Towards Unifying Multi-Lingual and Cross-Lingual Summarization

Anonymous ACL submission

Abstract

To adapt text summarization to the multilingual world, previous work proposes multi-lingual summarization (MLS) and cross-lingual summarization (CLS), respectively. However, these two tasks have been studied separately due to the different definitions, which limits the compatible and systematic research on both of them. In this paper, we aim to unify MLS and CLS into a more general setting, *i.e.*, many-to-many summarization (M2MS), where a single model could process documents in any language and generate their summaries also in any language. As the first step towards M2MS, we conduct preliminary studies to show that M2MS can better transfer task knowledge across different languages than MLS and CLS. Furthermore, we propose PISCES, a pre-trained M2MS model that learns language modeling, cross-lingual ability and summarization ability via three-stage pre-training. Experimental results indicate that our PISCES significantly outperforms the state-of-the-art baseline, especially in the zero-shot directions, where there is no training data from the source-language documents to the target-language summaries.[1]

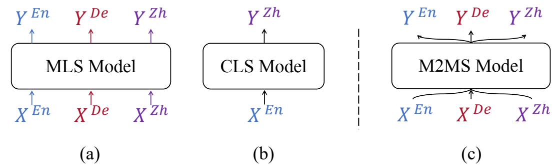


Figure 1: Illustration of (a) multi-lingual summarization, (b) cross-lingual summarization and (c) many-to-many summarization. X^i and Y^i denote the input document and output summary in language i, respectively. En: English; De: German; Zh: Chinese.

1 Introduction

The world we live in is multi-lingual. With globalization, text resources in various languages flood the Internet, where global users can easily access their desired information. Under this background, the text summarization community presents multi-lingual summarization (MLS) and cross-lingual summarization (CLS), respectively. As shown in Figure 1, MLS aims at building a unified model to process documents in multiple languages and generate summaries in the corresponding language (Giannakopoulos et al., 2015; Cao et al., 2020b; Hasan et al., 2021b; Wang et al., 2021; Varab and Schluter, 2021), while CLS generates a summary in the target language from the given document in a different source language (Leuski et al., 2003a; Wan et al., 2010; Wan, 2011; Yao et al., 2015; Zhu et al., 2019; Ladhak et al., 2020; Perez-Beltrachini and Lapata, 2021; Wang et al., 2022a,b). Despite the close relationship between MLS and CLS (*e.g.*, both tasks involve more than one language and require models to distill the key information from documents), previous work studies each task separately, hindering the systematic exploration for both of them.

In this paper, we aim to unify MLS and CLS into a more general setting named *many-to-many summarization* (M2MS). As its name implies, the goal of M2MS is to build a single summarization model to process a document in any source language and generate the corresponding summary in any given target language. In this manner, one M2MS model could perform more directions than MLS and CLS[2], thus reducing the used parameters. For example, one M2MS model involving n languages could replace one MLS model and $n\times(n-1)$ CLS models. To provide a deeper understanding of M2MS, we also conduct preliminary studies to systematically compare M2MS with MLS and CLS, respectively. In detail, following recent CLS work (Ladhak et al., 2020; Perez-Beltrachini and Lapata, 2021), we use mBART-50 (Tang et al., 2021) as the summarization model, and train the model in the settings of MLS, CLS and M2MS, respectively. After com-

[1] The codes and checkpoints will be released.

[2] We use "direction" to denote the summarization direction from the source to the target languages, e.g., English (documents) ⇒ Chinese (summaries).

paring the model performances, we find that the model trained in M2MS setting can better transfer task knowledge across different languages and combine the advantages of those trained in MLS and CLS settings. Therefore, we argue that it is promising to unify MLS and CLS into a more general setting, *i.e.*, M2MS.

Furthermore, we propose PISCES[3], a pre-trained M2MS model that learns language modeling, cross-lingual ability and summarization ability via three pre-training stages: (1) *meta pre-training* learns the general language modeling knowledge from multi-lingual unlabeled corpora; (2) *cross-lingual pre-training* makes the model aware of the transformation between different languages based on parallel corpora; (3) *task-specific pre-training* utilizes M2MS objective to simultaneously improve the cross-lingual ability and the summarization abilities of the model. Considering the high-quality M2MS samples are non-trivial to collect, we leverage a simple strategy to construct pseudo M2MS samples from multi-lingual unlabeled corpora. During the three-stage pre-training, PISCES gradually shifts from learning language modeling to the abilities required by M2MS. Among them, the learned cross-lingual ability plays a key role in enhancing the knowledge transferability of the downstream task (*i.e.*, summarization) from high-resource languages to low/zero-resource languages. Lastly, the pre-trained PISCES could be simply fine-tuned on M2MS with input source-language documents and output target-language summaries.

We evaluate PISCES on the WikiLingua (Ladhak et al., 2020) datasets. Experimental results show that PISCES achieves promising results compared with the state-of-the-art baseline (*i.e.*, mBART-50), especially in the zero-shot directions. Moreover, we find that PISCES is even able to generate summaries for documents whose language never occurs in the fine-tuning stage.

Our contributions are concluded as follows:

- To our knowledge, we are the first to unify MLS and CLS into a more general setting (M2MS). We also conduct preliminary studies to provide deeper analyses among MLS, CLS and M2MS.
- We propose PISCES, a pre-trained M2MS model that learns language modeling, cross-lingual ability and summarization ability through a carefully designed three-stage pre-training.
- We conduct extensive experiments and show that our PISCES achieves new state-of-the-art performance on the large-scale benchmark dataset. Besides, the effectiveness of PISCES in low/zero-resource languages is also demonstrated.

2 Related Work

Multi-Lingual Summarization. Multi-lingual summarization (MLS) aims to process documents in multiple languages and generate their summaries in the corresponding language. Giannakopoulos et al. (2015) present MultiLing-2015 dataset. Later, this task receives increasing attention (Vanetik and Litvak, 2015; Litvak et al., 2016). Recently, large-scale MLS datasets (Scialom et al., 2020; Varab and Schluter, 2021; Hasan et al., 2021b; Feng et al., 2022) together with sophisticated methods (Cao et al., 2020b; Chi et al., 2020; Wang et al., 2021) are proposed one after another.

Cross-Lingual Summarization. Given documents in one language, cross-lingual summarization (CLS) generates summaries in another language. Early work typically focuses on pipeline methods (Leuski et al., 2003b; Orăsan and Chiorean, 2008; Wan et al., 2010; Wan, 2011; Yao et al., 2015), *i.e.*, translation and then summarization or summarization and then translation. Recently, with the availability of large-scale CLS datasets (Zhu et al., 2019; Ladhak et al., 2020; Perez-Beltrachini and Lapata, 2021; Wang et al., 2022a), many researchers shift the research attention to end-to-end CLS models, including multi-task learning (Cao et al., 2020a; Bai et al., 2021; Liang et al., 2022), knowledge distillation (Nguyen and Tuan, 2022), resource-enhanced (Zhu et al., 2020) and pre-training (Xu et al., 2020; Chi et al., 2021) approaches.[4] Among them, most CLS work separately builds CLS models in each cross-lingual direction except for Hasan et al. (2021a), who jointly train mT5 (Xue et al., 2021) in multiple directions.

Different from previous MLS and CLS, we unify them into a more general setting, *i.e.*, M2MS.

Pre-Trained Models for Summarization. Pre-trained models have shown their superiority in summarization task, *e.g.*, BART (Lewis et al., 2020) and T5 (Raffel et al., 2020). To enhance the summarization ability during the pre-training stage, PEGASUS (Zhang et al., 2020a) introduces the gap sentence generation (GSG) objective to enable the

[3] PISCES: **P**re-tra**I**ning with gap-**S**entences and **C**ross-lingual d**E**noi**S**ing for many-to-many summarization.

[4] The taxonomy of end-to-end CLS approaches refers to Wang et al. (2022b).

Src \ Trg	Setting	En	Fr	Hi	Zh	Th	Tr
En	ONE	41.2 / 17.5 / 34.6 / 74.2	35.2 / 14.8 / 29.2 / 73.0	28.2 / 8.3 / 22.6 / 67.7	34.9 / 11.8 / 30.4 / 69.8	34.3 / 14.3 / 30.0 / 66.1	NA
	U-CLS	39.7 / 16.0 / 32.7 / 73.6	<u>36.8</u> / <u>15.3</u> / <u>29.9</u> / <u>73.6</u>	<u>31.2</u> / <u>9.2</u> / <u>23.9</u> / <u>69.0</u>	**37.9 / 13.9 / 32.7 / 71.5**	<u>38.9</u> / <u>17.9</u> / <u>33.4</u> / <u>68.9</u>	**3.2 / 0.3 / 3.0** / <u>48.9</u>
	MLS	<u>41.6</u> / <u>17.9</u> / <u>34.7</u> / <u>74.4</u>	5.3 / 0.8 / 4.8 / 63.8	3.3 / 0.7 / 3.1 / 53.7	14.6 / 0.9 / 14.5 / 60.1	20.8 / 5.7 / 20.0 / 54.1	2.5 / <u>0.2</u> / 2.4 / 47.3
	M2MS	**41.9 / 18.2 / 34.9 / 74.6**	**37.2 / 15.8 / 30.3 / 73.9**	**31.7 / 9.6 / 24.5 / 69.3**	**37.9 / 13.9 / 32.7 / 71.5**	**39.5 / 18.5 / 34.0 / 69.1**	**3.2** / <u>0.2</u> / **3.0 / 49.0**
Fr	ONE	35.6 / 13.6 / 29.8 / 72.1	37.8 / 17.4 / 31.2 / 73.9	NA	32.6 / 10.0 / 28.4 / 68.6	31.4 / 11.8 / 27.6 / 64.9	NA
	U-CLS	<u>37.5</u> / <u>14.4</u> / <u>30.7</u> / <u>72.9</u>	37.6 / 16.1 / 30.5 / 74.0	<u>28.2</u> / <u>7.6</u> / <u>22.0</u> / **68.1**	<u>36.7</u> / **12.8** / <u>31.3</u> / **70.9**	<u>37.3</u> / <u>16.2</u> / <u>32.1</u> / <u>68.1</u>	**3.3 / 0.3 / 3.1 / 49.4**
	MLS	8.8 / 2.2 / 7.6 / 64.3	**39.5 / 18.2 / 32.5 / 74.9**	2.1 / 0.4 / 1.9 / 53.3	13.5 / 1.0 / 13.2 / 57.5	18.5 / 3.3 / 17.9 / 54.5	2.1 / 0.1 / 2.1 / 46.8
	M2MS	**38.2 / 15.0 / 31.7 / 73.4**	<u>39.2</u> / <u>17.9</u> / <u>32.0</u> / <u>74.7</u>	**28.7 / 7.9 / 22.3 / 68.1**	**36.9 / 12.8 / 31.6 / 70.9**	**37.9 / 16.6 / 32.6 / 68.5**	<u>3.1</u> / <u>0.2</u> / <u>3.0</u> / <u>49.2</u>
Hi	ONE	32.2 / 10.9 / 26.1 / 70.2	NA	32.8 / 11.5 / 25.8 / 69.6	NA	NA	NA
	U-CLS	<u>36.8</u> / <u>14.0</u> / <u>29.8</u> / <u>72.2</u>	<u>31.9</u> / <u>11.6</u> / <u>24.7</u> / <u>71.4</u>	32.7 / 10.3 / 25.6 / 70.3	<u>32.6</u> / <u>10.2</u> / <u>27.3</u> / <u>68.6</u>	<u>34.9</u> / <u>14.3</u> / <u>29.4</u> / <u>67.1</u>	<u>3.3</u> / **0.3 / 3.2 / 50.0**
	MLS	11.1 / 3.3 / 9.3 / 57.7	11.6 / 3.2 / 9.5 / 59.3	**36.0 / 12.7 / 27.8 / 71.3**	14.2 / 2.8 / 12.8 / 57.2	23.1 / 6.0 / 21.3 / 57.9	2.1 / 0.1 / 2.0 / 46.7
	M2MS	**37.9 / 14.6 / 30.8 / 72.8**	**32.8 / 12.2 / 25.9 / 72.1**	<u>35.6</u> / <u>12.5</u> / **27.8** / <u>71.1</u>	**33.2 / 10.6 / 28.2 / 69.1**	**35.4 / 14.6 / 30.1 / 67.4**	**3.4 / 0.3 / 3.2** / <u>49.7</u>
Zh	ONE	34.6 / 11.8 / 28.4 / 71.4	31.5 / 11.4 / 25.4 / 71.0	NA	40.8 / 16.9 / 35.4 / 71.9	NA	NA
	U-CLS	<u>37.7</u> / <u>14.1</u> / <u>30.8</u> / <u>72.8</u>	<u>35.4</u> / <u>14.1</u> / <u>28.4</u> / <u>73.0</u>	<u>25.8</u> / <u>6.1</u> / <u>20.0</u> / <u>66.4</u>	39.6 / 15.1 / 34.2 / 72.2	<u>36.6</u> / **15.3** / <u>31.0</u> / <u>67.3</u>	<u>3.3</u> / **0.2** / <u>3.1</u> / **49.8**
	MLS	10.4 / 3.0 / 8.6 / 61.7	24.9 / 7.3 / 19.7 / 68.0	20.4 / 4.4 / 16.0 / 62.4	**42.8 / 17.9 / 37.0 / 73.1**	30.3 / 9.3 / 26.4 / 63.5	2.8 / **0.2** / 2.6 / 48.4
	M2MS	**39.2 / 15.1 / 32.0 / 73.4**	**36.0 / 14.5 / 29.0 / 73.3**	**27.0 / 6.6 / 20.8 / 66.9**	<u>41.7</u> / <u>17.0</u> / <u>35.9</u> / <u>72.7</u>	**36.8 / 15.3 / 31.4 / 67.6**	**3.4 / 0.2 / 3.2** / <u>49.6</u>
Th	ONE	32.1 / 11.1 / 26.4 / 70.4	27.9 / 2.7 / 22.7 / 69.4	NA	NA	37.8 / 17.6 / 33.0 / 67.4	NA
	U-CLS	<u>37.2</u> / <u>14.4</u> / <u>30.7</u> / <u>72.6</u>	<u>34.9</u> / <u>13.9</u> / <u>27.7</u> / <u>72.3</u>	<u>27.1</u> / <u>6.8</u> / <u>20.6</u> / <u>66.9</u>	<u>34.1</u> / <u>10.9</u> / <u>28.3</u> / <u>68.9</u>	39.9 / 18.4 / 34.3 / 69.5	**3.4 / 0.3 / 3.2 / 49.4**
	MLS	7.4 / 1.8 / 6.6 / 54.9	10.1 / 2.5 / 8.4 / 58.4	11.8 / 2.1 / 9.6 / 57.6	16.8 / 3.3 / 15.0 / 59.4	**43.3 / 22.3 / 37.1 / 70.3**	2.7 / **0.3** / 2.6 / 47.8
	M2MS	**38.5 / 15.4 / 31.9 / 73.4**	**35.6 / 14.2 / 28.3 / 72.9**	**27.8 / 7.3 / 21.4 / 67.4**	**34.6 / 11.3 / 29.0 / 69.4**	<u>42.2</u> / <u>20.8</u> / <u>36.2</u> / <u>70.1</u>	<u>3.3</u> / **0.3** / <u>3.1</u> / <u>49.3</u>
Tr	ONE	NA	NA	NA	NA	NA	NA
	U-CLS	**16.9 / 3.3 / 14.4 / 62.9**	**16.7 / 3.3 / 13.5 / 64.6**	**16.2 / 2.6 / 13.7 / 61.0**	**21.7 / 3.8 / 19.1 / 61.2**	**22.8 / 5.7 / 19.9 / 60.4**	**3.4 / 0.3 / 3.3 / 48.8**
	MLS	6.6 / 0.8 / 5.9 / 53.5	9.7 / 1.1 / 8.6 / 58.7	7.8 / 0.7 / 7.0 / 54.1	17.9 / 2.8 / 15.3 / 58.7	17.4 / 2.5 / 16.6 / 54.4	2.3 / 0.1 / 2.2 / 44.7
	M2MS	<u>15.7</u> / <u>2.6</u> / <u>13.4</u> / <u>62.1</u>	<u>16.0</u> / <u>3.2</u> / <u>13.2</u> / <u>64.4</u>	<u>14.9</u> / <u>2.3</u> / <u>12.6</u> / <u>60.1</u>	<u>19.9</u> / <u>3.0</u> / <u>17.6</u> / <u>60.0</u>	<u>21.4</u> / <u>4.8</u> / <u>19.3</u> / <u>59.9</u>	<u>3.1</u> / <u>0.2</u> / <u>3.0</u> / <u>48.4</u>

Table 1: Results on WikiLingua (ROUGE-1 / ROUGE-2 / ROUGE-L / BERTSCORE). Since there is no training data in zero-shot directions, mBART (ONE) cannot be trained and we denote the results as “NA”. The **bold** and <u>underline</u> denote the best and the second scores, respectively.

model to generate key sentences in an article from the remaining ones. Further, PRIMERA (Xiao et al., 2022) extends GSG from single-document to multi-document summarization. In dialogue scenarios, Wang et al. (2022a) present mDIALBART for cross-lingual dialogue summarization.

Among these pre-trained summarization models, PEGASUS and PRIMERA only focus on monolingual summarization. Though mDIALBART aims at CLS, the model is merely built for a single cross-lingual direction (*i.e.*, English ⇒ German/Chinese) and a specific scenario (*i.e.*, dialogue). Our PISCES is the first multi-lingual pre-trained model for general summarization.

3 Does Unifying All Directions in a Single Model Help Each Other?

As discussed previously, M2MS unifies all summarization directions in a single model. Therefore, we wonder *can such a setting help the model better transfer task knowledge across different languages compared with the settings of MLS and CLS?* To answer the question, we conduct preliminary studies to investigate the influence of different settings.

3.1 Setup

Data. The preliminary studies are conducted on WikiLingua (Ladhak et al., 2020), one of the largest CLS datasets. We focus on six languages, *i.e.*, English (En), French (Fr), Hindi (Hi), Chinese (Zh), Thai (Th) and Turkish (Tr). Among them, Tr serves as a zero-resource language, whose documents and summaries only appear in the validation and test sets. More details are given in Section 5.1.

Summarization Model. Following recent CLS literature (Ladhak et al., 2020; Perez-Beltrachini and Lapata, 2021), we use mBART-50 (Tang et al., 2021) as the summarization model, and train the model in the following four settings:

- mBART (ONE): We separately train several models, each of which is built and evaluated in one single direction. When the direction is cross-lingual (or monolingual), the corresonding model is a CLS (or monolingual summarization) model.
- mBART (U-CLS): We train a unified model with all cross-lingual samples, and test the model in all directions.
- mBART (MLS): We train one unified model with monolingual samples in all languages. Then, the trained model is evaluated in all directions.
- mBART (M2MS): It is a new setting introduced by this work, where the model is both trained and evaluated in all directions.

3.2 Analytic Results

Table 1 shows the results in terms of ROUGE (Lin, 2004) and BERTSCORE (Zhang et al., 2020b).

mBART (M2MS) vs. mBART (CLS). The results in all directions show that mBART (M2MS) outperforms mBART (CLS) in all metrics, illustrating that unifying all directions in a single model could transfer task knowledge across different languages.

mBART (M2MS) vs. mBART (MLS). Comparing mBART (M2MS) and mBART (MLS), it is apparent to find that mBART (M2MS) significantly outperforms mBART (MLS) in cross-lingual directions (*e.g.*, 26.9

	En⇒Fr	En⇒Hi	En⇒Zh	En⇒Th
mBART (MLS)	5.8	0.2	1.3	1.0
mBART (M2MS)	99.9	99.4	95.4	99.9
	Fr⇒Hi	Fr⇒Zh	Fr⇒Th	Th⇒En
mBART (MLS)	5.3	5.6	9.4	8.2
mBART (M2MS)	99.4	95.8	99.9	99.5

Table 2: Correct language rate (%) of the summaries generated by mBART (MLS) and mBART (M2MS).

vs. 11.7 ROUGE-1 in average), while achieving competitive results in monolingual directions (*e.g.*, 33.9 vs. 34.2 ROUGE-1 in average).

To give a deeper understanding of why mBART (MLS) performs poorly in cross-lingual directions, we analyze its generated summaries and find that most of them are not in the language we expected. Table 2 shows the rate of the generated summaries in the correct language.[5] The languages of the generated summaries are detected by *fastlangid*[6]. Compared with mBART (M2MS), mBART (MLS) struggles to generate summaries in the target language. We conjecture this is because that mBART (MLS) is only trained with monolingual data from multiple languages without any cross-lingual signals, resulting in limited cross-lingual ability.

Based on the above analyses, we argue that the summarization signals from cross-lingual directions could help mBART (M2MS) perform CLS and transfer the task knowledge to zero-shot directions, while mBART (MLS) does not own such abilities.

mBART (M2MS) vs. mBART (U-CLS). The only difference between mBART (M2MS) and mBART (U-CLS) is that the training data of mBART (M2MS) contains all monolingual samples, while mBART (U-CLS) does not. We find that the performance gap between mBART (M2MS) and mBART (U-CLS) is extremely smaller than that between mBART (M2MS) and mBART (CLS/MLS). In detail, mBART (M2MS) outperforms mBART (U-CLS) in most directions when the source and the target languages have been seen during the fine-tuning stage, *i.e.*, the source and the target languages are from {En, Fr, Hi, Zh, Th}. However, when the source or target language is unseen (*i.e.*, Tr), the performance of mBART (M2MS) is slightly worse than mBART (CLS). This is because the monolingual training data used in mBART (M2MS) makes the word embeddings of the unseen language[7] drift away from those of other languages (see details in Appendix A). Additionally, the cross-lingual signal between the unseen language and other languages never occurs in the fine-tuning stage, making it difficult to summarize from or to the unseen language.

3.3 Preliminary Conclusion

The preliminary studies comparing mBART trained in different settings indicate that (1) the multi-lingual model trained in M2MS setting can better transfer task knowledge across different languages than those trained in the settings of MLS, CLS and unified CLS. (2) Compared with unified CLS, M2MS helps the model achieve better transferability across visible languages, but sacrifices the transferability to unseen languages.

Grounding the above analyses, we argue that it is valuable to unify previous MLS and CLS to M2MS. Meanwhile, *how to improve the transferability to unseen languages* becomes a keypoint in M2MS.

4 PISCES

In this section, we propose PISCES, a pre-trained multi-lingual model for M2MS with the backbone of transformer (Vaswani et al., 2017).

Figure 2 shows the overview of PISCES, which contains three pre-training stages. Specifically, the meta pre-training (§ 4.1) lets the pre-trained model learn general language modeling via monolingual denoising objective in multiple languages. Then, to improve the transferability across different langauges, the cross-lingual pre-training (§ 4.2) adds noises to the source-language sentences, and encourages the model to translate them into parallel sentences in the target language. Note that the parallel sentences used in this stage might involve the languages which are not seen in downstream tasks, and it is the key to improving the transferability to these languages. Finally, to narrow the gap between the pre-training and fine-tuning stages, the task-specific pre-training (§ 4.3) trains the model with pseudo M2MS samples, which are constructed from the multi-lingual unlabeled corpora via gap sentences selection and machine translation. During the three-stage pre-training process, the model gradually learns the ability of language modeling, then the cross-lingual ability, and finally the adaptation to the specific task.

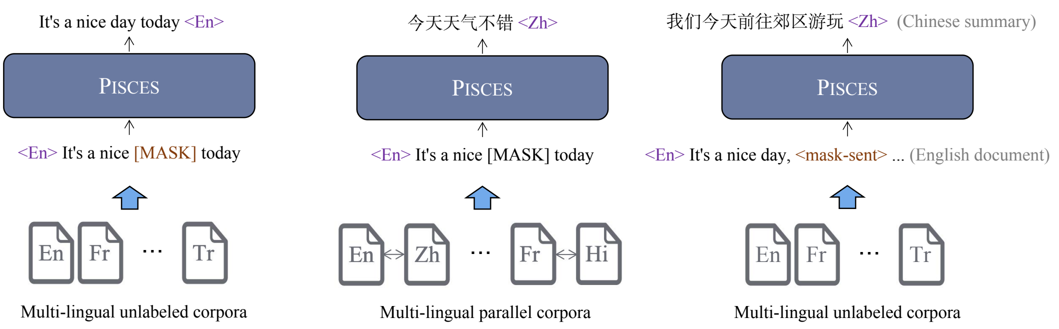
4.1 Meta Pre-Training

The goal of meta pre-training is to provide good initialization for the subsequent pre-training stages.

[5] Other directions also show similar situations.

[6] https://pypi.org/project/fastlangid/

[7] We use "unseen language" to indicate the language does not occur in the *fine-tuning* stage.



(a) Meta pre-training (b) Cross-lingual pre-training (c) Task-specific pre-training

Figure 2: Overview of the three-stage pre-training in PISCES. Specifically, (a) meta pre-training requires the model to generate original sentences based on the noisy counterparts; (b) cross-lingual pre-training generates the sentences in the target language based on the noisy parallel sentences in the source language; (c) task-specific pre-training utilizes pseudo M2MS samples to pre-train the model.

Here, we directly utilize mBART-50 (Tang et al., 2021) as the meta pre-trained model.

mBART-50 is a multi-lingual BART (Lewis et al., 2020) with the transformer encoder-decoder architecture. The model is pre-trained on large-scale multi-lingual unlabeled corpora to learn the multi-lingual language modeling. Specifically, following BART, the denoising task is used as the pre-training objective, and there are two types of noise: (1) *text infilling* randomly masks text spans in text sequences, and (2) *sentence permutation* randomly shuffles sentences in documents. The model is required to comprehend the noisy text sequences and recover them. To indicate the input and output languages, the language tags (*e.g.*, <En> and <Zh>) are appended at the inputs of encoder and decoder sides, respectively.

4.2 Cross-Lingual Pre-Training

Despite the effectiveness of mBART-50, the input and output sequences in its pre-training stage are always in the same language, resulting in the under-explored cross-lingual ability. However, such ability is indispensable for M2MS. Therefore, cross-lingual pre-training is designed to improve the cross-lingual transferability.

In detail, we propose a simple yet effective pre-training task, *i.e.*, cross-lingual denoising, which lets the model generate sentences in the target language based on their noisy parallel sentences in a different source language. The noise used in this stage is *text infilling*. In this way, the pre-trained model is required to not only understand the text in the source language but also learn the transformation between different languages.

4.3 Task-Specific Pre-Training

Task-specific pre-training aims to narrow the gap between the pre-training and fune-tuning stages. We directly adopt M2MS as its pre-training task. Grounding the truth that high-quality M2MS samples are difficult to collect, we construct the pseudo samples from multi-lingual unlabeled corpora.

In detail, for a source-language document $D = \{s_i^{src}\}_{i=1}^{|D|}$, where s_i^{src} denotes the i-th sentence in D. Following previous monolingual pre-trained summarization methods (Zhang et al., 2020a; Xiao et al., 2022), we calculate the importance of each sentence as $\mathcal{S}(s_i^{src}) = \text{ROUGE-1}(s_i^{src}, D/s_i^{src})$, where D/s_i^{src} indicates the rest of the document after s_i^{src} is removed. The sentences with high importance are selected as the gap sentences $S_*^{src} = \{s_{g_i}^{src}\}_{i=1}^{|S_*^{src}|}$ ($g_i \in \{1, 2, ..., |D|\}$), which are further translated to a different target language $S_*^{trg} = \{s_{g_i}^{trg}\}_{i=1}^{|S_*^{trg}|}$ via Google Translation[8]. In this manner, the source-language document D paired with source/target-language gap sentences S_*^{src}/S_*^{trg} could constitute a pseudo pre-training sample.

Quality Controlling. Since machine translation results might contain flaws, we further employ *round-trip translation* strategy as suggested by Zhu et al. (2019) and Feng et al. (2022). For each gap sentence $s_{g_i}^{src}$ in D, the translated counterpart $s_{g_i}^{trg}$ are translated back to the source language, which we denote as $s_{g_i}^{src'}$. If the ROUGE-1 score between $s_{g_i}^{src}$ and $s_{g_i}^{src'}$ is less than the pre-defined threshold λ, the corresponding pseudo sample will be discarded.

Input Format. To help the model trade off between (1) generating new sentences instead of trans-

[8] https://cloud.google.com/translate

Src \ Trg		En	Fr	Hi	Zh	Th	Tr
En	# Samples	124589 / 8351 / 8517	53232 / 5161 / 5258	5707 / 1538 / 2672	13462 / 2697 / 2713	9170 / 2883 / 2697	- / 267 / 2730
	# Avg. Tokens	492.8 / 47.3	521.3 / 55.4	500.6 / 71.8	516.8 / 49.4	524.2 / 48.4	458.3 / 54.3
Fr	# Samples	53232 / 5161 / 5258	53232 / 5161 / 5258	- / 1449 / 2337	10628 / 2605 / 2400	7281 / 2750 / 2386	- / 232 / 2391
	# Avg. Tokens	659.4 / 45.3	659.3 / 55.5	617.3 / 73.1	649.0 / 48.5	673.4 / 47.3	589.9 / 54.4
Hi	# Samples	5707 / 1538 / 2672	- / 1449 / 2337	5707 / 1538 / 2672	- / 1134 / 2000	- / 1266 / 2146	- / 180 / 2091
	# Avg. Tokens	682.1 / 46.2	668.3 / 58.2	684.3 / 72.3	637.9 / 50.5	626.1 / 48.7	627.4 / 53.0
Zh	# Samples	13462 / 2697 / 2713	10628 / 2605 / 2400	- / 1134 / 2000	13462 / 2697 / 2713	- / 2392 / 2218	- / 90 / 2147
	# Avg. Tokens	428.4 / 46.4	432.9 / 58.1	388.7 / 73.6	429.1 / 49.2	371.1 / 49.8	373.2 / 55.5
Th	# Samples	9170 / 2883 / 2697	7281 / 2750 / 2386	- / 1266 / 2146	- / 2392 / 2218	9170 / 2883 / 2697	- / 191 / 2172
	# Avg. Tokens	488.6 / 44.5	504.9 / 56.2	424.6 / 71.8	412.1 / 51.0	490.1 / 48.2	404.1 / 54.2
Tr	# Samples	- / 267 / 2730	- / 232 / 2391	- / 180 / 2091	- / 90 / 2147	- / 191 / 2172	- / 267 / 2730
	# Avg. Tokens	465.1 / 47.5	472.4 / 60.0	468.1 / 72.8	456.9 / 52.7	449.1 / 49.8	465.1 / 54.3

Table 3: Statistics of re-splitted WikiLingua. *# Samples* denotes the number of samples in training / validation / test set. *# Avg. Tokens* represents the average tokens in the documents and summaries, respectively. Green, light green and gray indicate the high-resource, low-resource and zero-shot directions, respectively.

lating part of input sentences, and (2) learning the translation pattern[9] (Zhu et al., 2020), half of source-language gap sentences in D are randomly masked with a special token <mask-sent>.[10]

5 Experiments

5.1 Benchmark Dataset

In order to evaluate M2MS models, two requirements should be met in datasets, *i.e.*, (1) involving multiple languages and summarization directions, and (2) having abundant samples in each direction. Currently, Wikilingua (Ladhak et al., 2020) is the only dataset that meets both the requirements as suggested by Wang et al. (2022b).

The original WikiLingua dataset, which involves 18 languages, is designed for CLS task. The 18 languages constitute 306 (18×17) cross-lingual directions, each of which contains about 18k CLS samples in average. For each document, WikiLingua also contains its summary in the original language. Therefore, the dataset could be used to evaluate M2MS models. However, the original splitting is for CLS. Thus, we re-split WikiLingua with the special consideration for M2MS: for each document in the test (or validation) set of one direction, the document and its parallel documents[11] are not allowed to appear in the training and validation (or test) sets of other directions. This rule reduces the likelihood that learning shortcuts. We also intentionally create several zero-shot directions.

We focus on six languages in this work: English (En), Chinese (Zh), French (Fr), Hindi (Hi), Turkish (Tr) and Thai (Th). After re-splitting, the statistics are shown in Table 3. There are **9 high-resource directions** each of which contains more than 10k training samples. The other **8 directions** with less than 10k training samples are considered as **low-resource directions**. The remaining 19 zero-shot directions have no training sample. According to *whether both the source and target languages appear in the whole training set*, we further divide them into **11 non-trivial and 8 conventional zero-shot directions**. Note that Tr never appears in the training set of any direction, thus, in other words, the non-trivial zero-shot directions involve Tr while the conventional counterparts do not. We call Tr an *unseen language*. Though there is no training data in a conventional zero-shot direction, both its source and target languages might have training data with a pivot language, making it less challenging than the non-trivial ones. Taking the conventional zero-shot direction Hi⇒Zh as an example, the training data in Hi⇒En and En⇒Zh could bridge the gap between Hi and Zh.

5.2 Implementation Details

We utilize mBART-50 (Tang et al., 2021) as the meta pre-trained model, and futher pre-train it via cross-lingual and task-specific pre-training stages. The implementation of mBART-50 is based on the Transformers (Wolf et al., 2020) library with default settings (12 encoder layers, 12 decoder layers and 1024 hidden states). In cross-lingual pre-training, we dynamically mask 0-15% tokens in the source-language sentences, and construct 20.6M samples from OPUS parallel corpora (Tiedemann and Thottingal, 2020). In task-specific pre-training, we construct 3.1M training samples from mC4 corpus (Xue et al., 2021). We set the total length of gap sentences to k% of the document length, and k

[9] In CLS, Zhu et al. (2019) find some words in summaries are directly translated from the source words.

[10] We also attempt to mask all gap sentences or do not mask any gap sentences, the results underperform that of masking half of the gap sentences.

[11] For each document, WikiLingua usually contains its parallel documents in other languages.

Non-Trivial Zero-Shot Directions									
Direction	Tr⇒Others					Avg.	Any⇒Tr		
	Tr⇒En	Tr⇒Fr	Tr⇒Hi	Tr⇒Zh	Tr⇒Th		En⇒Tr	Fr⇒Tr	Tr⇒Tr
mBART	10.6 / 62.1	10.8 / 64.4	9.9 / 60.1	13.5 / 60.0	15.2 / 59.9	12.0 / 61.3	2.1 / 49.0	2.1 / 49.2	2.1 / 48.4
PISCES	20.2 / 68.2	19.6 / 68.9	15.7 / 64.9	21.2 / 66.7	22.9 / 64.9	19.9 / 66.7	3.1 / 53.8	2.8 / 53.4	3.7 / 52.9
Δ	+ 9.6 / 6.1	+ 8.8 / 4.5	+ 5.8 / 4.8	+ 7.7 / 6.7	+ 7.7 / 5.0	+ 7.9 / 5.4	+ 1.0 / 4.8	+ 0.7 / 4.2	+ 1.6 / 4.5

Conventional Zero-Shot Directions									
Direction	Fr⇒Hi	Hi⇒Fr	Hi⇒Zh	Zh⇒Hi	Hi⇒Th	Th⇒Hi	Zh⇒Th	Th⇒Zh	Avg.
mBART	19.6 / 68.1	23.6 / 72.1	24.0 / 69.1	18.1 / 66.9	26.7 / 67.4	18.8 / 67.4	27.8/ 67.6	25.0 / 69.4	23.0 / 68.5
PISCES	21.4 / 69.1	26.1 / 72.9	26.1 / 70.4	20.3 / 68.5	29.1 / 68.5	21.4 / 69.0	29.9 / 68.9	27.0 / 71.0	25.2 / 69.8
Δ	+ 1.8 / 1.0	+ 2.5 / 0.8	+ 2.1 / 1.3	+ 2.2 / 1.6	+ 2.4 / 1.1	+ 2.6 / 1.6	+ 2.1 / 1.3	+ 2.0 / 1.6	+ 2.2 / 1.3

Low-Resource Directions									
Direction	Hi⇒Hi	Th⇒Th	En⇒Hi	Hi⇒En	En⇒Th	Th⇒En	Fr⇒Th	Th⇒Fr	Avg.
mBART	25.3 / 71.1	33.1 / 70.1	21.9 / 69.3	27.8 / 72.8	30.7 / 69.1	28.6 / 73.4	29.0 / 68.5	26.0 / 72.9	27.8 / 70.9
PISCES	26.5 / 71.8	34.2 / 70.7	23.7 / 70.3	29.5 / 73.6	31.9 / 70.1	30.0 / 74.0	30.0 / 69.2	27.4 / 73.8	29.2 / 71.7
Δ	+ 1.2 / 0.7	+ 1.1 / 0.6	+ 1.8 / 1.0	+ 1.7 / 0.8	+ 1.2 / 1.0	+ 1.4 / 0.6	+ 1.0 / 0.7	+ 1.4 / 0.9	+ 1.4 / 0.8

High-Resource Directions										
Direction	En⇒En	Fr⇒Fr	Zh⇒Zh	En⇒Fr	Fr⇒En	En⇒Zh	Zh⇒En	Fr⇒Zh	Zh⇒Fr	Avg.
mBART	31.7 / 74.6	29.7 / 74.7	31.5 / 72.7	27.8 / 73.9	28.3 / 73.4	28.2 / 71.5	28.8 / 73.4	27.1 / 70.9	26.5 / 73.3	28.8 / 73.2
PISCES	32.4 / 75.0	30.3 / 75.0	32.1 / 73.0	28.5 / 74.3	29.0 / 73.8	28.8 / 71.9	29.7 / 73.9	27.4 / 71.3	27.6 / 73.7	29.5 / 73.5
Δ	+ 0.7 / 0.4	+ 0.6 / 0.3	+ 0.6 / 0.3	+ 0.7 / 0.4	+ 0.7 / 0.4	+ 0.6 / 0.4	+ 0.9 / 0.5	+ 0.3 / 0.4	+ 1.1 / 0.4	+ 0.7 / 0.3

Table 4: Experimental results on WikiLingua. Avg. indicates the average score for each cluster of directions. PISCES is significantly better than mBART with t-test p < 0.01 in all directions.

is dynamically selected from $[5, 10, 15]$. The pre-defined λ in the round-trip translation is 0.7. All experimental results listed in this paper are the average of 3 runs. More details of the pre-training corpora as well as PISCES are given in Appendix B.

5.3 Baseline and Metrics

Baseline. We use mBART-50 (Tang et al., 2021) as the baseline, which has achieved state-of-the-art performances on many CLS/MLS datasets (Perez-Beltrachini and Lapata, 2021; Feng et al., 2022).

Metrics. We adopt ROUGE-1/2/L (Lin, 2004) and BERTSCORE (Zhang et al., 2020b) in our experiments. The ROUGE scores measure the lexical overlap between the generated summaries and corresponding references, while the BERTSCORE measures the semantic similarity. These metrics are calculated by *multi-lingual rouge*[12] and *bert-score*[13] toolkits, respectively. The BERTSCORE is based on *bert-base-multilingual-cased* model. The statistical significance test (Koehn, 2004) is also employed for a fair comparison.

5.4 Results & Analyses

Table 4 shows the results in terms of average ROUGE score (RS) and BERTSCORE (BS). Full results on ROUGE-1/2/L are given in Appendix C.

PISCES vs. mBART. Our PISCES outperforms mBART-50 in all directions, indicating its superiority. Specifically, PISCES achieves an average increase of 7.9 RS and 5.4 BS over mBART-50 in non-trivial zero-shot directions when the target language is not Tr.[14] The average improvement in conventional zero-shot directions is 2.2 RS / 1.3 BS, while the counterpart in low-resource directions is 1.4 RS / 0.8 BS. As for high-resource directions, PISCES outperforms mBART-50 by 0.7 RS and 0.3 BS in average. It is not difficult to find that the fewer resources in a direction, the greater the improvement brought by our PISCES. This finding also indicates the potentiality of our model when faced with the real-world scenario, since there are thousands of languages in the world and most directions are low-resource or zero-shot. Through the cross-lingual and task-specific pre-training stages, PISCES facilitates the transfer of task knowledge from high-resource directions to the low-resource and zero-shot ones.

Non-Trivial Zero-Shot Direction. As shown in Table 4, we divide the non-trivial zero-shot directions into two categories (*i.e.*, Tr⇒Others and Any⇒Tr) according to whether Tr is the target language. We discover that the results in Any⇒Tr directions[15] are significantly worse than the Tr⇒Others counterparts. This finding suggests that generating summaries in *unseen languages* is more difficult than understanding documents in *unseen languages*. This is because the encoder could partly understand

[12] https://github.com/csebuetnlp/xl-sum/tree/master/multilingual_rouge_scoring

[13] https://github.com/Tiiiger/bert_score

[14] We will discuss the situation where Tr is the target language in the next paragraph.

[15] Results on Hi/Zh/Th⇒Tr are given in Appendix C

	Fr⇒Hi	Hi⇒Fr	Hi⇒Zh	Zh⇒Hi
PISCES	**21.4 / 69.1**	**26.1 / 72.9**	**26.1 / 70.4**	**20.3 / 68.5**
w/o TS	20.7 / 68.6	25.2 / 72.8	25.1 / 69.9	19.5 / 67.9
w/o CL	20.6 / 68.8	25.2 / **72.9**	25.3 / 70.0	19.5 / 67.8
w/o TS & CL	19.6 / 68.1	23.6 / 72.1	24.0 / 69.1	18.1 / 66.9
	Hi⇒Th	**Th⇒Hi**	**Zh⇒Th**	**Th⇒Zh**
PISCES	**29.1 / 68.5**	**21.4 / 69.0**	**29.9 / 68.9**	**27.0 / 71.0**
w/o TS	28.2 / 68.1	20.3 / 68.3	28.7 / 68.3	25.8 / 70.3
w/o CL	28.0 / 68.0	20.3 / 68.4	29.0 / 68.5	26.0 / 70.4
w/o TS & CL	26.7 / 67.4	18.8 / 67.4	27.8 / 67.6	25.0 / 69.4

Table 5: Results of ablation studies.

the *unseen languages* through the shared vocabulary and the similar syntax constituent with other languages. But for the decoder, we only change its language tag to expect it can generate summaries in *unseen languages*. This requires the decoder to *simultaneously* (1) capture the relationships between the unseen language tag and the unseen language tokens and (2) summarize documents. However, the pre-trained model only meets the requirement (1) in the pre-training stage[16], while requirement (2) in the fine-tuning stage, making it hard to simultaneously meet both requirements, and consequently, cannot generate summaries in unseen languages. We reserve this challenge for future work.

5.5 Ablations

We conduct ablation studies to investigate the effect of the cross-lingual and task-specific pre-training stages. We run the following ablations:

- **PISCES w/o TS**. To demonstrate the effectiveness of the task-specific pre-training, we also pre-train a variant PISCES model which does not include the task-specific pre-training stage.
- **PISCES w/o CL**. To measure the effectiveness of the cross-lingual pre-training, we remove this stage in the whole pre-training process, resulting in another variant PISCES.
- **PISCES w/o TS & CL** removes both the cross-lingual and task-specific pre-training stages, which is the same as mBART-50.

As shown in Table 5, we conduct ablation studies in conventional zero-shot directions (other directions also show the same trends). In each case, the RS and BS are lower than vanilla PISCES. In addition, both PISCES w/o TS and PISCES w/o CL outperform PISCES w/o TS & CL. Therefore, the effectiveness of both stages is proved.

While one may argue that the effectiveness of meta pre-training is not demonstrated, note that its effectiveness is equivalent to that of mBART, which has been well-verified (Liu et al., 2020).

[16]Though PISCES has been pre-trained with pseudo M2MS samples, there is still a large gap between the pseudo samples and downstream samples, *e.g.*, text style and domain.

	How to Download Photos from Your iPhone to a Computer
Turkish Document	iPhone'un şarj kablosunun bir ucunu iPhone'un şarj girişine tak, ardından USB ucunu bilgisayarının USB girişlerinden birine tak. Kilidini açmak için parolanı (veya TouchID'ni ya da FaceID'ni) gir ve iPhone'undaki Home düğmesine bas. Devam etmeden önce, istenirse "Bu bilgisayara güvenilsin mi?" kısmında Güven seçeneğine dokun. Mac'in Dock'unda çok renkli bir çarkıfeleğe benzeyen Fotoğraflar uygulaması simgesine tıkla. Fotoğraflar uygulaması iPhone'unu bağladığında otomatik olarak açılabilir. iPhone'un simgesi, uygulamanın penceresinin sol üst köşesinde görünmelidir. Fotoğrafların alınıp içeri aktarılacağı yer olarak pencerenin sol tarafında iPhone'unun adına tıkla. Bunu penceredeki resimlere tıklayarak yap. Bilgisayarında olmayan tüm fotoğrafları içeri aktarmak istiyorsan bu adımı atla. Bu, pencerenin sağ üst köşesindedir. Seçtiğin fotoğraf sayısı bu butonda görünecektir (örneğin, 5 Seçileni İçeri Aktar). iPhone'undaki Mac bilgisayarında olmayan tüm fotoğrafları aktarmak istiyorsan Tüm Yeni Ögeleri İçeri Aktar seçeneğine tıkla. Bu, pencerenin sol tarafındadır. Az önce aktardığın fotoğraflar bu sayfada listelenir.
mBART	Examine the iphone's keyboard. Click the "screen" button to view the photos. Click the "screen" button to view the list of available photos.
PISCES	**Connect your iphone to** computer. **Unlock your iphone.** Click **the "photos" app**. **Select the photos you** wish **to download.** Click the "choose photos" option. **Select the photos you** wish **to download.** Click the "download" button.
Ground Truth	**Connect your iphone to** your mac. **Unlock your iphone.** Open **the photos app.** Select your iphone. **Select the photos you**'d like **to download.** Click import selected. Click imports.

Table 6: An example of Tr⇒En summarization.

5.6 Case Study

Table 6 shows an example Turkish document, the generated summary and the ground truth summary. Though the summary generated by PISCES contains a repeated sentence, it has good lexical and semantics overlaps with the ground truth. But for mBART-50, the generated summary is not relevant to the core idea of the document. These observations indicate that, through the cross-lingual and task-specific pre-training, our PISCES could better transfer the task knowledge from high-resource directions to zero-shot ones, and even has the ability to generate summaries for the documents whose language does not occur in the fine-tuning stage.

6 Conclusion

In this paper, we unify previous MLS and CLS to M2MS, a more general and more practical setting. Through carefully-designed preliminary studies, we argue that shifting research attention from MLS and CLS to M2MS is valuable.

In addition, we propose the first pre-trained M2MS model, *i.e.*, PISCES, which contains three pre-training stages to enable the model learn the multi-lingual language modeling, cross-lingual ability and summarization ability. Extensive experiments show its superiority compared with the state-of-the-art baseline (mBART-50). The case study further demonstrates that our model could even generate summaries for the documents whose language does not occur in the fine-tuning stage.

Ethical Considerations

In this section, we consider potential ethical issues of our model. In this paper, we propose PISCES which utilizes mBART-50 (Tang et al., 2021) as the meta pre-trained model and further suffers from the cross-lingual pre-training and task-specific pre-training stages. The pre-training samples are constructed from OPUS (Tiedemann and Thottingal, 2020) and mC4 (Xue et al., 2021) corpora. To construct the pseudo M2MS samples in the task-specific pre-training stage, Google Translation is also adopted to translate gap sentences. Therefore, PISCES might involve the same biases and toxic behaviors exhibited by language models, pre-training corpora and Google Translation.

Limitations

While we show that PISCES outperforms mBART-50 on WikiLingua (Ladhak et al., 2020), there are some limitations worth considering in future work: (1) PISCES still struggles to generate summaries in unseen languages (Section 5.4); (2) In this work, we focus on six languages in total, and future work could extend our method to more languages; (3) We only evaluate our model on the WikiLingua dataset due to the scarcity of datasets meeting M2MS requirements (Section 5.1).

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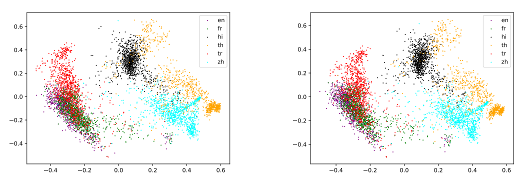
A Word Embeddings of the Unseen Language and Other Languages



(a) mBART (M2MS) (b) mBART (U-CLS)

Figure 3: Visualization of word embeddings from mBART (M2MS) and mBART (U-CLS). Tr is the unseen language.

To verify the word embeddings of the unseen language drift away from those of other languages after adding the monolingual training data, based on MUSE dictionary, we choose top frequent 1000 English words and the words with the same meaning in other five languages (*i.e.*, Fr, Hi, Zh, Th and Tr). Then, we calculate the embeddings of these words based on mBART (M2MS) and mBART (U-CLS), respectively. For the word that consists of multiple tokens, the word embedding is the average of embeddings of those tokens. As shown in Figure 3, we utilize Principal Component Analysis (PCA) to visualize the word embeddings from mBART (M2MS) and mBART (U-CLS). In the PCA space, we

Direction	MultiUN	CCMatrix	CCAligned	MultiCCAligned	XLEnt	Europarl	QED	TED	WMT	**Sum**
En⇔Fr	-	-	-	-	-	349291	152623	77188	4648	583750
En⇔Hi	-	2959722	-	-	405366	-	1211	9039	568	3375906
En⇔Th	-	-	1947729	-	246976	-	52140	30765	-	2277610
En⇔Tr	-	-	2496997	-	761750	-	94212	72674	3819	3429452
En⇔Zh	-	-	-	-	1258289	-	-	3158	3658	1265105
Fr⇔Hi	-	-	-	619040	97082	-	660	8816	-	725598
Fr⇔Th	-	-	-	737469	67292	-	34418	30024	-	869203
Fr⇔Tr	-	-	-	1321431	183282	-	61412	69931	-	1636056
Fr⇔Zh	1494829	-	-	-	211039	-	2041	3088	-	1710997
Hi⇔Th	-	-	-	436284	65870	-	484	4526	-	507164
Hi⇔Tr	-	1099853	-	-	111573	-	544	8384	-	1220354
Hi⇔Zh	-	445148	-	-	97732	-	15	650	-	543545
Th⇔Tr	-	-	-	617566	86156	-	40026	29602	-	773350
Th⇔Zh	-	-	-	-	54637	-	2390	2169	-	59196
Tr⇔Zh	-	1435286	-	-	169774	-	1885	3125	-	1610070
Total	1494829	5940009	4444726	3731790	3816818	349291	444061	353139	12693	20587356

Table 7: Statistics of the constructed cross-lingual pre-training samples. Each entry shows the number of samples for each language pair in the corresponding corpus.

En⇔Fr	En⇔Hi	En⇔Th	En⇔Tr	En⇔Zh	Fr⇔Hi	Fr⇔Th	Fr⇔Tr	Fr⇔Zh	Hi⇔Th	Hi⇔Tr
190916	190916	190916	190916	88636	188351	190916	190916	190916	158518	190578
Hi⇔Zh	Th⇔Tr	Th⇔Zh	Tr⇔Zh	En⇒En	Fr⇒Fr	Hi⇒Hi	Th⇒Th	Tr⇒Tr	Zh⇒Zh	**Total**
172039	190916	24160	190916	95458	95458	95458	95458	95458	95458	3113274

Table 8: Statistics of the constructed task-specific pre-training samples.

further calculate the central point of each language by averaging the word embeddings in the language. Then, we find the average distance between the central point of Tr and other languages is 0.426 / 0.407 for mBART (`M2MS`) / mBART (`U-CLS`). This distance in vanilla mBART-50 (Tang et al., 2021) is 0.398. Therefore, the monolingual training data used in mBART (`M2MS`) makes the word embeddings of the unseen language drift away from those of other languages.

B Implementation Details

Table 7 and Table 8 show the statistics of the constructed samples in the cross-lingual pre-training and task-specific pre-training stages, respectively. The cross-lingual pre-training and task-specific pre-training stages are conducted on 8 NVIDIA Tesla V100 GPUs with 32GB memory. In the cross-lingual pre-training stage, we pre-train the model for 150K steps, with early stopping, 32 batch size, 3e-5 learning rate following Xiao et al. (2022) and 10K warmup steps. In the task-specific pre-training stage, we pre-train the model for 100K steps, with early stopping, 4 batch size, 3e-5 learning rate and 10K warmup steps.

In the fine-tuning stage, we fine-tune the PISCES model on 8 NVIDIA Tesla V100 GPUs (32G) with 4 batch size, 10 epochs, 2K warmup steps, 3e-5 learning rate, and set the maximum number of tokens for input sequences to 1024. To balance the high-resource and low-resource language data, following Xue et al. (2021), we sample the training examples according to the probability $p(D) \propto |D|^{\alpha}$, where $p(D)$ is the probability of sampling training examples from a give direction during fine-tuning and $|D|$ is the number of original examples in the direction. We set the hyperparameter α to 0.5.

In the test process, we set the beam size and the maximum decoded length to 5 and 128, respectively.

C Full Results

Table 9 shows the experimental results in terms of ROUGE-1, ROUGE-2 and ROUGE-L, respectively.

Src \ Trg	Model	En	Fr	Hi	Zh	Th	Tr
En	mBART	41.9 / 18.2 / 34.9	37.2 / 15.8 / 30.3	31.7 / 9.6 / 24.5	37.9 / 13.9 / 32.7	39.5 / 18.5 / 34.0	3.2 / 0.2 / 3.0
	PISCES	42.8 / 18.8 / 35.5	38.1 / 16.4 / 31.1	33.7 / 10.8 / 26.6	38.8 / 14.2 / 33.3	40.9 / 19.3 / 35.6	4.5 / 0.7 / 4.2
Fr	mBART	38.2 / 15.0 / 31.7	39.2 / 17.9 / 32.0	28.7 / 7.9 / 22.3	36.9 / 12.8 / 31.6	37.9 / 16.6 / 32.6	3.1 / 0.2 / 3.0
	PISCES	39.2 / 15.4 / 32.4	40.0 / 18.3 / 32.5	31.3 / 8.8 / 24.2	37.4 / 13.0 / 31.9	39.2 / 17.3 / 33.6	4.1 / 0.6 / 3.8
Hi	mBART	37.9 / 14.6 / 30.8	32.8 / 12.2 / 25.9	35.6 / 12.5 / 27.8	33.2 / 10.6 / 28.2	35.4 / 14.6 / 30.1	3.4 / 0.3 / 3.2
	PISCES	39.8 / 16.0 / 32.7	35.7 / 14.1 / 28.4	37.2 / 13.6 / 28.8	35.9 / 11.8 / 30.7	38.1 / 16.6 / 32.6	4.0 / 0.6 / 3.8
Zh	mBART	39.2 / 15.1 / 32.0	36.0 / 14.5 / 29.0	27.0 / 6.6 / 20.8	41.7 / 17.0 / 35.9	36.8 / 15.3 / 31.4	3.4 / 0.2 / 3.2
	PISCES	40.3 / 15.8 / 33.0	37.4 / 15.4 / 29.9	29.6 / 8.2 / 23.2	42.5 / 17.5 / 36.3	39.2 / 17.0 / 33.6	4.3 / 0.6 / 4.0
Th	mBART	38.5 / 15.4 / 31.9	35.6 / 14.2 / 28.3	27.8 / 7.3 / 21.4	34.6 / 11.3 / 29.0	42.2 / 20.8 / 36.2	3.3 / 0.3 / 3.1
	PISCES	40.2 / 16.6 / 33.2	37.2 / 15.4 / 29.7	31.0 / 9.3 / 23.9	36.9 / 12.7 / 31.3	43.3 / 21.7 / 37.5	4.3 / 0.7 / 4.0
Tr	mBART	15.7 / 2.6 / 13.4	16.0 / 3.2 / 13.2	14.9 / 2.3 / 12.6	19.9 / 3.0 / 17.6	21.4 / 4.8 / 19.3	3.1 / 0.2 / 3.0
	PISCES	28.3 / 8.8 / 23.4	27.3 / 9.3 / 22.2	23.2 / 5.5 / 18.5	29.8 / 8.2 / 25.7	30.8 / 11.3 / 26.7	5.3 / 0.8 / 5.0

Table 9: Experimental results on WikiLingua (ROUGE-1 / ROUGE-2 / ROUGE-L). Green, light green and gray indicate the high-resource, low-resource and zero-shot directions, respectively.