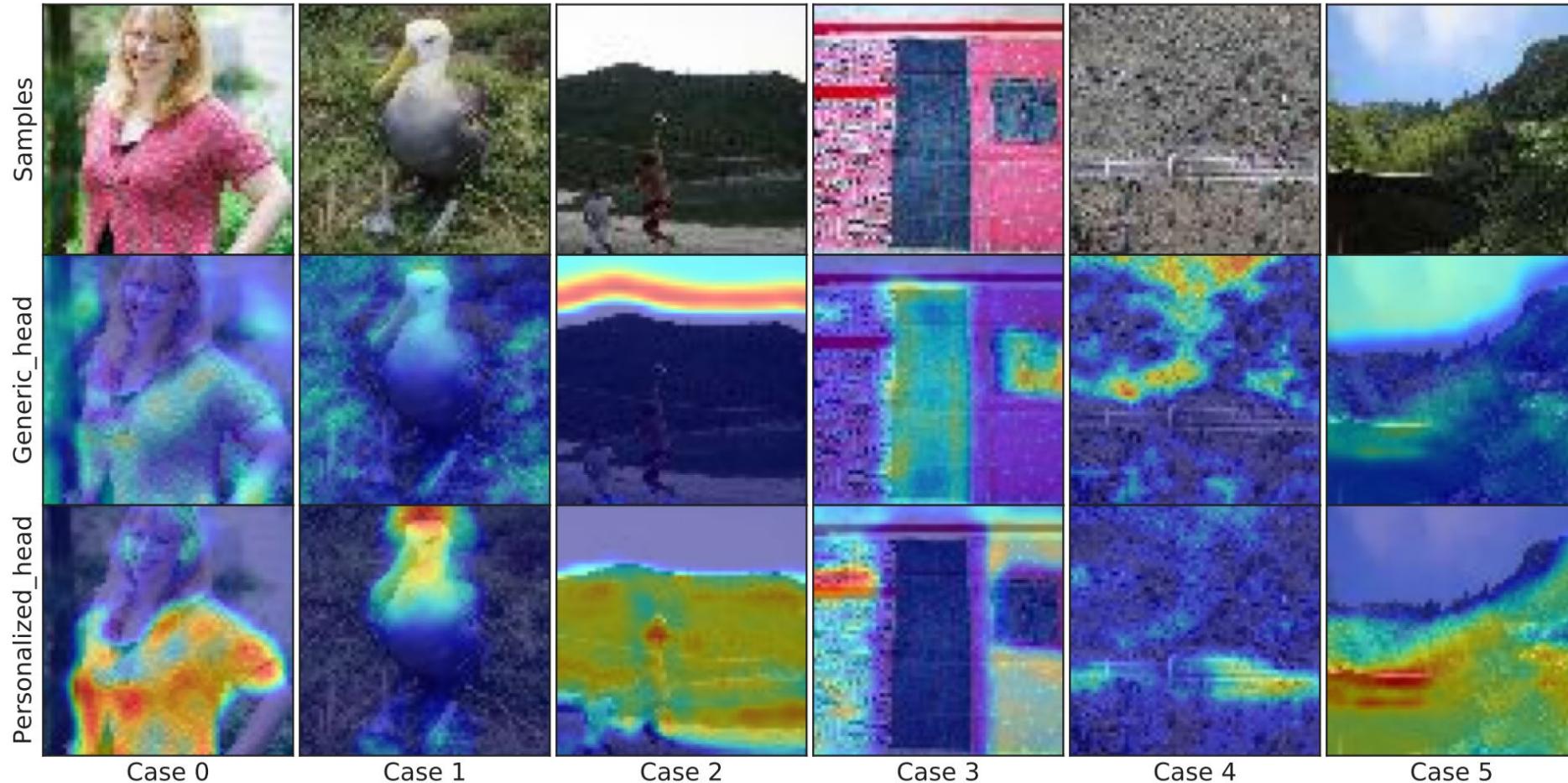
Data flow in the personalized model



Upload and download stream

FedCP

- Separating Feature Information



Six samples from the Tiny-ImageNet dataset

① Featured publications

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GPFL

- GPFL **introduces more global information** during local training to enhance local model
- CoV **eliminates the interaction between** global and personalized feature learning

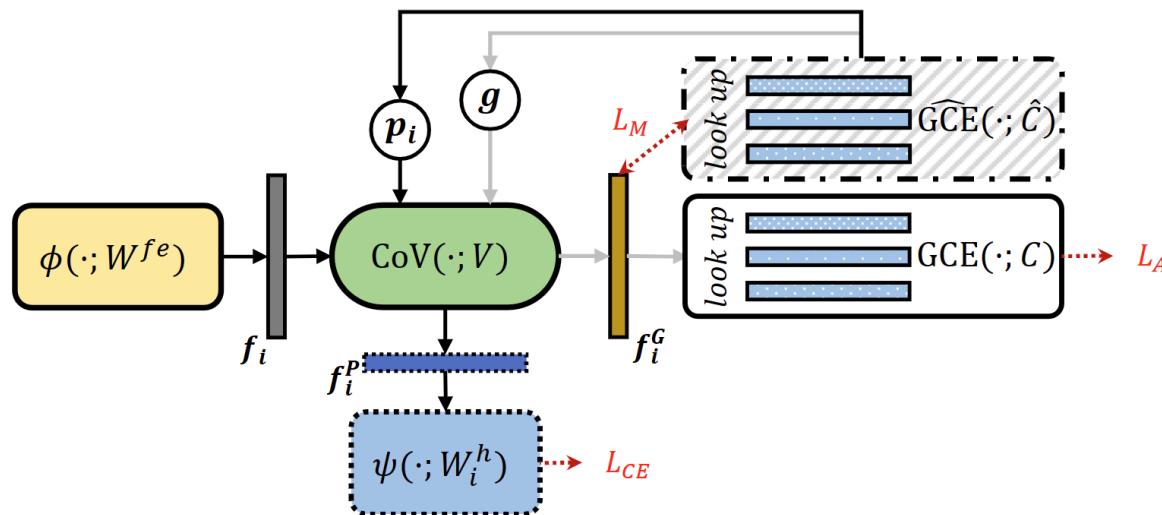
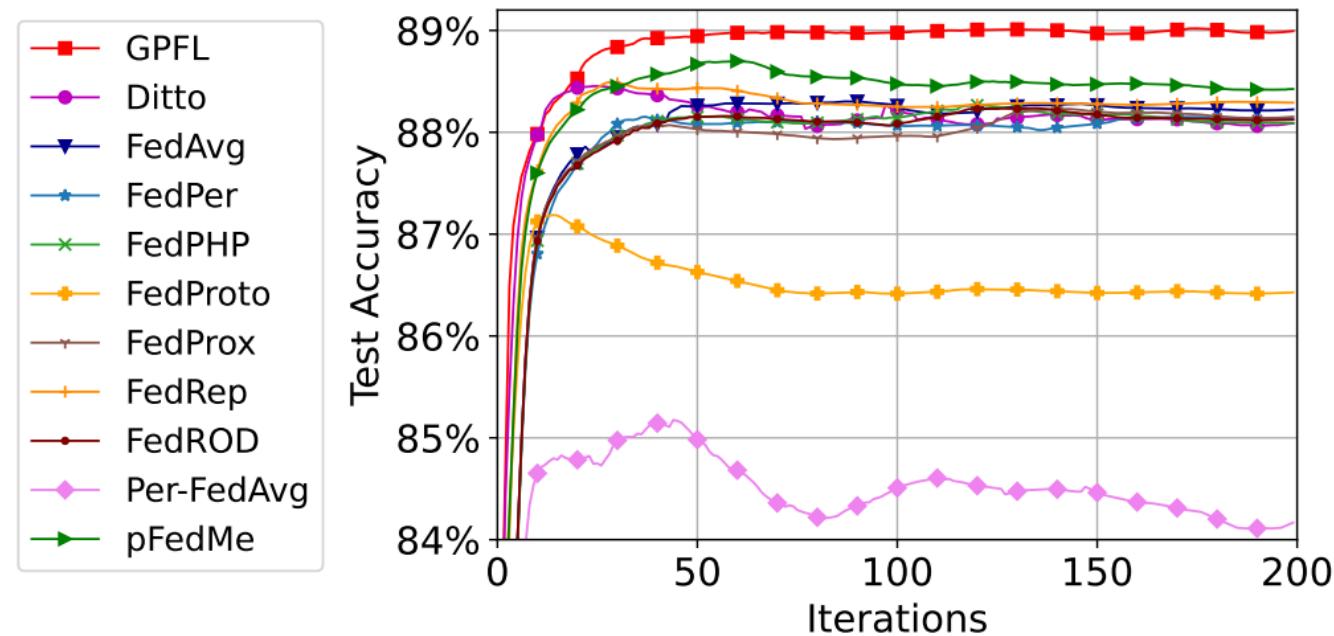


Illustration of client modules and data flow between them

GPFL

- Address the **overfitting** issue in pFL



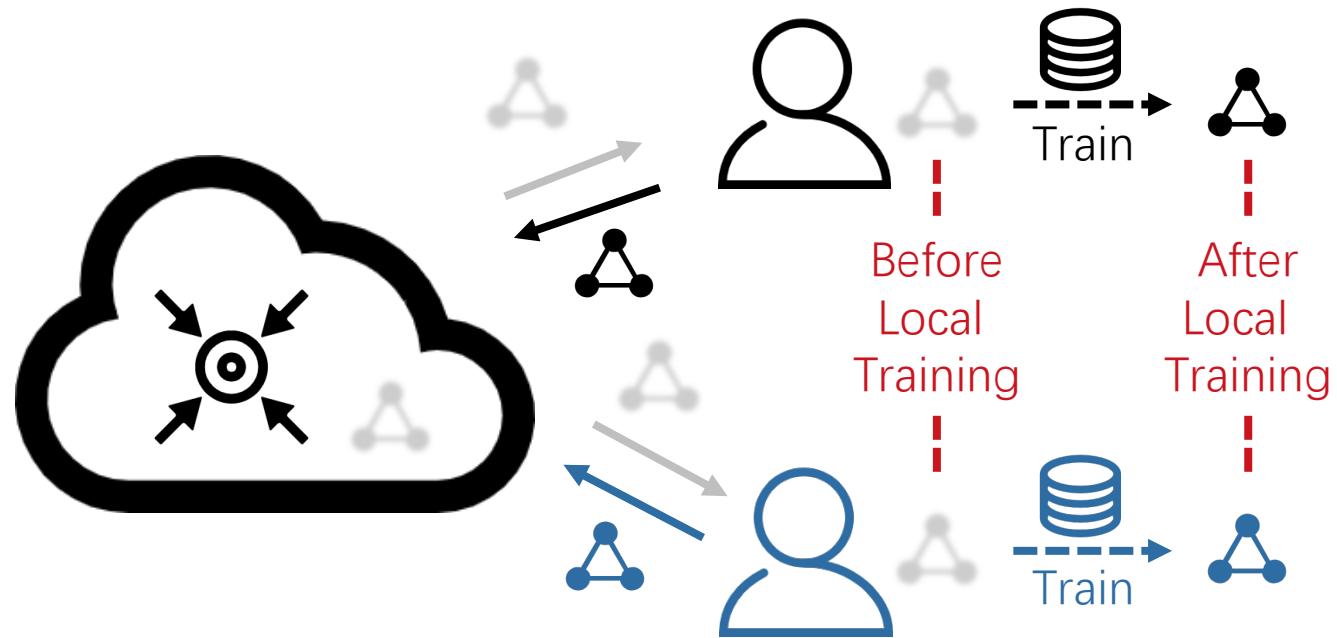
Test accuracy curves in the feature shift setting

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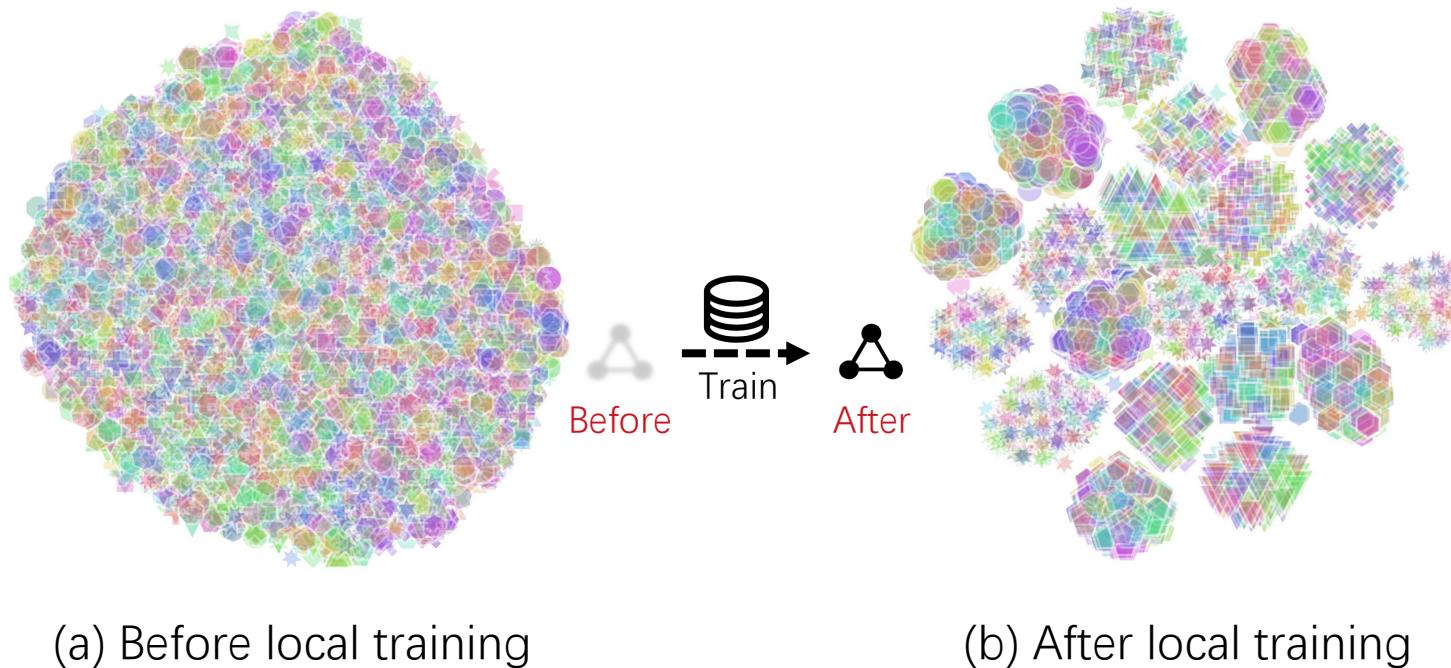
Local training

- Clients' local training turns the received global model to client-specific local models



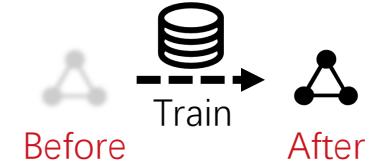
Representation bias phenomenon

- After local training, the feature representations are **biased** to client-specific domains

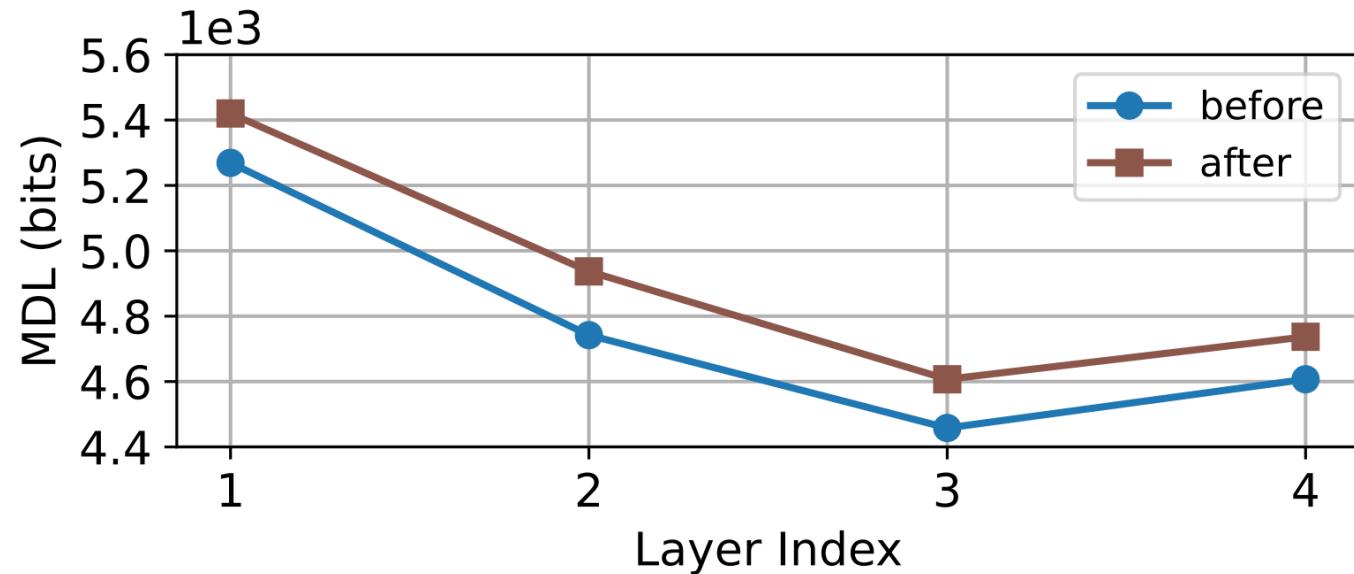


We use *color* and *shape* to distinguish *labels* and *clients*, respectively.

Representation degeneration phenomenon



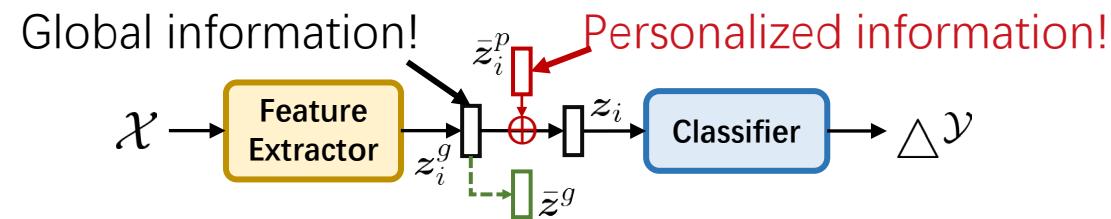
- At the same time, representations' quality is also **degenerated**



Per-layer MDL (bits) for representations before/after local training in FedAvg.
A large MDL value means low representation quality.

DBE

- Eliminate **domain bias**
- Improve **bi-directional knowledge transfer**



Local model (with PRBM and MR)

DBE

- **Local-to-global** knowledge transfer

Corollary 1. Consider a local data domain \mathcal{D}_i and a virtual global data domain \mathcal{D} for client i and the server, respectively. Let $\mathcal{D}_i = \langle \mathcal{U}_i, c^* \rangle$ and $\mathcal{D} = \langle \mathcal{U}, c^* \rangle$, where $c^* : \mathcal{X} \mapsto \mathcal{Y}$ is a ground-truth labeling function. Let \mathcal{H} be a hypothesis space of VC dimension d and $h : \mathcal{Z} \mapsto \mathcal{Y}, \forall h \in \mathcal{H}$. When using DBE, given a feature extraction function $\mathcal{F}^g : \mathcal{X} \mapsto \mathcal{Z}$ that shared between \mathcal{D}_i and \mathcal{D} , a random labeled sample of size m generated by applying \mathcal{F}^g to a random sample from \mathcal{U}_i labeled according to c^* , then for every $h^g \in \mathcal{H}$, with probability at least $1 - \delta$:

$$\mathcal{L}_{\mathcal{D}}(h^g) \leq \mathcal{L}_{\hat{\mathcal{D}}_i}(h^g) + \sqrt{\frac{4}{m} \left(d \log \frac{2em}{d} + \log \frac{4}{\delta} \right)} + d_{\mathcal{H}}(\tilde{\mathcal{U}}_i^g, \tilde{\mathcal{U}}^g) + \lambda_i,$$

where $\mathcal{L}_{\hat{\mathcal{D}}_i}$ is the empirical loss on \mathcal{D}_i , e is the base of the natural logarithm, and $d_{\mathcal{H}}(\cdot, \cdot)$ is the \mathcal{H} -divergence between two distributions. $\lambda_i := \min_{h^g} \mathcal{L}_{\mathcal{D}}(h^g) + \mathcal{L}_{\mathcal{D}_i}(h^g)$, $\tilde{\mathcal{U}}_i^g \subseteq \mathcal{Z}$, $\tilde{\mathcal{U}}^g \subseteq \mathcal{Z}$, and $d_{\mathcal{H}}(\tilde{\mathcal{U}}_i^g, \tilde{\mathcal{U}}^g) \leq d_{\mathcal{H}}(\tilde{\mathcal{U}}_i, \tilde{\mathcal{U}})$. $\tilde{\mathcal{U}}_i^g$ and $\tilde{\mathcal{U}}^g$ are the induced distributions of \mathcal{U}_i and \mathcal{U} under \mathcal{F}^g , respectively. $\tilde{\mathcal{U}}_i$ and $\tilde{\mathcal{U}}$ are the induced distributions of \mathcal{U}_i and \mathcal{U} under \mathcal{F} , respectively. \mathcal{F} is the feature extraction function in the original FedAvg without DBE.

DBE

- **Global-to-local** knowledge transfer

Corollary 2. Let \mathcal{D}_i , \mathcal{D} , \mathcal{F}^g , and λ_i defined as in Corollary I. Given a translation transformation function $PRBM : \mathcal{Z} \mapsto \mathcal{Z}$ that shared between \mathcal{D}_i and virtual \mathcal{D} , a random labeled sample of size m generated by applying \mathcal{F}' to a random sample from \mathcal{U}_i labeled according to c^* , $\mathcal{F}' = PRBM \circ \mathcal{F}^g : \mathcal{X} \mapsto \mathcal{Z}$, then for every $h' \in \mathcal{H}$, with probability at least $1 - \delta$:

$$\mathcal{L}_{\mathcal{D}_i}(h') \leq \mathcal{L}_{\hat{\mathcal{D}}}(h') + \sqrt{\frac{4}{m} \left(d \log \frac{2em}{d} + \log \frac{4}{\delta} \right)} + d_{\mathcal{H}}(\tilde{\mathcal{U}}', \tilde{\mathcal{U}}'_i) + \lambda_i,$$

where $d_{\mathcal{H}}(\tilde{\mathcal{U}}', \tilde{\mathcal{U}}'_i) = d_{\mathcal{H}}(\tilde{\mathcal{U}}^g, \tilde{\mathcal{U}}_i^g) \leq d_{\mathcal{H}}(\tilde{\mathcal{U}}, \tilde{\mathcal{U}}_i) = d_{\mathcal{H}}(\tilde{\mathcal{U}}_i, \tilde{\mathcal{U}})$. $\tilde{\mathcal{U}}'$ and $\tilde{\mathcal{U}}'_i$ are the induced distributions of \mathcal{U} and \mathcal{U}_i under \mathcal{F}' , respectively.

Please refer to our paper for proofs.

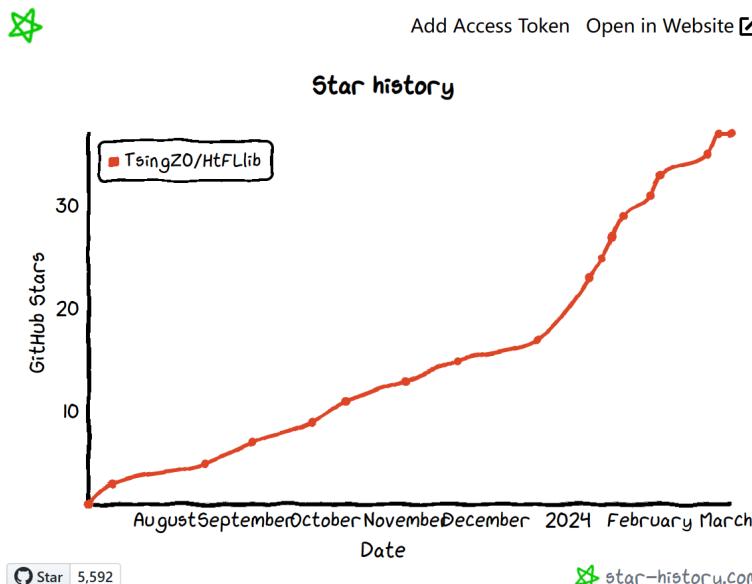
② Model heterogeneity issue in FL

- Communication overhead, device heterogeneity, and **intellectual property**
- Transmits **lightweight knowledge carriers** instead of exposing model parameters



② HtFLlib: HtFL Algorithm Library

- Burgeoning
- Beginner-friendly
- Data-free
- Comprehensive
- ...



Scenarios and datasets

Here, we only show the MNIST dataset in the *label skew* scenario generated via Dirichlet distribution for example. Please refer to my other repository [PFLlib](#) for more help.

You can also modify codes in PFLlib to support model heterogeneity scenarios, but it requires much effort. In this repository, you only need to configure `system/main.py` to support model heterogeneity scenarios.

Note: you may need to manually clean checkpoint files in the `temp/` folder via `system/clean_temp_files.py` if your program crashes accidentally. You can also set a checkpoint folder by yourself to prevent automatic deletion using the `-sfn` argument in the command line.

Data-free algorithms with code (updating)

Here, "data-free" refers to the absence of any additional dataset beyond the clients' private data.

- Local — Each client trains its model locally without federation.
- FedDistill — [Federated Knowledge Distillation 2020](#)
- FML — [Federated Mutual Learning 2020](#)
- LG-FedAvg — [Think Locally, Act Globally: Federated Learning with Local and Global Representations 2020](#)
- FedGen — [Data-Free Knowledge Distillation for Heterogeneous Federated Learning ICML 2021](#)
- FedProto — [FedProto: Federated Prototype Learning across Heterogeneous Clients AAAI 2022](#)
- FedKD — [Communication-efficient federated learning via knowledge distillation Nature Communications 2022](#)
- FedGH — [FedGH: Heterogeneous Federated Learning with Generalized Global Header ACM MM 2023](#)
- FedTGP — [FedTGP: Trainable Global Prototypes with Adaptive-Margin-Enhanced Contrastive Learning for Data and Model Heterogeneity in Federated Learning AAAI 2024](#)

② Featured publications

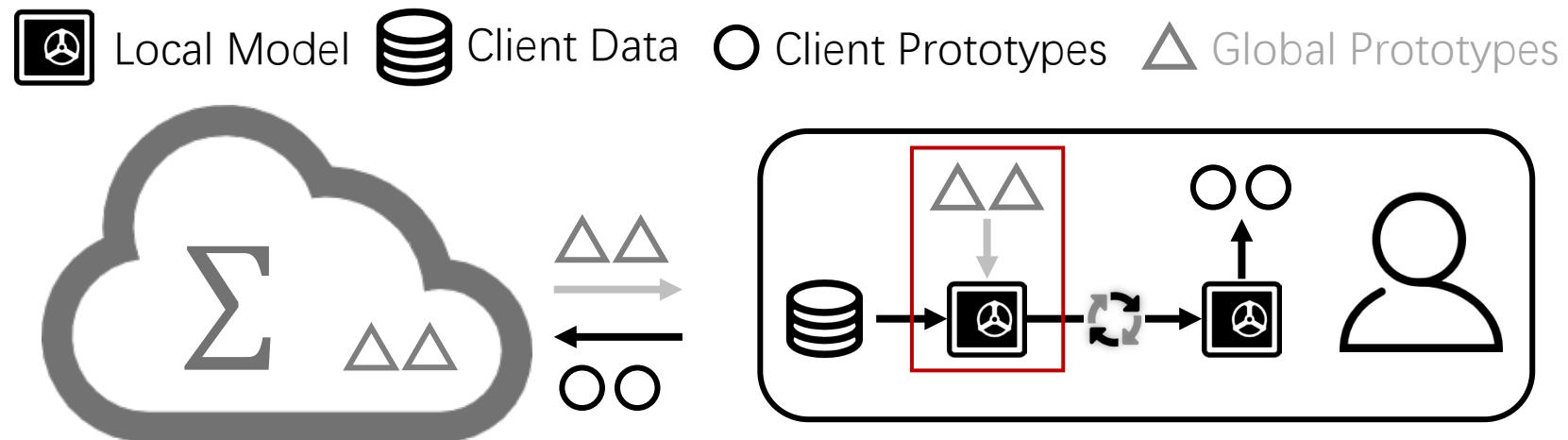
- **[AAAI'24]** FedTGP: Trainable Global Prototypes with Adaptive-Margin-Enhanced Contrastive Learning for Data and Model Heterogeneity in Federated Learning.
- **[CVPR'24]** FedKTL: An Upload-Efficient Knowledge Transfer Scheme With a Pre-trained Generator in Heterogeneous Federated Learning.
- **How can knowledge be shared and aggregated to benefit participants?**

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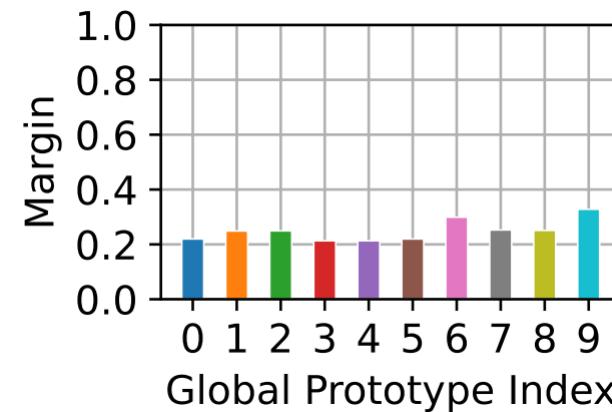
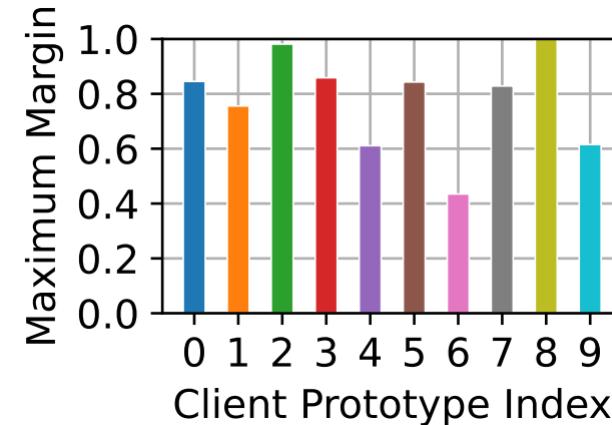
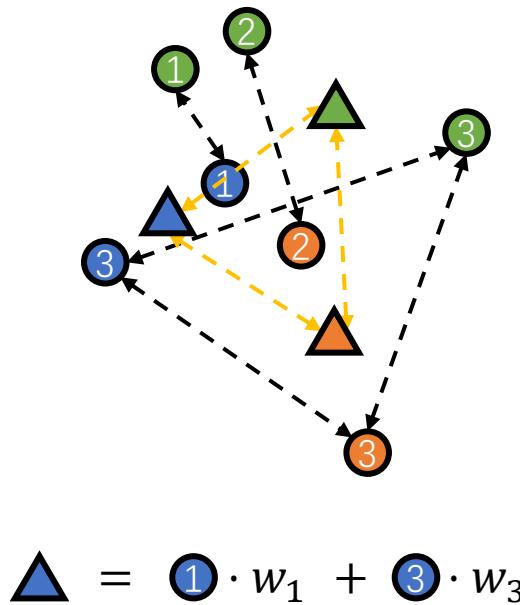
FedProto: share prototypes (class representatives)

- Share **client prototypes** with the server
- Aggregate client prototypes to generate **global prototypes**
- Train client models with both client data and global prototypes



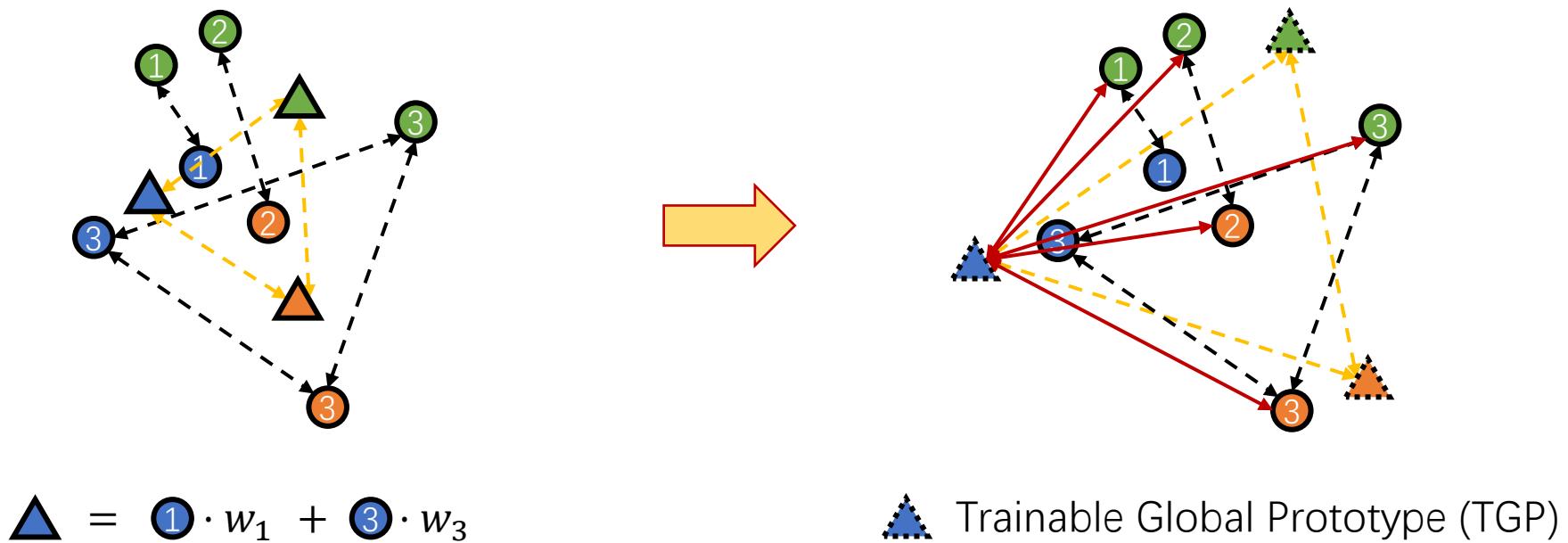
Issues of FedProto

- Global prototype (Δ) margin **shrinks** after weighted-averaging



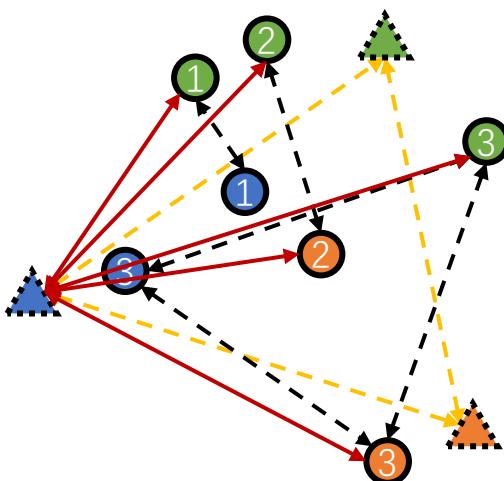
FedTGP

- Remove weighted-averaging
- Consider the uploaded client prototypes as data
- **Enlarge** the global prototype margin

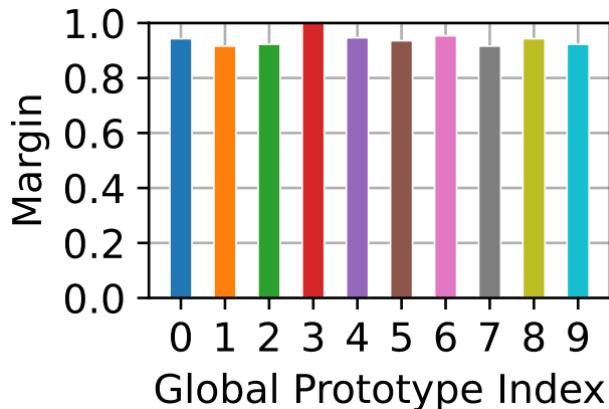
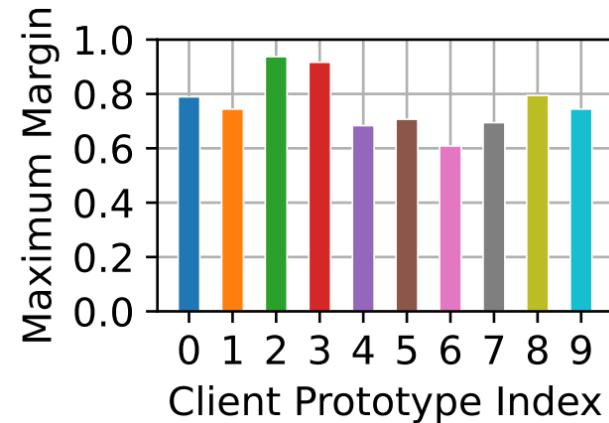


FedTGP

- Remove weighted-averaging
- Consider the uploaded client prototypes as data
- **Enlarge** the global prototype margin



▲ Trainable Global Prototype (TGP)



FedTGP

- Server objective: **Enlarge** the global prototype **margin** to improve discrimination
- **Train global prototypes** using **Adaptive-margin-enhanced Contrastive Learning (ACL)**

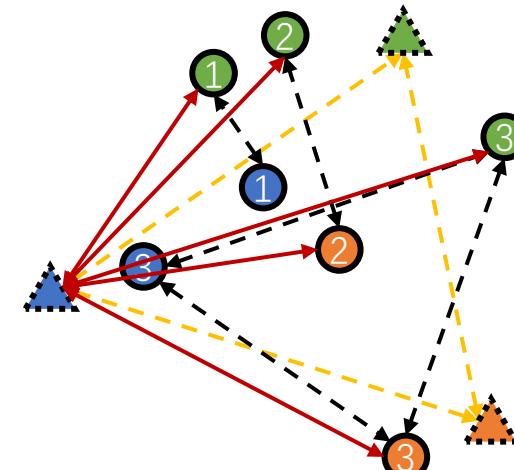
$$\min_{\hat{\mathcal{P}}} \sum_{c=1}^C \mathcal{L}_P^c,$$

$$\mathcal{L}_P^c = \sum_{i \in \mathcal{I}^t} -\log \frac{e^{-(\phi(P_i^c, \hat{P}^c) + \delta(t))}}{e^{-(\phi(P_i^c, \hat{P}^c) + \delta(t))} + \sum_{c'} e^{-\phi(P_i^c, \hat{P}^{c'})}}$$
$$\delta(t) = \min(\max_{c \in [C], c' \in [C], c \neq c'} \phi(Q_t^c, Q_t^{c'}), \tau),$$

$$Q_t^c = \frac{1}{|\mathcal{P}_t^c|} \sum_{i \in \mathcal{I}^t} P_i^c, \forall c \in [C]$$

τ is a margin threshold

maximum cluster margin



- ▲ \hat{P}^c : A TGP of class c
- ▲ $\hat{\mathcal{P}}$: All TGP
- P_i^c : A prototype of class c from client i

FedTGP

- **ACL** can also be applied to other tasks and scenarios

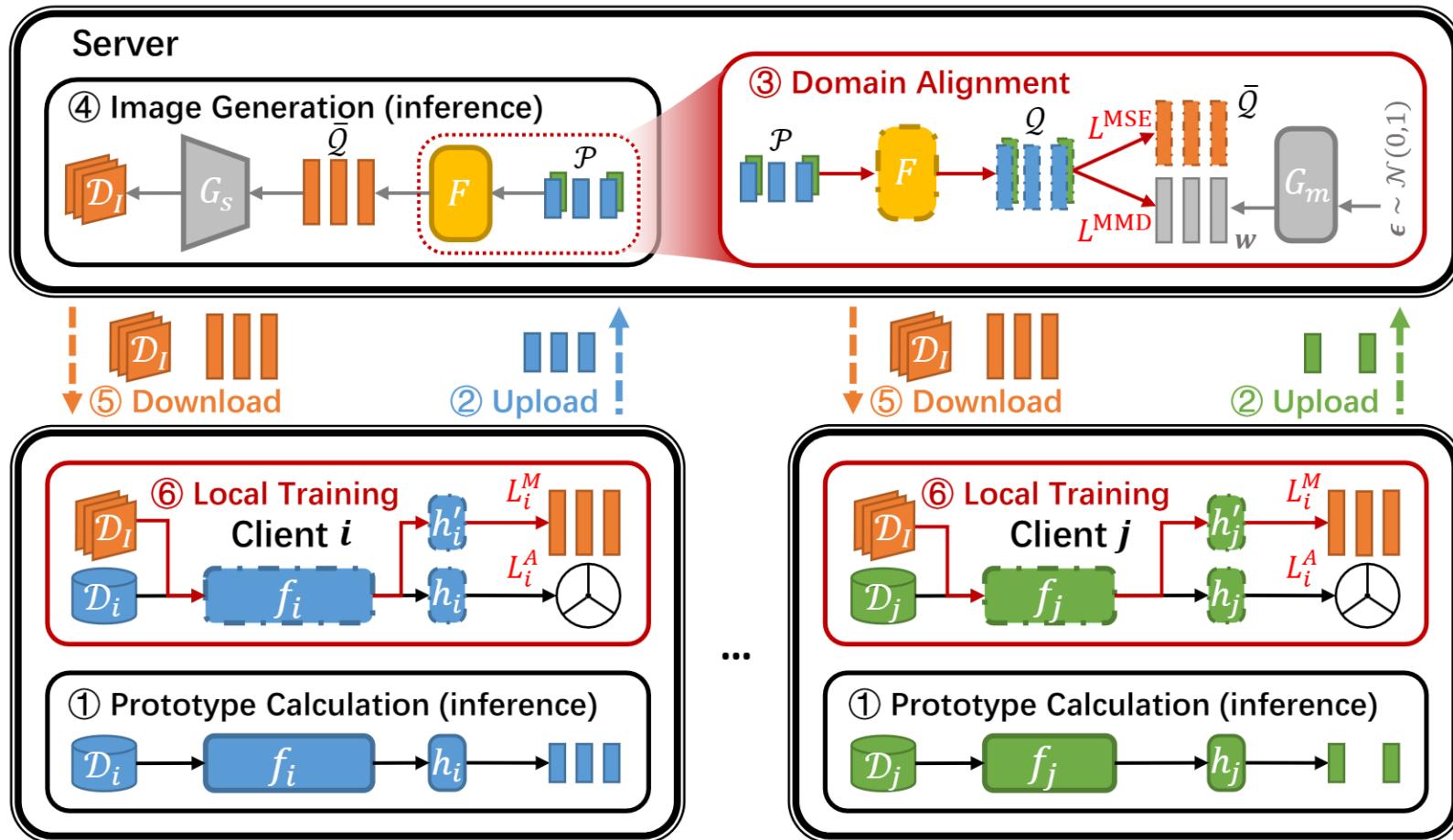
$$\mathcal{L}_P^c = \sum_{i \in \mathcal{I}^t} -\log \frac{e^{-(\phi(P_i^c, \hat{P}^c) + \delta(t))}}{e^{-(\phi(P_i^c, \hat{P}^c) + \delta(t))} + \sum_{c'} e^{-\phi(P_i^c, \hat{P}^{c'})}}$$

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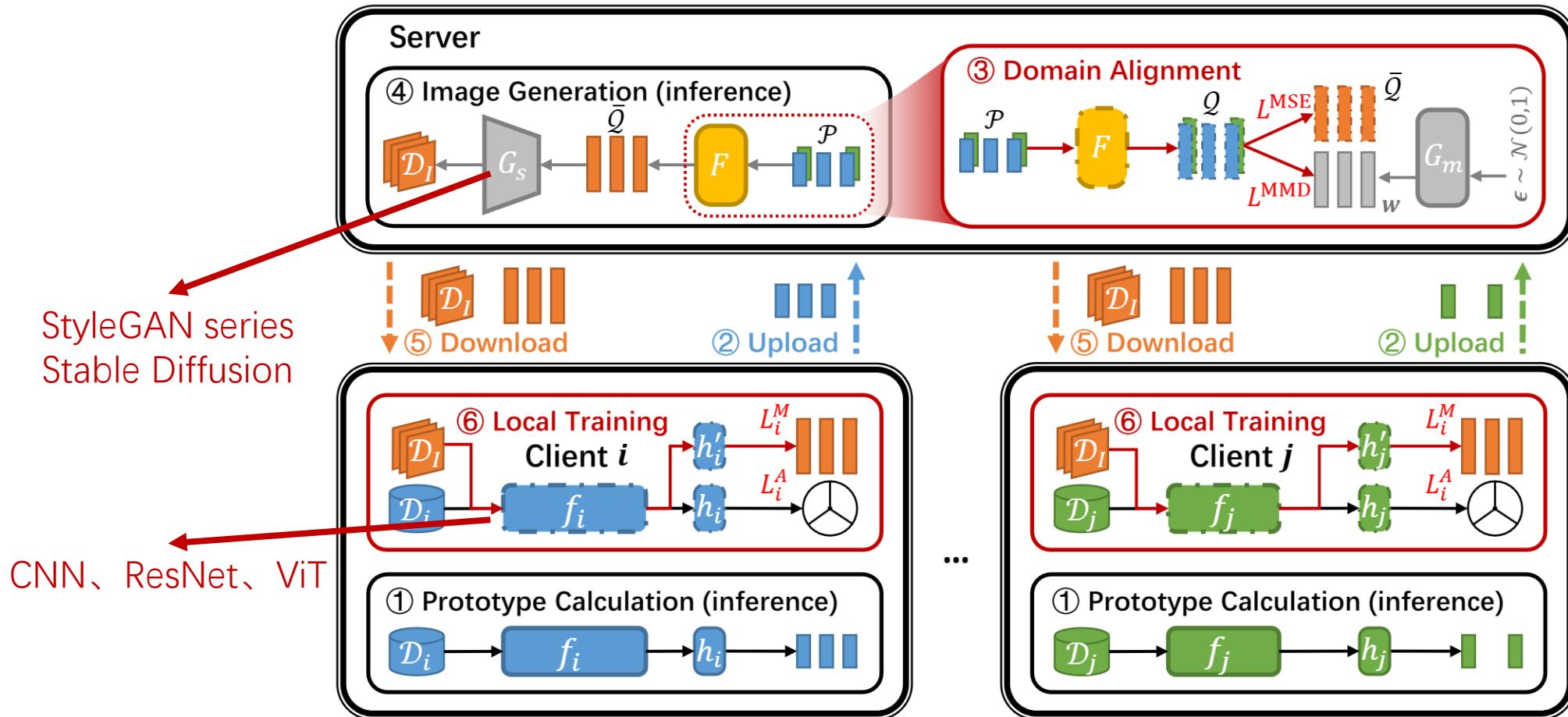
FedKTL

- Transform client prototypes to images **using a pre-trained generator on the server**
- **Transfer pre-existing knowledge** from the generator to client models



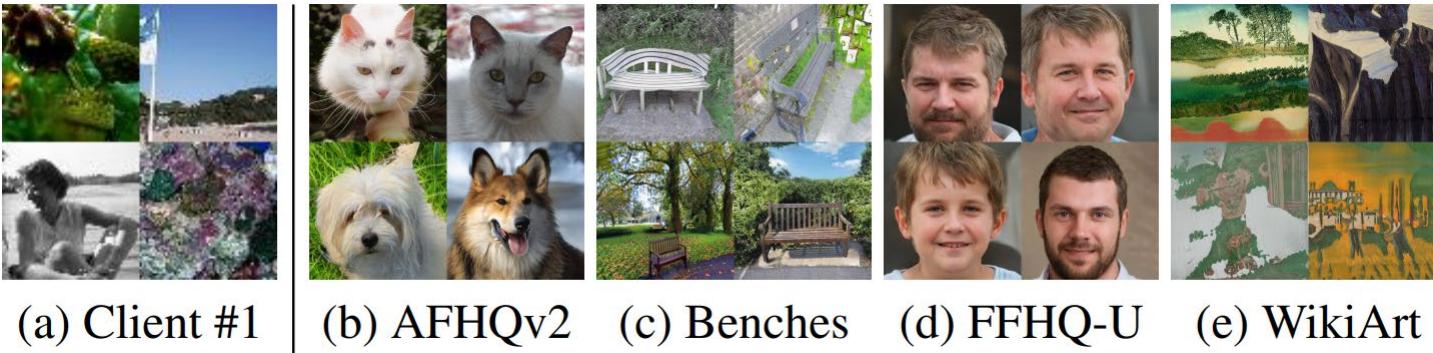
FedKTL

- Transform client prototypes to images **using a pre-trained generator on the server**
- **Transfer pre-existing knowledge** from the generator to client models



FedKTL

- FedKTL can **adapt to various generators** that were pre-trained using various datasets
- The **semantics of the generated images** can be different from clients' data



(a): Four images (one image per class) on client #1. (b), (c), (d), and (e): The images generated by different StyleGAN3s corresponding to the aforementioned four classes.

Feel free to contact me!

Home page: <https://github.com/TsingZ0>



Thanks!