Interplay of Machine Translation, Diacritics, and Diacritization

Wei-Rui Chen[λ] **Ife Adebara**[λ] **Muhammad Abdul-Mageed**[λ,γ,ψ]
[λ]Deep Learning & Natural Language Processing Group, The University of British Columbia
[γ]Department of Natural Language Processing & Department of Machine Learning, MBZUAI
[ψ] Invertible AI
{weirui.chen,ife.adebara,muhammad.mageed}@ubc.ca

Abstract

We investigate two research questions: (1) how do machine translation (MT) and diacritization influence the performance of each other in a multi-task learning setting (2) the effect of keeping (vs. removing) diacritics on MT performance. We examine these two questions in both high-resource (HR) and low-resource (LR) settings across 55 different languages (36 African languages and 19 European languages). For (1), results show that diacritization significantly benefits MT in the LR scenario, doubling or even tripling performance for some languages, but harms MT in the HR scenario. We find that MT harms diacritization in LR but benefits significantly in HR for some languages. For (2), MT performance is similar regardless of diacritics being kept or removed. In addition, we propose two classes of metrics to measure the complexity of a diacritical system, finding these metrics to correlate positively with the performance of our diacritization models. Overall, our work provides insights for developing MT and diacritization systems under different data size conditions and may have implications that generalize beyond the 55 languages we investigate.

1 Introduction

Diacritics are symbols added to a letter to modify its meaning, pronunciation, or phonetic value in an orthographic system (Protopapas and Gerakaki, 2009; Ball, 2001; Wells, 2000). These symbols can have a lexical or grammatical function (Janicki and Herman, 2005). In their lexical function, diacritics distinguish one word from another. For instance in Yorùbá, diacritics differentiate meanings in words such as: `ògún` (*a deity*), `ogun` (*battle*), `ògùn` (*a river*), `ogún` (*number 20 / inheritance*). On the other hand, diacritics also serve a grammatical function by distinguishing one grammatical category from another. For example in Iau, diacritics differentiate past and perfect verbs as in: `bá` (*'came'*) and `ba` *'has come'* (Hyman, 2016). Disregarding diacritics in certain tasks could result in the omission of crucial semantic information.

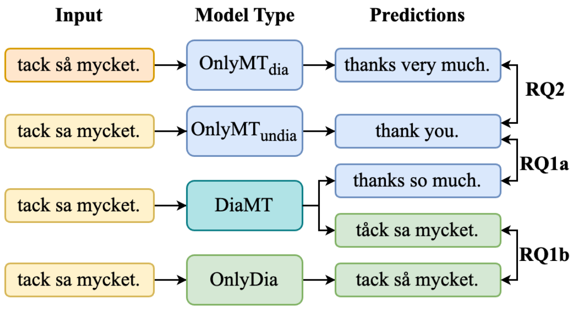

Figure 1: Illustration of our experimental setup, taking a Swedish datapoint 'tack så mycket.' (thank you very much.) as an example. To answer our (**RQ**s), we develop four types of models: three single-task models **OnlyMT**$_{\mathbf{dia}}$ (trained to translate with diacritized source), **OnlyMT**$_{\mathbf{undia}}$ (trained to translate with undiacritized source), and **OnlyDia** (trained to diacritize); and one multi-task model **DiaMT** (trained to translate and diacritize simultaneously).

Despite the important role of diacritics, we are not aware of work that investigates their effect on MT across languages. In this paper, we attempt to fill this knowledge gap by studying the interaction between machine translation (MT), diacritics and diacritization. Diacritization is the task of correctly attaching diacritics to characters. For the interplay between MT and diacritics, we test the effect of keeping and removing diacritics on MT. For the interplay of MT and diacritization, we design a multi-task setting that involves both MT and diacritization. The multi-task models learn to translate and attach diacritics to characters simultaneously. Specifically, we raise two main research questions: in a multi-task setting, whether or not, and if so to what extent does diacritization benefit MT (**RQ1a.**), and MT benefit diacritization (**RQ1b.**); and in a single-task setting, whether or

Proceedings of the 2024 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies (Volume 1: Long Papers), pages 7559–7601
June 16-21, 2024 ©2024 Association for Computational Linguistics

not, and if so to what extent, does keeping and removing diacritics affect performance of MT systems (**RQ2.**). An overview of our experimental setup is shown in Figure 1. We also examine how varying training data sizes, hereafter referred to as **'train sizes'**, impact the model's performance across various languages.

Our contributions can be summarized as follows: **(1)** We propose a novel approach to enhance the performance of low-resource machine translation by incorporating diacritization as a multi-task training. **(2)** We illustrate that, in a single-task setting, the choice of either retaining or omitting diacritics generally has minimal impact on machine translation performance. **(3)** We propose two categories of language-agnostic metrics designed to assess the complexity of the diacritical system in a language and examine their implications on diacritization performance. To the best of our knowledge, this study represents the most comprehensive analysis of the interplay between diacritics and machine translation. Drawing insights from our experimental findings, we offer practical guidelines for researchers and practitioners involved in developing machine translation or diacritization systems.

This paper is organized as follows. Section 2 is a literature review. Experimental settings are provided in Section 3. Section 4 presents information of the data and our proposed language-agnostic complexity metrics. In Section 5, we present and discuss our results and key findings. We conclude in Section 6.

2 Related Work

We first review existing literature on MT and diacritics, followed by work on diacritization as a standalone task, and finally we discuss the interplay between diacritization and MT.

MT and Diacritics. There are three primary approaches to handling diacritics in MT: diacritics removal, retention, and restoration. The decision to adopt any of these approaches is motivated by various factors. For example, the inconsistent use of diacritics in a dataset has been identified as a key reason to remove them (Sennrich et al., 2016a; Durrani et al., 2010). Removing diacritics may also be useful for addressing data sparsity and/or out-of-vocabulary issues (Williams et al., 2016). In certain instances, the removal of diacritics has been found to improve BLEU score (Sennrich et al., 2016a). While the reasons for diacritics removal are explicit in some cases, other studies have not explicitly stated their motivations (Stahlberg et al., 2018). Meanwhile, retaining diacritics can enhance performance for certain languages but may have a detrimental effect on others (Adebara and Abdul-Mageed, 2022). When to retain or remove diacritics remains an open question that this paper also hopes to address. Finally, restoration of diacritics has positive impact on MT systems in languages like Arabic and Yorùbá (Alqahtani et al., 2016; Adelani et al., 2021).

Diacritization. A number of works focus on the task of diacritization. For example, Belinkov and Glass (2015) employ a Bi-LSTM-based model to create a many to many recurrent neural network to perform diacritization. Mubarak et al. (2019) build a transformer-based sequence-to-sequence framework to train a diacritization model for Arabic. Laki and Yang (2020) create diacritization models with transformer architecture for 14 East European languages.

Improving Diacritization with MT. Thompson and Alshehri (2022) propose an approach for Arabic diacritization that uses MT as an auxiliary task in a multi-task setting. Their findings reveal that incorporating translation improves performance of diacritization. They hypothesize that this improvement stems from the implicit acquisition of semantic knowledge during the training of the MT process. While their experiments focus solely on Arabic, our study expands the scope to cover a broader range of languages, specifically 55 languages across African and European regions.

3 Experiments

3.1 Setup

We collect an extensive set of 55 language pairs where the target language is **always English** under different train sizes (five sizes for African languages and nine sizes for European languages, detailed in Section 4.2). For every pair of train size and language pair, e.g. (125k, *fr-en*) and (5k, *bex-en*) , we build four types of models as illustrated in Figure 1. We list each model type along with the corresponding research question in Table 1. For our single-task setting, there are three types of models: (i) models that perform MT and are trained with undiacritized source (**OnlyMT$_{\text{undia}}$**), (ii) models that perform MT and are trained with diacritized source (**OnlyMT$_{\text{dia}}$**), and (iii) models that perform diacritization (**OnlyDia**). The only distinction between the two OnlyMT models lies in whether diacritics are incorporated into the source sequences. For the multitask setting, (iv) a **DiaMT** model is trained to perform both diacritization and translation.

Models Compared			Research Question
DiaMT	vs.	OnlyMT$_{\text{undia}}$	Does diacritization benefit MT? (**RQ1a**)
DiaMT	vs.	OnlyDia	Does MT benefit diacritization? (**RQ1b**)
OnlyMT$_{\text{dia}}$	vs.	OnlyMT$_{\text{undia}}$	What effect does keeping/removing diacritics have on MT? (**RQ2**)

Table 1: Models compared and corresponding RQs.

3.2 Evaluation Metrics

We use BLEU score (Papineni et al., 2002) with SACREBLEU implementation (Post, 2018)[1] to measure the performance of MT. For diacritization, we adopt diacritization error rate (DER) and word error rate (WER) (Abandah et al., 2015) with implementation details described in Appendix B.

3.3 Models & Training

We adopt transformer architecture (Vaswani et al., 2017) for all models and train from scratch with the Fairseq library (Ott et al., 2019), each using a single Nvidia A100 GPU. For train sizes 1k, 2k, 3k, 4k, 5k, the number of steps is 30k. For higher train sizes, we use 100k steps for 25k, 500k steps for 125k, 1.5M steps for 625k, and 3M steps for 1M train size. We evaluate our test set on the model with the best performance (lowest loss) on development set. Detailed information about hyperparamter settings, software version and license are included in Appendix Table A.3.

4 Data

4.1 Data Sources

African languages. To conduct our study, we use a random sample of African languages from the parallel Bible Corpus (Mayer and Cysouw, 2014) which consists of 830 languages. Specifically, we focus on the subset of 297 African languages that use diacritics and randomly select 36 African languages from these. We use the Bible because we assume it will provide correct and consistently diacritized data for our experiments. In Table A.4, we present the diacritical systems found in these African languages. The table showcases a diverse range of diacritics with varying levels of complexity. Some languages have simple diacritical systems, where a single diacritic is applied to each character, as seen in languages such as Paasaal (*sig*) and Hdi (*xed*). In contrast, other languages have base characters capable of accommodating multiple diacritics. For instance, in the language Mundani (*mnf*), the character ậ̧ carries two diacritics simultaneously.

European Languages. We use 19 European languages from the European Parliament corpus (Koehn, 2005).[2] All of these languages use diacritics (Mihalcea, 2002; Wells, 2000) in their orthography. We select this corpus because we assume the diacritics in the document will be correct and consistent, given the domain it is derived from.

We observed code-switching phenomenon in the dataset. For example, a Spanish sentence may include French word(s). To ensure a clean comparison across these languages, we use fasttext tool (Joulin et al., 2016b,a) to identify and remove lines with heavy code-switching.[3] Specifically, we remove a line if the model prediction of the respective language is lower than 90%.[4] Furthermore, we remove overly long and short lines. Specifically, we remove lines with $>$ 500 or $<$ 6 characters.

4.2 Train Sizes

To determine any interaction between performance and data sizes, we experiment with varying amounts of training data across different experiments. We now provide details of these train sizes for African and European languages.

African. We shuffle the data before we split it into 80% for training (Train), 10% for development (Dev), and 10% for testing (Test). We have 5 train sizes for African languages (1k, 2k, 3k, 4k, 5k). Henceforth, the term '5k' is used to denote the full training set for each language, reflecting the approximate number of examples in these sets.[5] The

[1] https://pypi.org/project/sacrebleu/

[2] The data we use is the updated 2012 version which can be accessed at `https://www.statmt.org/europarl/`

[3] lid.176.bin edition of language identification tool with access at `https://fasttext.cc/docs/en/language-identification.html`

[4] In spite of this measure, a manual inspection still uncovers a few examples of foreign characters in the data, which we assume have a minimal adverse effect on our experiments. We show the diacritical system extracted from the data in Table A.5 which may include foreign characters and diacritics. For African languages, since the domain is the Bible, we assume there are no foreign or code-switched texts. Therefore, we do not carry out any data cleaning for African languages.

[5] Morokodo (*mgc*) has 2k as its largest train size as an exception.

number of examples for each language is listed in Appendix Table A.1.

European. We split the data and assign $1,500$ data points to Test, another $1,500$ data points to Dev, and the remaining data as Train. We then subset training data into the 9 train sizes in the set $\{$1k, 2k, 3k, 4k, 5k, 25k, 125k, 625k, 1M$\}$. The Train/Dev/Test split information is in Appendix Table A.2.

4.3 Data Processing

Model		Source	Target
OnlyDia		t a c k | s a | m y c k e t	t a c k | s a ◌̊ | m y c k e t
OnlyMT$_{\text{undia}}$		t a c k | s a | m y c k e t	thank you very much
OnlyMT$_{\text{dia}}$		t a c k | s a ◌̊ | m y c k e t	thank you very much
DiaMT	Dia	ε t a c k | s a | m y c k e t	t a c k | s a ◌̊ | m y c k e t
	MT	τ t a c k | s a | m y c k e t	thank you very much

Table 2: An example of source and target for four different types of models.

The format of source and target of the processed data can be seen in Table 2. We handle non-English (source languages) and English (target language) data differently. For non-English data with diacritics, we (1) decompose every character carrying diacritic(s) into a base character and independent diacritic(s) with NFKD normalization,[6] (2) replace word-boundary whitespaces with the symbol '|' to maintain information of word boundary after tokenization, (3) insert a whitespace between characters in preparation for whitespace tokenization, and (4) employ whitespace tokenization to build character-level vocabulary which includes characters and diacritics as tokens.[7] Decomposing text with NFKD to retrieve independent diacritics and build character-level vocabulary enables better generalization of the model for rare combinations of a base character and diacritic(s). In addition, it helps avoid data sparsity that can occur if word or sub-word tokenization is used. For example, the probability distribution of the variants of 'o' in the African language Fon (*fon*) is skewed. The probabilities are about $60.8\%, 38.1\%, 1.1\%$ for o, ó, ǒ, respectively. Without decomposition, it could be very difficult for the model to learn a decent embedding representation for ǒ since there is a limited number of examples from which the model can capture its linguistic information. By making each diacritic a token, the model may be able to learn a generalized pattern for diacritic ◌̌ because it can learn its linguistic behavior in not only ǒ but also other characters that carry this diacritic in this language, e.g., ě, ǐ.

For English data, we tokenize it with whitespace to form word-level tokens. We strive to minimize the introduction of uncontrolled variables by utilizing word-level tokenization. Unlike word-level tokenization, BPE (Sennrich et al., 2016b) and BPE-related implementations of subword tokenization can introduce additional uncontrolled variables to the experiments. In particular, the frequency component in BPE renders this method dependent on the corpus. The sampling and language model components in SentencePiece (Kudo and Richardson, 2018), render it both corpus-dependent and non-deterministic. If we adopt these methods, for a piece of text in English, it can be tokenized differently for different (1) language pairs and (2) train sizes. For (1), as an example, the word 'review' could be tokenized into ['rev', 'iew'] in the fr-en language pair, but ['re', 'view'] in the es-en language pair. Similarly for (2), 'review' can be tokenized differently in 25k and 1M train sizes. We use word-level tokenization to avoid inconsistency in tokenization. With word-level tokenization, a piece of English text is tokenized identically throughout different train sizes and language pairs. This enhances the comparability among different settings.

For **DiaMT**, we prepend a symbol (and a following whitespace), ε for diacritization and τ for MT, at the beginning of every source sequence to prime the model which of the two tasks (translation or diacritization) to perform for a specific input sequence. The source side for both sub-tasks is identical, except the prepended symbol. The potential advantage of this design is that the model may be able to gain positive transfer via attaining cross-task knowledge.

4.4 Post-processing Predictions

When processing non-English data, we use whitespace to separate characters and the symbol '|' to denote word boundaries. During post-processing for diacritization output, we consolidate the separated characters back into words and substitute the '|' symbol with whitespace to properly indicate word boundaries. It is after this post-processing step

[6] https://unicode.org/reports/tr15/

[7] An exception is the vocabulary for OnlyMT$_{\text{undia}}$ which has no diacritics because the source side is undiacritized and the target side is English, a language without diacritics (Mihalcea, 2002).

that we compute DER and WER metrics. In contrast, when performing MT, post-processing is not required. This is because the output is always in English, a language we process straightforwardly from the outset, thereby eliminating the need for any post-processing adjustments.

4.5 Complexity Metrics

Metric	Definition
DCR	Proportion of characters that carry diacritic(s) out of all characters.
DWR	Proportion of words with at least a character carrying diacritic(s) out of all words.
DBR	Average number of variants (including itself) of each base character.
DWSR	Average number of words with at least a character carrying diacritic(s) per sentence.
AED	Average entropy of the distributions of each base character's variant(s) and itself.
WAED	Weighted AED with weight being the proportion of the number of occurrence of each base character out of that of all base character(s).

Table 3: Definitions of Proposed Complexity Metrics.

The functional load of diacritics differs from one language to another (Roberts, 2009; Bird, 1999). As a result, we propose two classes of metrics which may be able to measure some aspects of the functional load of the diacritical system. We refer to these metrics as **complexity metrics**. They rely only on unlabeled corpora, unlike existing metrics which require a formal lexicon (Pauw et al., 2007). Thus, they are well suited for scenarios where lexicons are unavailable. Besides, they are **language-agnostic** such that they are applicable to any given language. They measure **(1)** the ratio of diacritics and character/word/sentence, and **(2)** the entropy of the probability distribution of character-diacritic combinations. A simplified example corpus and the computation of its complexity metrics values are given at Appendix Table E.2.

To determine **(1)**, we measure Diacritized Character Ratio (**DCR**), Diacritized Word Ratio (**DWR**), Diacritized Base character Ratio (**DBR**), and Diacritized Word Sentence Ratio (**DWSR**). To formulate the complexity metrics, for a corpus of any given language, let c, c_d be the number of characters and diacritized characters; let w, w_d be the number of words and words with at least one diacritized character; let b be the number of unique base characters, b_d be the number of unique character-diacritic(s) combinations and s be the number of sentences. Then, $DCR = c_d/c$, $DWR = w_d/w$, $DBR = b_d/b$, and $DWSR = w_d/s$.

For **(2)**, we measure Average Entropy of Diacritics (**AED**), and Weighted Average Entropy of Diacritics (**WAED**). AED serves as an assessment of the challenge faced by a diacritization model in diacritizing a character (including the decision not to diacritize). It is computed by averaging the entropies of the probability distribution of character-diacritic combinations for each base character. The more uniformly distributed they are, the more challenging it becomes for the model to make accurate predictions. WAED is the weighted edition of AED where the weight is the frequency of each base character.

It is important to mention that our proposed complexity metrics are theoretically data-dependent. That is, a single language can have different complexity metric values given different datasets and/or train sizes. However, empirically, as can be seen in Tables E.5 and E.6, the values are similar across different train sizes for each language. This demonstrates that our proposed complexity metrics are robust among different sizes of training data and can capture the complexity of a diacritical system consistently. The proposed metrics are useful because **(1)** they provide a quantitative view of the diacritical system, **(2)** it is straightforward to compute them, and **(3)** they show high correlation with model performance as discussed later in Section 5.3.

5 Results and Analyses

5.1 Findings to Research Questions

We discuss findings to our research questions based on results reported in Table 4 and the visualization shown in Figure 2. We report a significance test with paired t-test for the performance of each pair of compared models, along with Cohen's d (Cohen, 1977) to estimate the *effect sizes*, as significance tests alone may not capture the magnitude of the effect (Cumming, 2013). To interpret Cohen's d, we refer to the standard proposed in Sawilowsky (2009): 0.01 (very small), 0.2 (small), 0.5 (medium), 0.8 (large), 1.2 (very large), and 2.0 (huge).

RQ1a. Does diacritization benefit MT? As Figure 2 shows, on average, diacritization improves MT performance when train size is $\leq$ 5k and harms MT performance when train size is $>$ 5k. For each individual language, the performance gain is in general positive for both African and European languages as can be seen in Ap-

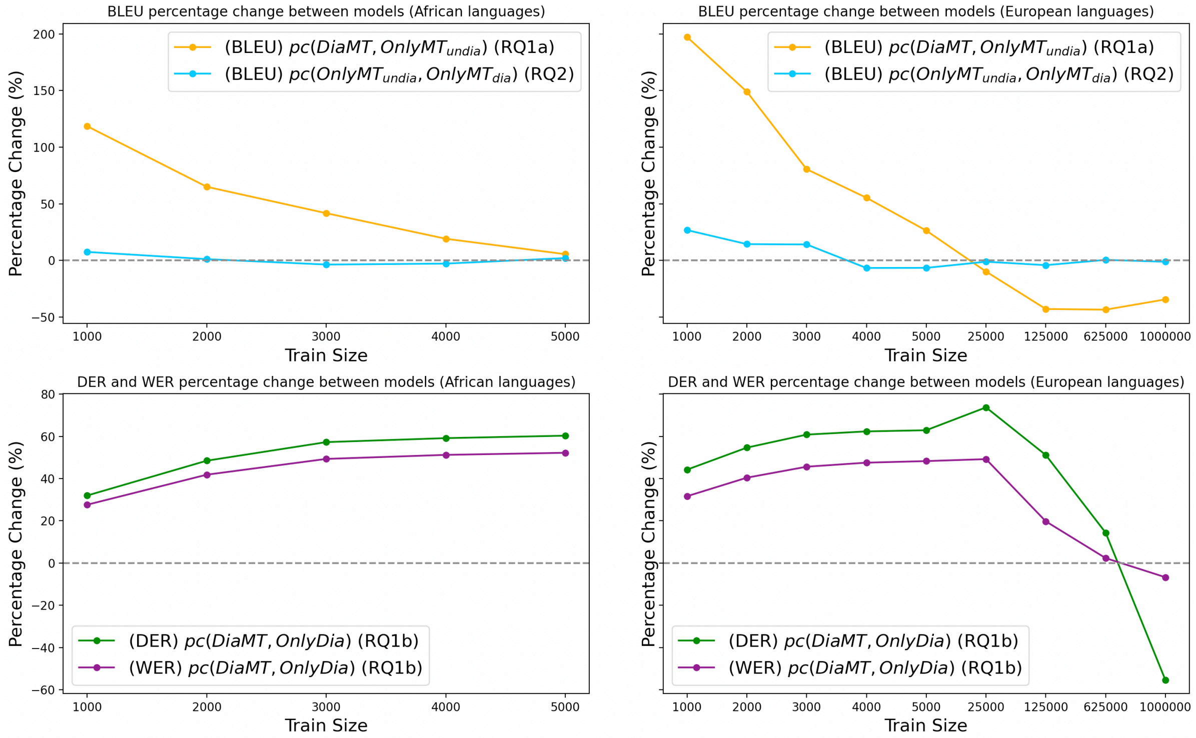

Figure 2: Percentage change of the BLEU/DER/WER averages among languages in each train size. $pc(m1, m2)$ is the percentage change of the metric values produced by model 1 (m1) over model 2 (m2) with $pc(m1, m2) = (m1 - m2)/m1$. We indicate the research question each line addresses in the legends. Left column: African languages. Right column: European languages. Top row: BLEU scores. Bottom row: DER and WER.

pendix Figures C.1 and C.2.[8] However, for > 5k train sizes, adding diacritization in general harms MT performance. As the significance tests in Table 4 show, $p(DM, OM_u)$, the p-values of paired t-test between the BLEU scores of DiaMT and OnlyMT$_{\text{undia}}$ are lower than 0.01 throughout all train sizes and language regions. This supports that adding diacritization will significantly affect MT performance, positively when $\leq$ 5k, and negatively when $>$ 5k. We observe a gradual decrease of effect size from 1k to 5k for both African and European languages, and a rapid increase after 25k for European languages. That is, the benefit of adding diacritization gradually reduces from 1k to 5k, and the harm grows rapidly after 25k from small to huge.

The unexpected negative transfer effect on MT performance following the inclusion of diacritization as an auxiliary task in higher-resource scenarios warrants careful examination. While it might be tempting to attribute this to an inadequately sized model struggling to learn both tasks simultaneously, our analysis, as detailed in **RQ1b**, reveals a contrary trend. Interestingly, certain languages exhibit enhanced diacritization performance after the incorporation of MT, indicating that the model's capacity is indeed sufficient to accommodate both tasks. Furthermore, the equitable distribution of data between MT and diacritization tasks, each constituting 50%, eliminates data imbalance as a contributing factor. Thus, the observed phenomenon likely originates from external variables, underscoring the need for further studies to pinpoint its underlying cause.

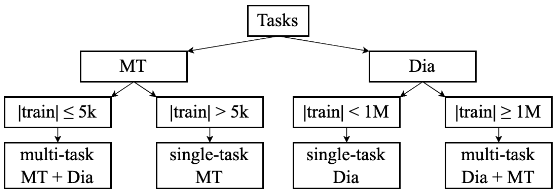

Figure 3: A guideline for training strategies under different data size conditions for diacritization (**Dia**) and/or machine translation (**MT**) derived by approaching RQ1a and RQ1b under different train sizes.

RQ1b. Does MT benefit diacritization? We find that adding MT as an auxiliary task on average un-

[8] The BLEU scores and exact percentage changes between DiaMT and OnlyMT$_{\text{undia}}$ are shown in Appendix Tables D.1 and D.2 where some of the languages achieve over 300% gain after adding diacritization when train size is $\leq$ 5k.

African Languages											
	Avg. BLEU			pv. BLEU		Avg. DER		pv. DER	Avg. WER		pv. WER
Size	DM	OM_u	OM_d	$p(OM_u, OM_d)(ES)$	$p(DM, OM_u)(ES)$	DM	OD	$p(DM, OD)(ES)$	DM	OD	$p(DM, OD)(ES)$
1k	2.306	1.055	0.981	>.05 (0.13)	<.01 (1.88)	0.428	0.291	<.01 (1.57)	0.478	0.346	<.01 (1.28)
2k	3.121	1.891	1.869	>.05 (0.04)	<.01 (1.61)	0.455	0.235	<.01 (2.62)	0.504	0.293	<.01 (2.05)
3k	3.384	2.388	2.477	>.05 (0.21)	<.01 (2.23)	0.487	0.208	<.01 (3.81)	0.536	0.271	<.01 (2.86)
4k	3.495	2.934	3.017	>.05 (0.20)	<.01 (1.37)	0.511	0.209	<.01 (3.89)	0.559	0.272	<.01 (2.96)
5k	3.577	3.390	3.319	>.05 (0.15)	<.01 (0.43)	0.512	0.203	<.01 (3.48)	0.559	0.267	<.01 (2.75)
European Languages											
1k	1.689	0.568	0.448	>.05 (0.43)	<.01 (2.87)	0.468	0.261	<.01 (4.01)	0.571	0.390	<.01 (3.10)
2k	1.994	0.801	0.700	>.05 (0.32)	<.01 (2.55)	0.489	0.222	<.01 (5.06)	0.591	0.352	<.01 (4.08)
3k	2.062	1.142	1.000	>.05 (0.39)	<.01 (1.72)	0.522	0.204	<.01 (6.32)	0.620	0.337	<.01 (5.13)
4k	2.273	1.463	1.567	>.05 (0.33)	<.01 (1.65)	0.555	0.209	<.01 (7.71)	0.649	0.340	<.01 (5.56)
5k	2.337	1.849	1.978	>.05 (0.23)	<.01 (0.88)	0.562	0.208	<.01 (6.48)	0.655	0.339	<.01 (5.45)
25k	4.496	4.984	5.039	>.05 (0.06)	<.01 (0.59)	0.296	0.078	<.01 (5.50)	0.420	0.213	<.01 (4.02)
125k	7.381	12.909	13.465	<.05 (0.17)	<.01 (2.21)	0.091	0.045	<.01 (1.52)	0.225	0.180	<.01 (1.05)
625k	12.085	21.357	21.246	>.05 (0.03)	<.01 (2.94)	0.025	0.021	>.05 (0.34)	0.163	0.159	>.05 (0.13)
1M	15.893	24.213	24.492	<.05 (0.08)	<.01 (2.44)	0.018	0.029	>.05 (0.50)	0.160	0.171	>.05 (0.33)

Table 4: Average (Avg.), p-value and effect size (ES) in terms of Cohen's d of BLEU of 3 different models, $OnlyMT_{undia}(OM_u)$, $OnlyMT_{dia}(OM_d)$ and $DiaMT(DM)$, and DER/WER of 2 different models $OnlyDia(OD)$ and $DiaMT(DM)$, at different train sizes (5 for African, 9 for European languages). $p(m1, m2)$ represents the p-value of two-sided paired t-test between BLEU/DER/WER produced by model $m1$ and model $m2$. Effect sizes are with respect to Cohen's d.

dermines diacritization performance except when train size is at 1M as can be seen in Appendix Figure 2. Appendix Figure C.5 and C.7 show that it is rare to have improvements in diacritization performance after adding MT with two exceptions: Fon (*fon*) at 1k and Sekpele (*lip*) at 2k. Appendix Figure C.6 and C.8 show a similar phenomenon. When train sizes are $\leq$ 125k, only Slovak (sk) (at 125k) experiences a small improvement on WER. When train size is 625k, two languages (Greek and Finnish) out of 10 languages, experience improvement. When train size is 1M, four languages, out of nine, experience a gain in DER and WER after adding MT: Greek (*el*), Finnish (*fi*), Italian (*it*), and Portuguese (*pt*) with Greek and Finnish experiencing a great boost. Greek has 79.6% and 28.3% of reduction in DER and WER, respectively. Finnish has 46.2% and 19.4% of reduction in DER and WER, respectively. Despite that the other five European languages do not enjoy the gain, they demonstrate manageable losses in DER and minimal losses in WER. Overall, the paired t-test indicates that adding MT significantly harms diacritization performance when $<$ 625k and a neutrality when $\geq$ 625k. We observe huge effect sizes for both DER and WER when train size $<$ 125k. The effect sizes reduce quickly after $\geq$ 125k to the values between very small to small. That is, the negative effect of adding MT to diacritization decreases as the train size goes up.

Thompson and Alshehri (2022) also find that when the dataset is large, Arabic diacritization can benefit from the addition of MT as an auxiliary task. Hence, we recommend adding MT to diacritization when training with $\geq$ 1M train size because there potentially can be a performance boost. Even if not, the negative effect is manageable.[9]

After studying RQ1a and RQ1b, a notable asymmetry emerges in the relationship between MT and diacritization at higher-resource scenarios when introduced as auxiliary tasks. Specifically, while the inclusion of diacritization adversely affects MT performance, the incorporation of MT may yield benefits for diacritization. To summarize, we propose a guideline of either training in single-task or multi-task fashion in Figure 3, tailored to varying sizes of the training set.

RQ2. What effect does removing/keeping diacritics have on MT? As introduced in Section 1, diacritics can carry semantic meanings. Removing diacritics can lead to the loss of the information. In MT, the lack of diacritics at source side can produce ambiguity and pose challenges to the MT system. Therefore, we hypothesize that removing diacritics ($\text{OnlyMT}_{\text{undia}}$) would negatively impact the MT performance, compared to diacritics being retained ($\text{OnlyMT}_{\text{dia}}$).

Nonetheless, our experimental results show that the MT system perform indifferently regardless of diacritics of source language being kept or removed. The mean difference of BLEU scores between $\text{OnlyMT}_{\text{undia}}$ and $\text{OnlyMT}_{\text{dia}}$ is consistently around zero throughout all train sizes and languages of both regions as can be seen in Fig-

[9] The DER/WER values and percentage change between DiaMT and OnlyDia are shown in Tables D.3 and D.4.

ure 2. As shown in Table 4, the p-values between the BLEU scores of OnlyMT$_{\text{undia}}$ and OnlyMT$_{\text{dia}}$ are consistently larger than 0.05 when $<$ 125k for both African and European languages. When $\geq$ 125k, there is inconsistency in the significance test results where we observe p values being less than 0.05 at 125k and 1M, but larger than 0.05 at 625k. At 125k, 625k, and 1M, 95%, 50%, and 89% of language pairs have better performance when source is diacritized, respectively. It seems that when $\geq$ 125k, the existence of diacritics may benefit translation performance. However, with a closer look into Table D.2, the percentage changes of the two models for each language are in general around zero at 1M train size. That is, the performance differences between two models are minimal at 1M. Despite that the paired t-test shows significance at 125k and 1M, the Cohen's d for 125k and 1M are 0.17 and 0.08, respectively. Both of them are between very small to small, indicating that the effects are little.

We speculate two potential reasons of the absent effect when diacritics are removed: (1) the contextual clues provided by adjacent words may enhance machine translation quality as effectively as the inclusion of diacritics. That is, MT systems are capable of inferring the missing information based on the contexts. As suggested in Adelani et al. (2021), an MT system may be capable of learning to disambiguate and generate correct translation even when diacritics are absent at the source side. (2) The infrequent incidence of ambiguity resulting from the removal of diacritics makes it negligible when assessing the performance difference between retaining and removing diacritics.

5.2 Function of Diacritics and MT Performance

Despite that we observe minimal impact on MT performance whether diacritics are removed or retained as discussed in our **RQ2**, the comparison is between OnlyMT$_{\text{dia}}$ and OnlyMT$_{\text{undia}}$ among languages with all types of diacritical functions. To further explore the effect, we investigate whether the way diacritics function in each language influences model performance of MT. This is motivated by linguistic studies which find a reading cost in humans when diacritics that perform lexical functions are mismatched (Labusch et al., 2023). We split the diacritical functions into *lexical function*, where diacritics influence the lexical semantics of a word and *grammatical function*, where the diacritics can change the grammatical structure of a sentence. Due to limited research on diacritics in African languages, our analysis concentrates on European languages. An overview of diacritical functions in these languages is provided in Appendix Table A.6. To conduct an analysis, we categorize European languages into three groups: *lex only*, *gra only*, *lex+gra*, which represent that diacritics have only lexical function, only grammatical function, and both, respectively. We inspect how different groups of diacritical functions will affect translation quality when diacritics are removed by comparing the average BLEU scores produced by OnlyMT$_{\text{dia}}$ and OnlyMT$_{\text{undia}}$ for each group at different train sizes.

We hypothesize that the removal of diacritics would harm languages whose diacritics have lexical function more than those having grammatical function, based on the assumption that grammatical information can be easier to infer from the contexts, compared to lexical information. Hence, we speculate that the differences between mean BLEU scores of OnlyMT$_{\text{dia}}$ and OnlyMT$_{\text{undia}}$ would be *lex+gra* $>$ *lex only* $>$ *gra only* where *lex+gra* having the largest difference because diacritics perform both functions for languages in this group and removing diacritics may lead to heavier loss in information compared to the other two groups. Experimental results, as can be seen in Figure 4, show that for train sizes $\leq$ 5k, the differences of average BLEU scores are all around zero among the three different groups without an obvious pattern. However, for $\geq 25k$, there is a somewhat consistent order of *lex+gra* $>$ *lex only* $>$ *gra only*, except that the difference for *lex only* is slightly higher than *lex+gra* at 625k; and *gra only* is slightly higher than *lex only* at 1M. In part, the experimental results align with our hypothesis.

Although the results show a tendency of performance loss after removing diacritics being *lex+gra* $>$ *lex only* $>$ *gra only*, it is noteworthy that this finding does not guarantee that languages categorized in these three groups will always follow the order. This is due to the fact that the differences for all three groups are consistently around zero, within the range of 0.66 to -0.78 BLEU score, reflecting the effect of removing diacritics is minimal as discussed in **RQ2**. Furthermore, this analysis is not conclusive for two reasons: (1) The categorization into groups may overlook subtle but significant linguistic nuances, as languages within the same group might exhibit distinct linguistic characteristics despite their shared classification. (2) A thorough investigation with a representative dataset specifically designed to include ample instances of lexical ambiguity and sentences prone to grammatical ambiguity, after removal of diacritics, is necessary to definitively ascertain the relationship between diacritical functions and MT performance. That is, additional research in this area is needed.

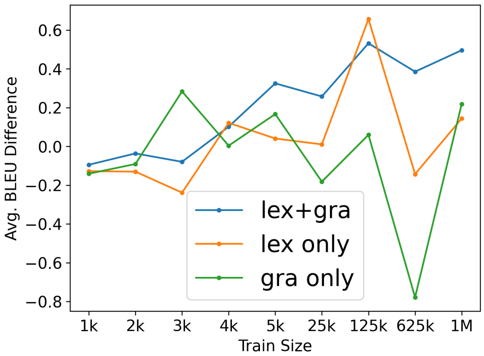

Figure 4: Differences of average BLEU scores between OnlyMT$_{\text{dia}}$ and OnlyMT$_{\text{undia}}$ for three different groups of diacritical functions (*lex only*, *gra only* and *lex+gra*) for European languages at different train sizes.

5.3 Positive Correlation Between Complexity and Performance Metrics

We propose two classes of complexity metrics as discussed in Section 4.5. The complexity metrics quantify the complexity of the diacritical system of a given language and anticipate that the higher the values of complexity metrics, the more difficult to restore diacritics (i.e. the worse the performance metrics: DER and WER). As for correlation analysis, the proposed complexity metrics exhibit a consistently positive correlation with diacritization performance metrics across both African and European languages at all train sizes. For instance, the substantial difference in complexity metric DCR between Gidar (*gid*) at 0.001 and Ndogo (*ndz*) at 0.258 corresponds to a divergent performance metric DER of 0.097 for *gid* and 0.330 for *ndz*.[10] We use the Train and Dev sets to compute complexity metrics while we measure performance on the Test set alone. We ensure that the data used to measure the complexity metrics and the data used to evaluate model performance are non-overlapping.

To assess the significance of these correlations, three measures, namely Pearson, Kendall, and Spearman correlations, were computed. The resulting p-values, which are predominantly lower than 0.05 across African and European languages and different train sizes, indicate statistical significance. Examples of profoundly high correlations between complexity and performance metrics include (DCR, DER) with pearson correlation at 0.885, and (WAED, WER) at 0.788 at 1M train size. A high correlation observed with larger training sizes bolsters confidence in the efficacy of the proposed complexity metrics. This finding solidifies the belief that the proposed metrics effectively quantify the complexity of the diacritical system of a language. The correlations between the proposed complexity metrics and DER/WER are detailed in Appendix Table E.3 for African languages and Table E.4 for European languages.

There are two exceptions to the strong correlations: DBR and AED. These metrics occasionally exhibit lower correlation with DER and WER. We speculate that (1) DBR in European languages can be biased due to the inclusion of foreign text, as discussed in Section 4.1. This may bring about the lower correlation between DBR and performance metrics. (2) The absence of taking character occurrence frequency into consideration may negatively influence the effectiveness of AED. To support this speculation, WAED, the weighted version of AED which takes frequency into consideration shows a high correlation with performance metrics across all train sizes and both language regions.

6 Conclusion

In this study, we empirically explore the interactions between machine translation (MT), diacritics, and diacritization. We conduct comprehensive experiments involving numerous African and European languages across different dataset sizes. In the multi-task learning setting, we observe that introducing diacritization is advantageous for MT in low-resource scenarios but detrimental otherwise. Additionally, we find that while MT generally has a negative impact on diacritization, it can facilitate substantial performance improvements for specific languages in high-resource settings. In the context of single-task learning, we determine that the removal or retention of diacritics has minimal influence on MT performance. To assess the complexity of diacritical systems, we propose six language-agnostic metrics, establishing a strong positive correlation with our model's performance.

[10] OnlyDia model at 5k as shown in Table D.3.

Limitations

For our machine translation experiments, we have limited our target language exclusively to English. Consequently, our findings may not be applicable to scenarios where the target language uses diacritics in its orthographic system. Moreover, the datasets used in this study are from religious and political domains, leading us to operate under the assumption that the texts are fully diacritized rather than partially. As such, this introduces a potential limitation to the generalizability of our results.

Ethics Statement

The datasets we employed in this study are derived from two publicly accessible sources: The Bibles and the European Parliament. We consciously chose not to collect or utilize data from any individual subjects to avoid privacy-related ethical issues.

Acknowledgements

We acknowledge support from Canada Research Chairs (CRC), the Natural Sciences and Engineering Research Council of Canada (NSERC; RGPIN-2018-04267), the Social Sciences and Humanities Research Council of Canada (SSHRC; 895-2020-1004; 895-2021-1008), Canadian Foundation for Innovation (CFI; 37771), Digital Research Alliance of Canada,[11] and UBC ARC-Sockeye.[12]

References

Gheith Abandah and Asma Abdel-Karim. 2020. Accurate and fast recurrent neural network solution for the automatic diacritization of arabic text. *Jordanian Journal of Computers and Information Technology*, 6(2).

Gheith Abandah, Alex Graves, Balkees Al-Shagoor, Alaa Arabiyat, Fuad Jamour, and Majid Al-Taee. 2015. Automatic diacritization of arabic text using recurrent neural networks. *International Journal on Document Analysis and Recognition (IJDAR)*, 18:183–197.

Ife Adebara and Muhammad Abdul-Mageed. 2022. Towards afrocentric NLP for African languages: Where we are and where we can go. In *Proceedings of the 60th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, pages 3814–3841, Dublin, Ireland. Association for Computational Linguistics.

David Adelani, Dana Ruiter, Jesujoba Alabi, Damilola Adebonojo, Adesina Ayeni, Mofe Adeyemi, Ayodele Esther Awokoya, and Cristina España-Bonet. 2021. The effect of domain and diacritics in Yoruba–English neural machine translation. In *Proceedings of Machine Translation Summit XVIII: Research Track*, pages 61–75, Virtual. Association for Machine Translation in the Americas.

Sawsan Alqahtani, Mahmoud Ghoneim, and Mona Diab. 2016. Investigating the impact of various partial diacritization schemes on Arabic-English statistical machine translation. In *Conferences of the Association for Machine Translation in the Americas: MT Researchers' Track*, pages 191–204, Austin, TX, USA. The Association for Machine Translation in the Americas.

Sawsan Alqahtani, Ajay Mishra, and Mona Diab. 2019. Efficient convolutional neural networks for diacritic restoration. 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 1442–1448, Hong Kong, China. Association for Computational Linguistics.

Eva Liina Asu and Pire Teras. 2009. Estonian. *Journal of the International Phonetic Association*, 39(3):367–372.

Martin J. Ball. 2001. On the status of diacritics. *Journal of the International Phonetic Association*, 31(2):259–264.

Hans Basbøll. 2005. *The phonology of Danish*. OUP Oxford.

Yonatan Belinkov and James Glass. 2015. Arabic diacritization with recurrent neural networks. In *Proceedings of the 2015 Conference on Empirical Methods in Natural Language Processing*, pages 2281–2285, Lisbon, Portugal. Association for Computational Linguistics.

Tilman Berger. 2012. *Religion and diacritics: The case of Czech orthography*. na.

Steven Bird. 1999. Strategies for representing tone in african writing systems. *Written language and literacy*, 2(1):1–44.

Dzintra Bond. 1978. Latvian long vowels and lengthened consonants: A study in phonetic interference. *Journal of Baltic Studies*, 9(1):73–79.

Jacob Cohen. 1977. Statistical power analysis for the behavioral sciences, rev.

Lucia Colombo and Simone Sulpizio. 2021. The role of orthographic cues to stress in italian visual word recognition. *Quarterly Journal of Experimental Psychology*, 74(9):1631–1641. PMID: 33719759.

Geoff Cumming. 2013. *Understanding the new statistics: Effect sizes, confidence intervals, and meta-analysis*. Routledge.

[11] https://alliancecan.ca

[12] https://arc.ubc.ca/ubc-arc-sockeye

Nadir Durrani, Hassan Sajjad, Alexander Fraser, and Helmut Schmid. 2010. Hindi-to-Urdu machine translation through transliteration. In *Proceedings of the 48th Annual Meeting of the Association for Computational Linguistics*, pages 465–474, Uppsala, Sweden. Association for Computational Linguistics.

Ali Fadel, Ibraheem Tuffaha, Bara' Al-Jawarneh, and Mahmoud Al-Ayyoub. 2019. Arabic text diacritization using deep neural networks.

Ramona Gönczöl. 2020. *Romanian: an essential grammar*. Routledge.

Osaama Hamed and Torsten Zesch. 2017. A survey and comparative study of arabic diacritization tools. *Journal for Language Technology and Computational Linguistics*, 32(1):27–47.

Adriana Hanulíkova and Silke Hamann. 2010. Illustrations of the ipa: Slovak. *Journal of the International Phonetic Association*, 40:373 – 378.

Peter Herrity. 2015. *Slovene: A comprehensive grammar*. Routledge.

Larry M Hyman. 2016. Lexical vs. grammatical tone: sorting out the differences. *Tonal Aspects Lang*, 2016:6–11.

Artur Janicki and Piotr Herman. 2005. Reconstruction of polish diacritics in a text-to-speech system. In *INTERSPEECH*, pages 1489–1492.

Armand Joulin, Edouard Grave, Piotr Bojanowski, Matthijs Douze, Hérve Jégou, and Tomas Mikolov. 2016a. Fasttext.zip: Compressing text classification models. *arXiv preprint arXiv:1612.03651*.

Armand Joulin, Edouard Grave, Piotr Bojanowski, and Tomas Mikolov. 2016b. Bag of tricks for efficient text classification. *arXiv preprint arXiv:1607.01759*.

Diederik P. Kingma and Jimmy Ba. 2017. Adam: A method for stochastic optimization.

Henning Klöter. 2011. *Phonology and Orthography*, pages 112 – 154. Brill, Leiden, The Netherlands.

Philipp Koehn. 2005. Europarl: A parallel corpus for statistical machine translation. In *Proceedings of Machine Translation Summit X: Papers*, pages 79–86, Phuket, Thailand.

Taku Kudo and John Richardson. 2018. SentencePiece: A simple and language independent subword tokenizer and detokenizer for neural text processing. In *Proceedings of the 2018 Conference on Empirical Methods in Natural Language Processing: System Demonstrations*, pages 66–71, Brussels, Belgium. Association for Computational Linguistics.

Dennis Kurzon. 2008. A brief note on diacritics. *Written Language &amp; Literacy*, 11(1):90–94.

Björn Köhnlein and Marc van Oostendorp. 2018. *Where Is the Dutch Stress System?: Some New Data*, page 346–360. Cambridge University Press.

Melanie Labusch, Stéphanie Massol, Ana Marcet, and Manuel Perea. 2023. Are goats chèvres, chévres, chēvres, and chevres? unveiling the orthographic code of diacritical vowels. *Journal of experimental psychology. Learning, memory, and cognition*, 49(2):301–319.

László János Laki and Zijian Gyozo Yang. 2020. Automatic diacritic restoration with transformer model based neural machine translation for east-central european languages. In *ICAI*, pages 190–202.

M.H. Mateus and E. d'Andrade. 2000. *The Phonology of Portuguese*. OUP Oxford.

Thomas Mayer and Michael Cysouw. 2014. Creating a massively parallel Bible corpus. In *Proceedings of the Ninth International Conference on Language Resources and Evaluation (LREC'14)*, pages 3158–3163, Reykjavik, Iceland. European Language Resources Association (ELRA).

Rada F. Mihalcea. 2002. Diacritics restoration: Learning from letters versus learning from words. In *Computational Linguistics and Intelligent Text Processing*, pages 339–348, Berlin, Heidelberg. Springer Berlin Heidelberg.

Hamdy Mubarak, Ahmed Abdelali, Hassan Sajjad, Younes Samih, and Kareem Darwish. 2019. Highly effective Arabic diacritization using sequence to sequence modeling. In *Proceedings of the 2019 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies, Volume 1 (Long and Short Papers)*, pages 2390–2395, Minneapolis, Minnesota. Association for Computational Linguistics.

Myle Ott, Sergey Edunov, Alexei Baevski, Angela Fan, Sam Gross, Nathan Ng, David Grangier, and Michael Auli. 2019. fairseq: A fast, extensible toolkit for sequence modeling. In *Proceedings of NAACL-HLT 2019: Demonstrations*.

Kishore Papineni, Salim Roukos, Todd Ward, and Wei-Jing Zhu. 2002. Bleu: a method for automatic evaluation of machine translation. In *Proceedings of the 40th Annual Meeting of the Association for Computational Linguistics*, pages 311–318, Philadelphia, Pennsylvania, USA. Association for Computational Linguistics.

Guy De Pauw, Peter W Wagacha, and Gilles-Maurice de Schryver. 2007. Automatic diacritic restoration for resource-scarce languages. In *International Conference on Text, Speech and Dialogue*, pages 170–179. Springer.

Manuel Perea, Jukka Hyönä, and Ana Marcet. 2022a. Does vowel harmony affect visual word recognition? evidence from finnish. *Journal of experimental psychology. Learning, memory, and cognition*, 48(12):2004–2014.

Manuel Perea, Melanie Labusch, and Ana Marcet. 2022b. How are words with diacritical vowels represented in the mental lexicon? evidence from spanish and german. *Language, Cognition and Neuroscience*, 37(4):457–468.

Matt Post. 2018. A call for clarity in reporting BLEU scores. In *Proceedings of the Third Conference on Machine Translation: Research Papers*, pages 186–191, Brussels, Belgium. Association for Computational Linguistics.

A. Protopapas. 2006. *On the Use and Usefulness of Stress Diacritics in Reading Greek*. Sprinher.

Athanassios Protopapas and Svetlana Gerakaki. 2009. Development of processing stress diacritics in reading greek. *Scientific Studies of Reading*, 13(6):453–483.

Han Qin, Guimin Chen, Yuanhe Tian, and Yan Song. 2021. Improving Arabic diacritization with regularized decoding and adversarial training. In *Proceedings of the 59th Annual Meeting of the Association for Computational Linguistics and the 11th International Joint Conference on Natural Language Processing (Volume 2: Short Papers)*, pages 534–542, Online. Association for Computational Linguistics.

T. Riad. 2014. *The Phonology of Swedish*. Oxford linguistics. OUP Oxford.

David Roberts. 2009. Visual crowding and the tone orthography of african languages. *Written Language & Literacy*, 12(1):140–155.

Shlomo S Sawilowsky. 2009. New effect size rules of thumb. *Journal of modern applied statistical methods*, 8(2):26.

Tim Schlippe, ThuyLinh Nguyen, and Stephan Vogel. 2008. Diacritization as a machine translation and as a sequence labeling problem. In *Proceedings of the 8th Conference of the Association for Machine Translation in the Americas: Student Research Workshop*, pages 270–278, Waikiki, USA. Association for Machine Translation in the Americas.

Rico Sennrich, Barry Haddow, and Alexandra Birch. 2016a. Edinburgh neural machine translation systems for WMT 16. *CoRR*, abs/1606.02891.

Rico Sennrich, Barry Haddow, and Alexandra Birch. 2016b. Neural machine translation of rare words with subword units. In *Proceedings of the 54th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*, pages 1715–1725, Berlin, Germany. Association for Computational Linguistics.

P. Siptár and M. Törkenczy. 2000. *The Phonology of Hungarian*. The Phonology of the World's Languages. OUP Oxford.

Felix Stahlberg, James Cross, and Veselin Stoyanov. 2018. Simple fusion: Return of the language model. *CoRR*, abs/1809.00125.

Giedrius Subačius. 2008. The letter and lithuanian cyrillic script: Two language planning strategies in the late nineteenth century. *Journal of Baltic Studies*, 39(1):73–82.

Brian Thompson and Ali Alshehri. 2022. Improving Arabic diacritization by learning to diacritize and translate. In *Proceedings of the 19th International Conference on Spoken Language Translation (IWSLT 2022)*, pages 11–21, Dublin, Ireland (inperson and online). Association for Computational Linguistics.

Ashish Vaswani, Noam Shazeer, Niki Parmar, Jakob Uszkoreit, Llion Jones, Aidan N Gomez, Łukasz Kaiser, and Illia Polosukhin. 2017. Attention is all you need. *Advances in neural information processing systems*, 30.

John C Wells. 2000. Orthographic diacritics and multilingual computing. *Language problems and language planning*, 24(3):249–272.

Philip Williams, Rico Sennrich, Maria Nădejde, Matthias Huck, Barry Haddow, and Ondřej Bojar. 2016. Edinburgh's statistical machine translation systems for WMT16. In *Proceedings of the First Conference on Machine Translation: Volume 2, Shared Task Papers*, pages 399–410, Berlin, Germany. Association for Computational Linguistics.

Appendices

There are five sections in the appendix:

- Appendix A includes
  - Number of examples for Train/Dev/Test splits for African languages (Table A.1) and European languages (Table A.2).
  - Hyperparameters and software information for the models we train (Table A.3).
  - Set of characters and their diacritical variants for African languages (Table A.4) and European languages (Table A.5).
  - Classification of lexical and/or grammatical function for each European language (Table A.6).
- Appendix B includes implementation details of diacritics error rate (DER) and word error rate (WER) metrics for measuring the performance of diacritization.
- Appendix C includes bar plots to demonstrate the comparison between different model settings which are visualization attempts to approach our research questions:
  - BLEU scores
    - (**RQ1a.**) DiaMT vs. OnlyMT$_{\text{undia}}$ for African languages in Figure C.1 and for European languages in Figure C.2
    - (**RQ2.**) OnlyMT$_{\text{dia}}$ vs. OnlyMT$_{\text{undia}}$ for African languages in Figure C.3 and for European languages in Figure C.4
  - DER and WER
    - (**RQ1b.**) DiaMT vs. OnlyDia
      - DER for African languages in Figure C.5 and for European languages in Figure C.6
      - WER for African languages in Figure C.7 and for European languages in Figure C.8
- Appendix D includes values of metrics (BLEU, DER, WER) to measure the performance of MT and diacritization for all models given different languages at different train sizes; and the percentage change between two different models.
  - BLEU scores for every African language (Table D.1) and European language (Table D.2).
  - DER and WER for every African language (Table D.3) and European language (Table D.4).
- Appendix E includes
  - Implementation details of our proposed language-agnostic complexity metrics designed to evaluate the complexity of the diacritical system of any given language.
  - Correlation analysis of our proposed complexity metrics and diacritization performance metrics (DER, WER) for both African and European languages (Table E.3 and E.4).
  - The values of complexity metrics for all 55 included African and European languages at different train sizes (Table E.5 and E.6).

A Miscellaneous

Code	Name	Train	Dev	Test
bex	JurModo	4,938	617	618
fon	Fon	4,948	619	619
mkl	Mokole	4,930	616	617
mnf	Mundani	4,921	615	616
bud	Bassar, Ntcham	4,950	619	619
eza	Ezaa	4,962	620	621
sig	Paasaal	4,932	616	617
bqc	Boko	4,956	619	620
kia	Kim	4,963	620	621
soy	Miyobe	4,957	620	620
nnw	Southern Nuni	4,928	616	616
sag	Sango	4,964	620	621
csk	JolaKasa	4,964	621	621
izz	Izii	4,964	621	621
bum	Bulu	4,964	620	621
gvl	Gulay	4,964	621	621
ndz	Ndogo	4,959	620	620
lip	Sekpele	4,934	617	617
ken	Kenyang	4,960	620	621
gid	Gidar	4,956	620	620
gng	Ngangam	4,853	607	607
muy	Muyang	4,952	619	619
niy	Ngiti	4,964	621	621
xed	Hdi	4,959	620	620
anv	Denya	4,958	620	620
lee	Lyele	4,939	617	618
ksf	Bafia	4,964	620	621
pkb	Pokomo	4,936	617	617
nko	Nkonya	4,930	616	617
lef	Lelemi	4,938	617	618
nhr	Naro	4,952	619	620
mgc	Morokodo	2,124	266	266
biv	Southern Birifor	4,964	620	621
maf	Mafa	4,964	621	621
giz	South Giziga	4,964	621	621
tui	Tupuri	4,961	620	621

Table A.1: The number of examples in Train/Dev/Test splits for African languages.

Code	Name	Train
cs	Czech	125,000
da	Danish	625,000
de	German	1,000,000
el	Greek	1,000,000
es	Spanish	1,000,000
et	Estonian	125,000
fi	Finnish	1,000,000
fr	French	1,000,000
hu	Hungarian	125,000
it	Italian	1,000,000
lt	Lithuanian	125,000
lv	Latvian	125,000
nl	Dutch	1,000,000
pl	Polish	125,000
pt	Portuguese	1,000,000
ro	Romanian	125,000
sk	Slovak	125,000
sl	Slovenian	25,000
sv	Swedish	1,000,000

Table A.2: The number of examples in Train split for European languages. Dev and Test have 1,500 datapoints for all languages.

Hyperparamter	Value
Encoder #layers	6
Encoder #heads	8
Encoder embedding dimensions	256
Encoder FFN dimension	1024
Decoder #layers	6
Decoder #heads	8
Decoder embedding dimensions	256
Decoder FFN dimension	1024
Dropout rate	0.2
Batch size	15
Beam size	6
Optimizer	Adam (Kingma and Ba, 2017)
Software	Fairseq
Version	v0.10.2
License	MIT License

Table A.3: Hyperparameters and software information for our transformer models. The estimated GPU hours to complete the experiments (including those taken during the development stage) is 7500. The link for Fairseq software is `https://github.com/facebookresearch/fairseq`. Our use is consistent with Fairseq's intended use, based on its license.

Lang	Base Character	Variants
anv	a, e, g, i, m, n, o, u, ŋ, ɔ, ɛ	á, a᷄, é, ǵ, í, ḿ, ń, ó, ú, ŋ́, ɔ́, ɛ́
bex	e, i, o	ë, ï, ö
biv	a, e, i, o, u, ɔ, ɛ, ɩ, ʊ	ã, ẽ, ĩ, õ, ũ, ɔ̃, ɛ̃, ɩ̃, ʊ̃
bqc	a, e, i, m, n, o, u, ɔ, ɛ, ɔ	á, à, ã, ã́, ã̀, è, é, ì, í, ĩ́, ĩ, ĩ̀, ḿ, ń, ǹ, ò, ó, ú, ṹ, ù, ũ, ũ̀, ɔ̃, ɛ̃, ɛ́, ɛ̃́, ɛ̀, ɛ̃̀, ɔ̃, ɔ́, ɔ̃́, ɔ̀, ɔ̃̀
bud	a, b, e, i, l, m, n, o, u, ŋ, ɔ	á, à, ā, b̀, b́, b̄, é, è, ē, í, ì, ī, ï, l̄, l̀, ĺ, m̀, ḿ, m̄, ǹ, n̄, ń, ò, ū, ú, ù, ŋ́, ɔ́, ɔ̃, ɔ̄
bum	e, n, o, u	é, ñ, ô, ü
csk	a, e, i, l, n, o, u	á, é, í, l̥, ñ, ó, ú
eza	a, e, i, o, u	á, à, ẹ, é, ẹ́, è, ẹ̀, í, ị, ì, ị́, ọ, ó, ò, ọ́, ọ̀, ụ, ú, ù, ụ̀, ụ́
fon	a, e, i, o, u, ɔ, ɛ	ǎ, á, é, ě, è, í, ǐ, ì, ó, ǒ, ǔ, ú, ɔ́, ɔ̌, ɛ́, ɛ̌
gid	a, e, i, o	ã, ẽ, ê, ĩ, õ
giz	a, e, i, o, u	ã, ẽ, ĩ, õ, ũ
gng	a, e, i, n, o, u, ɔ, ɛ	à, á, è, é, í, ì, ń, ñ, ò, ó, ù, ú, ɔ̀, ɔ́, ɛ̀, ɛ́
gvl	a, e, g, j, m, o, p, s, u, ɔ	à, á, è, é, ê, ĝ, ĵ, m̂, ḿ, m̀, ò, ó, p̂, ŝ, ú, ù, ɔ́
izz	a, e, i, m, n, o, u	á, à, ẹ, é, è, ẹ̀, ẹ́, ị, í, ì, m̀, ḿ, ǹ, ń, ọ, ọ̀, ó, ọ́, ò, ụ, ù, ú, ụ́, ụ̀
ken	a, e, i, n, o, u, ɔ, ɛ, ɨ, ʉ	á, ǎ, à, é, ě, è, í, ǐ, ì, ń, ǒ, ó, ò, ú, ǔ, ù, ɔ́, ɔ̀, ɔ̌, ɛ́, ɛ̌, ɛ̀, ɨ́, ɨ̀, ɨ̌, ʉ́, ʉ̀, ʉ̌
kia	a, e, i, o, u	a̰, á, á̰, à, ā, ḛ, é, ḛ́, è, ḭ, í, ḭ́, o̰, ó, ó̰, ò, ú, ṵ, ū, ù, ṵ́
ksf	a, e, g, i, m, n, o, s, u, ŋ, ɔ, ɛ	à, á, è, g̀, ì, m̀, ǹ, ò, s̀, ù, ŋ̀, ɔ̀, ɛ̀
lee	a, e, i, n, o, u, ɔ, ə, ɛ	ã, á, à, â, ǎ, ã̌, ã́, ã̀, ê, ẽ, è, é, ẽ́, ě, ẽ̀, ẽ̌, ì, í, ĩ́, ǐ, ĩ̀, ĩ̌, ĩ, ǹ, ń, ò, ó, ǒ, õ, ô, õ̀, õ̌, ṍ, ú, ù, ǔ, ũ, ṹ, ũ̌, ũ̀, ɔ́, ɔ̀, ɔ̃́, ɔ̌, ɔ̃̀, ɔ̃, ɔ̃̂, ɔ̃̌, ə́, ə̀, ə̃̀, ə̌, ə̃̌, ə̃́, ə̃, ɛ̀, ɛ́, ɛ̃̀, ɛ̌, ɛ̃, ɛ̃́, ɛ̃̌
lef	a, e, i, m, n, o, u, ɔ, ɛ	á, é, í, ḿ, ń, ó, ú, ɔ́, ɛ́
lip	a, e, i, m, n, o, u, ɔ, ɛ	ã, á, é, ẽ, í, ĩ, ḿ, ń, ó, ú, ũ, ɔ́, ɔ̃, ɛ̃, ɛ́
maf	a, e, i, o, u	â, á, à, è, é, ê, í, ì, ô, ö, ò, ü
mgc	e, i, o, r, u	ë, ï, ö, ṛ, ü
mkl	a, e, i, n, o, u, ɑ, ɔ, ɛ	à, á, é, è, í, ì, ĩ, ĩ́, ĩ̌, ǹ, ń, ò, ó, ù, ũ, ú, ɑ̀, ɑ́, ɑ̃, ɔ̃, ɔ̀, ɔ́, ɔ̃̌, ɛ̃, ɛ́, ɛ̀
mnf	a, e, i, o, u, ɔ, ə, ɨ	à, â, ą̂, ą̀, ǎ, ą̌, ą, è, ę̌, ê, ę, ě, ę̂, ę̀, ì, ǐ, î, ǫ, ò, ǒ, ǫ̀, ô, ǫ̌, ǫ̂, ù, û, ų, ǔ, ų̀, ų̌, ɔ̨, ɔ̀, ɔ̂, ɔ̨̀, ɔ̌, ɔ̨̂, ɔ̨̌, ə̀, ə̂, ə̌, ɨ̀, ɨ̨, ɨ̨̀, ɨ̌, ɨ̂, ɨ̨̂, ɨ̨̌
muy	a, e, i, o, u, ə	à, â, á, ê, è, é, ì, î, í, ò, ô, ù, ú, ə̀, ə̂, ə́
ndz	a, e, i, o, r, u	à, á, â, é, è, ê, í, ì, î, ò, ó, ô, ṛ, û, ù, ú
nhr	a, e, i, m, o, u	ã, á, à, a̱, ã̱, é, è, ẽ, í, ì, m̀, ḿ, ò, õ, ó, o̱, õ̱, ú, ù
niy	a, e, i, o, u, ɔ, ɛ, ɨ, ʉ	à, á, ǎ, è, ě, é, í, ì, ǐ, ò, ó, ǒ, ù, ú, ǔ, ɔ́, ɔ̌, ɔ̀, ɛ̀, ɛ̌, ɛ́, ɨ́, ɨ̀, ɨ̌, ʉ̀, ʉ́, ʉ̌
nko	a, e, i, o, u, ɔ, ɛ, ɩ, ʊ	á, é, í, ó, ú, ɔ́, ɛ́, ɩ́, ʊ́
nnw	a, e, m, n, o, p, u, y, ı, ɑ, ɔ, ə, ɛ, ɩ, ʊ	à, á, è, é, m̀, ḿ, ń, ó, ò, p̀, ù, ú, ý, ì, í, ɑ̀, ɑ́, ɔ̀, ɔ̀, ə̀, ə́, ə̌, ɛ̀, ɛ́, ɩ̀, ɩ́, ɩ̌, ʊ̀, ʊ́
pkb	b, d, t	ḅ, ḍ, d̯, t̯
sag	a, e, i, o	â, é, ë, ê, è, î, ï, ö, ô
sig	a, ʊ	á, ʊ̃
soy	a, e, i, m, n, o, u, ŋ, ɑ, ɔ, ɛ	á, é, ẽ, ẽ́, í, ĩ́, ĩ, ḿ, ń, ñ, ó, ṍ, õ, ú, ũ, ṹ, û, ŋ́, ɑ́, ɑ̃, ɑ̃́, ɔ́, ɔ̃́, ɔ̃, ɛ́, ɛ̀, ɛ̃, ɛ̃́
tui	a, c, e, i, n	ä, à, ç, è, ë, ï, ñ
xed	a, i	á, í

Table A.4: The base and diacritized forms occurred in the dataset of each included African language. The list for each language may not be exhaustive.

Lang	Base Character	Variants
cs	a, c, d, e, g, i, k, l, n, o, r, s, t, u, w, y, z, ε, η, ι, ο, υ, и	á, ä, ǎ, ă, à, â, ã, ą, å, ā, č, ć, ç, ď, ě, é, ė, è, ê, ę, ë, ē, ğ, ģ, í, ī, ï, ì, î, ĭ, i̊, ķ, ľ, ĺ, ň, ń, ñ, ņ, ó, ö, ő, ō, ò, õ, ô, ř, ŕ, š, ş, ś, ť, ţ, ů, ú, ü, ù, ū, ű, û, ų, ŵ, ý, ž, ż, ź, έ, ή, ί, ό, ύ, й
da	a, c, d, e, g, h, i, k, l, n, o, r, s, t, u, w, y, z, α, ε, η, ι, ο, υ, ω, и, i	å, ä, á, à, ã, ǎ, â, ă, ą, ā, ç, č, ć, d́, é, è, ë, ê, ė, ę, ě, ē, ğ, ģ, ǵ, h́, í, ì, ï, î, ī, ĭ, i̇, ķ, ľ, ĺ, ñ, ń, ň, ņ, ô, ö, ó, ò, õ, ő, ō, ŏ, ř, ŕ, ş, š, ś, ŝ, ţ, ť, ü, ú, ū, û, ų, ù, ů, ŵ, ý, ź, ž, ż, ά, έ, ή, ί, ό, ύ, ώ, й, ї
de	a, b, c, d, e, g, i, k, l, n, o, r, s, t, u, w, y, z, α, ε, η, ι, ο, υ, ω, и	ä, ǎ, á, à, â, ã, å, ă, ą, ā, b̧, ç, č, ć, ĉ, d́, é, è, ê, ė, ę, ë, ě, ē, ğ, ģ, í, ï, ì, ī, î, ĭ, i̇, ķ, ľ, ĺ, ļ, ñ, ń, ň, ņ, n̊, ö, ó, ô, ő, ò, õ, ŏ, ō, ř, ŕ, š, ş, ś, ṣ, ŝ, ţ, ť, t́, ü, ú, ū, ù, û, ǔ, ų, ů, ŵ, ý, ž, ż, ź, ά, έ, ή, ί, ό, ύ, ώ, й
el	a, c, d, e, g, i, k, l, m, n, o, r, s, t, u, w, y, z, α, β, γ, ε, η, θ, ι, μ, ν, ξ, ο, π, ρ, ς, σ, τ, υ, φ, ω, и	ǎ, á, ä, ã, à, â, ą, ă, å, ā, č, ç, ć, ĉ, d́, é, è, ê, ė, ě, ę, ë, ē, ğ, í, ï, ī, î, ì, ķ, ľ, m̧, ň, ń, ñ, ņ, ö, ó, ő, õ, ò, ô, ō, ř, ş, š, ś, ţ, ť, ü, ū, ú, û, ù, ǔ, ů, ų, ŵ, ý, ž, ź, ż, ά, ᾰ̈, ὰ, ᾶ, β́, γ́, έ, ε̉, ἕ, ή, η̩, ῆ, ἣ, η̈, θ́, ί, ϊ, ΐ, ι̧, ὶ, ῖ, ι̉, μ́, ν́, ν̈, ξ́, ό, ο̈, π́, ρ́, ς́, ς̊, ς̈, σ́, τ́, τ̈, ύ, ϋ, ΰ, ῦ, υ̉, φ́, ώ, ῶ, й
es	a, c, d, e, g, i, j, k, l, m, n, o, r, s, t, u, w, y, z, α, ε, η, ι, ο, υ, ω, и, i	á, ą, â, ä, ã, ǎ, à, å, ă, ā, č, ç, ć, ĉ, d́, d̈, é, è, ë, ê, ė, ě, ę, ē, ğ, ģ, í, ï, ī, ĭ, ì, î, i̇, į, j́, ķ, ľ, ĺ, l̄, ḿ, m̈, ñ, ń, ň, ņ, n̄, ó, ö, ò, ő, õ, ō, ô, ř, r̄, š, ş, ś, s̈, ṣ, s̄, ţ, ť, t́, ú, ü, ū, û, ù, ů, ǔ, ų, ŵ, ý, ȳ, ÿ, ž, ź, ż, z̄, ά, έ, ή, ϊ, ί, ό, ύ, ώ, й, ї
et	a, c, e, g, h, i, k, l, n, o, r, s, t, u, w, y, z, α, ε, η, ι, ο, υ, и	ä, á, ã, ǎ, â, à, ā, å, ă, ą, č, ç, ć, é, ė, è, ë, ê, ę, ě, ē, e̊, ğ, ģ, ḩ, í, į, ī, ï, i̇, î, ì, ķ, ľ, ń, ň, ñ, ņ, õ, ö, ó, ô, ő, ō, ŏ, ò, ř, ŗ, š, ş, ś, ṣ, ţ, ť, ü, ú, ū, û, ų, ù, ŵ, ý, ž, ż, ź, ά, έ, ή, ί, ό, ύ, й
fi	a, c, d, e, g, i, j, k, l, n, o, r, s, t, u, w, x, y, z, α, ε, η, ι, ο, υ, ω, и	ä, á, ã, ǎ, ą, å, à, â, ă, ā, č, ç, ć, ĉ, d́, ë, é, è, ê, ė, ę, ē, ě, ģ, ğ, í, ï, ī, î, ì, i̇, j́, ķ, ľ, ĺ, ļ, ń, ñ, ň, ņ, ö, ó, ő, ò, ô, õ, ō, ř, š, ş, ś, ṣ, ţ, t́, ť, ü, ú, û, ū, ù, ų, ů, ǔ, ẃ, ŵ, x́, ý, ž, ź, ż, ά, έ, ή, ί, ό, ύ, ώ, й
fr	a, c, d, e, g, i, k, l, n, o, r, s, t, u, w, y, z, α, ε, η, ι, ο, υ, и, i	à, á, â, ã, ä, å, ǎ, ą, ă, ā, ç, ć, č, ĉ, ḑ, d́, é, è, ê, ë, ė, ę, ě, ē, ğ, ģ, î, ï, í, ī, ĭ, ì, i̇, ķ, ľ, ļ, ĺ, ñ, ń, ň, ņ, ô, ó, ö, ò, ő, õ, ō, ř, ŕ, š, ş, ś, ṣ, ţ, ť, û, ù, ú, ü, ǔ, ū, ų, ů, ŵ, ý, ź, ž, ż, ά, έ, ή, ί, ό, ύ, й, ї
hu	a, c, e, g, i, k, l, n, o, r, s, t, u, w, y, z, α, ε, η, ι, ο, υ, ω	á, ä, ã, ǎ, à, â, ą, ă, å, ā, ç, č, ć, ĉ, é, è, ê, ě, ę, ė, ë, ē, ğ, í, ĭ, ī, ï, ì, î, ķ, ľ, ň, ń, ñ, ņ, ó, ö, ő, õ, ô, ò, ř, ŕ, ş, š, ś, ṣ, s̊, ţ, ť, ű, ü, ú, ū, û, ù, ŵ, ý, ž, ż, ź, ά, έ, ή, ί, ό, ύ, ώ
it	a, c, e, g, i, k, l, n, o, r, s, t, u, v, w, y, z, α, ε, η, ι, ο, υ, ω, и	à, á, ä, ã, ǎ, ą, å, â, ă, ā, a̧, č, ç, ć, è, é, ë, ê, ė, ę, ě, ȩ, ē, ğ, ģ, ì, í, ï, î, ī, i̇, į, ĭ, ķ, ĺ, ľ, ñ, ń, ň, ņ, ò, ö, ő, ó, ô, õ, ō, ř, ŕ, š, ş, ś, ţ, ť, ù, ü, ú, ū, û, ų, ů, v́, ŵ, ý, ž, ź, ż, ά, έ, ή, ί, ό, ύ, ώ, й
lt	a, c, d, e, g, i, k, l, n, o, r, s, t, u, w, y, z, α, ε, η, ι, ο, υ	ą, á, ä, ã, à, ǎ, â, å, ă, ā, č, ç, ć, ĉ, ḑ, ė, ę, é, è, ê, ē, ë, ě, ğ, ģ, į, í, ï, ī, ĭ, î, ì, ķ, ľ, ļ, ň, ń, ñ, ņ, ö, ó, ő, ô, ò, ǫ, õ, ř, ŗ, r̨, š, ş, ś, s̊, ṣ, ţ, ť, ų, ū, ü, ú, ù, û, ŵ, ý, y̨, ž, ź, ż, z̨, ά, έ, ή, ί, ό, ύ
lv	a, c, e, g, i, k, l, n, o, r, s, t, u, w, y, z, α, ε, η, ι, ο, υ, и	ā, á, ǎ, ą, ä, à, â, ã, å, ă, č, ç, ć, ĉ, ē, ê, é, è, ė, ę, ë, ě, ģ, ğ, ġ, ī, į, ï, í, î, ì, ĭ, ķ, ļ, ľ, ņ, ň, ñ, ń, ö, ő, ó, ō, ò, õ, ô, ř, ŗ, r̊, š, ś, ş, ṣ, ţ, ť, ū, ü, ú, ų, û, u̧, ù, ŵ, ý, ž, ż, ź, ά, έ, ή, ί, ό, ύ, й
nl	a, b, c, d, e, g, h, i, k, l, m, n, o, r, s, t, u, w, y, z, α, ε, η, ι, ο, υ, ω, e, и, i	á, ă, å, ä, à, ã, ą, â, ǎ, a̧, ā, b́, ć, ç, č, ĉ, d́, ď, ê, ë, é, è, ě, ė, ę, ē, ȩ, ğ, ǵ, ģ, h́, ï, í, ī, ì, î, ĭ, i̇, ķ, ľ, ĺ, ļ, ḿ, m̧, ň, ñ, ń, ņ, n̊, ó, ö, ő, ò, ô, õ, ō, ŕ, ř, ŗ, š, ś, ş, ṣ, ţ, ť, t́, t̊, ü, ú, ū, ù, ů, û, ǔ, ų, ŵ, ẃ, ý, ž, ż, ź, ά, έ, ή, ί, ό, ύ, ώ, ë, й, ї
pl	a, c, e, g, i, k, l, n, o, r, s, t, u, w, y, z, α, ε, η, ι, ο, υ, и	ą, á, ǎ, ã, â, ä, à, å, ā, ă, ć, ç, č, ĉ, ę, é, è, ê, ë, ė, ě, ē, ğ, ģ, ï, í, ĭ, ī, î, ì, ķ, ľ, ń, ñ, ň, ņ, ó, ö, ő, õ, ō, ò, ô, o̊, ř, ś, š, ş, ţ, ť, ú, ü, ū, ű, û, ù, ŵ, ý, ż, ź, ž, z̧, ά, έ, ή, ί, ό, ύ, й
pt	a, c, d, e, g, i, k, l, m, n, o, p, r, s, t, u, w, y, z, α, ε, η, ι, ο, υ, ω, и, i	à, ã, á, â, ä, ă, å, ą, ǎ, ā, ǻ, ç, č, ć, ĉ, d́, ď, ê, é, è, ė, ë, ę, ě, ē, ȩ, ğ, ģ, ǵ, í, ï, î, ì, i̧, ī, į, i̇, ķ, ľ, ĺ, ḿ, ñ, ň, ń, ņ, õ, ó, ô, ö, ò, ő, ṕ, ř, ŗ, ŕ, ş, š, ś, s̊, ŝ, ţ, ť, t́, ṭ, ú, ü, ū, ù, û, ů, ű, ų, ŵ, ý, ž, ź, ż, ά, έ, ή, ί, ό, ύ, ώ, й, ї
ro	a, c, e, g, i, k, l, n, o, r, s, t, u, w, y, z, α, ε, η, ι, ο, υ, ω, и	ă, â, á, ã, à, ä, ǎ, å, ą, ā, ç, ć, č, ĉ, è, é, ě, ê, ë, ė, ę, ē, ğ, î, í, ì, ī, ï, î, ĭ, ķ, ľ, ń, ň, ñ, ņ, ó, ő, ô, ö, ò, õ, ō, ř, ş, ṣ, š, ś, ţ, ṭ, ť, ü, ú, ū, ù, û, ŵ, ý, ž, ź, ż, ά, έ, ή, ί, ϊ, ό, ύ, ώ, й
sk	a, c, d, e, g, i, k, l, n, o, r, s, t, u, w, y, z, α, ε, η, ι, ο, υ, ω, и	á, ä, ǎ, ă, à, å, â, ã, ā, ą, č, ç, ć, ď, é, è, ë, ě, ę, ė, ê, ē, ğ, ģ, í, ī, ï, î, ì, ķ, ľ, ĺ, ň, ń, ñ, ņ, ô, ó, ö, ő, ò, ō, õ, ŕ, ř, š, ş, ś, ť, ţ, ú, ü, ū, ù, ű, û, ŵ, ý, ž, ż, ź, ά, έ, ή, ί, ϊ, ό, ύ, ώ, й
sl	a, c, d, e, g, i, j, k, l, n, o, r, s, t, u, w, y, z, α, ε, η, ι, ο, υ	ä, á, ã, ǎ, ă, â, ą, à, ā, å, č, ç, ć, ĉ, ď, é, è, ę, ė, ê, ë, ě, ȩ, ē, ğ, ģ, í, ï, ī, î, ì, ĭ, j̧, ķ, ľ, ĺ, ń, ñ, ň, ņ, ó, ö, ő, ò, ǫ, ō, õ, ô, ř, ŕ, š, ş, ś, ţ, ť, ü, ú, ű, ū, û, ů, u̧, ŵ, ý, ž, ź, ż, ά, έ, ή, ί, ό, ύ
sv	a, c, d, e, f, g, i, k, l, n, o, r, s, t, u, w, x, y, z, α, ε, η, ι, ο, υ, ω, и, i	ä, å, á, à, ã, ă, ǎ, â, ą, ā, ǻ, ç, ć, č, ĉ, d́, é, è, ê, ė, ë, ě, ę, ē, f́, ğ, ģ, í, ï, ī, ì, î, i̇, ķ, ľ, ļ, ĺ, ń, ñ, ň, ņ, ö, ó, ò, ő, õ, ô, ō, ř, š, ş, ś, ţ, ť, ü, ú, ū, û, ù, ů, ų, ǔ, ŵ, x́, ý, ÿ, ź, ż, ž, ά, έ, ή, ί, ό, ύ, ώ, й, ї

Table A.5: The base and diacritized forms occurred in the dataset of each included European language. Note that each of them may contain characters in other language (for example, in Spanish dataset, there can be French word) and therefore the base characters and variants may not be of that single language.

Lang.	Lexical	Grammatical	Citation
cs	vína (‘wine’), vina (‘guilt’)	-	(Berger, 2012; Kurzon, 2008; Wells, 2000)
da	hår (‘hair’), har (‘have’)	-	(Basbøll, 2005)
nl	-	to indicate stress in loan words as a question tag	(Köhnlein and Oostendorp, 2018)
et	möla (‘twaddle’) - mõla (‘paddle’)	-	(Asu and Teras, 2009)
de	bar (‘bar’), bär (‘bear’)	-	(Labusch et al., 2023; Perea et al., 2022b)
el	φώς (‘man’), φῶς (‘light’)	-	(Protopapas, 2006)
es	mí (‘me’), mi (‘my’)	to indicate stress	(Klöter, 2011; Labusch et al., 2023; Perea et al., 2022b)
fi	käsi (‘hand’), kasi (‘eight’)	-	(Perea et al., 2022a)
fr	-	to indicate deletion of an adjacent letter; to provide a pronunciation guide	(Labusch et al., 2023)
hu	hat (‘six’), hát (‘back’)	-	(Siptár and Törkenczy, 2000)
it	dì (‘day’), di (‘preposition’)	to indicate stress	(Colombo and Sulpizio, 2021)
lt	šáuk, (‘shoot’), šaũk, (‘shout’)	-	(Subačius, 2008)
lv	māti (‘mother’), mati (‘hair’)	-	(Bond, 1978)
pl	ząbka (‘tooth’), ‘żabka’ (‘frog’)	to indicate nominative noun or instrumental noun	(Janicki and Herman, 2005)
pt	por (‘by’), pôr (‘to put’)	for nasalization; contraction of two consecutive vowels	(Mateus and d’Andrade, 2000)
ro	în (‘in’), in (‘linen’)	to indicate stress	(Gönczöl, 2020)
sk	väzy (‘ligaments’), vazy (‘vases’)	-	(Hanulíkova and Hamann, 2010)
sl	pes (‘dog’), peš (‘on foot’)	-	(Herrity, 2015)
sv	Fåt (‘received’), rät (‘straight’)	-	(Riad, 2014)

Table A.6: Classification of the function(s) (lexical and/or grammatical) for each European language. For lexical function, we show minimal pairs where an alternation in diacritic changes the meaning to demonstrate that removing diacritic(s) can produce ambiguity. For Lithuania *(lt)*, Polish *(pl), and Swedish (sv)*, we show near minimal pairs. Both minimal pairs and near minimal pairs show that the undiacritized form poses ambiguity as there are more than one form to diacritize it. For grammatical function, we indicate the grammatical role(s) the diacritical system has in the language.

B Implementations of Diacritization Error Rate (DER) and Word Error Rate (WER)

In the field of diacritization system development, two primary methodologies emerge: sequence labeling and sequence-to-sequence modeling (Schlippe et al., 2008; Hamed and Zesch, 2017). In our research, we opt for the latter as our research question 1 (see Section 1 for details) requires the model to be able to perform both diacritization and machine translation tasks. However, employing sequence-to-sequence modeling presents challenges, particularly regarding alignment and potentially unequal input-output lengths (Alqahtani et al., 2019; Abandah and Abdel-Karim, 2020).

Previous studies employing encoder-decoder architectures for Arabic diacritization have leveraged Arabic linguistic rules to compute these metrics (Fadel et al., 2019; Qin et al., 2021; Thompson and Alshehri, 2022). To address the aforementioned issues, Thompson and Alshehri (2022) employ Arabic linguistic rules to constrain the decoder and guide the generation of subsequent tokens. However, the proposed decoding constraints cannot be directly applied, given that (1) the included 55 languages are non-Arabic (2) the potential for multiple diacritics to be attached to a single character in certain languages (see Table A.4).

Despite our comprehensive search, we were unable to locate implementation details for DER and WER in prior works that adopt a sequence-to-sequence approach (Fadel et al., 2019; Qin et al., 2021; Thompson and Alshehri, 2022; Mubarak et al., 2019). Therefore, we have developed our own DER and WER computation methods, as in Algorithms 1 and 2. Our approach adheres to the definitions of DER and WER established by Abandah et al. (2015).

In computing DER, we exclude words that exceed the length of the input sequence, while penalizing characters exceeding the length of a certain word, complying with DER's focus on character-level analysis. By restricting the comparison to characters within each word instead of directly comparing a predicted sequence to a gold standard sequence, we ensure a fairer evaluation. This approach maintains evaluation integrity when predictions align reasonably with the input, and prevents over-pessimistic assessments when deviations occur. Regarding WER, we penalize words surpassing the input sequence's length, reflecting WER's word-level focus.

Algorithm 1 Diacritization Error Rate (DER)

```
Require:
    Golds is a list of n gold standard sequences.
    Preds is a list of n post-processed predicted sequences (See Section 4.4 for details).
incorrect $\leftarrow 0$
correct $\leftarrow 0$
for $i$ in $[0, n-1]$ do
    gold_words $\leftarrow$ Golds[i].split(' ')
    pred_words $\leftarrow$ Preds[i].split(' ')
    for $j$ in $[0$, min(len(pred_words), len(gold_words)) $- 1]$ do
        gold_word $\leftarrow$ gold_words$[j]$
        pred_word $\leftarrow$ pred_words$[j]$
        incorrect $\leftarrow$ incorrect $+$ abs(len(pred_word) $-$ len(gold_word))
        for $k$ in $[0$, min(len(pred_word), len(gold_word)) $- 1]$ do
            if pred_word$[k]$ $==$ gold_word$[k]$ then
                correct $\leftarrow$ correct $+ 1$
            else
                incorrect $\leftarrow$ incorrect $+ 1$
            end if
        end for
    end for
end for
DER $\leftarrow$ incorrect/(incorrect $+$ correct)
```

Algorithm 2 Word Error Rate (WER)

```
Require:
    Golds is a list of n gold standard sequences.
    Preds is a list of n post-processed predicted sequences (See Section 4.4 for details).
incorrect $\leftarrow 0$
correct $\leftarrow 0$
for $i$ in $[0, n-1]$ do
    gold_words $\leftarrow$ Golds[i].split(' ')
    pred_words $\leftarrow$ Preds[i].split(' ')
    incorrect $\leftarrow$ incorrect $+$ abs(len(gold_words) $-$ len(pred_words))
    for $j$ in $[0$, min(len(pred_words), len(gold_words)) $- 1]$ do
        if gold_words$[j]$ $==$ pred_words$[j]$ then
            correct $\leftarrow$ correct $+ 1$
        else
            incorrect $\leftarrow$ incorrect $+ 1$
        end if
    end for
end for
WER $\leftarrow$ incorrect/(incorrect $+$ correct)
```

C Bar Plots

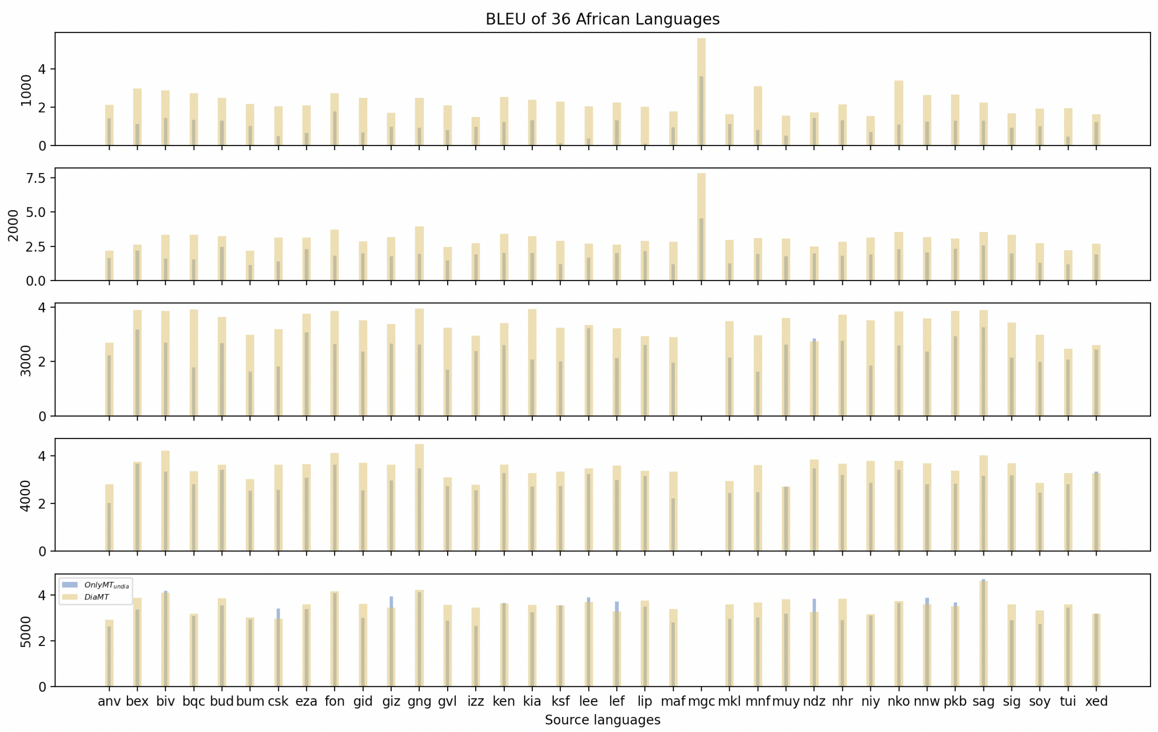

Figure C.1: BLEU comparison between DiaMT and OnlyMT$_{\text{undia}}$ for 36 African languages to English pairs.

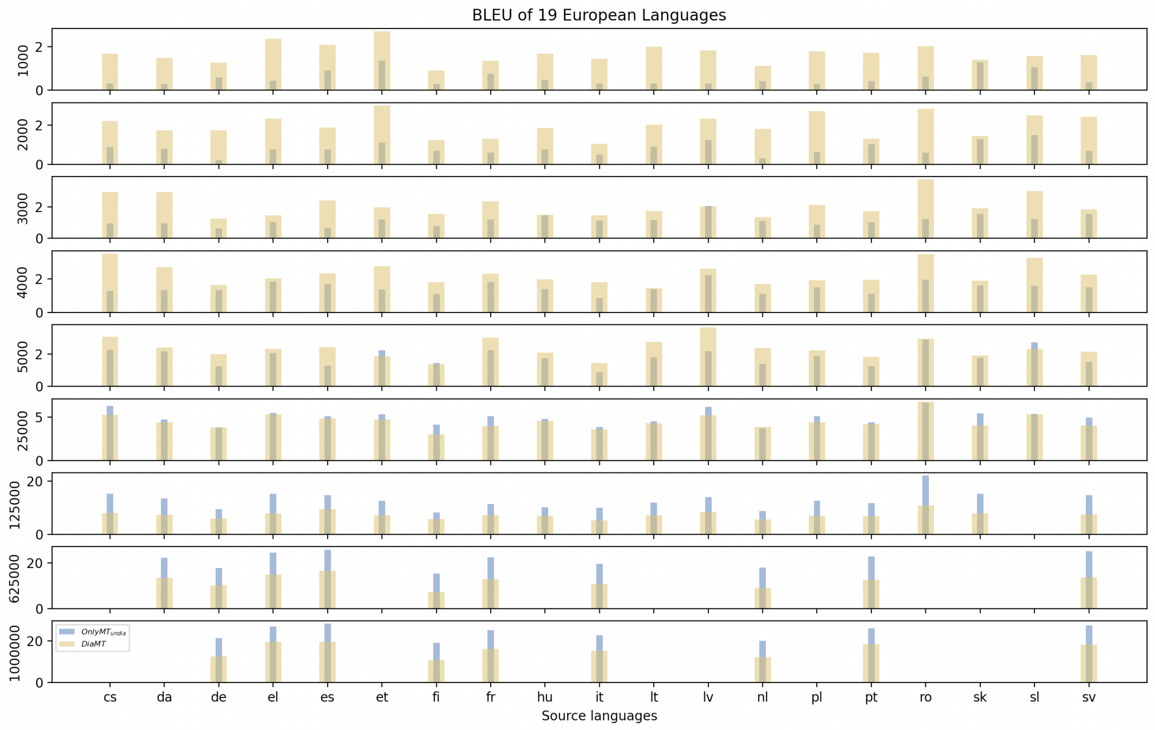

Figure C.2: BLEU comparison between DiaMT and OnlyMT$_{\text{undia}}$ for 19 European languages to English pairs.

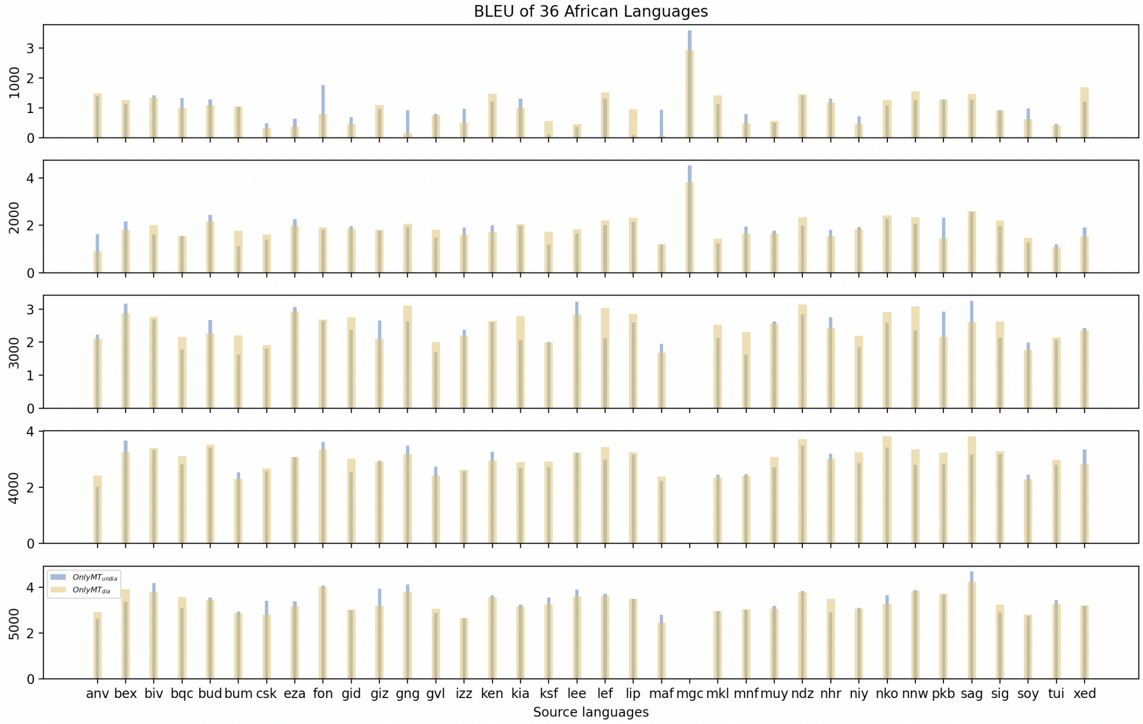

Figure C.3: BLEU comparison between $\text{OnlyMT}_{\text{undia}}$ and $\text{OnlyMT}_{\text{dia}}$ for 36 African languages to English pairs.

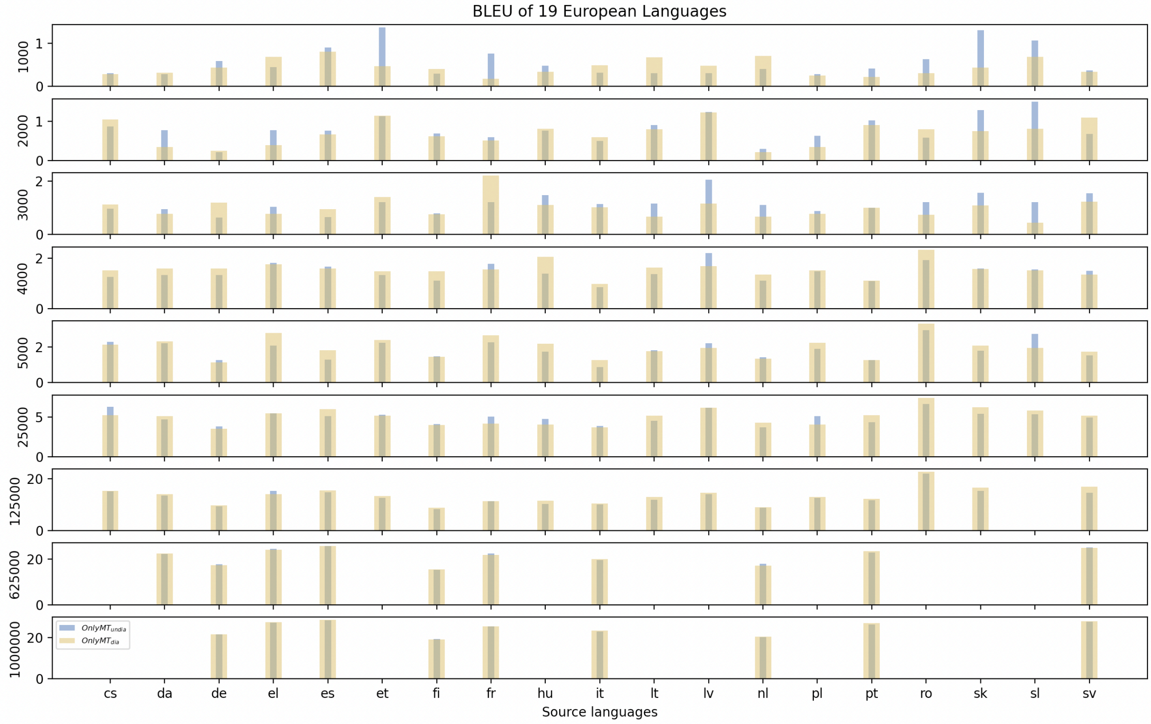

Figure C.4: BLEU comparison between $\text{OnlyMT}_{\text{undia}}$ and $\text{OnlyMT}_{\text{dia}}$ for 19 European languages to English pairs.

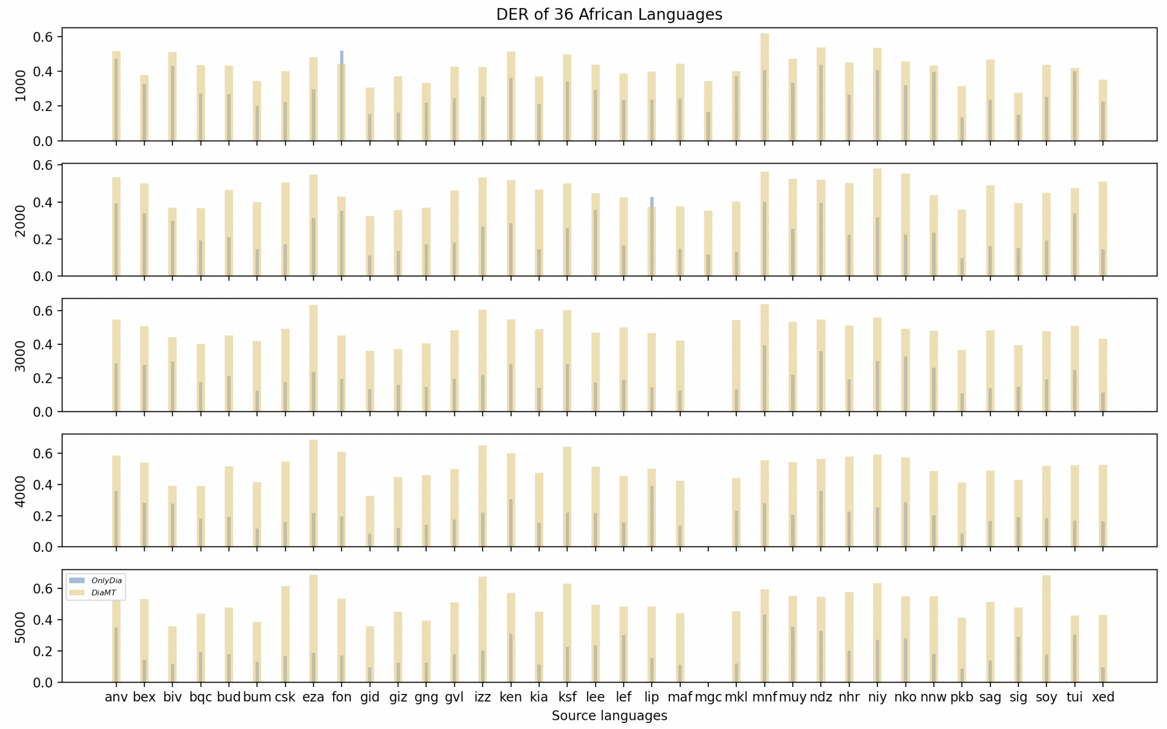

Figure C.5: DER comparison between OnlyDia and DiaMT for 36 African languages.

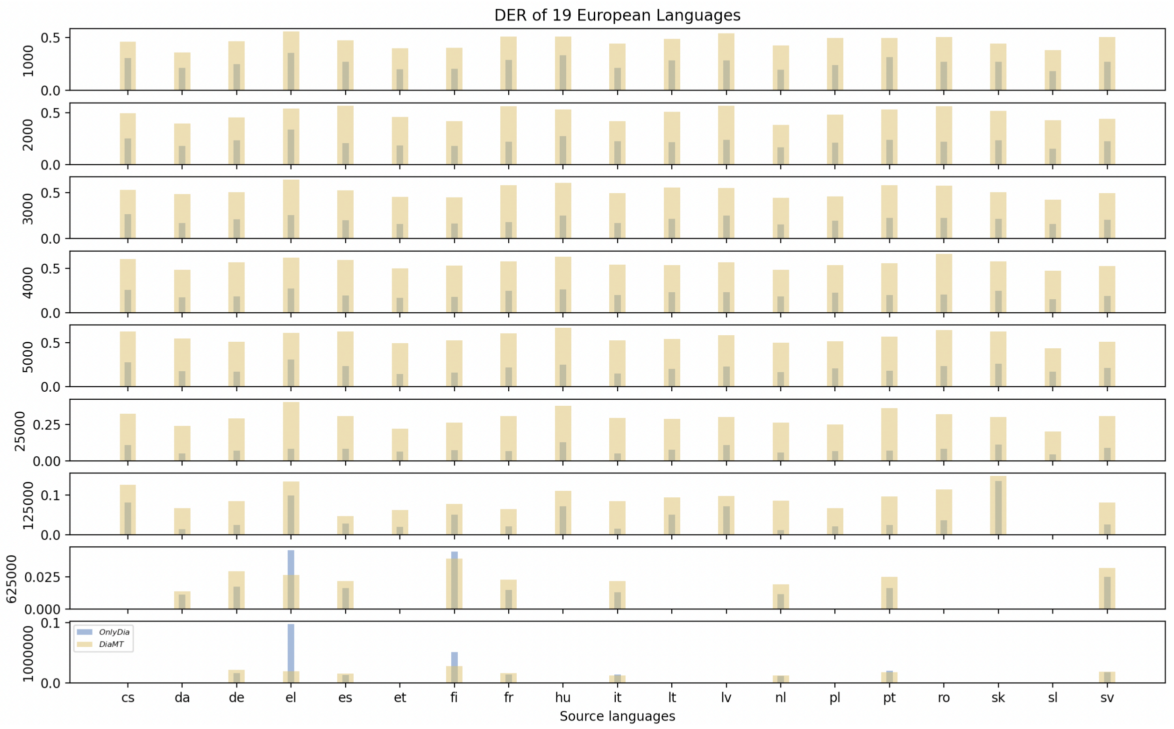

Figure C.6: DER comparison between OnlyDia and DiaMT for 19 European languages. Greek (*el*) and Finnish (*fi*) show significant performance gain after adding MT to form a multi-task setting at 1M train size.

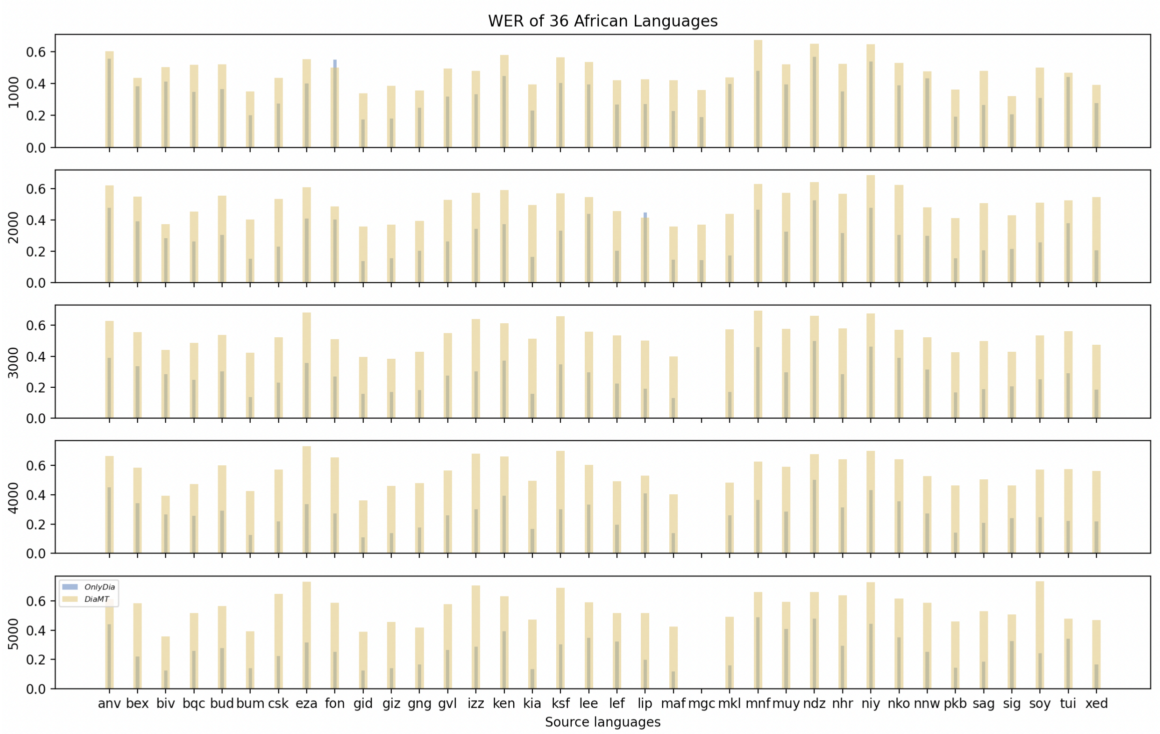

Figure C.7: WER comparison between OnlyDia and DiaMT for 36 African languages.

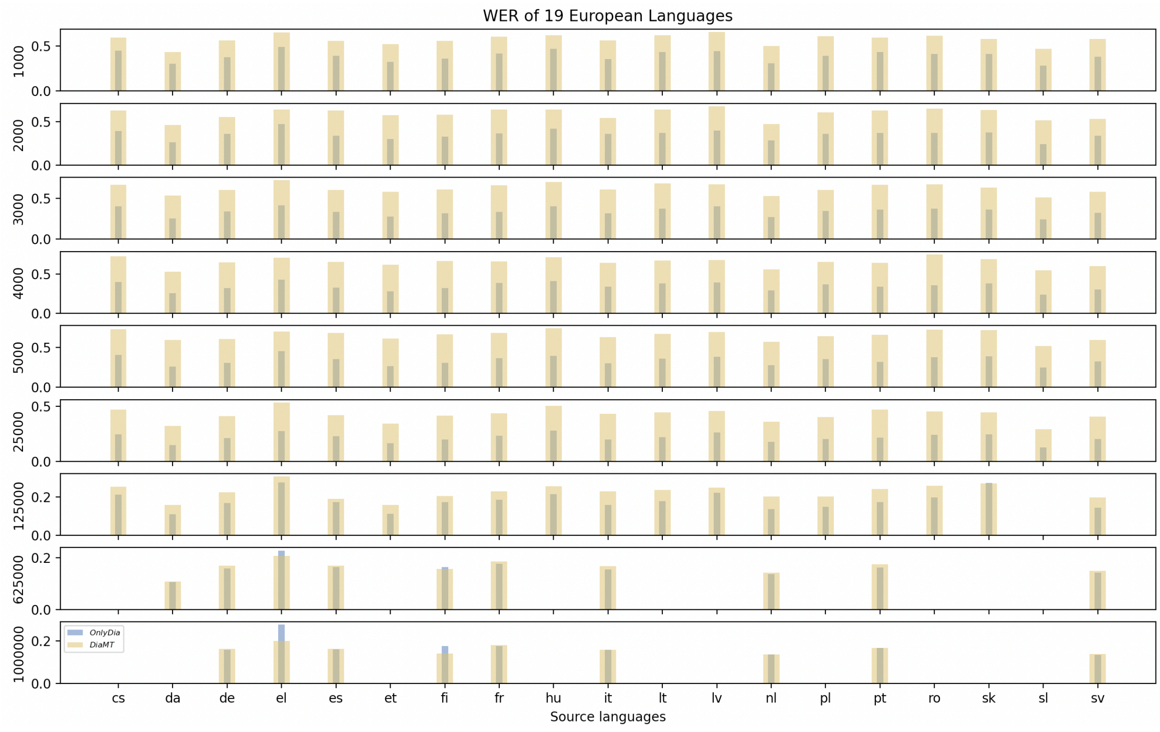

Figure C.8: WER comparison between OnlyDia and DiaMT for 19 European languages. Greek (*el*) and Finnish (*fi*) show significant performance gain after adding MT to form a multi-task setting at 1M train size.

D Performance Metrics

Table D.1: BLEU scores of 36 African languages in 5 train sizes produced by 3 models. The highest BLEU score out of the 3 models are boldfaced. DM, OM$_u$, OM$_d$ are shorthands for DiaMT, OnlyMT$_{undia}$, and OnlyMT$_d$, respectively. pc(m1, m2) is the percentage change of model m1 over model m2. The higher the percentage change, the better the model m1 is compared to model m2.

Size	Lang	DiaMT	OnlyMT$_{undia}$	OnlyMT$_{dia}$	pc(DM, OM$_u$)	pc(OM$_u$, OM$_d$)
1k	bex	**2.971**	1.122	1.263	+164.78%	-11.14%
	fon	**2.729**	1.764	0.799	+54.64%	+120.74%
	mkl	**1.616**	1.119	1.428	+44.42%	-21.63%
	mnf	**3.086**	0.792	0.474	+289.48%	+66.99%
	bud	**2.473**	1.281	1.087	+93.08%	+17.88%
	eza	**2.093**	0.637	0.368	+228.72%	+72.91%
	sig	**1.678**	0.913	0.898	+83.68%	+1.68%
	bqc	**2.725**	1.330	0.994	+104.82%	+33.86%
	kia	**2.376**	1.313	1.002	+81.02%	+30.97%
	soy	**1.919**	0.986	0.626	+94.49%	+57.65%
	nnw	**2.618**	1.242	1.545	+110.73%	-19.61%
	sag	**2.232**	1.273	1.467	+75.38%	-13.26%
	csk	**2.052**	0.486	0.318	+322.05%	+53.06%
	izz	**1.492**	0.963	0.498	+54.91%	+93.40%
	bum	**2.163**	1.027	1.039	+110.68%	-1.17%
	gvl	**2.097**	0.791	0.738	+165.00%	+7.17%
	ndz	**1.724**	1.420	1.451	+21.40%	-2.13%
	lip	**2.027**	0.081	0.944	+2410.38%	-91.45%
	ken	**2.523**	1.216	1.473	+107.39%	-17.40%
	gid	**2.488**	0.678	0.463	+267.12%	+46.41%
	gng	**2.471**	0.918	0.150	+169.12%	+513.48%
	muy	**1.557**	0.494	0.565	+215.51%	-12.72%
	niy	**1.522**	0.708	0.458	+114.99%	+54.57%
	xed	1.619	1.202	**1.692**	+34.71%	-28.96%
	anv	**2.105**	1.397	1.483	+50.68%	-5.82%
	lee	**2.045**	0.351	0.445	+482.62%	-21.08%
	ksf	**2.276**	0.099	0.554	+2197.03%	-82.13%
	pkb	**2.642**	1.279	1.286	+106.59%	-0.59%
	nko	**3.389**	1.083	1.261	+212.90%	-14.06%
	lef	**2.243**	1.314	1.516	+70.76%	-13.32%
	nhr	**2.142**	1.305	1.191	+64.11%	+9.62%
	mgc	**5.619**	3.609	2.948	+55.70%	+22.42%
	biv	**2.861**	1.424	1.338	+100.83%	+6.42%
	maf	**1.780**	0.942	0.058	+89.02%	+1516.17%
	giz	**1.694**	0.960	1.086	+76.35%	-11.56%
	tui	**1.953**	0.465	0.413	+320.20%	+12.41%
2k	bex	**2.639**	2.173	1.820	+21.44%	+19.39%
	fon	**3.713**	1.803	1.918	+105.93%	-5.99%
	mkl	**2.966**	1.248	1.436	+137.68%	-13.13%
	mnf	**3.086**	1.939	1.645	+59.17%	+17.88%
	bud	**3.226**	2.449	2.156	+31.71%	+13.59%
	eza	**3.129**	2.272	1.984	+37.71%	+14.55%
	sig	**3.341**	1.970	2.209	+69.56%	-10.83%
	bqc	**3.344**	1.553	1.561	+115.38%	-0.53%
	kia	**3.251**	1.997	2.041	+62.81%	-2.15%
	soy	**2.733**	1.288	1.472	+112.23%	-12.55%
	nnw	**3.161**	2.058	2.351	+53.58%	-12.46%
	sag	**3.548**	2.568	2.592	+38.13%	-0.90%
	csk	**3.128**	1.392	1.608	+124.68%	-13.41%
	izz	**2.721**	1.914	1.595	+42.16%	+20.01%
	bum	**2.191**	1.123	1.781	+95.19%	-36.96%
	gvl	**2.471**	1.470	1.813	+68.08%	-18.91%
	ndz	**2.490**	1.992	2.340	+25.00%	-14.84%
	lip	**2.903**	2.146	2.319	+35.30%	-7.47%
	ken	**3.408**	2.009	1.707	+69.64%	+17.70%
	gid	**2.857**	1.974	1.868	+44.70%	+5.69%
	gng	**3.953**	1.932	2.073	+104.56%	-6.81%
	muy	**3.074**	1.779	1.657	+72.78%	+7.35%

Continued on next page

Table D.1: BLEU scores of 36 African languages in 5 train sizes produced by 3 models. The highest BLEU score out of the 3 models are boldfaced. DM, OM$_{\mathrm{u}}$, OM$_{\mathrm{d}}$ are shorthands for DiaMT, OnlyMT$_{\mathrm{undia}}$, and OnlyMT$_{\mathrm{d}}$, respectively. pc(m1, m2) is the percentage change of model m1 over model m2. The higher the percentage change, the better the model m1 is compared to model m2.

Size	Lang	DiaMT	OnlyMT$_{\mathrm{undia}}$	OnlyMT$_{\mathrm{dia}}$	pc(DM, OM$_{\mathrm{u}}$)	pc(OM$_{\mathrm{u}}$, OM$_{\mathrm{d}}$)
2k	niy	**3.146**	1.922	1.835	+63.68%	+4.75%
	xed	**2.683**	1.910	1.526	+40.46%	+25.17%
	anv	**2.176**	1.626	0.899	+33.85%	+80.88%
	lee	**2.692**	1.659	1.840	+62.25%	-9.83%
	ksf	**2.882**	1.187	1.723	+142.90%	-31.14%
	pkb	**3.079**	2.321	1.443	+32.64%	+60.83%
	nko	**3.536**	2.284	2.415	+54.82%	-5.43%
	lef	**2.626**	1.999	2.212	+31.36%	-9.62%
	nhr	**2.827**	1.813	1.528	+55.96%	+18.60%
	mgc	**7.822**	4.517	3.818	+73.15%	+18.33%
	biv	**3.348**	1.612	2.006	+107.67%	-19.62%
	maf	**2.819**	1.198	1.199	+135.35%	-0.14%
	giz	**3.153**	1.771	1.811	+78.07%	-2.21%
	tui	**2.220**	1.203	1.088	+84.50%	+10.57%
3k	bex	**3.889**	3.168	2.867	+22.75%	+10.51%
	fon	**3.851**	2.645	2.684	+45.60%	-1.45%
	mkl	**3.478**	2.138	2.529	+62.67%	-15.45%
	mnf	**2.958**	1.627	2.308	+81.87%	-29.54%
	bud	**3.638**	2.669	2.261	+36.32%	+18.04%
	eza	**3.761**	3.065	2.930	+22.73%	+4.59%
	sig	**3.431**	2.136	2.629	+60.60%	-18.76%
	bqc	**3.910**	1.785	2.156	+119.03%	-17.18%
	kia	**3.921**	2.065	2.785	+89.90%	-25.86%
	soy	**2.982**	1.995	1.759	+49.46%	+13.45%
	nnw	**3.582**	2.364	3.074	+51.55%	-23.11%
	sag	**3.900**	3.252	2.614	+19.91%	+24.42%
	csk	**3.181**	1.812	1.906	+75.60%	-4.93%
	izz	**2.949**	2.375	2.192	+24.19%	+8.33%
	bum	**2.985**	1.631	2.204	+83.06%	-26.00%
	gvl	**3.233**	1.691	2.011	+91.22%	-15.94%
	ndz	2.746	2.846	**3.132**	-3.53%	-9.11%
	lip	**2.934**	2.598	2.849	+12.92%	-8.82%
	ken	**3.410**	2.605	2.641	+30.90%	-1.39%
	gid	**3.514**	2.372	2.750	+48.13%	-13.75%
	gng	**3.946**	2.627	3.113	+50.19%	-15.61%
	muy	**3.594**	2.624	2.563	+36.96%	+2.36%
	niy	**3.514**	1.844	2.196	+90.54%	-16.02%
	xed	**2.606**	2.433	2.356	+7.10%	+3.29%
	anv	**2.699**	2.233	2.108	+20.84%	+5.95%
	lee	**3.343**	3.221	2.836	+3.81%	+13.57%
	ksf	**3.247**	2.011	1.997	+61.50%	+0.70%
	pkb	**3.865**	2.923	2.162	+32.23%	+35.23%
	nko	**3.834**	2.592	2.915	+47.90%	-11.07%
	lef	**3.230**	2.124	3.039	+52.07%	-30.11%
	nhr	**3.728**	2.752	2.436	+35.44%	+13.00%
	biv	**3.851**	2.690	2.772	+43.13%	-2.96%
	maf	**2.893**	1.946	1.674	+48.64%	+16.27%
	giz	**3.372**	2.657	2.103	+26.91%	+26.33%
	tui	**2.470**	2.068	2.150	+19.46%	-3.82%
4k	bex	**3.735**	3.668	3.243	+1.83%	+13.10%
	fon	**4.112**	3.615	3.347	+13.75%	+8.03%
	mkl	**2.948**	2.441	2.341	+20.73%	+4.27%
	mnf	**3.598**	2.462	2.418	+46.14%	+1.80%
	bud	**3.626**	3.408	3.510	+6.39%	-2.89%
	eza	**3.648**	3.073	3.080	+18.71%	-0.22%
	sig	**3.686**	3.174	3.273	+16.11%	-3.03%
	bqc	**3.352**	2.806	3.105	+19.46%	-9.61%
	kia	**3.277**	2.702	2.899	+21.27%	-6.79%
	soy	**2.867**	2.444	2.282	+17.32%	+7.09%
	nnw	**3.686**	2.800	3.350	+31.65%	-16.43%
	sag	**4.014**	3.164	3.817	+26.86%	-17.12%

Continued on next page

Table D.1: BLEU scores of 36 African languages in 5 train sizes produced by 3 models. The highest BLEU score out of the 3 models are boldfaced. DM, OM$_{\text{u}}$, OM$_{\text{d}}$ are shorthands for DiaMT, OnlyMT$_{\text{undia}}$, and OnlyMT$_{\text{d}}$, respectively. pc(m1, m2) is the percentage change of model m1 over model m2. The higher the percentage change, the better the model m1 is compared to model m2.

Size	Lang	DiaMT	OnlyMT$_{\text{undia}}$	OnlyMT$_{\text{dia}}$	pc(DM, OM$_{\text{u}}$)	pc(OM$_{\text{u}}$, OM$_{\text{d}}$)
4k	csk	**3.625**	2.565	2.670	+41.29%	-3.92%
	izz	**2.784**	2.559	2.611	+8.79%	-2.00%
	bum	**3.012**	2.528	2.305	+19.13%	+9.70%
	gvl	**3.105**	2.727	2.422	+13.86%	+12.59%
	ndz	**3.850**	3.478	3.718	+10.68%	-6.44%
	lip	**3.377**	3.165	3.243	+6.68%	-2.39%
	ken	**3.631**	3.265	2.944	+11.20%	+10.92%
	gid	**3.696**	2.547	3.012	+45.10%	-15.43%
	gng	**4.494**	3.472	3.172	+29.46%	+9.45%
	muy	2.711	2.705	**3.080**	+0.20%	-12.17%
	niy	**3.782**	2.865	3.240	+31.99%	-11.56%
	xed	3.266	**3.338**	2.818	-2.14%	+18.46%
	anv	**2.805**	2.016	2.413	+39.09%	-16.43%
	lee	**3.471**	3.232	3.224	+7.39%	+0.25%
	ksf	**3.322**	2.719	2.905	+22.16%	-6.40%
	pkb	**3.380**	2.832	3.221	+19.34%	-12.07%
	nko	3.786	3.414	**3.809**	+10.89%	-10.36%
	lef	**3.579**	2.982	3.431	+20.03%	-13.09%
	nhr	**3.665**	3.201	3.017	+14.47%	+6.10%
	biv	**4.219**	3.331	3.394	+26.66%	-1.86%
	maf	**3.332**	2.222	2.375	+49.93%	-6.42%
	giz	**3.624**	2.954	2.915	+22.70%	+1.31%
	tui	**3.264**	2.799	2.983	+16.63%	-6.18%
5k	bex	3.883	3.368	**3.914**	+15.30%	-13.97%
	fon	**4.163**	4.080	4.013	+2.04%	+1.67%
	mkl	**3.578**	2.955	2.955	+21.10%	-0.01%
	mnf	**3.670**	3.012	3.035	+21.82%	-0.74%
	bud	**3.842**	3.554	3.437	+8.10%	+3.42%
	eza	**3.584**	3.393	3.190	+5.65%	+6.37%
	sig	**3.589**	2.898	3.247	+23.85%	-10.74%
	bqc	3.176	3.073	**3.575**	+3.36%	-14.05%
	kia	**3.560**	3.235	3.158	+10.07%	+2.42%
	soy	**3.323**	2.737	2.807	+21.38%	-2.47%
	nnw	3.582	**3.864**	3.842	-7.30%	+0.58%
	sag	4.615	**4.685**	4.240	-1.48%	+10.48%
	csk	2.962	**3.408**	2.784	-13.09%	+22.43%
	izz	**3.443**	2.645	2.647	+30.20%	-0.08%
	bum	**3.020**	2.929	2.882	+3.09%	+1.63%
	gvl	**3.573**	2.877	3.048	+24.21%	-5.61%
	ndz	3.253	**3.829**	3.778	-15.06%	+1.35%
	lip	**3.756**	3.477	3.490	+8.02%	-0.37%
	ken	3.628	**3.645**	3.558	-0.46%	+2.44%
	gid	**3.604**	3.004	3.011	+19.97%	-0.24%
	gng	**4.214**	4.126	3.801	+2.12%	+8.55%
	muy	**3.803**	3.172	3.058	+19.89%	+3.73%
	niy	**3.159**	3.094	3.050	+2.11%	+1.45%
	xed	3.173	3.189	**3.191**	-0.48%	-0.09%
	anv	**2.921**	2.639	2.908	+10.67%	-9.23%
	lee	3.698	**3.900**	3.577	-5.18%	+9.02%
	ksf	**3.553**	3.542	3.237	+0.30%	+9.44%
	pkb	3.510	3.678	**3.712**	-4.57%	-0.92%
	nko	**3.730**	3.650	3.258	+2.20%	+12.03%
	lef	3.280	**3.714**	3.633	-11.68%	+2.21%
	nhr	**3.839**	2.898	3.477	+32.50%	-16.66%
	biv	4.087	**4.185**	3.762	-2.33%	+11.25%
	maf	**3.379**	2.798	2.448	+20.78%	+14.30%
	giz	3.447	**3.936**	3.190	-12.44%	+23.41%
	tui	**3.597**	3.445	3.257	+4.41%	+5.75%

Table D.2: BLEU scores of 19 European languages in 9 train sizes produced by 3 models. The highest BLEU score out of the 3 models are boldfaced. DM, OM$_u$, OM$_d$ are shorthands for DiaMT, OnlyMT$_{undia}$, and OnlyMT$_d$, respectively. pc(m1, m2) is the percentage change of model m1 over model m2. The higher the percentage change, the better the model m1 is compared to model m2.

Size	Lang	DiaMT	OnlyMT$_{undia}$	OnlyMT$_{dia}$	pc(DM, OM$_u$)	pc(OM$_u$, OM$_d$)
1k	el	**2.363**	0.443	0.683	+433.32%	-35.10%
	cs	**1.685**	0.304	0.282	+453.47%	+7.85%
	da	**1.480**	0.279	0.318	+429.91%	-12.26%
	de	**1.272**	0.584	0.436	+117.95%	+33.77%
	es	**2.079**	0.904	0.808	+129.96%	+11.91%
	et	**2.701**	1.365	0.470	+97.83%	+190.56%
	fi	**0.908**	0.294	0.405	+208.70%	-27.31%
	fr	**1.367**	0.761	0.177	+79.69%	+330.52%
	hu	**1.684**	0.478	0.341	+252.32%	+40.03%
	it	**1.441**	0.315	0.491	+357.47%	-35.82%
	lt	**2.007**	0.302	0.675	+564.34%	-55.26%
	lv	**1.833**	0.301	0.484	+509.02%	-37.86%
	nl	**1.129**	0.403	0.706	+179.83%	-42.85%
	pl	**1.791**	0.288	0.256	+521.32%	+12.72%
	pt	**1.719**	0.410	0.215	+318.96%	+90.39%
	ro	**2.034**	0.633	0.308	+221.43%	+105.44%
	sk	**1.390**	1.302	0.439	+6.81%	+196.26%
	sl	**1.580**	1.061	0.686	+48.81%	+54.71%
	sv	**1.626**	0.369	0.334	+340.11%	+10.63%
2k	el	**2.336**	0.772	0.385	+202.46%	+100.61%
	cs	**2.230**	0.870	1.045	+156.25%	-16.74%
	da	**1.738**	0.776	0.347	+124.02%	+123.31%
	de	**1.739**	0.214	0.252	+710.98%	-14.76%
	es	**1.893**	0.759	0.670	+149.27%	+13.32%
	et	**3.018**	1.126	1.142	+168.07%	-1.42%
	fi	**1.232**	0.691	0.623	+78.33%	+10.91%
	fr	**1.312**	0.598	0.510	+119.45%	+17.25%
	hu	**1.856**	0.766	0.808	+142.24%	-5.24%
	it	**1.037**	0.494	0.589	+109.96%	-16.19%
	lt	**2.032**	0.906	0.801	+124.16%	+13.20%
	lv	**2.339**	1.241	1.223	+88.42%	+1.47%
	nl	**1.823**	0.299	0.206	+508.54%	+45.24%
	pl	**2.734**	0.632	0.342	+332.61%	+84.81%
	pt	**1.314**	1.021	0.909	+28.76%	+12.23%
	ro	**2.842**	0.582	0.798	+388.02%	-27.02%
	sk	**1.463**	1.289	0.747	+13.44%	+72.51%
	sl	**2.514**	1.502	0.805	+67.35%	+86.69%
	sv	**2.440**	0.680	1.096	+258.96%	-38.00%
3k	el	**1.470**	1.029	0.770	+42.81%	+33.63%
	cs	**2.949**	0.962	1.113	+206.45%	-13.59%
	da	**2.925**	0.946	0.766	+209.32%	+23.46%
	de	**1.237**	0.633	1.195	+95.38%	-46.98%
	es	**2.395**	0.647	0.943	+270.33%	-31.43%
	et	**1.974**	1.203	1.407	+64.08%	-14.51%
	fi	**1.543**	0.780	0.756	+97.81%	+3.23%
	fr	**2.343**	1.202	2.195	+94.87%	-45.22%
	hu	**1.484**	1.464	1.102	+1.36%	+32.87%
	it	**1.463**	1.129	1.009	+29.58%	+11.95%
	lt	**1.727**	1.162	0.661	+48.57%	+75.90%
	lv	2.023	**2.046**	1.147	-1.09%	+78.41%
	nl	**1.351**	1.099	0.674	+22.91%	+63.07%
	pl	**2.120**	0.875	0.762	+142.25%	+14.77%
	pt	**1.715**	1.000	1.006	+71.51%	-0.59%
	ro	**3.727**	1.208	0.743	+208.47%	+62.64%
	sk	**1.888**	1.559	1.093	+21.11%	+42.61%
	sl	**2.998**	1.208	0.441	+148.10%	+174.28%
	sv	**1.837**	1.542	1.224	+19.08%	+26.06%
4k	el	**2.021**	1.814	1.772	+11.39%	+2.35%
	cs	**3.496**	1.266	1.515	+176.28%	-16.45%
	da	**2.694**	1.336	1.601	+101.60%	-16.55%

Continued on next page

Table D.2: BLEU scores of 19 European languages in 9 train sizes produced by 3 models. The highest BLEU score out of the 3 models are boldfaced. DM, OM_u, OM_d are shorthands for DiaMT, $\text{OnlyMT}_\text{undia}$, and OnlyMT_d, respectively. pc(m1, m2) is the percentage change of model m1 over model m2. The higher the percentage change, the better the model m1 is compared to model m2.

Size	Lang	DiaMT	$\text{OnlyMT}_\text{undia}$	OnlyMT_dia	pc(DM, OM_u)	pc(OM_u, OM_d)
4k	de	**1.631**	1.338	1.602	+21.97%	-16.48%
	es	**2.314**	1.677	1.600	+38.00%	+4.82%
	et	**2.753**	1.340	1.488	+105.36%	-9.90%
	fi	**1.799**	1.114	1.482	+61.48%	-24.81%
	fr	**2.302**	1.790	1.557	+28.61%	+14.98%
	hu	1.970	1.387	**2.065**	+42.04%	-32.83%
	it	**1.811**	0.856	0.979	+111.52%	-12.57%
	lt	1.447	1.379	**1.637**	+4.98%	-15.79%
	lv	**2.597**	2.206	1.693	+17.72%	+30.31%
	nl	**1.697**	1.115	1.356	+52.23%	-17.81%
	pl	**1.902**	1.490	1.523	+27.64%	-2.15%
	pt	**1.937**	1.103	1.122	+75.65%	-1.73%
	ro	**3.470**	1.935	2.346	+79.36%	-17.53%
	sk	**1.880**	1.590	1.577	+18.18%	+0.87%
	sl	**3.235**	1.564	1.517	+106.86%	+3.08%
	sv	**2.240**	1.503	1.348	+49.03%	+11.47%
5k	el	2.321	2.076	**2.761**	+11.81%	-24.83%
	cs	**3.079**	2.281	2.131	+35.01%	+7.01%
	da	**2.428**	2.188	2.305	+10.99%	-5.09%
	de	**2.016**	1.247	1.126	+61.74%	+10.68%
	es	**2.442**	1.288	1.802	+89.62%	-28.53%
	et	1.862	2.234	**2.386**	-16.61%	-6.39%
	fi	1.370	**1.473**	1.452	-6.98%	+1.48%
	fr	**3.024**	2.259	2.648	+33.85%	-14.68%
	hu	2.086	1.738	**2.173**	+20.02%	-19.99%
	it	**1.450**	0.864	1.251	+67.85%	-30.90%
	lt	**2.762**	1.801	1.764	+53.39%	+2.10%
	lv	**3.662**	2.189	1.940	+67.25%	+12.88%
	nl	**2.396**	1.402	1.347	+70.89%	+4.04%
	pl	**2.259**	1.889	2.228	+19.60%	-15.22%
	pt	**1.851**	1.250	1.268	+48.06%	-1.37%
	ro	2.977	2.916	**3.285**	+2.08%	-11.23%
	sk	1.932	1.792	**2.068**	+7.85%	-13.38%
	sl	2.332	**2.730**	1.933	-14.57%	+41.24%
	sv	**2.160**	1.516	1.717	+42.50%	-11.71%
25k	el	5.316	**5.485**	5.451	-3.07%	+0.62%
	cs	5.226	**6.278**	5.230	-16.76%	+20.05%
	da	4.395	4.707	**5.110**	-6.63%	-7.89%
	de	3.799	**3.816**	3.505	-0.46%	+8.87%
	es	4.839	5.105	**6.021**	-5.21%	-15.22%
	et	4.720	**5.312**	5.179	-11.15%	+2.58%
	fi	3.012	**4.118**	3.967	-26.86%	+3.82%
	fr	3.952	**5.073**	4.160	-22.10%	+21.93%
	hu	4.555	**4.766**	4.022	-4.42%	+18.51%
	it	3.609	**3.846**	3.679	-6.16%	+4.53%
	lt	4.304	4.509	**5.139**	-4.54%	-12.26%
	lv	5.187	**6.161**	6.153	-15.81%	+0.13%
	nl	3.865	3.705	**4.255**	+4.29%	-12.92%
	pl	4.373	**5.091**	4.026	-14.10%	+26.44%
	pt	4.168	4.371	**5.218**	-4.66%	-16.23%
	ro	6.768	6.662	**7.420**	+1.59%	-10.22%
	sk	4.002	5.404	**6.231**	-25.95%	-13.26%
	sl	5.318	5.370	**5.800**	-0.97%	-7.42%
	sv	4.020	4.910	**5.178**	-18.14%	-5.17%
125k	el	7.959	**15.371**	14.007	-48.22%	+9.74%
	cs	8.162	15.207	**15.404**	-46.33%	-1.28%
	da	7.458	13.531	**14.038**	-44.88%	-3.61%
	de	6.014	9.442	**9.753**	-36.30%	-3.18%
	es	9.406	14.811	**15.585**	-36.50%	-4.96%
	et	7.225	12.657	**13.286**	-42.92%	-4.74%

Continued on next page

Table D.2: BLEU scores of 19 European languages in 9 train sizes produced by 3 models. The highest BLEU score out of the 3 models are boldfaced. DM, OM$_{\mathrm{u}}$, OM$_{\mathrm{d}}$ are shorthands for DiaMT, OnlyMT$_{\mathrm{undia}}$, and OnlyMT$_{\mathrm{d}}$, respectively. pc(m1, m2) is the percentage change of model m1 over model m2. The higher the percentage change, the better the model m1 is compared to model m2.

Size	Lang	DiaMT	OnlyMT$_{\mathrm{undia}}$	OnlyMT$_{\mathrm{dia}}$	pc(DM, OM$_{\mathrm{u}}$)	pc(OM$_{\mathrm{u}}$, OM$_{\mathrm{d}}$)
125k	fi	5.727	8.256	**8.826**	-30.63%	-6.46%
	fr	7.285	11.421	**11.451**	-36.21%	-0.26%
	hu	6.950	10.277	**11.469**	-32.38%	-10.39%
	it	5.200	10.023	**10.491**	-48.12%	-4.46%
	lt	7.228	11.913	**13.014**	-39.32%	-8.47%
	lv	8.407	14.056	**14.562**	-40.19%	-3.48%
	nl	5.547	8.862	**8.952**	-37.41%	-1.00%
	pl	6.989	12.667	**13.074**	-44.82%	-3.12%
	pt	6.893	11.786	**12.211**	-41.51%	-3.49%
	ro	10.953	22.082	**22.668**	-50.40%	-2.59%
	sk	7.961	15.309	**16.546**	-48.00%	-7.48%
	sv	7.500	14.692	**17.036**	-48.96%	-13.76%
625k	el	14.839	**24.398**	24.057	-39.18%	+1.42%
	da	13.473	22.328	**22.442**	-39.66%	-0.51%
	de	10.130	**17.755**	17.312	-42.95%	+2.56%
	es	16.397	**25.758**	25.753	-36.34%	+0.02%
	fi	7.315	15.329	**15.389**	-52.28%	-0.39%
	fr	12.707	**22.489**	21.858	-43.50%	+2.89%
	it	10.834	19.566	**20.046**	-44.63%	-2.39%
	nl	9.007	**18.030**	17.105	-50.05%	+5.41%
	pt	12.621	22.844	**23.526**	-44.75%	-2.90%
	sv	13.529	**25.070**	24.967	-46.03%	+0.41%
1M	el	19.648	27.089	**27.475**	-27.47%	-1.40%
	de	12.562	21.479	**21.566**	-41.52%	-0.40%
	es	19.741	28.380	**28.442**	-30.44%	-0.22%
	fi	10.747	**19.230**	18.995	-44.11%	+1.24%
	fr	16.156	25.248	**25.289**	-36.01%	-0.16%
	it	15.239	22.771	**23.383**	-33.08%	-2.62%
	nl	12.163	20.052	**20.449**	-39.34%	-1.94%
	pt	18.431	26.172	**26.987**	-29.58%	-3.02%
	sv	18.346	27.500	**27.839**	-33.29%	-1.22%

Table D.3: DER and WER of 36 African languages in 5 train sizes produced by 2 models. The lowest DER and WER scores out of the 2 models are boldfaced. DM$_{\text{D}}$, OD$_{\text{D}}$, DM$_{\text{W}}$, OD$_{\text{W}}$ are shorthands for DiaMT$_{\text{DER}}$, OnlyDia$_{\text{DER}}$, DiaMT$_{\text{WER}}$, and OnlyDia$_{\text{WER}}$, respectively. pc(m1, m2) is the percentage change of model m1 over model m2. The lower the percentage change, the better the model m1 is compared to model m2.

Size	Lang	DiaMT$_{\text{DER}}$	OnlyDia$_{\text{DER}}$	pc(DM$_{\text{D}}$,OD$_{\text{D}}$)	DiaMT$_{\text{WER}}$	OnlyDia$_{\text{WER}}$	pc(DM$_{\text{W}}$,OD$_{\text{W}}$)
1k	bex	0.379	**0.329**	+15.29%	0.435	**0.384**	+13.50%
	fon	**0.443**	0.520	-14.68%	**0.502**	0.552	-9.04%
	mkl	0.400	**0.372**	+7.62%	0.439	**0.399**	+9.94%
	mnf	0.620	**0.408**	+52.01%	0.676	**0.480**	+40.70%
	bud	0.434	**0.269**	+61.53%	0.521	**0.366**	+42.42%
	eza	0.482	**0.297**	+62.42%	0.554	**0.400**	+38.31%
	sig	0.277	**0.151**	+84.13%	0.323	**0.209**	+54.98%
	bqc	0.437	**0.272**	+60.75%	0.519	**0.348**	+48.91%
	kia	0.370	**0.213**	+73.75%	0.397	**0.231**	+71.64%
	soy	0.440	**0.253**	+74.00%	0.502	**0.312**	+61.13%
	nnw	0.434	**0.394**	+9.96%	0.478	**0.435**	+9.88%
	sag	0.469	**0.236**	+98.85%	0.482	**0.267**	+80.47%
	csk	0.401	**0.224**	+79.51%	0.437	**0.275**	+58.56%
	izz	0.425	**0.254**	+67.46%	0.480	**0.335**	+43.32%
	bum	0.344	**0.200**	+71.93%	0.351	**0.202**	+73.79%
	gvl	0.429	**0.244**	+75.58%	0.495	**0.320**	+54.58%
	ndz	0.540	**0.439**	+22.95%	0.651	**0.568**	+14.59%
	lip	0.398	**0.235**	+69.50%	0.429	**0.272**	+57.49%
	ken	0.514	**0.364**	+41.32%	0.581	**0.447**	+29.97%
	gid	0.306	**0.151**	+102.02%	0.340	**0.176**	+92.81%
	gng	0.334	**0.219**	+52.17%	0.357	**0.247**	+44.33%
	muy	0.475	**0.333**	+42.52%	0.521	**0.395**	+31.86%
	niy	0.535	**0.407**	+31.58%	0.648	**0.539**	+20.31%
	xed	0.351	**0.225**	+55.99%	0.392	**0.278**	+40.93%
	anv	0.517	**0.474**	+9.02%	0.603	**0.556**	+8.38%
	lee	0.440	**0.293**	+50.13%	0.536	**0.395**	+35.58%
	ksf	0.498	**0.341**	+45.93%	0.565	**0.404**	+40.11%
	pkb	0.315	**0.134**	+136.14%	0.365	**0.193**	+88.97%
	nko	0.458	**0.321**	+43.02%	0.532	**0.389**	+36.78%
	lef	0.387	**0.233**	+66.13%	0.421	**0.269**	+56.92%
	nhr	0.451	**0.265**	+70.47%	0.526	**0.351**	+49.80%
	mgc	0.344	**0.166**	+107.35%	0.360	**0.189**	+89.88%
	biv	0.510	**0.431**	+18.33%	0.504	**0.413**	+21.98%
	maf	0.444	**0.240**	+84.47%	0.422	**0.229**	+84.04%
	giz	0.371	**0.162**	+128.91%	0.386	**0.180**	+114.35%
	tui	0.419	**0.400**	+4.61%	0.468	**0.443**	+5.64%
2k	bex	0.500	**0.337**	+48.33%	0.548	**0.389**	+40.86%
	fon	0.429	**0.353**	+21.47%	0.487	**0.403**	+20.64%
	mkl	0.401	**0.133**	+202.72%	0.439	**0.172**	+155.29%
	mnf	0.563	**0.399**	+41.21%	0.628	**0.465**	+35.10%
	bud	0.465	**0.210**	+121.69%	0.554	**0.305**	+81.52%
	eza	0.548	**0.313**	+75.48%	0.608	**0.410**	+48.38%
	sig	0.394	**0.152**	+158.50%	0.430	**0.213**	+101.45%
	bqc	0.367	**0.191**	+91.97%	0.452	**0.263**	+71.79%
	kia	0.468	**0.143**	+227.17%	0.493	**0.164**	+200.68%
	soy	0.449	**0.193**	+132.57%	0.510	**0.256**	+99.45%
	nnw	0.437	**0.234**	+86.59%	0.479	**0.297**	+61.43%
	sag	0.491	**0.162**	+202.25%	0.507	**0.206**	+145.70%
	csk	0.506	**0.173**	+193.14%	0.533	**0.230**	+131.88%
	izz	0.533	**0.268**	+99.16%	0.571	**0.341**	+67.15%
	bum	0.400	**0.144**	+178.16%	0.402	**0.152**	+165.09%
	gvl	0.462	**0.182**	+154.05%	0.528	**0.262**	+101.08%
	ndz	0.521	**0.393**	+32.40%	0.639	**0.526**	+21.63%
	lip	**0.375**	0.427	-12.20%	**0.414**	0.446	-7.33%
	ken	0.518	**0.286**	+81.07%	0.590	**0.373**	+58.15%
	gid	0.324	**0.111**	+190.70%	0.357	**0.136**	+162.53%
	gng	0.370	**0.173**	+113.68%	0.393	**0.204**	+92.19%
	muy	0.525	**0.256**	+105.50%	0.572	**0.326**	+75.63%
	niy	0.580	**0.317**	+83.29%	0.684	**0.476**	+43.90%
	xed	0.511	**0.144**	+255.18%	0.546	**0.207**	+163.58%

Continued on next page

Table D.3: DER and WER of 36 African languages in 5 train sizes produced by 2 models. The lowest DER and WER scores out of the 2 models are boldfaced. DM$_{\text{D}}$, OD$_{\text{D}}$, DM$_{\text{W}}$, OD$_{\text{W}}$ are shorthands for DiaMT$_{\text{DER}}$, OnlyDia$_{\text{DER}}$, DiaMT$_{\text{WER}}$, and OnlyDia$_{\text{WER}}$, respectively. pc(m1, m2) is the percentage change of model m1 over model m2. The lower the percentage change, the better the model m1 is compared to model m2.

Size	Lang	DiaMT$_{\text{DER}}$	OnlyDia$_{\text{DER}}$	pc(DM$_{\text{D}}$,OD$_{\text{D}}$)	DiaMT$_{\text{WER}}$	OnlyDia$_{\text{WER}}$	pc(DM$_{\text{W}}$,OD$_{\text{W}}$)
2k	anv	0.534	**0.392**	+36.11%	0.619	**0.478**	+29.62%
	lee	0.446	**0.356**	+25.50%	0.546	**0.438**	+24.54%
	ksf	0.500	**0.260**	+92.45%	0.568	**0.332**	+71.27%
	pkb	0.359	**0.097**	+270.73%	0.411	**0.155**	+165.69%
	nko	0.554	**0.224**	+146.96%	0.622	**0.303**	+105.05%
	lef	0.424	**0.164**	+157.92%	0.457	**0.204**	+124.29%
	nhr	0.502	**0.222**	+125.87%	0.566	**0.317**	+78.39%
	mgc	0.355	**0.116**	+207.01%	0.371	**0.143**	+159.39%
	biv	0.369	**0.298**	+23.91%	0.373	**0.284**	+31.40%
	maf	0.377	**0.146**	+158.81%	0.358	**0.147**	+143.98%
	giz	0.355	**0.137**	+158.46%	0.371	**0.155**	+139.60%
	tui	0.475	**0.337**	+40.79%	0.525	**0.377**	+39.12%
3k	bex	0.509	**0.277**	+83.48%	0.556	**0.335**	+66.17%
	fon	0.453	**0.193**	+134.66%	0.511	**0.269**	+89.80%
	mkl	0.543	**0.129**	+320.15%	0.574	**0.169**	+239.95%
	mnf	0.639	**0.394**	+62.40%	0.695	**0.459**	+51.63%
	bud	0.451	**0.210**	+115.08%	0.538	**0.303**	+77.42%
	eza	0.633	**0.237**	+167.05%	0.682	**0.356**	+91.66%
	sig	0.395	**0.146**	+170.11%	0.428	**0.205**	+109.43%
	bqc	0.404	**0.173**	+132.87%	0.486	**0.246**	+97.71%
	kia	0.489	**0.140**	+249.77%	0.514	**0.155**	+230.41%
	soy	0.477	**0.190**	+151.06%	0.535	**0.250**	+114.28%
	nnw	0.480	**0.259**	+84.93%	0.522	**0.315**	+65.83%
	sag	0.484	**0.139**	+247.13%	0.497	**0.186**	+166.73%
	csk	0.490	**0.174**	+181.82%	0.522	**0.228**	+128.87%
	izz	0.604	**0.217**	+177.87%	0.640	**0.301**	+112.81%
	bum	0.419	**0.126**	+233.42%	0.424	**0.134**	+216.14%
	gvl	0.482	**0.194**	+149.05%	0.549	**0.276**	+98.96%
	ndz	0.548	**0.359**	+52.79%	0.662	**0.499**	+32.61%
	lip	0.466	**0.144**	+222.73%	0.501	**0.191**	+162.68%
	ken	0.547	**0.283**	+93.58%	0.613	**0.372**	+64.88%
	gid	0.360	**0.133**	+170.86%	0.395	**0.157**	+151.61%
	gng	0.406	**0.148**	+174.73%	0.430	**0.182**	+136.78%
	muy	0.533	**0.219**	+143.12%	0.577	**0.296**	+94.89%
	niy	0.557	**0.299**	+86.51%	0.676	**0.463**	+46.05%
	xed	0.434	**0.115**	+278.74%	0.474	**0.184**	+157.66%
	anv	0.547	**0.286**	+91.41%	0.630	**0.389**	+61.77%
	lee	0.469	**0.172**	+173.21%	0.560	**0.295**	+89.73%
	ksf	0.602	**0.283**	+112.98%	0.660	**0.348**	+89.72%
	pkb	0.367	**0.108**	+240.02%	0.425	**0.166**	+156.50%
	nko	0.492	**0.328**	+50.11%	0.570	**0.391**	+45.87%
	lef	0.501	**0.187**	+167.64%	0.534	**0.223**	+138.86%
	nhr	0.512	**0.190**	+169.21%	0.581	**0.284**	+104.41%
	biv	0.443	**0.296**	+49.73%	0.441	**0.283**	+55.92%
	maf	0.422	**0.125**	+238.63%	0.399	**0.130**	+206.54%
	giz	0.373	**0.159**	+134.82%	0.383	**0.168**	+128.71%
	tui	0.509	**0.246**	+107.13%	0.562	**0.291**	+93.25%
4k	bex	0.541	**0.283**	+90.91%	0.586	**0.341**	+72.00%
	fon	0.608	**0.195**	+212.10%	0.653	**0.271**	+141.44%
	mkl	0.440	**0.231**	+90.63%	0.481	**0.260**	+84.86%
	mnf	0.556	**0.278**	+99.72%	0.627	**0.365**	+71.78%
	bud	0.516	**0.193**	+167.13%	0.599	**0.291**	+105.50%
	eza	0.688	**0.217**	+217.17%	0.732	**0.337**	+117.22%
	sig	0.428	**0.189**	+126.06%	0.462	**0.241**	+91.87%
	bqc	0.391	**0.182**	+114.58%	0.472	**0.255**	+85.16%
	kia	0.474	**0.152**	+211.11%	0.496	**0.168**	+195.58%
	soy	0.518	**0.184**	+181.13%	0.571	**0.246**	+132.02%
	nnw	0.486	**0.203**	+139.40%	0.527	**0.273**	+93.32%
	sag	0.488	**0.167**	+192.92%	0.505	**0.207**	+143.79%
	csk	0.545	**0.160**	+241.34%	0.571	**0.217**	+163.93%
	izz	0.650	**0.220**	+195.77%	0.681	**0.302**	+125.71%

Continued on next page

Table D.3: DER and WER of 36 African languages in 5 train sizes produced by 2 models. The lowest DER and WER scores out of the 2 models are boldfaced. DM$_{\text{D}}$, OD$_{\text{D}}$, DM$_{\text{W}}$, OD$_{\text{W}}$ are shorthands for DiaMT$_{\text{DER}}$, OnlyDia$_{\text{DER}}$, DiaMT$_{\text{WER}}$, and OnlyDia$_{\text{WER}}$, respectively. pc(m1, m2) is the percentage change of model m1 over model m2. The lower the percentage change, the better the model m1 is compared to model m2.

Size	Lang	DiaMT$_{\text{DER}}$	OnlyDia$_{\text{DER}}$	pc(DM$_{\text{D}}$,OD$_{\text{D}}$)	DiaMT$_{\text{WER}}$	OnlyDia$_{\text{WER}}$	pc(DM$_{\text{W}}$,OD$_{\text{W}}$)
4k	bum	0.415	**0.118**	+251.30%	0.424	**0.126**	+236.71%
	gvl	0.497	**0.174**	+184.97%	0.566	**0.258**	+119.11%
	ndz	0.565	**0.357**	+58.34%	0.675	**0.501**	+34.73%
	lip	0.501	**0.390**	+28.45%	0.531	**0.408**	+30.02%
	ken	0.599	**0.307**	+94.97%	0.660	**0.394**	+67.32%
	gid	0.328	**0.086**	+283.23%	0.361	**0.110**	+228.29%
	gng	0.458	**0.142**	+223.44%	0.479	**0.177**	+170.99%
	muy	0.544	**0.204**	+166.17%	0.591	**0.286**	+106.82%
	niy	0.592	**0.253**	+134.08%	0.700	**0.431**	+62.38%
	xed	0.525	**0.162**	+224.47%	0.562	**0.218**	+157.70%
	anv	0.583	**0.357**	+63.52%	0.663	**0.449**	+47.52%
	lee	0.512	**0.217**	+135.90%	0.604	**0.331**	+82.51%
	ksf	0.641	**0.221**	+190.13%	0.699	**0.300**	+133.44%
	pkb	0.412	**0.086**	+377.14%	0.463	**0.142**	+224.93%
	nko	0.573	**0.287**	+99.85%	0.641	**0.354**	+80.83%
	lef	0.454	**0.158**	+188.10%	0.493	**0.196**	+150.89%
	nhr	0.579	**0.227**	+155.26%	0.642	**0.312**	+105.58%
	biv	0.390	**0.278**	+40.28%	0.394	**0.265**	+48.80%
	maf	0.422	**0.137**	+209.16%	0.404	**0.138**	+192.74%
	giz	0.449	**0.120**	+274.16%	0.459	**0.139**	+231.04%
	tui	0.521	**0.169**	+207.68%	0.574	**0.222**	+158.45%
5k	bex	0.533	**0.144**	+270.79%	0.583	**0.221**	+163.19%
	fon	0.536	**0.171**	+214.23%	0.588	**0.253**	+132.42%
	mkl	0.454	**0.120**	+279.24%	0.491	**0.159**	+209.50%
	mnf	0.596	**0.434**	+37.38%	0.661	**0.489**	+35.34%
	bud	0.479	**0.179**	+168.25%	0.566	**0.277**	+104.66%
	eza	0.687	**0.188**	+265.50%	0.731	**0.316**	+131.07%
	sig	0.479	**0.290**	+65.10%	0.509	**0.325**	+56.52%
	bqc	0.441	**0.193**	+127.91%	0.518	**0.258**	+100.45%
	kia	0.450	**0.113**	+298.43%	0.473	**0.133**	+255.41%
	soy	0.684	**0.180**	+279.85%	0.734	**0.242**	+202.99%
	nnw	0.549	**0.181**	+202.55%	0.587	**0.252**	+132.34%
	sag	0.515	**0.140**	+267.78%	0.530	**0.185**	+187.28%
	csk	0.615	**0.169**	+264.27%	0.647	**0.225**	+187.93%
	izz	0.675	**0.203**	+232.99%	0.706	**0.288**	+144.78%
	bum	0.387	**0.132**	+194.21%	0.392	**0.139**	+181.72%
	gvl	0.510	**0.181**	+182.14%	0.579	**0.264**	+119.31%
	ndz	0.546	**0.330**	+65.61%	0.662	**0.480**	+37.92%
	lip	0.484	**0.155**	+213.02%	0.516	**0.199**	+159.32%
	ken	0.570	**0.311**	+83.48%	0.632	**0.394**	+60.49%
	gid	0.360	**0.097**	+272.09%	0.391	**0.123**	+217.05%
	gng	0.396	**0.127**	+211.51%	0.419	**0.166**	+151.77%
	muy	0.553	**0.356**	+55.43%	0.594	**0.409**	+45.42%
	niy	0.635	**0.273**	+132.38%	0.729	**0.444**	+64.35%
	xed	0.430	**0.095**	+352.39%	0.469	**0.165**	+184.70%
	anv	0.523	**0.349**	+49.86%	0.614	**0.441**	+39.12%
	lee	0.497	**0.237**	+109.77%	0.590	**0.348**	+69.40%
	ksf	0.630	**0.226**	+178.96%	0.688	**0.303**	+127.04%
	pkb	0.414	**0.088**	+369.56%	0.460	**0.145**	+217.36%
	nko	0.550	**0.281**	+95.98%	0.617	**0.351**	+76.10%
	lef	0.483	**0.301**	+60.75%	0.518	**0.324**	+59.96%
	nhr	0.577	**0.205**	+182.17%	0.637	**0.295**	+115.85%
	biv	0.360	**0.118**	+206.06%	0.358	**0.125**	+187.14%
	maf	0.442	**0.111**	+299.20%	0.425	**0.117**	+263.49%
	giz	0.452	**0.125**	+260.40%	0.458	**0.142**	+222.80%
	tui	0.427	**0.304**	+40.55%	0.480	**0.343**	+39.92%

Table D.4: DER and WER of 19 European languages in 9 train sizes produced by 2 models. The lowest DER and WER scores out of the 2 models are boldfaced. DM$_{\text{D}}$, OD$_{\text{D}}$, DM$_{\text{W}}$, OD$_{\text{W}}$ are shorthands for DiaMT$_{\text{DER}}$, OnlyDia$_{\text{DER}}$, DiaMT$_{\text{WER}}$, and OnlyDia$_{\text{WER}}$, respectively. pc(m1, m2) is the percentage change of model m1 over model m2. The lower the percentage change, the better the model m1 is compared to model m2.

Size	Lang	DiaMT$_{\text{DER}}$	OnlyDia$_{\text{DER}}$	pc(DM$_{\text{D}}$,OD$_{\text{D}}$)	DiaMT$_{\text{WER}}$	OnlyDia$_{\text{WER}}$	pc(DM$_{\text{W}}$,OD$_{\text{W}}$)
1k	el	0.557	**0.356**	+56.76%	0.648	**0.491**	+31.87%
	cs	0.464	**0.308**	+50.90%	0.593	**0.445**	+33.17%
	da	0.360	**0.215**	+67.17%	0.430	**0.300**	+43.41%
	de	0.465	**0.248**	+87.62%	0.560	**0.376**	+49.04%
	es	0.476	**0.271**	+75.55%	0.557	**0.389**	+43.11%
	et	0.401	**0.200**	+100.50%	0.519	**0.321**	+61.78%
	fi	0.403	**0.207**	+94.85%	0.555	**0.361**	+53.95%
	fr	0.512	**0.289**	+77.22%	0.603	**0.418**	+44.40%
	hu	0.512	**0.335**	+52.95%	0.617	**0.467**	+32.25%
	it	0.446	**0.212**	+110.38%	0.560	**0.355**	+57.78%
	lt	0.487	**0.283**	+72.33%	0.617	**0.434**	+42.25%
	lv	0.542	**0.285**	+89.86%	0.653	**0.441**	+47.97%
	nl	0.425	**0.197**	+115.26%	0.501	**0.308**	+62.79%
	pl	0.497	**0.240**	+107.08%	0.610	**0.391**	+55.87%
	pt	0.498	**0.313**	+58.70%	0.593	**0.434**	+36.61%
	ro	0.508	**0.270**	+88.41%	0.613	**0.411**	+48.92%
	sk	0.446	**0.270**	+64.99%	0.575	**0.412**	+39.42%
	sl	0.383	**0.185**	+107.25%	0.466	**0.281**	+66.06%
	sv	0.505	**0.271**	+86.46%	0.578	**0.380**	+51.94%
2k	el	0.544	**0.340**	+59.89%	0.640	**0.474**	+34.98%
	cs	0.497	**0.251**	+97.77%	0.628	**0.389**	+61.18%
	da	0.396	**0.182**	+117.72%	0.463	**0.265**	+75.06%
	de	0.456	**0.236**	+93.19%	0.551	**0.361**	+52.78%
	es	0.568	**0.208**	+173.83%	0.630	**0.337**	+87.26%
	et	0.459	**0.186**	+146.18%	0.575	**0.299**	+92.18%
	fi	0.419	**0.181**	+131.59%	0.578	**0.328**	+76.25%
	fr	0.565	**0.222**	+154.53%	0.637	**0.366**	+74.24%
	hu	0.535	**0.276**	+94.25%	0.637	**0.419**	+52.18%
	it	0.420	**0.226**	+85.49%	0.540	**0.357**	+51.58%
	lt	0.510	**0.216**	+136.15%	0.637	**0.369**	+72.48%
	lv	0.571	**0.237**	+140.41%	0.677	**0.395**	+71.26%
	nl	0.384	**0.168**	+128.80%	0.473	**0.283**	+66.99%
	pl	0.483	**0.214**	+125.77%	0.605	**0.357**	+69.64%
	pt	0.534	**0.239**	+123.01%	0.629	**0.372**	+69.36%
	ro	0.564	**0.219**	+156.92%	0.651	**0.369**	+76.32%
	sk	0.518	**0.234**	+121.75%	0.631	**0.373**	+69.39%
	sl	0.431	**0.153**	+181.64%	0.513	**0.239**	+114.51%
	sv	0.445	**0.227**	+95.89%	0.532	**0.336**	+58.63%
3k	el	0.644	**0.255**	+152.68%	0.718	**0.413**	+73.81%
	cs	0.533	**0.266**	+100.49%	0.663	**0.402**	+65.06%
	da	0.484	**0.168**	+188.14%	0.533	**0.254**	+110.12%
	de	0.506	**0.210**	+140.89%	0.598	**0.336**	+78.08%
	es	0.529	**0.200**	+164.20%	0.601	**0.330**	+82.04%
	et	0.454	**0.159**	+186.09%	0.577	**0.273**	+110.97%
	fi	0.452	**0.166**	+172.87%	0.604	**0.314**	+92.78%
	fr	0.585	**0.178**	+228.82%	0.657	**0.334**	+96.61%
	hu	0.610	**0.253**	+140.64%	0.695	**0.398**	+74.55%
	it	0.499	**0.168**	+197.40%	0.608	**0.312**	+94.55%
	lt	0.559	**0.216**	+159.37%	0.678	**0.371**	+82.78%
	lv	0.556	**0.252**	+120.35%	0.667	**0.402**	+66.00%
	nl	0.447	**0.155**	+188.47%	0.526	**0.271**	+93.84%
	pl	0.461	**0.195**	+136.07%	0.598	**0.341**	+75.14%
	pt	0.583	**0.227**	+157.27%	0.666	**0.360**	+84.88%
	ro	0.577	**0.228**	+152.74%	0.669	**0.372**	+79.83%
	sk	0.507	**0.216**	+134.41%	0.630	**0.358**	+75.81%
	sl	0.427	**0.161**	+164.45%	0.512	**0.241**	+112.09%
	sv	0.496	**0.207**	+138.92%	0.577	**0.321**	+79.45%
4k	el	0.618	**0.270**	+128.83%	0.705	**0.427**	+65.19%
	cs	0.604	**0.258**	+133.97%	0.721	**0.394**	+83.10%
	da	0.481	**0.170**	+182.69%	0.528	**0.257**	+105.85%

Continued on next page

Table D.4: DER and WER of 19 European languages in 9 train sizes produced by 2 models. The lowest DER and WER scores out of the 2 models are boldfaced. DM$_{\text{D}}$, OD$_{\text{D}}$, DM$_{\text{W}}$, OD$_{\text{W}}$ are shorthands for DiaMT$_{\text{DER}}$, OnlyDia$_{\text{DER}}$, DiaMT$_{\text{WER}}$, and OnlyDia$_{\text{WER}}$, respectively. pc(m1, m2) is the percentage change of model m1 over model m2. The lower the percentage change, the better the model m1 is compared to model m2.

Size	Lang	DiaMT$_{\text{DER}}$	OnlyDia$_{\text{DER}}$	pc(DM$_{\text{D}}$,OD$_{\text{D}}$)	DiaMT$_{\text{WER}}$	OnlyDia$_{\text{WER}}$	pc(DM$_{\text{W}}$,OD$_{\text{W}}$)
4k	de	0.566	**0.183**	+208.93%	0.648	**0.317**	+104.64%
	es	0.593	**0.191**	+210.33%	0.655	**0.324**	+102.32%
	et	0.500	**0.165**	+202.62%	0.617	**0.280**	+120.53%
	fi	0.529	**0.176**	+200.90%	0.666	**0.318**	+109.26%
	fr	0.576	**0.245**	+134.79%	0.657	**0.382**	+71.82%
	hu	0.632	**0.263**	+139.90%	0.710	**0.405**	+75.20%
	it	0.541	**0.199**	+171.22%	0.641	**0.334**	+91.81%
	lt	0.537	**0.231**	+132.08%	0.667	**0.376**	+77.63%
	lv	0.564	**0.232**	+143.00%	0.678	**0.389**	+74.51%
	nl	0.481	**0.183**	+162.85%	0.557	**0.292**	+90.47%
	pl	0.536	**0.224**	+139.66%	0.652	**0.365**	+78.60%
	pt	0.554	**0.196**	+182.91%	0.643	**0.336**	+91.18%
	ro	0.661	**0.203**	+226.52%	0.748	**0.355**	+110.89%
	sk	0.578	**0.244**	+136.87%	0.689	**0.376**	+83.33%
	sl	0.473	**0.152**	+210.13%	0.546	**0.236**	+131.21%
	sv	0.523	**0.185**	+182.02%	0.600	**0.303**	+98.17%
5k	el	0.610	**0.310**	+96.67%	0.699	**0.453**	+54.31%
	cs	0.625	**0.278**	+125.01%	0.729	**0.405**	+79.80%
	da	0.550	**0.176**	+212.84%	0.597	**0.261**	+128.86%
	de	0.511	**0.168**	+203.34%	0.604	**0.305**	+98.31%
	es	0.625	**0.234**	+167.17%	0.681	**0.351**	+93.84%
	et	0.497	**0.145**	+241.71%	0.612	**0.264**	+132.09%
	fi	0.527	**0.162**	+224.40%	0.668	**0.309**	+115.86%
	fr	0.605	**0.220**	+175.28%	0.681	**0.364**	+87.19%
	hu	0.668	**0.249**	+168.02%	0.740	**0.393**	+88.11%
	it	0.526	**0.151**	+247.62%	0.632	**0.299**	+111.17%
	lt	0.545	**0.202**	+169.47%	0.674	**0.360**	+87.06%
	lv	0.585	**0.230**	+154.33%	0.696	**0.383**	+81.78%
	nl	0.502	**0.163**	+207.59%	0.570	**0.276**	+106.50%
	pl	0.518	**0.209**	+148.13%	0.641	**0.353**	+81.60%
	pt	0.569	**0.182**	+213.21%	0.658	**0.321**	+104.78%
	ro	0.642	**0.236**	+172.49%	0.726	**0.379**	+91.80%
	sk	0.629	**0.263**	+138.78%	0.721	**0.388**	+85.78%
	sl	0.434	**0.169**	+156.48%	0.521	**0.246**	+111.92%
	sv	0.512	**0.214**	+139.54%	0.593	**0.324**	+82.86%
25k	el	0.405	**0.084**	+382.09%	0.533	**0.273**	+95.21%
	cs	0.323	**0.110**	+195.10%	0.469	**0.245**	+91.38%
	da	0.240	**0.050**	+376.81%	0.322	**0.145**	+122.50%
	de	0.291	**0.071**	+312.39%	0.408	**0.210**	+94.08%
	es	0.306	**0.083**	+267.10%	0.417	**0.226**	+84.85%
	et	0.221	**0.064**	+243.91%	0.340	**0.162**	+110.21%
	fi	0.262	**0.071**	+269.04%	0.411	**0.199**	+107.00%
	fr	0.308	**0.067**	+363.22%	0.436	**0.231**	+89.02%
	hu	0.378	**0.127**	+198.30%	0.501	**0.276**	+81.23%
	it	0.295	**0.050**	+486.40%	0.429	**0.197**	+117.66%
	lt	0.289	**0.077**	+273.96%	0.442	**0.217**	+103.03%
	lv	0.301	**0.108**	+178.02%	0.454	**0.260**	+74.84%
	nl	0.264	**0.055**	+377.52%	0.360	**0.178**	+102.51%
	pl	0.250	**0.066**	+277.89%	0.399	**0.203**	+96.85%
	pt	0.363	**0.068**	+434.92%	0.469	**0.216**	+116.84%
	ro	0.320	**0.083**	+285.20%	0.452	**0.242**	+87.16%
	sk	0.303	**0.111**	+171.61%	0.444	**0.244**	+82.14%
	sl	0.200	**0.044**	+350.37%	0.289	**0.124**	+133.36%
	sv	0.307	**0.088**	+249.19%	0.406	**0.204**	+99.51%
125k	el	0.134	**0.098**	+35.70%	0.305	**0.275**	+11.00%
	cs	0.125	**0.081**	+54.39%	0.252	**0.211**	+19.89%
	da	0.067	**0.015**	+360.99%	0.157	**0.110**	+42.86%
	de	0.085	**0.025**	+243.59%	0.223	**0.167**	+33.73%
	es	0.047	**0.028**	+68.79%	0.190	**0.173**	+9.93%
	et	0.062	**0.020**	+202.85%	0.158	**0.113**	+39.70%

Continued on next page

Table D.4: DER and WER of 19 European languages in 9 train sizes produced by 2 models. The lowest DER and WER scores out of the 2 models are boldfaced. DM$_{\text{D}}$, OD$_{\text{D}}$, DM$_{\text{W}}$, OD$_{\text{W}}$ are shorthands for DiaMT$_{\text{DER}}$, OnlyDia$_{\text{DER}}$, DiaMT$_{\text{WER}}$, and OnlyDia$_{\text{WER}}$, respectively. pc(m1, m2) is the percentage change of model m1 over model m2. The lower the percentage change, the better the model m1 is compared to model m2.

Size	Lang	DiaMT$_{\text{DER}}$	OnlyDia$_{\text{DER}}$	pc(DM$_{\text{D}}$,OD$_{\text{D}}$)	DiaMT$_{\text{WER}}$	OnlyDia$_{\text{WER}}$	pc(DM$_{\text{W}}$,OD$_{\text{W}}$)
125k	fi	0.078	**0.051**	+52.76%	0.203	**0.172**	+17.74%
	fr	0.065	**0.021**	+211.43%	0.228	**0.185**	+22.76%
	hu	0.111	**0.071**	+55.06%	0.254	**0.215**	+18.44%
	it	0.084	**0.015**	+443.37%	0.228	**0.159**	+43.38%
	lt	0.094	**0.050**	+87.14%	0.236	**0.178**	+32.82%
	lv	0.098	**0.072**	+35.96%	0.248	**0.222**	+11.85%
	nl	0.085	**0.011**	+658.69%	0.201	**0.135**	+48.47%
	pl	0.067	**0.022**	+213.24%	0.202	**0.148**	+36.75%
	pt	0.097	**0.024**	+295.81%	0.239	**0.172**	+39.29%
	ro	0.114	**0.037**	+210.51%	0.257	**0.196**	+30.81%
	sk	0.148	**0.135**	+9.50%	**0.268**	0.271	-0.93%
	sv	0.081	**0.026**	+215.25%	0.196	**0.144**	+35.89%
625k	el	**0.026**	0.046	-42.14%	**0.207**	0.227	-9.01%
	da	0.014	**0.011**	+20.91%	0.108	**0.106**	+2.03%
	de	0.029	**0.017**	+67.84%	0.169	**0.158**	+6.39%
	es	0.021	**0.016**	+32.11%	0.168	**0.163**	+3.35%
	fi	**0.039**	0.044	-11.75%	**0.156**	0.164	-5.10%
	fr	0.023	**0.015**	+54.78%	0.186	**0.177**	+4.89%
	it	0.022	**0.013**	+65.54%	0.168	**0.155**	+8.31%
	nl	0.019	**0.011**	+67.21%	0.143	**0.135**	+5.25%
	pt	0.025	**0.016**	+52.92%	0.174	**0.162**	+7.29%
	sv	0.032	**0.025**	+27.32%	0.149	**0.143**	+4.51%
1M	el	**0.020**	0.098	-79.82%	**0.198**	0.276	-28.02%
	de	0.022	**0.017**	+31.38%	0.163	**0.158**	+3.09%
	es	0.016	**0.013**	+19.55%	0.163	**0.160**	+1.93%
	fi	**0.028**	0.052	-46.13%	**0.141**	0.175	-19.54%
	fr	0.017	**0.014**	+16.21%	0.180	**0.176**	+2.61%
	it	**0.013**	0.014	-7.60%	**0.157**	**0.157**	-0.13%
	nl	0.013	**0.012**	+9.09%	0.137	**0.135**	+1.05%
	pt	**0.018**	0.020	-11.33%	**0.166**	0.167	-0.37%
	sv	0.019	**0.018**	+6.08%	0.137	**0.135**	+1.84%

E Complexity Metrics

We propose two classes of complexity metrics to assess the complexity of the diacritical system of a given language. The first class is based on the ratio of diacritics and character/word/sentence. The second class is based on the entropy of combinations of diacritic(s) and characters, measuring from the perspective of probability distribution. For the first class, we propose diacritized character ratio (**DCR**), diacritized word ratio (**DWR**), diacritized base character ratio (**DBR**), and diacritized word sentence ratio (**DWSR**). For the second class, we propose average entropy of diacritics (**AED**), and weighted average entropy of diacritics (**WAED**). Their definition can be seen in Table E.1. An example corpus and the computation of values of complexity metrics is given in Table E.2.

Metric	Definition
DCR	Proportion of characters that carry diacritic(s) out of all characters.
DWR	Proportion of words with at least a character carrying diacritic(s) out of all words.
DBR	Average number of variants (including itself) of each base character.
DWSR	Average number of words with at least a character carrying diacritic(s) per sentence.
AED	Average entropy of the distributions of each base character's variant(s) and itself.
WAED	Weighted AED with weight being the proportion of the number of occurrence of each base character out of that of all base character(s).

Table E.1: Definitions of Proposed Complexity Metrics.

Corpus	Shë̲ wa̲nts â̲n â̲pple̲. I drink coconut wä̲të̲r for fun.
DCR	$\frac{5}{39} = 0.128$
DWR	$\frac{4}{10} = 0.4$
DBR	$\frac{5}{2} = 2.5$
DWSR	$\frac{4}{2} = 2$

P(X)	P(a):{a:0.25, â:0.5, ä:0.25}
	P(e):{e:0.33, ë:0.67}

H(P(X))	H(P(a)) = 1.05; H(P(e)) = 0.63
AED	$\frac{1}{2} \times H(P(a)) + \frac{1}{2} \times H(P(e)) = 0.845$
WAED	$\frac{4}{7} \times H(P(a)) + \frac{3}{7} \times H(P(e))$ = 0.875

Table E.2: An example of computing complexity metrics with a mock corpus where base characters are underlined. $P(\cdot)$ represents probability distribution. $H(\cdot)$ represents entropy.

In Table E.2, WAED is larger than AED because the total number of occurrences of the base character 'a' is larger than 'e' and therefore the weight ($\frac{4}{7}$) for its entropy is higher than that for 'e' ($\frac{3}{7}$) which draws the weighted average closer toward the entropy of 'a'. In contrast, AED gives even weight to each base character which is $\frac{1}{2}$ in this example and does not take frequency of each base character into consideration. WAED takes distribution of the language data into consideration when measuring the complexity of a diacritical system.

Stat/Train Size	1k	2k	3k	4k	5k
p(DCR,DER)	0.613 / <.05	0.581 / <.05	0.612 / <.05	0.468 / <.05	0.487 / <.05
s(DCR,DER)	0.681 / <.05	0.610 / <.05	0.641 / <.05	0.567 / <.05	0.564 / <.05
k(DCR,DER)	0.485 / <.05	0.444 / <.05	0.446 / <.05	0.396 / <.05	0.417 / <.05
p(DWR,DER)	0.608 / <.05	0.581 / <.05	0.621 / <.05	0.476 / <.05	0.500 / <.05
s(DWR,DER)	0.690 / <.05	0.620 / <.05	0.645 / <.05	0.573 / <.05	0.567 / <.05
k(DWR,DER)	0.491 / <.05	0.444 / <.05	0.446 / <.05	0.396 / <.05	0.424 / <.05
p(DBR,DER)	0.301 / >.05	0.343 / <.05	0.177 / >.05	0.172 / >.05	0.263 / >.05
s(DBR,DER)	0.367 / <.05	0.345 / <.05	0.169 / >.05	0.235 / >.05	0.262 / >.05
k(DBR,DER)	0.276 / <.05	0.246 / <.05	0.120 / >.05	0.200 / >.05	0.202 / >.05
p(DWSR,DER)	0.616 / <.05	0.620 / <.05	0.648 / <.05	0.505 / <.05	0.514 / <.05
s(DWSR,DER)	0.726 / <.05	0.677 / <.05	0.694 / <.05	0.617 / <.05	0.613 / <.05
k(DWSR,DER)	0.539 / <.05	0.520 / <.05	0.503 / <.05	0.460 / <.05	0.474 / <.05
p(AED,DER)	0.566 / <.05	0.555 / <.05	0.528 / <.05	0.386 / <.05	0.406 / <.05
s(AED,DER)	0.626 / <.05	0.564 / <.05	0.521 / <.05	0.481 / <.05	0.420 / <.05
k(AED,DER)	0.453 / <.05	0.425 / <.05	0.359 / <.05	0.332 / <.05	0.306 / <.05
p(WAED,DER)	0.522 / <.05	0.498 / <.05	0.517 / <.05	0.371 / <.05	0.391 / <.05
s(WAED,DER)	0.548 / <.05	0.479 / <.05	0.513 / <.05	0.453 / <.05	0.410 / <.05
k(WAED,DER)	0.389 / <.05	0.348 / <.05	0.342 / <.05	0.309 / <.05	0.303 / <.05
p(DCR,WER)	0.737 / <.05	0.696 / <.05	0.750 / <.05	0.673 / <.05	0.658 / <.05
s(DCR,WER)	0.701 / <.05	0.642 / <.05	0.724 / <.05	0.676 / <.05	0.620 / <.05
k(DCR,WER)	0.513 / <.05	0.458 / <.05	0.536 / <.05	0.482 / <.05	0.442 / <.05
p(DWR,WER)	0.738 / <.05	0.702 / <.05	0.762 / <.05	0.684 / <.05	0.673 / <.05
s(DWR,WER)	0.710 / <.05	0.654 / <.05	0.729 / <.05	0.683 / <.05	0.624 / <.05
k(DWR,WER)	0.519 / <.05	0.464 / <.05	0.536 / <.05	0.482 / <.05	0.449 / <.05
p(DBR,WER)	0.419 / <.05	0.428 / <.05	0.333 / >.05	0.331 / >.05	0.366 / <.05
s(DBR,WER)	0.405 / <.05	0.418 / <.05	0.299 / >.05	0.356 / <.05	0.331 / >.05
k(DBR,WER)	0.299 / <.05	0.292 / <.05	0.204 / >.05	0.284 / <.05	0.256 / <.05
p(DWSR,WER)	0.763 / <.05	0.758 / <.05	0.811 / <.05	0.736 / <.05	0.713 / <.05
s(DWSR,WER)	0.763 / <.05	0.727 / <.05	0.794 / <.05	0.745 / <.05	0.685 / <.05
k(DWSR,WER)	0.580 / <.05	0.550 / <.05	0.607 / <.05	0.560 / <.05	0.519 / <.05
p(AED,WER)	0.693 / <.05	0.663 / <.05	0.668 / <.05	0.588 / <.05	0.574 / <.05
s(AED,WER)	0.667 / <.05	0.616 / <.05	0.622 / <.05	0.593 / <.05	0.512 / <.05
k(AED,WER)	0.494 / <.05	0.452 / <.05	0.459 / <.05	0.432 / <.05	0.351 / <.05
p(WAED,WER)	0.660 / <.05	0.623 / <.05	0.673 / <.05	0.591 / <.05	0.575 / <.05
s(WAED,WER)	0.590 / <.05	0.541 / <.05	0.625 / <.05	0.592 / <.05	0.516 / <.05
k(WAED,WER)	0.431 / <.05	0.394 / <.05	0.435 / <.05	0.422 / <.05	0.355 / <.05

Table E.3: The Pearson (p), Spearman (s), and Kendall (k) correlation statistics and p value between complexity metrics (DCR, DWR, DBR, AED, WAED) and performance metrics (DER, WER) produced by OnlyDia model for African languages.

Stat/Train Size	1k	2k	3k	4k	5k	25k	125k	625k	1M
p(DCR,DER)	0.694 / <.05	0.636 / <.05	0.827 / <.05	0.778 / <.05	0.800 / <.05	0.857 / <.05	0.859 / <.05	0.867 / <.05	0.885 / <.05
s(DCR,DER)	0.618 / <.05	0.596 / <.05	0.786 / <.05	0.719 / <.05	0.737 / <.05	0.814 / <.05	0.892 / <.05	0.884 / <.05	0.879 / <.05
k(DCR,DER)	0.465 / <.05	0.427 / <.05	0.618 / <.05	0.516 / <.05	0.544 / <.05	0.649 / <.05	0.734 / <.05	0.750 / <.05	0.761 / <.05
p(DWR,DER)	0.688 / <.05	0.633 / <.05	0.823 / <.05	0.776 / <.05	0.793 / <.05	0.858 / <.05	0.859 / <.05	0.879 / <.05	0.892 / <.05
s(DWR,DER)	0.601 / <.05	0.579 / <.05	0.768 / <.05	0.670 / <.05	0.698 / <.05	0.807 / <.05	0.890 / <.05	0.884 / <.05	0.879 / <.05
k(DWR,DER)	0.465 / <.05	0.415 / <.05	0.582 / <.05	0.504 / <.05	0.509 / <.05	0.637 / <.05	0.721 / <.05	0.750 / <.05	0.761 / <.05
p(DBR,DER)	0.022 / >.05	-0.181 / >.05	-0.245 / >.05	-0.220 / >.05	-0.448 / >.05	-0.083 / >.05	-0.124 / >.05	-0.544 / >.05	-0.677 / <.05
s(DBR,DER)	0.080 / >.05	0.069 / >.05	-0.193 / >.05	-0.121 / >.05	-0.306 / >.05	-0.162 / >.05	-0.306 / >.05	-0.413 / >.05	-0.445 / >.05
k(DBR,DER)	0.083 / >.05	0.071 / >.05	-0.142 / >.05	-0.078 / >.05	-0.241 / >.05	-0.179 / >.05	-0.224 / >.05	-0.368 / >.05	-0.343 / >.05
p(DWSR,DER)	0.732 / <.05	0.700 / <.05	0.838 / <.05	0.805 / <.05	0.832 / <.05	0.854 / <.05	0.875 / <.05	0.859 / <.05	0.911 / <.05
s(DWSR,DER)	0.659 / <.05	0.621 / <.05	0.797 / <.05	0.736 / <.05	0.765 / <.05	0.808 / <.05	0.904 / <.05	0.884 / <.05	0.879 / <.05
k(DWSR,DER)	0.500 / <.05	0.474 / <.05	0.641 / <.05	0.563 / <.05	0.591 / <.05	0.649 / <.05	0.748 / <.05	0.750 / <.05	0.761 / <.05
p(AED,DER)	0.577 / <.05	0.499 / <.05	0.703 / <.05	0.654 / <.05	0.610 / <.05	0.783 / <.05	0.735 / <.05	0.359 / >.05	0.112 / >.05
s(AED,DER)	0.515 / <.05	0.530 / <.05	0.687 / <.05	0.596 / <.05	0.591 / <.05	0.711 / <.05	0.793 / <.05	0.366 / >.05	0.201 / >.05
k(AED,DER)	0.335 / <.05	0.333 / <.05	0.512 / <.05	0.446 / <.05	0.450 / <.05	0.543 / <.05	0.616 / <.05	0.250 / >.05	0.085 / >.05
p(WAED,DER)	0.787 / <.05	0.733 / <.05	0.826 / <.05	0.777 / <.05	0.807 / <.05	0.863 / <.05	0.835 / <.05	0.760 / <.05	0.783 / <.05
s(WAED,DER)	0.699 / <.05	0.688 / <.05	0.806 / <.05	0.777 / <.05	0.765 / <.05	0.833 / <.05	0.869 / <.05	0.817 / <.05	0.845 / <.05
k(WAED,DER)	0.559 / <.05	0.544 / <.05	0.629 / <.05	0.610 / <.05	0.591 / <.05	0.661 / <.05	0.721 / <.05	0.659 / <.05	0.704 / <.05
p(DCR,WER)	0.754 / <.05	0.691 / <.05	0.797 / <.05	0.749 / <.05	0.807 / <.05	0.728 / <.05	0.787 / <.05	0.789 / <.05	0.828 / <.05
s(DCR,WER)	0.789 / <.05	0.771 / <.05	0.821 / <.05	0.781 / <.05	0.849 / <.05	0.781 / <.05	0.793 / <.05	0.697 / <.05	0.636 / >.05
k(DCR,WER)	0.610 / <.05	0.571 / <.05	0.610 / <.05	0.587 / <.05	0.661 / <.05	0.567 / <.05	0.577 / <.05	0.556 / <.05	0.592 / <.05
p(DWR,WER)	0.751 / <.05	0.689 / <.05	0.794 / <.05	0.748 / <.05	0.802 / <.05	0.726 / <.05	0.784 / <.05	0.786 / <.05	0.827 / <.05
s(DWR,WER)	0.778 / <.05	0.746 / <.05	0.804 / <.05	0.739 / <.05	0.814 / <.05	0.746 / <.05	0.772 / <.05	0.697 / <.05	0.636 / >.05
k(DWR,WER)	0.610 / <.05	0.559 / <.05	0.598 / <.05	0.575 / <.05	0.649 / <.05	0.556 / <.05	0.564 / <.05	0.556 / <.05	0.592 / <.05
p(DBR,WER)	0.049 / >.05	-0.086 / >.05	-0.176 / >.05	-0.149 / >.05	-0.314 / >.05	-0.286 / >.05	-0.213 / >.05	-0.130 / >.05	-0.434 / >.05
s(DBR,WER)	-0.005 / >.05	-0.069 / >.05	-0.163 / >.05	-0.150 / >.05	-0.241 / >.05	-0.249 / >.05	-0.202 / >.05	-0.085 / >.05	-0.176 / >.05
k(DBR,WER)	0.006 / >.05	-0.048 / >.05	-0.112 / >.05	-0.102 / >.05	-0.194 / >.05	-0.243 / >.05	-0.172 / >.05	0.000 / >.05	-0.086 / >.05
p(DWSR,WER)	0.785 / <.05	0.740 / <.05	0.818 / <.05	0.780 / <.05	0.841 / <.05	0.763 / <.05	0.825 / <.05	0.818 / <.05	0.872 / <.05
s(DWSR,WER)	0.821 / <.05	0.785 / <.05	0.839 / <.05	0.792 / <.05	0.874 / <.05	0.791 / <.05	0.812 / <.05	0.697 / <.05	0.636 / >.05
k(DWSR,WER)	0.645 / <.05	0.606 / <.05	0.657 / <.05	0.610 / <.05	0.731 / <.05	0.591 / <.05	0.643 / <.05	0.556 / <.05	0.592 / <.05
p(AED,WER)	0.622 / <.05	0.540 / <.05	0.631 / <.05	0.593 / <.05	0.604 / <.05	0.585 / <.05	0.578 / <.05	-0.143 / >.05	-0.152 / >.05
s(AED,WER)	0.695 / <.05	0.673 / <.05	0.717 / <.05	0.626 / <.05	0.658 / <.05	0.642 / <.05	0.599 / <.05	-0.297 / >.05	-0.293 / >.05
k(AED,WER)	0.504 / <.05	0.453 / <.05	0.528 / <.05	0.446 / <.05	0.497 / <.05	0.450 / <.05	0.407 / <.05	-0.156 / >.05	-0.197 / >.05
p(WAED,WER)	0.819 / <.05	0.755 / <.05	0.802 / <.05	0.758 / <.05	0.834 / <.05	0.784 / <.05	0.775 / <.05	0.800 / <.05	0.788 / <.05
s(WAED,WER)	0.821 / <.05	0.783 / <.05	0.817 / <.05	0.798 / <.05	0.860 / <.05	0.823 / <.05	0.804 / <.05	0.685 / <.05	0.603 / >.05
k(WAED,WER)	0.657 / <.05	0.618 / <.05	0.622 / <.05	0.633 / <.05	0.708 / <.05	0.649 / <.05	0.616 / <.05	0.556 / <.05	0.535 / <.05

Table E.4: The Pearson (p), Spearman (s), and Kendall (k) correlation statistics and p value between complexity metrics (DCR, DWR, DBR, AED, WAED) and performance metrics (DER, WER) produced by OnlyDia model for European languages.

Table E.5: Complexity metrics for diacritical system of each African language at 5 train sizes. For a given language, a metric may occasionally have identical values throughout different train sizes because they are rounded to 3 digits.

		DCR	DWR	DBR	DWSR	AED	WAED
Lang	Size						
bex	1k	0.090	0.067	2.000	11.426	0.563	0.562
	2k	0.091	0.068	2.000	11.515	0.564	0.564
	3k	0.091	0.068	2.000	11.511	0.565	0.565
	4k	0.090	0.068	2.000	11.452	0.564	0.564
	5k	0.090	0.067	2.000	11.348	0.563	0.563
fon	1k	0.193	0.141	3.286	22.280	0.794	0.795
	2k	0.193	0.141	3.286	22.522	0.793	0.794
	3k	0.194	0.142	3.286	22.645	0.794	0.795
	4k	0.194	0.142	3.286	22.541	0.794	0.795
	5k	0.194	0.141	3.286	22.474	0.794	0.795
mkl	1k	0.072	0.052	3.556	6.665	0.334	0.398
	2k	0.072	0.052	3.556	6.637	0.332	0.397
	3k	0.072	0.053	3.556	6.646	0.332	0.398
	4k	0.072	0.053	3.556	6.642	0.332	0.398
	5k	0.072	0.052	3.556	6.629	0.332	0.397
mnf	1k	0.198	0.151	4.750	23.874	0.862	0.871
	2k	0.199	0.151	4.750	23.899	0.862	0.870
	3k	0.199	0.151	4.750	23.960	0.862	0.870
	4k	0.199	0.151	4.750	23.805	0.862	0.871
	5k	0.199	0.150	4.750	23.883	0.862	0.870
bud	1k	0.140	0.109	3.800	15.894	0.495	0.615
	2k	0.140	0.109	3.800	15.985	0.496	0.615
	3k	0.140	0.108	3.636	15.939	0.448	0.601
	4k	0.140	0.109	3.636	15.927	0.450	0.602
	5k	0.140	0.108	3.636	15.906	0.450	0.602
eza	1k	0.101	0.077	3.800	14.469	0.422	0.463
	2k	0.101	0.077	3.800	14.710	0.423	0.463
	3k	0.101	0.076	3.800	14.808	0.420	0.461
	4k	0.101	0.077	3.800	14.794	0.422	0.462
	5k	0.101	0.076	3.800	14.772	0.422	0.462
sig	1k	0.004	0.003	2.000	0.440	0.099	0.099
	2k	0.004	0.003	2.000	0.476	0.052	0.084
	3k	0.004	0.003	2.000	0.479	0.052	0.085
	4k	0.004	0.003	2.000	0.485	0.053	0.086
	5k	0.004	0.003	2.000	0.488	0.053	0.086
bqc	1k	0.195	0.147	3.300	13.789	0.661	0.812
	2k	0.194	0.146	3.300	13.683	0.659	0.811
	3k	0.194	0.146	3.300	13.670	0.657	0.809
	4k	0.193	0.145	3.300	13.600	0.656	0.809
	5k	0.194	0.144	3.300	13.650	0.656	0.809
kia	1k	0.022	0.015	3.400	1.911	0.184	0.212
	2k	0.022	0.016	3.600	1.944	0.189	0.214
	3k	0.022	0.015	3.800	1.917	0.189	0.213
	4k	0.022	0.016	4.200	1.939	0.190	0.215
	5k	0.022	0.015	4.200	1.919	0.189	0.214
soy	1k	0.123	0.096	2.909	13.394	0.457	0.488
	2k	0.122	0.095	2.909	13.400	0.456	0.488
	3k	0.122	0.095	2.909	13.469	0.455	0.487
	4k	0.122	0.095	2.909	13.455	0.454	0.487
	5k	0.122	0.095	2.909	13.471	0.455	0.487
nnw	1k	0.118	0.082	2.857	13.720	0.457	0.507
	2k	0.118	0.082	2.857	13.759	0.460	0.508
	3k	0.117	0.082	2.857	13.789	0.457	0.508
	4k	0.118	0.082	2.929	13.774	0.459	0.509
	5k	0.118	0.081	2.929	13.791	0.456	0.509
sag	1k	0.014	0.010	3.000	1.586	0.127	0.128
	2k	0.014	0.010	3.250	1.592	0.127	0.128
	3k	0.014	0.010	3.250	1.617	0.129	0.130
	4k	0.014	0.010	3.250	1.621	0.130	0.130
	5k	0.014	0.010	3.250	1.629	0.131	0.131
csk	1k	0.036	0.030	2.000	4.723	0.207	0.205

Continued on next page

Table E.5: Complexity metrics for diacritical system of each African language at 5 train sizes. For a given language, a metric may occasionally have identical values throughout different train sizes because they are rounded to 3 digits.

Lang	Size	DCR	DWR	DBR	DWSR	AED	WAED
csk	2k	0.036	0.030	2.000	4.700	0.207	0.205
	3k	0.036	0.029	2.000	4.685	0.206	0.205
	4k	0.036	0.030	2.000	4.712	0.207	0.205
	5k	0.037	0.030	2.000	4.718	0.208	0.206
izz	1k	0.103	0.078	3.429	13.685	0.305	0.411
	2k	0.103	0.079	3.429	13.705	0.303	0.409
	3k	0.104	0.079	3.571	13.738	0.304	0.410
	4k	0.103	0.078	3.571	13.667	0.303	0.410
	5k	0.103	0.078	3.571	13.611	0.304	0.409
bum	1k	0.084	0.062	2.000	7.378	0.363	0.445
	2k	0.084	0.062	2.000	7.445	0.364	0.445
	3k	0.084	0.062	2.000	7.501	0.364	0.445
	4k	0.084	0.062	2.000	7.477	0.366	0.446
	5k	0.084	0.061	2.000	7.458	0.366	0.446
gvl	1k	0.075	0.055	3.000	9.155	0.259	0.504
	2k	0.076	0.056	2.875	9.216	0.229	0.502
	3k	0.076	0.055	2.700	9.219	0.183	0.452
	4k	0.076	0.056	2.700	9.248	0.183	0.452
	5k	0.076	0.055	2.700	9.209	0.182	0.452
ndz	1k	0.258	0.192	3.667	42.915	0.965	1.024
	2k	0.258	0.192	3.667	42.549	0.965	1.024
	3k	0.258	0.192	3.667	42.994	0.966	1.024
	4k	0.258	0.192	3.667	42.987	0.966	1.024
	5k	0.258	0.191	3.667	42.835	0.966	1.024
lip	1k	0.021	0.016	2.500	2.416	0.167	0.175
	2k	0.021	0.016	2.444	2.418	0.150	0.164
	3k	0.021	0.016	2.667	2.415	0.150	0.165
	4k	0.021	0.016	2.667	2.422	0.151	0.165
	5k	0.021	0.016	2.667	2.408	0.150	0.164
ken	1k	0.119	0.093	3.800	14.357	0.630	0.588
	2k	0.119	0.094	3.800	14.292	0.629	0.589
	3k	0.119	0.094	3.800	14.356	0.630	0.590
	4k	0.119	0.094	3.800	14.337	0.631	0.590
	5k	0.119	0.093	3.800	14.291	0.631	0.590
gid	1k	0.001	0.001	2.250	0.070	0.018	0.016
	2k	0.001	0.001	2.250	0.076	0.019	0.016
	3k	0.001	0.001	2.250	0.075	0.018	0.016
	4k	0.001	0.001	2.250	0.074	0.018	0.016
	5k	0.001	0.001	2.250	0.075	0.018	0.016
gng	1k	0.047	0.034	3.000	4.666	0.283	0.299
	2k	0.047	0.033	3.000	4.612	0.281	0.297
	3k	0.047	0.034	3.000	4.622	0.280	0.298
	4k	0.047	0.033	3.000	4.566	0.279	0.297
	5k	0.047	0.033	3.000	4.541	0.278	0.296
muy	1k	0.034	0.026	3.333	4.746	0.234	0.268
	2k	0.034	0.026	3.667	4.765	0.235	0.268
	3k	0.034	0.026	3.667	4.819	0.235	0.268
	4k	0.034	0.026	3.667	4.817	0.235	0.268
	5k	0.034	0.026	3.667	4.824	0.234	0.268
niy	1k	0.254	0.201	4.000	42.593	1.045	1.056
	2k	0.253	0.200	4.000	42.478	1.043	1.055
	3k	0.253	0.200	4.000	42.504	1.043	1.055
	4k	0.253	0.200	4.000	42.470	1.043	1.055
	5k	0.253	0.199	4.000	42.235	1.042	1.055
xed	1k	0.011	0.008	2.000	1.280	0.086	0.137
	2k	0.011	0.008	2.000	1.292	0.087	0.139
	3k	0.011	0.008	2.000	1.304	0.088	0.139
	4k	0.011	0.008	2.000	1.294	0.089	0.139
	5k	0.011	0.008	2.000	1.298	0.089	0.139
anv	1k	0.148	0.117	2.000	18.907	0.472	0.496
	2k	0.147	0.116	2.000	18.594	0.376	0.435
	3k	0.147	0.116	2.000	18.642	0.342	0.433

Continued on next page

Table E.5: Complexity metrics for diacritical system of each African language at 5 train sizes. For a given language, a metric may occasionally have identical values throughout different train sizes because they are rounded to 3 digits.

		DCR	DWR	DBR	DWSR	AED	WAED
Lang	Size						
anv	4k	0.147	0.116	2.000	18.647	0.342	0.433
	5k	0.147	0.115	2.000	18.724	0.342	0.434
lee	1k	0.262	0.195	5.222	31.564	1.100	1.080
	2k	0.262	0.195	5.222	31.690	1.100	1.079
	3k	0.262	0.194	5.222	31.770	1.099	1.079
	4k	0.262	0.194	5.222	31.683	1.100	1.080
	5k	0.262	0.193	5.222	31.509	1.100	1.080
ksf	1k	0.154	0.119	2.091	18.205	0.388	0.499
	2k	0.154	0.119	2.091	18.283	0.390	0.500
	3k	0.154	0.119	2.083	18.353	0.357	0.478
	4k	0.154	0.119	2.083	18.316	0.357	0.478
	5k	0.154	0.119	2.083	18.301	0.357	0.478
pkb	1k	0.022	0.018	2.333	2.689	0.587	0.639
	2k	0.022	0.018	2.333	2.704	0.590	0.641
	3k	0.022	0.018	2.333	2.743	0.591	0.644
	4k	0.022	0.018	2.333	2.732	0.590	0.643
	5k	0.022	0.018	2.333	2.723	0.589	0.642
nko	1k	0.152	0.119	2.000	15.933	0.539	0.562
	2k	0.152	0.119	2.000	15.987	0.539	0.562
	3k	0.152	0.119	2.000	16.038	0.538	0.562
	4k	0.151	0.119	2.000	15.984	0.538	0.562
	5k	0.151	0.117	2.000	15.865	0.537	0.561
lef	1k	0.027	0.021	2.000	3.093	0.146	0.150
	2k	0.027	0.021	2.000	3.070	0.146	0.150
	3k	0.026	0.021	2.000	3.051	0.145	0.150
	4k	0.026	0.021	2.000	3.053	0.145	0.150
	5k	0.026	0.020	2.000	3.035	0.144	0.150
nhr	1k	0.159	0.120	3.833	20.830	0.729	0.793
	2k	0.159	0.120	3.833	20.924	0.732	0.794
	3k	0.159	0.120	3.833	20.815	0.730	0.793
	4k	0.159	0.120	3.833	20.784	0.731	0.792
	5k	0.158	0.119	3.833	20.770	0.731	0.792
mgc	1k	0.110	0.081	2.000	10.836	0.355	0.518
	2k	0.110	0.081	2.000	10.869	0.355	0.519
biv	1k	0.049	0.034	2.000	4.115	0.284	0.288
	2k	0.049	0.034	2.000	4.130	0.285	0.287
	3k	0.050	0.035	2.000	4.203	0.288	0.290
	4k	0.049	0.035	2.000	4.162	0.287	0.290
	5k	0.050	0.034	2.000	4.159	0.287	0.290
maf	1k	0.056	0.040	3.400	4.939	0.197	0.238
	2k	0.056	0.040	3.400	4.966	0.198	0.237
	3k	0.056	0.040	3.400	4.978	0.198	0.238
	4k	0.056	0.040	3.400	4.953	0.198	0.238
	5k	0.056	0.040	3.400	4.946	0.199	0.239
giz	1k	0.003	0.002	2.000	0.257	0.037	0.042
	2k	0.003	0.002	2.000	0.259	0.036	0.042
	3k	0.003	0.002	2.000	0.253	0.035	0.041
	4k	0.003	0.002	2.000	0.254	0.029	0.035
	5k	0.003	0.002	2.000	0.256	0.029	0.035
tui	1k	0.083	0.062	2.400	9.815	0.413	0.420
	2k	0.083	0.062	2.400	9.773	0.412	0.419
	3k	0.083	0.061	2.400	9.705	0.412	0.417
	4k	0.083	0.061	2.400	9.629	0.410	0.417
	5k	0.083	0.061	2.400	9.625	0.410	0.417

Table E.6: Complexity metrics for diacritical system of each European language at 9 train sizes. For a given language, a metric may occasionally have identical values throughout different train sizes because they are rounded to 3 digits.

		DCR	DWR	DBR	DWSR	AED	WAED
Lang	Size						
el	1k	0.102	0.086	2.286	16.310	0.282	0.475
	2k	0.102	0.086	2.286	16.190	0.281	0.475
	3k	0.102	0.086	2.412	16.155	0.235	0.404
	4k	0.102	0.086	2.444	16.145	0.224	0.380
	5k	0.102	0.086	2.500	16.114	0.202	0.380
	25k	0.102	0.087	2.760	16.005	0.162	0.354
	125k	0.102	0.087	3.394	15.951	0.126	0.298
	625k	0.102	0.087	3.649	15.945	0.125	0.294
	1M	0.102	0.087	3.632	15.947	0.121	0.294
cs	1k	0.125	0.106	2.643	16.582	0.354	0.409
	2k	0.124	0.106	2.786	16.555	0.354	0.408
	3k	0.124	0.106	2.786	16.448	0.353	0.408
	4k	0.124	0.106	3.000	16.497	0.354	0.408
	5k	0.124	0.106	3.143	16.450	0.354	0.408
	25k	0.125	0.106	3.643	16.348	0.354	0.409
	125k	0.125	0.106	4.375	16.311	0.310	0.393
da	1k	0.011	0.009	2.857	1.314	0.065	0.077
	2k	0.011	0.009	3.143	1.328	0.067	0.078
	3k	0.011	0.009	3.571	1.333	0.067	0.078
	4k	0.011	0.009	3.714	1.335	0.067	0.078
	5k	0.011	0.009	3.625	1.327	0.059	0.066
	25k	0.011	0.009	4.333	1.317	0.051	0.058
	125k	0.011	0.009	4.071	1.304	0.034	0.043
	625k	0.011	0.009	3.909	1.308	0.131	0.039
de	1k	0.017	0.014	3.250	2.416	0.132	0.091
	2k	0.017	0.014	3.375	2.401	0.131	0.090
	3k	0.017	0.014	3.625	2.400	0.131	0.090
	4k	0.017	0.014	3.556	2.400	0.116	0.086
	5k	0.017	0.014	3.667	2.412	0.116	0.086
	25k	0.017	0.014	4.000	2.401	0.095	0.075
	125k	0.017	0.014	3.938	2.414	0.097	0.063
	625k	0.017	0.014	3.917	2.408	0.194	0.061
	1M	0.017	0.014	4.083	2.407	0.192	0.061
es	1k	0.022	0.018	2.750	3.061	0.123	0.132
	2k	0.022	0.018	3.250	3.055	0.123	0.132
	3k	0.022	0.018	3.500	3.009	0.122	0.131
	4k	0.022	0.018	3.500	3.009	0.122	0.131
	5k	0.022	0.018	3.625	3.030	0.123	0.131
	25k	0.022	0.018	3.727	3.013	0.090	0.128
	125k	0.022	0.018	3.938	2.999	0.090	0.105
	625k	0.022	0.018	4.389	3.005	0.072	0.098
	1M	0.022	0.018	4.227	3.004	0.105	0.095
et	1k	0.035	0.030	3.500	4.546	0.239	0.193
	2k	0.034	0.030	3.750	4.523	0.243	0.192
	3k	0.035	0.030	3.889	4.522	0.217	0.179
	4k	0.035	0.030	4.000	4.528	0.216	0.179
	5k	0.034	0.030	4.222	4.497	0.214	0.178
	25k	0.034	0.030	4.067	4.487	0.131	0.130
	125k	0.034	0.030	4.500	4.465	0.124	0.128
fi	1k	0.052	0.046	2.625	7.081	0.140	0.225
	2k	0.052	0.046	3.000	7.070	0.135	0.225
	3k	0.052	0.045	3.000	7.023	0.104	0.191
	4k	0.052	0.045	3.200	7.049	0.105	0.191
	5k	0.052	0.045	3.300	7.105	0.106	0.191
	25k	0.052	0.045	3.917	7.107	0.095	0.186
	125k	0.052	0.045	4.200	7.093	0.122	0.153
	625k	0.052	0.045	3.750	7.086	0.177	0.143
	1M	0.052	0.045	3.833	7.086	0.167	0.143
fr	1k	0.035	0.029	3.556	4.892	0.102	0.193
	2k	0.035	0.029	3.556	4.924	0.101	0.192

Continued on next page

Table E.6: Complexity metrics for diacritical system of each European language at 9 train sizes. For a given language, a metric may occasionally have identical values throughout different train sizes because they are rounded to 3 digits.

		DCR	DWR	DBR	DWSR	AED	WAED
Lang	Size						
fr	3k	0.035	0.029	3.778	4.948	0.100	0.192
	4k	0.035	0.029	4.000	4.937	0.100	0.192
	5k	0.035	0.029	3.900	4.957	0.090	0.175
	25k	0.035	0.029	3.923	4.941	0.070	0.158
	125k	0.035	0.029	4.500	4.903	0.064	0.148
	625k	0.035	0.029	4.263	4.905	0.098	0.141
	1M	0.035	0.029	4.474	4.905	0.093	0.141
hu	1k	0.109	0.094	2.800	15.589	0.330	0.424
	2k	0.109	0.094	3.300	15.703	0.330	0.425
	3k	0.108	0.094	3.400	15.618	0.330	0.424
	4k	0.108	0.093	3.500	15.564	0.329	0.424
	5k	0.108	0.094	3.455	15.607	0.299	0.400
	25k	0.108	0.093	4.083	15.689	0.274	0.370
	125k	0.108	0.093	3.789	15.635	0.262	0.327
it	1k	0.007	0.006	3.286	1.027	0.060	0.062
	2k	0.007	0.006	3.250	1.045	0.053	0.060
	3k	0.007	0.006	3.625	1.034	0.052	0.059
	4k	0.007	0.006	4.000	1.033	0.053	0.060
	5k	0.007	0.006	4.000	1.016	0.052	0.059
	25k	0.007	0.006	4.300	1.015	0.042	0.052
	125k	0.007	0.006	4.571	1.020	0.030	0.044
	625k	0.007	0.006	5.071	1.023	0.031	0.044
	1M	0.007	0.006	4.750	1.023	0.043	0.044
lt	1k	0.068	0.058	3.200	8.618	0.327	0.307
	2k	0.068	0.058	3.091	8.590	0.297	0.286
	3k	0.067	0.058	3.182	8.589	0.297	0.286
	4k	0.068	0.058	3.273	8.634	0.298	0.287
	5k	0.068	0.058	3.273	8.663	0.298	0.287
	25k	0.068	0.058	3.857	8.641	0.234	0.243
	125k	0.067	0.058	3.889	8.635	0.266	0.235
lv	1k	0.104	0.089	3.214	13.917	0.264	0.355
	2k	0.103	0.088	3.214	13.830	0.262	0.354
	3k	0.103	0.088	3.200	13.790	0.244	0.333
	4k	0.103	0.088	3.333	13.814	0.242	0.333
	5k	0.103	0.088	3.333	13.795	0.241	0.333
	25k	0.103	0.088	3.933	13.779	0.238	0.333
	125k	0.103	0.089	4.312	13.808	0.252	0.333
nl	1k	0.001	0.001	2.769	0.173	0.103	0.015
	2k	0.001	0.001	2.786	0.173	0.094	0.014
	3k	0.001	0.001	2.857	0.171	0.093	0.013
	4k	0.001	0.001	2.857	0.171	0.093	0.013
	5k	0.001	0.001	2.929	0.173	0.092	0.013
	25k	0.001	0.001	3.235	0.180	0.075	0.012
	125k	0.001	0.001	3.944	0.176	0.071	0.011
	625k	0.001	0.001	3.917	0.178	0.139	0.010
	1M	0.001	0.001	4.000	0.177	0.132	0.010
pl	1k	0.051	0.044	3.200	6.775	0.224	0.263
	2k	0.051	0.044	3.500	6.778	0.224	0.263
	3k	0.051	0.044	4.000	6.739	0.224	0.263
	4k	0.051	0.044	4.000	6.803	0.224	0.264
	5k	0.051	0.044	4.000	6.829	0.224	0.264
	25k	0.051	0.044	4.000	6.920	0.196	0.222
	125k	0.051	0.044	3.824	6.918	0.186	0.209
pt	1k	0.040	0.033	4.000	5.509	0.233	0.252
	2k	0.040	0.033	3.556	5.541	0.182	0.233
	3k	0.040	0.033	3.500	5.560	0.164	0.216
	4k	0.040	0.033	3.700	5.565	0.164	0.216
	5k	0.040	0.033	3.700	5.589	0.164	0.217
	25k	0.040	0.033	3.769	5.575	0.128	0.207
	125k	0.040	0.033	4.357	5.584	0.119	0.191
	625k	0.040	0.033	4.222	5.580	0.099	0.172

Continued on next page

Table E.6: Complexity metrics for diacritical system of each European language at 9 train sizes. For a given language, a metric may occasionally have identical values throughout different train sizes because they are rounded to 3 digits.

Lang	Size	DCR	DWR	DBR	DWSR	AED	WAED
pt	1M	0.040	0.033	4.579	5.580	0.093	0.172
ro	1k	0.061	0.051	3.333	8.793	0.212	0.260
	2k	0.061	0.051	3.556	8.778	0.213	0.260
	3k	0.061	0.051	3.889	8.768	0.212	0.260
	4k	0.061	0.051	3.800	8.767	0.192	0.258
	5k	0.061	0.051	3.800	8.781	0.192	0.258
	25k	0.062	0.052	3.688	8.710	0.261	0.256
	125k	0.061	0.051	3.737	8.723	0.214	0.221
sk	1k	0.102	0.087	2.857	14.268	0.365	0.358
	2k	0.103	0.087	2.857	14.417	0.365	0.359
	3k	0.103	0.087	3.143	14.355	0.366	0.359
	4k	0.103	0.087	3.286	14.394	0.366	0.359
	5k	0.103	0.087	3.357	14.443	0.366	0.359
	25k	0.102	0.087	3.800	14.407	0.341	0.357
	125k	0.102	0.087	4.333	14.388	0.341	0.357
sl	1k	0.035	0.029	2.500	4.095	0.202	0.140
	2k	0.035	0.029	2.556	4.069	0.180	0.135
	3k	0.035	0.029	2.778	4.082	0.179	0.134
	4k	0.035	0.029	2.909	4.075	0.162	0.117
	5k	0.035	0.029	3.000	4.056	0.160	0.117
	25k	0.035	0.029	3.643	4.092	0.124	0.100
sv	1k	0.051	0.043	3.333	6.550	0.204	0.321
	2k	0.051	0.043	3.667	6.566	0.205	0.321
	3k	0.051	0.043	3.667	6.588	0.204	0.321
	4k	0.051	0.043	3.571	6.590	0.175	0.313
	5k	0.051	0.043	3.500	6.615	0.154	0.267
	25k	0.051	0.043	4.000	6.650	0.097	0.195
	125k	0.051	0.043	3.895	6.680	0.198	0.183
	625k	0.051	0.043	3.957	6.679	0.206	0.169
	1M	0.051	0.043	4.000	6.682	0.196	0.169