Incorporating External POS Tagger for Punctuation Restoration

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Introduction

- Punctuation restoration plays a vital role in post-processing in automatic speech recognition (ASR)
- Recent works treat punctuation restoration as a sequence labeling task
- Huge efforts have been devoted to investigating better model structures, including MLP, CRF, RNNs, CNNs, Transformers, and various top layers with pre-train LMs

Contributions

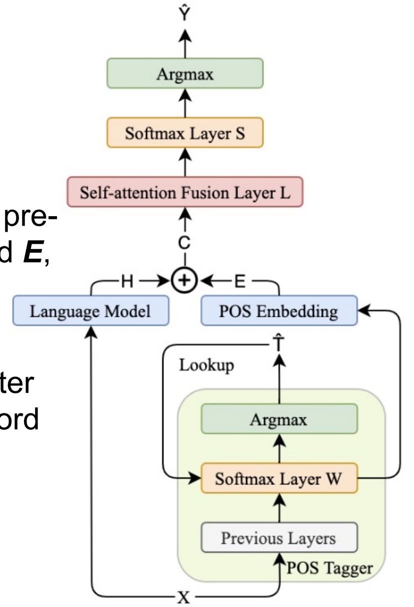
- We propose a novel framework to employ an external POS tagger to provide syntactic information for punctuation restoration, as well as a new stochastic sampling scheme called sequence boundary sampling (SBS) to better adapt to pre-trained LMs.
- With RoBERTa, our method sets a new state-of-the-art on IWSLT datasets in terms of Micro F1. Further with Funnel Transformer, we push the gap between our method and previous studies.
- As an ablation study, we examine the punctuation restoration performance of a wide range of pre-trained LMs in a fair and comparable setting, which provides a wide set of pre-trained LM benchmarks on this task.

Our Method

We apply an external POS tagger to generate the POS Tag Sequence ***T_hat***, as shown in Table 1.

We utilize the softmax layer weights ***W*** from the POS tagger, and elements in ***T_hat*** serve as indexes to lookup for the corresponding columns in ***W*** to form a pre-trained POS tag Embedding ***E***. Given the concatenation of LM hidden states ***H*** and ***E***, we feed it to a self-attention-based fusion layer ***L***. After that, we can get predicted ***Y_hat***.

Since we don't have sentence boundaries in ASR outputs, we propose SBS to better make use of pre-train LMs in this task, where we uniformly select a range of the word stream to form a token sequence instead of truncation or sliding window.



Data and Code

https://github.com/ShiningLab/POS-Tagger-for-Punctuation-Restoration

Table 2: *Evaluation results on Ref. in terms of P(%), R(%), Micro F$_1$(%), and Mean F$_1$(%).*

Language Model	Modification	*COMMA*			*PERIOD*			*QUESTION*			*Overall*			
		P	*R*	*F$_1$*	*P*	*R*	*F$_1$*	*P*	*R*	*F$_1$*	*P*	*R*	*Micro F$_1$*	*Mean F$_1$*
None	DNN-A [1]	48.6	42.4	45.3	59.7	68.3	63.7	-	-	-	54.8	53.6	54.2	36.3
	CNN-2A [1]	48.1	44.5	46.2	57.6	69.0	62.8	-	-	-	53.4	55.0	54.2	36.3
	T-BRNN-pre [4]	65.5	47.1	54.8	73.3	72.5	72.9	70.7	63.0	66.7	70.0	59.7	64.4	64.8
	Teacher-Ensemble [24]	66.2	59.9	62.9	75.1	73.7	74.4	72.3	63.8	67.8	71.2	65.8	-	68.4
	SAPR [6]	57.2	50.8	55.9	**96.7***	**97.3***	**96.8***	70.6	69.2	70.3	78.2	74.4	77.4	74.3
	DRNN-LWMA-pre [7]	62.9	60.8	61.9	77.3	73.7	75.5	69.6	69.6	69.6	69.9	67.2	68.6	69.0
	Self-attention [9]	67.4	61.1	64.1	82.5	77.4	79.9	80.1	70.2	74.8	76.7	69.6	-	72.9
	CT-transformer [10]	68.8	69.8	69.3	78.4	82.1	80.2	76.0	82.6	79.2	73.7	76.0	74.9	76.2
bert-base-uncased	Transfer [14]	72.1	72.4	72.3	82.6	83.5	83.1	77.4	89.1	82.8	77.4	81.7	-	79.4
	Adversarial [21]	74.2	69.7	71.9	84.6	79.2	81.8	76.0	70.4	73.1	78.3	73.1	-	75.6
	FL [17]	74.4	77.1	75.7	87.9	88.2	88.1	74.2	88.5	80.7	78.8	84.6	81.6	81.5
	Bi-LSTM [16]	71.7	70.1	70.9	82.5	83.1	82.8	75.0	84.8	79.6	77.0	76.8	76.9	77.8
	Ours: POS Fusion + SBS	69.9	72.0	70.9	81.9	85.5	83.7	76.5	84.8	80.4	75.9	78.8	77.3	78.3
bert-large-uncased	Transfer [14]	70.8	74.3	72.5	84.9	83.3	84.1	82.7	93.5	87.8	79.5	83.7	-	81.4
	Bi-LSTM [16]	72.6	72.8	72.7	84.8	84.6	84.7	70.0	91.3	79.2	78.3	79.0	78.6	78.9
	Pre-trained POS Fusion + SBS	74.7	71.2	72.9	83.4	87.2	85.2	78.4	87.0	82.5	79.1	79.3	79.2	80.2
roberta-base	Aggregate [15]	76.9	75.4	76.2	86.1	89.3	87.7	**88.9***	87.0	87.9	84.0	83.9	-	83.9
	Bi-LSTM [16]	73.6	75.1	74.3	84.9	87.6	86.2	77.4	89.1	82.8	79.2	81.5	80.3	81.1
	Ours: POS Fusion + SBS	75.2	76.5	75.9	86.0	87.9	86.9	73.2	89.1	80.4	80.3	82.3	81.3	81.1
roberta-large	Aggregate [15]	74.3	76.9	75.5	85.8	91.6	88.6	83.7	89.1	86.3	81.3	**85.9***	-	83.5
	Bi-LSTM [16]	76.9	75.8	76.3	86.8	90.5	88.6	72.9	93.5	81.9	81.6	83.3	82.4	82.3
	Bi-LSTM + augmentation [16]	76.8	76.6	76.7	88.6	89.2	88.9	82.7	93.5	87.8	82.6	83.1	82.9	84.5
	Ours: POS Fusion + SBS	77.4	79.4	78.4	87.7	89.6	88.6	80.4	89.1	84.5	82.4	84.6	83.5	83.9
funnel-transformer-xlarge	None	75.5	**82.4***	**78.8***	88.7	89.0	88.9	82.4	91.3	86.6	81.7	85.8	83.7	84.7
	SBS	77.2	80.1	78.6	88.4	89.4	88.9	86.3	**95.7***	**90.7***	82.7	85.0	83.8	**86.1***
	-POS embedding +SBS	76.4	80.9	78.6	87.9	90.2	89.0	82.4	91.3	86.6	81.9	85.6	83.7	84.7
	POS Fusion + SBS	**78.9***	78.0	78.4	86.5	93.4	89.8	87.5	91.3	89.4	**82.9***	85.7	**84.3***	85.9

Table 1: *An example of pre-processed data to align with BERT (bert-base-uncased).*

Raw Word Sequence		adrian	kohler	well	we	’re	here	today	to	talk	about	the	puppet	horse					
Raw Label Sequence		O	COMMA	COMMA	O	O	O	O	O	O	O	O	O	PERIOD					
Token Sequence (X)	⟨ BOS ⟩	[CLS]	adrian	ko	##hler	well	we	’	re	here	today	to	talk	about	the	puppet	horse	[SEP]	⟨ EOS ⟩
Label Sequence (Y)		O	O	O	COMMA	COMMA	O	O	O	O	O	O	O	O	O	O	PERIOD	O	
POS Tag Sequence ($\hat{T}$)		X	PROPN	X	PROPN	INTJ	PRON	X	VERB	ADV	NOUN	PART	VERB	ADP	DET	NOUN	NOUN	X	
Position Mask		0	1	0	1	1	1	0	1	1	1	1	1	1	1	1	1	0	

Table 3: *Evaluation results on ASR in terms of P(%), R(%), Micro F$_1$(%), and Mean F$_1$(%).*

Language Model	Modification	*COMMA*			*PERIOD*			*QUESTION*			*Overall*			
		P	*R*	*F$_1$*	*P*	*R*	*F$_1$*	*P*	*R*	*F$_1$*	*P*	*R*	*Micro F$_1$*	*Mean F$_1$*
None	T-BRNN-pre [4]	59.6	42.9	49.9	70.7	72.0	71.4	60.7	48.6	54.0	66.0	57.3	61.4	58.4
	Teacher-Ensemble [24]	60.6	58.3	59.4	71.7	72.9	72.3	66.2	55.8	60.6	66.2	62.3	-	64.1
	Self-attention [9]	64.0	59.6	61.7	75.5	75.8	75.6	**72.6***	65.9	**69.1***	70.7	67.1	-	68.8
bert-base-uncased	Adversarial [21]	**70.7***	68.1	**69.4***	77.6	77.5	77.5	68.4	66.0	67.2	**72.2***	70.5	-	**71.4***
	FL [17]	59.0	**76.6***	66.7	78.7	79.9	79.3	60.5	71.5	65.6	66.1	76.0	70.7	70.5
	Bi-LSTM [16]	49.3	64.2	55.8	75.3	76.3	75.8	44.7	60.0	51.2	60.4	70.0	64.9	61.0
	Ours: POS Fusion + SBS	49.3	65.6	56.3	73.6	78.8	76.1	48.9	62.9	55.0	60.0	72.0	65.4	62.5
bert-large-uncased	Bi-LSTM [16]	49.9	67.0	57.2	77.0	78.9	77.9	50.0	74.3	59.8	61.4	73.0	66.7	65.0
	Ours: POS Fusion + SBS	54.7	64.3	59.1	75.8	82.5	79.0	48.8	60.0	53.9	64.6	73.2	68.6	64.0
roberta-base	Bi-LSTM [16]	51.9	69.3	59.3	77.5	80.3	78.9	50.0	65.7	56.8	62.8	74.7	68.2	65.0
	Ours: POS Fusion + SBS	55.5	68.7	61.4	78.0	81.1	79.5	51.1	68.6	58.5	65.5	74.8	69.8	66.5
roberta-large	Bi-LSTM [16]	56.6	67.9	61.8	78.7	85.3	81.9	46.6	77.1	58.1	66.5	76.7	71.3	67.3
	Bi-LSTM + augmentation [16]	64.1	68.8	66.3	81.0	83.7	82.3	55.3	74.3	63.4	72.0	76.2	**74.0***	70.7
	Ours: POS Fusion + SBS	59.6	68.0	63.5	79.5	86.0	82.6	50.0	77.1	60.7	68.8	77.0	72.7	68.9
funnel-transformer-xlarge	None	52.6	76.5	62.3	**81.2***	81.8	81.5	53.1	74.3	61.9	64.1	79.1	70.8	68.6
	SBS	54.4	72.8	62.3	81.0	82.9	82.0	59.6	80.0	68.3	65.9	77.9	71.4	70.8
	-POS embedding +SBS	54.8	73.4	62.8	80.7	85.3	**82.9***	54.7	**82.9***	65.9	66.0	**79.5***	72.1	70.5
	POS Fusion + SBS	56.6	71.6	63.2	79.0	**87.0***	82.8	60.5	74.3	66.7	66.9	79.3	72.6	70.9