HePCo: Data-Free Heterogeneous Prompt Consolidation for Continual Federated Learning

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Abstract

In this paper, we focus on the important yet understudied problem of Continual Federated Learning (CFL), where a server communicates with a set of clients to incrementally learn new concepts over time without sharing or storing any data. The complexity of this problem is compounded by challenges from both the Continual and Federated Learning perspectives. Specifically, models trained in a CFL setup suffer from catastrophic forgetting which is exacerbated by data heterogeneity across clients. Existing attempts at this problem tend to impose large overheads on clients and communication channels or require access to stored data which renders them unsuitable for real-world use due to privacy. We study this problem in the context of Foundation Models and showcase their effectiveness in mitigating forgetting while minimizing overhead costs and without requiring access to any stored data. We achieve this by leveraging a prompting based approach (such that only prompts and classifier heads have to be communicated) and proposing a novel and lightweight generation and distillation scheme to aggregate client models at the server. We formulate this problem for image classification and establish strong baselines for comparison, conduct experiments on CIFAR-100 as well as challenging, large-scale datasets like ImageNet-R and DomainNet. Our approach outperforms both existing methods and our own baselines by more than 7% while significantly reducing communication and client-level computation costs.

1 Introduction

Federated Learning (FL) is a privacy-preserving learning paradigm that enables learning a global model through communication with a distributed set of clients. These clients have exclusive access to private data, and collaborate with a central server to learn a shared task by communicating parameters such as model weights, gradients, or learning statistics. For example, the popular FedAvg [1] method works by iteratively aggregating client models by averaging model weights. Classical FL methods such as FedAvg have garnered significant attention due to the increasing demand for user privacy and the growth of edge computing.

However, currently most federated learning methods focus on learning statically, that is across a fixed set of categories determined *a-priori*. In non-federated works, on the other hand, there has been a great deal of progress on learning an increasing number of categories incrementally, referred to as *continual* learning (and more specifically *class-incremental learning*) [2, 3]. In addition to the problem of catastrophic forgetting, incremental learning breaks current assumptions in FL, namely that the data is Independent and Identically Distributed (IID), has been shown to cause issues of model divergence [4, 5]. While *heterogeneous federated learning* [5] approaches have been developed, they do not support the *dynamic data distributions* that occur in continual learning and the real-world.

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International Workshop on Federated Learning in the Age of Foundation Models in Conjunction with NeurIPS 2023 (FL@FM-NeurIPS'23). This workshop does not have official proceedings and this paper is non-archival.

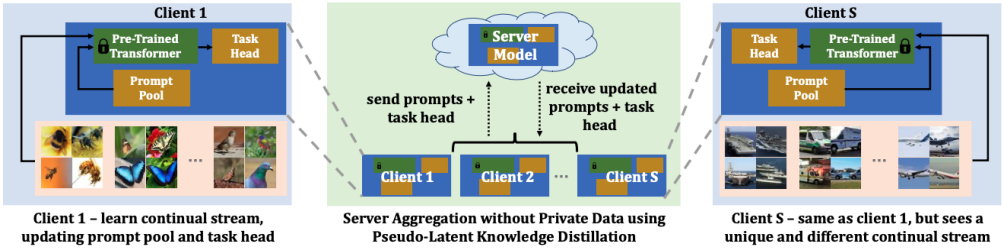

Figure 1: Prompt learning using Foundation Models for communication efficient Continual Federated Learning.

Such a setting has immense practical impact and finds direct applications in healthcare, autonomous vehicles, and chat-bots.

Therefore, in this paper we look at the understudied problem of *Continual Federated Learning (CFL)* [6, 7, 8]. While a few CFL methods exist, they address the issue of forgetting using approaches such as: inter-client interference reduction, knowledge distillation and image-level generative replay. Specifically, they often communicate full model weights, real/synthesized image-level data, or gradients. Additionally, some methods store old data in memory buffers or train a generative model to mimic local data; at the very least, all methods share complete models parameters with the server which can lead to privacy leaks with advancements in model inversion and other extraction techniques [9]. *As a result, many of these methods fail to effectively uphold the principles of CFL, such as communication efficiency, computational efficiency and privacy*.

To mitigate forgetting while adhering to the core principles of CFL, we propose HePCo: **He**terogeneous **P**rompt **Co**nsolidation (Fig. 1). Our method is driven by the goals of (i) minimizing communication costs, (ii) improving client privacy, and (iii) client-level computation efficiency. We first propose to leverage *prompting*-based methods, which have shown successful results in the rehearsal-free continual learning setting. This also has the benefit of utilizing frozen Foundation Models, meaning that only prompts and classifiers have to be transmitted, reducing communication costs. The key contribution of our approach is then to answer the question of how to merge prompts from different clients in a scalable manner. Towards this end we propose a lightweight method for generating pseudo-data and distilling client model information. Importantly, we distill data from both the past task label distribution as well as the current task label distribution, preventing both catastrophic forgetting and performance degradation due to client heterogeneity.

2 Related Work

Continual Federated Learning methods currently suffer from various limitations in terms of performance, efficiency and privacy. FedWeiT [6] aims to learn better client models by minimizing interference across client weights. FedWeiT incurs considerable overheads in terms of communication, computation and storage. GLFC [10] uses a prototype based approach with a memory buffer to store old data. This poses a threat to privacy of client data. CFed [7] proposes a distillation based approach that makes use of an unlabelled surrogate dataset to aggregate client models as well as to rehearse old tasks. However the requirement for a curated dataset can severely impact real-world applicability. TARGET [11] combats forgetting through a generative replay of images from past tasks. However, CFed and TARGET introduce overheads at both client and server sides, which may not be ideal for some practical scenarios. FedCIL [8] leverages an Auxiliary Classifier GAN (ACGAN) to alleviate forgetting by synthesizing old images for replay. However, generating images to mimic local datasets can be viewed as a privacy risk especially in light of recent research on model inversion attacks [9]. In contrast, our approach prioritizes client privacy by generating in the latent space which cannot easily be traced back to the image space. Further, this benefits communication and compute efficiency.

3 Problem Formulation

In this section, we describe the formulation by introducing the class-incremental learning and heterogeneous federated learning aspects in our CFL setting.

Class-Incremental Federated Learning. We focus on the *class-incremental* learning scenario, where a model is tasked with learning new classes over time. Under this setting, a global model is learned through a sequence of *N global* tasks $T = \{T^1, T^2, ..., T^N\}$. As this is done in a federated setup, each task is learned through *R* independent rounds by randomly sampling a set of *stateless* clients *C* = $\{c_1, c_2, c_3, ..., c_S\}$ in each round. In a *stateless* setting, new clients are visited in each round. Previously seen data cannot be accessed at any time during the training.

Heterogeneous Federated Learning. To simulate a real-world heterogeneous federated learning scenario, we use three configuration parameters to control the level of heterogeneity with increasing granularity: *split ratio*, *category ratio*, and *imbalance ratio*. At the top level, the most common heterogeneity is varying local dataset sizes. A specific client c_i can be exposed to a subset of the current task dataset D^t as their local dataset D_i^t, and the size $|D_i^t|$ varies from each other. We denote this as the *split ratio* $\gamma = |D_i^t|/|D^t|$. At a lower level, the local dataset D_i^t consists of a subset of the categories from those in the current global task. Specifically, a global task T^t consists of categories K^t, where $|K^t|$ [2] denotes the number of unique categories [3]. In a given round *r*, each client c_i sees data containing $K_i^t \in K^t$ categories. We denote $\kappa = K_i^t/K^t$ as the *category ratio* which is a value between 0 and 1. At the lowest level, each category can have a different amount of data. We follow [12] to also create an artificial long-tail distribution for local data which is different for each client. This distribution is governed by an *imbalance ratio* β. If $\beta = 1$, each client c_i is allocated samples uniformly from K_i^t categories. In summary, a smaller split ratio γ, a smaller category ratio κ, or a smaller imbalance ratio β increases heterogeneity thereby increasing the complexity of the task.

As discussed before, combining client models in a heterogeneous setting causes the obtained model to forget global knowledge from the previous rounds as shown by [13, 14]. Also, training clients on locally-available datasets induces forgetting of global knowledge outside the local distributions. *Intra-task forgetting* [7] measures such performance drops induced by the data heterogeneity (non-IIDness) across clients. *Inter-task forgetting* measures the drop in performance on old tasks $\{T^1, T^2, ..., T^{t-1}\}$ after learning a new task T^t.

4 Method

In this section, we describe our novel approach called HePCo (**H**eterogenous **P**rompt **Co**nsolidation) which tackles forgetting and heterogeneity using a data-free distillation strategy applied in the model's latent space. Unlike prior CFL works, we first propose to leverage the current state of art *prompting methods* in continual learning. Such methods optimize learnable parameters that augment the input to a pretrained transformer model (prompt tuning) or its underlying attention mechanism (prefix tuning). These methods have been shown to obtain strong performance without requiring rehearsal.

Despite these advantages, there is a key challenge in applying prompting to the CFL setting: It is not obvious how the server should *combine* prompts learned by the individual clients on subsets of the categories within a task. Naively performing weight averaging performs poorly (as we show in Sec. 5) and simply maintaining a growing prompt pool scales poorly with the number of clients.Our key novelty is therefore to propose a lightweight *data-free distillation method*, performed in the latent-space of the model, which greatly mitigates intra-task and inter-task forgetting. Doing so, we prioritize privacy and efficiency, which are crucial for federated learning. In summary, in our method communication between clients and the server is low, the information is effectively distilled, and the method achieves state-of-art performance. Below we detail our method and depict it in Fig. 2.

4.1 Client Side : Decomposed Prompting

L2P (Learning to Prompt) [15] is a continual learning method that maintains a prompt pool $P = \{P_1, P_2, \cdots, P_M\}$ of size M, where $P_i \in \mathbb{R}^{L_p \times D}$ are prompt parameters with L_p as the prompt length (chosen as a hyperparameter) and D the embedding dimension. Each prompt P_i has an associated key $k_i \in \mathbb{R}^{\mathbb{D}}$. An input image x is converted into a visual query $q(x) \in \mathbb{R}^{\mathbb{D}}$ by passing through the frozen vision transformer encoder θ_{pt}. Prompts are selected from the pool by measuring the cosine similarity between associated keys and the visual query to be inserted into the transformer.

[2] We use the terms 'category', 'class', and 'label' interchangeably to refer to the target classification label.

[3] $|\cdot|$ corresponds to set cardinality.

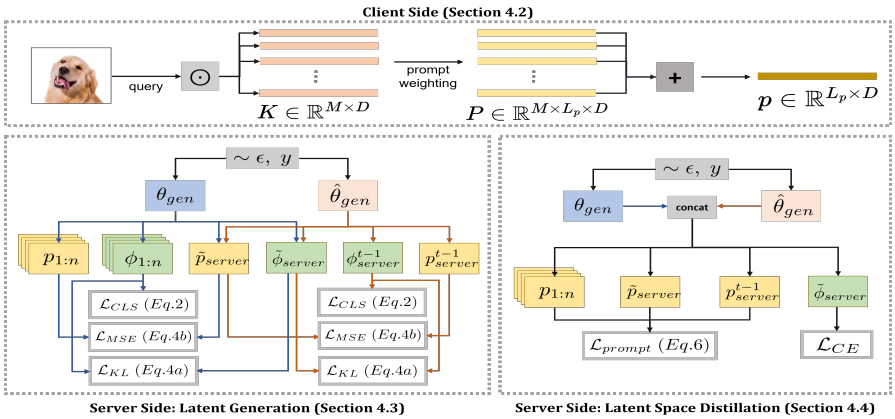

Figure 2: Latent generation and distillation with underlying *decomposed prompting* scheme.

While L2P is quite successful in protecting against forgetting, its performance is restrained by certain design choices [16]. Specifically, L2P uses discrete prompts that restrict capacity and introduces an additional hyperparameter (given by N). Instead, we form our final prompt $\boldsymbol{p}$ by taking sum of the individual prompts P_i weighted by the cosine scores. This allows us to effectively learn end-to-end, different from the decoupled optimization in L2P. In our setting, each client learns the key and prompt matrices while keeping the ViT backbone frozen. After each round, the key, prompt, and classifier weights are transmitted to the server, significantly reducing communication costs compared to sharing complete models. This also safeguards privacy by preventing the server from replicating client models since it has no knowledge of the specific layers where these prompts need to be inserted.

4.2 Server Side : Latent Generation

At the end of each round, the server receives $|C|$ prompt and classifier weights collected from the active clients. First, we simply average these weights to form intermediate server weights. Due to data heterogeneity, the local model weights diverge which degrade the performance of this aggregated model. We therefore propose to fine-tune the server model using data-free distillation in the latent space to prevent this degradation. We generate pseudo data in the latent space of the *visual query* $q(x) \in \mathbb{R}^{\mathbb{D}}$ which is essentially the output space of the vision encoder. The advantage of generating in this space is that it allows us to fine-tune *both* the classifier and the key-prompt weights without needing a forward-pass through the encoder! We use a lightweight feedforward neural network as our conditional generator with a D dimensional output. We encode a class label (from categories in current task t) using an embedding layer and concatenate the obtained class embedding with noise vector of dimension D_{noise} drawn from the standard normal distribution $\mathcal{N}(\mathbf{0}, \mathbf{1})$ to form the input of the generator. From the generator, we obtain a pseudo latent of dimension D conditioned on the class label as follows:

$$z = G(\epsilon, y; \theta_{gen}), \tag{1}$$

where $z \in \mathbb{R}^D$ is the generated pseudo latent and $\epsilon \in \mathbb{R}^{D_{noise}} \sim \mathcal{N}(\mathbf{0}, \mathbf{1})$ is the noise vector. For effective knowledge distillation, pseudo data should conform to the latent space of the client models. We optimize for a classification loss which is a sum of classification losses for each individual client, similar to [17]. The total classification loss can be given as:

$$\mathcal{L}_{cls} = \sum_{c \in C} \mathcal{L}^c_{cls} \quad \text{and,} \tag{2}$$

$$\mathcal{L}^c_{cls} = \sum_{c \in C} \mathcal{L}_{CE}(\phi(z; w_c), y) \tag{3}$$

where $\mathcal{L}^c_{cls}$ is the cross-entropy loss between the prediction of local model c given latent z and sampled class label y. Here, ϕ denotes the classifer (last layer). However, optimizing for just the classification loss encourages the generator to produce pseudo latents which are easy to be classified and hence less effective for distillation. Our goal is to generate latents that create a discrepancy between the intermediate server model and clients, thereby providing a learning opportunity for the server. To promote the generation of such *hard samples*, we maximize two disagreement losses (one for prompts and one for classifier) between server and client models. To measure the disagreement with respect to the classifier, we compute the Kullback-Leibler (KL) divergence between the predictions of the intermediate server model and each individual client model. Next, to measure the disagreement with

respect to the prompting mechanism, we introduce a Mean-Squared Error (MSE) loss between the final prompts generated by the server and all clients. By training the generator to maximize these losses, we increase the potency of pseudo-latents for effective distillation in both parts of the network.

$$\mathcal{L}_{KL} = \sum_{c \in C} \sigma(\phi(z; w)) || \sigma(\phi(z; w_c)) \tag{4a}$$

$$\mathcal{L}_{MSE} = \sum_{c \in C} \mathcal{L}_{MSE}(\rho(z; w), \rho(z, w_c)) \tag{4b}$$

where σ denotes the softmax function and ρ denotes the prompting mechanism described in 4.1. We train the generator by optimizing for these these losses jointly as:

$$\min_{\theta_{gen}} \mathbb{E}_{\epsilon \sim \mathcal{N}(\mathbf{0}, \mathbf{1})} \left[\mathcal{L}_{cls} - \lambda_{KL} \mathcal{L}_{KL} - \lambda_{MSE} \mathcal{L}_{MSE} \right] \tag{5}$$

A model fine-tuned with only current task pseudo-data suffers from inter-task forgetting as shown in our ablation experiments in Appendix B. To prevent this, we train a separate copy of the generator ($\hat{\theta}_{gen}$) to generate latents corresponding to the previously seen tasks. Here the classification loss $\mathcal{L}_{cls}$ is computed for the previous task server model and $\mathcal{L}_{dis}$ is measured between previous and intermediate server model.

4.3 Server Side : Latent Space Knowledge Distillation

Once the generator is trained to generate pseudo-latents corresponding to the current and previous tasks, we use it to efficiently fine-tune the classifier and prompting components of the intermediate server model. We use the key, prompt and classifier weights corresponding to the current round client models and the last-task server model to fine-tune the server model. As it operates in a low dimensional latent space, this distillation process is computationally cheap compared to traditional distillation that trains the entire network. While we introduce additional server overhead, it is important to note that, in the context of CFL, clients are typically edge devices with limited computing power, while servers have ample computational resources. We prioritize client-level efficiency while making efficient use of the server's resources. In Appendix, we compute this overhead and show that it is competitive to that incurred by existing state-of-the-art (SOTA) methods. To perform knowledge distillation, we first generate a batch of pseudo-data from the generators corresponding to the current round and previous task. We mix the current and previous task batches to form a single composite batch according to a hyperparameter named *replay ratio* which determines the size of the previous task batch relative to the current round batch.

First, to fine-tune the weights used for prompting, we pass the pseudo-data through the prompting mechanism of a model to obtain final prompts $\boldsymbol{p}$ which would serve as the target for distillation. Note, we do not require full models to generate these targets. Now to fine-tune the server model, we optimize for the Mean Squared Error (MSE) loss between the final prompts generated by the intermediate server model and each individual model (clients and last-task server).

$$\mathcal{L}_{prompt} = \sum_{c \in C} \mathcal{L}^{c}_{MSE} + \zeta^{y}_{t-1} L^{t-1}_{MSE}, \tag{6}$$

where $\mathcal{L}^{c}_{MSE}$ denotes the MSE loss between client c and the intermediate server model and L^{t-1}_{MSE} denotes the MSE loss between the intermediate model and the previous task server model. Further, ζ^{y}_{t-1} is an indicator variable which is set to 1 if y was seen in previous tasks and 0 if present in current task. Finally, to fine-tune the classifier of the server model, we minimize the cross entropy loss. The cross-entropy loss is computed between the predictions of the server for a batch of pseudo latents and the class labels that the pseudo latents were conditioned on.

5 Experiments

Setup. We appropriately adapt three image classification datasets commonly used in continual learning [16], to fit our specific setting. ImageNet-R and DomainNet capture real-world distribution shifts that can be challenging for models pre-trained on ImageNet to generalize to and are widely recognized benchmarks for evaluating continual learning in Foundation Models. We divide these datasets into 10-task (CIFAR-100, ImageNet-R) and 5-task (DomainNet) benchmarks. For all experiments reported in Table 1, we consider a class balanced setting ($\beta = 1$) and use a category ratio $\kappa = 0.6$ which means

Table 1: **Results (%)** for the class-balanced setups reported over 3 independent trials.

Datasets ($\beta = 1$)	CIFAR-100		ImageNet-R		DomainNet	
Method	A_N (↑)	F_N (↓)	A_N (↑)	F_N (↓)	A_N (↑)	F_N (↓)
Prompting (Centralized)	85.35	-	72.28	-	71.33	-
FedAvg-FT	10.23 ± 1.10	31.74 ± 0.80	12.03 ± 0.75	29.07 ± 0.66	18.76 ± 0.44	32.81 ± 1.22
FedLwF.MC [20]	59.08 ± 1.06	12.39 ± 0.76	52.87 ± 0.61	13.34 ± 0.38	62.39 ± 1.12	10.76 ± 0.50
FedAvg-Prompt	67.34 ± 1.42	8.38 ± 0.42	51.15 ± 0.68	8.84 ± 0.52	51.03 ± 2.23	12.03 ± 0.45
CFed [7]	72.26 ± 1.56	8.82 ± 0.64	45.64 ± 1.32	11.74 ± 1.22	63.32 ± 0.78	7.12 ± 0.66
TARGET [11]	73.56 ± 1.42	6.83 ± 0.91	52.38 ± 1.16	8.88 ± 0.96	61.84 ± 1.66	7.94 ± 0.52
HePCo (Ours)	$\mathbf{76.54 \pm 1.14}$	$\mathbf{6.61 \pm 0.73}$	$\mathbf{59.96 \pm 0.94}$	$\mathbf{7.08 \pm 0.40}$	$\mathbf{64.01 \pm 0.36}$	$\mathbf{6.83 \pm 0.31}$

Table 2: **Results (%)** for class-imbalanced setup

Datasets	CIFAR-100		ImageNet-R		DomainNet	
Method	A_N (↑)		A_N (↑)		A_N (↑)	
Imbalance ratio (β)	$\beta = 0.05$	$\beta = 0.01$	$\beta = 0.05$	$\beta = 0.01$	$\beta = 0.05$	$\beta = 0.01$
FedAvg-FT	8.81 ± 1.53	9.18 ± 1.26	9.26 ± 1.02	8.88 ± 1.24	13.02 ± 1.29	11.65 ± 1.84
FedLwF.MC [20]	50.40 ± 0.88	40.39 ± 1.06	19.94 ± 0.78	13.34 ± 1.41	57.34 ± 0.84	52.46 ± 0.72
FedAvg-Prompt	62.72 ± 1.79	54.43 ± 1.57	36.51 ± 0.86	28.16 ± 1.12	47.73 ± 1.25	43.23 ± 1.03
CFed [7]	70.26 ± 1.20	$\mathbf{62.04 \pm 1.62}$	34.62 ± 1.41	25.74 ± 1.08	59.89 ± 0.68	55.22 ± 0.80
TARGET [11]	66.47 ± 1.22	58.13 ± 1.54	30.20 ± 1.35	19.84 ± 1.41	56.44 ± 0.45	51.82 ± 0.58
HePCo (Ours)	$\mathbf{70.34 \pm 1.08}$	61.70 ± 1.48	$\mathbf{45.45 \pm 0.98}$	$\mathbf{41.68 \pm 1.44}$	$\mathbf{61.10 \pm 0.76}$	$\mathbf{58.82 \pm 0.84}$

that if a task contains 10 categories, each active client is randomly assigned 6 of these categories. Further, we use a uniform split ratio $\gamma = 0.1$ which allows a client to be assigned 10% of the examples corresponding to the subset of categories. We evaluate all methods using the standard continual learning metrics of final average accuracy A_N and average forgetting F_N [18, 19]. As noted by [16], A_N is the more informative metric as it encompasses both forgetting and plasticity (new task performance). *We conduct further analysis with respect to efficiency and overhead costs in the Appendix C.*

Baselines. For fair comparison with existing SOTA methods, we adapt their implementations to use the same ViT backbone. We introduce a simple yet strong baseline *FedAvg-Prompt*, where the server model is aggregated by simply averaging the prompt components of the clients. For completeness, we also report the naive sequentially finetuned baseline that we call *FedAvg-FT*. Finally, we report the performance of our *decomposed prompting* scheme in a centralized, traditional continual learning setting. This can be thought of as an upper bound for all prompt-based methods included here.

5.1 Main Results

The results presented in Tables 1 and 2 demonstrate the dominant performance of our method across all datasets and setups. The gains achieved by our method are more pronounced in the ImageNet-R setup which has longer task sequences and offer a significant shift from the pretrained distribution. All baselines that fine-tune the entire model are seen to struggle with longer sequences (CIFAR, Imagenet-R), showing significant forgetting. Under the class-balanced setting of Table 1, our approach achieves absolute improvements of more than **7%** on ImageNet-R in average accuracy compared to TARGET [11], which is the current SOTA. For the class-imbalanced settings in Table 2, our approach outperforms the competition by *even wider* margins. The notable performance drops observed across all methods highlight the complexity of this setting. Most importantly, HePCo achieves these solid results while enjoying low communication costs and without introducing any additional costs at the client-side. Furthermore, our approach faithfully aligns with the principles of Federated Learning (FL) by not assuming access to any storage, be it surrogate datasets or generated images, in contrast to other methods we have compared against. *We include further analysis in Appendix B.*

6 Conclusion

In conclusion, we propose HePCo (Heterogeneous Prompt Consolidation) for continual federated learning. Our method harnesses the prompt learning capabilities of foundation models to facilitate a data-free distillation framework for consolidating heterogeneous clients. We demonstrate the superior performance of our method through a series of experiments that emulate challenging real-world scenarios. By requiring clients to share parts of their models, we significantly reduce communication costs and enhance privacy. Importantly, our approach does not impose any additional overheads on the client side, making it highly valuable for real-world deployment. We include a discussion on the limitations of our work in Appendix D.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. 2239292

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Appendix

A Experimental Details

Implementation Details. For fair comparison, we use the ViT-B/16 backbone pretrained on Imagenet-1K as the encoder for all methods. We resize images to 224×224 and normalize to [0,1]. We implement our methods in PyTorch and use the PyTorch Image Models library [21] to obtain pretrained checkpoints. In our experiments, the total number of classes for CIFAR-100, ImageNet-R and DomainNet are 100, 200 and 345 respectively. We use 2 NVIDIA A40 GPUs for all experiments.

Training Details. For all methods, we use the Adam [22] optimizer with $\beta_1 = 0.9$ and $\beta_2 = 0.999$ and train for 10 local epochs in each round. We learn each task through $R = 10$ communication rounds by selecting $C = 5$ stateless clients per round. Thus, we have 100 total rounds for a 10-task setup and 50 for a 5-task setup.

Hyperparameter Search. As done in DualPrompt [23] we use 20% of the training dataset as our validation data and conduct a hyperparameter search. We arrive at using a batch size of 64 for both local and server-side training. We use a learning rate of $1e^{-3}$ for our method and the prompting-based baselines and a learning rate of $5e^{-5}$ for all baselines that tune the entire model (FedAvg, FedLwF.MC). We search for learning rates in the values of $\{1e^{-6}, 5e^{-5}, 1e^{-5}, 5e^{-4}, 1e^{-4}, 5e^{-3}, 1e^{-3}, 5e^{-2}, 1e^{-2}\}$. For our method, we use a three-layer fully-connected network as our generator. We encode the class label using an embedding matrix of embedding length 64 and concatenate it with a noise vector of dimension 64. Our generator architecture can be described with having the following input sizes per layer : [128, 256, 1024] and an output size of 768 which is the dimension of the visual query. We train the generator for 100 epochs using a batch size of 64 and a learning rate of $1e^{-4}$ using the Adam optimizer. We fine-tune the server model using a learning rate of $1e^{-4}$ for 200 epochs. We use a *replay ratio* of 0.5 for our method, which means we mix 50 pseudo-latents corresponding to previous tasks for every 100 pseudo-latents corresponding to the current task. We conduct a search over values like [0, 0.125, 0.25, 0.375, 0.5, 0.625, 0.75, 0.875, 1] and find 0.5 to result into the best average accuracy A_N. We observe a *stability-plasticity* trade-off controlled by this hyperparameter with larger values leading to lower forgetting (F_N) but lower current task accuracies (*plasticity*) and smaller values yielding the opposite effect. Through the hyperparameter search we choose λ_{KL} and λ_{MSE} values to be 1 and 0.1 respectively.

B Ablation Studies

We perform ablations experiments on CIFAR-100 in the class-balanced setting from Table 1 and report in Table A

Ablating distillation of previous server model. By removing the previous task server model from the distillation and generation steps, we highlight its efficacy in alleviating forgetting. By ablating this component, we observe a significant drop in performance indicated by a rise in forgetting (F_N) and a drop in average accuracy (A_N). The underlying intuition is that without the replay of past task data, the method strongly prioritizes learning of the current task leading to a loss of knowledge from previously seen tasks.

Ablating disagreement losses in generation. To demonstrate the effectiveness of disagreement losses in generation, we set both the lambda coefficients to zero and observe a 6% drop. As discussed before, the intuition here is that in absence of the disagreement losses, the generator is prone to generate easily discriminable examples that lead to low classification loss but are less effective in distillation. To further highlight the importance of the individual losses, i.e $\mathcal{L}_{MSE}$ and $\mathcal{L}_{KL}$, we individually ablate them and observe performance drops.

Ablating distillation targets. In this experiment, we avoid distillation for the prompt components and the classifier separately and observe a decline in performance in both cases. The drop in performance is more pronounced when we ablate distillation for the classifier. This experiment highlights our decision to fine-tune both prompt components and classifiers by operating in the latent space.

Varying the category ratio. Figure A shows the performance of all methods for different values of *category ratio*. We observe that HePCo consistently outperforms competing methods without requir-

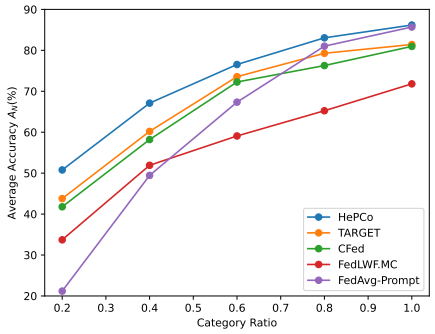

Figure A: Comparison of the methods under different category ratios

Method	A_N (↑)
HePCo (Ours)	$\mathbf{76.54 \pm 1.14}$
Ablate previous server model	61.15 ± 2.13
Ablate $\mathcal{L}_{KL}$ & $\mathcal{L}_{MSE}$	70.22 ± 1.45
Ablate $\mathcal{L}_{KL}$	71.39 ± 1.34
Ablate $\mathcal{L}_{MSE}$	74.11 ± 1.31
Ablate prompt distillation	74.42 ± 1.22
Ablate classifier distillation	68.46 ± 0.91

Table A: **Ablation Results (%) on 10-task CIFAR 100**. A_N gives the accuracy averaged over tasks and F_N gives the average forgetting.

ing any hyperparameter or design changes. The performance gap between HePCo and the competing methods widens with the category ratio, indicating its effectiveness in settings with high heterogeneity.

C Overhead Costs

Memory Overhead. Our method introduces additional parameters forming the prompting mechanism. The additional parameters amount to ~9.4% of the original size of the ViT encoder. Our method only needs to communicate the total learnable parameters in the model which includes the classifier and prompt components amounting to ~9.5% of the original model size. Methods that finetune the entire model need to learn and communicate all parameters in the encoder and classifier. Hence, our approach required only 9.5% of the communication costs compared to these approaches. Furthermore, the current state-of-the-art methods like CFed and TARGET require communicating a dataset of images (obtained from the surrogate dataset or a generative mechanism) after every round or task which significantly increases the communication overhead in addition to sharing complete models!

Computation Overhead. Our method does not require any extra computation at the client side but introduces an overhead at the server side. This overhead includes the time required to train the generators and perform knowledge distillation. To quantify this overhead, we conducted benchmarking using 2 NVIDIA TITAN RTX GPUs in a 5 client setup, as described in the experiments section. Our method adds an extra 220 seconds of computational time at the server side per round, in contrast to the 166 seconds introduced by CFed and the 190 seconds incurred by TARGET. It is crucial to emphasize that our method imposes no additional overhead on the client side, unlike CFed and TARGET, where the client is effectively responsible for learning the current task and distilling knowledge from past tasks. In most practical federated learning scenarios, edge devices have limited computational capacity compared to the server. Our approach prioritizes client-level efficiency, even if it entails a slight trade-off in server-level efficiency.

Storage Overhead. As our method operates in a stateless FL setup, we do not require clients to maintain any state information or additional storage. Our approach requires the server model to store the classifier and prompt components corresponding to the last task model which is used in distillation resulting into a storage cost equal to ~9.5% of the base encoder model size. Other baselines [20] incur extra storage costs at the client side equal to the size of entire encoder and classifier i.e ~86M parameters. Additionally, CFed and TARGET incur costs equivalent to storing an entire image dataset at both server and individual client levels.

In summary, our approach attains state-of-the-art performance while imposing lower overheads compared to existing methods.

D Discussion

Limitations. It is worth noting that prompting-based methods are still relatively new and not extensively studied, making the interpretation of these prompts challenging. Therefore, future work should focus on testing the robustness of these methods in diverse setups to ensure their effectiveness in different scenarios. One potential limitation of this work is in the computation overhead introduced

at the server, which may be an issue for some use-cases. Although the generation and distillation procedures are relatively lightweight, they still rely on server-side compute resources, which may not be universally accessible in all scenarios. Additionally, our approach necessitates clients to use pretrained vision transformers, leaving open the question of how this framework can be extended to accommodate other architectures. These are interesting avenues for future research.

Broader Impact. The machine learning community is increasingly leaning towards the adoption of large-scale models for various applications. However, updating these models with new data poses a significant challenge. Retraining models from scratch each time new data arrives is computationally expensive and can have substantial financial [24] and environmental [25, 26] implications. Our approach offers a solution by enabling incremental learning on new data without the need for complete model retraining. Additionally, our use of prompting techniques allows for significant reductions in communication and local computation costs while enhancing privacy, which is especially critical for on-device edge computing applications.