FedBABU: Towards Enhanced Representation for Federated Image Classification

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Abstract

Federated learning has evolved to improve a single global model under data heterogeneity (as a curse) or to develop multiple personalized models using data heterogeneity (as a blessing). However, there has been little research considering both directions simultaneously. In this paper, we first investigate the relationship between them by analyzing Federated Averaging [31] at the client level and determine that a better federated global model performance does not constantly improve personalization. To elucidate the cause of this personalization performance degradation problem, we decompose the entire network into the body (i.e., extractor), related to universality, and the head (i.e., classifier), related to personalization. We then point out that this problem stems from training the head. Based on this observation, we propose a novel federated learning algorithm, coined as FedBABU, which updates only the body of the model during federated training (i.e., the head is randomly initialized and *never* updated), and the head is fine-tuned for personalization during the evaluation process. Extensive experiments show consistent performance improvements and an efficient personalization of FedBABU.

1 Introduction

Federated learning (FL) [31], a distributed learning framework with personalized data, has become an attractive field of research. From the early days of this field, improving *a single global model* across devices has been the main objective [48, 13, 28, 1], where the global model suffers from data heterogeneity. Many researchers have recently focused on *multiple personalized models* by leveraging data heterogeneity across devices as a blessing in disguise [4, 12, 47, 14, 37, 38]. Although many studies have been conducted on each research line, there remains a lack of research on how to train a good global model for personalization purposes [22, 23]. In this study, for personalized training, each local client model starts from a global model that learns information from all clients and leverages the global model to fit its own data distribution.

In [23], personalization methods that adapt the global model through fine-tuning on each device were analyzed. They observed that the effects of fine-tuning are encouraging and that training in a central location increases the initial accuracy (of a single global model) while decreasing the personalized accuracy (of on-device fine-tuned models). We focus on *why* opposite changes in the two performances appear. This suggests that the factors for universality and personalization must be dealt with separately, inspiring us to decouple the entire network into the body related to generality and the head related to specialty, as in [24, 45, 44, 10] for advanced analysis. Note that popular networks have one linear layer (e.g., MobileNet [21] and ResNet [20]), and the head is defined as this linear layer and the body is defined as all the layers except the head. The body of the model is related to representation learning, and the head of the model is related to linear decision boundary learning. We shed light on the cause of the personalization performance degradation problem by decoupling parameters, pointing out that such a problem stems from training the head.

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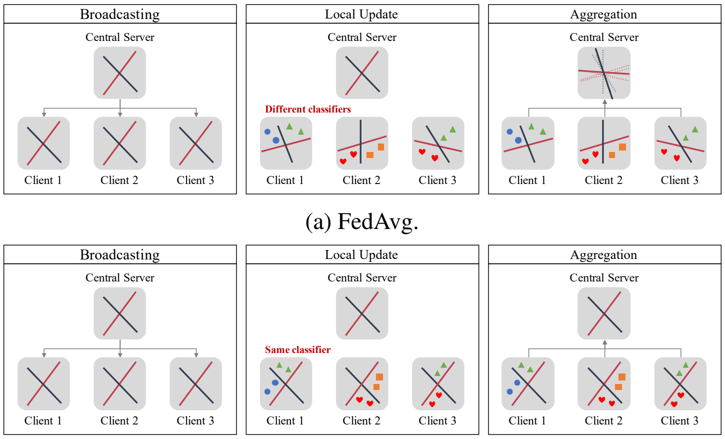

(a) FedAvg.

(b) FedBABU.

Figure 1: **Difference in the local update and aggregation stages between FedAvg and FedBABU**. In the figure, the lines represent the decision boundaries defined by the head (i.e., the last linear classifier) of the network. Different shapes indicate different classes. It is assumed that each client has two classes. (a) FedAvg updates the entire network during local updates on each client, and then the local networks are aggregated entirely. Therefore, the heads of all clients and the head of the server are different. Whereas, (b) FedBABU only updates the body (i.e., all the layers except the head) during local updates on each client, and then the local networks are aggregated body-partially. Therefore, the heads of all clients and the head of the server are the same.

Inspired by the above observations, we propose an algorithm to learn a single global model that can be efficiently personalized by simply changing the Federated Averaging (FedAvg) algorithm. FedAvg consists of four stages: client sampling, broadcasting, local update, and aggregation. In the client sampling stage, clients are sampled because the number of clients is so large that not all clients can participate per round. In the broadcasting stage, the server sends a global model (i.e., an initial random model at the first broadcast stage or an aggregated model afterward) to the participating clients. In the local update stage, the broadcast model of each device is trained based on its own data set. In the aggregation stage, locally updated models are sent to the server and are aggregated by averaging. Among the four stages, we focus on the *local update* stage from both the universality and personalization perspectives. *Here, we only update the body of the model in the local update stage, i.e., the head is never updated during federated training.* From this, we propose FedBABU, **Fed**erated Averaging with **B**ody **A**ggregation and **B**ody **U**pdate. Figure 1 describes the difference during the local update and aggregation stages between FedAvg and FedBABU. *Intuitively, our approach is a type of representation learning based on the same fixed criteria across all clients.* This simple change improves the representation power of a single global model and enables the trained single global model to be personalized more accurately and rapidly than FedAvg.

Our contributions are summarized as follows:

- We investigate the connection between a single global model and fine-tuned personalized models by analyzing the FedAvg algorithm at the client level and show that training the head using centralized data has a negative impact on personalization.
- We demonstrate that a fixed random classifier can have comparable performance as a learned classifier under a centralized setting. From this observation, we suggest that sharing a fixed random classifier across all clients can be more potent for matched aggregation than averaging each learned classifier in federated settings.
- We propose a novel algorithm, **FedBABU**, that reduces the update and aggregation parts from the entire model to the body of the model during federated training.
- We show that FedBABU is efficient, particularly under more significant data heterogeneity. Furthermore, a single global model trained with the FedBABU algorithm can be personalized rapidly (even with one fine-tuning epoch), and the personalization performance of FedBABU overwhelms that of other existing personalization FL algorithms.
- We adapt the body update and body aggregation idea to the regularization-based federated learning algorithm (such as FedProx [28]). We show that regularization reduces the personalization capabilities and that this problem is mitigated through BABU.

2 Related Works

FL for a Single Global Model Canonical federated learning, FedAvg proposed by [31], aims to learn a single global model that collects the benefits of affluent data without storing the raw data of the clients in a central server, reducing the communication costs through local updates. However, it is difficult to develop a globally optimal model for non-independent and identically distributed (non-IID) data derived from various clients. To solve this problem, studies have been conducted that make the data distribution of the clients IID-like or add regularization to the distance from the global model during local updates. [48] suggested that all clients share a subset of public data, and [13] augmented data for balancing the label distribution of clients. Recently, [28, 1] penalized local models that have a large divergence from the global model, adding a regularization term to the local optimization process and allowing the global model to converge more reliably. However, it should be noted that a single global model trained using the above methods is not optimized for each client.

Personalized FL Personalized federated learning aims to learn personalized local models stylized to each client. Although local models can be developed without federation, this method suffers from a limited amount of data. Therefore, to maintain the benefits of the federation and personalized models, many other methods have been applied to FL: clustering, multi-task learning, transfer learning, and meta-learning. [3, 30] clustered similar clients to match the data distribution within a cluster and learned separate models for each cluster without inter-cluster federation. Similar to clustering, multi-task learning aims to learn models for related clients simultaneously. Note that clustering ties related clients into a single cluster, whereas multi-task learning does not. The generalization of each model can be improved by sharing representations between the related clients. [38, 12] showed that multi-task learning is an appropriate learning scheme for personalized FL. Transfer learning is also a recommended learning scheme because it aims to deliver knowledge among clients. In addition, [43, 7] utilized transfer learning to enhance local models by transferring knowledge between related clients. Unlike the aforementioned methods that develop local models during training, [4, 14] attempted to develop a good initialized shared global model using bi-level optimization through a Model-Agnostic Meta-Learning (MAML) approach [15]. A well-initialized model can be personalized through updates on each client (such as inner updates in MAML). [23] argued that the FedAvg algorithm could be interpreted as a meta-learning algorithm, and a personalized local model with high accuracy can be obtained through fine-tuning from a global model learned using FedAvg. In addition, various technologies and algorithms for personalized FL are presented, and it will be helpful to read [40, 25] for more details.

Decoupling the Body (Extractor) and the Head (Classifier) for Personalized FL The training scheme through decoupling the entire network into the body and the head has been used in various fields, including long-tail recognition [24, 45], noisy label learning [46], and meta-learning [32, 34][1]. For personalized FL, there have been attempts to use this decoupling approach. For a consistent explanation, we describe each algorithm from the perspective of local update and aggregation parts. FedPer [2] learns the entire network jointly during local updates and aggregates the bottom layers only. When the bottom layers are matched with the body, the body is shared on all clients and the head is personalized to each client. LG-FedAvg [29] learns the entire network jointly during local updates and aggregates the top layers only based on the pre-trained global network via FedAvg. When the top layers are matched with the head, the body is personalized to each client and the head is shared on all clients. FedRep [9] learns the entire network sequentially during local updates and aggregates the body only. In the local update stage, each client first learns a classifier only with the aggregated representation, and then learns an extractor only with its own classifier with a single epoch. Unlike the above decoupling methods, we propose a FedBABU algorithm that learns only the body with a randomly initialized classifier during local updates and aggregates only the body. It is thought that fixing a classifier during the entire federated training provides the same guidelines on learning representations across all clients. Personalized local models are then obtained by fine-tuning the head.

3 Preliminaries

FL training procedure We summarize the training procedure of FL following the aforementioned four stages with formal notations. Let $\{1, \cdots, N\}$ be the set of all clients. Then, the participating

[1] Although there are more studies related to decoupling parameters [35, 26, 16, 8], we focus on decoupling the entire network into the body and head.

clients in the communication round k with client fraction ratio f is $C^k = \{C_i^k\}_{i=1}^{\lfloor Nf \rfloor}$. By broadcasting, the local parameters of the participating clients $\{\theta_i^k(0)\}_{i=1}^{\lfloor Nf \rfloor}$ are initialized by the global parameter θ_G^{k-1}, that is, $\theta_i^k(0) \leftarrow \theta_G^{k-1}$ for all $i \in [1, \lfloor Nf \rfloor]$ and $k \in [1, \mathrm{K}]$. Note that θ_G^0 is randomly initialized first. On its own device, each local model is updated using a locally kept data set. After local epochs τ, the locally updated models become $\{\theta_i^k(\tau I_i^k)\}_{i=1}^{\lfloor Nf \rfloor}$, where I_i^k is the number of iterations of one epoch on client C_i^k (i.e., $\lceil \frac{n_{C_i^k}}{B} \rceil$), $n_{C_i^k}$ is the number of data samples for client C_i^k, and B is the batch size. Therefore, τI_i^k is the total number of updates. Note that our research deals with a balanced environment in which all clients have the same size data set (i.e., I_i^k is a constant for all k and i). Finally, the global parameter θ_G^k is aggregated by $\sum_{i=1}^{\lfloor Nf \rfloor} \frac{n_{C_i^k}}{n} \theta_i^k(\tau I_i^k)$, where $n = \sum_{i=1}^{\lfloor Nf \rfloor} n_{C_i^k}$, at the server. For our algorithm, the parameters θ are decoupled into the extractor parameters θ_{ext} and the classifier parameters θ_{cls}.

Experimental setup We mainly use MobileNet on CIFAR100.[2] We set the number of clients to 100, and then each client has 500 training data and 100 test data. The classes in the training and test data sets are the same. For the heterogeneous distribution of client data, we refer to the experimental setting in [31]. We sort the data by label and divide the data into the same-sized shards. Because there is no overlapping data between shards, the size of a shard is defined by $\frac{|D|}{N \times s}$, where $|D|$ is the data set size, N is the total number of clients, and s is the number of shards per user. We control FL environments with three hyperparameters: client fraction ratio f, local epochs τ, and shards per user s. f is the ratio of participating clients in the total number of clients in every round, and a small f is natural in the FL settings because the total number of clients is numerous. Local epochs τ are equal to the interval between two consecutive communication rounds. To fix the number of total updates for the consistency in all experiments, we fix the product of communication rounds and local epochs to 320 (e.g., if local epochs are 4, then the total number of communication rounds is 80). τ is closely related to the trade-off between accuracy and communication costs. A small τ provides an accurate federation but requires considerable communication costs. s is related to the maximum number of classes each user can have; hence, as s decreases, the degree of data heterogeneity increases.

Evaluation We calculate the *initial accuracy* and *personalized accuracy* of FedAvg and FedBABU following the federated personalization evaluation procedure proposed in [42] to analyze the algorithms at the client level: (1) the learned global model is broadcast to all clients, and is then evaluated on the test data set of each client D_i^{ts} (referred to as the *initial accuracy*), (2) the learned global model is personalized using the training data set of each client D_i^{tr} by fine-tuning with the fine-tuning epochs of τ_f, and the personalized models are then evaluated on the test data set of each client D_i^{ts} (referred to as the *personalized accuracy*). In addition, we calculate the *personalized accuracy* of other personalized FL algorithms (such as FedPer, LG-FedAvg, and FedRep). The algorithm 2 in Appendix A describes the evaluation procedure. The values (X±Y) in all tables indicate the mean±standard deviation of the accuracies across all clients. Here, reducing the variance over the clients could be an interesting topic, but is beyond the scope of this study.

4 Personalization of a Single Global Model

Table 1: Initial and personalized accuracy of FedAvg on CIFAR100 under various FL settings with 100 clients. MobileNet is used. The initial and personalized accuracy indicate the evaluated performance without fine-tuning and after five fine-tuning epochs on each client, respectively.

FL settings		s=100 (heterogeneity ↓)		s=50		s=10 (heterogeneity ↑)	
f	τ	Initial	Personalized	Initial	Personalized	Initial	Personalized
1.0	1	46.93±5.47	51.93±5.19	45.68±5.50	57.84±5.08	37.27±6.97	77.46±5.78
	4	37.44±4.98	42.66±5.09	36.05±4.04	47.17±4.26	24.17±5.50	70.41±6.83
	10	29.58±4.87	34.62±4.97	29.57±4.29	40.59±5.23	17.85±7.38	63.51±7.38
0.1	1	39.07±5.22	43.92±5.55	38.20±5.73	49.55±5.36	29.12±7.11	71.24±7.82
	4	35.39±4.58	39.67±5.21	33.49±4.72	43.63±4.77	21.14±6.86	67.14±6.72
	10	28.18±4.83	33.13±5.22	27.34±4.96	38.09±5.17	14.40±5.64	62.67±6.52

[2] We also use 4convNet on CIFAR10 and ResNet on CIFAR100. The details of the architectures used are presented in Appendix A. The results of 4convNet and ResNet are presented in Appendix E and Appendix I, respectively.

Table 2: Initial and personalized accuracy of FedAvg on CIFAR100 under a realistic FL setting (N=100, f=0.1, τ=10) according to p, which is the percentage of all client data that the server also has. Here, the entire network (F) or body (B) is updated on the server using the available data.

	s=100 (heterogeneity ↓)		s=50		s=10 (heterogeneity ↑)	
p	Initial	Personalized	Initial	Personalized	Initial	Personalized
0.00	28.18±4.83	33.13±5.22	27.34±4.96	38.09±5.17	14.40±5.64	62.67±6.52
0.05 (F)	29.23±5.03	32.59±5.24	27.13±4.34	34.34±4.78	18.22±5.64	54.68±6.77
0.10 (F)	30.59±4.93	33.34±5.30	29.62±4.27	35.50±4.84	19.24±5.15	49.62±7.48
0.05 (B)	28.50±4.93	33.03±5.36	27.96±4.86	39.10±5.55	14.78±5.59	60.19±6.46
0.10 (B)	32.90±4.77	36.82±4.66	32.81±4.97	40.80±5.62	18.35±6.75	60.94±7.30

We first investigate personalization of a single global model using the FedAvg algorithm, following [42, 23], to connect a single global model to multiple personalized models. We evaluate both the initial accuracy and personalized accuracy, assuming that the test data sets are not gathered in the server but scattered on the clients. Table 1 describes the accuracy of FedAvg on CIFAR100 according to different FL settings (f, τ, and s) with 100 clients. The initial and personalized accuracy indicate the evaluated performance without fine-tuning and with five fine-tuning epochs for each client, respectively. As previous studies have shown, the more realistic the setting is (i.e., a smaller f, larger τ, and smaller s), the lower the initial accuracy. Moreover, the tendency of the personalized models to converge higher than the global model observed in [23] is the same. More interestingly, it is shown that the gap between the initial accuracy and the personalized accuracy increases significantly as the data become more heterogeneous. It is thought that a small s makes local tasks to be easy because the label distribution owned by each client is limited and the number of samples per class increases.

In addition, we conduct an intriguing experiment in which the initial accuracy increases but the personalized accuracy decreases, maintaining the FL training procedures. In [23], the authors showed that centralized trained models are more difficult to personalize. Similarly, we design an experiment where the federated trained models are more difficult to personalize. We assume that the server has a small portion of p of the non-privacy data of the clients[3] such that the non-privacy data can be used in the server to mitigate the degradation derived from data heterogeneity. We update the global model using the non-privacy data after every aggregation with only one epoch. Table 2 describes the result of this experiment. We update the entire network (F in Table 2) on the server. As p increases, the initial accuracy increases, as expected. However, the personalized accuracy decreases under significant data heterogeneity (s=10). This result implies that boosting a single global model can hurt personalization, which may be considered more important than the initial performance. Therefore, we agree that the development of an excellent global model should even consider the ability to be adequately fine-tuned or personalized.

To investigate the cause of personalization performance degradation, we hypothesize that unnecessary and confusing information for personalization is injected into a model, particularly a classifier, when a global model is trained on the server. To capture this, we only update the body (B in Table 2) on the server by zeroing the learning rate corresponding to a classifier. By narrowing the update parts, the personalization degradation problem is remedied significantly without affecting the initial accuracy. From this observation, we argue that training the head using harmonized data has a negative impact on personalization.[4]

5 FedBABU: Federated Averaging with Body Aggregation and Body Update

In this section, we propose a novel algorithm that learns a better single global model to be personalized efficiently. Inspired by prior studies on long-tailed recognition [45, 24], fine-tuning [10], and self-supervised learning [18], as well as our data sharing experiment, we decouple the entire network into the body (i.e., extractor) and the head (i.e., classifier). Extractors are trained for generalization, and classifiers are then trained for specialization. We apply this idea to federated learning by *never* training classifiers in the federated training phase (i.e., developing a single global model) and by fine-tuning classifiers for personalization (in the evaluation process).

[3] Non-privacy data are sampled randomly in our experiment, which can violate the FL environments. However, this experiment is conducted simply as motivation for our study.

[4] We also investigate personalization of centralized trained models such as [23], and the results are reported in Appendix K. In the centralized training case, training the head also has a negative impact on personalization.

5.1 Frozen Classifier in the Centralized Setting

Before proposing our algorithm, we empirically demonstrate that a model with an initialized and fixed classifier (body in Figure 2) has a performance comparable to a model that jointly learns an extractor and a classifier (full in Figure 2). Figure 2 depicts the test accuracy curve of MobileNet on CIFAR100 for various training scenarios in the centralized setting. The blue line represents the accuracy when all layers are trained, the red line represents the accuracy when only the body of the model is trained, and the green line represents the accuracy when only the head of the model is trained. It turns out that the fully trained model and the fixed classifier have almost the same performance, whereas the fixed extractor performs poorly. Thus, we claim that *randomly initialized fixed classifiers are acceptable, whereas randomly initialized fixed extractors are unacceptable. Initialized classifiers are thought to serve as guidelines*. This characteristic is derived from the orthogonal initialization [36] on the head, which is explained in Appendix B.

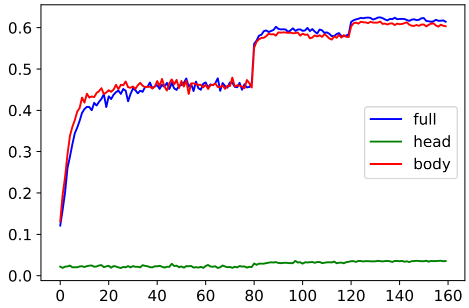

Figure 2: Test accuracy curves according to the update part in the centralized setting.

5.2 FedBABU Algorithm

Based on the insights and results in Section 5.1, we propose a new FL algorithm, called FedBABU (**Fed**erated Averaging with **B**ody **A**ggregation and **B**ody **U**pdate). Extractors are trained only, whereas classifiers are never trained during federated training. Therefore, there is no need to aggregate the head. Formally, the model parameters θ are decoupled into the extractor parameters θ_{ext} and the classifier parameters θ_{cls}. Note that θ_{cls} on any client is fixed with the classifier parameters of a randomly initialized global parameters θ_G^0 until a single global model converges. This is implemented by zeroing the learning rate corresponding to the classifier. *Intuitively, it is thought that the same fixed classifier on all clients serves as the same criteria on learning representations across all clients despite the passage of training time.* The FedBABU algorithm is described in Appendix A. In this section, we demonstrate the ability related to personalization of FedBABU (from Section 5.2.1 to Section 5.2.3). We further show our algorithm's applicability (Section 5.2.4).

5.2.1 Personalization of FedBABU

To investigate the dominant factor for personalization, we compare the performance according to the fine-tuned part. Table 3 describes the results of this experiment. Global models are fine-tuned with five epochs based on the training data set of each client. It is shown that fine-tuning including the head (i.e., Head or Full in Table 3) is better for personalization than body-partially fine-tuning (i.e., Body in Table 3). For consistency of the evaluation, for FedBABU, we fine-tune the entire model in the remainder of this paper. Note that the computational costs can be reduced by fine-tuning only the head in the case of FedBABU without performance degradation; however, in the case of FedAvg, a performance gap appears (Appendix D). The personalization of FedBABU looks similar to the linear evaluation protocol, which adds a linear layer to the well-trained extractor and makes it suitable for multiple tasks.

Table 3: Personalized accuracy of MobileNet on CIFAR100 according to the fine-tuned part. The fine-tuning epochs is 5, and f is 0.1.

Hyperparameter		Update part for personalization		
s	τ	Body	Head	Full
100	1	44.26±5.12	49.76±5.03	49.67±4.92
	4	39.61±4.68	44.74±5.02	44.74±5.10
	10	32.45±5.42	36.48±5.04	35.94±5.06
50	1	48.54±5.23	56.76±5.68	56.69±5.16
	4	41.27±5.04	49.45±5.41	49.55±5.58
	10	35.42±5.60	42.55±5.70	42.63±5.59
10	1	72.81±7.32	75.97±6.29	76.02±6.29
	4	69.12±6.70	70.74±6.47	71.00±6.63
	10	64.77±7.14	66.28±6.77	66.32±7.02

5.2.2 Personalization Performance Comparison

We compare FedBABU with existing methods from the perspective of personalization. Details of evaluation procedure and implementations of each algorithm are presented in Appendix A. Table 4 describes the personalized accuracy of various algorithms. Interestingly, FedAvg overwhelms other recent personalized FL algorithms on CIFAR100 in most cases.[5] These results are similar to recent trends in the field of meta-learning, where fine-tuning based on well-trained representations overwhelms advanced few-shot classification algorithms for heterogeneous tasks [5, 6, 11, 41]. FedBABU (ours) further overwhelms FedAvg. It is believed that enhanced representation by freezing the head during federated training improve performance, explained in Appendix O.

[5] The reason why FedAvg+Fine-tuning is effective itself needs to be discussed more.

Table 4: Personalized accuracy comparison on CIFAR100 under various settings with 100 clients. MobileNet is used. **Bold** indicates the best accuracy.

Hyperparameter			Personalized accuracy						
s	f	τ	FedBABU (Ours)	FedAvg [31]	FedPer [2]	LG-FedAvg [29]	FedRep [9]	Per-FedAvg [14]	Local-only
100	1.0	1	**55.79±4.57**	51.93±5.19	51.95±5.30	53.01±5.26	18.29±3.59	47.09±7.35	20.6±3.15
		4	**44.49±4.91**	42.66±5.09	40.87±5.05	43.09±4.74	15.32±3.79	39.07±7.59	
		10	33.20±4.54	**34.62±4.97**	32.91±4.97	34.64±5.03	13.45±3.26	30.22±6.59	
	0.1	1	**49.67±4.92**	43.92±5.55	45.17±4.70	40.91±5.50	23.84±3.92	48.10±7.42	
		4	**44.74±5.10**	39.67±5.21	39.30±4.92	37.87±4.99	16.01±3.48	33.70±7.04	
		10	**35.94±5.06**	33.13±5.22	32.08±4.97	30.08±5.34	11.11±3.13	25.82±5.83	
50	1.0	1	**61.09±4.91**	57.84±5.08	57.16±5.26	58.44±5.53	24.75±5.02	43.75±7.94	28.02±4.01
		4	**51.56±5.04**	47.17±4.26	48.89±5.40	47.78±4.72	21.55±4.36	37.59±7.87	
		10	**42.09±5.12**	40.59±5.23	39.90±5.54	40.32±4.70	19.92±4.50	28.75±6.40	
	0.1	1	**56.69±5.16**	49.55±5.36	51.63±5.27	42.64±5.55	32.88±5.09	43.96±7.40	
		4	**49.55±5.58**	43.63±4.77	46.31±5.63	38.54±4.71	21.13±3.96	28.67±6.98	
		10	**42.63±5.59**	38.09±5.17	39.81±4.88	30.79±6.12	15.15±4.01	21.64±6.16	
10	1.0	1	**79.17±6.51**	77.46±5.78	74.71±6.35	77.49±5.60	61.28±8.27	36.59±8.98	61.52±7.22
		4	**74.60±6.69**	70.41±6.83	65.61±7.13	69.97±6.42	50.59±7.94	18.31±10.57	
		10	**66.64±6.84**	63.51±7.38	59.71±7.35	61.50±7.28	42.13±7.53	11.54±8.87	
	0.1	1	**76.02±6.29**	71.24±7.82	69.36±6.77	51.75±9.32	60.13±7.72	31.21±11.66	
		4	**71.00±6.63**	67.14±6.72	62.62±7.63	35.80±10.55	45.91±7.68	14.34±9.51	
		10	**66.32±7.02**	62.67±6.52	59.50±7.33	25.04±12.02	34.30±7.84	9.17±6.95	

5.2.3 Personalization Speed of FedAvg and FedBABU

Table 5: Performance according to the fine-tune epochs (FL setting: f=0.1, and τ=10).

s	Algorithm	Fine-tune epochs (τ_f)								
		0 (Initial)	1	2	3	4	5	10	15	20
50	FedAvg	27.34±4.96	29.17±5.01	32.39±4.77	34.97±5.13	36.78±5.13	38.09±5.17	40.56±5.43	41.20±5.51	40.86±5.13
	FedBABU	27.91±5.27	35.20±5.58	40.60±5.47	42.12±5.61	42.74±5.60	42.63±5.59	41.94±5.68	41.19±5.52	40.61±5.28
10	FedAvg	14.40±5.64	27.43±6.46	48.63±7.30	58.08±6.11	61.27±6.15	62.67±6.52	63.91±6.49	64.56±6.45	64.89±6.53
	FedBABU	18.50±7.82	63.29±7.55	66.05±6.93	66.10±6.54	66.40±7.24	66.32±7.02	66.07±7.57	66.24±7.67	66.32±7.71

We investigate the personalization speed of FedAvg and FedBABU by controlling the fine-tuning epochs τ_f in the evaluation process. Table 5 describes the initial (when τ_f is 0) and personalized (otherwise) accuracy of FedAvg and FedBABU. Here, 1 epoch is equal to 10 updates in our case because each client has 500 training samples and the batch size is 50. It is shown that FedAvg requires sufficient epochs for fine-tuning, as reported in [23]. Notably, FedBABU achieves better accuracy with a small number of epochs. It means that FedBABU can personalize accurately and rapidly, especially when fine-tuning is either costly or restricted.

5.2.4 Body Aggregation and Body Update on the FedProx

Table 6: Initial and personalized accuracy of FedProx and FedProx+BABU with μ of 0.01 on CIFAR100 with 100 clients and f of 0.1.

FL settings		s=100 (heterogeneity ↓)		s=50		s=10 (heterogeneity ↑)	
Algorithm	τ	Initial	Personalized	Initial	Personalized	Initial	Personalized
FedProx	1	46.52±4.56	50.95±4.65	42.20±4.90	51.29±5.20	28.16±9.00	66.39±7.79
	4	36.54±4.74	39.83±4.71	33.59±4.80	40.17±5.11	18.20±7.62	41.56±9.34
	10	28.63±4.40	31.90±4.16	26.88±4.59	32.92±5.00	13.62±7.73	43.48±9.32
FedProx +BABU	1	48.53±5.15	57.44±4.72	46.25±5.31	63.12±5.25	33.13±8.11	78.86±5.70
	4	37.17±4.41	45.26±4.76	33.86±5.44	50.18±5.14	22.94±9.90	75.71±5.33
	10	27.79±3.95	35.68±4.34	27.48±5.22	42.37±6.10	15.66±8.29	67.15±7.10

FedProx [28] regularizes the distance between a global model and local models to prevent local models from deviating. The degree of regularization is controlled by μ. Note that when μ is 0.0, FedProx is reduced to FedAvg. Table 6 describes the initial and personalized accuracy of FedProx and FedProx+BABU with μ of 0.01 when f=0.1, and the results when f=1.0 are reported in Appendix L. The global models trained by FedProx reduce the personalization capabilities compared to FedAvg (refer to Table 1 when f=0.1), particularly under realistic FL settings. We adapt the body aggregation and body update idea to the FedProx algorithm, referred to as FedProx+BABU, which performs better than personalization of FedAvg. Furthermore, FedProx+BABU also has an improved personalized performance compared to FedBABU (refer to Table 4 when f=0.1). This means that the regularization of the body is still meaningful. Our algorithm and various experiments suggest future directions of federated learning: *Which parts should be federated and enhanced? Representation!*

6 Conclusion

In this study, we focused on how to train a good federated global model for personalization purposes. Based on parameter decoupling, we proposed the FedBABU algorithm, which learns a shared global model that can rapidly adapt to heterogeneous data on each client. This global model can be efficiently personalized by fine-tuning each client's model using its own data set. Extensive experimental results showed that FedBABU outperforms various personalized FL algorithms. Our improvement emphasizes the importance of federating and enhancing the representation for FL.

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A Implementation Detail

Our implementations are based on the code presented by [29].[6] The learning rate starts with 0.1 and is decayed 0.1 times at half and three-quarters of total communication rounds. All the reported results are based on the last model. For computation costs, we used a single TITAN RTX and the entire training time of FedBABU on CIFAR100 using mobileNet takes $\sim$2 hours when f=1.0 and τ=1. Therefore, as f decreases and τ increases, it takes less time.

A.1 Architectures

In our experiments, we employ the 4convNet, MobileNet, and ResNet. 4convNet has 4 convolution modules with a linear classifier, and each module consists of a 3×3 convolution layer with 64 filters, batch normalization, a ReLU non-linearity, a 2×2 max-pool. MobileNet [21] includes depthwise convolution and pointwise convolution, and ResNet [20] includes skip connection.[7] Please refer to each paper in detail.

```
4convNet(
  (features): Sequential(
    (0): Sequential(
      (0): Conv2d(3, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True, track_running_stats=False)
      (2): ReLU()
      (3): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
    )
    (1): Sequential(
      (0): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True, track_running_stats=False)
      (2): ReLU()
      (3): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
    )
    (2): Sequential(
      (0): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True, track_running_stats=False)
      (2): ReLU()
      (3): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
    )
    (3): Sequential(
      (0): Conv2d(64, 64, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
      (1): BatchNorm2d(64, eps=1e-05, momentum=0.1, affine=True, track_running_stats=False)
      (2): ReLU()
      (3): MaxPool2d(kernel_size=2, stride=2, padding=0, dilation=1, ceil_mode=False)
    )
  )
  (linear): Linear(in_features=256, out_features=10, bias=True)
)
```

A.2 Hyperparameters

For **LG-FedAvg**, FedAvg models corresponding to the FL settings in Table 21 are used as an initialization. It is then trained about a quarter of FedAvg training with a learning rate of 0.001. For **FedRep**, the number of local epochs for head and body updates were set to τ and 1, respectively. For **Per-FedAvg**, we used the first-order (FO) version, and the β value was set as the learning rate value corresponding to the communication round.

A.3 FedBABU algorithm

Algorithm 1 describes the training procedure of FedBABU. All notations are explained in the FL training procedure paragraph in Section 3. Line 3-4, Line 6, Line 7, and Line 9 correspond to the client sampling, broadcasting, local update, and aggregation stage, respectively. In the ClientBodyUpdate function, a local extractor parameter $\theta_{i,ext}^{k}$ is always updated based on the same classifier $\theta_{G,cls}^{0}$ (Line 16). Then, the global extractor parameter $\theta_{G,ext}^{k}$ is only aggregated (Line 9). Therefore, the final global parameter θ_{G}^{K} (Line 11) and the initialized global parameter θ_{G}^{0} (Line 1) have the same classifier parameter $\theta_{G,cls}^{0}$.

[6] https://github.com/pliang279/LG-FedAvg

[7] We use two architectures from https://github.com/kuangliu/pytorch-cifar

Algorithm 1 Training procedure of FedBABU.

```
initialize $\theta_G^0 = \{\theta_{G,ext}^0, \theta_{G,cls}^0\}$
for each round $k$ = 1, $\cdots$, K do
    $m \leftarrow max(\lfloor Nf \rfloor, 1)$
    $C^k \leftarrow$ random subset of $m$ clients
    for each client $C_i^k \in C^k$ in parallel do
        $\theta_i^k(0) \leftarrow \theta_G^{k-1} = \{\theta_{G,ext}^{k-1}, \theta_{G,cls}^0\}$
        $\theta_{i,ext}^k(\tau I_i^k) \leftarrow$ ClientBodyUpdate($\theta_i^k(0), \tau$)
    end for
    $\theta_{G,ext}^k \leftarrow \sum_{i=1}^m \frac{n_{C_i^k}}{n} \theta_{i,ext}^k(\tau I_i^k), n = \sum_{i=1}^m n_{C_i^k}$
end for
return $\theta_G^{\mathrm{K}} = \{\theta_{G,ext}^{\mathrm{K}}, \theta_{G,cls}^0\}$

function ClientBodyUpdate($\theta_i^k$)
    $I_i^k \leftarrow \lceil \frac{n_{C_i^k}}{B} \rceil$
    for each local epoch 1, $\cdots$, $\tau$ do
        for each iteration 1, $\cdots$, $I_i^k$ do
            $\theta_{i,ext}^k \leftarrow SGD(\theta_{i,ext}^k, \theta_{G,cls}^0)$
        end for
    end for
    return $\theta_{i,ext}^k$
end function
```

A.4 Evaluation of FL algorithms

In FL algorithms, because the parts that need to be shared over all clients after federated training may not be shared due to client fraction, we evaluate these algorithms as follows:

Algorithm 2 Evaluation procedure of FedAvg, FedBABU, FedPer, LG-FedAvg, and FedRep.

```
1: initlist = [ ]                                                    (If $alg$ is FedAvg or FedBABU)
2: perlist = [ ]
3: for each client $i \in [1, N]$ in parallel do
4:     $\theta_{i,s}(0) \leftarrow \theta_{G,s}^{\mathrm{K}}$
5:     $Acc_{init} \leftarrow$ Eval($\theta_i(0); D_i^{ts}$)                 (If $alg$ is FedAvg or FedBABU)
6:     initlist.append($Acc_{init}$)                                 (If $alg$ is FedAvg or FedBABU)
7:     $\theta_i(\tau_f I_i) \leftarrow$ Fine-tune($alg, \theta_i(0), \tau_f; D_i^{tr}$)
8:     $Acc_{per} \leftarrow$ Eval($\theta_i(\tau_f I_i); D_i^{ts}$)
9:     perlist.append($Acc_{per}$)
10: end for
11: return initlist, perlist

12: function Fine-tune($alg, \theta_i, \tau_f$)
13:     $I_i \leftarrow \lceil \frac{n_{C_i}}{B} \rceil$
14:     for each fine-tune epoch 1, $\cdots$, $\tau_f$ do
15:         for each iteration 1, $\cdots$, $I_i$ do
16:             $\theta_i \leftarrow SGD(\theta_i)$          (If $alg$ is FedAvg or FedBABU or FedPer or LG-FedAvg)
17:             $\theta_{i,cls} \leftarrow SGD(\theta_i)$                               (If $alg$ is FedRep)
18:         end for
19:     end for
20:     for each iteration 1, $\cdots$, $I_i$ do                                (If $alg$ is FedRep)
21:         $\theta_{i,ext} \leftarrow SGD(\theta_i)$
22:     end for
23:     return $\theta_i$
24: end function
```

where $\theta_{G,s}^{\mathrm{K}}$ indicates the shared parts after federated training (i.e., full in the cases of FedAvg and FedBABU, body in the cases of FedPer and FedRep, and head in the case of LG-FedAvg). All notations are explained in the evaluation paragraph in Section 3. Because communication round k is not related to evaluation, it is emitted. For FedAvg and FedBABU, *initial accuracy* is also calculated. Although all clients have different personalized models because some parts are not shared after broadcasting except for FedAvg and FedBABU, it is not completely personalized because there is a common part $\theta_{G,s}^{\mathrm{K}}$. Therefore, we fine-tune all algorithms. FedRep trains models sequentially (Line 17 and 21), while others jointly (Line 16). Finally, the mean and standard deviation of initlist and perlist are reported as *initial accuracy* and *personalized accuracy* in our paper.

B Orthogonality of Random Initialization

We hypothesize that the orthogonal initialization [36] on the head, through which the row vectors of the classifier parameters $\theta_{cls} \in \mathbb{R}^{C \times d}$ are orthogonal, is the best for the body-only update rule. At each update, the output of the extractor is pulled toward its label's row of θ_{cls} and pushed apart from the other rows of θ_{cls} through backpropagation. Therefore, orthogonal weight initialization can separate the outputs of the extractor well based on their class labels. Note that distribution-based random initializations, such as Xaiver [17] and He [19], have almost orthogonal rows because the orthogonality of two random vectors is observed in high dimensions with high probability [27].

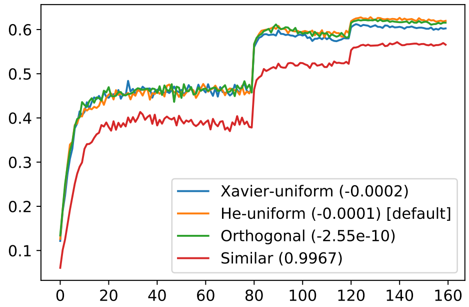

Figure 3: Test accuracy curves according to the initialization method when the body is only trained in the centralized setting. The values in parentheses indicate the average of cosine similarities between row vectors.

Figure 3 shows test accuracy curves for many different initialization methods when only the body is trained in the centralized setting.[8] When the row vectors are initialized similarly, a convergence gap appears (green and red lines in Figure 3), as expected. More experiments in the centralized setting are reported in Appendix C and Appendix I. Based on these empirical and theoretical results, we used He (uniform) initialization, the default setting in PyTorch [33], in the remainder of our paper.

This characteristic can be proved. Xavier [17] and He [19] are representative distribution-based random initialization methods, controlling the variance of parameters using network size to avoid the exploding/vanishing gradient problem. Two initialization methods use uniform and normal distribution. In detail, each element follows $\mathcal{U}(-a, a)$ or $\mathcal{N}(0, \sigma^2)$ independently, where a and σ are defined by non-linearity (such as ReLU and Tanh) and layer input-output size. Because we used the ReLU non-linear function in our implementations, we calculate a and σ by multiplying $\sqrt{2}$, for scaling of ReLU non-linearity.

Because we focus on initialization on the head, we specify $\theta_{cls} \in \mathbb{R}^{C \times d}$, where C is the number of classes (i.e., layer output size) and d is the dimension of the last representation (i.e., layer input size). Namely, each element random variable $\{w_{i,j}\}_{i \in [1,C], j \in [1,d]}$ follows $\mathcal{U}(-a, a)$ or $\mathcal{N}(0, \sigma^2)$ independently.

When $w_{i,j} \sim \mathcal{U}(-a, a)$, in Xavier initialization, a is defined as $\sqrt{2} \times \sqrt{\frac{6}{d+C}}$. Similarly, in He initialization, a is defined as $\sqrt{2} \times \sqrt{\frac{3}{d}}$ or $\sqrt{2} \times \sqrt{\frac{3}{C}}$ depending on which to be preserved, forward pass or backward pass. When $w_{i,j} \sim \mathcal{N}(0, \sigma^2)$, in Xavier initialization, σ is defined as $\sqrt{2} \times \sqrt{\frac{2}{d+C}}$. Similarly, in He initialization, σ is defined as $\sqrt{2} \times \sqrt{\frac{1}{d}}$ or $\sqrt{2} \times \sqrt{\frac{1}{C}}$ depending on which to be preserved, forward pass or backward pass. However, It is noted that a in the uniform distribution and σ in the normal distribution do not affect proof on orthogonality, therefore we keep the form of $\mathcal{U}(-a, a)$ and $\mathcal{N}(0, \sigma^2)$ for simplicity.

We first consider $2d$ independent random variables $\{w_{i,j}\}_{i \in \{p,q\}, j \in [1,d]}$ for any $p \neq q \in [1, C]$. Then, we can define d independent random variables $\{w_{p,j} w_{q,j}\}_{j \in [1,d]}$ from the above $2d$ independent random variables. Then, for all $j \in [1, d]$, $\mathbb{E}[w_{p,j} w_{q,j}] = \mathbb{E}[w_{p,j}]\mathbb{E}[w_{q,j}] = 0$ and $\mathbb{V}[w_{p,j} w_{q,j}] = \mathbb{V}[w_{p,j}]\mathbb{E}[w_{q,j}]^2 + \mathbb{V}[w_{p,j}]\mathbb{V}[w_{q,j}] + \mathbb{E}[w_{p,j}]^2 \mathbb{V}[w_{q,j}] = \mathbb{V}[w_{p,j}]\mathbb{V}[w_{q,j}]$ because each element in θ_{cls} follows $\mathcal{U}(-a, a)$ or $\mathcal{N}(0, \sigma^2)$ independently. Let $S_d = \frac{1}{d} \sum_{j=1}^{d} w_{p,j} w_{q,j}$. Then, by the Weak Law of Large Numbers, $\lim_{d \to \infty} P(|S_d - \mathbb{E}[S_d]| > \epsilon) = \lim_{d \to \infty} P(|S_d| > \epsilon) = 0$ for all $\epsilon > 0$ because $\{w_{p,j} w_{q,j}\}_{j \in [1,d]}$ are independent random variables and there is V such that $\mathbb{V}[w_{p,j} w_{q,j}] < V$ for all j.

[8] All initialization methods except for 'similar' are provided by PyTorch [33]. Here, 'similar' initialization is implemented using a uniform distribution on [0.45, 0.55], and then each row vector is unitized by dividing the norm corresponding to the row vector.

C Accuracy Curves in the Centralized Setting

When 4convNet is used on CIFAR10, a similar tendency appears. Comparing Figure 2 and Figure 4, the importance of learning representation is emphasized more when tasks are difficult. In addition, Figure 5 shows the necessity of orthogonality when the body is only trained and approximation of random initialization to the orthogonal initialization using 4convNet on CIFAR10.

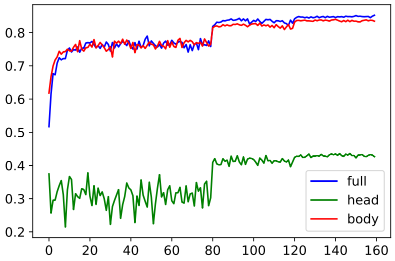

Figure 4: Test accuracy curves of 4convNet on CIFAR10 according to the update part in the centralized setting.

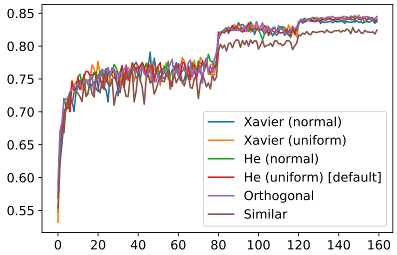

Figure 5: Test accuracy curves of 4convNet on CIFAR10 according to the initialization method when the body is only trained.

D Personalization of FedAvg

To investigate the dominant factor for personalization of FedAvg, we compare performance according to the fine-tuned part. Table 7 describes the personalized accuracy in various FL settings. For personalization, global models are fine-tuned with 5 epochs based on each client's training data sets. It is shown that fine-tuning the entire network (Full in Table 7) is better for personalization than partial fine-tuning (Body or Head in Table 7). Therefore, for FedAvg, we personalize global models by fine-tuning the entire network.

Table 7: Personalized accuracy of MobileNet on CIFAR100 according to the fine-tuned part. The fine-tuning epochs is 5 and f is 0.1.

Hyperparameter		Update part for personalization		
s	τ	Body	Head	Full
100	1	41.00±5.35	43.18±5.34	43.92±5.55
	4	37.43±4.98	38.29±4.96	39.67±5.21
	10	30.62±4.95	31.92±5.04	33.13±5.22
50	1	43.61±5.54	47.51±5.61	49.55±5.36
	4	37.99±4.68	41.48±4.61	43.63±4.77
	10	32.20±4.92	36.06±5.31	38.09±5.17
10	1	56.00±8.66	69.70±7.88	71.24±7.82
	4	34.49±7.92	65.32±6.81	67.14±6.72
	10	27.94±6.96	60.24±6.16	62.67±6.52

E Results of 4convNet on CIFAR10

We also evaluate algorithms on CIFAR10 using 4convNet. Table 8 and Table 9 are the experiment results corresponding to the Table 21 and Table 4 in the main paper, respectively. The tendency of performance comparison and the superiority of our algorithm appears similarly when using 4convNet on CIFAR10.

Table 8: Initial accuracy of FedAvg and FedBABU according to the existence of classifier on CIFAR10 under various settings with 100 clients. The used network is 4convNet.

Hyperparameter			FedAvg		FedBABU	
s	f	τ	w/ classifier	w/o classifier	w/ classifier	w/o classifier
10	1.0	1	68.89±6.35	74.41±6.25	71.50±7.35	75.00±7.46
		4	61.56±6.84	66.17±7.44	68.40±6.67	71.77±7.29
		10	60.06±5.68	65.21±7.94	64.66±6.00	69.04±6.68
	0.1	1	63.79±7.59	69.48±6.72	69.36±5.61	71.21±6.87
		4	59.65±8.03	66.11±7.37	66.80±7.43	69.27±8.05
		10	57.32±6.76	63.19±6.81	62.68±7.06	67.58±6.42
5	1.0	1	66.56±9.39	80.73±8.27	68.54±8.45	80.53±7.99
		4	52.60±7.79	70.53±9.15	63.79±9.12	78.34±8.30
		10	51.55±8.23	71.03±8.77	61.10±9.80	77.13±7.10
	0.1	1	55.13±8.57	71.27±10.03	63.44±9.82	77.64±8.26
		4	48.77±8.54	68.64±11.36	59.93±8.32	74.61±8.81
		10	46.32±10.52	67.07±8.77	55.55±9.90	73.29±9.25
2	1.0	1	59.47±15.16	88.60±6.96	63.51±14.63	88.34±7.05
		4	41.08±13.42	83.87±10.92	55.43±15.76	88.80±8.57
		10	39.47±13.44	82.41±10.79	48.52±13.47	86.33±8.93
	0.1	1	40.48±14.59	81.43±12.74	57.22±14.05	86.81±8.31
		4	26.72±14.54	78.56±12.58	44.39±16.49	83.12±9.68
		10	22.29±16.39	73.54±10.97	36.57±17.23	84.37±10.52

Table 9: Personalized accuracy comparison on CIFAR10 under various settings with 100 clients. The used network is 4convNet. **Bold** indicates the best accuracy except for Local-Only algorithm.

Hyperparameter			Personalized accuracy						
s	f	τ	FedBABU (Ours)	FedAvg [31]	FedPer [2]	LG-FedAvg [29]	FedRep [9]	Per-FedAvg [14]	Local-Only
10	1.0	1	**80.52±5.51**	79.72±5.24	78.51±5.66	80.37±5.32	71.96±6.62	79.89±5.84	55.40±11.78
		4	**79.30±5.67**	73.35±6.15	71.04±7.50	74.75±5.87	63.71±7.01	72.10±6.57	
		10	**76.86±5.08**	71.03±5.86	69.25±7.07	71.91±5.72	60.27±7.13	66.52±7.64	
	0.1	1	**78.80±5.51**	73.05±5.94	77.22±5.57	67.95±7.00	78.21±5.38	77.23±5.48	
		4	**77.45±6.23**	71.06±6.19	71.13±6.78	64.17±7.29	68.78±6.91	67.32±7.99	
		10	**76.25±6.16**	69.11±5.70	66.43±6.59	61.15±7.32	60.70±8.76	61.22±8.14	
5	1.0	1	**85.17±6.43**	83.82±6.75	84.50±5.70	85.04±6.35	78.98±8.29	74.96±7.36	68.79±13.38
		4	**83.65±5.99**	77.47±8.32	76.96±8.65	77.54±8.14	73.05±9.11	65.17±10.71	
		10	**83.48±6.13**	77.01±7.80	76.17±8.11	77.28±7.52	70.62±7.36	53.31±12.12	
	0.1	1	**82.76±6.47**	75.08±9.34	80.69±7.63	63.30±10.62	83.71±7.05	72.15±10.22	
		4	**81.31±7.17**	74.87±9.64	74.74±8.04	59.17±10.18	77.64±7.51	58.32±11.28	
		10	**80.99±7.64**	74.29±8.29	74.92±8.32	55.19±13.91	68.71±10.47	47.48±13.76	
2	1.0	1	91.41±6.50	91.40±6.12	91.75±6.90	**92.35±5.44**	91.11±8.21	72.02±14.48	90.85±9.10
		4	**91.24±7.33**	88.91±9.06	89.14±8.44	88.67±9.03	87.74±8.08	43.41±23.51	
		10	**90.53±7.20**	88.48±8.44	88.15±9.20	87.38±8.56	86.19±9.50	36.42±18.35	
	0.1	1	90.98±6.22	86.36±10.57	90.33±7.52	68.63±14.34	**91.88±7.37**	63.28±13.77	
		4	**87.85±8.57**	85.94±10.72	86.84±10.2	47.00±24.75	86.68±10.13	32.19±19.63	
		10	**88.93±9.33**	85.14±10.73	86.69±8.04	33.30±22.29	83.85±11.20	26.61±19.52	

F Ablation Study According to the Local Update Parts of 4convNet

We decouple the entire network in more detail during local updates to investigate whether the body should be totally trained. For this ablation study, we used 4convNet on CIFAR10. Table 10 and Table 11 show the initial and personalized accuracy according to the local update parts, respectively. For consistency, all cases are personalized by fine-tuning the entire network in this experiment. In all cases, FedBABU has the best performance, which implies that the body must be totally trained at least when using 4convNet. It is believed that the same (body-totally) or similar (body except for a few top layers) trends appear when large networks are used.

Table 10: Initial accuracy comparison on CIFAR10 under various settings with 100 clients. The used network is 4convNet.

Hyperparameter			Local update parts				
s	f	τ	Conv1	Conv12	Conv123	Conv1234 (FedBABU)	Conv1234+Linear (FedAvg)
10	1.0	1	25.22±8.34	47.23±6.91	68.44±6.65	71.50±7.35	68.89±6.35
		4	23.02±9.57	45.73±7.55	60.25±7.69	68.40±6.67	61.56±6.84
		10	17.80±8.15	42.51±7.03	60.48±6.96	64.66±6.00	60.06±5.68
	0.1	1	19.33±7.71	42.84±8.15	62.71±7.67	69.36±5.61	63.79±7.59
		4	19.85±8.96	41.58±8.37	55.26±6.65	66.80±7.43	59.65±8.03
		10	18.99±9.10	44.38±7.49	54.61±6.66	62.68±7.06	57.32±6.76
5	1.0	1	23.42±8.35	44.35±9.59	64.27±10.48	68.54±8.45	66.56±9.39
		4	22.34±9.48	40.07±8.83	54.50±9.21	63.79±9.12	52.60±7.79
		10	18.94±10.38	39.59±9.03	51.25±9.22	61.10±9.80	51.55±8.23
	0.1	1	20.78±7.96	38.90±10.02	52.14±8.95	63.44±9.82	55.13±8.57
		4	19.33±10.59	40.71±9.19	47.66±11.17	59.93±8.32	48.77±8.54
		10	23.71±8.86	36.74±9.72	46.97±9.81	55.55±9.90	46.32±10.52
2	1.0	1	18.72±16.35	45.01±13.57	58.86±15.93	63.51±14.63	59.47±15.16
		4	20.08±10.09	34.58±11.84	40.56±12.73	55.43±15.76	41.08±13.42
		10	18.81±14.56	29.74±10.94	37.75±12.08	48.52±13.47	39.47±13.44
	0.1	1	16.17±18.73	37.08±12.45	45.57±13.36	57.22±14.05	40.48±14.59
		4	14.09±18.82	28.75±14.13	25.12±15.63	44.39±16.49	26.72±14.54
		10	17.40±10.53	23.73±17.87	23.16±19.27	36.57±17.23	22.29±16.39

Table 11: Personalized accuracy comparison on CIFAR10 under various settings with 100 clients. The used network is 4convNet.

Hyperparameter			Local update parts				
s	f	τ	Conv1	Conv12	Conv123	Conv1234 (FedBABU)	Conv1234+Linear (FedAvg)
10	1.0	1	55.94±7.28	64.88±8.34	78.74±5.24	80.52±5.51	79.72±5.24
		4	53.06±7.17	62.84±6.57	71.85±6.11	79.30±5.67	73.35±6.15
		10	52.89±7.14	62.02±6.48	71.16±6.24	76.86±5.08	71.03±5.86
	0.1	1	53.85±8.04	64.40±6.47	72.79±6.46	78.80±5.51	73.05±5.94
		4	50.75±8.21	61.79±6.84	66.45±7.31	77.45±6.23	71.06±6.19
		10	51.95±7.45	62.72±7.64	67.41±6.31	76.25±6.16	69.11±5.70
5	1.0	1	67.49±9.74	74.39±7.74	82.55±6.50	85.17±6.43	83.82±6.75
		4	66.12±10.02	71.77±8.48	79.68±6.77	83.65±5.99	77.47±8.32
		10	64.87±8.21	69.73±9.10	76.25±8.51	83.48±6.13	77.01±7.80
	0.1	1	65.50±9.00	74.50±8.77	74.50±8.77	82.76±6.47	75.08±9.34
		4	65.05±8.56	70.80±9.29	75.44±8.06	81.31±7.17	74.87±9.64
		10	65.61±8.73	69.66±8.68	74.79±7.85	80.99±7.64	74.29±8.29
2	1.0	1	85.44±9.20	88.20±8.86	90.61±6.48	91.41±6.50	91.40±6.12
		4	84.46±9.30	83.94±10.18	88.86±8.62	91.24±7.33	88.91±9.06
		10	81.62±9.66	86.20±10.72	88.58±9.01	90.53±7.20	88.48±8.44
	0.1	1	85.46±9.68	85.78±9.73	88.18±8.41	90.98±6.22	86.36±10.57
		4	82.74±10.45	85.13±9.77	85.91±10.87	87.85±8.57	85.94±10.72
		10	82.52±10.02	84.98±9.25	85.46±9.74	88.93±9.33	85.14±10.73

G Effect of Massiveness on Performance

We increase the number of clients from 100 to 500, and then each client has 100 training data and 20 test data. Table 12 describes the initial and personalized accuracy of FedAvg and FedBABU on CIFAR100 under various FL settings with 500 clients. The performance of FedAvg is slightly better than that of FedBABU in many cases; however, FedBABU overwhelms FedBABU in the case of extreme FL setting (s=10, f=0.1, and τ=10). More interestingly, if each client has a few data samples, then local epochs τ should be more than 1. It is thought that massiveness makes data size insufficient on each client (when the total number of data is fixed) and brings out other problems.

Table 12: Initial and personalized accuracy of FedAvg and FedBABU on CIFAR100 under various settings with 500 clients. The used network is MobileNet.

Hyperparameter			Initial accuracy		Personalized accuracy	
s	f	τ	FedAvg	FedBABU	FedAvg	FedBABU
100	1.0	1	13.71±7.58	11.85±7.13	16.12±7.99	15.00±7.54
		4	18.98±8.57	16.79±8.38	21.17±9.05	19.94±8.64
		10	15.70±8.18	15.66±8.23	17.54±8.91	18.47±8.61
	0.1	1	14.59±7.72	10.53±7.25	16.46±8.27	13.90±7.96
		4	18.90±8.33	17.36±8.85	20.88±8.85	20.30±9.27
		10	16.79±7.90	14.38±8.14	18.22±8.37	16.76±8.33
50	1.0	1	13.67±8.05	11.04±7.01	19.29±9.31	17.39±8.11
		4	18.36±8.60	16.60±8.43	22.76±9.05	23.15±9.51
		10	15.95±8.57	14.81±8.24	19.57±9.28	21.38±9.78
	0.1	1	14.58±8.33	10.72±6.81	19.65±9.14	16.05±8.11
		4	18.28±8.79	16.79±9.04	22.39±9.78	23.57±9.79
		10	15.79±8.21	15.07±7.97	18.52±8.69	20.83±8.90
10	1.0	1	9.91±7.14	7.41±6.55	37.62±11.76	35.02±10.71
		4	15.34±8.49	12.67±7.58	39.91±12.43	49.07±11.13
		10	12.99±7.98	12.93±8.15	35.47±11.29	48.07±12.25
	0.1	1	10.96±7.22	8.42±6.58	38.95±11.63	35.13±10.85
		4	15.03±8.27	13.99±7.82	37.92±11.64	49.96±11.94
		10	12.39±7.65	13.29±7.40	32.41±10.91	49.83±11.74

H Effect of Momentum during Local Updates on Performance

We investigate the effect of momentum during local updates on the performance of FedAvg and FedBABU. Table 13 describes the initial and personalized accuracy according to the momentum during local updates. The momentum for personalization fine-tuning is the same as the momentum in federated training. In both cases of FedAvg and FedBABU, appropriate momentum improves the performance, especially personalized accuracy. However, when the extreme momentum (m=0.99) is used, FedAvg completely loses the ability to train models, while FedBABU has robust performance.

Table 13: Initial and personalized accuracy according to momentum (m) during local updates under a realistic FL setting (N=100, f=0.1, and τ=10).

	Initial accuracy					
m	$s = 100$		$s = 50$		$s = 10$	
	FedAvg	FedBABU	FedAvg	FedBABU	FedAvg	FedBABU
0.0	26.07±3.83	26.38±3.98	24.71±4.15	24.72±4.67	15.44±7.16	13.66±6.15
0.5	26.63±4.61	27.01±4.62	26.27±4.87	27.58±4.75	16.60±6.14	17.98±6.55
0.9	28.18±4.83	29.38±4.74	27.34±4.96	27.91±5.27	14.40±5.64	18.50±7.82
0.99	19.84±4.12	30.62±4.60	1.00±1.40	30.01±5.19	1.00±3.32	15.68±7.11
	Personalized accuracy					
m	$s = 100$		$s = 50$		$s = 10$	
	FedAvg	FedBABU	FedAvg	FedBABU	FedAvg	FedBABU
0.0	28.46±4.05	30.24±4.39	30.02±4.65	33.43±5.26	40.80±9.00	59.85±7.41
0.5	30.44±4.37	32.70±4.65	33.64±4.78	38.65±5.14	54.32±8.33	67.34±6.32
0.9	33.13±5.22	35.94±5.06	38.09±5.17	42.63±5.59	62.67±6.52	66.32±7.02
0.99	23.88±4.34	34.17±4.75	1.12±1.48	42.17±5.32	1.00±3.32	61.02±7.84

I Results of ResNet18 and ResNet50 on CIFAR100

In this section, we experiment with ResNet18 and ResNet50. In the centralized setting, test accuracy curves according to the update part (Figure 6 and Figure 8) and according to the initialization method (Figure 7 and Figure 9) have the same trend as we have seen before. Table 14 and Table 15 are the results of ResNet18 and ResNet50, respectively. It is shown that the performance gap between FedAvg and FedBABU increases when ResNet is used rather than when MobileNet (in the main paper) is used. Furthermore, it is observed that as the complexity of the model increases (ResNet18 → ResNet50), the performance of FedAvg decreases, while that of FedBABU does not.

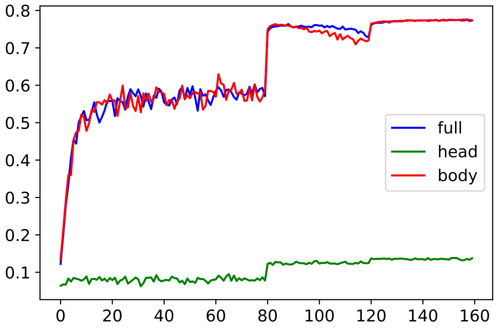

Figure 6: Test accuracy curves of ResNet18 on CIFAR100 according to the update part in the centralized setting.

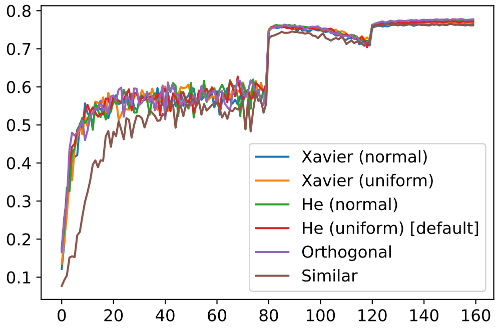

Figure 7: Test accuracy curves of ResNet18 on CIFAR100 according to the initialization method when the body is only trained.

Table 14: Initial and personalized accuracy of FedAvg and FedBABU on CIFAR100 under various settings with 100 clients. The used network is ResNet18. f is 0.1.

Hyperparameter		Initial accuracy		Personalized accuracy	
s	τ	FedAvg	FedBABU	FedAvg	FedBABU
100	1	57.26±4.71	59.87±4.27	60.39±5.16	66.48±4.43
	4	44.79±4.70	49.02±5.01	49.32±4.90	55.65±4.81
	10	34.52±4.73	40.60±5.62	39.04±4.77	47.42±5.66
50	1	53.73±4.97	59.23±5.10	63.21±5.33	71.16±4.75
	4	42.47±5.21	49.03±4.56	52.76±5.99	62.54±4.92
	10	37.09±4.20	40.71±4.98	47.13±4.47	54.99±5.37
10	1	42.88±8.08	53.65±7.53	76.84±7.08	83.83±5.22
	4	29.15±8.18	39.76±8.23	67.29±6.42	77.40±6.45
	10	26.54±7.66	30.96±8.09	66.18±7.29	72.49±6.19

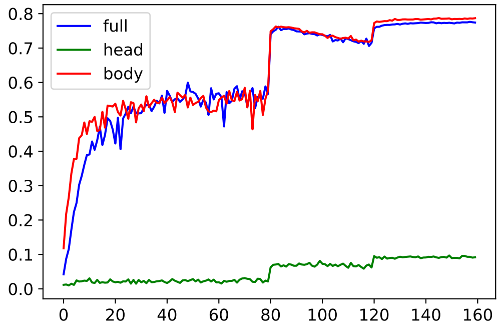

Figure 8: Test accuracy curves of ResNet50 on CIFAR100 according to the update part in the centralized setting.

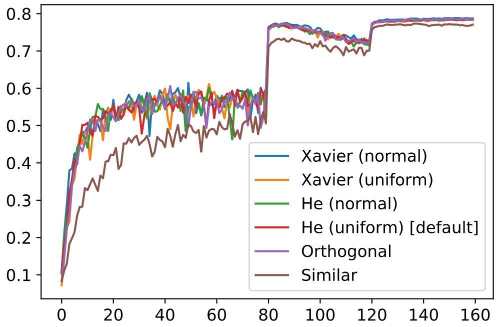

Figure 9: Test accuracy curves of ResNet50 on CIFAR100 according to the initialization method when the body is only trained.

Table 15: Initial and personalized accuracy of FedAvg and FedBABU on CIFAR100 under various settings with 100 clients. The used network is ResNet50. f is 0.1.

Hyperparameter		Initial accuracy		Personalized accuracy	
s	τ	FedAvg	FedBABU	FedAvg	FedBABU
100	1	42.89±5.34	60.78±4.74	47.59±5.16	65.74±4.72
	4	33.59±4.35	50.71±4.37	39.56±4.43	56.35±4.43
	10	32.88±4.23	40.59±4.65	37.32±4.47	45.52±5.29
50	1	42.14±5.27	59.51±4.69	53.04±5.28	70.58±5.06
	4	30.97±4.43	48.65±4.94	42.76±4.95	59.64±5.74
	10	30.90±4.76	41.14±5.47	43.28±5.49	52.13±5.14
10	1	28.18±7.99	51.17±6.97	65.50±6.92	81.43±6.20
	4	19.31±7.56	38.45±9.50	58.92±7.40	73.86±6.96
	10	18.41±7.42	30.22±8.26	59.50±7.30	68.42±8.04

J Results on In-Distribution (ID) and Out-of-Distribution (OOD) Classes

To investigate the accuracy of in-distribution (ID) and out-of-distribution (OOD) classes, we scatter IID-like test set (s=100) to all clients. Namely, some classes are in test data set (s=100), but not in training data set (s=50 or s=10). Table 16 describes the results of FedAvg and FedBABU on this experiment. Here, in-distribution accuracy is the test accuracy of the classes present in the training data set; otherwise, out-of-distribution accuracy. Before personalization (Before in tables), FedBABU beats FedAvg from both ID and OOD. After personalization (After in tables), FedBABU becomes fit only for the ID classes than OOD classes.

Table 16: In-distribution (ID) and out-of-distribution (OOD) accuracy of FedAvg and FedBABU before/after personalization under various settings with 100 clients. The used network is MobileNet.

Algorithm			FedAvg				FedBABU			
Hyperparameter			ID accuracy		OOD accuracy		ID accuracy		OOD accuracy	
s	f	τ	Before	After	Before	After	Before	After	Before	After
50	1.0	1	47.30±7.05	55.14±7.57	46.46±6.74	32.85±6.67	48.30±7.75	57.92±7.98	47.81±6.56	24.06±5.27
		4	37.30±8.56	45.30±8.61	37.24±6.29	27.05±5.71	38.99±7.73	49.70±8.00	37.76±5.71	13.88±4.78
		10	30.98±7.57	38.46±9.04	30.54±5.98	20.14±5.18	27.63±7.41	37.40±8.06	29.69±6.24	5.72±3.32
	0.1	1	39.90±7.55	47.06±7.96	39.06±6.17	28.32±5.76	42.98±8.20	53.35±7.73	42.14±7.49	16.04±5.08
		4	33.23±7.88	41.25±8.19	35.70±6.15	27.38±5.63	37.07±8.02	47.04±9.18	36.34±6.10	11.67±4.32
		10	28.70±7.77	36.32±7.41	27.15±6.00	18.05±5.44	28.26±8.44	38.74±9.08	29.06±5.61	6.70±2.94
10	1.0	1	42.16±18.36	78.14±16.62	41.51±5.12	14.25±3.37	45.76±16.41	79.60±11.35	44.93±5.13	3.93±2.24
		4	30.60±15.77	68.38±16.14	31.43±5.02	7.13±3.10	38.43±17.27	71.59±15.29	37.05±5.19	0.13±0.36
		10	26.30±16.40	61.21±17.16	23.70±4.50	2.27±1.48	27.20±15.12	64.21±16.24	25.49±4.42	0.00±0.00
	0.1	1	34.47±18.00	69.23±14.87	34.10±4.87	9.74±2.95	42.57±19.11	75.18±16.46	39.64±5.04	3.32±1.89
		4	26.86±16.09	64.24±16.45	27.09±4.55	6.03±2.73	31.31±17.27	68.38±15.55	30.75±5.23	0.06±0.24
		10	18.42±12.83	56.21±17.46	19.67±3.89	2.95±1.92	22.30±14.65	64.73±17.16	22.46±4.71	0.00±0.00

K Personalization of the Centralized Model

In [23], they showed that localizing centralized initial models is harder. Similarly, we investigate the personalization of the centralized model under different heterogeneity. First, we train two models with 10 epochs, one is entirely updated (F in Table 17), and another is body-partially updated (B in Table 17) using all training data set. Then, the trained model is broadcast to each client and then evaluated. Table 17 describes the results of this experiment. It is demonstrated that if models are updated body-partially, then personalization ability does not hurt even under centralized training.

Table 17: Personalization of the centralized models. F is trained entirely, and B is trained body-partially in the centralized setting.

s	Model	Fine-tune epochs (τ_f)					
		0 (Initial)	1	2	3	4	5
100	F	40.25±4.75	40.77±4.72	41.80±4.86	42.43±4.78	43.32±4.72	44.15±4.61
	B	39.64±4.96	43.37±5.41	47.66±5.08	50.16±5.24	51.09±5.00	52.15±5.04
50	F	37.92±5.48	38.93±5.52	40.68±5.48	42.40±5.33	43.86±5.39	45.27±5.43
	B	37.18±5.21	43.66±5.34	51.14±5.49	54.67±5.06	56.34±4.82	57.36±5.21
10	F	25.46±6.23	28.04±6.88	33.43±7.32	39.56±7.66	44.74±7.43	50.32±7.05
	B	23.86±5.08	48.63±5.39	69.14±5.78	74.32±5.35	75.90±5.49	76.47±5.48

L FedProx with Body Aggregation and Body Update

Even when all clients are active every communication round (i.e., f=1.0), the personalized performance of FedProx+BABU beats not only that of FedAvg but also that of FedBABU.

Table 18: Initial and personalized accuracy of FedProx and FedProx+BABU with μ of 0.01 on CIFAR100 with 100 clients and f of 1.0.

FL settings		s=100 (heterogeneity ↓)		s=50		s=10 (heterogeneity ↑)	
Algorithm	τ	Initial	Personalized	Initial	Personalized	Initial	Personalized
FedProx	1	42.25±4.58	56.22±4.54	52.08±4.92	59.95±4.99	44.39±7.53	78.96±6.16
	4	40.32±4.70	43.17±4.62	40.11±5.80	45.99±6.05	29.73±6.74	67.66±7.67
	10	30.75±4.53	33.43±4.48	29.44±4.24	35.65±4.60	19.63±5.73	57.83±7.13
FedProx +BABU	1	55.02±4.42	61.48±4.83	54.13±4.86	66.54±4.68	50.42±9.63	83.75±5.97
	4	39.01±4.97	46.31±4.98	38.79±5.15	52.96±5.46	34.09±7.28	77.28±5.96
	10	28.69±4.64	36.29±4.45	30.39±5.39	44.46±5.49	25.16±5.84	69.77±6.26

M Personalization Performance Comparison (Dirichlet Distribution)

We evaluate ours and existing algorithms under unbalanced and non-IID settings derived from the Dirichlet distribution. Figure 10 and 11 describe the distributions of train and test data points and non-IID depending on β, which is the hyperparameter of the Dirichlet distribution. Table 19 describes the results on Dirichlet distribution-based non-IID CIFAR100 in the realistic FL setting (f=0.1 and τ=10).

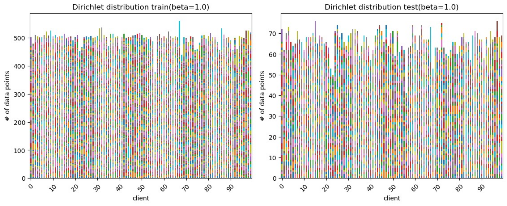

Figure 10: Data distribution ($\beta = 1.0$).

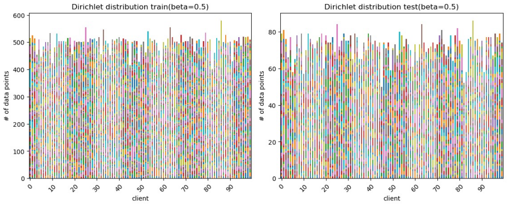

Figure 11: Data distribution ($\beta = 0.5$).

Table 19: Personalized accuracy comparison on Dirichlet distribution-based non-IID CIFAR100 with 100 clients (FL setting: f=0.1, and τ=10). The used network is MobileNet.

	Personalized accuracy						
β	FedBABU (Ours)	FedAvg	FedPer	LG-FedAvg	FedRep	Per-FedAvg	Local-only
1.0	34.92±6.22	32.10±6.15	34.21±5.68	25.00±6.12	12.68±5.27	18.85±4.97	23.73±5.71
0.5	44.67±5.80	40.21±5.68	35.62±6.17	27.24±6.73	12.52±4.32	18.36±5.01	31.24±5.49

N Personalization Performance Comparison on EMNIST

Table 20 describes the results on EMNIST using a network that consists of three convolution layers and a linear classifier. We set the number of users to 1488, and the number of data points per user was approximately 450. We fixed the fraction ratio at 0.1 and local epochs at 10 (which is the realistic setting used in our paper). The results demonstrate that FedBABU also has the best performance on EMNIST.

Table 20: Personalized accuracy comparison on EMNIST with 1488 clients (FL setting: f=0.1, and τ=10). The used network is 3convNet.

	Personalized accuracy						
s	FedBABU (Ours)	FedAvg	FedPer	LG-FedAvg	FedRep	Per-FedAvg	Local-Only
60	85.27±5.33	84.52±4.62	54.68±6.77	82.75±4.78	75.28±5.21	78.45±5.22	72.50±5.91
30	89.30±5.03	85.46±5.16	58.72±8.04	81.64±5.80	82.03±5.34	80.61±6.02	81.63±5.73
6	95.96±5.00	89.83±7.72	64.86±15.09	73.50±13.02	94.61±5.11	62.94±14.86	96.06±3.89

O Representation Power of a Single Global Model Trained by FedAvg and FedBABU

Higher initial accuracy is often required because some clients may not have data for personalization in practice. In addition, the representation power of the initial models is related to the performance of downstream or personal tasks. To capture the representation power, the ‘without (w/o) classifier’ accuracy is calculated by replacing the trained classifier with the nearest template following [24, 39, 34, 32]: (1) Using the trained global model and training data set on each client, the representations of each class are averaged into the template of each class. Then, (2) the Euclidean distances between the test samples and the templates are measured, and test samples are classified into the nearest template’s class. Templates are created for each client because raw data cannot be moved.

Table 21 describes the initial accuracy of FedAvg and FedBABU according to the existence of the classifier. Because all clients share the same criteria and learn representations based on that criteria during federated training in FedBABU, improved representation power is expected. When evaluated

Table 21: Initial accuracy of FedAvg and FedBABU on CIFAR100 under various settings with 100 clients. The trained classifier is replaced with the nearest template to calculate 'w/o classifier' accuracy. MobileNet is used.

Hyperparameter			FedAvg		FedBABU	
s	f	τ	w/ classifier	w/o classifier	w/ classifier	w/o classifier
100	1.0	1	46.93±5.47	46.07±4.97	48.61±4.75	49.48±4.84
		4	37.44±4.98	33.51±4.64	37.32±4.39	37.22±4.93
		10	29.58±4.87	24.96±4.84	26.69±4.50	27.85±4.55
	0.1	1	39.07±5.22	37.34±5.64	41.02±4.99	41.29±5.21
		4	35.39±4.58	32.50±4.25	36.77±4.47	36.86±4.39
		10	28.18±4.83	24.85±4.43	29.38±4.74	29.37±4.32
50	1.0	1	45.68±5.50	53.40±5.25	47.19±4.77	55.62±5.50
		4	36.05±4.04	42.63±4.92	37.27±5.25	45.89±5.47
		10	29.57±4.29	34.10±4.51	28.43±4.72	36.11±5.01
	0.1	1	38.20±5.73	44.66±5.53	41.33±5.10	49.30±5.64
		4	33.49±4.72	39.93±5.42	34.68±4.58	42.38±4.98
		10	27.34±4.96	33.50±5.33	27.91±5.27	36.72±5.53
10	1.0	1	37.27±6.97	66.80±7.22	45.32±8.52	71.33±6.55
		4	24.17±5.50	58.72±6.68	32.91±7.07	64.68±7.23
		10	17.85±7.38	51.61±7.73	22.15±5.72	55.13±7.04
	0.1	1	29.12±7.11	60.19±8.29	35.05±7.63	65.93±7.14
		4	21.14±6.86	55.09±6.85	25.67±7.31	59.35±6.33
		10	14.40±5.64	50.24±6.39	18.50±7.82	55.07±7.88

without a classifier, FedBABU has an improved performance compared to FedAvg in all cases, particularly under large data heterogeneity. Specifically, when s = 100 (i.e., each client has most of the classes of CIFAR100), the performance gap depends on whether the classifier exists or not in FedAvg, but not in FedBABU. This means that the features through FedBABU are well represented to the extent that there is nothing to be supplemented through the classifier. When s is small, the performance is better when there is no classifier. Because templates are constructed based on the training data set on each client, it is not possible to classify test samples into classes that the client does not have. In other words, restrictions on the output distribution of each client lead to tremendous performance gains, even without training the global model. Therefore, it is expected that fine-tuning the global models with a strong representation can boost personalization.

P FedBABU with Body Update on the Server

Table 22: Initial and personalized accuracy of FedBABU on CIFAR100 under realistic FL settings (N=100, f=0.1, and τ=10) according to the p, which is the percentage of all client data that the server also has. Here, the body is updated only on the server using available data.

	s=100 (heterogeneity ↓)		s=50		s=10 (heterogeneity ↑)	
p	Initial	Personalized	Initial	Personalized	Initial	Personalized
0.00	29.38±4.74	35.94±5.06	27.91±5.27	42.63±5.59	18.50±7.82	66.32±7.02
0.05	28.68±4.65	36.25±4.77	26.94±4.98	41.01±5.34	21.32±5.85	66.56±7.24
0.10	32.49±4.52	39.93±4.76	31.39±4.84	47.02±5.54	24.34±5.32	68.95±6.92

Let us repeat the experiment in Section 4 again, where the server has a small portion p of the non-privacy data of the clients. Table 22 describes the initial and personalized accuracy of FedBABU when the global model is body-partially updated on the server using available data (such as experiments (B) in Table 2). FedBABU with body updates on the server improves personalization compared to FedAvg with body updates on the server, maintaining the initial accuracy (refer to (B) in Table 2). This result demonstrates that training the head negatively affects personalization even when trained locally. In addition, the performance of FedBABU improves as p increases. This implies that there is room for enhancing the representation beyond that of FedBABU.