

Scaling Down to Scale Up: A Guide to Parameter-Efficient Fine-Tuning

Vladislav Lialin

University of Massachusetts Lowell

VLIALIN@CS.UML.EDU *

Vijeta Deshpande

University of Massachusetts Lowell

VIJETA_DESHPANDE@STUDENT.UML.EDU

Xiaowei Yao

University of Massachusetts Lowell

XIAOWEI_YAO@STUDENT.UML.EDU

Anna Rumshisky

University of Massachusetts Lowell

ARUM@CS.UML.EDU

Amazon Alexa AI

Abstract

This paper presents a systematic overview of **parameter-efficient fine-tuning methods**, covering over 50 papers published between early 2019 and mid-2024. These methods aim to address the challenges of **fine-tuning large language models by training only a small subset of parameters**. We provide a taxonomy that covers a broad range of methods and present a detailed method comparison with a specific focus on real-life efficiency in fine-tuning multibillion-scale language models. We also conduct an extensive head-to-head experimental comparison of 15 diverse PEFT methods, evaluating their performance and efficiency on models up to 11B parameters. Our findings reveal that methods previously shown to surpass a strong LoRA baseline face difficulties in resource-constrained settings, where hyperparameter optimization is limited and the network is fine-tuned only for a few epochs. Finally, we provide a set of practical recommendations for using PEFT methods and outline potential future research directions.

Keywords: Parameter-Efficient Fine-Tuning, Large Language Models

1 Introduction

In October 2018, BERT Large (Devlin et al., 2019) with 350 million parameters was the biggest Transformer model (Vaswani et al., 2017) ever trained. At the time, contemporary hardware struggled to fine-tune this model. The section “Out-of-memory issues” on BERT’s GitHub¹ specifies the maximum batch size for BERT Large given 12Gb of GPU RAM and 512 tokens as **zero**. Five years in, publicly available models grew to 176 billion parameters (Scao et al., 2022; Zhang et al., 2022; Zeng et al., 2022), i.e. by a factor of 500. Published literature includes models up to 1 trillion parameters (Chowdhery et al., 2022; Shoyebi et al., 2019; Fedus et al., 2021). However, single-GPU

One thing that should be learned from the bitter lesson is the great power of general purpose methods, of methods that continue to scale with increased computation...

Rich Sutton, The Bitter Lesson

*. Correspondence to: vlad.lialin@gmail.com

RAM increased less than 10 times due to the high cost of HBM memory. Model size scales almost **two orders of magnitude quicker** than computational resources making fine-tuning the largest models to downstream tasks infeasible for most and impractical for everyone.

In-context learning (Radford et al., 2019) thus became the new normal, the standard way to pass downstream task training data to billion-scale language models. However, the limited context length imposed by the transformer architecture (Vaswani et al., 2017; Huang et al., 2018), the absence of ICL abilities in moderately large language models (Lu et al., 2023), the quadratic increase in computational cost with an increase in context length (or demonstrations in ICL) (Keles et al., 2023), and the sensitivity of ICL performance (Bertsch et al., 2024) present challenges in the utility, reliability, and efficiency of ICL. In cases where the model performs at par or better in the ICL setting compared to the fine-tuned model, fine-tuning is still a lucrative strategy due to the impractical inference cost of ICL (Bertsch et al., 2024). Thus, we, as a community of researchers and engineers, **need efficient ways to train on downstream task data.**

Parameter-efficient fine-tuning (PEFT) aims to resolve this problem by **only training a small set of parameters, which might be a subset of the existing model parameters or a set of newly added parameters.** These methods differ in parameter and memory efficiency, training speed, final model quality, and additional inference costs (if any).

In the last few years, more than a hundred PEFT papers have been published, with several studies (Ding et al., 2022) providing a good overview of the most popular methods, such as **Adapters** (Houlsby et al., 2019), **BitFit** (Ben-Zaken et al., 2021), **LoRA** (Hu et al., 2022), **Compacter** (Karimi Mahabadi et al., 2021), and **Soft Prompts** (Liu et al., 2021; Li and Liang, 2021).

Pfeiffer et al. (2023) presented a survey on modular deep learning, providing an overview of several similar methods from the perspective of modularity and multi-task inference. Our focus differs by concentrating on PEFT methods, specifically for fine-tuning large language models, where minimizing RAM consumption and training time without sacrificing performance is crucial.

This survey presents a systematic overview, comparison, and taxonomy of 30 parameter-efficient fine-tuning methods. Over the last year, research efforts have also focused on replicating the success of PEFT in the pre-training regime. Hence, we also discuss a few prominent methods that aim to achieve efficiency gains during pre-training. We discuss 30 methods in-depth, covering over 50 papers published from early 2019 to mid-2024. We highlight the current unresolved challenges in PEFT, including the limited theoretical understanding, the performance gap between PEFT and traditional fine-tuning, and reporting issues.

We conduct the most extensive experimental comparison of PEFT methods, evaluating 14 methods and their variations across five datasets and three model sizes (0.7B, 3B, and 11B). The study includes a detailed comparison of these methods' efficiency in terms of GPU memory consumption and throughput. Our findings reveal that methods previously shown to outperform LoRA struggle to do so in resource-constrained settings and exhibit high hyperparameter sensitivity in hybrid PEFT methods.

We found that Kronecker-based reparametrizations, while not enhancing memory efficiency compared to matrix-product counterparts, can improve training and inference speeds with efficient implementation. Surprisingly, Layer Norm tuning performs exceptionally well

1. github.com/google-research/bert

compared to most PEFT methods in our study. We also note a significant discrepancy between reported and actual trainable parameter counts in PEFT methods. This leads to unforeseen outcomes, such as the high computational costs of Prompt Tuning and Hybrid methods. Our code is available on Github².

In conclusion, we suggest several avenues for improvement, such as developing standardized PEFT benchmarks, conducting in-depth studies on hyperparameters and interpretability, exploring the difference in training dynamics of reparametrized neural networks, further improving training and inference efficiency of PEFT methods, and utility of PEFT methods with quantized backbone models.

2 Background: Transformer

Many of the parameter-efficient fine-tuning techniques discussed in this survey can be applied to all neural networks, though some are specifically designed for the Transformer architecture (Vaswani et al., 2017). Given that Transformers are the largest neural networks ever trained, these methods are particularly valuable. Thus, we present a brief overview of the Transformer to provide context for these techniques.

The core building block of the Transformer architecture consists of multi-head attention (MHA) followed by a fully-connected layer (FFN), as illustrated in Figure 1. Both attention and fully-connected layers incorporate residual connections (He et al., 2016) and Layer Normalization (Ba et al., 2016) to improve trainability.

The heart of the Transformer is the attention operation (Bahdanau et al., 2014). It computes the softmax-normalized weighted average of the input tokens. Attention weights are computed according to the pairwise dot-product between each token key and query. Keys and queries are typically computed as simple linear projections of the input tokens. Equation 1 describes it in the NamedTensor notation (Chiang et al., 2021).

$$\begin{aligned}
 \text{Att} &: \mathbb{R}^{\text{key}} \times \mathbb{R}^{\text{seq} \times \text{key}} \times \mathbb{R}^{\text{seq} \times \text{val}} \rightarrow \mathbb{R}^{\text{val}} \\
 \text{Att}(Q, K, V) &= \left(\text{softmax}_{\text{seq}} \frac{Q \odot_{\text{key}} K}{\sqrt{|\text{key}|}} \right) \odot_{\text{seq}} V \\
 Q(x) &= x \cdot W_Q + b_k, \\
 K(x) &= x \cdot W_K + b_q, \\
 V(x) &= x \cdot W_V + b_v,
 \end{aligned} \tag{1}$$

$$\begin{aligned}
 W_Q, W_K &\in \mathbf{R}^{\text{input} \times \text{key}}, W_V \in \mathbf{R}^{\text{input} \times \text{val}} \\
 b_Q, b_K &\in \mathbf{R}^{\text{key}}, b_V \in \mathbf{R}^{\text{val}}
 \end{aligned}$$

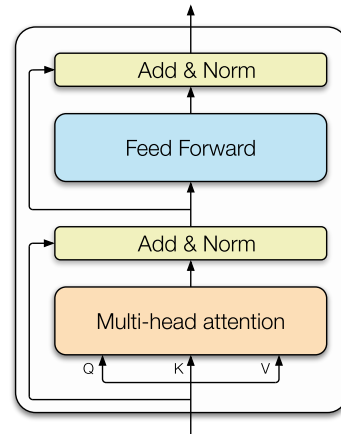


Figure 1: Basic Transformer block

2. github.com/guitaricet/peft_comparison

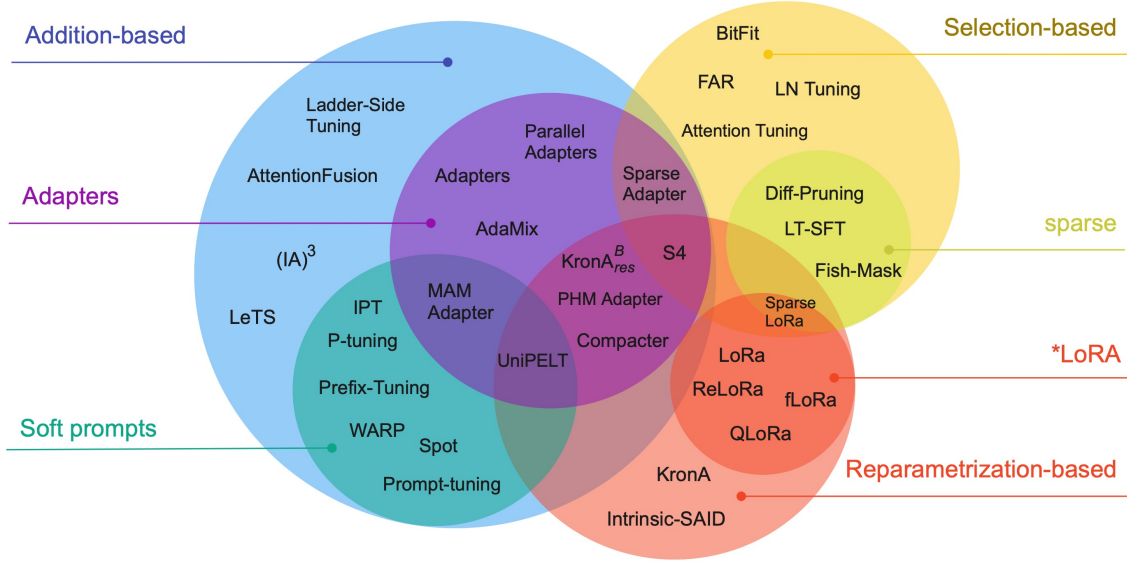


Figure 2: Parameter-efficient fine-tuning methods taxonomy. We identify three main classes of methods: **Addition-based**, **Selection-based**, and **Reparametrization-based**. Within additive methods, we distinguish two large included groups: **Adapter-like** methods and **Soft prompts**.

A number of methods act specifically on the matrices W_K , W_Q , W_V ; they provide the main mechanism to pass information from one token to another and control what information (value) is being passed.

Although specific implementations of the Transformer may vary, such as incorporating a cross-attention layer in seq2seq networks or using LayerNorm before sublayers (Pre-LN), most parameter-efficient fine-tuning methods for Transformers only rely on the basic MHA + FFN structure. These methods can be readily adapted to architectural variations.

3 Taxonomy of PEFT: a birds-eye view

PEFT methods can be categorized by their approach or objective. In terms of approach, they can **introduce new parameters**, **fine-tune existing ones**, or **reparameterize them**. In terms of objectives, they aim to minimize memory footprint, improve storage efficiency, or add modularity. In this section, we begin by presenting a taxonomy based on the former. Figure 2 and Sections 3.1-3.4 present an overview of the taxonomy and illustrate over 30 PEFT methods. In the following sections, we describe these PEFT methods in detail, **accompanied by easy-to-understand pseudo-code**, in Sections 5 - 10.

3.1 Addition-based methods

Addition-based methods augment the pre-trained model with additional parameters or layers and train only the newly introduced elements. This is the largest and most widely explored

category of PEFT methods. Within this category, two large subcategories have emerged: Adapter-like methods and Soft Prompts.

Adapters Adapters (Houlsby et al., 2019) are a type of additive PEFT method that introduces small fully-connected networks after Transformer sub-layers. The idea has been widely adopted (Pfeiffer et al., 2020b)³, and multiple variations of Adapters have been proposed. These variations include modifying the placement of adapters (He et al., 2022a; Zhu et al., 2021), pruning (He et al., 2022b), and using reparametrization to reduce the number of trainable parameters (Karimi Mahabadi et al., 2021). Section 5 discusses Adapter-based methods in detail.

Soft Prompts Language model prompting (Radford et al., 2019) aims to control the behavior of a language model by modifying the input text, which typically consists of a task description accompanied by a few in-context examples. However, these methods are difficult to optimize and are inherently limited by the maximum model input length. To address these drawbacks, the concept of “soft” prompts was introduced (Liu et al., 2021; Lester et al., 2021; Li and Liang, 2021), where a part of the model’s input embeddings is fine-tuned via gradient descent. This pivots the problem of finding prompts in a discrete space to a continuous optimization problem. Soft prompts can be trained for the input layer only (Liu et al., 2021; Lester et al., 2021) or for all layers (Li and Liang, 2021). Recent advancements explore how soft prompts could be pre-trained or partially reused to reduce the fine-tuning costs (Vu et al., 2021; Hambardzumyan et al., 2021; Su et al., 2021; Qin et al., 2021). We discuss Soft Prompts in Section 6.

Other additive approaches Additive methods are a diverse category of parameter-efficient fine-tuning techniques that extend beyond adapters and soft prompts. We discuss these in Section 7.

Why add parameters? Although these methods introduce additional parameters to the network, they achieve significant speed and memory improvements. This is achieved by reducing the size of the gradients and optimizer states. In the case of Adam (Kingma and Ba, 2015), for every byte of trainable parameter, one extra byte is needed for its gradient, and two more bytes are needed to store the optimizer state: the first and second moments of the gradient. In practice, training a model requires 12-20 times more GPU memory than the model weights. By saving memory on optimizer states, gradients, and quantizing frozen model parameters (Dettmers et al., 2023), additive PEFT methods enable the fine-tuning of much larger networks or the use of larger microbatch sizes⁴, which improves training throughput on GPUs. Moreover, the optimizer update step takes less time for PEFT methods than for full fine-tuning due to the smaller number of parameters to be updated. This effect is very noticeable in practice. Finally, optimizing fewer parameters in distributed setups drastically reduces communication volume.

3. github.com/adaptor-hub/adaptor-transformers

4. Batch size = microbatch size \times gradient accumulation \times num. devices

5. Depends on sparse operations hardware support.

3.2 Selection-based methods

Arguably the earliest example of selective PEFT is fine-tuning only a few top layers of a network (Donahue et al., 2014). Modern approaches are usually based on the type of layer (Gheini et al., 2021; AkbarTajari et al., 2022) or the internal structure, such as tuning only model biases (Ben-Zaken et al., 2021) or particular rows (Vucetic et al., 2022).

Sparse training is another version of selective PEFT that often ignores the structure and selects parameters to tune based on carefully designed selection criteria (Sung et al., 2021; Ansell et al., 2022; Guo et al., 2020). However, sparse parameter updates present multiple engineering and efficiency challenges. Some of them have been tackled in recent research on parameter reconfiguration (Vucetic et al., 2022) (Section 8.3) and NxM sparsity (Holmes et al., 2021). Nevertheless, unrestricted unstructured sparsity is still impractical on contemporary hardware.

We discuss selective methods in detail in Section 8.

3.3 Reparametrization-based methods

Reparametrization-based parameter-efficient fine-tuning methods leverage low-rank representations to minimize the number of trainable parameters. The notion that neural networks have low-dimensional representations has been widely explored in both empirical and theoretical analyses of deep learning (Maddox et al., 2020; Li et al., 2018; Arora et al., 2018; Malladi et al., 2022).

Aghajanyan et al. (2020) have demonstrated that fine-tuning can be performed effectively in low-rank subspaces. Furthermore, they showed that the size of the subspace that needs adaptation is smaller for larger models or models pre-trained for longer periods. Their approach, referred to as Intrinsic SAID (Section 9.1), employs the Fastfood transform (Le et al., 2013) to reparametrize the update to neural network parameters. This inspired multiple methods, such as IntrinsicSAID, LoRA, and KronA (Sections 9.1, 9.2, 9.3).

However, perhaps the most well-known reparametrization-based method is Low-Rank Adaptation or LoRA (Hu et al., 2022), which employs a simple low-rank matrix decomposition to parametrize the weight update $\delta W = W^{\text{down}} W^{\text{up}}$. This approach is straightforward to implement and has been evaluated on models with up to 175 billion parameters. We provide a detailed discussion of this method in Section 9.2. More recent works (Karimi Mahabadi et al., 2021; Edalati et al., 2022) have also explored the use of Kronecker product reparametrization ($\delta W = A \otimes B$), which yields a more favorable tradeoff between rank and parameter count. Reparametrization-based methods have recently become widely popular, demonstrating their effectiveness on models up to 175B parameters (Hu et al., 2022). Section 9 discusses these methods in detail.

3.4 Hybrid methods

A number of methods combine ideas from multiple categories of PEFT (He et al., 2022a,b; Mao et al., 2021; Karimi Mahabadi et al., 2021). This allows the use of different algorithmic tradeoffs to optimize for a specific goal, such as the number of trainable parameters. For instance, the MAM Adapter (Section 10.2) incorporates both Adapters and Prompt tuning. UniPELT (Section 10.3) adds LoRA to the mixture. Compacter and KronA_{res}^B reparametrize

Method	Type	Efficiency			Inference overhead
		Disk	RAM	BP	
Adapters (Houlsby et al., 2019)	A	✓	✓	✗	+ FFN
AdaMix (Wang et al., 2022)	A	✓	✓	✗	+ FFN
SparseAdapter (He et al., 2022b)	AS	✓	✓	✗	+ FFN
Cross-Attn tuning (Gheini et al., 2021)	S	✓	✓	✗	No overhead
BitFit (Ben-Zaken et al., 2021)	S	✓	✓	✗	No overhead
DiffPruning (Guo et al., 2020)	S	✓	✗	✗	No overhead
Fish-Mask (Sung et al., 2021)	S	✓	✗ ⁵	✗	No overhead
LT-SFT (Ansell et al., 2022)	S	✓	✗ ⁵	✗	No overhead
Prompt Tuning (Lester et al., 2021)	A	✓	✓	✗	+ input
Prefix-Tuning (Li and Liang, 2021)	A	✓	✓	✗	+ input
Spot (Vu et al., 2021)	A	✓	✓	✗	+ input
IPT (Qin et al., 2021)	A	✓	✓	✗	+ FFN and input
MAM Adapter (He et al., 2022a)	A	✓	✓	✗	+ FFN and input
Parallel Adapter (He et al., 2022a)	A	✓	✓	✗	+ FFN
Intrinsinc SAID (Aghajanyan et al., 2020)	R	✓	✗	✗	No overhead
LoRa (Hu et al., 2022)	R	✓	✓	✗	No overhead
DoRA (Liu et al., 2024)	R	✓	✓	✗	No overhead
UniPELT (Mao et al., 2021)	AR	✓	✓	✗	+ FFN and input
Compacter (Karimi Mahabadi et al., 2021)	AR	✓	✓	✗	+ FFN
PHM Adapter (Karimi Mahabadi et al., 2021)	AR	✓	✓	✗	+ FFN
KronA (Edalati et al., 2022)	R	✓	✓	✗	No overhead
KronA ^{B_{res}} (Edalati et al., 2022)	AR	✓	✓	✗	+ linear layer
(IA) ³ (Liu et al., 2022)	A	✓	✓	✗	+ gating
Attention Fusion (Cao et al., 2022)	A	✓	✓	✓	+ decoder
LeTS (Fu et al., 2021)	A	✓	✓	✓	+ FFN
Ladder Side-Tuning (Sung et al., 2022)	A	✓	✓	✓	+ decoder
FAR (Vucetic et al., 2022)	S	✓	✓	✗	No overhead
S4-model (Chen et al., 2023)	ARS	✓	✓	✗	+ FFN and input

Table 1: Comparing PEFT methods across storage (**disk**), memory (**RAM**), and computational efficiency in terms of reducing backpropagation costs (**BP**) and **inference overhead**. The ✓ means that the method is more effective than full fine-tuning, the ✗ means that it is less efficient than full fine-tuning.

Types: **A** – additive, **S** – selective, **R** – reparametrization-based.

the adapters using the Kronecker product to reduce their parameter count (Sections 10.4 and 9.3).

4 A Deep Dive into PEFT

In the following sections, we dive into the details of various parameter-efficient fine-tuning approaches. We describe the distinctions and tradeoffs between them in terms of the dimensions outlined in Section 11. We **bold** a one-sentence summary of each method to simplify **skimming**.

Method	%Trainable parameters	%Changed parameters	Evaluated on		
			<1B	<20B	>20B
Adapters	0.1 - 6	0.1 - 6	✓	✓	✓
AdaMix	0.1 - 0.2	0.1 - 0.2	✓	✗	✗
SparseAdapter	2.0	2.0	✓	✗	✗
BitFit	0.05 - 0.1	0.05 - 0.1	✓	✓	✓
DiffPruning	200	0.5	✓	✗	✗
Fish-Mask	0.01 - 0.5	0.01 - 0.5	✓	✓	✗
Prompt Tuning	0.1	0.1	✓	✓	✓
Prefix-Tuning	0.1 - 4.0	0.1 - 4.0	✓	✓	✓
IPT	56.0	56.0	✓	✗	✗
MAM Adapter	0.5	0.5	✓	✗	✗
Parallel Adapter	0.5	0.5	✓	✗	✗
Intrinsinc SAID	0.001 - 0.1	100	✓	✓	✗
LoRa	0.01 - 0.5	~ 30	✓	✓	✓
DoRA	0.01 - 0.5	~ 30	✗	✓	✗
UniPELT	1.0	1.0	✓	✗	✗
Compacter	0.05-0.07	~ 0.1	✓	✓	✗
PHM Adapter	0.2	~ 1.0	✓	✗	✗
KronA	0.07	~ 30.0	✓	✗	✗
KronA ^B _{res}	0.07	~ 1.0	✓	✗	✗
(IA) ³	0.02	0.02	✗	✓	✗
Ladder Side-Tuning	7.5	7.5	✓	✓	✗
FAR	6.6-26.4	6.6-26.4	✓	✗	✗
S4-model	0.5	> 0.5	✓	✓	✗

Table 2: What model sizes PEFT methods have been evaluated on and their typical amount of trainable parameters as reported in the literature. For updated number of trainable parameters lookup Table 5.

In the method description, we also indicate whether it has been applied to models with fewer than 1 billion, 20 billion, or more than 20 billion parameters. We stick to indicating parameter counts where possible because the words “small” and “large” change their meaning too quickly. For a summary, refer to Table 2. Finally, we provide a brief pseudo-PyTorch implementation of the most important part of the algorithm where feasible.

5 Additive methods: Adapters

We begin our exploration of PEFT methods with one of the largest sub-families: methods that add fully-connected networks between model layers, known as adapters.

5.1 Adapters

Houlsby et al. (2019) introduced the idea of adapters for NLP. Rebuffi et al. (Rebuffi et al., 2017, 2018) initially proposed similar concepts for image classification tasks, and Houlsby et al. extended this concept to NLP by **proposing the addition of fully-connected networks after attention and FFN layers in Transformer**. Unlike the transformer FFN

block, Adapters usually have a smaller hidden dimension than the input. Adapters have demonstrated impressive parameter efficiency, showing that it is possible to achieve full fine-tuning performance by tuning less than 4% of the total model parameters.

```
def transformer_block_with_adapter(x):
    residual = x
    x = SelfAttention(x)
    x = FFN(x)
    x = Adapter(x) # Adapter after FFN
    x = LN(x + residual)
```

Pfeiffer et al. (2020a) found that inserting the adapter only after the self-attention layer (after normalization) achieves similar performance as using two adapters per transformer block.

5.2 AdaMix

AdaMix (Wang et al., 2022) improves the performance of adapters by **utilizing multiple adapters in a mixture-of-experts (MoE) fashion** (Shazeer et al., 2017). This means each adapter layer consists of a set of layers (experts), and for each forward pass, only a small set of experts is activated. In contrast to a regular MoE, which selects and weights multiple experts using a routing network, AdaMix randomly selects a single expert for each forward pass to minimize computational costs.

To stabilize training, the authors propose consistency regularization, which minimizes the symmetrized KL divergence between two models' forward passes with different sets of experts selected. Another difference from a regular MoE layer is that up and down projections of the adapter are selected independently. After training, the adapter weights are averaged across the experts to reduce inference costs.

```
def transformer_block_with_adamix(x):
    residual = x
    x = SelfAttention(x)
    x = LN(x + residual)
    residual = x
    x = FFN(x)
    # adamix starts here
    x = random_choice(experts_up)(x)
    x = nonlinearity(x)
    x = random_choice(experts_down)(x)
    x = LN(x + residual)
    return x

def consistency_regularization(x):
    logits1 = transformer_adamix(x)
    # second pass uses different experts
    logits2 = transformer_adamix(x)
    r = symmetrized_KL(logits1, logits2)
    return r
```

Although AdaMix achieves better performance than regular adapters with the same inference cost, it can use more memory during training. Wang et al. (2022) show that AdaMix can use much smaller adapter hidden states than regular adapters, which amortizes trainable parameter overhead over the number of experts ($\sim 4-8$). However, consistency

regularization increases computational memory requirements, as it needs to keep two versions of the hidden states and gradients over two forward passes with different experts.

6 Additive Methods: Soft Prompts

Prompting language models has demonstrated remarkable performance in zero- and few-shot scenarios (Brown et al., 2020; Schick and Schütze, 2021). However, optimizing discrete natural language prompts or using in-context learning becomes impractical with many training examples. To overcome this challenge, the concept of “soft” or “continuous” prompts was proposed (Li and Liang, 2021; Lester et al., 2021; Liu et al., 2021), converting the discrete optimization problem of finding the best “hard” prompt into a continuous one.

6.1 Prompt Tuning

Prompt tuning (Lester et al., 2021) proposes to **prepend the input embeddings**. These tensors are commonly referred to as “soft prompts,” and they are optimized directly through gradient descent.

```
def prompt_tuning_attention(input_ids):
    q = x @ W_q
    k = cat([s_k, x]) @ W_k # prepend a
    v = cat([s_v, x]) @ W_v # soft prompt
    return softmax(q @ k.T) @ v
```

Ablation studies by ? on prompt length (1 to 150 tokens) and model size (10M to 11B parameters) reveal that prompt tuning becomes more parameter efficient as the model size increases. For instance, prompt tuning of T5-11B achieves the same SuperGLUE (Wang et al., 2019) performance with either 5 or 150 soft prompt tokens.

Furthermore, efficiency increases more rapidly with model size. T5-large performance saturates at prompt length 20 or 20K trainable parameters (0.002%), and T5-XL performance saturates at prompt length 5, also 20K trainable parameters (0.0002%). However, prompt tuning only becomes comparable with full fine-tuning at the 10B model scale. Additionally, increasing sequence length by 20-100 tokens can significantly increase computation, given the quadratic complexity of the transformer. Overall, soft prompts are incredibly parameter-efficient but come with inference overhead and are more applicable to larger models.

6.2 Prefix Tuning

Li and Liang (2021) independently develop the idea of soft prompts with a distinctive flavor: **shared trainable parameters are prepended to the hidden states of all layers**. The same prefix $\mathbf{P}_\theta \in \mathbf{R}^{l \times h}$ is prepended to all of the hidden states. They observe that directly optimizing the soft prompt leads to instabilities during training. Instead, soft prompts are parameterized through a feed-forward network $\mathbf{P}_\theta = \text{FFN}(\hat{\mathbf{P}}_\theta)$. During training, $\hat{\mathbf{P}}_\theta$ and the parameters of the FFN are optimized. After training, only \mathbf{P}_θ is needed for inference, and the FFN can be discarded.

Pseudocode for a single layer:

```
def transformer_block_for_prefix_tuning(x):
    soft_prompt = FFN(soft_prompt)
    x = concat([soft_prompt, x], dim=seq)
    return transformer_block(x)
```

Note that the approach is very similar to Prompt Tuning (Section 6.1), but the soft prompts are added in each layer.

In their experiments, Li and Liang (2021) apply prefix tuning to the BART (Lewis et al., 2019) model (less than 1B parameters) for different generation tasks and show a performance close to full fine-tuning by training only 0.1% of the parameters. Soft prompt lengths used in the study vary from 10 to 200 tokens.

6.3 Adaptive Prefix Tuning

Zhang et al. (2023b) extends prefix tuning and proposes adaptive changes to the prompt length. The authors achieve the **adaptive adjustment via gating and scaling of the input to each layer**. Specifically, the input to each transformer layer is first passed through an FFN (W) with sigmoid activation. The sigmoid-activated values act as gates for each pseudo token added in the soft prompt, providing a structure to adaptively select or deselect certain soft tokens in certain layers. Furthermore, the sigmoid-activated values are scaled with separate λ parameters. W and λ are both learnable parameters and are separately defined for each layer in the language model. Hence, W and λ cause significant computation, memory, and storage overhead on top of the prefix-tuning approach (Li and Liang, 2021).

```
def adaptive_adjustment(x, layer_index):
    alpha = sigmoid(W[layer_index, ...] @ x)
    adaptive_factor = lambda_[layer_index] * alpha
    return adaptive_factor

def prefix_tuning(x, layer_index):
    # adaptive gating and scaling
    adaptive_factor = adaptive_adjustment(x, layer_index)

    # soft prompt
    soft_prompt = FFN(soft_prompt)
    soft_prompt *= adaptive_factor

    # regular prefix-tuning
    x = concat([soft_prompt, x], dim=seq)
    return transformer_block(x)
```

However, the overhead is shown to be beneficial in the BERT and DeBERTa series models. Adaptive prefix tuning consistently outperforms the standard prefix tuning approach and even surpasses the full fine-tuning performance in most cases.

6.4 Intrinsic Prompt Tuning (IPT)

Prompt tuning is slow to converge. A few studies (Su et al., 2021; Vu et al., 2021) have proposed pre-training soft prompts to improve performance and convergence speed. However, these methods do not provide solutions to reduce the number of parameters per task.

Qin et al. (2021) hypothesize that the high-dimensional space used to define a soft prompt contains a low-dimensional “intrinsic task subspace” and **learn it using an autoencoder in a multi-task fashion**.

The IPT method works in three steps. First, given a set of training tasks, their soft prompts are learned in the standard way (Section 6.1). Then, these prompts are used to train an autoencoder that compresses their dimensionality. After this, the encoder part is discarded, and only the input to the autoencoder decoder is trained on new tasks.

```
def autoencoder(soft_prompt):
    soft_prompt = soft_prompt.flatten()
    P = FFN_A(soft_prompt) # encoder
    P = FFN_B(P)           # decoder
    P = P.reshape(prompt_len, hidden)
    return P

def ipt_model(x):
    P = FFN_B(intrinsic_subspace_prompt)
    P = P.reshape(prompt_len, hidden)
    x = concat([P, x], dim=seq)
    return model(x)
```

Even though the IPT framework reduces the number of parameters for the unseen tasks, this reduction comes at the price of training the autoencoder. The authors conduct experiments with the BART-base model and a prompt length of 100. The resulting autoencoder, which is implemented⁵ as a fully-connected network that accepts a one-dimensional tensor of size 76800, reaches 78 million parameters. This constitutes over 56% of the total parameters in the BART-base model. Therefore, significantly more efficient methods of prompt autoencoding are required to make IPT practically applicable.

7 Additive Methods: Other Approaches

7.1 Ladder-Side Tuning (LST)

Ladder-Side Tuning (Sung et al., 2022) **trains a small transformer network on the side of the pre-trained network**. This side network combines the hidden states of the pre-trained backbone network with its own hidden states.

This way, the side network only uses the pre-trained model as a feature extractor, and backpropagation must only be computed through the side network, saving on both memory and compute during training. To improve the performance and parameter efficiency of LST, the side network is initialized from the structurally pruned pre-trained model parameters and uses half as many layers.

Here h_{pt} is the output of the corresponding layer of the pre-trained network, and α is an input-independent trainable scalar gate:

```
def ladder_side_layer(x, h_pt):
    h_pt = h_pt @ W_down # to x.shape
    gate = sigmoid(alpha)
    x = gate * x + (1 - gate) * h_pt
    return transformer_block(x)
```

5. github.com/thunlp/Intrinsic-Prompt-Tuning

```
def ladder_side_network(x):
    with no_grad():
        H_pt = pretrained_network(x, return_all_hiddens=True)
    for i in range(layers):
        layer = ladder_side_layers[i]
        x = layer(x, H_pt[i])
    return x
```

LST demonstrated a three-fold RAM reduction in fine-tuning T5-Base compared to full fine-tuning and a two-fold RAM usage reduction compared to LoRA (Section 9.2) with a small degradation in accuracy. Moreover, LST outperforms these methods when controlling for RAM usage.

7.2 (IA)³

Liu et al. (2022) proposes a new parameter-efficient method to multi-task fine-tune T0 (Liu et al., 2022). Their proposed fine-tuning method, (IA)³, learns new parameters l_v , l_k , and l_{ff} , which **rescale key, value, and hidden FFN activations**. Specifically:

```
def transformer_block_with_ia3(x):
    residual = x
    x = ia3_self_attention(x)
    x = LN(x + residual)
    residual = x
    x = x @ W_1          # FFN input
    x = l_ff * gelu(x)    # (IA)3 scaling
    x = x @ W_2          # FFN output
    x = LN(x + residual)
    return x

def ia3_self_attention(x):
    k, q, v = x @ W_k, x @ W_q, x @ W_v
    k = l_k * k
    v = l_v * v
    return softmax(q @ k.T) @ v
```

Training only these three vectors, l_v , l_k , and l_{ff} , for each transformer block leads to high parameter efficiency. For T0-3B, it only updates about 0.02% of model parameters and outperforms other methods, including Compacter (Section 10.4), which has a similar parameter count, and LoRA (Section 9.2), which has 16 times more trainable parameters. Unlike adapter-tuned models, (IA)³-tuned models exhibit minimal overhead. Vectors l_v and l_k can be integrated into the corresponding linear layers, and the only overhead comes from l_{ff} .

8 Selective Methods

Selective methods fine-tune a subset of the existing parameters of the model. It could be a layer depth-based selection, layer type-based selection, or even individual parameter selection.

8.1 BitFit

Ben-Zaken et al. (2021) proposes to **only fine-tune the biases of the network**. That is, for every layer, W is unchanged and only b is trained.

BitFit only updates about 0.05% of the model parameters. The original paper demonstrated that the method achieves similar or better performance than full fine-tuning in low- and medium-data scenarios for BERT models (less than 1B parameters). Further research showed that for models larger than 1B parameters, BitFit significantly underperforms compared to full fine-tuning and other PEFT methods (Sanh et al., 2022; Liu et al., 2022; Hu et al., 2022).

```
params = (p for n, p in model.named_parameters()
          if "bias" in n)
optimizer = Optimizer(params)
```

Bias-less architectures In our experimental comparison, we noticed that several popular architectures do not use bias terms in the network. For example, T5 only uses bias terms in the relative attention weights, and LLaMA does not use bias terms throughout the network.

8.2 DiffPruning

DiffPruning (Guo et al., 2020) aims to achieve parameter efficiency by learning a sparse update of a neural network’s weights. The method introduces a learnable binary mask on the weights, denoted by $\delta = z \circ \Delta W$, where \circ represents the Hadamard product. This **parameter mask is learned during model fine-tuning** as part of the regularization objective, which is a differentiable approximation to the L_0 norm of the update vector δ .

DiffPruning achieves comparable performance to full fine-tuning while modifying only 0.5% of the model parameters in <1B scenarios. This makes it a useful method for multi-task deployment in edge (mobile) scenarios where storage is limited. However, this method requires more memory than traditional fine-tuning, as it involves optimizing all parameters during training in addition to the learnable binary mask.

8.3 Freeze and Reconfigure (FAR)

FAR (Vucetic et al., 2022) **selects columns of parameter matrices to train and reconfigures linear layers into trainable and frozen components**. The method operates in two stages. In the first stage, the most important rows of parameter matrices are identified for updating. This process is similar to structured pruning and can use any pruning method. In their paper, the authors fine-tune the model on a percentage of the data and select the top- r rows based on the L_1 distance between the fine-tuned and original models.

In the second stage, the network is reconfigured by splitting each parameter matrix $W \in \mathbb{R}^{in \times h}$ into a trainable component $W_t \in \mathbb{R}^{in \times h'}$ and a frozen component $W_f \in \mathbb{R}^{in \times (h-h')}$, where h' is the desired number of trainable parameters. The matrix multiplications with W_t and W_f are computed independently, and the results are concatenated. A similar operation is performed on biases.

```
def far_layer(x):
    h1 = x @ W_t
    h2 = x @ W_f
    return concat([h1, h2], dim=-1)
```

While this approach creates additional compute overhead during training, it provides great flexibility in terms of parameter selection on modern hardware using standard frameworks like PyTorch. After training, the parameters can be reconfigured back, removing any inference overhead.

The original paper focused on edge scenarios and used DistilBERT (66M parameters) for their experiments. It was only applied to feed-forward layers, as these make up the majority of the DistilBERT parameters. FAR achieved similar performance to fine-tuning on GLUE and SQuAD 2.0 (Rajpurkar et al., 2018) while updating only 6% of the parameters.

8.4 FishMask

FishMask (Sung et al., 2021) is a **sparse fine-tuning method that selects the top-p parameters of the model based on their Fisher information**. Fisher information is estimated in a common way through a diagonal approximation.

$$\hat{F}_\theta = \frac{1}{N} \sum_{i=1}^N \mathbb{E}_{y \sim p_\theta(y|x_i)} (\nabla_\theta \log p_\theta(y|x_i))^2$$

Or in pseudocode:

```
sparsity = 0.99
N = len(data)
for x, y in data:
    loss = loss_fn(model(x), y)
    loss.backward()
    for n, p in model.named_params():
        fisher[n] += p.grad ** 2 / N

threshold = percentile(fisher, sparsity)
masks = {n: f > threshold
          for n, f in fisher.items()}
```

FishMask requires computing gradients for all parameters on several batches of the data. However, after the highest-Fisher parameters are selected, only they need to be optimized.

The method generally performs on par with adapters but sub-par to LoRA and (IA)³ (Sections 9.2 and 7.2). It has been evaluated on BERT (less than 1B parameters) and T0-3B models. However, FishMask is computationally intensive and inefficient on contemporary deep learning hardware due to the lack of support for sparse operations.

8.5 DiffFit

Xie et al. (2023) combines various selective approaches with additive style scaling and specifically targets tuning of the diffusion model. In their study, Xie et al. (2023) **tunes the bias, layer normalization, and embedding parameters and adds new scaling pa-**

rameters for residual mixing. The scaling parameters are added separately for the self-attention and the FFN layers. The pseudocode for the scaling is as follows:

```
def forward(x, c, t):
    x += gamma_1 * self_attn(x, c, t)
    x += gamma_2 * FFN(x, c, t)
    return x
```

The authors conduct experiments focused on diffusion models and show that DiffFit outperforms other PEFT approaches. In addition, due to the minor overhead of the scaling parameters, DiffFit provides faster tuning speed and minimal degradation in inference and storage efficiency.

9 Reparametrization-based methods

These methods use the idea of reparametrizing the weights of the network using a low-rank transformation. This decreases the trainable parameter count while still allowing the method to work with high-dimensional matrices, such as the pre-trained parameters of the networks.

9.1 Intrinsic SAID

In their work, Aghajanyan et al. (2020) investigates the intrinsic dimensionality of fine-tuning and demonstrates that this process can be performed in a low-rank subspace. Specifically, they use the **Fastfood transform to reparametrize the update to the model weights**. Fastfood is a compute-efficient dimensionality expansion transform $F : \mathbf{R}^d \rightarrow \mathbf{R}^D$ that can be done in $O(D \log d)$ time and $O(D)$ memory.

They show that larger models require changes in a lower-rank subspace compared to smaller models to achieve the same fine-tuning performance. This observation motivates both scaling large models and parameter-efficient fine-tuning. It is important to note that, unlike methods that select a particular subset of parameters for fine-tuning, Intrinsic SAID updates all model parameters in a low-rank manner, i.e., $\theta = \theta_0 + F(\theta^d)$, where $\theta_0 \in \mathbf{R}^D$ denotes the pre-trained model parameters and $\theta^d \in \mathbf{R}^d$ denotes the parameters to be optimized. Therefore, while the number of optimizable parameters is low, the $O(D)$ memory complexity of Fastfood and the update to all of the model’s parameters make Intrinsic SAID impractical for fine-tuning large networks. For more details on Fastfood, we refer the reader to the original paper by Le et al. (2013).

9.2 LoRA

LoRA (Hu et al., 2022) takes inspiration from Intrinsic SAID and proposes a simpler way to perform low-rank fine-tuning. **Parameter update for a weight matrix in LoRA is decomposed into a product of two low-rank matrices:**

$$\delta W = W_A W_B, \quad W_A \in \mathbf{R}^{\text{in} \times r}, W_B \in \mathbf{R}^{r \times \text{out}}.$$

All pre-trained model parameters are kept frozen, and only W_A and W_B matrices are trainable. The scaling factor is constant and typically equals $\frac{1}{r}$. After training, they can be integrated into the original W by just adding the matrix $W_A W_B$ to the original matrix W .

Pseudocode is very simple:

```
def lora_linear(x):
    h = x @ W          # regular linear
    dh = x @ W_A @ W_B # low-rank update
    h += scale * dh     # scaling
    return h
```

In Transformers, LoRA is typically used for W_K and W_V projection matrices in multi-head attention modules. However, to achieve the best possible performance, it is best to apply LoRA to all weight matrices in the model (Dettmers et al., 2023). The method outperforms BitFit and Adapters and has been evaluated on models with up to 175B parameters.

9.3 KronA

KronA (Edalati et al., 2022) replaces matrix factorization $\delta W = W_A W_B$ in LoRA with a **matrix factorization through a Kronecker product** $\delta W = W_A \otimes W_B$.

This yields a better rank-to-parameters tradeoff because the Kronecker product preserves the rank of the original matrices being multiplied. Or, in other words, $\text{rank}(A \otimes B) = \text{rank } A \cdot \text{rank } B$. Additionally, Edalati et al. (2022) uses an efficient Kronecker product-vector product operation $x(A \otimes B)$, which avoids representing δW explicitly and leads to significant speedups. KronA_{res}^B , also presented in Edalati et al. (2022), is a parallel adapter that uses Kronecker product parameterization of the weights and includes a residual connection.

Krona pseudocode:

```
def krona_linear(x):
    x = x @ W # regular linear
    x += kronecker_vector_prod(x, W_A, W_B)
    return scale * x

# same as x @ kronecker_product(A, B)
def kronecker_vector_prod(x, A, B):
    x = x.reshape(A.shape[1], B.shape[1])
    x = A.T @ x @ B
    return x.reshape(-1)
```

On GLUE, KronA methods perform on par or better than adapters (Section 5.1), LoRA (Section 9.2), and Compacter (Section 10.4) at the same trainable parameter count of 0.07%, while being significantly faster than adapters or Compacter at inference time. The method was evaluated only on small models (less than 1B parameters).

Background: Kronecker product Kronecker product is a tensor operation defined as

$$\mathbf{A} \otimes \mathbf{B} : \mathbf{R}^{n \times m} \times \mathbf{R}^{k \times l} \rightarrow \mathbf{R}^{nk \times ml}$$

$$\mathbf{A} \otimes \mathbf{B} = \begin{bmatrix} a_{1,1}\mathbf{B} & \cdots & a_{1,n}\mathbf{B} \\ \vdots & \ddots & \vdots \\ a_{m,1}\mathbf{B} & \cdots & a_{m,n}\mathbf{B} \end{bmatrix} \quad (2)$$

It can be easily implemented ⁶ in PyTorch using the command `torch.einsum`

```
def batched_kronecker_product(a, b):
    bs, i, j = a.shape
    bs, k, m = b.shape
    res = einsum("bij,bkm->bikjm", a, b)
    return res.view(bs, i * k, j * m)
```

9.4 DoRA

In the study conducted by Liu et al. (2024), the authors examine the differences between full fine-tuning and LoRA fine-tuning. Particularly, the authors analyze the change in direction (ΔD) and magnitude (ΔM) of the weight matrices, comparing pre- and post-full fine-tuning checkpoints. With values of ΔD and ΔM calculated for various checkpoints and multiple layers, the authors show the existence of an inverse relationship between ΔD and ΔM for full fine-tuning. However, for LoRA tuning, the ΔD and ΔM are directly proportional to each other. Hence, the authors propose DoRA, a method that **decouples magnitude from the rest of the weight update**, similar to weight normalization (Salimans and Kingma, 2016). The implementation of DoRA is as follows:

```
def initialize_m(W):
    # learnable scaling factor (magnitude component)
    m = Parameter(l2_norm(W), requires_grad=True)
    return m

def dora_linear(x):
    W_cur = W + (W_A @ W_B)
    v = W_cur / l2_norm(W_cur) # normalize weight
    W_cur = m * v              # mult. by learnable magnitude

    # regular forward pass
    return x @ W_cur + b
```

The authors theoretically show that with the proposed scaling, an inverse relationship between ΔD and ΔM can be achieved with LoRA-style fine-tuning. In other words, DoRA can achieve either large directional changes with small adjustments to the magnitude, or vice versa. Experiments conducted on various tasks and models show consistent improvements in DoRA over LoRA. Interestingly, DoRA improves sample efficiency on instruction tuning tasks and shows significant performance improvements in the low-rank (4, 8) regime over LoRA.

9.5 GLoRA

In LoRA, the pre-trained weights are varied only through addition. While effective, more difficult tasks might benefit from further scaling and activation. Following the same hypothesis, Chavan et al. (2023) proposes a variation of LoRA called GLoRA (short for Generalized-LoRA). In GLoRA, the authors improve the capability of LoRA at the cost of **more learnable parameters that scale and shift parameters or activations or both**. However,

6. Source: github.com/rabeehk/compacter

all learnable parameters of GLoRA are merged back into the frozen model, hence incurring no additional inference cost. The GLoRA update can be written as follows:

$$f(x) = (W_0 + W_0 A + B)x + C W_0 + D b_0 + E + b_0$$

Where, W_0 and b_0 are pre-trained parameters and are kept frozen during the fine-tuning process. The GLoRA parameters, A, B, C, D , and E are learnable and are tuned during fine-tuning. In the above expression, the matrix B replicates the LoRA update. All other learnable parameters i.e., A, C, D , and E hence, add an overhead for fine-tuning compared to LoRA. However, to reduce this overhead, matrices A, B and C can be implemented with low-rank approximation i.e., $A = A_{in} \cdot A_{out}$ such that $A_{in} \in \mathbb{R}^{d_1 \times r}$ and $A_{out} \in \mathbb{R}^{r \times d_2}$, for $A \in \mathbb{R}^{d_1 \times d_2}$. The authors also specify that all new parameters (A to E) can be converted into vectors or scalars to manage the computational budget.

```
def glora_linear(x):
    # adjustment to the input
    W_cur = W_0 + A W_0 + B
    h = x @ W_cur + C W_0

    # add bias (mostly not present in recent transformer LLMs)
    if bias_present:
        h += D b_0 + E + b_0

    return h
```

In the above GLoRA update, all learnable parameters (A, B, C, D , and E) can merge back into the original model after fine-tuning. Across various suites of vision and language tasks, the authors show that GLoRA outperforms LoRA. When the number of trainable parameters is held constant for both LoRA and GLoRA, GLoRA outperforms LoRA on the VTAB-1K benchmark. Additionally, GLoRA shows better sample efficiency than LoRA and other PEFT methods with a comparable number of trainable parameters.

9.6 AdaLoRA

In AdaLoRA, Zhang et al. (Zhang et al., 2023a) introduce an adaptive method to reduce the ranks of the W_A and W_B matrices in LoRA. **They reformulate the LoRA update in an SVD-like format:**

$$W = W + W_A \Lambda W_B$$

where Λ is a diagonal matrix representing singular values. To adjust the rank, the authors prune Λ , affecting the dimensions of W_A and W_B based on importance scores that reflect the impact on loss. These scores are smoothed exponentially to guide parameter elimination. The method includes regularization to preserve orthogonality between W_A and W_B . Their experiments with DeBERTa-base and BART-large demonstrate that AdaLoRA outperforms LoRA and other parameter-efficient fine-tuning (PEFT) methods under a parameter budget constraint. The study highlights that the initial transformer layers do not need high-rank updates. However, it requires tracking additional variables (namely I, \bar{I}, \bar{U} , and S , refer to (Zhang et al., 2023a)) to prune Λ values. This can induce significant memory overhead as the language model size or the rank is scaled. Nonetheless, AdaLoRA presents insightful findings that motivate the need to develop a selective ranking strategy for LoRA that can

function without significant memory overhead. We present a simplified pseudocode of the main operations in AdaLoRA as follows,

```
def prune(W_A, ..., dW_A, ..., k):
    # calculate the importance score
    s = importance_score(W_A, ..., dW_A, ...)

    # find bottom-k values
    indices = find_bottom_k(s, k)

    # prune
    W_A[indices, :] = W_A[indices, :].detach()
    W_B[:, indices] = W_A[:, indices].detach()
    lambda_[indices] = 0
    lambda_[indices] = lambda_[indices].detach()
    return W_A, W_B, lambda_

def ada_lora_linear(x):
    h = x @ W # regular linear
    h += x @ W_A @ lambda_ @ W_B # low-rank update
    return h
```

9.7 GaLore

Usually PEFT methods improve computational efficiency by reducing the number of trainable parameters at the cost of lowering the expressivity. Zhao et al. (2024) propose to **train all model’s parameters, but using low-rank regularization of gradients**. In essence, GaLore makes full-tuning efficient by lowering the memory consumption of optimizer states (first and second momentum). The authors additionally provide a theoretical justification of the method.

Based on the theoretical analysis, the authors propose GaLore with the following salient properties: 1. No low-rank approximation of parameter matrices; 2. Decomposition of gradients in lower dimensional space; 3. Gradient regularization in lower dimensional space; 4. Projection of the regularized gradient in the original space and updating parameters. GaLore achieves a reduction in memory benefits by reducing storage requirements for the gradient statistics (first- and second-order momentum) and by making the gradient regularization leaner.

```
def galore_update(w, grad, lr):
    u, s, v = SVD(grad)
    m, n = u.shape[-1], v.shape[0]
    p = u if m < n else v
    grad_ = p.T @ grad
    # update optimizer momentum
    m, v = update_momentum(grad_)
    # regularize grad
    g = m / (sqrt(v) + eps)
    # project back
    grad = alpha * (p @ g)
    return w - lr * grad # param update

def update_momentum(grad_):
    # first order
    m = beta_1 * m + (1 - beta_1) * grad_
```

```
m \= (1 - beta_1**t)
# second order
v = beta_2 * m + (1 - beta_2) * grad_**2
v \= (1 - beta_2**t)
return m, v
```

The authors evaluate the proposed method for pre-training as well as fine-tuning. On the pre-training end, GaLore achieves better validation perplexity on C4 data compared to LoRA (Hu et al., 2022) and ReLoRA (Lialin et al., 2023) for a range of model sizes varying from 60M to 1B. Compared to full-rank pre-training GaLore achieves comparable but slightly worse perplexity values while significantly reducing memory usage. For the fine-tuning end, the authors fine-tuned RoBERTa-base on GLUE tasks and highlighted the benefit of GaLore over LoRA.

9.8 Quantization and LoRA

In LoRA, the language model is held frozen in full precision. Due to the increasing size of language models, the frozen language model causes a significantly large memory footprint. Hence, recent studies have focused on reducing the memory load of backbone LLMs by reducing the precision of the backbone LLM parameters.

A study conducted by Dettmers et al. (2023) addresses this issue with QLoRA. The authors achieve memory benefits in three ways. First, the authors introduce a 4-bit NormalFloat quantization method that reduces the memory required to store the backbone model. Second, the authors reduce the memory footprint of quantization constants by introducing double quantization, i.e., quantization of the quantization constants. Both of the first two steps realize significant memory gains in storing the backbone model on GPU. Lastly, the authors implement a paging mechanism between the CPU and GPU for optimizer states, offloading optimizer states to the CPU in case of memory spikes. With extensive experiments, the authors highlight the performance benefits of their proposed quantization approach.

However, post-training quantization of the final LoRA-tuned model often results in performance discrepancies (Xu et al., 2023). In another study, Xu et al. (2023) presents a group-wise quantization strategy that overcomes the need for post-training quantization, hence leading to better performance, even in lower precision regimes. More studies have proposed better quantization-aware fine-tuning methods in recent literature, e.g., IR-QLoRA (Qin et al., 2024), LoftQ (Li et al., 2023), L4Q (Jeon et al., 2024), LQ-LoRA (Guo et al., 2023).

10 Hybrid Approaches

Hybrid methods leverage the strengths of various techniques while mitigating their weaknesses to improve the performance and efficiency of PEFT.

10.1 SparseAdapter

He et al. (2022b) propose a *Large-Sparse* strategy to train adapter layers. In this strategy, they use a **large hidden dimension for the added module and prune around 40%**

of the values at initialization. *Large-Sparse* consistently outperforms its non-sparse counterpart with the same trainable parameter count. However, training and inference costs can be higher depending on hardware support for sparse tensors and operations. It is also worth noting that computing the pruning mask for this method may require obtaining gradients for all newly added parameters.

10.2 MAM Adapters

In their study, He et al. (2022a) thoroughly investigated adapter placement and soft prompts. They concluded that scaled parallel adapters outperform sequentially-placed adapters and that placing an adapter in parallel to FFN outperforms multi-head attention-parallel adapters. They also noticed that soft prompts can efficiently modify attentions by only changing 0.1% of the parameters and propose to 'mix-and-match' (MAM) these ideas. Their final model, **MAM Adapter, is a combination of scaled parallel adapter for the FFN layer and soft prompt.**

```
def transformer_block_mam(x):
    x = concat([x, soft_prompt], dim=seq)
    residual = x
    x = SelfAttention(x)
    x = LN(x + residual)
    x_a = FFN(x) # parallel adapter
    x_a = scale * x_a
    x = LN(x + x_adapter)
    return x
```

The MAM method outperforms BitFit and PromptTuning by a large margin and consistently outperforms LoRA (Section 9.2), Adapters (Section 5.1), and Prefix Tuning (Section 6.2) with a 200 soft prompt length and 7% extra parameters. The experiments were conducted on models with fewer than 1 billion parameters.

It is worth noting that parallel adapters were independently studied by Zhu et al. (2021) in the domain of machine translation.

10.3 UniPELT

UniPELT (Mao et al., 2021) is a **gated combination of LoRA, Prefix-tuning, and Adapters**. LoRA reparametrization is used for W_Q and W_V attention matrices, prefix-tuning is applied to keys and values of each layer, and adapters are added after the feed-forward layer of the transformer block. For each of the modules, gating is implemented as a linear layer projecting the module input into a dimension of size one, sigmoid activation, and averaging the resulting vector over the sequence length. Trainable parameters include LoRA matrices W_A, W_B , prompt tuning parameters P_q, P_k , adapter parameters, and gating function weights.

Schematic implementation of UniPELT (omitting attention heads for simplicity):

```
def transformer_block_with_unipelt(x):
    residual = x
    x = unipelt_self_attention(x)
    x = LN(x + residual)
    residual = x
```



```

x = FFN(x)
adapter_gate = gate(x)
x = adapter_gate * FFN(x)
x = LN(x + residual)
return x

def unipelt_self_attention(x):
    k, q, v = x @ W_k, x @ W_q, x @ W_v
    # lora for queries and values
    lora_gate = gate(x)
    q += lora_gate * W_qA @ W_aB
    v += lora_gate * W_vA @ W_vB
    # prefix tuning
    pt_gate = gate(x)
    q_prefix = pt_gate * P_q
    k_prefix = pt_gate * P_k
    return softmax(q @ k.T) @ v

def gate(x):
    x = Linear(x)
    x = sigmoid(x)
    return mean(x, dim=seq)

```

UniPELT demonstrates significant improvements over individual LoRA, Adapters, and Prefix Tuning approaches in low-data scenarios with only 100 examples. In higher data scenarios, UniPELT performs on par or better than these approaches. Mao et al. (2021) reports that UniPELT uses 1.3% trainable model parameters on BERT models with fewer than 1 billion parameters.

10.4 Compacter

Compacter (Karimi Mahabadi et al., 2021) **utilizes the Kronecker product, low-rank matrices, and parameter sharing across layers to produce adapter weights**. Each parameter W in an adapter is equal to the sum of Kronecker products

$$\hat{W} = \sum_{i=0}^n A_i \otimes B_i \quad (3)$$

$$\hat{W} \in \mathbf{R}^{k \times d}, A_i \in \mathbf{R}^{n \times n}, B_i \in \mathbf{R}^{\frac{k}{n} \times \frac{d}{n}}.$$

A linear layer $x\hat{W} + b$ with this parameterization is called a parametrized hypercomplex multiplication (PHM) layer (Zhang et al., 2021). Compacter takes this idea further, parametrizing B_i similar to LoRA (Section 9.2) as $B_i = B_i^{\text{down}} B_i^{\text{up}}$, where all matrices are of rank at most r . Matrices A_i are shared across all adapter layers for further parameter efficiency. The corresponding layer is referred to as Low-rank PHM (LPHM). Note that all A_i and B_i tensors are 3D tensors with the first dimension equal to n , the number of Kronecker products in the PHM layer. Compacter layer pseudocode:

```

def compacter(x):
    x = LPHM(x) # Essentially an FFN
    x = gelu(x) # but
    x = LPHM(x) # LPHM replaces linear
    return x

```

```
def lphm_forward(x):
    B = B_d @ B_u
    W = batched_kronecker_product(A, B)
    W = sum(W, dim=0)
    return x @ W + b
```

Compacter comes in two flavors: two adapters per transformer block or a single adapter after a feedforward layer (Compacter++). With only 0.05% additional parameters, Compacter++ performs on par or better than adapters with 0.8% additional parameters. The model has been evaluated on T5 Base (less than 1B parameters) and T0-3B models.

10.5 S4

Chen et al. (2023) conducted a search of various **combinations of parameter-efficient fine-tuning techniques**. Their search space includes dividing consecutive layers into four uneven groups, allocating varying amounts of trainable parameters to each layer, determining which groups to fine-tune, and which PEFT methods to apply to each group.

Their proposed method, S4, divides layers into four groups ($G_{1,2,3,4}$) using a “spindle” pattern: more layers are allocated to the middle groups and fewer to the top and bottom groups. All groups are trainable, with trainable parameters uniformly allocated across the layers within each group. Different combinations of PEFT methods are applied to different groups. Specifically:

$$\begin{aligned} G_1 &: A, L & G_3 &: A, P, B \\ G_2 &: A, P & G_4 &: P, B, L \end{aligned} \tag{4}$$

where A stands for Adapters (Section 5.1), P for Prefix-Tuning (Section 6.2), B for BitFit (Section 8.1), and L for LoRA (Section 9.2).

The search experiments were conducted on the T5-base model and the GLUE dataset with 0.5% trainable parameters. The S4 method was then applied to T5-3B, RoBERTa, and XL-Net, consistently outperforming individual BitFit, Prefix Tuning, LoRA, and Adapters across different architectures, model sizes, and tasks.

11 Comparison of PEFT Methods

Parameter efficiency involves multiple aspects: storage, memory, computation, and performance. However, achieving parameter efficiency alone does not necessarily lead to reduced RAM usage or faster training. When evaluating PEFT methods, it is important to consider various aspects of performance and efficiency, yet many publications focus solely on downstream performance and the number of parameters used by the PEFT method.

The “number of parameters” is a commonly reported metric in PEFT literature, but it can refer to different things: the number of **trainable parameters**, **changed parameters**, or the **rank of the update** (e.g., Aghajanyan et al. (2020)). In some cases, the number of trainable vs. changed parameters can differ by orders of magnitude. Examples include DiffPruning and LT-SFT (Guo et al., 2020; Ansell et al., 2022), which first fine-tune the full network and then prune the update afterward, or Prefix Tuning (Li and Liang, 2021), which uses an FCN reparametrization of the prompt parameters.

We provide a detailed comparison of the trainable and updated parameters for 28 PEFT methods in Table 2 and discuss this issue further in Section ???. Generally, sparse methods tend to have more trainable than changed parameters, while reparametrization methods often have fewer trainable parameters due to the nature of reparametrization.

In our study, we consider **five key dimensions** essential to benchmark the effectiveness of parameter-efficient fine-tuning methods. These dimensions include storage efficiency, memory efficiency, computational efficiency, inference overhead, and downstream performance metrics (e.g. accuracy). Our analysis of the published literature shows that while these dimensions are interconnected, improvements along one of the axes do not necessarily translate into improvements along the others. For example, optimizing for parameter efficiency alone does not guarantee reduced RAM usage. Table 1 summarizes our findings.

Despite their significance, PEFT performance metrics such as memory efficiency, training speed, and inference overhead (e.g., throughput) are only occasionally quantified in the papers. However, presenting these metrics only helps to further analyze a particular PEFT method of interest, in isolation. Head-to-head comparison across different PEFT methods is still challenging, primarily because of the impact of experimental setup on performance metrics. Thus, to address this gap, we fix the experimental set-up and perform a **large-scale experimental comparison of PEFT methods** as a part of this survey. We discuss details of the experimental setup and our results in the following sections.

11.1 Experimental Comparison: Setup

Our experimental comparison is designed to provide a comprehensive evaluation of PEFT methods, exceeding the scope and depth of existing studies such as Ding et al. (2022). We have carefully selected 14 PEFT methods representing diverse categories within our taxonomy – including Additive, Selective, Reparametrization-based, and Hybrid methods – to ensure a broad and inclusive analysis. Notably, we exclude sparse selective methods, acknowledging their limited practicality on modern hardware and their primary focus on storage efficiency. Furthermore, our study omits BitFit in the context of T5 networks, which do not utilize biases. In addition to these PEFT methods, we include a full fine-tuning baseline to provide a reference point for both downstream task performance and efficiency metrics. Unlike Ding et al. (2022), which limited their experimental comparison to four PEFT methods and focused primarily on downstream performance and memory consumption, our experimental design covers a wider range of methods and evaluates them in all the following: memory efficiency, training speed, inference speed, and downstream performance.

Datasets We use both natural language understanding (NLU) and natural language generation (NLG) tasks for the comparison of the methods.

While the GLUE benchmark (Wang et al., 2018) is commonly used to evaluate parameter-efficient fine-tuning methods in the existing literature, many models now match or exceed human performance on GLUE tasks, some even with no or minimal training⁷. This makes GLUE less effective at evaluating fine-tuning procedure performance. More recently, proposed alternatives to GLUE include MMLU (Hendrycks et al., 2021), HELM (Liang et al.,

7. gluebenchmark.com/leaderboard

2023), and BigBench (Srivastava et al., 2022). MMLU emphasizes zero- or few-shot evaluations, making it unsuitable for assessing fine-tuning. Both HELM and BigBench present computational challenges due to their task diversity, especially when comparing a broad range of methods and models of up to 11B parameters.

In contrast, SuperGLUE tasks remain both demanding (with only a few models surpassing the human baseline) and computationally manageable. Specifically, we selected BoolQ, RTE, and COPA for this study. BoolQ is a yes/no question-answering dataset mainly evaluating models’ world knowledge. COPA focuses on commonsense causal reasoning, for example, “Premise: The man broke his toe. What was the CAUSE of this? Alternative 1: He got a hole in his sock. Alternative 2: He dropped a hammer on his foot.” RTE is a natural language inference dataset where, given a premise, the model needs to predict if the hypothesis can be inferred from it, contradicts it, or is not relevant.

For more diverse comparisons, we also include one natural language generation dataset: CNN-Dailymail (See et al., 2017), a large (300K training examples) summarization dataset. From the surveyed literature, we found that summarization usually highlights differences between PEFT methods and full fine-tuning, making this dataset particularly useful.

Models To compare parameter-efficient fine-tuning methods, we apply them to three sizes of T5: Large (0.7B), 3B, and 11B (Raffel et al., 2019). The range from 0.7B to 11B models not only tests each method’s effectiveness at different scales but also presents common challenges associated with large-scale model training. A key aspect of this comparison is to demonstrate how PEFT methods can address practical issues such as memory constraints. For instance, the 11B model allows us to compare PEFT methods’ performance and efficiency in one of the most relevant practical cases when full fine-tuning does not fit even into 80GB of GPU memory.

PEFT Methods We use the following fine-tuning methods in our comparison:

- Full tuning – regular fine-tuning of all model parameters
- Housby – Adapters inserted after the attention and FCN layers of the Transformer as described in Section 5 (Housby et al., 2019)
- Pfeiffer – Adapters inserted only after the FCN layers (Pfeiffer et al., 2023)
- Parallel Adapter – scaled parallel adapter as described in (He et al., 2022a)
- IA3 – (IA)³ learns re-scaling vectors for keys, values, and hidden FFN activations (Section 7.2) ()
- Prefix Tuning – learns a prefix added to keys and values and uses FCN reparametrization for these parameters (Section 6.2) (Li and Liang, 2021)
- Prompt Tuning – learns a prefix added to keys directly (Section 6.1) (Lester et al., 2021)
- LN tuning – fine-tune only layer-norm parameters (AkbarTajari et al., 2022)
- LoRA (q and v) – LoRA applied to the query and value networks only (Section 9.2) (Hu et al., 2022)
- LoRA (all linear) – LoRA applied to all linear layers in the model (Hu et al., 2022)

- KronA – LoRA-like Kronecker product-based reparametrization of the weight matrices (Section 9.3) (Edalati et al., 2022)
- MAM – Mix-and-Match Adapters (Section 10.2) ()
- Compacter – Kronecker product-based reparametrization of Adapter layers as described in Section 10.4 (Karimi Mahabadi et al., 2021)
- Compacter++ – Compacter layers that are only applied after the FCN in the Transformer, similar to the idea of Pfeiffer vs Houlsby Adapters ()
- UniPELT – a hybrid method that combines LoRA, Prefix Tuning, and Adapters through gating (Section 10.3) (Mao et al., 2021)

Metrics In our evaluation, we focus on assessing PEFT method efficiency in terms of memory consumption, training speed, and inference speed, and then compare models on downstream metrics.

To quantify memory efficiency, we track the maximum RAM consumption during training using `torch.cuda.max_memory_allocated()`. Training speed is quantified by the number of input tokens processed per second during training and for inference – during evaluation. We do not explicitly merge reparametrization-based methods into model weights during evaluation to present results for a typical use-case when methods like LoRA are used in the adapter fashion. When merged, there should be no difference between reparametrization-based methods and regular training in terms of the inference speed. We use accuracy for SuperGLUE datasets and ROUGE-L for summarization.

Implementation details and hyperparameters All models are fine-tuned in text-to-text fashion following Raffel et al. (2019). We use Adapters and PEFT libraries (Poth et al., 2023; Mangrulkar et al., 2022) for most of the methods and implement several methods in our repository⁸ from scratch. When using existing implementations, we utilize default architecture hyperparameters for the method from the corresponding library, which are usually close to the hyperparameters reported in the method’s original paper.

For all NLU datasets, we perform a learning rate sweep over values {1e-3, 1e-4, and 1e-5} and select the best, which we then train on two more random seeds to estimate the standard deviation. Our preliminary experiments indicate a negligible impact of weight decay in our setup (<0.01). Due to computational constraints, CNN/Dailymail experiments only use one seed and a learning rate of 1e-3, which we found to perform consistently well across PEFT methods. We estimate the standard deviation of CNN/Dailymail runs via several random seeds on randomly selected PEFT methods and find it to be lower than 0.5 ROUGE-L points, which we use for the standard deviation estimate for the rest of the methods.

We use a maximum input sequence length of 512 tokens in all our experiments. In NLU experiments, the maximum output sequence length is 8, and for summarization, it is 128 tokens.

Each NLU model undergoes training for either 3 epochs or a minimum of 100 update steps. For CNN/Dailymail, the training duration is set to one epoch (9 thousand update steps). We use a batch size of 32 in all our experiments, utilizing gradient accumulation to achieve this batch size when needed. While all SuperGLUE tasks converge by the end of

8. github.com/guitaricet/peft_comparison

Model	Datasets	Microbatch size
T5 _{LARGE}	RTE, COPA	32
T5 _{LARGE}	BoolQ	16
T5 _{LARGE}	CNN	4
T5 _{3B}	RTE, COPA	4
T5 _{3B}	BoolQ	2
T5 _{3B}	CNN	1
T5 _{11B}	RTE, COPA, BoolQ, CNN	1

Table 3: Microbatch sizes used in our experiments

training in most of our experiments, we observe that CNN/Dailymail continues to improve throughout the training and does not plateau. Our setup thereby favors methods exhibiting faster learning, which is especially relevant for low-resource scenarios commonly faced in PEFT applications.

In total, we train three models of size 0.7-11B parameters with 14 PEFT methods, five runs for each of the three NLU datasets, and one for the summarization dataset. Together with the full fine-tuning baseline, this brings the total experiment count to around 700. We report raw (non-aggregated) results in Appendix B.

Hardware setup We estimate throughput using a single A100 40GB GPU for most of the experiments, with several exceptions due to out-of-memory issues. UniPELT, MAM, and Prefix Tuning for T5-11B were trained with a single A100 80GB GPU, which should give comparable throughput numbers to the A100 40GB. Full fine-tuning T5-11B experiments were performed with two A100 80GB GPUs using model-parallel distributed training. RAM estimates for this model training are the total memory consumption of both GPUs, which should give an estimate comparable to the rest of the experiments, as optimizer states are not shared between GPUs in model-parallel training.

Table 3 specifies the number of examples processed simultaneously (microbatch size) in our experiments. Microbatch sizes are kept consistent across different tuning methods to enable fair comparison of memory efficiency. This also allows us to isolate the throughput improvements from the PEFT method itself, rather than increased batch size. Methods with lower memory consumption could further benefit from increased batch sizes.

11.2 Comparison Results: Downstream Performance

Table 4 shows downstream metrics averaged over the datasets. Scores are averaged, and standard deviations are aggregated using the Euclidean mean of per-dataset variances. This table compares the downstream performance of PEFT methods across model scales. Non-aggregated results for all our experiments are available in Appendix B.

We note a few key observations:

Houlsby Adapters and LoRA consistently perform the best Houlsby Adapters and LoRA are the only methods that consistently achieve full-tuning performance with little to no effort in hyperparameter tuning.

Method	T5 _{LARGE}	T5 _{3B}	T5 _{11B}
Additive methods			
Adapters (Houlsby)	67.34 ± 9.58	<u>74.66</u> ± 1.68	76.16 ± 1.47
Adapters (Pfeiffer)	62.93 ± 3.52	<u>69.92</u> ± 5.61	50.72 ± 1.69
Parallel Adapter	<u>66.78</u> ± 3.85	<u>74.15</u> ± 0.88	<u>68.74</u> ± 12.73
IA3	55.06 ± 1.80	41.77 ± 0.50	61.05 ± 3.42
Prefix Tuning	45.05 ± 3.89	48.90 ± 5.37	51.93 ± 2.21
Prompt Tuning	8.97 ± 30.91	8.38 ± 0.50	-
Selective methods			
LN Tuning	<u>64.68</u> ± 4.59	72.95 ± 1.38	73.77 ± 0.93
Reparametrization-based methods			
LoRA (q and v)	67.42 ± 2.32	75.49 ± 1.71	76.20 ± 1.27
LoRA (all linear)	68.76 ± 1.83	75.22 ± 1.28	76.58 ± 2.16
KronA	<u>65.68</u> ± 3.27	71.98 ± 0.57	<u>72.13</u> ± 7.30
Hybrid methods			
MAM	46.90 ± 6.47	45.57 ± 4.67	51.49 ± 0.54
Compacter	64.48 ± 1.81	70.72 ± 0.87	74.33 ± 1.40
Compacter++	64.78 ± 2.23	71.00 ± 1.62	74.72 ± 0.82
Unipelt	44.10 ± 15.48	47.16 ± 4.84	52.29 ± 3.09
Full tuning	67.22	74.83	73.25

Table 4: Average model performance on our collection of datasets (Section 11.1) with 95% confidence intervals (two standard deviations). We **bold** values that outperform full-tuning by mean value. We underline values that achieve full-tuning performance within the confidence interval.

Hybrid methods are especially sensitive to hyperparameters MAM Adapters and UniPELT were consistently hard to train. While the results in Table 4 include only the best model from our sweep over three learning rates, additional experiments to improve MAM and UniPELT only marginally improved their performance. We attribute this to the generally poor performance of Prompt Tuning when trained in a compute-limited scenario.

Prefix Tuning and Prompt Tuning significantly differ in performance Prefix Tuning (Li and Liang, 2021) and Prompt Tuning (Lester et al., 2021) are two different PEFT methods that are easy to confuse in terms of naming and concept. Both methods use the idea of continuous prompt optimization, but Prefix Tuning reparametrizes the trainable prefix via a fully-connected network (Section 6.2). In contrast, Prompt Tuning directly optimizes the prefix, albeit at the cost of slower convergence and typically much larger prefix length. We observe significant differences between these methods in our experiments. Both of them suffer from slow convergence, which substantially hurts performance in our setup. However, Prompt Tuning never outperformed the constant prediction baseline.⁹ Additionally, Prompt Tuning was extremely sensitive to the random seed (especially for T5-large and 3B models), as observed by its high standard deviation from the mean.

9. Since we use a text-to-text approach, results worse than the constant prediction are expected. A badly trained network will never generate a correct class name.

Multiple methods underperform their reported values Multiple methods that had claimed to outperform Adapters or LoRA (virtually all other methods) do not perform well in our setup. This includes most of the methods with the exception of Parallel Adapter, Compacter, and KronA, which perform on par with the best methods in several cases, especially for 11B models.

Pfeiffer Adapters Perform Significantly Worse Than Houlsby Pfeiffer et al. (2020a) observes that inserting adapters only after the FCN in the Transformer achieves similar performance as inserting adapters after both FCN and Attention (MHA) layers. However, in our experiments we find a significant and consistent difference of up to 15 points that increases with model scale. This highlights the importance of evaluating methods for both small and large models.

Layer Norm Tuning is unexpectedly competitive Layer Norm parameters are rarely used for parameter-efficient fine-tuning; we found only a few mentions of the method (AkbarTajari et al., 2022; Liu et al., 2022). However, it can be implemented in one line of code and shows performance competitive to full fine-tuning for T5-Large and T5-11B. We want to highlight this result and recommend using LN tuning as a baseline for future PEFT work.

11.3 Comparison Results: Efficiency

Table 5 presents a detailed comparison of efficiency and performance for the 14 PEFT methods compared in our study. We show the actual number of **trainable parameters** (as opposed to changed parameters), the maximum GPU memory consumption during training, and the throughput in ktok/s (thousands of tokens per second) both during training and inference.

All PEFT methods reduce memory consumption As expected, all methods from our study significantly reduce memory consumption. The smallest improvement we see is **4GB** in the UniPELT and T5-Large combination, which is quite considerable because it is 10% of the GPU RAM. The biggest improvement is **71.5GB** in the Compacter++ and T5-11B combination. This allows fine-tuning T5-11B on a single 40GB GPU instead of two 80GB GPUs and dramatically improves training speed by a factor of more than two.

Smaller models (<1B) can train slower with PEFT Any PEFT (Parameter-Efficient Fine-Tuning) method that adds parameters to the network involves additional forward (and potentially backward) pass overhead. For sufficiently large models or when only a few parameters are added, this overhead can be negligible. However, if the method adds too many parameters, it can lead to **slower training compared to regular fine-tuning**. We observe this in T5-Large models, which are small only compared to billion-scale models, as they have 738M parameters¹⁰. For instance, applying LoRA to all T5-Large parameters results in a 20% training slowdown. Similar slowdowns are noted for MAM adapters, Compacter, and UniPELT, with 20%, 5%, and 40% slower training, respectively, compared to full fine-tuning. Despite these slowdowns, they all offer memory improvements.

PEFT significantly affects inference speed In all PEFT methods that add trainable parameters to the network, we observe a significant slowdown in inference speed. The

10. T5-Large is significantly bigger than BERT and RoBERTa models

Model	PEFT Method	Score	Trainable params		RAM	Throughput	
			Millions	%	(GB)	Train.	Infer.
T5 _{Large}	Full tuning	67.22	737.67	100	20.7	100	100
T5 _{Large}	Houlsby	67.34 ± 9.58	12.69	1.720	12.1	101.7	70.1
T5 _{Large}	Pfeiffer	62.93 ± 3.52	6.34	0.860	14.0	108.6	76.8
T5 _{Large}	Parallel Adapter	66.78 ± 3.85	50.41	6.833	14.7	123.1	73.2
T5 _{Large}	IA3	55.06 ± 1.80	0.34	0.047	16.2	124.7	76.2
T5 _{Large}	Prefix tuning	45.05 ± 3.89	77.31	10.481	15.4	113.2	65.0
T5 _{Large}	Prompt tuning	8.97 ± 30.91	4.42	0.600	10.6	108.8	64.5
T5 _{Large}	LN tuning	64.68 ± 4.59	0.12	0.017	14.6	143.2	103.1
T5 _{Large}	LoRa (q and v)	67.42 ± 2.32	2.36	0.320	14.3	123.7	87.4
T5 _{Large}	LoRA (all)	68.76 ± 1.83	8.65	1.173	15.9	80.9	66.9
T5 _{Large}	KronA	65.68 ± 3.27	0.22	0.030	14.6	109.3	82.3
T5 _{Large}	Compacter	64.48 ± 1.81	0.30	0.041	14.4	81.3	59.0
T5 _{Large}	Compacter++	64.78 ± 2.23	0.15	0.021	13.9	95.4	68.1
T5 _{Large}	MAM	46.90 ± 6.47	171.07	23.191	16.6	106.1	59.1
T5 _{Large}	Unipelt	44.10 ± 15.48	86.22	11.689	16.7	61.1	45.2
T5 _{3B}	Full tuning	74.83	2851.60	100	32.9	100	100.0
T5 _{3B}	Houlsby	74.66 ± 1.68	12.69	0.445	9.3	93.1	58.2
T5 _{3B}	Pfeiffer	69.92 ± 5.61	6.34	0.223	9.6	102.9	64.5
T5 _{3B}	Parallel Adapter	74.15 ± 0.88	50.41	1.768	10.0	102.7	61.2
T5 _{3B}	IA3	41.77 ± 0.50	1.38	0.048	10.8	103.9	65.6
T5 _{3B}	Prefix tuning	48.90 ± 5.37	77.25	2.709	12.3	105.2	56.8
T5 _{3B}	Prompt tuning	8.38 ± 0.50	17.69	0.621	8.9	100.0	58.8
T5 _{3B}	LN tuning	72.95 ± 1.38	0.12	0.004	9.7	140.7	101.8
T5 _{3B}	LoRa (q and v)	75.49 ± 1.71	3.93	0.138	9.6	103.0	79.8
T5 _{3B}	LoRA (all)	75.22 ± 1.28	25.17	0.883	10.6	70.2	56.7
T5 _{3B}	KronA	71.98 ± 0.57	0.41	0.014	10.8	81.2	74.0
T5 _{3B}	Compacter	70.72 ± 0.87	0.30	0.011	9.7	71.5	46.0
T5 _{3B}	Compacter++	71.00 ± 1.62	0.15	0.005	9.5	86.9	54.3
T5 _{3B}	MAM	45.57 ± 4.67	171.07	5.999	14.2	84.5	52.1
T5 _{3B}	Unipelt	47.16 ± 4.84	316.70	11.106	12.8	51.0	38.2
T5 _{11B}	Full tuning	73.25	11307.32	100	104.9	100.0	100
T5 _{11B}	Houlsby	76.16 ± 1.47	12.69	0.112	28.8	214.9	70.3
T5 _{11B}	Pfeiffer	50.72 ± 1.69	6.34	0.056	28.6	239.5	76.3
T5 _{11B}	Parallel Adapter	68.74 ± 12.73	50.41	0.446	29.0	233.3	73.9
T5 _{11B}	IA3	61.05 ± 3.42	3.48	0.031	31.0	232.2	75.5
T5 _{11B}	Prefix tuning	51.93 ± 2.21	1211.99	10.719	37.9	182.3	62.3
T5 _{11B}	Prompt tuning	-	70.78	0.626	30.2	209.5	64.0
T5 _{11B}	LN tuning	73.77 ± 0.93	0.12	0.001	28.4	275.9	97.8
T5 _{11B}	LoRa (q and v)	76.20 ± 1.27	20.05	0.177	28.9	216.9	81.3
T5 _{11B}	LoRA (all)	76.58 ± 2.16	91.23	0.807	30.8	161.7	62.4
T5 _{11B}	KronA	72.13 ± 7.30	0.77	0.007	33.2	174.0	71.8
T5 _{11B}	Compacter	74.33 ± 1.40	0.30	0.003	28.6	162.7	56.8
T5 _{11B}	Compacter++	74.72 ± 0.82	0.15	0.001	28.5	208.8	64.2
T5 _{11B}	MAM	51.49 ± 0.54	1262.39	11.164	43.3	152.8	57.3
T5 _{11B}	Unipelt	52.29 ± 3.09	1224.78	10.832	38.9	100.2	46.8

Table 5: Average model performance on our collection of datasets and efficiency metrics: number of trainable parameters, GPU memory consumption, training and inference throughput. We use **bold** scores to indicate that method outperforms full fine-tuning. Gray values for inference throughput indicate that PEFT weights can be merged into the network (made 100%) if needed. Throughput 95%-confidence intervals are: ± 6 (T5_{LARGE}), ± 7 (T5_{3B}), and ± 3 (T5_{11B}).

slowdown ranges from 33-55% for T5-Large, 20-60% for T5-3B, and 20-55% for T5-11B (absolute points). Within the set of additive methods, we observe that Pfeiffer adapters and (IA)³ offer the best inference speeds. It is important to note that in our throughput estimation for reparametrization-based methods, we did not merge the method parameters into the network. If merged, they would have the same inference speed as regular fine-tuning, as no additional parameters are present. However, methods like LoRA are increasingly used in modular approaches, such as referenced in (Huang et al., 2023), without merging LoRA parameters. The results from Table 5 are relevant for these scenarios.

Kronecker-Based Reparametrizations Do Not Improve Memory Efficiency, But Improve Speed Across different model scales, we observe that extremely parameter-efficient methods like Compacter and KronA, which employ Kronecker products to enhance parameter efficiency, do not significantly reduce memory usage. Despite training with two orders of magnitude fewer parameters than LoRA, the memory consumption of Compacter and KronA is nearly identical to that of LoRA. For instance, LoRA optimizes 20 million parameters for T5-11B, while KronA and Compacter each optimize less than 0.5 million. Nevertheless, all methods consume approximately 28.6GB of GPU memory. This result becomes intuitive in hindsight: beyond a certain point, the memory used for optimizer states and gradients becomes negligible, overshadowed by other factors such as model weights and hidden states. Nevertheless, we observe significant training and inference speed improvements with KronA over LoRA. This likely occurs due to the efficient Kronecker-vector product implementation in KronA (Section 9.3).

In conclusion, our experimental comparison shows several expected results, such as significant improvements in memory consumption and speed. However, we also observed some surprising results. Notably, we observed that methods like Layer Norm Tuning, which are often overlooked, can be unexpectedly effective. Additionally, the effects of various PEFT methods on inference speed, especially in larger models, highlight the complex trade-offs between efficiency and performance. These insights emphasize the need for a comprehensive evaluation of PEFT methods, taking into account not only memory and speed but also their scalability across different model sizes.

Based on our experiments, we note a few key take-away points for the practitioners.

Key Findings:

- Houlby Adapters (Houlby et al., 2019) and LoRA (Hu et al., 2022) perform at par or better than full-tuning, with little to no effort in hyperparameter tuning.
- Layer Norm (AkbarTajari et al., 2022) tuning provides a highly competitive and efficient method that is easy to implement.

12 Challenges and guidelines

Survey papers tend to discuss reporting issues, and this one is no exception. We identified several challenges and inconsistencies that make it difficult to evaluate PEFT methods and draw direct comparisons between different PEFT methods, which warrant discussion.

Reporting parameter count One of the primary challenges stems from the difference in the way researchers report parameter counts. These inconsistencies arise from the inherent complexity of the problem. Parameter counts can be categorized into three types: the number of **trainable parameters**, the number of **changed parameters** between the original and fine-tuned models, and the **rank** of the difference between the original and fine-tuned models. These parameter counts are not equivalent. For example, IntrinsicSAID (Section 9.1) learns a low-rank (~ 100 - 1000) transformation of model parameters. However, it changes all (100%) of the model’s parameters. DiffPruning (Section 8.2) learns an update of 0.5% of the parameters, but it actually trains 200% of the parameters: fine-tuning the model and learning the binary mask. For reparameterization-based methods (Sections 9.2, 9.3, 10.4), memory requirements may vary depending on the implementation design choices. Of the three types, the number of trainable parameters is the most reliable predictor of memory efficiency. However, it is still imperfect: Ladder-side Tuning trains more parameters than LoRA or BitFit, but it uses less RAM by avoiding backpropagation to the main network.

Guideline - 1: Explicit reporting of the number of parameters and the type i.e. trainable parameters or changed parameters or rank of the changes to the model being tuned.

Reporting efficiency Evaluating the efficiency of PEFT methods solely based on parameter count is challenging due to the non-linear relationship between parameter count and efficiency. Efficiency in training time is better assessed through memory consumption and training speed. Most PEFT categories, except for Sparse-selective methods, significantly improve RAM usage. However, the Intrinsic SAID (Aghajanyan et al., 2020) method, which is Reparametrization-based, can result in higher memory usage than full training due to the Fastfood transformation’s demands. Our experiments revealed that modularity in hybrid PEFT (e.g., MAM adapters (), UniPELT (Mao et al., 2021)) methods comes at the cost of notably higher memory consumption. This emphasizes the need for studies to report memory consumption to help practitioners make informed decisions. We also noticed considerable variability in training speed even with similar RAM usage, suggesting that RAM consumption should be considered alongside training speed. After training, the storage space required for the changed parameters is crucial for evaluating PEFT methods. Unlike full fine-tuning, which alters all model parameters, PEFT only requires saving a subset, significantly improving storage efficiency. However, methods like IPT require saving different parameter sets at various training stages, making clear reporting of space requirements essential. Inference latency is another critical factor in practice. Additive methods typically introduce overhead because they require computations on both the original network and the added parameters, whereas Selective methods do not, as they operate on existing model weights. Moreover, additive and reparametrization-based methods (e.g., LoRA, KronA) offer advantages in multi-task inference by reducing memory usage from $O(NM)$ to $O(M + NA)$, where A is the number of added weights per task. Some additive methods, like LST, can also enhance inference speed by using the original network solely as a feature extractor. For further details on multi-task training and inference, we refer readers to Modular Deep Learning (Pfeiffer et al., 2023).

Guideline - 2: Explicit reporting of memory (RAM) consumption during training, token throughput during training and inference, and storage requirements are necessary to evaluate the efficiency of the PEFT method. Furthermore, if the proposed methods consist of multiple stages, all metrics should be reported for each stage.

Model sizes Another challenge arises from the variation in model sizes used in the evaluation of PEFT methods. It is important to assess methods fine-tuning different model sizes, especially $>1\text{B}$ and $<20\text{B}$ parameters. With the increase in the backbone model size, the need and usefulness of PEFT methods increase rapidly. Several studies (Aghajanyan et al., 2020; Hu et al., 2022) have demonstrated that larger models require fewer parameters to be updated during fine-tuning, both in terms of percentage and when the model is large enough, sometimes even in absolute terms (Li and Liang, 2021). We would like to particularly stress this, considering that even recent papers often focus solely on BERT. Furthermore, in our experiments, Layer Norm tuning (AkbarTajari et al., 2022) was the only consistently efficient method at different scales, while maintaining a competitive performance now downstream tasks. For all other methods, efficiency, and performance considerably varies at different model sizes. Thus, model size must be considered when reporting PEFT methods.

Guideline - 3: Efficiency metrics and downstream performance should be reported across multiple model scales. Authors should also consider reporting fine-tuning results for the model sizes that are most commonly used by the research community at the time of experimentation.

Method Implementation Another issue encountered is the state of published implementations. Many codebases are simply copies of the Transformers library (Wolf et al., 2020) or other repositories with only minor modifications. These copies often do not use git forks, making it difficult to identify the differences unless they are highlighted in the README file. But even when differences are easy to find, the code is frequently not readable or reusable. Users are often required to install a modified version of the Transformers library, which conflicts with the most recent version and lacks documentation or examples of how to reuse the method outside of the existing codebase. Despite these challenges, there are some methods with reusable implementations worth highlighting, such as LoRA¹¹ and Compacter¹². These implementations stand out for their user-friendliness and adaptability, providing a solid foundation for further research and development.

Guideline - 4: The study presenting a PEFT method should be accompanied by an easy-to-use implementation of the method.

Comparison Intuitively, the presented PEFT method should be compared against popular approaches (e.g., LoRA, BitFit, Adapters) and the methods that share conceptual and architectural similarities with the presented method. However, the absence of standard benchmarks and metrics complicates the comparison of PEFT methods. New methods are

11. github.com/microsoft/LoRA

12. github.com/rabeehk/compacter








		Additive			Selective		Reparam.	Hybrid
		Adapters	Soft prompts	Other	Structured	Sparse		
Storage efficiency		✓	✓	✓	✓	✓	✓	✓
Training	RAM	✓	✓	✓	✓	✗	✓	maybe
	Speed	✗	✗	maybe	maybe	✗	✓	maybe
Inference	Single-task	✗ Adds overhead			✓ No overhead		✓	maybe
	Mutli-task	✓ Allows efficient inference			maybe ✗		maybe	maybe
Implemented in					✗	✗		

Table 6: Comparison of PEFT categories in terms of the axes outlined in Section ?? . For training, we evaluate methods by their memory (RAM) efficiency and speed relative to full training. ✓ means more effective than regular training, ✗ means less effective, and maybe suggests it might vary based on the specific method within the category. For inference, the table shows whether a method introduces single-task overhead and if it facilitates efficient multi-task inference. Lastly, the table highlights if these methods are implemented in popular open-source libraries: HuggingFace PEFT () and AdapterHub () .

often evaluated on different model/dataset combinations, making it challenging to draw meaningful conclusions. We would like to highlight the papers that report a variety of metrics on standard datasets, simplifying comparison to other methods. For example, KronA (Edalati et al., 2022) evaluated T5-base on the GLUE benchmark and reported accuracy, training time, and inference time while maintaining the same number of trainable parameters. UniPELT (Mao et al., 2021) assessed BERT on the GLUE benchmark and reported accuracy, training time, and inference latency, although it used different parameter counts for various methods. LST (Sung et al., 2022) evaluated different T5 sizes on the GLUE benchmark, reporting metrics such as accuracy, training time, the number of updated parameters, and memory usage. MAM (He et al., 2022a) applied multiple models to the XSUM benchmark and reported accuracy across a range of trainable parameters, although memory comparisons were not provided. However, even these papers lack full comparability due to differences in their evaluation settings, such as varying parameter counts or the absence of certain metrics like memory comparisons. These inconsistencies highlight the need for a standardized benchmark and unified metrics to facilitate more accurate comparisons and evaluations of PEFT methods. Based on our survey and experiments we identified the principal qualities of each of the categories and summarized them in this section and Table 6.

Call for community efforts in developing standardized benchmarks and competition for evaluation of PEFT methods.

13 Discussion

The growing accessibility of large language models (Zhang et al., 2022; Zeng et al., 2022; Khrushchev et al., 2022; Touvron et al., 2023) and the democratization of their inference

through low-bit quantization (Dettmers et al., 2022; Dettmers and Zettlemoyer, 2022) have enabled the research community to study, experiment, and tackle new tasks with relatively modest compute budgets. Parameter-efficient fine-tuning is the next step that allows us not just to infer, but to modify these models.

Some methods, including Adapters, Prompt Tuning, LoRA, and (IA)³, have shown their practicality at scale (Table 2). However, in practice, matching the performance of full fine-tuning remains a challenge. One of the reasons is high **sensitivity to hyperparameters**, with optimal hyperparameters often significantly deviating from those used in full fine-tuning due to the varying number of trainable parameters. For instance, the optimal learning rate for parameter-efficient fine-tuning is generally much higher than that for full fine-tuning. The research community should promote in-depth investigations into the impact of hyperparameters on these methods and find reasonable defaults, as parameter-efficient fine-tuning of large models can be noticeably costly at the 20-100B scale. Additionally, efforts should be directed towards developing methods that minimize hyperparameter sensitivity, such as pre-training new parameters (Vu et al., 2021; Su et al., 2021).

Examining the taxonomy of methods and the progress made thus far, it is evident that low-rank reparameterization has been remarkably successful in enhancing parameter efficiency. LoRA-style (Section 9.2) and Kronecker-product (Sections 10.4 and 9.3) reparameterizations both decrease the number of trainable parameters while requiring minimal extra computation. A possible future direction for finding new PEFT models is exploring different **reparametrization techniques** with favorable trainable parameter count vs. rank ratio.

Another possible direction for improvement is utilizing what we know about **how transformer models process texts** (Rogers et al., 2020). Most of the PEFT methods work uniformly for the model, while we know that models process input differently at different layers. Utilizing this knowledge or building systems that have an adaptive number of parameters per layer could further improve parameter efficiency and accuracy.

In many respects, fine-tuning large language models faces the same challenges as those encountered in **edge machine learning** – we consistently face constraints on memory, computation, and even energy consumption. Techniques like quantization and pruning (Gupta et al., 2015; LeCun et al., 1989) that are widely used in edge machine learning now benefit large language models. As we move forward, it is not only plausible but also likely that more ideas could be exchanged between these two areas. Cross-disciplinary collaboration could facilitate the exchange of ideas, accelerating innovation and progress in parameter-efficient fine-tuning.

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References

- Armen Aghajanyan, Luke Zettlemoyer, and Sonal Gupta. Intrinsic dimensionality explains the effectiveness of language model fine-tuning. In Annual Meeting of the Association for Computational Linguistics, 2020.
- Mohammad AkbarTajari, Sara Rajaei, and Mohammad Taher Pilehvar. An empirical study on the transferability of transformer modules in parameter-efficient fine-tuning. In Yoav Goldberg, Zornitsa Kozareva, and Yue Zhang, editors, Proceedings of the 2022 Conference on Empirical Methods in Natural Language Processing, pages 10617–10625, Abu Dhabi, United Arab Emirates, December 2022. Association for Computational Linguistics. doi: 10.18653/v1/2022.emnlp-main.726. URL <https://aclanthology.org/2022.emnlp-main.726>.
- 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, Dublin, Ireland, May 2022. Association for Computational Linguistics. doi: 10.18653/v1/2022.acl-long.125. URL <https://aclanthology.org/2022.acl-long.125>.
- Sanjeev Arora, Rong Ge, Behnam Neyshabur, and Yi Zhang. Stronger generalization bounds for deep nets via a compression approach. In International Conference on Machine Learning, 2018.
- Jimmy Ba, Jamie Ryan Kiros, and Geoffrey E. Hinton. Layer normalization. ArXiv, abs/1607.06450, 2016.
- Dzmitry Bahdanau, Kyunghyun Cho, and Yoshua Bengio. Neural machine translation by jointly learning to align and translate. arXiv preprint arXiv:1409.0473, 2014.
- Elad Ben-Zaken, Shauli Ravfogel, and Yoav Goldberg. Bitfit: Simple parameter-efficient fine-tuning for transformer-based masked language-models. ArXiv, abs/2106.10199, 2021.
- Amanda Bertsch, Maor Ivgi, Uri Alon, Jonathan Berant, Matthew R Gormley, and Graham Neubig. In-context learning with long-context models: An in-depth exploration. arXiv preprint arXiv:2405.00200, 2024.
- 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/2020/file/1457c0d6bfc4967418bfb8ac142f64a-Paper.pdf>.

- Jin Cao, Chandan Prakash, and Wael Hamza. Attention fusion: a light yet efficient late fusion mechanism for task adaptation in nlu. In NAACL-HLT, 2022.
- Arnav Chavan, Zhuang Liu, Deepak Gupta, Eric Xing, and Zhiqiang Shen. One-for-all: Generalized lora for parameter-efficient fine-tuning. arXiv preprint arXiv:2306.07967, 2023.
- Jiaao Chen, Aston Zhang, Xingjian Shi, Mu Li, Alexander J. Smola, and Diyi Yang. Parameter-efficient fine-tuning design spaces. ArXiv, abs/2301.01821, 2023.
- David Chiang, Alexander M. Rush, and Boaz Barak. Named tensor notation. ArXiv, abs/2102.13196, 2021.
- Aakanksha Chowdhery, Sharan Narang, Jacob Devlin, Maarten Bosma, Gaurav Mishra, Adam Roberts, Paul Barham, Hyung Won Chung, Charles Sutton, Sebastian Gehrmann, Parker Schuh, Kensen Shi, Sasha Tsvyashchenko, Joshua Maynez, Abhishek Rao, Parker Barnes, Yi Tay, Noam M. Shazeer, Vinodkumar Prabhakaran, Emily Reif, Nan Du, Benton C. Hutchinson, Reiner Pope, James Bradbury, Jacob Austin, Michael Isard, Guy Gur-Ari, Pengcheng Yin, Toju Duke, Anselm Levskaya, Sanjay Ghemawat, Sunipa Dev, Henryk Michalewski, Xavier Garcia, Vedant Misra, Kevin Robinson, Liam Fedus, Denny Zhou, Daphne Ippolito, David Luan, Hyeontaek Lim, Barret Zoph, Alexander Spiridonov, Ryan Sepassi, David Dohan, Shivani Agrawal, Mark Omernick, Andrew M. Dai, Thanumalayan Sankaranarayanan Pillai, Marie Pellat, Aitor Lewkowycz, Erica Moreira, Rewon Child, Oleksandr Polozov, Katherine Lee, Zongwei Zhou, Xuezhi Wang, Brennan Saeta, Mark Díaz, Orhan Firat, Michele Catasta, Jason Wei, Kathleen S. Meier-Hellstern, Douglas Eck, Jeff Dean, Slav Petrov, and Noah Fiedel. Palm: Scaling language modeling with pathways. ArXiv, abs/2204.02311, 2022.
- Tim Dettmers and Luke Zettlemoyer. The case for 4-bit precision: k-bit inference scaling laws. ArXiv, abs/2212.09720, 2022.
- Tim Dettmers, Mike Lewis, Younes Belkada, and Luke Zettlemoyer. Llm.int8(): 8-bit matrix multiplication for transformers at scale. arXiv preprint arXiv:2208.07339, 2022.
- Tim Dettmers, Artidoro Pagnoni, Ari Holtzman, and Luke Zettlemoyer. Qlora: Efficient finetuning of quantized llms, 2023.
- 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>.
- Ning Ding, Yujia Qin, Guang Yang, Fu Wei, Zonghan Yang, Yusheng Su, Shengding Hu, Yulin Chen, Chi-Min Chan, Weize Chen, Jing Yi, Weilin Zhao, Xiaozhi Wang, Zhiyuan Liu, Haitao Zheng, Jianfei Chen, Yang Liu, Jie Tang, Juan Li, and Maosong Sun. Delta tuning: A comprehensive study of parameter efficient methods for pre-trained language models. ArXiv, abs/2203.06904, 2022.

- Jeff Donahue, Yangqing Jia, Oriol Vinyals, Judy Hoffman, Ning Zhang, Eric Tzeng, and Trevor Darrell. Decaf: A deep convolutional activation feature for generic visual recognition. In Eric P. Xing and Tony Jebara, editors, Proceedings of the 31st International Conference on Machine Learning, volume 32 of Proceedings of Machine Learning Research, pages 647–655, Beijing, China, 22–24 Jun 2014. PMLR. URL <https://proceedings.mlr.press/v32/donahue14.html>.
- Ali Edalati, Marzieh S. Tahaei, Ivan Kobyzev, V. Nia, James J. Clark, and Mehdi Rezagholizadeh. Krona: Parameter efficient tuning with kronecker adapter. ArXiv, abs/2212.10650, 2022.
- William Fedus, Barret Zoph, and Noam M. Shazeer. Switch transformers: Scaling to trillion parameter models with simple and efficient sparsity. ArXiv, abs/2101.03961, 2021.
- Cheng Fu, Hanxian Huang, Xinyun Chen, Yuandong Tian, and Jishen Zhao. Learn-to-share: A hardware-friendly transfer learning framework exploiting computation and parameter sharing. In Marina Meila and Tong Zhang, editors, Proceedings of the 38th International Conference on Machine Learning, volume 139 of Proceedings of Machine Learning Research, pages 3469–3479. PMLR, 18–24 Jul 2021. URL <https://proceedings.mlr.press/v139/fu21a.html>.
- Mozhdeh Gheini, Xiang Ren, and Jonathan May. Cross-attention is all you need: Adapting pretrained transformers for machine translation. In Conference on Empirical Methods in Natural Language Processing, 2021.
- Demi Guo, Alexander M. Rush, and Yoon Kim. Parameter-efficient transfer learning with diff pruning. In Annual Meeting of the Association for Computational Linguistics, 2020.
- Han Guo, Philip Greengard, Eric P Xing, and Yoon Kim. Lq-lora: Low-rank plus quantized matrix decomposition for efficient language model finetuning. arXiv preprint arXiv:2311.12023, 2023.
- Suyog Gupta, Ankur Agrawal, Kailash Gopalakrishnan, and Pritish Narayanan. Deep learning with limited numerical precision. In Francis Bach and David Blei, editors, Proceedings of the 32nd International Conference on Machine Learning, volume 37 of Proceedings of Machine Learning Research, pages 1737–1746, Lille, France, 07–09 Jul 2015. PMLR. URL <https://proceedings.mlr.press/v37/gupta15.html>.
- Karen Hambardzumyan, Hrant Khachatrian, and Jonathan May. Warp: Word-level adversarial reprogramming. In Annual Meeting of the Association for Computational Linguistics, 2021.
- Junxian He, Chunting Zhou, Xuezhe Ma, Taylor Berg-Kirkpatrick, and Graham Neubig. Towards a unified view of parameter-efficient transfer learning. In International Conference on Learning Representations, 2022a. URL <https://openreview.net/forum?id=ORDcd5Axok>.
- Kaiming He, Xiangyu Zhang, Shaoqing Ren, and Jian Sun. Deep residual learning for image recognition. 2016 IEEE Conference on Computer Vision and Pattern Recognition

- (CVPR), Jun 2016. doi: 10.1109/cvpr.2016.90. URL <http://dx.doi.org/10.1109/cvpr.2016.90>.
- Shwai He, Liang Ding, Daize Dong, Jeremy Zhang, and Dacheng Tao. SparseAdapter: An easy approach for improving the parameter-efficiency of adapters. In Findings of the Association for Computational Linguistics: EMNLP 2022, pages 2184–2190, Abu Dhabi, United Arab Emirates, December 2022b. Association for Computational Linguistics. URL <https://aclanthology.org/2022.findings-emnlp.160>.
- Dan Hendrycks, Collin Burns, Steven Basart, Andy Zou, Mantas Mazeika, Dawn Song, and Jacob Steinhardt. Measuring massive multitask language understanding. In International Conference on Learning Representations, 2021. URL <https://openreview.net/forum?id=d7KBjmI3GmQ>.
- Connor Holmes, Minjia Zhang, Yuxiong He, and Bo Wu. Nxmttransformer: Semi-structured sparsification for natural language understanding via admm. In M. Ranzato, A. Beygelzimer, Y. Dauphin, P.S. Liang, and J. Wortman Vaughan, editors, Advances in Neural Information Processing Systems, volume 34, pages 1818–1830. Curran Associates, Inc., 2021. URL <https://proceedings.neurips.cc/paper/2021/file/0e4f5cc9f4f3f7f1651a6b9f9214e5b1-Paper.pdf>.
- Neil Houlsby, Andrei Giurgiu, Stanislaw Jastrzebski, Bruna Morrone, Quentin de Larousilhe, Andrea Gesmundo, Mona Attariyan, and Sylvain Gelly. Parameter-efficient transfer learning for nlp. In International Conference on Machine Learning, 2019.
- Edward J Hu, yelong shen, Phillip Wallis, Zeyuan Allen-Zhu, Yuanzhi Li, Shean Wang, Lu Wang, and Weizhu Chen. LoRA: Low-rank adaptation of large language models. In International Conference on Learning Representations, 2022. URL <https://openreview.net/forum?id=nZeVKeeFYf9>.
- Cheng-Zhi Anna Huang, Ashish Vaswani, Jakob Uszkoreit, Noam Shazeer, Ian Simon, Curtis Hawthorne, Andrew M Dai, Matthew D Hoffman, Monica Dinculescu, and Douglas Eck. Music transformer. arXiv preprint arXiv:1809.04281, 2018.
- Chengsong Huang, Qian Liu, Bill Yuchen Lin, Tianyu Pang, Chao Du, and Min Lin. Lora-hub: Efficient cross-task generalization via dynamic lora composition, 2023.
- Hyesung Jeon, Yulhwa Kim, and Jae-joon Kim. L4q: Parameter efficient quantization-aware training on large language models via lora-wise lsq. arXiv preprint arXiv:2402.04902, 2024.
- Rabeeh Karimi Mahabadi, James Henderson, and Sebastian Ruder. Compacter: Efficient low-rank hypercomplex adapter layers. In M. Ranzato, A. Beygelzimer, Y. Dauphin, P.S. Liang, and J. Wortman Vaughan, editors, Advances in Neural Information Processing Systems, volume 34, pages 1022–1035. Curran Associates, Inc., 2021. URL <https://proceedings.neurips.cc/paper/2021/file/081be9fdff07f3bc808f935906ef70c0-Paper.pdf>.
- Feyza Duman Keles, Pruthuvi Mahesakya Wijewardena, and Chinmay Hegde. On the computational complexity of self-attention. In International Conference on Algorithmic Learning Theory, pages 597–619. PMLR, 2023.

- Mikhail Khurshchev, Ruslan Vasilev, Alexey Petrov, and Nikolay Zinov. YaLM 100B, 6 2022. URL <https://github.com/yandex/YaLM-100B>.
- Diederik P. Kingma and Jimmy Ba. Adam: A method for stochastic optimization. In Yoshua Bengio and Yann LeCun, editors, 3rd International Conference on Learning Representations, ICLR 2015, San Diego, CA, USA, May 7-9, 2015, Conference Track Proceedings, 2015. URL <http://arxiv.org/abs/1412.6980>.
- Quoc V. Le, Tamás Sarlós, and Alex Smola. Fastfood: Approximate kernel expansions in loglinear time. ArXiv, abs/1408.3060, 2013.
- Yann LeCun, John Denker, and Sara Solla. Optimal brain damage. In D. Touretzky, editor, Advances in Neural Information Processing Systems, volume 2. Morgan-Kaufmann, 1989. URL <https://proceedings.neurips.cc/paper/1989/file/6c9882bbac1c7093bd25041881277658-Paper.pdf>.
- Brian Lester, Rami Al-Rfou, and Noah Constant. The power of scale for parameter-efficient prompt tuning. ArXiv, abs/2104.08691, 2021.
- Mike Lewis, Yinhan Liu, Naman Goyal, Marjan Ghazvininejad, Abdelrahman Mohamed, Omer Levy, Ves Stoyanov, and Luke Zettlemoyer. Bart: Denoising sequence-to-sequence pre-training for natural language generation, translation, and comprehension. arXiv preprint arXiv:1910.13461, 2019.
- Chunyuan Li, Heerad Farkhor, Rosanne Liu, and Jason Yosinski. Measuring the intrinsic dimension of objective landscapes. In International Conference on Learning Representations, 2018.
- Xiang Lisa Li and Percy Liang. Prefix-tuning: Optimizing continuous prompts for generation. In Proceedings of the 59th Annual Meeting of the Association for Computational Linguistics and the 11th International Joint Conference on Natural Language Processing (Volume 1: Long Papers), pages 4582–4597, Online, August 2021. Association for Computational Linguistics. doi: 10.18653/v1/2021.acl-long.353. URL <https://aclanthology.org/2021.acl-long.353>.
- Yixiao Li, Yifan Yu, Chen Liang, Pengcheng He, Nikos Karampatziakis, Weizhu Chen, and Tuo Zhao. Loftq: Lora-fine-tuning-aware quantization for large language models. arXiv preprint arXiv:2310.08659, 2023.
- Vladislav Lialin, Namrata Shivagunde, Sherin Muckatira, and Anna Rumshisky. Stack more layers differently: High-rank training through low-rank updates. arXiv preprint arXiv:2307.05695, 2023.
- Percy Liang, Rishi Bommasani, Tony Lee, Dimitris Tsipras, Dilara Soylu, Michihiro Yasunaga, Yian Zhang, Deepak Narayanan, Yuhuai Wu, Ananya Kumar, Benjamin Newman, Binhang Yuan, Bobby Yan, Ce Zhang, Christian Cosgrove, Christopher D. Manning, Christopher Ré, Diana Acosta-Navas, Drew A. Hudson, Eric Zelikman, Esin Durmus, Faisal Ladhak, Frieda Rong, Hongyu Ren, Huaxiu Yao, Jue Wang, Keshav Santhanam,

- Laurel Orr, Lucia Zheng, Mert Yuksekgonul, Mirac Suzgun, Nathan Kim, Neel Guha, Niladri Chatterji, Omar Khattab, Peter Henderson, Qian Huang, Ryan Chi, Sang Michael Xie, Shibani Santurkar, Surya Ganguli, Tatsunori Hashimoto, Thomas Icard, Tianyi Zhang, Vishrav Chaudhary, William Wang, Xuechen Li, Yifan Mai, Yuhui Zhang, and Yuta Koreeda. Holistic evaluation of language models, 2023.
- Haokun Liu, Derek Tam, Mohammed Muqeeth, Jay Mohta, Tenghao Huang, Mohit Bansal, and Colin Raffel. Few-shot parameter-efficient fine-tuning is better and cheaper than in-context learning. ArXiv, abs/2205.05638, 2022.
- Shih-Yang Liu, Chien-Yi Wang, Hongxu Yin, Pavlo Molchanov, Yu-Chiang Frank Wang, Kwang-Ting Cheng, and Min-Hung Chen. Dora: Weight-decomposed low-rank adaptation. arXiv preprint arXiv:2402.09353, 2024.
- Xiao Liu, Yanan Zheng, Zhengxiao Du, Ming Ding, Yujie Qian, Zhilin Yang, and Jie Tang. Gpt understands, too. ArXiv, abs/2103.10385, 2021.
- Sheng Lu, Irina Bigoulaeva, Rachneet Sachdeva, Harish Tayyar Madabushi, and Iryna Gurevych. Are emergent abilities in large language models just in-context learning? arXiv preprint arXiv:2309.01809, 2023.
- Wesley J. Maddox, Gregory Benton, and Andrew Gordon Wilson. Rethinking parameter counting: Effective dimensionality revisited. arXiv preprint arXiv:2003.02139, 2020.
- Sadhika Malladi, Alexander Wettig, Dingli Yu, Danqi Chen, and Sanjeev Arora. A kernel-based view of language model fine-tuning. arXiv preprint arXiv:2210.05643, 2022.
- Sourab Mangrulkar, Sylvain Gugger, Lysandre Debut, Younes Belkada, Sayak Paul, and Benjamin Bossan. Peft: State-of-the-art parameter-efficient fine-tuning methods. <https://github.com/huggingface/peft>, 2022.
- Yuning Mao, Lambert Mathias, Rui Hou, Amjad Almahairi, Hao Ma, Jiawei Han, Wen tau Yih, and Madian Khabsa. Unipelt: A unified framework for parameter-efficient language model tuning. ArXiv, abs/2110.07577, 2021.
- Jonas Pfeiffer, Aishwarya Kamath, Andreas Rücklé, Kyunghyun Cho, and Iryna Gurevych. Adapterfusion: Non-destructive task composition for transfer learning. ArXiv, abs/2005.00247, 2020a.
- Jonas Pfeiffer, Andreas Rücklé, Clifton Poth, Aishwarya Kamath, Ivan Vulić, Sebastian Ruder, Kyunghyun Cho, and Iryna Gurevych. Adapterhub: A framework for adapting transformers. Proceedings of the 2020 Conference on Empirical Methods in Natural Language Processing: System Demonstrations, 2020b. doi: 10.18653/v1/2020.emnlp-demos.7. URL <http://dx.doi.org/10.18653/v1/2020.emnlp-demos.7>.
- Jonas Pfeiffer, Sebastian Ruder, Ivan Vulic, and E. Ponti. Modular deep learning. ArXiv, abs/2302.11529, 2023.

- Clifton Poth, Hannah Sterz, Indraneil Paul, Sukannya Purkayastha, Leon Englander, Timo Imhof, Ivan Vuli, Sebastian Ruder, Iryna Gurevych, and Jonas Pfeiffer. Adapters: A unified library for parameter-efficient and modular transfer learning. In Yansong Feng and Els Lefever, editors, Proceedings of the 2023 Conference on Empirical Methods in Natural Language Processing: System Demonstrations, pages 149–160, Singapore, December 2023. Association for Computational Linguistics. doi: 10.18653/v1/2023.emnlp-demo.13. URL <https://aclanthology.org/2023.emnlp-demo.13>.
- Haotong Qin, Xudong Ma, Xingyu Zheng, Xiaoyang Li, Yang Zhang, Shouda Liu, Jie Luo, Xianglong Liu, and Michele Magno. Accurate lora-finetuning quantization of llms via information retention. arXiv preprint arXiv:2402.05445, 2024.
- Yujia Qin, Xiaozhi Wang, Yusheng Su, Yankai Lin, Ning Ding, Jing Yi, Weize Chen, Zhiyuan Liu, Juanzi Li, Lei Hou, Peng Li, Maosong Sun, and Jie Zhou. Exploring universal intrinsic task subspace via prompt tuning. 2021.
- Alec Radford, Jeff Wu, Rewon Child, David Luan, Dario Amodei, and Ilya Sutskever. Language models are unsupervised multitask learners. 2019.
- Colin Raffel, Noam Shazeer, Adam Roberts, Katherine Lee, Sharan Narang, Michael Matena, Yanqi Zhou, Wei Li, and Peter J Liu. Exploring the limits of transfer learning with a unified text-to-text transformer. arXiv preprint arXiv:1910.10683, 2019.
- Pranav Rajpurkar, Robin Jia, and Percy Liang. Know what you don’t know: Unanswerable questions for squad. Proceedings of the 56th Annual Meeting of the Association for Computational Linguistics (Volume 2: Short Papers), 2018. doi: 10.18653/v1/p18-2124. URL <http://dx.doi.org/10.18653/v1/P18-2124>.
- Sylvestre-Alvise Rebuffi, Hakan Bilen, and Andrea Vedaldi. Learning multiple visual domains with residual adapters. In I. Guyon, U. Von Luxburg, S. Bengio, H. Wallach, R. Fergus, S. Vishwanathan, and R. Garnett, editors, Advances in Neural Information Processing Systems, volume 30. Curran Associates, Inc., 2017. URL <https://proceedings.neurips.cc/paper/2017/file/e7b24b112a44fdd9ee93bdf998c6ca0e-Paper.pdf>.
- Sylvestre-Alvise Rebuffi, Hakan Bilen, and Andrea Vedaldi. Efficient parametrization of multi-domain deep neural networks. 2018 IEEE/CVF Conference on Computer Vision and Pattern Recognition, pages 8119–8127, 2018.
- Anna Rogers, Olga Kovaleva, and Anna Rumshisky. A primer in BERTology: What we know about how BERT works. Transactions of the Association for Computational Linguistics, 8:842–866, 2020. doi: 10.1162/tacl_a_00349. URL <https://aclanthology.org/2020.tacl-1.54>.
- Tim Salimans and Diederik P. Kingma. Weight normalization: a simple reparameterization to accelerate training of deep neural networks. In Proceedings of the 30th International Conference on Neural Information Processing Systems, NIPS’16, page 901–909, Red Hook, NY, USA, 2016. Curran Associates Inc. ISBN 9781510838819.

Victor Sanh, Albert Webson, Colin Raffel, Stephen Bach, Lintang Sutawika, Zaid Alyafeai, Antoine Chaffin, Arnaud Stiegler, Arun Raja, Manan Dey, M Saiful Bari, Canwen Xu, Urmish Thakker, Shanya Sharma Sharma, Eliza Szczechla, Taewoon Kim, Gunjan Chhablani, Nihal Nayak, Debajyoti Datta, Jonathan Chang, Mike Tian-Jian Jiang, Han Wang, Matteo Manica, Sheng Shen, Zheng Xin Yong, Harshit Pandey, Rachel Bawden, Thomas Wang, Trishala Neeraj, Jos Rozen, Abheesht Sharma, Andrea Santilli, Thibault Fevry, Jason Alan Fries, Ryan Teehan, Teven Le Scao, Stella Biderman, Leo Gao, Thomas Wolf, and Alexander M Rush. Multitask prompted training enables zero-shot task generalization. In *International Conference on Learning Representations*, 2022. URL <https://openreview.net/forum?id=9Vrb9D0WI4>.

Teven Le Scao, Angela Fan, Christopher Akiki, Elizabeth-Jane Pavlick, Suzana Ilić, Daniel Hesslow, Roman Castagn'e, Alexandra Sasha Luccioni, Francois Yvon, Matthias Gall'e, Jonathan Tow, Alexander M. Rush, Stella Rose Biderman, Albert Webson, Pawan Sasanka Ammanamanchi, Thomas Wang, Benoît Sagot, Niklas Muennighoff, Albert Villanova del Moral, Olatunji Ruwase, Rachel Bawden, Stas Bekman, Angelina McMillan-Major, Iz Beltagy, Huu Nguyen, Lucile Saulnier, Samson Tan, Pedro Ortiz Suarez, Victor Sanh, Hugo Laurencon, Yacine Jernite, Julien Launay, Margaret Mitchell, Colin Raffel, Aaron Gokaslan, Adi Simhi, Aitor Soroa Etxabe, Alham Fikri Aji, Amit Alfassy, Anna Rogers, Ariel Kreisberg Nitzav, Canwen Xu, Chenghao Mou, Chris C. Emezue, Christopher Klamm, Colin Leong, Daniel Alexander van Strien, David Ifeoluwa Adelani, Dragomir R. Radev, Eduardo G. Ponferrada, Efrat Levkovich, Ethan Kim, Eyal Bar Natan, Francesco De Toni, Gérard Dupont, Germán Kruszewski, Giada Pistilli, Hady ElSahar, Hamza Benyamina, Hieu Tran, Ian Yu, Idris Abdulmumin, Isaac Johnson, Itziar Gonzalez-Dios, Javier de la Rosa, Jenny Chim, Jesse Dodge, Jian Zhu, Jonathan Chang, Jorg Froberg, Josephine L. Tobing, Joydeep Bhattacharjee, Khalid Almubarak, Kimbo Chen, Kyle Lo, Leandro von Werra, Leon Weber, Long Phan, Loubna Ben Allal, Ludovic Tanguy, Manan Dey, Manuel Romero Muñoz, Maraim Masoud, Mar'ia Grandury, Mario vSavsko, Max Huang, Maximin Coavoux, Mayank Singh, Mike Tian-Jian Jiang, Minh Chien Vu, Mohammad Ali Jauhar, Mustafa Ghaleb, Nishant Subramani, Nora Kassner, Nurulaqilla Khamis, Olivier Nguyen, Omar Espejel, Ona de Gibert, Paulo Villegas, Peter Henderson, Pierre Colombo, Priscilla Amuok, Quentin Lhoest, Rheza Harliman, Rishi Bommasani, Roberto L'opez, Rui Ribeiro, Salomey Osei, Sampo Pyysalo, Sebastian Nagel, Shamik Bose, Shamsuddeen Hassan Muhammad, Shanya Sharma, S. Longpre, Somaieh Nikpoor, Stanislav Silberberg, Suhas Pai, Sydney Zink, Tiago Timponi Torrent, Timo Schick, Tristan Thrush, Valentin Danchev, Vassilina Nikoulina, Veronika Laippala, Violette Lepercq, Vrinda Prabhu, Zaid Alyafeai, Zeerak Talat, Arun Raja, Benjamin Heinzerling, Chenglei Si, Elizabeth Salesky, Sabrina J. Mielke, Wilson Y. Lee, Abheesht Sharma, Andrea Santilli, Antoine Chaffin, Arnaud Stiegler, Debajyoti Datta, Eliza Szczechla, Gunjan Chhablani, Han Wang, Harshit Pandey, Hendrik Strobelt, Jason Alan Fries, Jos Rozen, Leo Gao, Lintang Sutawika, M Saiful Bari, Maged S. Al-shaibani, Matteo Manica, Nihal V. Nayak, Ryan Teehan, Samuel Albanie, Sheng Shen, Srulik Ben-David, Stephen H. Bach, Taewoon Kim, Tali Bers, Thibault Févry, Trishala Neeraj, Urmish Thakker, Vikas Raunak, Xiang Tang, Zheng Xin Yong, Zhiqing Sun, Shaked Brody, Y Uri, Hadar Tojarieh, Adam Roberts, Hyung Won Chung, Jaesung Tae, Jason

Phang, Ofir Press, Conglong Li, Deepak Narayanan, Hatim Bourfoune, Jared Casper, Jeff Rasley, Max Ryabinin, Mayank Mishra, Minjia Zhang, Mohammad Shoeybi, Myr-iam Peyrounette, Nicolas Patry, Nouamane Tazi, Omar Sanseviero, Patrick von Platen, Pierre Cornette, Pierre Francois Lavall’ee, Rémi Lacroix, Samyam Rajbhandari, San- chit Gandhi, Shaden Smith, Stéphane Requena, Suraj Patil, Tim Dettmers, Ahmed Baruwa, Amanpreet Singh, Anastasia Cheveleva, Anne-Laure Ligozat, Arjun Subramo- nian, Aur’elie N’ev’eol, Charles Lovering, Daniel H Garrette, Deepak R. Tunuguntla, Ehud Reiter, Ekaterina Taktasheva, Ekaterina Voloshina, Eli Bogdanov, Genta Indra Winata, Hailey Schoelkopf, Jan-Christoph Kalo, Jekaterina Novikova, Jessica Zosa Forde, Jordan Clive, Jungo Kasai, Ken Kawamura, Liam Hazan, Marine Carpuat, Miruna Clinciu, Na- joun Kim, Newton Cheng, Oleg Serikov, Omer Antverg, Oskar van der Wal, Rui Zhang, Ruochen Zhang, Sebastian Gehrmann, S. Osher Pais, Tatiana Shavrina, Thomas Scialom, Tian Yun, Tomasz Limisiewicz, Verena Rieser, Vitaly Protasov, Vladislav Mikhailov, Yada Pruksachatkun, Yonatan Belinkov, Zachary Bamberger, Zdenvek Kasner, Alice Rueda, Amanda Pestana, Amir Feizpour, Ammar Khan, Amy Faranak, Ananda Santa Rosa San- tos, Anthony Hevia, Antigona Undreaj, Arash Aghagol, Arezoo Abdollahi, Aycha Tam- mour, Azadeh HajiHosseini, Bahareh Behroozi, Benjamin Olusola Ajibade, Bharat Ku- mar Saxena, Carlos Muñoz Ferrandis, Danish Contractor, David M. Lansky, Davis David, Douwe Kiela, Duong Anh Nguyen, Edward Tan, Emily Baylor, Ezinwanne Ozoani, Fa- tim T Mirza, Frankline Ononiwu, Habib Rezanejad, H.A. Jones, Indrani Bhattacharya, Irene Solaiman, Irina Sedenko, Isar Nejadgholi, Jan Passmore, Joshua Seltzer, Julio Bo- nis Sanz, Karen Fort, Livia Macedo Dutra, Mairon Samagaio, Maraim Elbadri, Margot Mieskes, Marissa Gerchick, Martha Akinlolu, Michael McKenna, Mike Qiu, M. K. K. Ghauri, Mykola Burynok, Nafis Abrar, Nazneen Rajani, Nour Elkott, Nourhan Fahmy, Olanrewaju Modupe Samuel, Ran An, R. P. Kromann, Ryan Hao, Samira Alizadeh, Sar- mad Shubber, Silas L. Wang, Sourav Roy, Sylvain Viguier, Thanh-Cong Le, Tobi Oyeade, Trieu Nguyen Hai Le, Yoyo Yang, Zachary Kyle Nguyen, Abhinav Ramesh Kashyap, Al- fredo Palasciano, Alison Callahan, Anima Shukla, Antonio Miranda-Escalada, Ayush Ku- mar Singh, Benjamin Beilharz, Bo Wang, Caio Matheus Fonseca de Brito, Chenxi Zhou, Chirag Jain, Chuxin Xu, Clémentine Fourrier, Daniel Le’on Perin’an, Daniel Molano, Dian Yu, Enrique Manjavacas, Fabio Barth, Florian Fuhrmann, Gabriel Altay, Giyased- din Bayrak, Gully A. Burns, Helena U. Vrabec, Iman I.B. Bello, Isha Dash, Ji Soo Kang, John Giorgi, Jonas Golde, Jose David Posada, Karthi Sivaraman, Lokesh Bulchandani, Lu Liu, Luisa Shinzato, Madeleine Hahn de Bykhovetz, Maiko Takeuchi, Marc Pàmies, María Andrea Castillo, Marianna Nezhurina, Mario Sanger, Matthias Samwald, Michael Cullan, Michael Weinberg, M Wolf, Mina Mihaljcic, Minna Liu, Moritz Freidank, Myung- sun Kang, Natasha Seelam, Nathan Dahlberg, Nicholas Michio Broad, Nikolaus Muellner, Pascale Fung, Patricia Haller, R. Chandrasekhar, R. Eisenberg, Robert Martin, Rodrigo L. Canalli, Rosaline Su, Ruisi Su, Samuel Cahyawijaya, Samuele Garda, Shlok S Deshmukh, Shubhanshu Mishra, Sid Kiblawi, Simon Ott, Sincee Sang-aaroonsiri, Srishti Kumar, Stefan Schweter, Sushil Pratap Bharati, T. A. Laud, Th’eo Gigant, Tomoya Kainuma, Woj- ciech Kusa, Yanis Labrak, Yashasvi Bajaj, Y. Venkatraman, Yifan Xu, Ying Xu, Yun- chao Xu, Zhee Xao Tan, Zhongli Xie, Zifan Ye, Mathilde Bras, Younes Belkada, and Thomas Wolf. Bloom: A 176b-parameter open-access multilingual language model. [ArXiv, abs/2211.05100v2](https://arxiv.org/abs/2211.05100v2), 2022.

- Timo Schick and Hinrich Schütze. It’s not just size that matters: Small language models are also few-shot learners. In Proceedings of the 2021 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, pages 2339–2352, Online, June 2021. Association for Computational Linguistics. doi: 10.18653/v1/2021.naacl-main.185. URL <https://aclanthology.org/2021.naacl-main.185>.
- Abigail See, Peter J. Liu, and Christopher D. Manning. Get to the point: Summarization with pointer-generator networks. In Proceedings of the 55th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers), pages 1073–1083, Vancouver, Canada, July 2017. Association for Computational Linguistics. doi: 10.18653/v1/P17-1099. URL <https://www.aclweb.org/anthology/P17-1099>.
- Noam Shazeer, *Azalia Mirhoseini, *Krzysztof Maziarczyk, Andy Davis, Quoc Le, Geoffrey Hinton, and Jeff Dean. Outrageously large neural networks: The sparsely-gated mixture-of-experts layer. In International Conference on Learning Representations, 2017. URL <https://openreview.net/forum?id=B1ckMDqlg>.
- Mohammad Shoeybi, Mostofa Patwary, Raul Puri, Patrick LeGresley, Jared Casper, and Bryan Catanzaro. Megatron-lm: Training multi-billion parameter language models using model parallelism. ArXiv, abs/1909.08053, 2019.
- Aarohi Srivastava, Abhinav Rastogi, Abhishek Rao, Abu Awal Md Shoeb, Abubakar Abid, Adam Fisch, Adam R. Brown, Adam Santoro, Aditya Gupta, Adrià Garriga-Alonso, Agnieszka Kluska, Aitor Lewkowycz, Akshat Agarwal, Alethea Power, Alex Ray, Alex Warstadt, Alexander W. Kocurek, Ali Safaya, Ali Tazarv, Alice Xiang, Alicia Parrish, Allen Nie, Aman Hussain, Amanda Askell, Amanda Dsouza, Ambrose Slone, Ameet Rahane, Anantharaman S. Iyer, Anders Andreassen, Andrea Madotto, Andrea Santilli, Andreas Stuhlmüller, Andrew Dai, Andrew La, Andrew Lampinen, Andy Zou, Angela Jiang, Angelica Chen, Anh Vuong, Animesh Gupta, Anna Gottardi, Antonio Norelli, Anu Venkatesh, Arash Gholamidavoodi, Arfa Tabassum, Arul Menezes, Arun Kirubakaran, Asher Mullokandov, Ashish Sabharwal, Austin Herrick, Avia Efrat, Aykut Erdem, Ayla Karakaş, B. Ryan Roberts, Bao Sheng Loe, Barret Zoph, Bartłomiej Bojanowski, Batuhan Özyurt, Behnam Hedayatnia, Behnam Neyshabur, Benjamin Inden, Benno Stein, Berk Ekmekci, Bill Yuchen Lin, Blake Howald, Cameron Diao, Cameron Dour, Catherine Stinson, Cedrick Argueta, César Ferri Ramírez, Chandan Singh, Charles Rathkopf, Chenlin Meng, Chitta Baral, Chiyu Wu, Chris Callison-Burch, Chris Waites, Christian Voigt, Christopher D. Manning, Christopher Potts, Cindy Ramirez, Clara E. Rivera, Clemencia Siro, Colin Raffel, Courtney Ashcraft, Cristina Garbacea, Damien Sileo, Dan Garrette, Dan Hendrycks, Dan Kilman, Dan Roth, Daniel Freeman, Daniel Khashabi, Daniel Levy, Daniel Moseguí González, Danielle Perszyk, Danny Hernandez, Danqi Chen, Daphne Ippolito, Dar Gilboa, David Dohan, David Drakard, David Jurgens, Debajyoti Datta, Deep Ganguli, Denis Emelin, Denis Kleyko, Deniz Yuret, Derek Chen, Derek Tam, Dieuwke Hupkes, Diganta Misra, Dilyar Buzan, Dimitri Coelho Mollo, Diyi Yang, Dong-Ho Lee, Ekaterina Shutova, Ekin Dogus Cubuk, Elad Segal, Eleanor Hagerman, Elizabeth Barnes, Elizabeth Donoway, Ellie Pavlick, Emanuele Rodola, Emma Lam, Eric Chu, Eric Tang, Erkut Erdem, Ernie Chang, Ethan A. Chi, Ethan Dyer, Ethan Jerzak,

Ethan Kim, Eunice Engefu Manyasi, Evgenii Zheltonozhskii, Fanyue Xia, Fatemeh Siar, Fernando Martínez-Plumed, Francesca Happé, Francois Chollet, Frieda Rong, Gaurav Mishra, Genta Indra Winata, Gerard de Melo, Germán Kruszewski, Giambattista Parascandolo, Giorgio Mariani, Gloria Wang, Gonzalo Jaimovitch-López, Gregor Betz, Guy Gur-Ari, Hana Galijasevic, Hannah Kim, Hannah Rashkin, Hannaneh Hajishirzi, Harsh Mehta, Hayden Bogar, Henry Shevlin, Hinrich Schütze, Hiromu Yakura, Hongming Zhang, Hugh Mee Wong, Ian Ng, Isaac Noble, Jaap Jumelet, Jack Geissinger, Jackson Kernion, Jacob Hilton, Jaehoon Lee, Jaime Fernández Fisac, James B. Simon, James Koppel, James Zheng, James Zou, Jan Kocoń, Jana Thompson, Jared Kaplan, Jarema Radom, Jascha Sohl-Dickstein, Jason Phang, Jason Wei, Jason Yosinski, Jekaterina Novikova, Jelle Bosscher, Jennifer Marsh, Jeremy Kim, Jeroen Taal, Jesse Engel, Jesujoba Alabi, Jiacheng Xu, Jiaming Song, Jillian Tang, Joan Waweru, John Burden, John Miller, John U. Balis, Jonathan Berant, Jörg Frohberg, Jos Rozen, Jose Hernandez-Orallo, Joseph Boudeman, Joseph Jones, Joshua B. Tenenbaum, Joshua S. Rule, Joyce Chua, Kamil Kancierz, Karen Livescu, Karl Krauth, Karthik Gopalakrishnan, Katerina Ignatyeva, Katja Markert, Kaustubh D. Dhole, Kevin Gimpel, Kevin Omondi, Kory Mathewson, Kristen Chiafullo, Ksenia Shkaruta, Kumar Shridhar, Kyle McDonell, Kyle Richardson, Laria Reynolds, Leo Gao, Li Zhang, Liam Dugan, Lianhui Qin, Lidia Contreras-Ochando, Louis-Philippe Morency, Luca Moschella, Lucas Lam, Lucy Noble, Ludwig Schmidt, Luheng He, Luis Oliveros Colón, Luke Metz, Lütü Kerem Şenel, Maarten Bosma, Maarten Sap, Maartje ter Hoeve, Maheen Farooqi, Manaal Faruqui, Mantas Mazeika, Marco Baturan, Marco Marelli, Marco Maru, Maria Jose Ramírez Quintana, Marie Tolkiehn, Mario Giulianelli, Martha Lewis, Martin Potthast, Matthew L. Leavitt, Matthias Hagen, Mátyás Schubert, Medina Orduna Baitemirova, Melody Arnaud, Melvin McElrath, Michael A. Yee, Michael Cohen, Michael Gu, Michael Ivanitskiy, Michael Starritt, Michael Strube, Michał Śwędrowski, Michele Bevilacqua, Michihiro Yasunaga, Mihir Kale, Mike Cain, Mimeo Xu, Mirac Suzgun, Mo Tiwari, Mohit Bansal, Moin Aminnaseri, Mor Geva, Mozhdeh Gheini, Mukund Varma T, Nanyun Peng, Nathan Chi, Nayeon Lee, Neta Gur-Ari Krakover, Nicholas Cameron, Nicholas Roberts, Nick Doiron, Nikita Nangia, Niklas Deckers, Niklas Muennighoff, Nitish Shirish Keskar, Niveditha S. Iyer, Noah Constant, Noah Fiedel, Nuan Wen, Oliver Zhang, Omar Agha, Omar Elbaghdadi, Omer Levy, Owain Evans, Pablo Antonio Moreno Casares, Parth Doshi, Pascale Fung, Paul Pu Liang, Paul Vicol, Pegah Alipoormolabashi, Peiyuan Liao, Percy Liang, Peter Chang, Peter Eckersley, Phu Mon Htut, Pinyu Hwang, Piotr Miłkowski, Piyush Patil, Pouya Pezeshkpour, Priti Oli, Qiaozhu Mei, Qing Lyu, Qinlang Chen, Rabin Banjade, Rachel Etta Rudolph, Raefer Gabriel, Rahel Habacker, Ramón Risco Delgado, Raphaël Milliére, Rhythm Garg, Richard Barnes, Rif A. Saurous, Riku Arakawa, Robbe Raymaekers, Robert Frank, Rohan Sikand, Roman Novak, Roman Sitelew, Ronan LeBras, Rosanne Liu, Rowan Jacobs, Rui Zhang, Ruslan Salakhutdinov, Ryan Chi, Ryan Lee, Ryan Stovall, Ryan Teehan, Rylan Yang, Sahib Singh, Saif M. Mohammad, Sajant Anand, Sam Dillavou, Sam Shleifer, Sam Wiseman, Samuel Gruetter, Samuel R. Bowman, Samuel S. Schoenholz, Sanghyun Han, Sanjeev Kwatra, Sarah A. Rous, Sarik Ghazarian, Sayan Ghosh, Sean Casey, Sebastian Bischoff, Sebastian Gehrmann, Sebastian Schuster, Sepideh Sadeghi, Shadi Hamdan, Sharon Zhou, Shashank Srivastava, Sherry Shi, Shikhar Singh, Shima Asaadi, Shixiang Shane Gu, Shubh Pachchigar, Shubham Toshniwal, Shyam Upadhyay,

- Shyamolima, Debnath, Siamak Shakeri, Simon Thormeyer, Simone Melzi, Siva Reddy, Sneha Priscilla Makini, Soo-Hwan Lee, Spencer Torene, Sriharsha Hatwar, Stanislas Dehaene, Stefan Divic, Stefano Ermon, Stella Biderman, Stephanie Lin, Stephen Prasad, Steven T. Piantadosi, Stuart M. Shieber, Summer Mishnerghi, Svetlana Kiritchenko, Swaroop Mishra, Tal Linzen, Tal Schuster, Tao Li, Tao Yu, Tariq Ali, Tatsuo Hashimoto, Te-Lin Wu, Théo Desbordes, Theodore Rothschild, Thomas Phan, Tianle Wang, Tiberius Nkinyili, Timo Schick, Timofei Kornev, Timothy Telleen-Lawton, Titus Tunduny, Tobias Gerstenberg, Trenton Chang, Trishala Neeraj, Tushar Khot, Tyler Shultz, Uri Shaham, Vedant Misra, Vera Demberg, Victoria Nyamai, Vikas Raunak, Vinay Ramasesh, Vinay Uday Prabhu, Vishakh Padmakumar, Vivek Srikumar, William Fedus, William Saunders, William Zhang, Wout Vossen, Xiang Ren, Xiaoyu Tong, Xinran Zhao, Xinyi Wu, Xudong Shen, Yadollah Yaghoobzadeh, Yair Lakretz, Yangqiu Song, Yasaman Bahri, Yejin Choi, Yichi Yang, Yiding Hao, Yifu Chen, Yonatan Belinkov, Yu Hou, Yufang Hou, Yuntao Bai, Zachary Seid, Zhuoye Zhao, Zijian Wang, Zijie J. Wang, Zirui Wang, and Ziyi Wu. Beyond the imitation game: Quantifying and extrapolating the capabilities of language models, 2022.
- Yusheng Su, Xiaozhi Wang, Yujia Qin, Chi-Min Chan, Yankai Lin, Zhiyuan Liu, Peng Li, Juan-Zi Li, Lei Hou, Maosong Sun, and Jie Zhou. On transferability of prompt tuning for natural language understanding. *ArXiv*, abs/2111.06719, 2021.
- Yi-Lin Sung, Varun Nair, and Colin A Raffel. Training neural networks with fixed sparse masks. In M. Ranzato, A. Beygelzimer, Y. Dauphin, P.S. Liang, and J. Wortman Vaughan, editors, *Advances in Neural Information Processing Systems*, volume 34, pages 24193–24205. Curran Associates, Inc., 2021. URL <https://proceedings.neurips.cc/paper/2021/file/cb2653f548f8709598e8b5156738cc51-Paper.pdf>.
- Yi-Lin Sung, Jaemin Cho, and Mohit Bansal. Lst: Ladder side-tuning for parameter and memory efficient transfer learning. *ArXiv*, abs/2206.06522, 2022.
- Hugo Touvron, Thibaut Lavril, Gautier Izacard, Xavier Martinet, Marie-Anne Lachaux, Timothée Lacroix, Baptiste Rozière, Naman Goyal, Eric Hambro, Faisal Azhar, et al. Llama: Open and efficient foundation language models. *arXiv preprint arXiv:2302.13971*, 2023.
- Ashish Vaswani, Noam Shazeer, Niki Parmar, Jakob Uszkoreit, Llion Jones, Aidan N Gomez, Łukasz Kaiser, and Illia Polosukhin. Attention is all you need. In *Advances in neural information processing systems*, pages 5998–6008, 2017.
- Tu Vu, Brian Lester, Noah Constant, Rami Al-Rfou, and Daniel Matthew Cer. Spot: Better frozen model adaptation through soft prompt transfer. In *Annual Meeting of the Association for Computational Linguistics*, 2021.
- Danilo Vucetic, Mohammadreza Tayaranian, Maryam Ziaeeefard, James J. Clark, Brett H. Meyer, and Warren J. Gross. Efficient fine-tuning of bert models on the edge. *2022 IEEE International Symposium on Circuits and Systems (ISCAS)*, pages 1838–1842, 2022.

- Alex Wang, Amanpreet Singh, Julian Michael, Felix Hill, Omer Levy, and Samuel R Bowman. Glue: A multi-task benchmark and analysis platform for natural language understanding. [arXiv preprint arXiv:1804.07461](#), 2018.
- Alex Wang, Yada Pruksachatkun, Nikita Nangia, Amanpreet Singh, Julian Michael, Felix Hill, Omer Levy, and Samuel R Bowman. Superglue: A stickier benchmark for general-purpose language understanding systems. [arXiv preprint arXiv:1905.00537](#), 2019.
- Yaqing Wang, Subhabrata Mukherjee, Xiaodong Liu, Jing Gao, Ahmed Hassan Awadallah, and Jianfeng Gao. Adamix: Mixture-of-adapter for parameter-efficient tuning of large language models. [ArXiv](#), abs/2205.12410, 2022.
- Thomas Wolf, Lysandre Debut, Victor Sanh, Julien Chaumond, Clement Delangue, Anthony Moi, Pierric Cistac, Clara Ma, Yacine Jernite, Julien Plu, Canwen Xu, Teven Le Scao, Sylvain Gugger, Mariama Drame, Quentin Lhoest, and Alexander M. Rush. Transformers: State-of-the-Art Natural Language Processing. pages 38–45. Association for Computational Linguistics, 10 2020. URL <https://www.aclweb.org/anthology/2020.emnlp-demos.6>.
- Enze Xie, Lewei Yao, Han Shi, Zhili Liu, Daquan Zhou, Zhaoqiang Liu, Jiawei Li, and Zhen-guo Li. Difffit: Unlocking transferability of large diffusion models via simple parameter-efficient fine-tuning. [arXiv preprint arXiv:2304.06648](#), 2023.
- Yuhui Xu, Lingxi Xie, Xiaotao Gu, Xin Chen, Heng Chang, Hengheng Zhang, Zhensu Chen, Xiaopeng Zhang, and Qi Tian. Qa-lora: Quantization-aware low-rank adaptation of large language models. [arXiv preprint arXiv:2309.14717](#), 2023.
- Aohan Zeng, Xiao Liu, Zhengxiao Du, Zihan Wang, Hanyu Lai, Ming Ding, Zhuoyi Yang, Yifan Xu, Wendi Zheng, Xiao Xia, Weng Lam Tam, Zixuan Ma, Yufei Xue, Jidong Zhai, Wenguang Chen, Peng Zhang, Yuxiao Dong, and Jie Tang. Glm-130b: An open bilingual pre-trained model, 2022.
- Aston Zhang, Yi Tay, Shuai Zhang, Alvin Chan, Anh Tuan Luu, Siu Cheung Hui, and Jie Fu. Beyond fully-connected layers with quaternions: Parameterization of hypercomplex multiplications with $1/n$ parameters. In [International Conference on Learning Representations](#), 2021.
- Qingru Zhang, Minshuo Chen, Alexander Bukharin, Pengcheng He, Yu Cheng, Weizhu Chen, and Tuo Zhao. Adaptive budget allocation for parameter-efficient fine-tuning. [arXiv preprint arXiv:2303.10512](#), 2023a.
- Susan Zhang, Stephen Roller, Naman Goyal, Mikel Artetxe, Moya Chen, Shuohui Chen, Christopher Dewan, Mona Diab, Xian Li, Xi Victoria Lin, Todor Mihaylov, Myle Ott, Sam Shleifer, Kurt Shuster, Daniel Simig, Punit Singh Koura, Anjali Sridhar, Tianlu Wang, and Luke Zettlemoyer. Opt: Open pre-trained transformer language models, 2022.
- Zhen-Ru Zhang, Chuanqi Tan, Haiyang Xu, Chengyu Wang, Jun Huang, and Songfang Huang. Towards adaptive prefix tuning for parameter-efficient language model fine-tuning. [arXiv preprint arXiv:2305.15212](#), 2023b.

Jiawei Zhao, Zhenyu Zhang, Beidi Chen, Zhangyang Wang, Anima Anandkumar, and Yuan-dong Tian. Galore: Memory-efficient llm training by gradient low-rank projection. arXiv preprint arXiv:2403.03507, 2024.

Yaoming Zhu, Jiangtao Feng, Chengqi Zhao, Mingxuan Wang, and Lei Li. Counter-interference adapter for multilingual machine translation. In Findings of the Association for Computational Linguistics: EMNLP 2021, pages 2812–2823, Punta Cana, Dominican Republic, November 2021. Association for Computational Linguistics. doi: 10.18653/v1/2021.findings-emnlp.240. URL <https://aclanthology.org/2021.findings-emnlp.240>.

Appendix A. Prompts

Prompts used in our experimental comparison

- BoolQ: "Given a passage and a yes/no question, identify if the answer is *yes* or *no*."
- CB: "Given a premise, identify if the hypothesis entails, contradicts or is neutral to the premise."
- COPA: "Given a premise, a question (cause/effect) and two alternative choices, identify plausible answer from the alternative choices."
- RTE: "Given a premise, identify if the hypothesis entails premise or not."

Appendix B. PEFT Comparison: full experimental results

The following table contains raw results used to produce Tables 4 and 5. Before these experiments, each model-method-dataset combination was swept over learning rates 1e-3, 1e-4, 5e-5. In our initial experiments we also included a sweep over weight decay (0 and 0.1), but we found it to minimally affect the results of these models on these datasets, always less than 0.01.

Model	Method	Dataset	Seed	Score
T5 3B	Full tuning	RTE		90.70
T5 3B	Full tuning	COPA		92.00
T5 3B	Full tuning	BoolQ		89.30
T5 3B	Full tuning	CNN		27.32
T5 3B	Adapters (Houlsby)	RTE	0	90.61
T5 3B	Adapters (Houlsby)	RTE	1	90.25
T5 3B	Adapters (Houlsby)	RTE	42	90.61
T5 3B	Adapters (Houlsby)	COPA	0	93.00
T5 3B	Adapters (Houlsby)	COPA	1	92.00
T5 3B	Adapters (Houlsby)	COPA	42	90.00
T5 3B	Adapters (Houlsby)	BoolQ	0	89.17
T5 3B	Adapters (Houlsby)	BoolQ	1	88.59
T5 3B	Adapters (Houlsby)	BoolQ	42	88.35
T5 3B	Adapters (Houlsby)	CNN	42	27.77
T5 3B	Adapters (Pfeiffer)	RTE	0	86.63
T5 3B	Adapters (Pfeiffer)	RTE	1	84.84
T5 3B	Adapters (Pfeiffer)	RTE	42	85.92
T5 3B	Adapters (Pfeiffer)	COPA	0	76.00
T5 3B	Adapters (Pfeiffer)	COPA	1	70.00

T5 3B	Adapters (Pfeiffer)	COPA	42	81.00
T5 3B	Adapters (Pfeiffer)	BoolQ	0	88.53
T5 3B	Adapters (Pfeiffer)	BoolQ	1	89.11
T5 3B	Adapters (Pfeiffer)	BoolQ	42	88.81
T5 3B	Adapters (Pfeiffer)	CNN	0	29.40
T5 3B	Scaled Parallel	RTE	0	90.61
T5 3B	Scaled Parallel	RTE	1	91.34
T5 3B	Scaled Parallel	RTE	42	89.89
T5 3B	Scaled Parallel	COPA	0	87.00
T5 3B	Scaled Parallel	COPA	1	87.00
T5 3B	Scaled Parallel	COPA	42	87.00
T5 3B	Scaled Parallel	BoolQ	0	88.90
T5 3B	Scaled Parallel	BoolQ	1	88.93
T5 3B	Scaled Parallel	BoolQ	42	89.02
T5 3B	Scaled Parallel	CNN	0	30.03
T5 3B	Ln tuning	RTE	0	87.37
T5 3B	Ln tuning	RTE	1	87.00
T5 3B	Ln tuning	RTE	42	88.45
T5 3B	Ln tuning	COPA	0	89.00
T5 3B	Ln tuning	COPA	1	89.00
T5 3B	Ln tuning	COPA	42	87.00
T5 3B	Ln tuning	BoolQ	0	87.25
T5 3B	Ln tuning	BoolQ	1	87.49
T5 3B	Ln tuning	BoolQ	42	87.49
T5 3B	Ln tuning	CNN	0	28.43
T5 3B	LoRa (q and v)	RTE	0	91.70
T5 3B	LoRa (q and v)	RTE	1	90.25
T5 3B	LoRa (q and v)	RTE	42	89.17
T5 3B	LoRa (q and v)	COPA	0	94.00
T5 3B	LoRa (q and v)	COPA	1	92.00
T5 3B	LoRa (q and v)	COPA	42	93.00
T5 3B	LoRa (q and v)	BoolQ	0	89.08
T5 3B	LoRa (q and v)	BoolQ	1	88.69
T5 3B	LoRa (q and v)	BoolQ	42	88.53
T5 3B	LoRa (q and v)	CNN	0	29.80
T5 3B	LoRa (all)	RTE	0	89.89
T5 3B	LoRa (all)	RTE	1	89.89
T5 3B	LoRa (all)	RTE	42	89.53
T5 3B	LoRa (all)	COPA	0	94.00
T5 3B	LoRa (all)	COPA	1	94.00
T5 3B	LoRa (all)	COPA	42	92.00
T5 3B	LoRa (all)	BoolQ	0	88.65
T5 3B	LoRa (all)	BoolQ	1	88.78
T5 3B	LoRa (all)	BoolQ	42	88.81
T5 3B	LoRa (all)	CNN	0	29.02
T5 3B	Krona	RTE	0	88.09
T5 3B	Krona	RTE	1	88.09
T5 3B	Krona	RTE	42	88.45
T5 3B	Krona	COPA	0	84.00
T5 3B	Krona	COPA	1	84.00
T5 3B	Krona	COPA	42	84.00
T5 3B	Krona	BoolQ	0	87.68
T5 3B	Krona	BoolQ	1	87.98
T5 3B	Krona	BoolQ	42	87.68
T5 3B	Krona	CNN	0	27.94
T5 3B	Compacter	RTE	0	88.09
T5 3B	Compacter	RTE	1	88.09
T5 3B	Compacter	RTE	42	88.81
T5 3B	Compacter	COPA	0	79.00
T5 3B	Compacter	COPA	1	79.00
T5 3B	Compacter	COPA	42	80.00
T5 3B	Compacter	BoolQ	0	87.50
T5 3B	Compacter	BoolQ	1	87.65
T5 3B	Compacter	BoolQ	42	87.61
T5 3B	Compacter	CNN	0	27.64
T5 3B	Compacter++	RTE	0	88.45
T5 3B	Compacter++	RTE	1	88.09
T5 3B	Compacter++	RTE	42	88.09
T5 3B	Compacter++	COPA	0	79.00

T5 3B	Compacter++	COPA	1	82.00
T5 3B	Compacter++	COPA	42	80.00
T5 3B	Compacter++	BoolQ	0	87.75
T5 3B	Compacter++	BoolQ	1	87.62
T5 3B	Compacter++	BoolQ	42	87.75
T5 3B	Compacter++	CNN	0	27.74
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T5 3B	IA3	RTE	0	51.26
T5 3B	IA3	RTE	1	51.26
T5 3B	IA3	RTE	42	51.26
T5 3B	IA3	COPA	0	1.00
T5 3B	IA3	COPA	1	1.00
T5 3B	IA3	COPA	42	1.00
T5 3B	IA3	BoolQ	0	87.28
T5 3B	IA3	BoolQ	1	87.28
T5 3B	IA3	BoolQ	42	87.28
T5 3B	IA3	CNN	0	27.55
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T5 3B	IA3 (min steps 500)	RTE	0	51.26
T5 3B	IA3 (min steps 500)	RTE	1	51.26
T5 3B	IA3 (min steps 500)	RTE	42	51.26
T5 3B	IA3 (min steps 500)	COPA	0	1.00
T5 3B	IA3 (min steps 500)	COPA	1	1.00
T5 3B	IA3 (min steps 500)	COPA	42	1.00
T5 3B	IA3 (min steps 500)	BoolQ	0	88.12
T5 3B	IA3 (min steps 500)	BoolQ	1	88.12
T5 3B	IA3 (min steps 500)	BoolQ	42	88.12
T5 3B	IA3 (min steps 500)	CNN	0	
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T5 3B	MAM	RTE	0	52.71
T5 3B	MAM	RTE	1	53.07
T5 3B	MAM	RTE	42	53.43
T5 3B	MAM	COPA	0	55.00
T5 3B	MAM	COPA	1	55.00
T5 3B	MAM	COPA	42	63.00
T5 3B	MAM	BoolQ	0	64.36
T5 3B	MAM	BoolQ	1	63.86
T5 3B	MAM	BoolQ	42	64.36
T5 3B	MAM	CNN	0	7.36
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T5 3B	Prefix_tuning	RTE	0	55.23
T5 3B	Prefix_tuning	RTE	1	51.99
T5 3B	Prefix_tuning	RTE	42	53.79
T5 3B	Prefix_tuning	COPA	0	61.00
T5 3B	Prefix_tuning	COPA	1	58.00
T5 3B	Prefix_tuning	COPA	42	51.00
T5 3B	Prefix_tuning	BoolQ	0	64.85
T5 3B	Prefix_tuning	BoolQ	1	65.35
T5 3B	Prefix_tuning	BoolQ	42	63.86
T5 3B	Prefix_tuning	CNN	0	21.34
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T5 3B	Prefix_tuning_flat	RTE	0	
T5 3B	Prefix_tuning_flat	RTE	1	
T5 3B	Prefix_tuning_flat	RTE	42	
T5 3B	Prefix_tuning_flat	COPA	0	
T5 3B	Prefix_tuning_flat	COPA	1	
T5 3B	Prefix_tuning_flat	COPA	42	
T5 3B	Prefix_tuning_flat	BoolQ	0	
T5 3B	Prefix_tuning_flat	BoolQ	1	
T5 3B	Prefix_tuning_flat	BoolQ	42	
T5 3B	Prefix_tuning_flat	CNN	0	8.38
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T5 3B	Unipelt	RTE	0	53.07
T5 3B	Unipelt	RTE	1	52.71
T5 3B	Unipelt	RTE	42	54.51
T5 3B	Unipelt	COPA	0	57.00
T5 3B	Unipelt	COPA	1	57.00
T5 3B	Unipelt	COPA	42	57.00
T5 3B	Unipelt	BoolQ	0	64.36
T5 3B	Unipelt	BoolQ	1	63.86
T5 3B	Unipelt	BoolQ	42	55.94
T5 3B	Unipelt	CNN	0	16.84
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T5 11B	Full tuning	RTE		91.09
T5 11B	Full tuning	COPA		85.71
T5 11B	Full tuning	BoolQ		88.89

T5 11B	Full tuning	CNN		27.32
T5 11B	Adapters (Houlsby)	RTE	0	92.06
T5 11B	Adapters (Houlsby)	RTE	1	90.25
T5 11B	Adapters (Houlsby)	RTE	42	90.97
T5 11B	Adapters (Houlsby)	COPA	0	94.00
T5 11B	Adapters (Houlsby)	COPA	1	93.00
T5 11B	Adapters (Houlsby)	COPA	42	92.00
T5 11B	Adapters (Houlsby)	BoolQ	0	92.57
T5 11B	Adapters (Houlsby)	BoolQ	1	92.08
T5 11B	Adapters (Houlsby)	BoolQ	42	92.57
T5 11B	Adapters (Houlsby)	CNN	0	28.12
T5 11B	Adapters (Pfeiffer)	RTE	0	52.71
T5 11B	Adapters (Pfeiffer)	RTE	1	52.71
T5 11B	Adapters (Pfeiffer)	RTE	42	54.51
T5 11B	Adapters (Pfeiffer)	COPA	0	55.00
T5 11B	Adapters (Pfeiffer)	COPA	1	55.00
T5 11B	Adapters (Pfeiffer)	COPA	42	55.00
T5 11B	Adapters (Pfeiffer)	BoolQ	0	63.82
T5 11B	Adapters (Pfeiffer)	BoolQ	1	65.84
T5 11B	Adapters (Pfeiffer)	BoolQ	42	63.61
T5 11B	Adapters (Pfeiffer)	CNN	0	30.14
T5 11B	Scaled Parallel	RTE	0	90.61
T5 11B	Scaled Parallel	RTE	1	90.97
T5 11B	Scaled Parallel	RTE	42	90.25
T5 11B	Scaled Parallel	COPA	0	69.00
T5 11B	Scaled Parallel	COPA	1	79.00
T5 11B	Scaled Parallel	COPA	42	55.00
T5 11B	Scaled Parallel	BoolQ	0	85.64
T5 11B	Scaled Parallel	BoolQ	1	92.08
T5 11B	Scaled Parallel	BoolQ	42	84.65
T5 11B	Scaled Parallel	CNN	0	29.21
T5 11B	Ln tuning	RTE	0	88.09
T5 11B	Ln tuning	RTE	1	88.45
T5 11B	Ln tuning	RTE	42	88.09
T5 11B	Ln tuning	COPA	0	90.00
T5 11B	Ln tuning	COPA	1	90.00
T5 11B	Ln tuning	COPA	42	91.00
T5 11B	Ln tuning	BoolQ	0	90.59
T5 11B	Ln tuning	BoolQ	1	90.10
T5 11B	Ln tuning	BoolQ	42	91.09
T5 11B	Ln tuning	CNN	0	25.96
T5 11B	Ln tuning	CNN	1	
T5 11B	Ln tuning	CNN	42	
T5 11B	LoRa (q and v)	RTE	0	89.89
T5 11B	LoRa (q and v)	RTE	1	91.34
T5 11B	LoRa (q and v)	RTE	42	91.34
T5 11B	LoRa (q and v)	COPA	0	93.00
T5 11B	LoRa (q and v)	COPA	1	92.00
T5 11B	LoRa (q and v)	COPA	42	92.00
T5 11B	LoRa (q and v)	BoolQ	0	92.08
T5 11B	LoRa (q and v)	BoolQ	1	93.07
T5 11B	LoRa (q and v)	BoolQ	42	92.08
T5 11B	LoRa (q and v)	CNN	0	29.19
T5 11B	LoRa (q and v)	CNN	1	
T5 11B	LoRa (q and v)	CNN	42	
T5 11B	LoRa (all)	RTE	0	92.78
T5 11B	LoRa (all)	RTE	1	91.70
T5 11B	LoRa (all)	RTE	42	90.97
T5 11B	LoRa (all)	COPA	0	94.00
T5 11B	LoRa (all)	COPA	1	94.00
T5 11B	LoRa (all)	COPA	42	91.00
T5 11B	LoRa (all)	BoolQ	0	92.57
T5 11B	LoRa (all)	BoolQ	1	93.56
T5 11B	LoRa (all)	BoolQ	42	92.08
T5 11B	LoRa (all)	CNN	0	28.75
T5 11B	LoRa (all)	CNN	1	

T5 11B	LoRa (all)	CNN	42	
T5 11B	Krona	RTE	0	86.11
T5 11B	Krona	RTE	1	89.53
T5 11B	Krona	RTE	42	85.71
T5 11B	Krona	COPA	0	89.00
T5 11B	Krona	COPA	1	89.00
T5 11B	Krona	COPA	42	76.92
T5 11B	Krona	BoolQ	0	88.61
T5 11B	Krona	BoolQ	1	
T5 11B	Krona	BoolQ	42	
T5 11B	Krona	CNN	0	27.83
T5 11B	Krona	CNN	1	
T5 11B	Krona	CNN	42	
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T5 11B	Compacter	RTE	0	87.73
T5 11B	Compacter	RTE	1	88.81
T5 11B	Compacter	RTE	42	88.09
T5 11B	Compacter	COPA	0	88.00
T5 11B	Compacter	COPA	1	90.00
T5 11B	Compacter	COPA	42	88.00
T5 11B	Compacter	BoolQ	0	90.59
T5 11B	Compacter	BoolQ	1	91.09
T5 11B	Compacter	BoolQ	42	91.09
T5 11B	Compacter	CNN	0	29.52
T5 11B	Compacter	CNN	1	
T5 11B	Compacter	CNN	24	
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T5 11B	Compacter++	RTE	0	88.45
T5 11B	Compacter++	RTE	1	88.45
T5 11B	Compacter++	RTE	42	88.45
T5 11B	Compacter++	COPA	0	90.00
T5 11B	Compacter++	COPA	1	89.00
T5 11B	Compacter++	COPA	42	90.00
T5 11B	Compacter++	BoolQ	0	91.09
T5 11B	Compacter++	BoolQ	1	91.58
T5 11B	Compacter++	BoolQ	42	91.09
T5 11B	Compacter++	CNN	0	29.50
T5 11B	Compacter++	CNN	1	
T5 11B	Compacter++	CNN	42	
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T5 11B	IA3	RTE	0	87.36
T5 11B	IA3	RTE	1	
T5 11B	IA3	RTE	42	
T5 11B	IA3	COPA	0	37.00
T5 11B	IA3	COPA	1	
T5 11B	IA3	COPA	42	
T5 11B	IA3	BoolQ	0	88.12
T5 11B	IA3	BoolQ	1	
T5 11B	IA3	BoolQ	42	
T5 11B	IA3	CNN	0	27.83
T5 11B	IA3	CNN	1	
T5 11B	IA3	CNN	42	
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T5 11B	Prefix_tuning	RTE	0	54.15
T5 11B	Prefix_tuning	RTE	1	54.87
T5 11B	Prefix_tuning	RTE	42	53.79
T5 11B	Prefix_tuning	COPA	0	53.00
T5 11B	Prefix_tuning	COPA	1	55.00
T5 11B	Prefix_tuning	COPA	42	57.00
T5 11B	Prefix_tuning	BoolQ	0	70.30
T5 11B	Prefix_tuning	BoolQ	1	70.30
T5 11B	Prefix_tuning	BoolQ	42	71.29
T5 11B	Prefix_tuning	CNN	0	27.83
T5 11B	Prefix_tuning	CNN	1	
T5 11B	Prefix_tuning	CNN	42	
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T5 11B	MAM	RTE	0	53.07
T5 11B	MAM	RTE	1	52.71
T5 11B	MAM	RTE	42	52.71
T5 11B	MAM	COPA	0	55.00
T5 11B	MAM	COPA	1	55.00
T5 11B	MAM	COPA	42	55.00
T5 11B	MAM	BoolQ	0	70.30
T5 11B	MAM	BoolQ	1	70.30
T5 11B	MAM	BoolQ	42	70.30
T5 11B	MAM	CNN	0	27.83
T5 11B	MAM	CNN	1	

T5 11B	MAM	CNN	42	
T5 11B	Unipelt	RTE	0	52.71
T5 11B	Unipelt	RTE	1	52.71
T5 11B	Unipelt	RTE	42	52.71
T5 11B	Unipelt	COPA	0	55.00
T5 11B	Unipelt	COPA	1	61.00
T5 11B	Unipelt	COPA	42	58.00
T5 11B	Unipelt	BoolQ	0	70.30
T5 11B	Unipelt	BoolQ	1	70.30
T5 11B	Unipelt	BoolQ	42	
T5 11B	Unipelt	CNN	0	27.83
T5 11B	Unipelt	CNN	1	
T5 11B	Unipelt	CNN	42	
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T5 Large	Full tuning	RTE	42	87.00
T5 Large	Full tuning	RTE	1	87.00
T5 Large	Full tuning	RTE	0	86.28
T5 Large	Full tuning	COPA	42	73.00
T5 Large	Full tuning	COPA	1	70.00
T5 Large	Full tuning	COPA	0	68.00
T5 Large	Full tuning	BoolQ	42	85.38
T5 Large	Full tuning	BoolQ	1	84.83
T5 Large	Full tuning	BoolQ	0	84.43
T5 Large	Full tuning	CNN	42	26.79
T5 Large	Full tuning	CNN	1	26.76
T5 Large	Full tuning	CNN	0	27.20
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T5 Large	Adapters (Houlsby)	RTE	42	87.73
T5 Large	Adapters (Houlsby)	RTE	1	89.17
T5 Large	Adapters (Houlsby)	RTE	0	89.53
T5 Large	Adapters (Houlsby)	COPA	42	72.00
T5 Large	Adapters (Houlsby)	COPA	1	75.00
T5 Large	Adapters (Houlsby)	COPA	0	55.00
T5 Large	Adapters (Houlsby)	COPA	42	60.00
T5 Large	Adapters (Houlsby)	COPA	1	72.00
T5 Large	Adapters (Houlsby)	COPA	0	80.00
T5 Large	Adapters (Houlsby)	BoolQ	42	84.98
T5 Large	Adapters (Houlsby)	BoolQ	1	84.53
T5 Large	Adapters (Houlsby)	BoolQ	0	85.44
T5 Large	Adapters (Houlsby)	CNN	42	26.77
T5 Large	Adapters (Houlsby)	CNN	1	25.97
T5 Large	Adapters (Houlsby)	CNN	0	26.96
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T5 Large	Adapters (Pfeiffer)	RTE	42	86.64
T5 Large	Adapters (Pfeiffer)	RTE	1	87.00
T5 Large	Adapters (Pfeiffer)	RTE	0	87.36
T5 Large	Adapters (Pfeiffer)	COPA	42	56.00
T5 Large	Adapters (Pfeiffer)	COPA	1	50.00
T5 Large	Adapters (Pfeiffer)	COPA	0	50.00
T5 Large	Adapters (Pfeiffer)	BoolQ	42	85.63
T5 Large	Adapters (Pfeiffer)	BoolQ	1	85.87
T5 Large	Adapters (Pfeiffer)	BoolQ	0	85.54
T5 Large	Adapters (Pfeiffer)	CNN	42	26.51
T5 Large	Adapters (Pfeiffer)	CNN	1	27.29
T5 Large	Adapters (Pfeiffer)	CNN	0	27.29
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T5 Large	Scaled Parallel	BoolQ	42	84.74
T5 Large	Scaled Parallel	BoolQ	1	85.23
T5 Large	Scaled Parallel	BoolQ	0	84.98
T5 Large	Scaled Parallel	COPA	42	66.00
T5 Large	Scaled Parallel	COPA	1	72.00
T5 Large	Scaled Parallel	COPA	0	65.00
T5 Large	Scaled Parallel	RTE	42	87.36
T5 Large	Scaled Parallel	RTE	1	88.45
T5 Large	Scaled Parallel	RTE	0	87.36
T5 Large	Scaled Parallel	CNN	42	26.84
T5 Large	Scaled Parallel	CNN	1	26.59
T5 Large	Scaled Parallel	CNN	0	26.75
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T5 Large	Ln tuning	BoolQ	42	83.46
T5 Large	Ln tuning	BoolQ	1	83.55
T5 Large	Ln tuning	BoolQ	0	83.24
T5 Large	Ln tuning	COPA	42	60.00
T5 Large	Ln tuning	COPA	1	69.00

T5 Large	Ln tuning	COPA	0	63.00
T5 Large	Ln tuning	RTE	42	85.92
T5 Large	Ln tuning	RTE	1	85.92
T5 Large	Ln tuning	RTE	0	85.56
T5 Large	Ln tuning	CNN	42	
T5 Large	Ln tuning	CNN	1	25.50
T5 Large	Ln tuning	CNN	0	25.50
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T5 Large	LoRa (q and v)	RTE	42	88.45
T5 Large	LoRa (q and v)	RTE	1	87.00
T5 Large	LoRa (q and v)	RTE	0	87.00
T5 Large	LoRa (q and v)	COPA	42	71.00
T5 Large	LoRa (q and v)	COPA	1	73.00
T5 Large	LoRa (q and v)	COPA	0	70.00
T5 Large	LoRa (q and v)	BoolQ	9803	81.75
T5 Large	LoRa (q and v)	BoolQ	9486	84.65
T5 Large	LoRa (q and v)	BoolQ	9247	83.42
T5 Large	LoRa (q and v)	CNN	42	27.61
T5 Large	LoRa (q and v)	CNN	1	
T5 Large	LoRa (q and v)	CNN	0	
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T5 Large	LoRa (all)	RTE		87.73
T5 Large	LoRa (all)	RTE		87.73
T5 Large	LoRa (all)	RTE		87.73
T5 Large	LoRa (all)	COPA		76.00
T5 Large	LoRa (all)	COPA		73.00
T5 Large	LoRa (all)	COPA		76.00
T5 Large	LoRa (all)	BoolQ	42	85.35
T5 Large	LoRa (all)	BoolQ	1	85.02
T5 Large	LoRa (all)	BoolQ	0	85.66
T5 Large	LoRa (all)	CNN	42	27.68
T5 Large	LoRa (all)	CNN	1	26.25
T5 Large	LoRa (all)	CNN	0	
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T5 Large	Krona	RTE	42	86.28
T5 Large	Krona	RTE	1	86.64
T5 Large	Krona	RTE	0	86.28
T5 Large	Krona	COPA	42	65.00
T5 Large	Krona	COPA	1	70.00
T5 Large	Krona	COPA	0	64.00
T5 Large	Krona	BoolQ	42	83.06
T5 Large	Krona	BoolQ	1	83.55
T5 Large	Krona	BoolQ	0	83.64
T5 Large	Krona	CNN	42	26.56
T5 Large	Krona	CNN	1	
T5 Large	Krona	CNN	0	
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T5 Large	Compacter	BoolQ	42	83.73
T5 Large	Compacter	BoolQ	1	83.76
T5 Large	Compacter	BoolQ	0	83.61
T5 Large	Compacter	COPA	42	61.00
T5 Large	Compacter	COPA	1	64.00
T5 Large	Compacter	COPA	0	61.00
T5 Large	Compacter	RTE	42	85.20
T5 Large	Compacter	RTE	1	85.20
T5 Large	Compacter	RTE	0	85.56
T5 Large	Compacter	CNN	42	
T5 Large	Compacter	CNN	1	26.57
T5 Large	Compacter	CNN	0	27.25
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T5 Large	Compacter++	BoolQ	42	84.07
T5 Large	Compacter++	BoolQ	1	83.76
T5 Large	Compacter++	BoolQ	0	83.46
T5 Large	Compacter++	COPA	42	61.00
T5 Large	Compacter++	COPA	1	65.00
T5 Large	Compacter++	COPA	0	64.00
T5 Large	Compacter++	RTE	42	85.56
T5 Large	Compacter++	RTE	1	84.84
T5 Large	Compacter++	RTE	0	84.48
T5 Large	Compacter++	CNN	42	27.08
T5 Large	Compacter++	CNN	1	
T5 Large	Compacter++	CNN	0	
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T5 Large	IA3	RTE	42	51.26
T5 Large	IA3	RTE	1	51.26

T5 Large	IA3	RTE	0	51.26
T5 Large	IA3	COPA	42	63.00
T5 Large	IA3	COPA	1	63.00
T5 Large	IA3	COPA	0	60.00
T5 Large	IA3	BoolQ	42	82.84
T5 Large	IA3	BoolQ	1	82.84
T5 Large	IA3	BoolQ	0	82.84
T5 Large	IA3	CNN	42	24.13
T5 Large	IA3	CNN	1	
T5 Large	IA3	CNN	0	
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T5 Large	MAM	BoolQ	42	64.65
T5 Large	MAM	BoolQ	1	63.88
T5 Large	MAM	BoolQ	0	64.46
T5 Large	MAM	COPA	42	54.00
T5 Large	MAM	COPA	1	55.00
T5 Large	MAM	COPA	0	45.00
T5 Large	MAM	RTE	42	46.93
T5 Large	MAM	RTE	1	52.71
T5 Large	MAM	RTE	0	52.71
T5 Large	MAM	CNN	42	21.15
T5 Large	MAM	CNN	1	
T5 Large	MAM	CNN	0	
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T5 Large	Prefix_tuning	BoolQ	42	62.17
T5 Large	Prefix_tuning	BoolQ	1	62.17
T5 Large	Prefix_tuning	BoolQ	0	62.17
T5 Large	Prefix_tuning	COPA	42	50.00
T5 Large	Prefix_tuning	COPA	1	51.00
T5 Large	Prefix_tuning	COPA	0	55.00
T5 Large	Prefix_tuning	RTE	42	50.90
T5 Large	Prefix_tuning	RTE	1	46.57
T5 Large	Prefix_tuning	RTE	0	50.54
T5 Large	Prefix_tuning	CNN	42	14.92
T5 Large	Prefix_tuning	CNN	1	17.37
T5 Large	Prefix_tuning	CNN	0	17.73
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T5 Large	Prefix_tuning_flat	BoolQ	42	0.24
T5 Large	Prefix_tuning_flat	BoolQ	1	61.35
T5 Large	Prefix_tuning_flat	BoolQ	0	22.81
T5 Large	Prefix_tuning_flat	COPA	42	0.00
T5 Large	Prefix_tuning_flat	COPA	1	0.00
T5 Large	Prefix_tuning_flat	COPA	0	0.00
T5 Large	Prefix_tuning_flat	RTE	42	0.00
T5 Large	Prefix_tuning_flat	RTE	1	0.00
T5 Large	Prefix_tuning_flat	RTE	0	0.00
T5 Large	Prefix_tuning_flat	CNN	42	7.23
T5 Large	Prefix_tuning_flat	CNN	1	7.26
T5 Large	Prefix_tuning_flat	CNN	0	8.73
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T5 Large	Unipelt	RTE	42	52.71
T5 Large	Unipelt	RTE	1	52.71
T5 Large	Unipelt	RTE	0	52.71
T5 Large	Unipelt	COPA	42	45.00
T5 Large	Unipelt	COPA	1	55.00
T5 Large	Unipelt	COPA	0	57.00
T5 Large	Unipelt	BoolQ	42	62.17
T5 Large	Unipelt	BoolQ	1	62.17
T5 Large	Unipelt	BoolQ	0	37.83
T5 Large	Unipelt	CNN	42	16.54
T5 Large	Unipelt	CNN	1	18.23
T5 Large	Unipelt	CNN	0	17.18