
Improving Language Plasticity via Pretraining with Active Forgetting

Yihong Chen[†] Kelly Marchisio[‡] Roberta Raileanu[§] David Ifeoluwa Adelani[†]
Pontus Stenetorp[†] Sebastian Riedel[†] Mikel Artetxe[¶]

[†]UCL Centre for Artificial Intelligence

[§]Meta AI [¶]Reka AI [‡]Cohere AI

{yihong.chen, d.adelani, p.stenetorp, s.riedel}@cs.ucl.ac.uk
mikel@reka.ai kelly@cohere.com raileanu@meta.com

Abstract

Pretrained language models (PLMs) are today the primary model for natural language processing. Despite their impressive downstream performance, it can be difficult to apply PLMs to new languages, a barrier to making their capabilities universally accessible. While prior work has shown it possible to address this issue by learning a new embedding layer for the new language, doing so is both data and compute inefficient. We propose to use an *active forgetting* mechanism during pretraining, as a simple way of creating PLMs that can quickly adapt to new languages. Concretely, by resetting the embedding layer every K updates during pretraining, we encourage the PLM to improve its ability of learning new embeddings within limited number of updates, similar to a meta-learning effect. Experiments with RoBERTa show that models pretrained with our forgetting mechanism not only demonstrate faster convergence during language adaptation, but also outperform standard ones in a low-data regime, particularly for languages that are distant from English. Code will be available at <https://github.com/facebookresearch/language-model-plasticity>.

1 Introduction

Pretrained language models (PLMs) have been swiftly reshaping the landscape of natural language processing (NLP) by improving upon standardized benchmarks across the board [Radford and Narasimhan, 2018, Devlin et al., 2019, Liu et al., 2019, Brown et al., 2020]. At their core, they acquire knowledge by ingesting large datasets and store this knowledge in their parameters during pretraining. Using finetuning or prompting [Brown et al., 2020], such knowledge can then be applied to downstream applications, such as semantic analysis, question answering, and others.

Despite their success, PLMs still have a number of shortcomings [Weidinger et al., 2021, 2022]. In particular, it requires massive data and computation to pretrain them [Gururangan et al., 2020, Kaplan et al., 2020, Hernandez et al., 2021, Hu et al., 2021, Touvron et al., 2023]. Naively retraining a new PLM to accommodate every lingual space shift ¹ would be prohibitively expensive. This makes it a highly relevant research target to create PLMs that can be efficiently adapted to new lingual spaces.

While forgetting in the context of both human and machine learning is often perceived as something negative (for instance catastrophic forgetting [McCloskey and Cohen, 1989, Ratcliff, 1990, Kirkpatrick et al., 2017]), recent works have shown that for artificial neural networks forgetting

¹We use the term *lingual space shift* to describe changes in language usage between pretraining and the target downstream application, caused by factors such as language change, time evolution, or domain switch. A model with high *language plasticity* would quickly adapt to these shifts.

can also play a positive role in increasing their “plasticity”, such as improving generalization to unseen data [Zhou et al., 2022, Chen et al., 2022, Igl et al., 2021], enabling learning in low-data regimes [Alabdulmohsin et al., 2021, Taha et al., 2021], or counteracting primacy bias [Nikishin et al., 2022, D’Oro et al., 2023]. Given these developments, in this work we ask whether we can draw upon forgetting as a mechanism to improve *pretraining* and imbue PLMs with similar benefits.

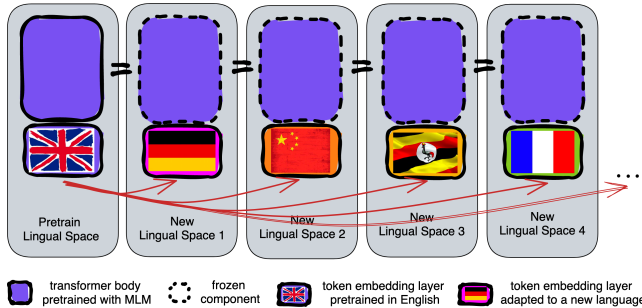


Figure 1: *Rewiring* via relearning token embeddings: where the transformer body (the purple part) is “frozen” and reused for a new language, but the token embeddings are relearned to suit the new language.

untouched throughout pretraining. We study whether this forgetting approach creates a PLM that can easily *rewire* (Figure 1) to an unseen (possibly distant) language. Intuitively, resetting embeddings forces the transformer body to re-derive reasoning each time instead of relying on memorized shortcuts. Through repetition, the body learns more abstract, high-level reasoning. A model with greater abstraction can easily transfer across languages, since high-level reasoning is more language-agnostic.

Our zero-shot evaluations on several cross-lingual transfer benchmarks show that for cases where unlabeled adaptation corpus for the unseen language has as few as 5 million tokens (a low-data regime), forgetting PLMs outperforms the baseline by large margins: average gains of +21.2% on XNLI, +33.8% on MLQA, and +60.9% on XQuAD. In addition, models pretrained using active forgetting converge faster during language adaptation. Finally, we find that forgetting is especially beneficial for languages that *are distant from* English, such as Arabic, Hindi, Thai, and Turkish.

2 Rewire PLMs for New Languages

Using unlabeled data, [Artetxe et al., 2020] demonstrates the possibility of rewiring a monolingual PLM for a new language; they propose to relearn the embedding layer for the new language while keeping all the other parameters frozen. The underlying assumption is that the token embedding layer and the transformer body (the non-token-embedding parameters) divide up the responsibility in a way that the former handles language-specific lexical meanings, while the latter deals with high-level general reasoning. Hence, rewiring an English PLM for a new language boils down to separately adapting the former with unlabeled data in the new language and the latter with English task data. The procedure can be summarized as follows:

1. **Pretrain:** A transformer-based model is pretrained on an *English* corpus. In our experiments, we choose to pretrain RoBERTa-base [Liu et al., 2019], a 12-layer transformer-based model, on English CC100 [Conneau et al., 2020].
2. **Language Adapt:** The **token embedding layer** is finetuned using unlabelled data in the new language, while the transformer body is frozen.
3. **Task Adapt:** The **transformer body** is finetuned using downstream task data in English, while the token embedding layer is frozen.
4. **Assemble:** The final model is assembled by taking the adapted token embedding layer from stage 2 and the adapted transformer body from stage 3.

It is well established in the NLP community that models struggle to generalize across languages without substantial intervention [Conneau et al., 2020, Pfeiffer et al., 2020, 2022, Ansell et al., 2022], which is especially true for low-resources languages. We thus see this as a promising testing ground for forgetting techniques. Our focus is on the input layer of the PLM, the *token embedding layer*, as learning it has been shown to be highly effective when adapting between languages [Artetxe et al., 2020].

Concretely, we introduce an *active forgetting* mechanism, that resets token embeddings at regular intervals, while leaving all other parameters

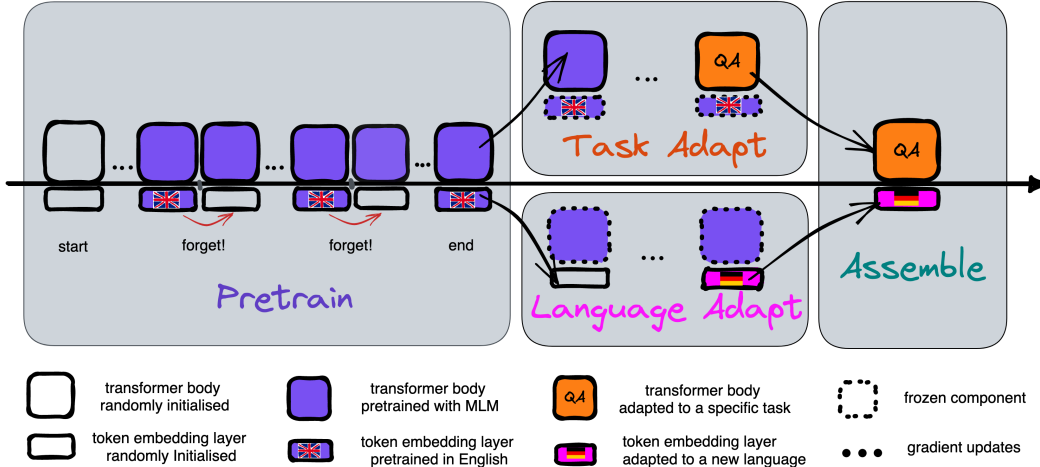


Figure 2: Unsupervised zero-shot cross-lingual transfer. **Left:** in the pretrain stage, we compare standard pretraining with forgetting pretraining, where the token embeddings are actively forgotten at a regular interval while the transformer body is learned as the standard pretraining. **Middle:** the task adapt stage and the language adapt stage separately adapt the transformer body using English task data and the token embeddings using unlabeled data in the new language. **Right:** the assemble stage reassemble the adapted body and token embedding layer into a usable PLM.

2.1 On The Difficulty of Rewiring PLMs via Relearning the Token Embeddings

While the above procedure [Artetxe et al., 2020] offers a general framework for rewiring a monolingual PLM with unlabelled data in the new language, it is unclear how efficient such rewiring can be, including both sample efficiency and computational efficiency. To better understand the difficulty of rewiring PLMs via relearning the token embeddings, we design an experiment where we relearn the token embedding layer using varying amounts of adaptation data. For illustration purpose, we pick English as the pseudo “adaptation language” because the English dataset is large enough to bootstrap a series of sub-datasets with varying quantity. We create sub-datasets with [1K, 10K, 100K, 1M, 5M, 10M, 100M, 1B, 10B] tokens and relearn the English embeddings while keeping the transformer body frozen.

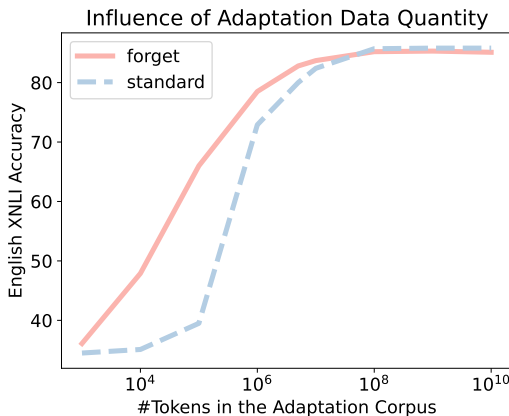


Figure 3: The rewiring performance for standard PLMs (blue dashed line) drops drastically if the adaptation tokens $\leq 10M$.

The dashed blue line in Figure 3 summarizes the influence of the adaptation data quantity on the quality of the rewired PLMs (relearned embeddings assembled with the English NLI task body). We can see that the standard PLMs are easy to rewire if there is enough adaptation data. However if the adaptation corpus contains fewer than 10 million tokens, the performance of the rewired standard PLMs (the blue dashed line in the figure) drops drastically as the adaptation data quantity goes down, from near 80 to around 35, a random-guessing level for NLI tasks. This motivates us to create more rewirable PLMs, i.e. PLMs with more plasticity so that the rewiring process can be faster and consume less data.

3 Pretrain Easy-to-Rewire PLMs via Active Forgetting

Recent works have shown that incorporating forgetting through iterative weights resetting can increase the “plasticity” of neural networks, enabling them to learn from small data and generalize better to unseen data in supervised learning [Alabdulmohsin et al., 2021, Taha et al., 2021, Zhou et al., 2022]. Building on these efforts, we study if we can bring such forgetting into the *pretrain* stage so that the resulting PLM would have more plasticity, allowing easier rewiring to new languages.

Our Hypothesis. In effect, when [Artetxe et al., 2020] relearned the token embedding layer, the reinitialization of the embeddings can be seen as forgetting applied *once* at the start of the *language adapt* stage. However, the PLM (specifically the transformer body) has never encountered forgetting before this stage and may struggle to handle this new situation. Without early exposure to forgetting, the PLM might suffer from slow recovery caused by forgetting before eventually benefiting from it. The learning of a new lexical embedding layer in a PLM henceforth consumes lots of data in new languages along with long training horizons as shown in Section 2.1. In this paper, to ensure swift learning of the new languages with both high sample efficiency and convergence rate, we argue that the PLM must be exposed to forgetting during pretraining, allowing itself to maximize the positive impact of forgetting and minimizing the cost of recovery.

Our Method. With this hypothesis in mind, we propose to add an *active forgetting* mechanism to the pretraining procedure, which resets the token embedding layer periodically as described in Algorithm 1. Concretely, the forgetting mechanism operates by intentionally clearing the weights of the embedding layer, which stores the static representations for all tokens, and reinitializing them to a new set of random values every K gradient updates. Since pretraining involves advanced training strategies, like optimizers with states and learning rate schedulers, we also reset them together with the token embedding layer. We refer to language models pretrained with such active forgetting mechanism as *forgetting PLMs*, in contrast to *standard PLMs* which are pretrained in a standard way. The pretraining loss curve of a forgetting PLM is episodic (Figure 4), like in reinforcement learning or meta-learning. This episodic learning demonstrates that the active forgetting mechanism can introduce diversity without requiring actual new data. Each forgetting event kind of “branches out” a novel environment for the model to explore, as if initiating a new episode of learning.

Research Questions. To further examine the proposed forgetting mechanism, we compare *forgetting PLMs* and *standard PLMs* on sample efficiency and convergence speed during *language adapt*, two key aspects of model plasticity. Our research investigates:

- RQ1: Real-world low-resource languages often have scarce data for adapting models. Does pretraining with active forgetting impart enough plasticity to forgetting PLMs, enabling them to learn new languages even with such limited data?
- RQ2: Deploying PLMs frequently encounters computational limitations. Endowed with more plasticity, can forgetting PLMs reduce adaptation time for such low-compute scenarios?
- RQ3: New languages may be very similar or different from pretraining languages. Does this similarity/difference impact the relative benefit of forgetting PLMs over standard PLMs?

4 Evaluate Forgetting PLMs for Unsupervised Cross-Lingual Transfer

To evaluate the effectiveness of forgetting PLMs and address RQ1-RQ3, we conduct experiments on several cross-lingual transfer benchmarks.

4.1 Experimental Setup

In our work, we closely follow the setup in [Artetxe et al., 2020] and [Marchisio et al., 2022]. Our *pretraining* model is RoBERTa-base, a standard 12-layer transformer-based language model. We trained language-specific sentencepiece tokenizers [Kudo and Richardson, 2018] with a vocabulary size of 50K over the corresponding data subsets in CC100. The model was pretrained with the English subset of the CC-100 dataset. The pretraining process consists of 125K updates, with a batch size of 2048. We used a learning rate scheduler with linear decay and an initial learning rate of $7e - 4$, with

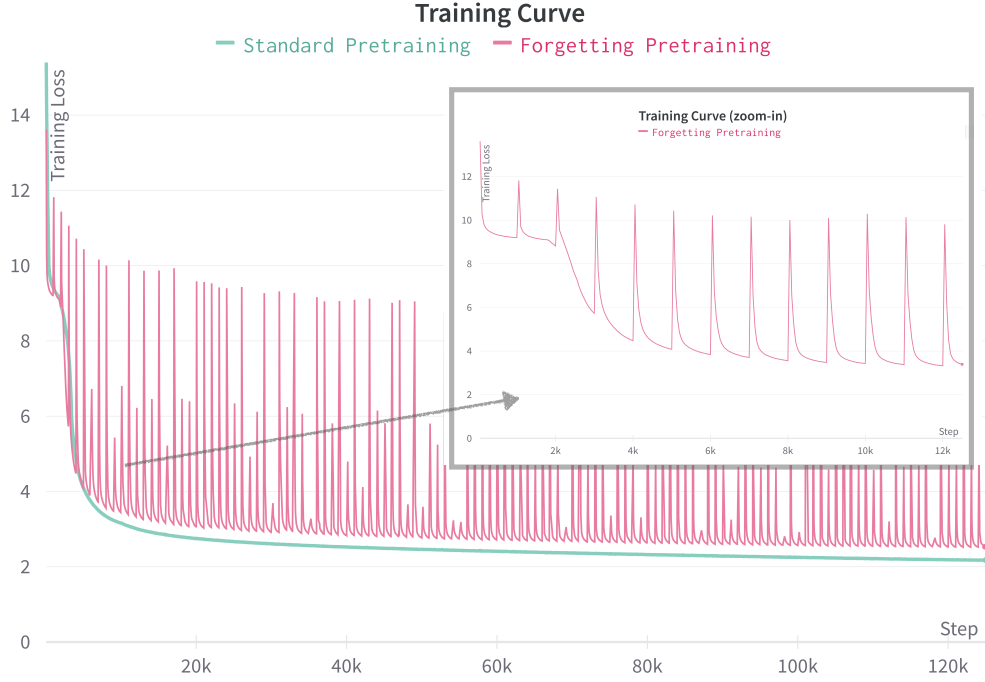


Figure 4: Pretraining loss curves of forgetting and standard language models. The forgetting mechanism brings an episodic pattern into the loss curve: every embedding forgetting produces a loss spike, from which the model learn to recover. Through such repeats of forget-relearn, the model gets used to learn new embeddings from scratch.

Algorithm 1 Active forgetting mechanism. The token embedding layer is reset every K updates.

Input: K , interval between two consecutive forgetting; $n_{\text{body/emb}}$, current effective number of updates for the body or the token embedding layer; $\alpha_{\text{body/emb}}$, current learning rate for the body or the token embedding layer; $P_{\text{body/emb}}^n$, parameters after the n^{th} update for the body or the token embedding layer; $O_{\text{body/emb}}^n$, optimizer states after the n^{th} update for the body or the token embedding layer; Θ , randomly initialized embedding parameters, each element drawn from $\mathcal{N}(0, 0.02)$; f , the function that computes the gradients w.r.t the parameters using the sampled data; g , the function that updates the parameters based on the gradients (e.g. one step in Adam optimizer) s , the function that updates the learning rate (e.g. one step in the polynomial learning rate scheduler).

Output: the updated parameters and optimizer states $P^{(n)} = \{P_{\text{emb}}^{(n)}, P_{\text{body}}^{(n)}\}$, $O^{(n)} = \{O_{\text{emb}}^{(n)}, O_{\text{body}}^{(n)}\}$.

- 1: $n_{\text{emb}} = n \bmod K$
 - 2: $\alpha_{\text{body}} = s(n_{\text{body}})$ {adjust learning rate based on n }
 - 3: $\alpha_{\text{emb}} = s(n_{\text{emb}})$
 - 4: $G^{(n)} = f(P^{(n-1)}, \cdot)$ {compute all gradients}
 - 5: $P_{\text{body}}^{(n)}, o_{\text{body}}^{(n)} = g(G_{\text{body}}^{(n)}, P_{\text{body}}^{(n-1)}, o_{\text{body}}^{(n-1)}, \alpha_{\text{body}}, n)$ {update the transformer body}
 - 6: **if** $n_{\text{emb}} == 0$ **then**
 - 7: $P_{\text{emb}}^{(n)} = \Theta$ {periodical reset token embeddings and the relevant optimizer states}
 - 8: $o_{\text{emb}}^{(n-1)} = 0$
 - 9: **end if**
 - 10: $P_{\text{emb}}^{(n)}, o_{\text{emb}}^{(n)} = g(G_{\text{emb}}^{(n)}, P_{\text{emb}}^{(n-1)}, o_{\text{emb}}^{(n-1)}, \alpha_{\text{emb}}, n_{\text{emb}})$ {update the token embeddings}
-

Method	vi	sw	es	bg	de	fr	el	ru
Standard	65.8	55.6	68.0	65.5	62.2	63.5	63.1	56.9
Forgetting	62.8	59.5	74.0	71.7	68.5	71.2	70.8	65.8
Relative Gain	-4.6%	+7.0%	+8.8%	+9.5%	+10.1%	+12.1%	+12.2%	+15.6%

Table 1: Accuracy comparison of forgetting and standard PLMs on XNLI (table continues).

Method	zh	ur	hi	tr	ar	th	Avg	en
Standard	53.2	36.8	39.7	38.9	41.2	35.3	53.3	86.1
Forgetting	63.5	45.8	52.9	52.7	59.5	59.7	62.7	85.1
Relative Gain	+19.4%	+24.5%	+33.2%	+35.5%	+44.4%	+69.1%	+21.2%	-1.2%

Table 2: Accuracy comparison of forgetting and standard PLMs on XNLI (table continued). On average, forgetting PLMs achieve a 21.2% relative gain in accuracy compared to standard PLMs across the languages tested, where averaged relative gain = $\frac{\sum_{x \in \{\text{languages}\}} \text{Relative Gain of } x}{\#\text{Languages}}$.

10K warm-up updates. Checkpoints were saved every 500 updates and we always choose the last pretraining checkpoint where possible for optimal performance. For forgetting pretraining, we chose the checkpoint corresponding to the best validation perplexity since the last checkpoint might have token embeddings reset. We set the frequency of forgetting $K = 1000$ and used a clip-norm of 0.5.

During the **language adapt** stage, we kept most of the hyper-parameters the same as for pretraining. We finetuned the token embedding layer while keeping the others frozen, as described in Section 2. Note that *no* forgetting happens during this stage because we want the models to learn the new languages as well as possible. In the **task adapt** stage, both models were finetuned for 10 epochs on the English task data, specifically MultiNLI [Williams et al., 2018] for the NLI task and SQUAD [Rajpurkar et al., 2016] for the QA task. After the **assemble** stage, we evaluate the zero-shot performance of the assembled model on XNLI [Conneau et al., 2018], a cross-lingual NLI task, along with XQuAD [Artetxe et al., 2020] and MLQA [Lewis et al., 2020], two cross-lingual QA tasks. We report the NLI accuracy and QA F1 on the test sets.

Our experiments were implemented using fairseq [Ott et al., 2019]. The pretraining and language adaptation experiments were conducted on 32 Tesla V100 GPUs (each with 32 GB memory) and took approximately 24-36 hours to complete. The time taken for both stages were quite close to each other even though the latter only involved tuning the embeddings. This demonstrates the importance of reducing the computational cost of the language adaptation stage.

Differing from prior work [Artetxe et al., 2020, Marchisio et al., 2022], we focus on **language adapt** in low-data regimes. We simulate low-resources scenarios by limiting the adaptation data for each downstream language to only 5M subword tokens from CC100. This is in contrast with conventional setups, where all the tokens in the corresponding languages in CC100 are used for language adaptation. As Table 6 shows, such setups consume several orders of magnitude more data than our 5M-token setup; for instance, the Swahili CC100 subset contains 345M tokens, roughly 69 times larger than our corpus, and the Russian subset contains 34.9B tokens, roughly 6,980 times larger. Therefore, PLMs that can successfully learn new languages with rich data under traditional setups may struggle to do so with our limited 5M-token corpus.

4.2 Forgetting PLMs Work Better in Low-Data Regimes (RQ1)

Standard PLMs struggle in low-data language adaptation, dropping from 86.1 English NLI accuracy to just 53.3 average accuracy on XNLI with limited 5M token adaptation data. Compared to prior work which uses full data from Wikipedia [Artetxe et al., 2020] or from CC100 [Marchisio et al., 2022], the average accuracy on XNLI drops about 18% (from 66.8/66.3 to 53.3). This indicates standard PLMs are not coping well with the low-data regime. In contrast, forgetting PLMs achieve decent 62.7 average XNLI accuracy, a +21.2% relative gain over standard PLMs, as shown in Table 2.

Forgetting PLMs also outperform standard PLMs on MLQA and XQuAD, with average F1 relative gains of +33.8% and +60.9% across languages, as respectively demonstrated in Table 3 and Table 4. Across NLI and QA tasks, forgetting PLMs consistently surpass standard PLMs in low-data regimes.

Method	es	vi	de	zh	hi	ar	Avg	en
Standard	49.4	38.3	45.3	34.1	17.7	20.8	34.3	78.9
Forgetting	55.3	45.0	53.4	43.0	28.8	34.7	43.4	78.3
Relative Gain	+12.0%	+17.6%	+17.8%	+26.2%	+62.5%	+67.0%	+33.8%	-0.8%

Table 3: F1-score comparison of forgetting and standard PLMs on MLQA. On average, forgetting PLMs achieve a 33.8% relative gain in F1 compared to standard PLMs across the languages tested, where averaged relative gain = $\frac{\sum_{x \in \{\text{languages}\}} \text{Relative Gain of } x}{\#\text{Languages}}$.

Method	vi	es	ru	de	el	zh	hi	ar	th	tr	Avg
Standard	49.7	57.7	49.4	50.9	48.5	32.4	21.4	22.2	15.4	13.0	36.1
Forgetting	52.9	64.6	56.5	60.9	59.9	43.7	33.3	38.7	38.4	41.4	49.0
Relative Gain	+6.4%	+12.0%	+14.5%	+19.7%	+23.6%	+34.6%	+55.8%	+74.2%	+149.7%	+218.8%	+60.9%

Table 4: F1-score comparison of forgetting and standard PLMs on XQuAD. On average, forgetting PLMs achieve a 60.9% relative gain in F1 compared to standard PLMs across the languages tested, where averaged relative gain = $\frac{\sum_{x \in \{\text{languages}\}} \text{Relative Gain of } x}{\#\text{Languages}}$.

Why do forgetting PLMs handle the low-data regime better? We hypothesize this is because forgetting PLMs are more robust to different embedding initializations. They encode more universal knowledge in the transformer body. Standard PLMs may encode more “shortcut” knowledge relying on certain embedding initializations. In low data, standard PLMs cannot adjust embeddings towards shortcut routes without access to enough data. Forgetting PLMs do not rely on shortcuts so perform better.

4.3 Forgetting PLMs Learn New Languages with Fewer Parameter Updates (RQ2)

We are also interested in how quickly forgetting PLMs and standard PLMs can learn new languages. Figure 5 summarizes adaptation curves on XNLI, MLQA and XQuAD, with each point representing the averaged performance across all languages. In just 5K steps (4% of full adaptation), forgetting PLMs reach 57.8 accuracy on XNLI while standard PLMs struggle at random guessing levels of 37.2. Similar trends hold for MLQA and XQuAD. After 5K steps, forgetting PLMs achieve 92% of their full performance on XQuAD versus just 53% for standard PLMs (see the last plot in Figure 5).

Why do forgetting PLMs converge faster? We hypothesize it is because periodical embedding resetting forces the body to gradually locate itself on a particular manifold, where it can easily cooperate with new embeddings. This makes the body encourage larger embedding updates when adapting to new languages. Active forgetting simulates language switching during pretraining² introducing diversity without new data. This allows faster adaptation to real new languages.

4.4 Languages That Are Distant To English Benefit Most From Forgetting PLMs (RQ3)

Up to this point, we have primarily presented the averaged performance. In this section, we delve into a detailed comparison of language-specific performance between forgetting PLMs and standard PLMs on XNLI, MLQA, and XQuAD. To gain a deeper insight into which languages benefit the most from the use of forgetting, we present the relative performance changes in Figure 6 for XNLI and MLQA. The results for XQuAD can be found in Figure 8 in the appendix. Across the spectrum of languages (Table 5), we observe that forgetting provides greater benefits for languages distant to the pretraining language (English) in terms of language family, script and morphology. Specifically, forgetting brings large relative gains for languages such as *Arabic*, *Hindi*, *Thai*, *Turkish*, and *Urdu* compared to closer languages like *German*. Script seems important - forgetting helps Vietnamese and Swahili less despite their distance from English, likely due to the shared Latin script. Examining adaptation curves within the first 5K steps, forgetting PLMs reach substantially superior performance over standard PLMs for almost all languages except Urdu, while standard PLMs struggle at random guess levels (see Figure 7 and Appendix D). This demonstrates forgetting PLMs’ ability to efficiently adapt to new languages, particularly dissimilar ones, in low-data settings.

²Precisely, it simulates vocabulary swappings, causing drastic changes to the input of the body.

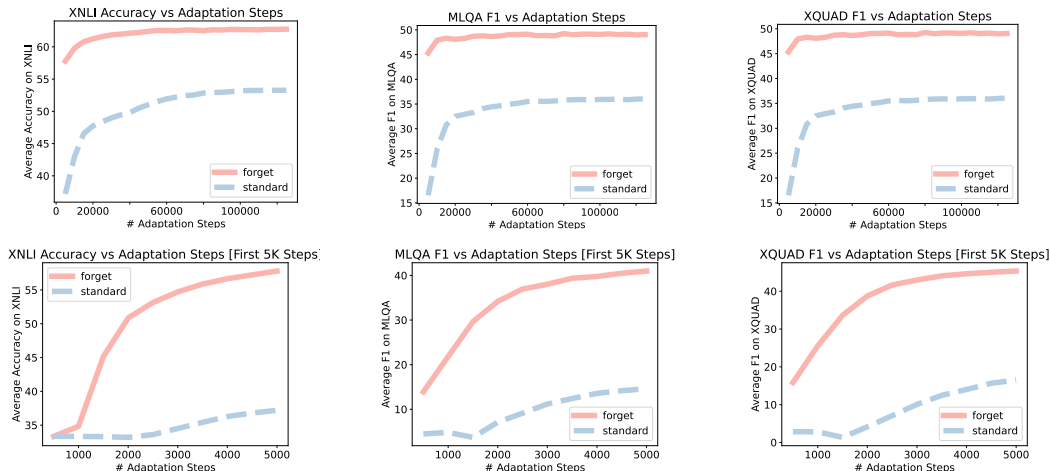


Figure 5: Adaptation curves on XNLI, MLQA, and XQuAD. Numbers aggregated across languages. The first row contains the full adaptation curves, which comprises 125K adaptation steps. The second row contains the zoom-in versions of curves for the first 5K adaptation steps. Forgetting PLMs converge faster than standard PLMs; for instance, on XQuAD (the last plot), forgetting PLMs reach 92% of their final performance within 5K updates, while standard PLMs only reached 53% of their final performance at that point.

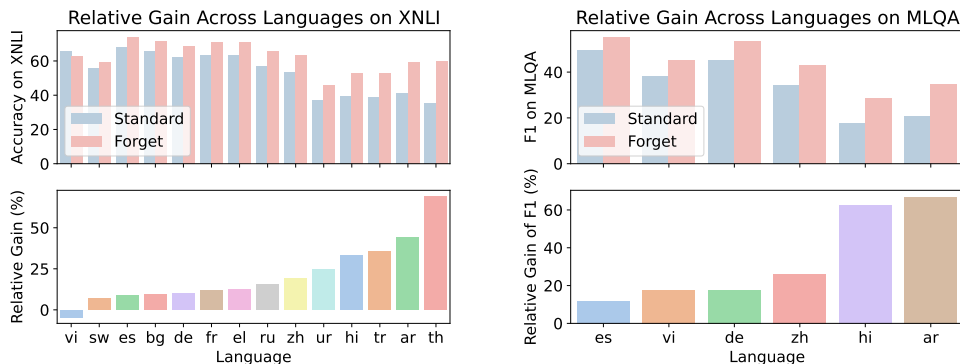


Figure 6: Relative gains of forgetting PLMs over standard PLMs across languages. Forgetting yields substantial relative gains for languages like Arabic, Hindi, Thai, Turkish, and Urdu. However, for languages closely related to English, such as German, the relative gains from forgetting are modest.

5 Related Work

5.1 Forgetting and its Positive Roles

The common perception of forgetting is that it implies weak memory and a loss of acquired knowledge, thus it is often regarded as a sign of *un-intelligence* or an undesirable property. In neural networks, *catastrophic forgetting* [McCloskey and Cohen, 1989, Ratcliff, 1990, Kirkpatrick et al., 2017] is portrayed as a forgetting phenomenon where neural networks lose the ability to predict old patterns after new inputs alter their weights. Forgetting in this context has negative consequences, as the new knowledge overwrites the old. Plenty of prior research strives to overcome catastrophic forgetting and enable continual learning [Schmidhuber, 2013, Kirkpatrick et al., 2017, Lopez-Paz and Ranzato, 2017, Shin et al., 2017, Schwarz et al., 2018, Mallya and Lazebnik, 2018, Parisi et al., 2019, Rolnick et al., 2019, Beaulieu et al., 2020, Veniat et al., 2020, Gaya et al., 2023, Khetarpal et al., 2022].

Our work differs from the above ones in that our subject is *intentional forgetting* rather than passive forgetting and its associated negative impact. To put it in another way, we seek to understand how

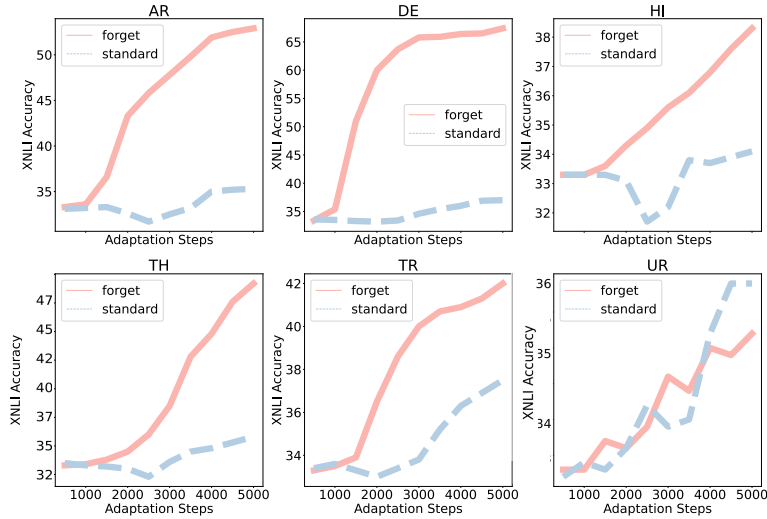


Figure 7: Adaptation curves on XNLI within 5K updates for individual languages: Bulgaria, Greek, Spanish, French, Russian, Swahili, Vietnamese and Chinese. For all languages except Urdu, the forgetting PLMs converge faster than the standard PLMs during the language adaptation stage.

forgetting – if purposely incorporated as an active process during training – might *help* new learning. Similar positive roles of forgetting have been discussed in the literature. Specifically, [Pastötter et al. \[2008\]](#) demonstrate forgetting enhances the learning of new information by resetting the encoding process and holding the attention at high levels; [Levy et al. \[2007\]](#) show that it helps second language acquisition by inhibiting the native language; [Barrett and Zollman \[2009\]](#) find it promote the emergence of an optimal language by preventing partial success from reinforce sub-optimal practice. [Nørby \[2015\]](#) further suggests forgetting serves adaptive functions, helping people regulate emotions, acquiring knowledge and staying attuned to the context. More recently [Anderson and Hulbert \[2021\]](#) reviews evidence on active forgetting by prefrontal control and shows how it can adapt the memory to suit either emotional or cognitive goals.

5.2 Forgetting Via Partial Neural Weights Reset

In neural networks, forgetting can be instantiated in many forms. A simple way is to reset subsets of parameters before the next round of learning. Iterations of such resetting have been shown to benefit generalization with low compute and low data for computer vision tasks [\[Frankle and Carbin, 2019, Alabdulmohsin et al., 2021, Taha et al., 2021, Ramkumar et al., 2023\]](#). More recently, [Zhou et al. \[2022\]](#) demonstrate a similar forgetting strategy helps image classification and language emergence. Closely linked to our method, [Chen et al. \[2022\]](#) forget node embeddings in order to truncate infinite message-passing among nodes and thereby aid new graph reasoning with new nodes. Our work uses similar forgetting mechanism over token embeddings, improving new language reasoning with new tokens. As far as we know, *we are the first to bring forgetting into pretraining and demonstrate that forgetting pretraining boosts linguistic plasticity*. A relevant thread in reinforcement learning (RL) research studies the plasticity loss phenomenon [\[Lyle et al., 2023, Nikishin et al., 2023\]](#). Recent work explores similar forgetting approaches to improve plasticity. [Igl et al. \[2021\]](#) periodically reset the current policy by distilling it into a reinitialized network throughout training. Intuitively, this releases network capacity storing suboptimal policies and opens up space for the the yet-to-be-discovered optimal (final) policy. Simpler methods just reset an agent’s last layers [\[Nikishin et al., 2022\]](#), preventing overfitting to early experiences and *primacy bias*. Resetting parameters also improves sample efficiency by allowing more updates per environment interaction [\[D’Oro et al., 2023\]](#).

5.3 Making Pretrained Language Models Multilingual

Pretraining on multilingual data makes PLMs multilingual [\[Conneau et al., 2020\]](#) but has downsides like needing large multilingual corpus with appropriate mixing, potential interference among lan-

guages, and difficulty of covering all languages. Alternatively, the line of research on cross-lingual transfer makes PLMs multilingual by extending English-only PLMs to other languages. [Artetxe et al., 2020] demonstrate possibility of such extension by relearning the embedding layer with unsupervised data from the new language. [Marchisio et al., 2022] further increase computational efficiency using a mini-model proxy. [Liu et al., 2023a] use a similar partial reset-reinit approach in vision-language settings. Approaches based on adapters and sparse finetuning have also been proposed [Pfeiffer et al., 2020, 2022, 2021, Ansell et al., 2022]. Adapters are bottleneck layers (usually placed after the feedforward layers) that add extra capacity when adapting to a different task or language. Our proposed forgetting mechanism can be applied to adapter-based methods as we can allow forgetting to happen in the adapter layers. The current choice of forgetting embeddings keeps the architecture intact and incurs no additional hyperparameter tuning, allowing us to understand the fundamental capability of forgetting pretraining.

6 Conclusion & Future work

6.1 Conclusions

While forgetting is usually perceived as negative, recent work points out that it can also be beneficial in certain cases, particularly for quickly learning new tasks, training in non-stationary environments [Igl et al., 2021, Nikishin et al., 2022, D’Oro et al., 2023] and improving sample efficiency [Taha et al., 2021, Zhou et al., 2022]. Joining this line of work, our paper demonstrates that forgetting techniques can improve pretrained language models by imbuing them with more linguistic plasticity. Specifically, our proposed *active forgetting* mechanism can create PLMs that are easier to rewire for new lingual spaces. Experiments with RoBERTa show that models pretrained via active forgetting can better learn from small amounts of data while also enjoying faster convergence during language adaptation, particularly for languages distant from English.

Going beyond language adaptation, we argue that PLMs with more plasticity are a promising direction for future research, as they allow easier adaptation to various tasks, domains, languages and can evolve faster as the real world changes. Unlike symbolic methods, such as knowledge graphs, which can easily rewire a fact by modifying the corresponding knowledge triplet, current static PLMs are harder to rewire since changing one fact via updating model weights may disrupt multiple other facts without substantial post-hoc intervention. Improving the rewirability via forgetting pretraining thus can be seen as one way of imbuing PLMs with similar benefits as symbolic methods (making the resulted model more controllable i.e. can be modified with tiny cost), complementing the line of post-hoc model editing research [Mitchell et al., 2021, 2022].

6.2 Limitations

Our work uses the simplest forgetting approach - directly resetting embeddings to random initialization. Advanced techniques like gradually injecting noise could be explored. We focus on masked language modeling pretraining with language-specific tokenizers. Applying active forgetting to auto-regressive LMs, other pretraining methods (e.g. deberta pretraining [He et al., 2021b]), and various tokenization is promising future work. More broadly, current large language models need more plasticity to expand across tools, tasks, and domains. Our work takes an initial step, showing directly resetting embeddings can significantly improve model plasticity. Further research on more sophisticated forgetting techniques during pretraining could unlock additional gains.

On the theory front, potential connections can be made between forgetting and meta-learning [Schaul and Schmidhuber, 2010, Thrun and Pratt, 2012, Andrychowicz et al., 2016, Finn et al., 2017] since both attempt to learn solutions that can quickly adapt themselves to new inputs. Another possible theoretical explanation for why active forgetting works so well might be related to the flatness of the solution in the loss landscape [Alabdulmohsin et al., 2021]. Flatter minima tend to enjoy better generalization [Liu et al., 2023b]. Thus, it might be worthwhile to study the flatness of the transformer body during the forgetting pretraining.

Acknowledgments and Disclosure of Funding

We would like to thank our reviewers for their valuable suggestions. We are also grateful to those who engaged in interesting discussions during the project, including Pasquale Minervini, Xuanli He, Jiayi Wang, Yuxiang Wu, Hila Gonen, Dieuwke Hupkes, Fabio Petroni, Naila Murray, Alexis Thual, Nicola Cancedda, Yingchen Xu, and Hubert Jacob Banville. Yihong would like to express her thanks to the FAIR-UCL PhD program for generously funding her PhD. David Adelani acknowledges the support of DeepMind Academic Fellowship programme.

References

- David Ifeoluwa Adelani, Jade Abbott, Graham Neubig, Daniel D’souza, Julia Kreutzer, Constantine Lignos, Chester Palen-Michel, Happy Buzaaba, Shruti Rijhwani, Sebastian Ruder, et al. Masakhaner: Named entity recognition for african languages. *Transactions of the Association for Computational Linguistics*, 9:1116–1131, 2021.
- David Ifeoluwa Adelani, Graham Neubig, Sebastian Ruder, Shruti Rijhwani, Michael Beukman, Chester Palen-Michel, Constantine Lignos, Jesujoba O Alabi, Shamsuddeen H Muhammad, Peter Nabende, et al. Masakhaner 2.0: Africa-centric transfer learning for named entity recognition. In *2022 Conference on Empirical Methods in Natural Language Processing (EMNLP 2022), Abu Dhabi, United Arab Emirates, December 7-11, 2022*, pages 4488–4508. Association for Computational Linguistics (ACL), 2022.
- Ibrahim Alabdulmohsin, Hartmut Maennel, and Daniel Keysers. The impact of reinitialization on generalization in convolutional neural networks. *arXiv preprint arXiv:2109.00267*, 2021.
- Jesujoba O. Alabi, David Ifeoluwa Adelani, Marius Mosbach, and Dietrich Klakow. Adapting pre-trained language models to African languages via multilingual adaptive fine-tuning. In *Proceedings of the 29th International Conference on Computational Linguistics*, pages 4336–4349, Gyeongju, Republic of Korea, October 2022. International Committee on Computational Linguistics. URL <https://aclanthology.org/2022.coling-1.382>.
- Michael C. Anderson and Justin C. Hulbert. Active forgetting: Adaptation of memory by prefrontal control. *Annual Review of Psychology*, 72(1):1–36, 2021. doi: 10.1146/annurev-psych-072720-094140. URL <https://doi.org/10.1146/annurev-psych-072720-094140>. PMID: 32928060.
- Marcin Andrychowicz, Misha Denil, Sergio Gomez, Matthew W Hoffman, David Pfau, Tom Schaul, Brendan Shillingford, and Nando De Freitas. Learning to learn by gradient descent by gradient descent. *Advances in neural information processing systems*, 29, 2016.
- Alan Ansell, Edoardo Ponti, Anna Korhonen, and Ivan Vulić. Composable sparse fine-tuning for cross-lingual transfer. In *Proceedings of the 60th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, pages 1778–1796, 2022.
- Mikel Artetxe, Sebastian Ruder, and Dani Yogatama. On the cross-lingual transferability of monolingual representations. In *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics*, pages 4623–4637, 2020.
- Jeffrey Barrett and Kevin JS Zollman. The role of forgetting in the evolution and learning of language. *Journal of Experimental & Theoretical Artificial Intelligence*, 21(4):293–309, 2009.
- Shawn Beaulieu, Lapo Frati, Thomas Miconi, Joel Lehman, Kenneth O Stanley, Jeff Clune, and Nick Cheney. Learning to continually learn. *arXiv preprint arXiv:2002.09571*, 2020.
- Tom Brown, Benjamin Mann, Nick Ryder, Melanie Subbiah, Jared D Kaplan, Prafulla Dhariwal, Arvind Neelakantan, Pranav Shyam, Girish Sastry, Amanda Askell, Sandhini Agarwal, Ariel Herbert-Voss, Gretchen Krueger, Tom Henighan, Rewon Child, Aditya Ramesh, Daniel Ziegler, Jeffrey Wu, Clemens Winter, Chris Hesse, Mark Chen, Eric Sigler, Mateusz Litwin, Scott Gray, Benjamin Chess, Jack Clark, Christopher Berner, Sam McCandlish, Alec Radford, Ilya Sutskever, and Dario Amodei. Language models are few-shot

- learners. In H. Larochelle, M. Ranzato, R. Hadsell, M.F. Balcan, and H. Lin, editors, *Advances in Neural Information Processing Systems*, volume 33, pages 1877–1901. Curran Associates, Inc., 2020. URL https://proceedings.neurips.cc/paper_files/paper/2020/file/1457c0d6bfc4967418bfb8ac142f64a-Paper.pdf.
- Yihong Chen, Pushkar Mishra, Luca Franceschi, Pasquale Minervini, Pontus Stenetorp, and Sebastian Riedel. Refactor gnns: Revisiting factorisation-based models from a message-passing perspective. In *Advances in Neural Information Processing Systems*, 2022.
- Alexis Conneau, Ruty Rinott, Guillaume Lample, Adina Williams, Samuel Bowman, Holger Schwenk, and Veselin Stoyanov. XNLI: Evaluating cross-lingual sentence representations. In *Proceedings of the 2018 Conference on Empirical Methods in Natural Language Processing*, pages 2475–2485, Brussels, Belgium, October–November 2018. Association for Computational Linguistics. doi: 10.18653/v1/D18-1269. URL <https://aclanthology.org/D18-1269>.
- Alexis Conneau, Kartikay Khandelwal, Naman Goyal, Vishrav Chaudhary, Guillaume Wenzek, Francisco Guzmán, Edouard Grave, Myle Ott, Luke Zettlemoyer, and Veselin Stoyanov. Un-supervised cross-lingual representation learning at scale. In *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics*, pages 8440–8451, Online, July 2020. Association for Computational Linguistics. doi: 10.18653/v1/2020.acl-main.747. URL <https://aclanthology.org/2020.acl-main.747>.
- Jacob Devlin, Ming-Wei Chang, Kenton Lee, and Kristina Toutanova. BERT: Pre-training of deep bidirectional transformers for language understanding. In *Proceedings of the 2019 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, Volume 1 (Long and Short Papers)*, pages 4171–4186, Minneapolis, Minnesota, June 2019. Association for Computational Linguistics. doi: 10.18653/v1/N19-1423. URL <https://aclanthology.org/N19-1423>.
- Pierluca D’Oro, Max Schwarzer, Evgenii Nikishin, Pierre-Luc Bacon, Marc G Bellemare, and Aaron Courville. Sample-efficient reinforcement learning by breaking the replay ratio barrier. In *The Eleventh International Conference on Learning Representations*, 2023. URL <https://openreview.net/forum?id=OpC-9aBBVJe>.
- Abteen Ebrahimi, Manuel Mager, Arturo Oncevay, Vishrav Chaudhary, Luis Chiruzzo, Angela Fan, John Ortega, Ricardo Ramos, Annette Rios Gonzales, Ivan Meza-Ruiz, et al. Americasnli: Evaluating zero-shot natural language understanding of pretrained multilingual models in truly low-resource languages. In *Proceedings of the 60th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, pages 6279–6299, 2022.
- Chelsea Finn, Pieter Abbeel, and Sergey Levine. Model-agnostic meta-learning for fast adaptation of deep networks. In *International conference on machine learning*, pages 1126–1135. PMLR, 2017.
- Jonathan Frankle and Michael Carbin. The lottery ticket hypothesis: Finding sparse, trainable neural networks. In *International Conference on Learning Representations*, 2019. URL <https://openreview.net/forum?id=rJl-b3RcF7>.
- Jean-Baptiste Gaya, Thang Doan, Lucas Caccia, Laure Soulier, Ludovic Denoyer, and Roberta Raileanu. Building a subspace of policies for scalable continual learning. In *The Eleventh International Conference on Learning Representations*, 2023. URL <https://openreview.net/forum?id=UKr0MwZM6fL>.
- Suchin Gururangan, Ana Marasović, Swabha Swayamdipta, Kyle Lo, Iz Beltagy, Doug Downey, and Noah A Smith. Don’t stop pretraining: Adapt language models to domains and tasks. In *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics*, pages 8342–8360, 2020.
- Pengcheng He, Jianfeng Gao, and Weizhu Chen. Deberv3: Improving deberta using electra-style pre-training with gradient-disentangled embedding sharing, 2021a.
- Pengcheng He, Xiaodong Liu, Jianfeng Gao, and Weizhu Chen. Deberta: Decoding-enhanced bert with disentangled attention. In *International Conference on Learning Representations*, 2021b. URL <https://openreview.net/forum?id=XPZTaotutsD>.

- Danny Hernandez, Jared Kaplan, Tom Henighan, and Sam McCandlish. Scaling laws for transfer. *arXiv preprint arXiv:2102.01293*, 2021.
- Edward J Hu, Phillip Wallis, Zeyuan Allen-Zhu, Yuanzhi Li, Shean Wang, Lu Wang, Weizhu Chen, et al. Lora: Low-rank adaptation of large language models. In *International Conference on Learning Representations*, 2021.
- Maximilian Igl, Gregory Farquhar, Jelena Luketina, Wendelin Boehmer, and Shimon Whiteson. Transient non-stationarity and generalisation in deep reinforcement learning. In *International Conference on Learning Representations*, 2021. URL <https://openreview.net/forum?id=Qun8fv4qSby>.
- Jared Kaplan, Sam McCandlish, Tom Henighan, Tom B Brown, Benjamin Chess, Rewon Child, Scott Gray, Alec Radford, Jeffrey Wu, and Dario Amodei. Scaling laws for neural language models. *arXiv preprint arXiv:2001.08361*, 2020.
- Khimya Khetarpal, Matthew Riemer, Irina Rish, and Doina Precup. Towards continual reinforcement learning: A review and perspectives. *Journal of Artificial Intelligence Research*, 75:1401–1476, 2022.
- James Kirkpatrick, Razvan Pascanu, Neil Rabinowitz, Joel Veness, Guillaume Desjardins, Andrei A Rusu, Kieran Milan, John Quan, Tiago Ramalho, Agnieszka Grabska-Barwinska, et al. Overcoming catastrophic forgetting in neural networks. *Proceedings of the national academy of sciences*, 114(13):3521–3526, 2017.
- Taku Kudo and John Richardson. Sentencepiece: A simple and language independent subword tokenizer and detokenizer for neural text processing. In *Proceedings of the 2018 Conference on Empirical Methods in Natural Language Processing: System Demonstrations*, pages 66–71, 2018.
- Benjamin J Levy, Nathan D McVeigh, Alejandra Marful, and Michael C Anderson. Inhibiting your native language: The role of retrieval-induced forgetting during second-language acquisition. *Psychological Science*, 18(1):29–34, 2007.
- Patrick Lewis, Barlas Oguz, Ruty Rinott, Sebastian Riedel, and Holger Schwenk. Mlqa: Evaluating cross-lingual extractive question answering. In *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics*, pages 7315–7330, 2020.
- Chen Liu, Jonas Pfeiffer, Anna Korhonen, Ivan Vulić, and Iryna Gurevych. Delving deeper into cross-lingual visual question answering. In *Findings of the Association for Computational Linguistics: EACL 2023*, pages 2408–2423, 2023a.
- Hong Liu, Sang Michael Xie, Zhiyuan Li, and Tengyu Ma. Same pre-training loss, better downstream: Implicit bias matters for language models. In *Proceedings of the 40th International Conference on Machine Learning*, 2023b.
- Yinhan Liu, Myle Ott, Naman Goyal, Jingfei Du, Mandar Joshi, Danqi Chen, Omer Levy, Mike Lewis, Luke Zettlemoyer, and Veselin Stoyanov. Roberta: A robustly optimized BERT pretraining approach. *CoRR*, abs/1907.11692, 2019. URL <http://arxiv.org/abs/1907.11692>.
- David Lopez-Paz and Marc’Aurelio Ranzato. Gradient episodic memory for continual learning. *Advances in neural information processing systems*, 30, 2017.
- Clare Lyle, Zeyu Zheng, Evgenii Nikishin, Bernardo Avila Pires, Razvan Pascanu, and Will Dabney. Understanding plasticity in neural networks. In Andreas Krause, Emma Brunskill, Kyunghyun Cho, Barbara Engelhardt, Sivan Sabato, and Jonathan Scarlett, editors, *Proceedings of the 40th International Conference on Machine Learning*, volume 202 of *Proceedings of Machine Learning Research*, pages 23190–23211. PMLR, 23–29 Jul 2023. URL <https://proceedings.mlr.press/v202/lyle23b.html>.
- Arun Mallya and Svetlana Lazebnik. Packnet: Adding multiple tasks to a single network by iterative pruning. In *Proceedings of the IEEE conference on Computer Vision and Pattern Recognition*, pages 7765–7773, 2018.

- Kelly Marchisio, Patrick Lewis, Yihong Chen, and Mikel Artetxe. Mini-model adaptation: Efficiently extending pretrained models to new languages via aligned shallow training. *arXiv preprint arXiv:2212.10503*, 2022.
- Michael McCloskey and Neal J. Cohen. Catastrophic interference in connectionist networks: The sequential learning problem. volume 24 of *Psychology of Learning and Motivation*, pages 109–165. Academic Press, 1989. doi: [https://doi.org/10.1016/S0079-7421\(08\)60536-8](https://doi.org/10.1016/S0079-7421(08)60536-8). URL <https://www.sciencedirect.com/science/article/pii/S0079742108605368>.
- Eric Mitchell, Charles Lin, Antoine Bosselut, Chelsea Finn, and Christopher D Manning. Fast model editing at scale. In *International Conference on Learning Representations*, 2021.
- Eric Mitchell, Charles Lin, Antoine Bosselut, Christopher D Manning, and Chelsea Finn. Memory-based model editing at scale. In *International Conference on Machine Learning*, pages 15817–15831. PMLR, 2022.
- Evgenii Nikishin, Max Schwarzer, Pierluca D’Oro, Pierre-Luc Bacon, and Aaron Courville. The primacy bias in deep reinforcement learning. In *International Conference on Machine Learning*, pages 16828–16847. PMLR, 2022.
- Evgenii Nikishin, Junhyuk Oh, Georg Ostrovski, Clare Lyle, Razvan Pascanu, Will Dabney, and Andre Barreto. Deep reinforcement learning with plasticity injection. In *Workshop on Reincarnating Reinforcement Learning at ICLR 2023*, 2023. URL <https://openreview.net/forum?id=O9cJADBZT1>.
- Simon Nørby. Why forget? on the adaptive value of memory loss. *Perspectives on Psychological Science*, 10(5):551–578, 2015. doi: [10.1177/1745691615596787](https://doi.org/10.1177/1745691615596787). URL <https://doi.org/10.1177/1745691615596787>. PMID: 26385996.
- Myle Ott, Sergey Edunov, Alexei Baevski, Angela Fan, Sam Gross, Nathan Ng, David Grangier, and Michael Auli. fairseq: A fast, extensible toolkit for sequence modeling. In *Proceedings of the 2019 Conference of the North American Chapter of the Association for Computational Linguistics (Demonstrations)*, pages 48–53, 2019.
- German I Parisi, Ronald Kemker, Jose L Part, Christopher Kanan, and Stefan Wermter. Continual lifelong learning with neural networks: A review. *Neural networks*, 113:54–71, 2019.
- Bernhard Pastötter, Karl-Heinz Bäuml, and Simon Hanslmayr. Oscillatory brain activity before and after an internal context change—evidence for a reset of encoding processes. *NeuroImage*, 43(1): 173–181, 2008.
- Jonas Pfeiffer, Ivan Vulić, Iryna Gurevych, and Sebastian Ruder. MAD-X: An Adapter-Based Framework for Multi-Task Cross-Lingual Transfer. In *Proceedings of the 2020 Conference on Empirical Methods in Natural Language Processing (EMNLP)*, pages 7654–7673, Online, November 2020. Association for Computational Linguistics. doi: [10.18653/v1/2020.emnlp-main.617](https://doi.org/10.18653/v1/2020.emnlp-main.617). URL <https://aclanthology.org/2020.emnlp-main.617>.
- Jonas Pfeiffer, Ivan Vulić, Iryna Gurevych, and Sebastian Ruder. Unks everywhere: Adapting multilingual language models to new scripts. In *Proceedings of the 2021 Conference on Empirical Methods in Natural Language Processing*, pages 10186–10203, 2021.
- Jonas Pfeiffer, Naman Goyal, Xi Lin, Xian Li, James Cross, Sebastian Riedel, and Mikel Artetxe. Lifting the curse of multilinguality by pre-training modular transformers. In *Proceedings of the 2022 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies*, pages 3479–3495, 2022.
- Alec Radford and Karthik Narasimhan. Improving language understanding by generative pre-training. 2018.
- Pranav Rajpurkar, Jian Zhang, Konstantin Lopyrev, and Percy Liang. Squad: 100,000+ questions for machine comprehension of text. In *Proceedings of the 2016 Conference on Empirical Methods in Natural Language Processing*, pages 2383–2392, 2016.

- Vijaya Raghavan T Ramkumar, Elahe Arani, and Bahram Zonooz. Learn, unlearn and relearn: An online learning paradigm for deep neural networks. *Transactions on Machine Learning Research*, 2023. ISSN 2835-8856. URL <https://openreview.net/forum?id=WN1O2MJDST>.
- Roger Ratcliff. Connectionist models of recognition memory: constraints imposed by learning and forgetting functions. *Psychological review*, 97(2):285, 1990.
- David Rolnick, Arun Ahuja, Jonathan Schwarz, Timothy Lillicrap, and Gregory Wayne. Experience replay for continual learning. *Advances in Neural Information Processing Systems*, 32, 2019.
- Tom Schaul and Jürgen Schmidhuber. Metalearning. *Scholarpedia*, 5(6):4650, 2010.
- Jürgen Schmidhuber. Powerplay: Training an increasingly general problem solver by continually searching for the simplest still unsolvable problem. *Frontiers in psychology*, 4:313, 2013.
- Jonathan Schwarz, Wojciech Czarnecki, Jelena Luketina, Agnieszka Grabska-Barwinska, Yee Whye Teh, Razvan Pascanu, and Raia Hadsell. Progress & compress: A scalable framework for continual learning. In *International conference on machine learning*, pages 4528–4537. PMLR, 2018.
- Hanul Shin, Jung Kwon Lee, Jaehong Kim, and Jiwon Kim. Continual learning with deep generative replay. *Advances in neural information processing systems*, 30, 2017.
- Ahmed Taha, Abhinav Shrivastava, and Larry S Davis. Knowledge evolution in neural networks. In *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition*, pages 12843–12852, 2021.
- Y. Tang, C. Tran, Xian Li, Peng-Jen Chen, Naman Goyal, Vishrav Chaudhary, Jiatao Gu, and Angela Fan. Multilingual translation with extensible multilingual pretraining and finetuning. *ArXiv*, abs/2008.00401, 2020. URL <https://api.semanticscholar.org/CorpusID:220936592>.
- Sebastian Thrun and Lorien Pratt. *Learning to learn*. Springer Science & Business Media, 2012.
- Hugo Touvron, Thibaut Lavril, Gautier Izacard, Xavier Martinet, Marie-Anne Lachaux, Timothée Lacroix, Baptiste Rozière, Naman Goyal, Eric Hambro, Faisal Azhar, Aurelien Rodriguez, Armand Joulin, Edouard Grave, and Guillaume Lample. Llama: Open and efficient foundation language models, 2023.
- Tom Veniat, Ludovic Denoyer, and Marc’ Aurelio Ranzato. Efficient continual learning with modular networks and task-driven priors. *arXiv preprint arXiv:2012.12631*, 2020.
- Laura Weidinger, John Mellor, Maribeth Rauh, Conor Griffin, Jonathan Uesato, Po-Sen Huang, Myra Cheng, Mia Glaese, Borja Balle, Atoosa Kasirzadeh, Zac Kenton, Sasha Brown, Will Hawkins, Tom Stepleton, Courtney Biles, Abeba Birhane, Julia Haas, Laura Rimell, Lisa Anne Hendricks, William Isaac, Sean Legassick, Geoffrey Irving, and Iason Gabriel. Ethical and social risks of harm from language models. *CoRR*, abs/2112.04359, 2021. URL <https://arxiv.org/abs/2112.04359>.
- Laura Weidinger, Jonathan Uesato, Maribeth Rauh, Conor Griffin, Po-Sen Huang, John Mellor, Amelia Glaese, Myra Cheng, Borja Balle, Atoosa Kasirzadeh, et al. Taxonomy of risks posed by language models. In *2022 ACM Conference on Fairness, Accountability, and Transparency*, pages 214–229, 2022.
- Adina Williams, Nikita Nangia, and Samuel Bowman. A broad-coverage challenge corpus for sentence understanding through inference. In *Proceedings of the 2018 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, Volume 1 (Long Papers)*, pages 1112–1122, 2018.
- Hattie Zhou, Ankit Vani, Hugo Larochelle, and Aaron Courville. Fortuitous forgetting in connectionist networks. In *International Conference on Learning Representations*, 2022.