Unsupervised Cross-Task Generalization via Retrieval Augmentation

Anonymous Author(s)
Affiliation
Address
email

Abstract

Humans can perform unseen tasks by recalling relevant skills that are acquired previously and then generalizing them to the target tasks, even if there is no supervision at all. In this paper, we aim to improve such cross-task generalization ability of massive multi-task language models such as T0 (Sanh et al., 2021) in an unsupervised setting. We propose a retrieval-augmentation method named `ReCross` that takes a few *unlabelled* examples as queries to retrieve a small subset of upstream data and uses them to update the multi-task model for better generalization. Our empirical results show that the proposed `ReCross` consistently outperforms non-retrieval baselines by a significant margin. [1]

1 Introduction

Advances in pre-training techniques for large language models (LMs) have considerably improved natural language processing (NLP) models on various important tasks via fine-tuning with labeled data. While these fine-tuned models are impressive on their target tasks, they can hardly generalize to unseen tasks. This thus makes it difficult to approach the general linguistic intelligence that we ultimately want an NLP model to enjoy. A promising avenue is to train a massively multi-task model that learns a large set of NLP tasks. However, in real-world applications, users often expect a multi-task NLP model can also perform unseen tasks that they are interested in. These users may only be able to provide a few *unlabeled* examples (i.e., the input-only data) of the target tasks with natural-language instructions. How can we generalize the multi-task model to unseen tasks without labels? This desirable ability is dubbed as "unsupervised cross-task generalization."

Recent studies show that multi-task prompted training makes language models better in cross-task generalization, especially when natural-language instructions are used for formatting the training data (Ye et al., 2021; Sanh et al., 2021; Wei et al., 2021). The general recipe is to first fine-tune a text-to-text language model such as T5 (Raffel et al., 2020) on a multi-task mixture of diverse NLP datasets that are converted to sequence-to-sequence formats. We use the term *upstream learning* to refer to this multi-task training stage. Given a target task that is unseen during upstream learning, we want the upstream multi-task model to also perform well on it via reusing the previously acquired knowledge. FLAN (Wei et al., 2021) and T0 (Sanh et al., 2021) both use natural language (NL) instructions as prompts to reformat the data of various NLP tasks for upstream learning and generalization. Their results suggest that NL instructions are keys to unsupervised cross-task generalization.

Despite of the exciting results from Wei et al. (2021) and Sanh et al. (2021), their studies are limited to the analysis on the task generalization performance of the *frozen, target-agnostic* upstream models (i.e., FLAN and T0). We argue that the generalization performance can be further improved, if we can exploit the unlabeled data of target tasks as hints for adjusting the upstream model to a more

[1] Our data, code, and appendix are uploaded and will be publicly available.

Submitted to 36th Conference on Neural Information Processing Systems (NeurIPS 2022). Do not distribute.

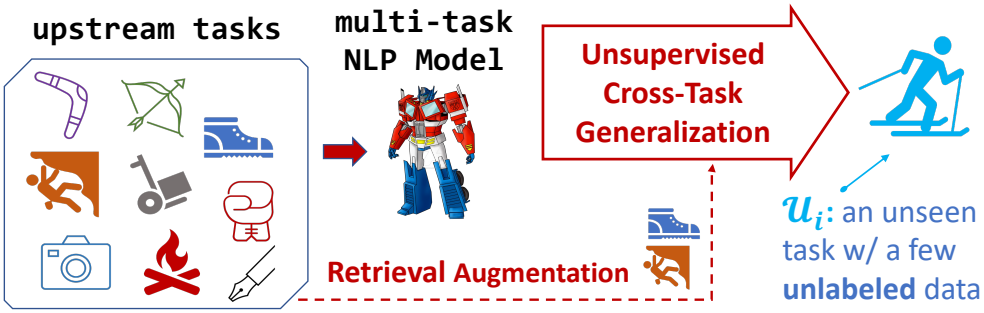

Figure 1: **The unsupervised cross-task generalization problem.** In the upstream training stage, we train a multi-task NLP model, $\mathcal{M}$, with a diverse collection of upstream task. In the generalization stage, given an unseen task $\mathcal{U}_i$ with a few unlabeled examples Q_i, we want to update the upstream model (via retrieval augmentation) such that it can generalize to the target task. **(updated!)**

dedicated, target-aware model. Intuitively, the upstream examples that share similar skills with the target task should help the task generalization if the upstream model could recap these skills via retrieving. Motivated by this idea, we propose to further improve the cross-task generalization ability of upstream models via *retrieval augmentation* from the upstream data.

The key challenge of such retrieval augmentation is to predict the example-level utility for cross-task generalization, which we introduce with details in Sec. 2. To address the challenges, we present a two-stage retrieval-augmentation framework, ReCross, for unsupervised cross-task generalization in Section 3, . Specifically, we pre-compute a dense index by encoding all upstream data as dense vectors. Given a set of unlabeled examples, we first use them to retrieve an initial set of upstream data by using encoded queries to efficiently search over the dense index. Then, we apply the reranking module for carefully analyzing the utility of each candidate example. To get such a reranker, we fine-tune a cross-encoder model with distant supervision mined by a novel algorithm. Finally, we take top-ranking retrieved data to fine-tune the upstream model for a few steps and use this updated model for inference on the target task in the future (i.e., the retrieval augmentation and model update is a one-time procedure for each unseen task).

To more efficiently evaluate generalization methods without losing the generality, we train a variant of T0-like models, named BART0, which has comparable performance with T0-3B yet is 8x smaller. Our extensive experiments show that the proposed ReCross outperforms the baseline methods by a large margin. For example, ReCross improves the non-retrieval methods by 4 points (in exact-match) on the overall performance of 10 target tasks and similarly on BigBench tasks. We also analyze the distribution of the retrieved data to better understand the behavior of retrieval-augmentation methods and find that ReCross has a very different distribution compared to semantic retrieval baselines.

2 Problem Formulation

Massively Multi-Task Language Models. To build a general NLP model that can serve a wide range of real-world downstream applications, it is important to train a massively multi-task upstream model. We assume there are N different **upstream tasks** (e.g., sentiment analysis of IMDB reviews), dubbed as $\{\mathcal{T}_1, \ldots, \mathcal{T}_N\}$. We use D to denote the collection of all labeled data for these upstream tasks (i.e., the **upstream data**), which are then used for training a massive multi-task model $\mathcal{M}$ (e.g., BART, T5, and other Transformer-based models). The datasets of these upstream tasks are all converted to a shared *text-to-text* format using natural-language instruction templates such as PromptSource (Bach et al., 2022) to reformat data of different NLP tasks. This pipeline has become a common approach, adopted by several recent massive multi-task models for NLP, such as T0 (Sanh et al., 2021), FLAN (Wei et al., 2021), and CrossFit (Ye et al., 2021).

Unsupervised Cross-Task Generalization. In real-world scenarios, it is very common that users want a general multi-task model to perform tasks of their interest, even if their target tasks are never seen before by the upstream model. For these unseen target tasks, users usually can provide only a few *unlabeled* examples (i.e., the input-only data) of them for specifying the task instructions. This is the reason why we need to study how to generalize a multi-task LM to unseen tasks with only a few *unlabeled* examples, i.e., *unsupervised cross-task generalization*. For instance, in Fig. 1, the *unseen*

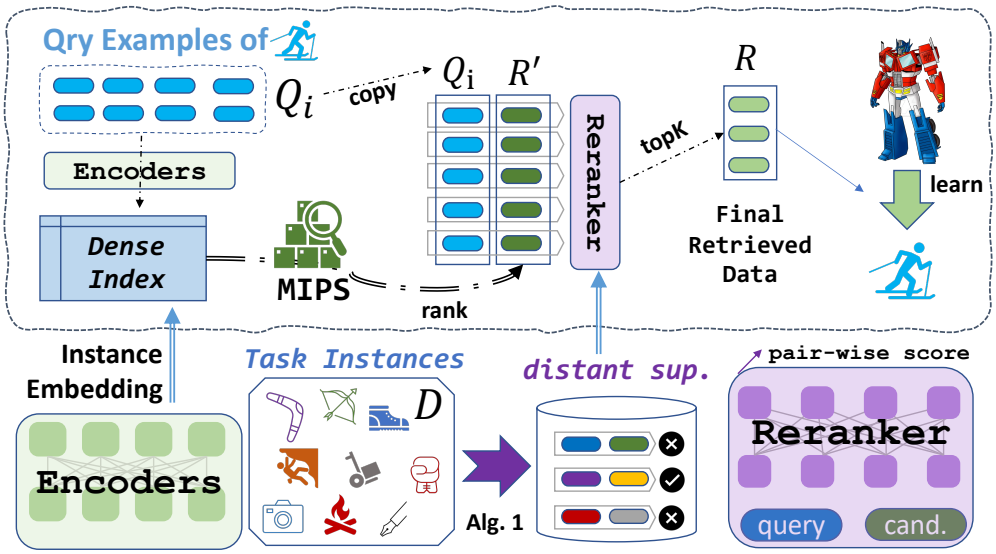

Figure 2: **ReCross is a retrieval-augmentation method for unsupervised cross-task generalization.** We reuse the encoder layers of the upstream model (green) to build a dense index, which consists of vectors of the upstream examples D. We also propose an algorithm to generate distant supervision for training a reranker, which takes a pair of examples as input and outputs a score. During the evaluation, we encode query examples Q_i for querying the index to get initial ranking results R', and then pair them with the queries again for reranking. Finally, we take the top-K results (i.e., R) for generalizing the upstream model $\mathcal{M}$ to the unseen task $\mathcal{U}_i$. **(updated!)**

task $\mathcal{U}_i$ is a coreference-resolution task that is not covered by the upstream training (the top-right box in Fig. 1). We have only a few inputs for it as the "*hints*" for cross-task generalization, which we call query examples Q_i. Our objective is to use the query examples Q_i to enhance the performance of upstream model $\mathcal{M}$ on the unseen task $\mathcal{U}_i$. For evaluating such unsupervised cross-task generalization methods, we test the enhanced model with a held-out labeled data of each target task.

Challenges. Standard fine-tuning approaches (with or without meta-learning designs) for few-shot cross-task generalization are not feasible here. We have to adjust the upstream model based on only a few *input-only* examples for the unseen task. Intuitively, upstream examples that share similar skills with the target task $\mathcal{U}_i$ should be more beneficial than other upstream data. Thus, one naive idea is to first estimate the utility of each upstream example for $\mathcal{U}_i$ and then re-train a dedicated model $\mathcal{M}_i$ via a weighted learning method (e.g., examples of more utility are trained with larger loss). **(updated!)**

However, such a target-aware weighted re-training method cannot scale, because the upstream data is usually very large and there can be a large number of unseen tasks from users in real-world applications. In addition, it is particularly challenging to estimate the utility scores of upstream data for a given unseen task, as we do not have ground-truth annotations for learning this. Although there are some existing studies on task-to-task relatedness and transferability (Vu et al., 2020; Lange et al., 2021; Padmakumar et al., 2022), most of them are not designed for unsupervised settings and few are done with multi-task (prompted) upstream models. Moreover, these prior analysis are mainly limited to the task-level analysis and they may not directly generalize to studying example-level utility, which is particularly important for the problem setup of this work.

3 ReCross: Retrieval Augmentation for Cross-Task Generalization

3.1 Overview

To address the above challenges for unsupervised cross-task generalization, we propose a retrieval-augmentation method named ReCross. The ReCross method is also based on the simple idea that we should exploit the upstream examples that enjoy better utility for a given unseen target task. Instead of costly re-training from the scratch, our method first retrieves a small subset of the upstream data for each unseen task, and then uses them for efficiently fine-tuning the upstream model such that the updated model is generalized. This can ensure the scalibity to a great extent and benefit upstream models from re-learning target-specific acquired knowledge for cross-task generalization.

Ideally, we aim to retrieve the upstream examples that are the most beneficial ones for generalizing the upstream model towards a particular unseen task — ranking the upstream data by their example-level utility. To achieve this goal while preserving the efficiency, we first use the query examples to retrieve initial candidates via efficient maximum inner product search (MIPS) over a dense index, which consists of embedding vectors of all upstream examples (Section 3.2).

Based on the candidates from dense retrieval, we learn a reranking module for further improving the retrieval results (Section 3.3). The reranker is based on the cross-encoder architecture that takes a query-candidate pair of examples and outputs a more curated score of utility. Recall that we do not have any annotation for such example-level utility scores, and the only allowed resources are the upstream data and model. Therefore, we propose an algorithm to mine distant supervision from the upstream data for learning the reranker (Section 3.4). The overview of ReCross is shown in Fig. 5.

3.2 Dense Retrieval

To efficiently estimate the example-level utility for generalization, we propose to first employ a dense retrieval module that ensures high scaliblity. Specifically, we build a matrix $\mathbf{D} \in \mathbb{R}^{|D| \times d}$, where each upstream example in D is encoded with a dense vector. Based on this dense index, we can now estimate the utility of an upstream example with its cosine distances to the encoded query examples in Q. That is to say, the upstream examples that are the nearest neighbors of query examples, are more likely to be beneficial for generalizing the upstream model $\mathcal{M}$ to the unseen target task.

To retrieve the candidate set R', we use MIPS to search for the top-K examples for each query example in Q, so $K = \lceil |R'|/|Q| \rceil$. (We introduce the details and other aggregation strategies in Appendix.) This dense-retrieval process is very efficient as we pre-compute the upstream index and perform MIPS for querying the candidates over the index on-the-fly during the generalization stage. We use the FAISS library (Johnson et al., 2019) in our implementation.

Instance embeddings. The example encoder is a key component of the dense-retrieval pipeline. An ideal example encoder is supposed to represent the underlying skills behind an example such that we can use the distances in the result embedding space to estimate utility for cross-task generalization. As we do not have annotations of utility scores for training an encoder, one may want to use pre-trained sentence embedding models such as SentenceBERT (Reimers and Gurevych, 2019). Our empirical results show that such semantics-based encoders cannot lead to much improvement over random retrieval results. We think there are two reasons for this failure. First, the *semantic* similarities between examples are not suitable for estimating the utility for generalization. Second, the *external* encoding modules do not reflect the nature of the upstream model which we want to generalize.

To address these two issues, we propose to use the encoding layers of upstream model $\mathcal{M}$ for computing the example embeddings. Without loss of generality, let us assume $\mathcal{M}$ to be a *text-to-text* Transformer that has multiple layers for both encoders and decoders such as BART. We encode an example by first obtaining the hidden representation of each token at the last encoder layer (i.e., a sequence of token vectors), and then performing mean-pooling over them to get a single dense vector to represent this example. By doing this, the produced example embeddings reflect the internal features of the upstream model, which are more relevant to the "thinking process" of the upstream model for the examples instead of the shallow semantic information.

3.3 Reranking Module

Weakness of the dense retrieval. Although dense retrieval is very efficient thanks to the MIPS support, the retrieval performance is limited by its two major weakness. First, it is a dual-encoder architecture that encodes the candidate example and the query example *separately*, which ignores informative features behind token-to-token attention across a pair of example. Second, it is too costly to frequently update the example encoder, which prevents us from learning to refine the retrieval results with distant supervision (if any). Therefore, we design a re-ranking stage where we train a cross-encoder to further enhance the dense-retrieval results with mined distant supervision (Sec. 3.4).

Encoding query-candidate pairs. The cross-encoder architecture has been widely used in sentence-pair classification tasks such as natural language inference and paraphrase detection. We here use a cross-encoder to encode the *concatenation* of a query example and a candidate example. Specifically,

we fine-tune a RoBERTa (Liu et al., 2019) model to classify whether an example pair is a positive or negative match. The confidence of classifying such a pair to be positive can thus be used as the utility score of the candidate upstream example for this query example. On top of this, we then develop a reranking module for further improving retrieval performance as follows.

Scoring paired data. To re-rank the initially retrieved data by the dense retriever, we apply the cross-encoder on all pairs of query examples Q and candidate retrieved examples R', producing scores of all $|Q| * |R|'$ query-candidate pairs. For each candidate example $r \in R'$, we use the average of all cross-encoder scores involving r as its utility score. Finally, we take the top-K examples based on this new ranking of candidate examples in R' as the final retrieved data R. We use *upsampling ratio* μ to denote the ratio between R' and R, i.e., $\mu = |R'|/|R|$.

3.4 Mining Distant Supervision for Reranking

How do we train such a re-ranking module? Recall that we only have access to the upstream data D and must not use any data from the unseen tasks at this stage. Inspired by meta-learning works, we propose an algorithm (Alg. 1) to mine distant supervision data for creating a *training-as-testing* environment for learning the reranker. Our key motivation is to examine the utility scores of candidate examples by assessing the generalization performance of updated models that are fine-tuned with these candidates as if we use them for real unseen tasks. Such more realistic estimation of utility scores can thus help us train a reranker to predict.

Algorithm 1: Distant Supervision Creation

Input: $\mathcal{M}$; D; $\mathcal{T}_q$
Output: $Z = (Z_q, Z_p, Z_n)$

$D_{\mathcal{T}_q} \leftarrow \{x \in D | x \text{ is an example of } \mathcal{T}_q\}$
$Z_q \leftarrow \text{Sample}(D_{\mathcal{T}_q})$; $H_q \leftarrow \text{Sample}(D_{\mathcal{T}_q})$
$R_Z \leftarrow \text{DenseRetrieve}(Z_q, D)$
/* Delete retrieved examples from the same task as queries. */
$R_Z \leftarrow R_Z.\text{discard}(D_{\mathcal{T}_q})$
foreach *round* **do**
  $R_Z.\text{shuffle}()$
  /* Split retrieved examples into n groups */
  $\{G_1, ..., G_n\} \leftarrow R_Z.\text{split}()$
  foreach G_i *in* $\{G_1, ..., G_n\}$ **do**
    $\mathcal{M}' \leftarrow \mathcal{M}.\text{copy}()$
    $\mathcal{M}'.\text{fine_tune}(G_i)$
    $\ell \leftarrow \mathcal{M}'.\text{calc_loss}(H_q)$
    foreach $x \in G_i$ **do**
      $scores[x].\text{append}(\ell)$
      /* Score each in the group w/ the loss. */
/* Use mean group score as score for single examples */
foreach $x \in R_Z$ **do**
  $score[x] \leftarrow \text{mean}(scores[x])$
/* Sort R_Z by $score$ in increasing order. */
$R_Z.\text{sort}(\text{key: score, order: increasing})$
$Z_p \leftarrow$ First W items of R_Z
$Z_n \leftarrow$ Last W items of R_Z

Specifically, we define a data point of such distant supervision as a tuple $Z = (Z_q, Z_p, Z_n)$: 1) Z_q is a set of query examples of a particular task $\mathcal{T}_q$; 2) Z_p is the set of positive examples from other tasks; 3) Z_n is the set of negative examples from other tasks. We expect that Z_p is of more utility for generalization than Z_n if Z_q would be a query set for the target task $\mathcal{T}_q$. To this end, we first randomly sample an upstream task $\mathcal{T}_q$ and use a small subset of its training data as the Z_q. Here, we also sample a larger held-out set H_q examples of task $\mathcal{T}_q$ to facilitate utility estimation. Then, we apply the dense retriever using Z_q as the query examples and get the retrieval results R_Z. This R_Z is thus the candidate pool where we create Z_p and Z_n. That is, $Z_p \subset R_Z$ and $Z_n \subset R_Z$. We discard examples that are from the $\mathcal{T}_q$, so that the generated tuples are closer to the real scenarios where we use the reranker on the query sets of unseen tasks.

Our criteria to select Z_p and Z_n from R_Z is motivated by the hypothesis that a more suitable set of retrieved examples should improve the performance $\mathcal{M}$ on $\mathcal{T}_i$ after fine-tuning with it. Therefore, we iteratively sample a small subset from R_Z, then fine-tune $\mathcal{M}$ with it, and finally use the fine-tuned model to evaluate on Z'_q. The performance of such a temporarily fine-tuned model can be seen as the utility score—how well this subset can help generalize $\mathcal{M}$ to the unseen task $\mathcal{T}_q$. Through multiple rounds of such sample-train-test procedures, we can thus score each example in R_Z by taking the average of all test results where it is involved. With such a new ranking of examples in R_Z, we take the best W examples as Z_p and the worst W as Z_n.

With such distant supervision, we then can create pair of query-positive instances and query-negative instances via pairing Z_q with Z_p and Z_n respectively. Now we can fine-tune a RoBERTa-base model by concatenating each pair and learning a binary-classification objective. The output logits of this trained model will be used for the reranking procedure as shown in Sec. 3.3.

3.5 Re-learning via Fine-Tuning with Retrieved Data

When we have the final retrieved data R_i for a certain query set Q_i, we can now enhance the upstream model $\mathcal{M}$ for the unseen task $\mathcal{U}_i$. We use a small learning rate to continually fine-tune $\mathcal{M}$ with the retrieved upstream examples R_i for a small number of steps. We find that the learning rate has to be very small so that this step can be seen as a natural continuation of the finished upstream training and avoid overfitting the retrieved data. We acknowledge that there could be more effective methods to reuse the query examples Q as guidance for fine-tuning, and we leave this as future work. Please find more discussion on the hyper-parameter selection and configuration in our appendix.

4 Evaluation

In this section, we first introduce the experimental setups, including the task distribution, upstream learning details, and the configurations of the main experiments. We present experimental results and reveal some non-trivial findings with extensive analysis that justify the effectiveness of ReCross.

4.1 Evaluating Unsupervised Cross-Task Generalization

We follow Sanh et al. (2021) to use the templates from PromptSource (Bach et al., 2022) for converting data of different types of NLP tasks to text-to-text formats. In total, we have 36 upstream tasks and 10 target unseen tasks for our main experiments. The upstream tasks are the same as the ones that the T0 models used for upstream learning. We follow the evaluation protocol proposed by Sanh et al. (2021) and select the target tasks that are significantly different from the upstream tasks. Besides, we also include 5 additional tasks from the BIG-bench project (BIG-bench collaboration, 2021) to create an even more out-of-distribution set of unseen tasks for analysis.

Metric. When we apply the natural-language templates for the test examples, we only keep the templates that can be evaluated with an exact match (classification, question answering, answer selection, etc.) so that it is feasible to use exact-match for evaluating all tasks. To allow a smoother grading, our metric also counts the cases when outputs and truths are sub-strings of each other, which we call **SoftEM**. The SoftEM metric can better fit the data annotations produced by PromptSource than the standard EM and provide a more accurate assessment. We discuss this further in Appendix D.1 and report the results with the standard EM (Table 7). We present the results in SoftEM in the main paper, while both support our findings.

4.2 BART0: Upstream Learning with a Smaller LM

The T0(pp) models are all very huge, and the smallest version, T0-3B (3 billion parameters), is still too large to be fine-tuned on popular affordable GPUs. We need a parameter-efficient alternative that makes the study on cross-task generalization more accessible to a broader community while keeping the generality. Thus, we fine-tune a BART-large (Lewis et al., 2020a) (0.4 billion parameters) following the recipe of training T0. Specifically, we sample 50k examples at most from each upstream task to build a large upstream dataset consisting of 1.7 million examples (i.e., $|D| = 1.7$m), and then we fine-tune a BART-large with 22k steps with this upstream dataset. Finally, we use the fine-tuned checkpoint as our upstream model $\mathcal{M}$ and name it **BART0**. Surprisingly, we find that BART0 and T0-3B have comparable zero-shot performance on the unseen target tasks, even though T0-3B is about 8x larger than BART0. More implementation details are shown in Appendix.

4.3 Setup and Configurations

In our main experiments, we use $|Q_i|$ = 16 query examples for each unseen task $\mathcal{U}_i$ and retrieve $|R_i|$ = 512 examples for augmenting BART0. In the fine-tuning stage, we use a learning rate of 1e-6 and a batch size of 4 to continually fine-tune all layers of BART0 for 2 epochs. As for re-ranking, we set the upsampling ratio $\mu = 2$, meaning that we first retrieve 1024 examples for reranking and use the top 512 ones as the final retrieved data. To obtain more convincing evaluation results, we average the scores of all target tasks to show the general zero-shot performance. For each task $\mathcal{U}_i$, we use five different query sets, $\{Q_i^{(1)}, \ldots, Q_i^{(5)}\}$, to conduct **five individual rounds of retrieval**, thus resulting in five average scores for all tasks. To get a comprehensive assessment, we report the mean, std, median, min, and max of these five overall scores in the lower part of Table 1. We present ablation study on hyper-parameter configurations in Table 3 and include more details in Appendix.

Target Task	T0-3B	**BART0**	Random	SBERT	ReCross†	**ReCross**	Δ
anli_r3	26.00	30.50	$35.34_{\pm 1.52}$	$32.64_{\pm 2.53}$	$36.70_{\pm 0.53}$	$35.76_{\pm 0.90}$	5.26
h-swag	34.40	39.40	$33.84_{\pm 5.59}$	$30.92_{\pm 7.82}$	$44.36_{\pm 3.07}$	$47.28_{\pm 2.95}$	7.88
cb	53.93	39.64	$47.07_{\pm 1.25}$	$48.00_{\pm 3.28}$	$44.50_{\pm 4.20}$	$44.79_{\pm 3.36}$	5.15
wic	45.70	46.70	$41.04_{\pm 2.18}$	$46.78_{\pm 2.22}$	$49.90_{\pm 0.50}$	$50.58_{\pm 0.24}$	3.88
wsc	50.00	57.88	$52.50_{\pm 2.29}$	$52.69_{\pm 6.13}$	$59.27_{\pm 1.96}$	$61.46_{\pm 1.47}$	3.58
winogrande	47.60	51.10	$52.68_{\pm 0.83}$	$52.18_{\pm 3.20}$	$54.60_{\pm 1.35}$	$55.46_{\pm 0.88}$	4.36
arc-chan.	41.30	35.70	$33.28_{\pm 1.50}$	$37.90_{\pm 1.22}$	$37.78_{\pm 0.73}$	$38.44_{\pm 0.99}$	2.74
obqa	38.50	34.40	$28.72_{\pm 2.46}$	$33.28_{\pm 1.24}$	$36.98_{\pm 1.55}$	$39.58_{\pm 2.80}$	5.18
piqa	45.30	36.10	$37.00_{\pm 2.71}$	$38.54_{\pm 2.17}$	$41.34_{\pm 1.75}$	$41.42_{\pm 1.02}$	5.32
squadv2	30.60	32.40	$29.86_{\pm 5.46}$	$29.46_{\pm 0.84}$	$30.26_{\pm 1.54}$	$30.58_{\pm 1.61}$	-1.82
All@mean	41.33	40.38	$39.13_{\pm 2.06}$	$40.24_{\pm 1.61}$	$43.57_{\pm 0.68}$	$44.53_{\pm 0.42}$	4.15
@median	41.33	40.38	39.93	40.91	43.43	44.31	3.93
@min	41.33	40.38	35.66	38.28	42.65	44.16	3.77
@max	41.33	40.38	40.59	41.76	44.51	45.07	4.69

Table 1: **The main experimental results (%) for unsupervised cross-task generalization in SoftEM.** Each result in the upper section is the average (and the std) performance of using 5 different query sets for a task. The lower section of this table reports the mean, max, min, and median of the overall performance (i.e., the average performance on all tasks) of these five rounds.

4.4 Experimental Results

BART0 vs T0-3B. As mentioned earlier, we find that BART0 is comparable with the much larger T0-3B in terms of their zero-shot performance on our unseen tasks (41.33 vs 40.38). As we use BART0 as our base model for testing different retrieval-augmentation methods, its overall performance *40.38* is what we want retrieval-augmentation methods to beat. Note that when using BART0 and T0-3B for non-retrieval zero-shot inference, they do not use any information from the query examples, so their mean, median, min, and max are always the same.

Random Retrieval. The *Random* column shows the results when we randomly sample R_i from the upstream data D without using any information from Q_i. The max performance among the multiple rounds of random retrieval is usually comparable to or larger than the performance of the vanilla BART0 for all tasks. For example, although the mean performance of random retrieval for SquadV2 is 29.86, which is smaller than BART0's 32.40, the max of random retrieval is 35.32. These maximum performance of "lucky" rounds of random retrieval suggest that it is promising to develop better retrieval augmentation methods. Plus, it also suggests that if given suitable retrieved data, such a simple "re-learning" method could already enhance the upstream model.

SBERT and ReCross†. We use SentenceBERT (SBERT) as a strong baseline method to create a dense index of the upstream data, compared with our proposed indexing method, ReCross† (i.e., ReCross without reranking). We can see that ReCross† always outperforms the other methods. Even its minimum performance in the five rounds (*42.65*) is better than the maximum of the SBERT (*41.76)*. Besides, the standard deviation also becomes much smaller (1.61→ 0.68), which means that improvement by the ReCross† is more consistent under different query sets.

The SBERT indexing relies mainly on the *semantic similarities* between a query example and the upstream data. Instead, our proposed ReCross† uses the hidden representations inside the upstream model $\mathcal{M}$ for representing examples. We believe using such an indexing method can better help us find examples that share *similar reasoning skills* acquired by the upstream model.

ReCross = ReCross† + Reranking. The full version of our ReCross with reranking can further improve the performance substantially on multiple dimensions. Both all@mean and median are improved by 1 point from the ReCross†, and the std is also reduced from 0.68 to 0.42. The last column (Δ) in Table 1 shows its improvement compared to the base model BART0, and we can see that ReCross consistently outperforms non-retrieval methods (e.g., BART0) by a significant gap.

To explore the potential benefits of retrieval-augmentation methods such as our ReCross, we also conduct the same experiments on five tasks selected from the BIG-Bench project. The results are shown in Table 2, where we can see that ReCross still outperforms the non-retrieval methods. An interesting case is the movie_dialog task, where the prompt in the template requires a model to output

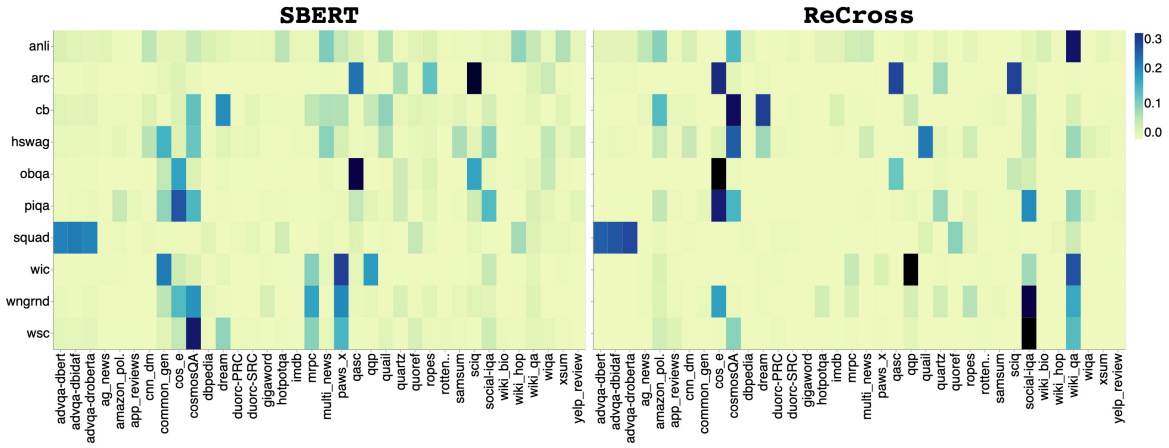

Figure 3: **The mapping between unseen tasks (as rows) and upstream tasks (as columns).** The darker upstream tasks take more percentage in retrieved data. For example, for the task `WIC`, ReCross retrieves a plurality of examples from `QQP` (about 30% of the retrieved examples).

"same" or "different." However, both T0-3B and BART0 fail to follow the prompt instruction, and can only output "yes/no." Only via retrieval-augmentation, we can see the performance improvement on this task.

4.5 Analysis & More Findings.

More configurations. We have used a particular configuration in our main experiments that are in Table 1, which is $|Q|$=16, $|R|$=512, and $|u|$=2. In Table 3, we explore more configurations as ablation studies. The "Main Exp." row refers to the results shown in Table 1, and the configurations of other rows are only changed with one factor at a time. Even using a single query example, ReCross is better than BART0. However, when increasing the query size to 32, we find that the performance starts to decrease, meaning that there could be an optimal query size for a certain $|R|$=512. We find that increasing $|R|$ is generally beneficial, while the all@mean decreases when $|R|$ is changed from 512 to 1024, although the max and the median slightly increased. Finally, we see that increasing μ increases the std. and does not improve the overall performance.

Task	T0-3B	BART0	ReCross
hindu_knowledge	24.75	23.48	$24.87_{\pm 0.27}$
known_unknowns	47.83	43.48	$47.17_{\pm 1.65}$
logic_grid_puzzle	23.60	20.70	$17.12_{\pm 6.29}$
strategyqa	47.70	48.30	$49.76_{\pm 0.80}$
movie_dialog	0.00	4.40	$37.22_{\pm 13.26}$
All@Mean	28.78	28.07	$35.23_{\pm 2.85}$

Table 2: **Results on a subset of BigBench tasks.**

Retrieved data distribution. Figure 3 presents the difference between the methods in terms of their retrieved data. We draw the distribution of the retrieved data among different upstream tasks for each unseen task individually. From the heatmap, we can see that ReCross tends to have more dominant retrieved tasks (i.e., darker cells), while SBERT's results are more sparse. They both can identify that `squad` is most similar to the `adversarial_qa` tasks. Their behaviors are very different too. Taking the unseen task `winogrande` (wngrnd) as an example, we can see that the SBERT retrieves from multiple upstream tasks such as `paws-x` and `cosmosQA` , but the ReCross mainly retrieves from `social-iqa`, `wiki-qa`, and `cos-e`. The experimental results in Table 1 show that ReCross produces a better performance than SBERT (i.e., 55.46 vs 52.18), while it is not clear how we can predict such task correlation in advance. This suggests that we should explore more about the utility of instances and tasks in future work.

Setup\All@	Mean	std.	Min	Max	Median
Main Exp.	44.53	0.42	44.16	45.07	44.31
$\|Q\|$=1	43.20	0.83	42.58	44.58	42.88
$\|Q\|$=8	43.67	0.90	42.09	44.32	43.90
$\|Q\|$=32	42.52	1.17	40.52	43.40	42.96
$\|R\|$=256	40.80	0.83	39.45	41.68	40.96
$\|R\|$=1024	44.02	1.43	42.26	45.35	44.59
μ=3	43.92	0.58	43.08	44.57	43.89
μ=4	43.91	0.99	42.76	45.10	44.26

Table 3: **The ablation study of ReCross.**

Others. Due to the space limit, we leave more additional analysis and discussion in Appendix. Those discussions include research questions such as: 1) Can we run Alg. 1 for multiple iterations to further improve the reranker? 2) How do we explain the exceptional results in Table 1? 3) What if we remove a group of upstream tasks? Can we know better about the retrieval behavior? 4) Can ReCross work with larger base models such as T0? 5) What if there are no NL templates from users?

5 Related Work

Multi-task training for task generalization. Text-to-text Transformer language models such as T5 enable us to train a multi-task NLP model with a more straightforward recipe: mixing the data of multiple tasks into a unified seq2seq format, and then fine-tuning text-to-text LMs for implicit multi-task learning. UnifiedQA (Khashabi et al., 2020) is among the first works in this direction. Although it shows great generalization performance within QA tasks, it can hardly generalize to other NLP tasks. Recent works, such as CrossFit (Ye et al., 2021), ExT5 (Aribandi et al., 2022), FLAN (Wei et al., 2021), and T0 (Sanh et al., 2021), focus on how to generalize a massively multi-task model across task boundaries in a much broader context (i.e., cross-task generalization).

Particularly, in the CrossFit framework (Ye et al., 2021), cross-task generalization requires a small number of labeled instances of the target task for fine-tuning. It is because the templates of CrossFit use the task names as the hard prefixes. Therefore, it is necessary to fine-tune the upstream model with a few examples that have the target task names as prefixes (i.e., few-shot learning), but this largely limits the application scenarios of these multi-task NLP models in practice. We instead focus on *unsupervised* cross-task generalization, where there is no *labeled* data of an unseen task (i.e., zero-shot learning). Using natural-language instructions as prompts, both FLAN and T0 show that it is promising to perform *zero-shot* cross-task generalization.

In this work, we also focus on such an unsupervised setting for cross-task generalization, while our problem setup is a bit different from the ones used in T0 and FLAN. As for the assumption about the unlabeled data, their setups can be seen as a special case of ours when $|Q| = 1$ for all unseen tasks. The evaluation protocols of T0 and FLAN assess the generalization performance of the upstream model as it is, and thus their evaluation is more about the quality of templates and the upstream training tricks. In contrast, our evaluation protocol can also study how to efficiently adjust the upstream model such that the updated models can generalize to new tasks without labeled data. Thus, we believe ours is a more general setup for studying unsupervised cross-task generalization.

Retrieval augmentation in NLP. We aim to retrieve useful examples from the upstream data and re-learning them for cross-task generalization. The proposed ReCross pipeline is inspired by open-ended QA methods such as DPR (Karpukhin et al., 2020), DrFact (Lin et al., 2021), and RAG (Lewis et al., 2020b). Retrieval augmentation also shows great performance in pre-training LMs (Guu et al., 2020). Besides, Wang et al. (2022) show that learning with similar data via retrieval augmentation can improve the performance of a task-specific model. Rubin et al. (2021) show that retrieving better demonstration examples are also helpful for in-context few-shot learning of GPT-3 style language models (Brown et al., 2020). The key challenge in the problem setup of this work is to predict the utility of the examples for unseen tasks with the consideration of efficiency and scalibility. We have discussed more details about this challenge and related works in Sec. 2.

6 Conclusion & Future Directions

We demonstrate that retrieval augmentation can largely improve the cross-task generalization ability to multitask LMs in unsupervised settings. Our proposed method, ReCross, is a straightforward yet effective retrieval method that combines both efficient dense retrieval and effective pair-wise reranking. Our empirical results show that it significantly outperforms both non-retrieval methods and other baseline methods. We perform ablation studies showing the impact of changing query sizes, retrieval sizes, upsampling ratios, etc. We also find the distribution of retrieved data for analyzing the behavior differences between ReCross and others. We believe that our paper will spur further research on retrieval-augmentation methods for cross-task generalization. Interesting future directions include: 1) improve the re-learning stage by including more information from query examples, 2) extend the distant supervision mining process as a self-training procedure, 3) rigorously analyze the correlation between upstream data and target tasks, etc.

References

Vamsi Aribandi, Yi Tay, Tal Schuster, Jinfeng Rao, Huaixiu Steven Zheng, Sanket Vaibhav Mehta, Honglei Zhuang, Vinh Q. Tran, Dara Bahri, Jianmo Ni, Jai Gupta, Kai Hui, Sebastian Ruder, and Donald Metzler. 2022. Ext5: Towards extreme multi-task scaling for transfer learning. In *International Conference on Learning Representations*.

Stephen H. Bach, Victor Sanh, Zheng-Xin Yong, Albert Webson, Colin Raffel, Nihal V. Nayak, Abheesht Sharma, Taewoon Kim, M Saiful Bari, Thibault Fevry, Zaid Alyafeai, Manan Dey, Andrea Santilli, Zhiqing Sun, Srulik Ben-David, Canwen Xu, Gunjan Chhablani, Han Wang, Jason Alan Fries, Maged S. Al-shaibani, Shanya Sharma, Urmish Thakker, Khalid Almubarak, Xiangru Tang, Xiangru Tang, Mike Tian-Jian Jiang, and Alexander M. Rush. 2022. Promptsource: An integrated development environment and repository for natural language prompts.

BIG-bench collaboration. 2021. Beyond the imitation game: Measuring and extrapolating the capabilities of language models. *In preparation*.

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. In *Advances in Neural Information Processing Systems 33: Annual Conference on Neural Information Processing Systems 2020, NeurIPS 2020, December 6-12, 2020, virtual*.

Kelvin Guu, Kenton Lee, Zora Tung, Panupong Pasupat, and Ming-Wei Chang. 2020. Realm: Retrieval-augmented language model pre-training. *ArXiv*, abs/2002.08909.

Jeff Johnson, Matthijs Douze, and Hervé Jégou. 2019. Billion-scale similarity search with gpus. *IEEE Transactions on Big Data*.

Vladimir Karpukhin, Barlas Oguz, Sewon Min, Patrick Lewis, Ledell Wu, Sergey Edunov, Danqi Chen, and Wen-tau Yih. 2020. Dense passage retrieval for open-domain question answering. In *Proceedings of the 2020 Conference on Empirical Methods in Natural Language Processing (EMNLP)*, pages 6769–6781, Online. Association for Computational Linguistics.

Daniel Khashabi, Sewon Min, Tushar Khot, Ashish Sabharwal, Oyvind Tafjord, Peter Clark, and Hannaneh Hajishirzi. 2020. UNIFIEDQA: Crossing format boundaries with a single QA system. In *Findings of the Association for Computational Linguistics: EMNLP 2020*, pages 1896–1907, Online. Association for Computational Linguistics.

Lukas Lange, Jannik Strötgen, Heike Adel, and Dietrich Klakow. 2021. To share or not to share: Predicting sets of sources for model transfer learning. In *EMNLP*.

Mike Lewis, Yinhan Liu, Naman Goyal, Marjan Ghazvininejad, Abdelrahman Mohamed, Omer Levy, Veselin Stoyanov, and Luke Zettlemoyer. 2020a. BART: Denoising sequence-to-sequence pre-training for natural language generation, translation, and comprehension. In *Proceedings of the 58th Annual Meeting of the Association for Computational Linguistics*, pages 7871–7880, Online. Association for Computational Linguistics.

Patrick S. H. Lewis, Ethan Perez, Aleksandra Piktus, Fabio Petroni, Vladimir Karpukhin, Naman Goyal, Heinrich Küttler, Mike Lewis, Wen-tau Yih, Tim Rocktäschel, Sebastian Riedel, and Douwe Kiela. 2020b. Retrieval-augmented generation for knowledge-intensive NLP tasks. In *Advances in Neural Information Processing Systems 33: Annual Conference on Neural Information Processing Systems 2020, NeurIPS 2020, December 6-12, 2020, virtual*.

Bill Yuchen Lin, Haitian Sun, Bhuwan Dhingra, Manzil Zaheer, Xiang Ren, and William Cohen. 2021. Differentiable open-ended commonsense reasoning. In *Proceedings of the 2021 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies*, pages 4611–4625, Online. Association for Computational Linguistics.

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. *ArXiv preprint*, abs/1907.11692.

Vishakh Padmakumar, Leonard Lausen, Miguel Ballesteros, Sheng Zha, He He, and George Karypis. 2022. Exploring the role of task transferability in large-scale multi-task learning. *ArXiv*, abs/2204.11117.

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. *Journal of Machine Learning Research*, 21(140):1–67.

Nils Reimers and Iryna Gurevych. 2019. Sentence-BERT: Sentence embeddings using Siamese BERT-networks. In *Proceedings of the 2019 Conference on Empirical Methods in Natural Language Processing and the 9th International Joint Conference on Natural Language Processing (EMNLP-IJCNLP)*, pages 3982–3992, Hong Kong, China. Association for Computational Linguistics.

Ohad Rubin, Jonathan Herzig, and Jonathan Berant. 2021. Learning to retrieve prompts for in-context learning. *ArXiv*, abs/2112.08633.

Victor Sanh, Albert Webson, Colin Raffel, Stephen H. Bach, Lintang Sutawika, Zaid Alyafeai, Antoine Chaffin, Arnaud Stiegler, Teven Le Scao, 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, Stella Biderman, Leo Gao, Tali Bers, Thomas Wolf, and Alexander M. Rush. 2021. Multitask prompted training enables zero-shot task generalization.

Tu Vu, Tong Wang, Tsendsuren Munkhdalai, Alessandro Sordoni, Adam Trischler, Andrew Mattarella-Micke, Subhransu Maji, and Mohit Iyyer. 2020. Exploring and predicting transferability across nlp tasks. In *EMNLP*.

Shuo Wang, Yichong Xu, Yuwei Fang, Yang Liu, S. Sun, Ruochen Xu, Chenguang Zhu, and Michael Zeng. 2022. Training data is more valuable than you think: A simple and effective method by retrieving from training data. In *ACL*.

Jason Wei, Maarten Bosma, Vincent Zhao, Kelvin Guu, Adams Wei Yu, Brian Lester, Nan Du, Andrew M. Dai, and Quoc V. Le. 2021. Finetuned language models are zero-shot learners. *ArXiv preprint*, abs/2109.01652.

Qinyuan Ye, Bill Yuchen Lin, and Xiang Ren. 2021. CrossFit: A few-shot learning challenge for cross-task generalization in NLP. In *Proceedings of the 2021 Conference on Empirical Methods in Natural Language Processing*, pages 7163–7189, Online and Punta Cana, Dominican Republic. Association for Computational Linguistics.

Checklist

1. For all authors...
   (a) Do the main claims made in the abstract and introduction accurately reflect the paper's contributions and scope? [Yes]
   (b) Did you describe the limitations of your work? [Yes] Please see the experiment analysis sections and the appendix.
   (c) Did you discuss any potential negative societal impacts of your work? [Yes] Please check the appendix.
   (d) Have you read the ethics review guidelines and ensured that your paper conforms to them? [Yes]
2. If you are including theoretical results...
   (a) Did you state the full set of assumptions of all theoretical results? [N/A]

(b) Did you include complete proofs of all theoretical results? [N/A]

3. If you ran experiments...

   (a) Did you include the code, data, and instructions needed to reproduce the main experimental results (either in the supplemental material or as a URL)? [Yes] We include our code, data, and instructions in our supplemental material for reproducing all results presented in the paper. As the data is quite large, we also include a script to download it.

   (b) Did you specify all the training details (e.g., data splits, hyperparameters, how they were chosen)? [Yes] We have specified the details of the base model (i.e., BART0) and the configurations for our retrieval-augmentation methods. Please check the experiment section and the appendix respectively.

   (c) Did you report error bars (e.g., with respect to the random seed after running experiments multiple times)? [Yes] All our results are based on five different rounds, where each we use a different set of query examples. We also report multiple dimensions of the statistics in our table (e.g., the median, min, max, std, and mean).

   (d) Did you include the total amount of compute and the type of resources used (e.g., type of GPUs, internal cluster, or cloud provider)? [Yes] We show these details in our appendix.

4. If you are using existing assets (e.g., code, data, models) or curating/releasing new assets...

   (a) If your work uses existing assets, did you cite the creators? [Yes]

   (b) Did you mention the license of the assets? [Yes]

   (c) Did you include any new assets either in the supplemental material or as a URL? [Yes]

   (d) Did you discuss whether and how consent was obtained from people whose data you're using/curating? [Yes] The data we used are all open-source and publicly available via the "datasets" library from HuggingFace.

   (e) Did you discuss whether the data you are using/curating contains personally identifiable information or offensive content? [Yes] Please refer to our appendix and the links to the used datasets.

5. If you used crowdsourcing or conducted research with human subjects...

   (a) Did you include the full text of instructions given to participants and screenshots, if applicable? [N/A]

   (b) Did you describe any potential participant risks, with links to Institutional Review Board (IRB) approvals, if applicable? [N/A]

   (c) Did you include the estimated hourly wage paid to participants and the total amount spent on participant compensation? [N/A]