

Simple and Effective Input Reformulations for Translation

Brian Yu, Hansen Lillemark, Kurt Keutzer

University of California, Berkeley

Berkeley Artificial Intelligence Research (BAIR)

{bri25yu,hillemark,keutzer}@berkeley.edu

Abstract

Foundation language models learn from their finetuning input context in different ways. In this paper, we reformulate inputs during finetuning for challenging translation tasks, leveraging model strengths from pretraining in novel ways to improve downstream performance. These reformulations are simple data level modifications, require no additional collection of training data or modification of data at inference time. They can be applied either on single language pair translation tasks or massively multilingual translation tasks. Experiments with these techniques demonstrate significant performance improvements up to 3.5chrF ++ on the Flores200 translation benchmark. We hope our research accessibly improves finetuning data efficiency, enabling more effective training to scalably improve state-of-the-art performance. Our code is released here.

1 Introduction

Foundation language models (FLMs) are powerful and task-agnostic models. They are pretrained on language understanding objectives, enabling strong performance on downstream language tasks (Brown et al., 2020; Shoeybi et al., 2020; Xue et al., 2021; Hoffmann et al., 2022; Chowdhery et al., 2022; Zhang et al., 2022a; Chung et al., 2022; Workshop, 2023; Touvron et al., 2023). FLMs are then either prompted or finetuned for downstream use.

In this paper, we present three different data efficient techniques for improving translation performance, applied to the multilingual FLM mT5 during finetuning (Xue et al., 2021). In our first approach, we train mT5 on a Classical Tibetan

to English (tib2eng) translation task. mT5 struggles heavily in the initial training steps. Thus, for the first 20% of finetuning, we apply the "Partial Output English Scaffold" or POSE reformulation, shown in Figure 1. Tib2eng translation examples consist of a Classical Tibetan source and English target translation pair. POSE simply appends a prefix of the target English output to the Classical Tibetan input. We see qualitative improvements in the variance of the training curves. When evaluated on the same test set with no reformulations, POSE significantly increases overall translation performance compared to the direct finetuning baseline, up to 10.3%/2.8 BLEU.

The POSE setup had many adjustable hyperparameters relating to task difficulty, task curriculum, and substring selection for scaffolding. We find that input reformulation setups should consist of 20% less informative examples, and 80% harder and more informative examples. More ablation details can be found below.

Second, we approach the massively multilingual Flores200 translation benchmark (NLLB- Team et al., 2022). mT5 does not struggle in the initial steps of finetuning on Flores200 in the same way it did on tib2eng. Even so, we begin by replicating the tib2eng POSE setup on Flores200 by appending a partial output of the target translation to the input translation. As expected, this setup matched but did not improve upon the baseline performance.

The Flores200 benchmark consists of parallel examples of the same sentence in different languages. In our second approach, we extend the tib2eng POSE reformulation to create the "Parallel Scaffold in English" or ParSE reformulation, shown in Figure 1. ParSE appends the corresponding full parallel English translation (provided by Flores200) to the input. Following the tib2eng setup, we use

a data mix of 20% baseline (less informative) and 80% ParSE (more informative) examples. ParSE significantly improves translation performance, up to 17.2%/3.5 chrF++

We postulate that POSE and ParSE improve translation performance in part because they enable mT5 to attend to an in-distribution pretrain language with strong monolingual performance. In our third approach, we explore the efficacy of parallel scaffolding that does not require strong monolingual performance using the "Mixed-language Parallel Scaffold" or MiPS reformulation, shown in Figure 1. MiPS appends a different parallel translation to both the input and output for a total of 4 distinct languages per input. Again, we use a data mix of 20% baseline and 80% MiPS examples. MiPS also improves translation performance, up to 9.1%/1.6 chrF++. Scaffolding with the strongest performing pretraining language (ParSE) outperforms scaffolding with a mix of other languages (MiPS).

Finally, we perform analysis on the languages in the translation set. Using a balanced dataset like Flores200 allows mT5 to partially overcome pre-training dataset size biases. Naturally, translating into lower resource languages is more difficult than translating into higher resource languages, but we find that the ParSE and MiPS reformulations improve translation into all languages across the board, rather than disproportionately improving performance on high resource languages.

In summary, we propose input reformulations on translation tasks. These reformulations require no additional data, have few hyperparameters, and are simple to implement. When finetuning on a single language pair translation task, if the target output language is in the model’s pretraining dataset distribution, the POSE reformulation can be applied. When translating between multiple language pairs, the ParSE reformulation can be applied to the strongest performing pretraining language.

2 Related work

Our work can be viewed as a data efficiency technique for translation. Past works in translation have explored data augmentation (Sennrich et al., 2016; Fadaee et al., 2017), sample re-weighting (Shu et al., 2019; Ren et al., 2019; Gu et al., 2018), and curriculum learning (Kočmi and Bojar, 2017;

Zhang et al., 2018; Platanios et al., 2019; Zhang et al., 2019; NLLB- Team et al., 2022). These approaches vary in effectiveness, are not generalizable, and introduce complexity into the training process. Curriculum learning approaches in particular are typically complicated and unsuccessful, because they are designed using intuition on how humans treat inputs, which may differ from how models treat inputs. In contrast, our input reformulations are simple and can be directly applied to any sequence-to-sequence task.

Previous work has explored prompting a frozen language model using manually curated prompts (Brown et al., 2020; Touvron et al., 2023; Petroni et al., 2019). Results are typically sensitive to the exact prompt used. This technique cannot be applied to larger corpora because it is limited by the number of examples that can feasibly fit into a single input context. Other works have explored finetuning with a fixed prompt without leveraging the target output as a part of the input (Radford et al., 2018, 2019; Dong et al., 2019; Devlin et al., 2019; Lewis et al., 2019; Sun et al., 2019; Liu et al., 2019; Clark et al., 2020; Yang et al., 2020; Raffel et al., 2020; Gao et al., 2021; Schick and Schütze, 2021; au2 et al., 2021; Xue et al., 2021; He et al., 2021; Taori et al., 2023).

Following the success of fixed prompt techniques, other works proposed prompt tuning setups (Shin et al., 2020; Schick et al., 2020; Li and Liang, 2021; Hambardzumyan et al., 2021; Lester et al., 2021; Zhong et al., 2021b; Wallace et al., 2021; Haviv et al., 2021; Jiang et al., 2020; Chen et al., 2022; Qin and Eisner, 2021; Liu et al., 2021; Han et al., 2021; Zhong et al., 2021a; Lu et al., 2022; Ben-David et al., 2022; Wang et al., 2022a; Zhou et al., 2023b). These prompt tuning setups were typically used in the context of compute efficiency: training a smaller number of prompt-related parameters to input into a larger frozen language model. These setups are an orthogonal improvement to our proposed input reformulations.

Previous approaches also investigated dataset improvements for better downstream task performance. These approaches gathered additional data for model training to augment the model’s input context (Chung et al., 2022; Wei et al., 2023; Wang et al., 2023a; Iyer et al., 2023; Min et al., 2022; Wei et al., 2022; Wang et al., 2022b; Gu et al., 2023; Wang et al., 2023b; Zhang et al., 2022b; Press et

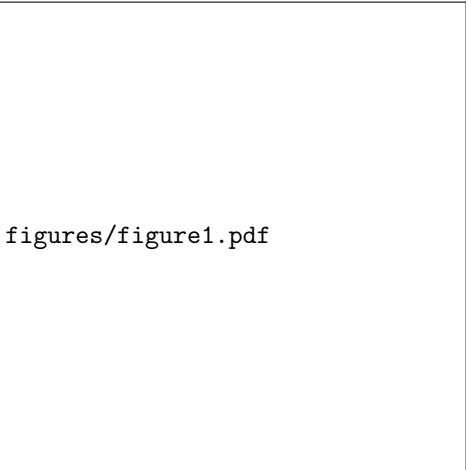


Figure 1: Task reformulations. Baseline: a direct translation pair. POSE: append a prefix of the target translation to the input translation. ParSE: append a parallel English translation to the input translation. MiPS: append a different parallel translation to both the input and output.

al., 2023; Zhou et al., 2023a). They require large, specific, and high quality datasets to be collected. On the other hand, our input reformulations require no additional data.

Overall, our approach differs from previously explored approaches by avoiding prompts and leveraging the target output as a part of the input reformulation. Our input reformulations are a data-level change that can be easily applied to any training setup.

IMAGE NOT PROVIDED

3 Experiments on a difficult single language pair translation task

3.1 Setup

We perform experiments on a Classical Tibetan to English (tib2eng) dataset. Critically, Classical Tibetan is not found in mT5’s pretraining dataset, while English is. As a result, the tib2eng dataset is challenging for mT5. Additionally, mT5’s tokenizer was not trained on Tibetan. We use mT5’s current tokenizer and use the byte- level fallback capabil-

ities of the underlying SentencePiece tokenizer to encode unknown tokens (Xue et al., 2021). We use the BLEU metric (Papineni et al., 2002) for evaluation.

The dataset consists of 450k train, 5k validation, and 5k test translation pairs. The tokenized Tibetan inputs are mean 72 and median 51 tokens long; we use a maximum sequence length of 256. We train for 10k steps and a batch size of 512 translation pairs (about 35k tokens per batch, about 350M tokens total), equivalent to 11 epochs. We use the AdamW (Loshchilov and Hutter, 2019) optimizer with parameters $\beta_1 = 0.9$, $\beta_2 = 0.999$, and weight decay 0. We use a constant learning rate schedule with no warmup. The models converge successfully under this data compute budget. We ablate over learning rates in $\{1e-3, 2e-3, 3e-3\}$ for 600M and 1B parameter models (the default finetuning learning rate for mT5 is $1e-3$ (Xue et al., 2021)) and $\{3e-4, 5e-4, 1e-3\}$ for 3B parameter models, where we found lower learning rates to be empirically better.

We perform evaluation on the models and save checkpoints every 200 steps, for a total of 50 evaluations, and we use the highest scoring checkpoint for all results. Models were trained on GPU nodes of either 8 NVIDIA A5000 24GB GPUs or 8 NVIDIA A6000 48GB GPUs. The typical train time varied from 8 hours for the smallest models to 80 hours for the largest. We leverage the Deepspeed library <https://www.deepspeed.ai/> for training in the half precision bf16, as well as for effective multi-GPU training.

In all the following results tables, we report the highest test set BLEU scores and standard deviation (std) values over learning rates.

3.2 Motivation

We begin by training baseline mT5 models on the tib2eng dataset. The resulting training curves are shown in Figure 3 with the blue colored curves. Clearly, mT5 struggles in the first 2000 steps or 20% of the training steps. With the intuition of reducing task difficulty, we design an easier task reformulation to apply only in the first 20% of training. First, we select a prefix from the target English translation. The length of this prefix is uniformly randomly chosen over the full length of the English translation. Then, we append this English prefix

to the Classical Tibetan translation input. Intuitively, we ”scaffold” the Classical Tibetan input with a partial English translation. We use a partial prefix of the English translation so the model doesn’t degenerate into simply outputting all the English in the input. We name this reformulation ”Partial Output Scaffold English” or POSE. An example of POSE is found in Figure 2. The next 4 subsections cover ablations over the finetuning reformulation setup. For direct results on the POSE task, which ended up being the most successful, see section 3.7.

3.3 Modulating task difficulty

The POSE reformulation is easier than the baseline task. In order to modulate task difficulty, we ablate over different amounts of training examples that use this reformulation: 0% baseline), 20% 50% and 100% all reformulated).

Results are found in Table 1. The best condition involves reformulating the first 20% of training examples, achieving 24.6 BLEU, 1.3 BLEU higher than the baseline. We hypothesize that making the task too easy e.g. 50% or 100% reformulated makes the task less informative, which hurts downstream performance. All of the reformulated runs have low variance across the learning rates, suggesting that models are better conditioned while training on easier tasks.

Table 1: Task difficulty experiment results on mT5 600M.

Difficulty ↓ % reform	BLEU	Std
Least difficult 100%	21.1	0.29
50%	23.9	0.05
20%	24.6	0.26
Most difficult 0%	23.5	1.64

3.4 Optimizing the curriculum

We attempt to optimize the curriculum using human intuition in 3 setups. (Curriculum 1): Instead of reformulating only the first 20% of training examples (i.e. all examples in the first 2000 steps), we rigidly add 100% of the output to the input at the beginning of training, and linearly scale down to 0% added at the end of training. (Curriculum 2):

Instead of reformulating 100% of training examples in the first 2000 steps, we reformulate 80% of the inputs for the first 2000 steps, linearly scale down from 80% reformulated to 40% reformulated for the next 4000 steps, and reformulate no examples for the last 4000 steps. (Curriculum 3): Instead of using uniformly random length prefixes for the first 20% of training examples, we rigidly add 100% of the output to the input and linearly scale down to 0% at the end of 2000 steps.

Results are found in Table 2. Even though these setups have merit using human intuition, mT5 performs markedly worse on all of them in either performance, stability, or both. The best performing runs perform better than POSE, but at the cost of stability.

Table 2: Curriculum experiment results on mT5 600M.

Setup	BLEU	Std
Baseline	23.5	1.64
POSE	24.6	0.26
(Curriculum 1)	17.4	0.85
(Curriculum 2)	24.9	0.74
(Curriculum 3)	24.7	2.50

3.5 Modulating scaffold substring

Rather than using just a prefix of the target English output, we experiment with setups that append both a portion of the target English prefix and a portion of the target English suffix (”prefix+suffix” reformulation). The total selected length remains the same for the prefix+suffix experiments. The prefix+suffix input reformulation is still in natural language, but using different pieces of the target output. Additionally, we perform a more fine-grained sweep over how many initial training examples are reformulated.

Results are found in Table 3. The prefix+suffix reformulation performs better and is less varied than the baseline, but performs worse than the prefix-only reformulation. We hypothesize that the prefix-only reformulation performs the best because it is the simplest. Over different amounts of initial training examples reformulated, 12% reformulated had the best raw performance, closely followed by 20%. We chose to stick with the 20%

experiment due to the lower variance.

Table 3: Prefix+ suffix experiment results on mT5 600M.

Substring	% reform	BLEU	Std
Baseline	0%	23.5	1.64
Prefix	20%	24.6	0.26
Prefix+ suffix	12%	24.8	0.55
Prefix+ suffix	20%	24.5	0.90
Prefix+ suffix	40%	24.0	0.12

3.6 Matching the pretraining task

We hypothesize that matching the pretraining task smooths performance similar to the POSE reformulation. We experiment on 4 masking setups: (Mask 1) mask in the first 20% of finetuning steps with $p = 0.1$ (Mask 2) mask in the last 20% of finetuning steps with $p = 0.1$ (MASK 3) mask in the last 50% of finetuning steps with $p = 0.25$ and (Mask 4) span- mask in the last 50% of finetuning steps with $p = 0.25$. Results are found in Table 4. Masking setups have less variance compared to the baseline or previous best setup, most likely because they are closer to the pretraining task distribution. Setup (Mask 1) performs better than the POSE reformulation with slightly higher variance. However, we retain the POSE reformulation as the best because it is simpler than setup (Mask 1). The other masking setups (Mask 2), (Mask 3), and (Mask 4) result in lower performance, most likely because the task is less informative to the actual downstream translation task.

Table 4: Matching pretraining experiment results on mT5 600M with masking.

Setup	BLEU	Std
Baseline	23.5	1.64
POSE	24.6	0.26
(Mask 1)	24.9	0.35
(Mask 2)	23.6	0.20
(Mask 3)	23.0	0.15
(Mask 4)	23.4	0.04

3.7 Final results and comparison to state-of-the-art

We select the best setup based on stability, simplicity, and performance. The best reformulation was still the original POSE reformulation. We compare performance of the baseline and POSE mT5 conditions with the state- of- the- art translation model NLLB (NLLB- Team et al., 2022). Because NLLB is a translation- only model, our input reformulations cannot be applied to it. NLLB’s encoded input lengths are mean 26 / median 19 tokens. For NLLB, We ablate over learning rates in {3e- 4, 5e- 4, 1e- 3}. For the NLLB tib2eng baseline, we use a linear warmup of 1000 steps, 10% of the total number of updates, with constant learning rate afterwards. The final results comparing the finetuning of mT5 baseline, mT5 POSE, and NLLB on the tib2eng task are shown in Table 5 and Figure 3.

The POSE reformulation stabilizes training and improves performance, with the largest mT5 3B model exceeding the performance of NLLB 600M. Additionally, while the baseline runs have converged, the mT5 POSE and NLLB models could be trained further for higher performance. NLLB has strong performance on this finetuning task despite not being trained on Classical Tibetan. This is because NLLB was trained on modern Tibetan, similar to classical Tibetan, and because NLLB is a translation- only model with a strong translation inductive prior. Our finetuning paradigm begins to bridge the gap between FLMs such as mT5, and task- specific translation- only models such as NLLB.

Table 5: Main results on the tib2eng translation task for mT5. Values shown are test set BLEU scores. The difference shown is the improvement gained by using the input finetuning reformulations. The NLLB column is the test set BLEU score for the corresponding sized NLLB model.

Params	NLLB	Baseline	POSE	Diff
600M	29.3	23.5	24.6	+1.1
1B	32.3	27.2	28.3	+1.1
3B	34.4	27.3	30.1	+2.8

4 Experiments on a massively multilingual translation task

4.1 Setup

The Flores200 dataset consists of around 3,000 parallel sentences in 204 different languages, meaning each sentence is translated into all 204 languages with high fidelity (NLLB- Team et al., 2022; Goyal et al., 2021; Guzman et al., 2019). This dataset is challenging for mT5 not only because of the sheer number of languages, but also because mT5 was not pretrained on over half of the languages present in the dataset. The Flores200 dataset is purported for evaluation with a separate, partially parallel train set, but the fully parallel nature of the Flores200 dataset enables interesting reformulations for finetuning. We take translation pairs from the Flores200 dev set as our training set, and translation pairs from the devtest set as our validation and test sets.

Our reformulated Flores200 dataset for training consists of 20M train, 5k validation, and 10k test translation pairs. Following the tokenization setup for the tib2eng task, mT5’s tokenizer yields inputs of mean 52 / median 46 tokens and we use a max sequence length of 256. We follow the NLLB team and perform evaluation on the Flores200 task using the chrF++ metric (Popović, 2015) with the xx- yy condition to present the final average score across languages (NLLB- Team et al., 2022). We ablate over the learning rates {1e- 4, 2e- 4, 3e- 4}, where we found lower learning rates to be empirically better. We train for 10k steps with a batch size of 2048 examples (approximately 105,000 tokens).

4.2 Designing task reformulations

For the tib2eng task, we designed POSE to mitigate mT5’s struggles early in finetuning. mT5 does not struggle in the same manner on Flores200. Even so, we begin by replicating the tib2eng POSE setup on Flores200 by appending a partial output of the target translation to the input translation. We experiment on mT5 300M. The baseline model achieves 16.8 validation set chrF++ and the reformulated model achieves 16.7 validation set chrF++. As expected, this setup matched but did not improve

upon the baseline performance.

mT5 has strong English performance because it was pretrained on orders of magnitude more English data than other languages. So, we look to leverage this strong capability in an input reformulation. The Flores200 benchmark consists of parallel examples of the same sentence in different languages. We extend the tib2eng POSE reformulation to the ”Parallel Scaffold in English” or ParSE reformulation. ParSE appends a full parallel English translation to the input translation. For the ParSE setup, we provide the intuition that English is used as a pivot language between the two other languages.

We explore the efficacy of parallel scaffolding without using English using the ”Mixed- language Parallel Scaffold” or MiPS reformulation. MiPS appends a different parallel translation to both the input and output for a total of 4 distinct language translations per input. For simplicity, we use any combination of languages in Flores200, regardless if they’re in or out of mT5’s pretraining distribution. Examples of the ParSE and MiPS reformulations are shown in Figures 1 and 4.

For both the ParSE and MiPS reformulations, we follow the tib2eng setup and a data mix of 20% baseline (less informative) and 80% reformulated (more informative) examples. We use a data mix rather than reformulating the last 80% of training examples to further simplify setup and expose the model to the input reformulations early in training. The input reformulations use up to twice the number of examples per input so we reduce the per-step batch size by a factor of two from 2048 to 1024 in order to hold the data and compute budgets constant across experiments.

4.3 Results

Our results are presented in Figure 5 and Table 6. We observe positive effects on performance similar to the tib2eng results. For the ParSE reformulation, the model learns slightly slower initially, but learns much more over the course of training. For the MiPS reformulation, the model learns faster and better than the baseline. Clearly, our input reformulation scheme improves performance, beyond just relying on strong English performance. We hypothesize that both tasks successfully improve performance, in part because they allow for direct at-

tention between the input context in different languages, aligning representations across languages.

Interestingly, the ParSE reformulation performs the best, but also has the highest variance over the learning rates. The need for lower learning rates typically indicates poor conditioning, so the input task is likely more ill-conditioned than the baseline. One possible explanation is that mT5 is learning the languages in Flores200 that were not present in its training set.

Table 6: Results on the Flores200 translation task for mT5. Values shown are test set chrF++ scores. The NLLB column is the task performance of a corresponding size NLLB model. For the NLLB score, we use the 200xx – yy chrF++ scores listed here.

Params	NLLB	Baseline	ParSE	MiPS
600M	39.5	17.6	20.7	19.2
1B	41.5	20.3	23.8	21.6
3B	41.8	23.2	25.1	23.6

4.4 Analysis on mT5’s pretraining dataset and Flores200

Flores200 contains 204 languages, while mT5 was only pretrained on 95 of them. We perform additional analysis on how being pretrained on a language affects the post-finetuning performance on Flores200, as well as how the pretraining data size for a specific language affects performance, shown in Figure 6. Translating from a language in the pretraining set into other languages is more difficult than translating from other languages into a language in the pretraining set. This is most likely because decoding into lower-resource languages is more difficult than encoding them.

When translating from a language in the pretraining set into other languages, pretraining data size is slightly correlated with better performance. However, this correlation is small considering the large range of dataset sizes. The ParSE and MiPS reformulations improve performance across the board, not depending on pretraining data size. Using a balanced finetuning dataset like Flores200 helps mitigate some of the language frequency related pretraining biases of mT5.

The performance improvement using ParSE when translating from English into other languages is much more pronounced. This can be seen visually in Figure 6 for the rightmost datapoint in each plot in the top row. The corresponding numbers in Table 7 for 3B models shows the increase for from-English is 6.3chrF++. This makes intuitive sense since the model has seen significantly more English in the input during finetuning.

We break down the performance of different model sizes and reformulation setups in Table 7.

Interestingly, the ParSE and MiPS reformulations improve performance involving lower-resource languages, sometimes at a slight cost to performance on higher resource languages. For example, the 3B baseline and ParSE conditions perform about the same when translating from languages in the pretrain dataset to other languages in the pretrain dataset. The ParSE condition performs 1.3 chrF++ worse than the baseline when translating from out-pretrain to in-pretrain languages. However, the ParSE condition performs significantly better than the baseline condition on the in-out and out-out language pairs, with chrF++ improvements of 5.3 and 3.6 respectively. Explanations for this requires further targeted experimental investigations.

5 Conclusion

We have explored how FLMs learn from their input contexts. We provide two separate techniques that can be applied to any translation use case. For the case of a single language pair translation task, we recommend POSE. For the case of a multi-language pair translation task, we recommend ParSE and MiPS. For challenging translation tasks, our scaffolding reformulations produce better conditioned training curves and significantly better performance. These input reformulations are simple to understand and implement, robust over hyperparameters, general to translation tasks, and effective. We hope our technique is used to accessibly improve data efficiency on translation tasks.

6 Limitations

Our proposed technique has only been applied to two challenging translation tasks, where the input and output are both information rich and sequential in nature. Mechanically, these ideas can be applied to other tasks such as sequence classification. Intuitively, doing so would enable the model to attend to multiple inputs in its input context in order to better denoise the inputs. This allows the model to learn more effectively. Similar techniques can be applied to other tasks, even explored further in pretraining (Lample and Conneau, 2019).

The baseline model used here was mT5, a relatively old FLM. As a result, our baseline results are low compared to state-of-the-art NLLB results. Unfortunately, there are no better FLMs in the parameter ranges from 600M to 3B. We believe there is still much to explore here with better FLMs, larger parameter counts, and other creative reformulations. We believe that FLMs will eventually outperform translation-only models like NLLB, due to the flexibility given by the capability to understand inputs. The input reformulations presented in this paper, which begin to bridge the performance gap between NLLB and mT5, are one example of how FLMs are more flexible in various input contexts.

7 Ethics Statement

As with all work today in deep learning and large models, there are many biases introduced during large data pretraining and finetuning. We did our best to choose datasets and models which acknowledge and attempt to mitigate these biases as much as they can, and encourage the development of even better datasets and models in the future. Because the techniques introduced in this paper are input reformulations that don't introduce new data, we believe they are at least not introducing many additional risks, and are generally safe to introduce to other models and techniques. Additionally, one surprising outcome of our work is that heavy language-oriented pretraining biases were mitigated by finetuning on a language-balanced dataset. This is critical for equity with regards to multilingual applications of language models.

We believe the priority of ethics in this line of

research is to ensure that the future integration of these technologies into society as safe, ethical, and trustworthy. High quality training is critical. Understanding how different inputs affect downstream performance is an important stepping stone. We encourage further research in this direction to improve model understanding and control.

Furthermore, we aim to increase accessibility of high quality, task-specific, and compute friendly large language models by improving data efficiency.

8 Acknowledgements

We would like to thank Prof. Kurt Keutzer for his wisdom and hardware.

References

- [1] Robert L. Logan IV au2, Ivana Balažević, Eric Wallace, Fabio Petroni, Sameer Singh, and Sebastian Riedel. 2021. Cutting down on prompts and parameters: Simple few-shot learning with language models.
- [2] Eyal Ben-David, Nadav Oved, and Roi Reichart. 2022. Pada: Example-based prompt learning for on-the-fly adaptation to unseen domains.
- [3] Tom B. Brown, Benjamin Mann, Nick Ryder, Melanie Subbiah, Jared 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 M. Ziegler, Jeffrey Wu, Clemens Winter, Christopher Hesse, Mark Chen, Eric Sigler, Mateusz Litwin, Scott Gray, Benjamin Chess, Jack Clark, Christopher Berner, Sam McCandlish, Alec Radford, Ilya Sutskever, and Dario Amodei. 2020. Language models are few-shot learners.
- [4] Xiang Chen, Ningyu Zhang, Xin Xie, Shumin Deng, Yunzhi Yao, Chuanqi Tan, Fei Huang, Luo Si, and Huajun Chen. 2022. KnowPrompt: Knowledge-aware prompt-tuning with synergistic optimization for relation extraction. In Proceedings of the ACM Web Conference 2022. ACM.

- [5] 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 Shazeer, Vinodkumar Prabhakaran, Emily Reif, Nan Du, Ben 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 Sankaranarayana Pillai, Marie Pellat, Aitor Lewkowycz, Erica Moreira, Rewon Child, Oleksandr Polozov, Katherine Lee, Zongwei Zhou, Xuezhi Wang, Brennan Saeta, Mark Diaz, Orhan Firat, Michele Catasta, Jason Wei, Kathy Meier-Hellstern, Douglas Eck, Jeff Dean, Slav Petrov, and Noah Fiedel. 2022. Palm: Scaling language modeling with pathways.
- [6] Hyung Won Chung, Le Hou, Shayne Longpre, Barret Zoph, Yi Tay, William Fedus, Yunxuan Li, Xuezhi Wang, Mostafa Dehghani, Siddhartha Brahma, Albert Webson, Shixiang Shane Gu, Zhuyun Dai, Mirac Suzgun, Xinyun Chen, Aakanksha Chowdhery, Alex Castro-Ros, Marie Pellat, Kevin Robinson, Dasha Valter, Sharan Narang, Gaurav Mishra, Adams Yu, Vincent Zhao, Yanping Huang, Andrew Dai, Hongkun Yu, Slav Petrov, Ed H. Chi, Jeff Dean, Jacob Devlin, Adam Roberts, Denny Zhou, Quoc V. Le, and Jason Wei. 2022. Scaling instruction-finetuned language models.
- [7] Kevin Clark, Minh-Thang Luong, Quoc V. Le, and Christopher D. Manning. 2020. Electra: Pre-training text encoders as discriminators rather than generators.
- [8] Jacob Devlin, Ming-Wei Chang, Kenton Lee, and Kristina Toutanova. 2019. Bert: Pre-training of deep bidirectional transformers for language understanding.
- [9] Li Dong, Nan Yang, Wenhui Wang, Furu Wei, Xiaodong Liu, Yu Wang, Jianfeng Gao, Ming Zhou, and Hsiao-Wuen Hon. 2019. Unified language model pre-training for natural language understanding and generation. In Advances in Neural Information Processing Systems, volume 32. Curran Associates, Inc.
- [10] Marzieh Fadaee, Arianna Bisazza, and Christof Monz. 2017. Data augmentation for low-resource neural machine translation. In Proceedings of the 55th Annual Meeting of the Association for Computational Linguistics (Volume 2: Short Papers), pages 567–573, Vancouver, Canada. Association for Computational Linguistics.
- [11] Tianyu Gao, Adam Fisch, and Danqi Chen. 2021. Making pre-trained language models better few-shot learners.
- [12] Naman Goyal, Cynthia Gao, Vishrav Chaudhary, Peng-Jen Chen, Guillaume Wenzek, Da Ju, Sanjana Krishnan, Marc'Aurelio Ranzato, Francisco Guzman, and Angela Fan. 2021. The flores-101 evaluation benchmark for low-resource and multilingual machine translation.
- [13] Jiatao Gu, Yong Wang, Yun Chen, Kyunghyun Cho, and Victor O. K. Li. 2018. Meta-learning for low-resource neural machine translation.
- [14] Yuxian Gu, Li Dong, Furu Wei, and Minlie Huang. 2023. Pre-training to learn in context.
- [15] Francisco Guzman, Peng-Jen Chen, Myle Ott, Juan Pino, Guillaume Lample, Philipp Koehn, Vishrav Chaudhary, and Marc'Aurelio Ranzato. 2019. The flores evaluation datasets for low-resource machine translation: Nepali-english and sinhala-english.
- [16] Karen Hambardzumyan, Hrant Khachatrian, and Jonathan May. 2021. Warp: Word-level adversarial reprogramming.
- [17] Xu Han, Weilin Zhao, Ning Ding, Zhiyuan Liu, and Maosong Sun. 2021. Ptr: Prompt tuning with rules for text classification.

- [18] Adi Haviv, Jonathan Berant, and Amir Globerson. 2021. BERTese: Learning to speak to BERT. In Proceedings of the 16th Conference of the European Chapter of the Association for Computational Linguistics: Main Volume, pages 3618- 3623, Online. Association for Computational Linguistics.
- [19] Pengcheng He, Xiaodong Liu, Jianfeng Gao, and Weizhu Chen. 2021. Deberta: Decoding-enhanced bert with disentangled attention.
- [20] Jordan Hoffmann, Sebastian Borgeaud, Arthur Mensch, Elena Buchatskaya, Trevor Cai, Eliza Rutherford, Diego de Las Casas, Lisa Anne Hendricks, Johannes Welbl, Aidan Clark, Tom Hennigan, Eric Noland, Katie Millican, George van den Driessche, Bogdan Damoc, Aurelia Guy, Simon Osindero, Karen Simonyan, Erich Elsen, Jack W. Rae, Oriol Vinyals, and Laurent Sifre. 2022. Training compute-optimal large language models.
- [21] Srinivasan Iyer, Xi Victoria Lin, Ramakanth Pasunuru, Todor Mihaylov, Daniel Simig, Ping Yu, Kurt Shuster, Tianlu Wang, Qing Liu, Punit Singh Koura, Xian Li, Brian O’Horo, Gabriel Pereyra, Jeff Wang, Christopher Dewan, Asli Celikyilmaz, Luke Zettlemoyer, and Ves Stoyanov. 2023. Opt-iml: Scaling language model instruction meta learning through the lens of generalization.
- [22] Zhengbao Jiang, Frank F. Xu, Jun Araki, and Graham Neubig. 2020. How can we know what language models know?
- [23] Tom Kocijan and Ondrej Bojar. 2017. Curriculum learning and minibatch bucketing in neural machine translation. In RANLP 2017 - Recent Advances in Natural Language Processing Meet Deep Learning. Inoma Ltd. Shoumen, Bulgaria.
- [24] Guillaume Lample and Alexis Conneau. 2019. Cross-lingual language model pretraining.
- [25] Brian Lester, Rami Al-Rfou, and Noah Constant. 2021. The power of scale for parameter-efficient prompt tuning.
- [26] Mike Lewis, Yinhan Liu, Naman Goyal, Marjan Ghazvininejad, Abdelrahman Mohamed, Omer Levy, Ves Stoyanov, and Luke Zettlemoyer. 2019. Bart: Denoising sequence-to-sequence pre-training for natural language generation, translation, and comprehension.
- [27] Xiang Lisa Li and Percy Liang. 2021. Prefix-tuning: Optimizing continuous prompts for generation.
- [28] Jiachang Liu, Dinghan Shen, Yizhe Zhang, Bill Dolan, Lawrence Carin, and Weizhu Chen. 2021. What makes good in-context examples for gpt- 3?
- [29] Yinhan Liu, Myle Ott, Naman Goyal, Jingfei Du, Mandar Joshi, Danqi Chen, Omer Levy, Mike Lewis, Luke Zettlemoyer, and Veselin Stoyanov. 2019. Roberta: A robustly optimized bert pretraining approach.
- [30] Ilya Loshchilov and Frank Hutter. 2019. Decoupled weight decay regularization.
- [31] Yao Lu, Max Bartolo, Alastair Moore, Sebastian Riedel, and Pontus Stenetorp. 2022. Fantastically ordered prompts and where to find them: Overcoming few-shot prompt order sensitivity.
- [32] Sewon Min, Mike Lewis, Luke Zettlemoyer, and Hannaneh Hajishirzi. 2022. Metaicl: Learning to learn in context.
- [33] NLLB- Team, Marta R. Costa-jussa, James Cross, Onur Celebi, Maha Elbayad, Kenneth Heafield, Kevin Heffernan, Elahe Kalbassi, Janice Lam, Daniel Licht, Jean Maillard, Anna Sun, Skyler Wang, Guillaume Wenzek, Al Youngblood, Bapi Akula, Loic Barrault, Gabriel Mejia Gonzalez, Prangthip Hansanti, John Hoffman, Semarley Jarrett, Kaushik Ram Sadagopan, Dirk Rowe, Shannon Spruit, Chau Tran, Pierre Andrews, Necip Fazil Ayan, Shruti Bhosale, Sergey Edunov, Angela Fan, Cynthia Gao, Vedanuj Goswami, Francisco Guzman, Philipp Koehn, Alexandre Mourachko, Christophe Ropers, Safiyyah Saleem, Holger Schwenk, and Jeff Wang. 2022. No language left behind: Scaling human-centered machine translation.
- [34] Kishore Papineni, Salim Roukos, Todd Ward, and Wei- Jing Zhu. 2002. Bleu: a method for

- automatic evaluation of machine translation. In Proceedings of the 40th Annual Meeting of the Association for Computational Linguistics, pages 311- 318, Philadelphia, Pennsylvania, USA. Association for Computational Linguistics.
- [35] Fabio Petroni, Tim Rocktaschel, Patrick Lewis, Anton Bakhtin, Yuxiang Wu, Alexander H. Miller, and Sebastian Riedel. 2019. Language models as knowledge bases?
- [36] Emmanouil Antonios Platanios, Otilia Stretcu, Graham Neubig, Barnabas Poczos, and Tom M. Mitchell. 2019. Competence-based curriculum learning for neural machine translation.
- [37] Maja Popovic. 2015. chrF: character n- gram F- score for automatic MT evaluation. In Proceedings of the Tenth Workshop on Statistical Machine Translation, pages 392- 395, Lisbon, Portugal. Association for Computational Linguistics.
- [38] Ofir Press, Muru Zhang, Sewon Min, Ludwig Schmidt, Noah A. Smith, and Mike Lewis. 2023. Measuring and narrowing the compositionality gap in language models.
- [39] Guanghui Qin and Jason Eisner. 2021. Learning how to ask: Querying lms with mixtures of soft prompts.
- [40] Alec Radford, Karthik Narasimhan, Tim Salimans, and Ilya Sutskever. 2018. Improving language understanding by generative pre- training.
- [41] Alec Radford, Jeffrey Wu, Rewon Child, David Luan, Dario Amodei, and Ilya Sutskever. 2019. Language models are unsupervised multitask learners.
- [42] Colin Raffel, Noam Shazeer, Adam Roberts, Katherine Lee, Sharan Narang, Michael Matena, Yanqi Zhou, Wei Li, and Peter J. Liu. 2020. Exploring the limits of transfer learning with a unified text- to- text transformer.
- [43] Mengye Ren, Wenyuan Zeng, Bin Yang, and Raquel Urtasun. 2019. Learning to reweight examples for robust deep learning.
- [44] Timo Schick and Hinrich Schutze. 2021. Exploiting cloze questions for few shot text classification and natural language inference.
- [45] Rico Sennrich, Barry Haddow, and Alexandra Birch. 2016. Improving neural machine translation models with monolingual data. In Proceedings of the 54th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers), pages 86- 96, Berlin, Germany. Association for Computational Linguistics.
- [46] Taylor Shin, Yasaman Razeghi, Robert L. Logan IV au2, Eric Wallace, and Sameer Singh. 2020. Autoprompt: Eliciting knowledge from language models with automatically generated prompts.
- [47] Mohammad Shoeybi, Mostofa Patwary, Raul Puri, Patrick LeGresley, Jared Casper, and Bryan Catanzaro. 2020. Megatron- Im: Training multi- billion parameter language models using model parallelism.
- [48] Jun Shu, Qi Xie, Lixuan Yi, Qian Zhao, Sanping Zhou, Zongben Xu, and Deyu Meng. 2019. Meta- weightnet: Learning an explicit mapping for sample weighting.
- [49] Yu Sun, Shuohuan Wang, Yukun Li, Shikun Feng, Xuyi Chen, Han Zhang, Xin Tian, Danxiang Zhu, Hao Tian, and Hua Wu. 2019. Ernie: Enhanced representation through knowledge integration.
- [50] Rohan Taori, Ishaan Gulrajani, Tianyi Zhang, Yann Dubois, Xuechen Li, Carlos Guestrin, Percy Liang, and Tatsunori B. Hashimoto. 2023. Stanford alpaca: An instruction- following llama model. https://github.com/tatsu-lab/stanford_alpaca.
- [51] Hugo Touvron, Thibaut Lavril, Gautier Izacard, Xavier Martinet, Marie- Anne Lachaux, Timothée Lacroix, Baptiste Rozière, Naman Goyal, Eric Hambro, Faisal Azhar, Aurelien Rodriguez, Armand Joulin, Edouard Grave, and Guillaume Lample. 2023. Llama: Open and efficient foundation language models.
- [52] Eric Wallace, Shi Feng, Nikhil Kandpal, Matt Gardner, and Sameer Singh. 2021. Universal

- adversarial triggers for attacking and analyzing nlp.
- [53] Boshi Wang, Xiang Deng, and Huan Sun. 2022a. Iteratively prompt pre-trained language models for chain of thought. In Proceedings of the 2022 Conference on Empirical Methods in Natural Language Processing, pages 2714- 2730, Abu Dhabi, United Arab Emirates. Association for Computational Linguistics.
- [54] Xuezhi Wang, Jason Wei, Dale Schuurmans, Quoc Le, Ed Chi, Sharan Narang, Aakanksha Chowdhery, and Denny Zhou. 2023a. Self-consistency improves chain of thought reasoning in language models.
- [55] Jason Wei, Maarten Bosma, Vincent Y. Zhao, Kelvin Guu, Adams Wei Yu, Brian Lester, Nan Du, Andrew M. Dai, and Quoc V. Le. 2022. Finetuned language models are zero-shot learners.
- [56] Jason Wei, Xuezhi Wang, Dale Schuurmans, Maarten Bosma, Brian Ichter, Fei Xia, Ed Chi, Quoc Le, and Denny Zhou. 2023. Chain-of-thought prompting elicits reasoning in large language models.
- [57] BigScience Workshop. 2023. Bloom: A 176b-parameter open-access multilingual language model.
- [58] Linting Xue, Noah Constant, Adam Roberts, Mihir Kale, Rami Al-Rfou, Aditya Siddhant, Aditya Barua, and Colin Raffel. 2021. mt5: A massively multilingual pre-trained text-to-text transformer.
- [59] Zhilin Yang, Zihang Dai, Yiming Yang, Jaime Carbonell, Ruslan Salakhutdinov, and Quoc V. Le. 2020. Xlnet: Generalized autoregressive pretraining for language understanding.
- [60] Susan Zhang, Stephen Roller, Naman Goyal, Mikel Artetxe, Moya Chen, Shuhui 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. 2022a. Opt: Open pre-trained transformer language models.
- [61] Xuan Zhang, Gaurav Kumar, Huda Khayrallah, Kenton Murray, Jeremy Gwinnup, Marianna J Martindale, Paul McNamee, Kevin Duh, and Marine Carpuat. 2018. An empirical exploration of curriculum learning for neural machine translation.
- [62] Xuan Zhang, Pamela Shapiro, Gaurav Kumar, Paul McNamee, Marine Carpuat, and Kevin Duh. 2019. Curriculum learning for domain adaptation in neural machine translation.
- [63] Zhuosheng Zhang, Aston Zhang, Mu Li, and Alex Smola. 2022b. Automatic chain of thought prompting in large language models.
- [64] Ruiqi Zhong, Kristy Lee, Zheng Zhang, and Dan Klein. 2021a. Adapting language models for zero-shot learning by meta-tuning on dataset and prompt collections.
- [65] Zexuan Zhong, Dan Friedman, and Danqi Chen. 2021b. Factual probing is [MASK]: Learning vs. learning to recall. In Proceedings of the 2021 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, pages 5017- 5033, Online. Association for Computational Linguistics.
- [66] Denny Zhou, Nathanael Scharli, Le Hou, Jason Wei, Nathan Scales, Xuezhi Wang, Dale Schuurmans, Claire Cui, Olivier Bousquet, Quoc Le, and Ed Chi. 2023a. Least-to-most prompting enables complex reasoning in large language models.
- [67] Yongchao Zhou, Andrei Ioan Muresanu, Ziwen Han, Keiran Paster, Silviu Pitis, Harris Chan, and Jimmy Ba. 2023b. Large language models are human-level prompt engineers.

A Appendix

A.1 Flores200 in- and out-pretrain results

Table 7: Breakdown of model and setup performance over different splits of the Flores200 dataset. "In" refers to a language that was found in the mT5 pretraining dataset and "out" refers to a language that was not. "To Eng" and "From Eng" is referred to as xx-eng and eng-xx in some other papers, respectively. Notably, the proposed techniques improve "To Eng" performance up to 4.2 chrF++ and "From Eng" performance up to 9.4 chrF++, in the 600M case. We hypothesize this difference in improvement is due to the finetuning task including more English examples in the input, helping with downstream English translations as well as other language translations.

Params	Setup	In-in	Out-in	In-out	Out-out	To Eng	From Eng	Avg
600M	Baseline	20.5	19.2	17.2	16.4	21.2	20.2	17.6
	ParSE	24.5	21.1	21.2	18.7	25.4	29.6	20.7
	MiPS	22.6	20.5	19.1	17.7	23.9	22.8	19.2
1B	Baseline	28.3	23.6	17.1	15.2	33.8	24.6	20.3
	ParSE	30.9	25.2	22.7	19.3	34.6	32.9	23.8
	MiPS	27.8	23.6	19.9	17.7	31.3	25.8	21.6
3B	Baseline	33.2	27.3	19.3	16.9	41.0	29.0	23.2
	ParSE	33.0	26.0	24.6	20.5	37.9	35.3	25.1
	MiPS	30.5	25.5	22.3	19.5	34.8	28.8	23.6