

From Word Segmentation to POS Tagging for Vietnamese

Dat Quoc Nguyen¹, Thanh Vu², Dai Quoc Nguyen³, Mark Dras¹ and Mark Johnson¹

¹Department of Computing, Macquarie University, Australia

{dat.nguyen, mark.dras, mark.johnson}@mq.edu.au

²NIHR Innovation Observatory, Newcastle University, United Kingdom

thanh.vu@newcastle.ac.uk

³PRaDA Centre, Deakin University, Australia

dai.nguyen@deakin.edu.au

Abstract

This paper presents an empirical comparison of two strategies for Vietnamese Part-of-Speech (POS) tagging from unsegmented text: (i) a pipeline strategy where we consider the output of a word segmenter as the input of a POS tagger, and (ii) a joint strategy where we predict a combined segmentation and POS tag for each syllable. We also make a comparison between state-of-the-art (SOTA) feature-based and neural network-based models. On the benchmark Vietnamese treebank (Nguyen et al., 2009), experimental results show that the pipeline strategy produces better scores of POS tagging from unsegmented text than the joint strategy, and the highest accuracy is obtained by using a feature-based model.

1 Introduction

POS tagging is one of the most fundamental natural language processing (NLP) tasks. In English where white space is a strong indicator of word boundaries, POS tagging is an important first step towards many other NLP tasks. However, white space when written in Vietnamese is also used to separate syllables that constitute words. So for Vietnamese NLP, word segmentation is referred to as the key first step (Dien et al., 2001).

When applying POS tagging to real-world Vietnamese text where gold word-segmentation is not available, the pipeline strategy is to first segment the text by using a word segmenter, and then feed the word-segmented text—which is the output of the word segmenter—as the input to a POS tagger. For example, given a written text “thuế thu nhập cá nhân” (individual_{cá_nhân} income_{thu_nhập} tax_{thuế}) consisting of 5 syllables, the word seg-

menter returns a two-word phrase “thuế_thu_nhập cá_nhân.”¹ Then given the input segmented text “thuế_thu_nhập cá_nhân”, the POS tagger returns “thuế_thu_nhập/N cá_nhân/N.”

A class of approaches to POS tagging from unsegmented text that has been actively explored in other languages, such as in Chinese and Japanese, is joint word segmentation and POS tagging (Zhang and Clark, 2008). A possible joint strategy is to assign a combined segmentation and POS tag to each syllable (Kruengkrai et al., 2009). For example, given the input text “thuế thu nhập cá nhân”, the joint strategy would produce “thuế/B- N thu/I-N nhập/I-N cá/B-N nhân/I-N”, where B refers to the beginning of a word and I refers to the inside of a word. Shao et al. (2017) showed that this joint strategy gives SOTA results for Chinese POS tagging by utilizing a BiLSTM-CNN-CRF model (Ma and Hovy, 2016).

In this paper, we present the first empirical study comparing the joint and pipeline strategies for Vietnamese POS tagging from unsegmented text. In addition, we make a comparison between SOTA feature-based and neural network-based models, which, to the best of our knowledge, has not done in any prior work on Vietnamese. On the benchmark Vietnamese treebank (Nguyen et al., 2009), we show that the pipeline strategy produces better scores than the joint strategy. We also show that the highest tagging accuracy is obtained by using a traditional feature-based model rather than neural network-based models.

2 Related work

2.1 Word segmentation

Nguyen et al. (2006), Dinh and Vu (2006) and

¹In the traditional underscore-based representation in Vietnamese word segmentation (Nguyen et al., 2009), white space is only used to separate words while underscore is used to separate syllables inside a word.

Tran et al. (2010) considered the Vietnamese word segmentation task as a sequence labeling task, using either a CRF, SVM or MaxEnt model to assign each syllable a segmentation tag such as B or I. In addition, Le et al. (2008), Pham et al. (2009) and Tran et al. (2012) used the maximum matching method (NanYuan and YanBin, 1991) to generate all possible segmentations for each input sentence; then to select the best segmentation, Le et al. (2008) and Tran et al. (2012) applied n-gram language model while Pham et al. (2009) employed POS information from an external POS tagger. Later, Liu and Lin (2014) and Nguyen and Le (2016) proposed approaches based on point-wise prediction, where a binary classifier is trained to identify whether or not there is a word boundary at each point between two syllables. Furthermore, Nguyen et al. (2017b) proposed a rule-based approach which gets the highest results to date in terms of both segmentation accuracy and speed.

2.2 POS tagging

Regarding Vietnamese POS tagging, Dien and Kiem (2003) projected POS annotations from English to Vietnamese via a bilingual corpus of word alignments. As a standard sequence labeling task, previous research has applied the CRF, SVM or MaxEnt model to assign each word a POS tag (Nghiem et al., 2008; Tran et al., 2009; Le-Hong et al., 2010; Nguyen et al., 2010; Tran et al., 2010; Bach et al., 2013). In addition, Nguyen et al. (2011) proposed a rule-based approach to automatically construct transformation rules for POS tagging in the form of a Ripple Down Rules tree (Compton and Jansen, 1990), leading to a development of the RDRPOSTagger (Nguyen et al., 2014a) which was the best system for the POS tagging shared task at the 2013 Vietnamese Language and Speech Processing (VLSP) workshop.

Nguyen et al. (2016a) and Nguyen et al. (2016b) later showed that SOTA accuracies at 94+% in the Vietnamese POS tagging task are obtained by simply retraining existing English POS taggers on Vietnamese data, showing that the MarMoT tagger (Mueller et al., 2013) and the Stanford POS tagger (Toutanova et al., 2003) obtain higher accuracies than RDRPOSTagger. Nguyen et al. (2016a) also showed that a simple lexicon-based approach assigning each word by its most probable POS tag gains a promising accuracy at 91%. Note that both Nguyen et al. (2016a) and Nguyen et al. (2016b)

did not experiment with neural network models. Pham et al. (2017) recently applied the BiLSTM-CNN-CRF (Ma and Hovy, 2016) for Vietnamese POS tagging, however, they did not experiment with SOTA feature-based models.

Previously, only Takahashi and Yamamoto (2016) carried out joint word segmentation and POS tagging for Vietnamese, to predicting a combined segmentation and POS tag to each syllable. In particular, Takahashi and Yamamoto (2016) experimented with traditional SVM- and CRF-based toolkits on a dataset of about 7k sentences and reported results of joint prediction only, i.e., they did not compare to the pipeline strategy. The CoNLL 2017 shared task on Universal Dependencies (UD) parsing from raw text (Zeman et al., 2017) provided some results to the pipeline strategy from word segmentation to POS tagging, however, the Vietnamese dataset in the UD project is very small, consisting of 1,400 training sentences. Furthermore, Nguyen et al. (2017a) provided a pre-trained jPTDP model for joint POS tagging and dependency parsing for Vietnamese,² which obtains a tagging accuracy at 93.0%, a UAS score at 77.7% and a LAS score at 69.5% when evaluated on the Vietnamese dependency treebank VnDT of 10k sentences (Nguyen et al., 2014b).

3 Experimental methodology

We compare the joint word segmentation and POS tagging strategy to the pipeline strategy on the benchmark Vietnamese treebank (Nguyen et al., 2009) using well-known POS tagging models.

3.1 Joint segmentation and POS tagging

Following Kruengkrai et al. (2009), Takahashi and Yamamoto (2016) and Shao et al. (2017), we formalize the joint word segmentation and POS tagging problem for Vietnamese as a sequence labeling task to assigning a combined segmentation and POS tag to each syllable. For example, given a manually POS-annotated training corpus “Cuộc/Nc điều_tra/V đường_như/X không/R tiến_triển/V ./CH” ‘The investigation seems to be making no progress’, we transform this corpus into a syllable-based representation as follows: “Cuộc/B-Nc điều/B-V tra/I-V đường/B-X như/I-X không/B-R tiến/B-V triển/I-V ./B-CH”, where segmentation tags B and I denote beginning and in-

²<https://drive.google.com/drive/folders/0B5eBgC8jrKtpUmhhSmtFLWdrTzQ>

side of a word, respectively, while Nc, V, X, R and CH are POS tags. Then we train sequence labeling models on the syllable-based transformed corpus.

3.2 Dataset

The Vietnamese treebank (Nguyen et al., 2009) is the largest annotated corpus for Vietnamese, providing a set of 27,870 manually POS-annotated sentences for training and development (about 23 words per sentence on average) and a test set of 2120 manually POS-annotated sentences (about 31 words per sentence).³ From the set of 27,870 sentences, we use the first 27k sentences for training and the last 870 sentences for development.

3.3 Models

For both joint and pipeline strategies, we use the following models:

- RDRPOSTagger (Nguyen et al., 2014a) is a transformation rule-based learning model which obtained the highest accuracy at the VLSP 2013 POS tagging shared task.⁴
- MarMoT (Mueller et al., 2013) is a generic CRF framework and a SOTA POS and morphological tagger.⁵
- BiLSTM-CRF (Huang et al., 2015) is a sequence labeling model which extends the BiLSTM model with a CRF layer.
- BiLSTM-CRF + CNN-char, i.e. BiLSTM-CNN-CRF, is an extension of the BiLSTM-CRF, using CNN to derive character-based representations (Ma and Hovy, 2016).
- BiLSTM-CRF + LSTM-char is another extension of the BiLSTM-CRF, using BiLSTM to derive the character-based representations (Lample et al., 2016).

Here, for the pipeline strategy, we train these models to predict POS tags with respect to (w.r.t.) gold word segmentation. In addition, we also re-train the fast and accurate Vietnamese word segmenter RDRsegmenter (Nguyen et al., 2017b) using the training set of 27k sentences.⁶

³The data was officially used for the Vietnamese POS tagging shared task at the second VLSP 2013 workshop.

⁴<http://rdrpostagger.sourceforge.net>

⁵<http://cistern.cis.lmu.de/marmot>

⁶RDRsegmenter obtains a segmentation speed at 60k words per second, computed on a personal computer of Intel Core i7 2.2 GHz. RDRsegmenter is available at: <https://github.com/datquocnguyen/RDRsegmenter>

Model	Pipeline	Joint
BiLSTM-CRF	100	200
+ CNN-char	100	250
+ LSTM-char	150	250

Table 1: Optimal number of LSTM units.

3.4 Implementation details

We use the original pure Java implementations of RDRPOSTagger and MarMoT with default hyper-parameter settings in our experiments. Instead of using implementations independently provided by authors of BiLSTM-CRF, BiLSTM-CRF + CNN-char⁷ and BiLSTM-CRF + LSTM-char, we use a reimplementation which is optimized for performance of all these models from Reimers and Gurevych (2017).⁸

For three BiLSTM-CRF-based models, we use default hyper-parameters provided by Reimers and Gurevych (2017) with the following exceptions: we use a dropout rate at 0.5 (Ma and Hovy, 2016) with the frequency threshold of 5 for unknown word and syllable types. We initialize word and syllable embeddings with 100-dimensional pre-trained embeddings,⁹ then learn them together with other model parameters during training by using Nadam (Dozat, 2016). For training, we run for 100 epochs. We perform a grid search of hyper-parameters to select the number of BiLSTM layers from {1, 2, 3} and the number of LSTM units in each layer from {50, 100, 150, 200, 250, 300}. Early stopping is applied when no performance improvement on the development set is obtained after 5 contiguous epochs. For both pipeline and joint strategies, we find the highest performance on the development set is when using two stacked BiLSTM layers. Table 1 presents the optimal number of LSTM units.

Here the performance is evaluated by F1 score, based on the number of correctly segmented and tagged words (Zhang and Clark, 2008). In the case of gold word segmentation, F1 score for POS tagging is in fact the tagging accuracy.

⁷<https://github.com/XuezheMax/LasagneNLP>

⁸<https://github.com/UKPLab/emnlp2017-bilstm-cnn-crf>

⁹Pre-trained word and syllable embeddings are learned by training the Word2Vec Skip-gram model (Mikolov et al., 2013) on a Vietnamese news corpus which is available at: <http://mim.hus.vnu.edu.vn/phuonglh/corpus/baomoi.zip>

Model	Accuracy	Speed
RDRPOSTagger	95.11	180k
MarMoT	95.88	25k
BiLSTM-CRF	95.06	3k
+ CNN-char	95.40	2.5k
+ LSTM-char	95.31	1.5k

Table 2: POS tagging accuracies (in %) on the test set w.r.t. gold word segmentation. “Speed” denotes the tagging speed, i.e. the number of words per second, computed on a personal computer of Intel Core i7 2.2 GHz (model loading time is not taken into account).

4 Main results

Table 2 presents POS tagging accuracy and tagging speed of each model on the test set w.r.t. gold word segmentation, in which MarMoT is the most accurate model while RDRPOSTagger is the fastest one. In particular, MarMoT obtains 0.5%+ higher accuracy than the three BiLSTM-based models. This is not surprising as the training set of 27k sentences is relatively small compared to the training data available in other languages such as English or Chinese.

Table 3 presents F1 scores for word segmentation and POS tagging in a real-world application scenario where the gold word-segmentation is not available. Comparing the results in Table 2 to results for the pipeline strategy, we observe a drop of about 2% for all models when using predicted segmentation instead of gold segmentation. Also, Table 3 clearly shows that the pipeline strategy helps produce better results than the joint strategy. In addition, pre-designed features in both RDRPOSTagger and MarMoT are designed to capture word-level information rather than syllable-level information, so it is also not surprising that for the joint strategy RDRPOSTagger is significantly lower while MarMoT is lower than the BiLSTM-CRF model with additional character-based representations.

Tables 2 and 3 suggest that for a practical application to Vietnamese where performance accuracy is preferred, we should consider using the pipeline strategy with a traditional SOTA feature-based tagger such as MarMoT. If speed is preferred such as in big data, RDRPOSTagger would be a superior alternative. With the current state of training data available in Vietnamese, future research should focus on incorporating Vietnamese linguistics

	Model	WSeg	PTag
Pipeline	RDRPOSTagger	97.75	93.39
	MarMoT	97.75	93.96
	BiLSTM-CRF	97.75	93.25
	+ CNN-char	97.75	93.55
	+ LSTM-char	97.75	93.46
Joint	RDRPOSTagger	93.73	87.53
	MarMoT	96.50	92.78
	BiLSTM-CRF	96.15	92.43
	+ CNN-char	96.66	92.79
	+ LSTM-char	96.76	92.95

Table 3: F1 scores (in %) for word segmentation (**WSeg**) and POS tagging (**PTag**) from unsegmented text. The pipeline strategy uses RDRsegmenter for word segmentation. In preliminary experiments, where we also train the five models above to predict a segmentation tag B or I for each syllable, we then find that RDRsegmenter obtains better word segmentation score than those five models.

tic features into the traditional feature-based sequence taggers.

5 Conclusion

We have presented empirical comparisons between two strategies for Vietnamese POS tagging from unsegmented text and between SOTA feature- and neural network-based models. Experimental results on the benchmark Vietnamese treebank (Nguyen et al., 2009) show that the pipeline strategy produces higher scores of POS tagging from unsegmented text than the joint strategy. In addition, we also show that a traditional feature-based model (i.e. MarMoT) obtains better POS tagging accuracy than neural network-based models. We provide a pre-trained MarMoT model for Vietnamese POS tagging at <https://github.com/datquocnguyen/VnMarMoT>.

Acknowledgments

This research was partially supported by the Australian Government through the Australian Research Council’s Discovery Projects funding scheme (project DP160102156). This research was also partially supported by NICTA, funded by the Australian Government through the Department of Communications and the Australian Research Council through the ICT Centre of Excellence Program.

References

- Ngo Xuan Bach, Kunihiro Hiraishi, Nguyen Le Minh, and Akira Shimazu. 2013. Dual decomposition for Vietnamese part-of-speech tagging. In *Proceedings of the 17th International Conference on Knowledge Based and Intelligent Information and Engineering Systems*. pages 123–131.
- P. Compton and R. Jansen. 1990. A Philosophical Basis for Knowledge Acquisition. *Knowledge Acquisition* 2(3):241–257.
- Dinh Dien and Hoang Kiem. 2003. POS-Tagger for English-Vietnamese Bilingual Corpus. In *Proceedings of the HLT-NAACL 2003 Workshop on Building and Using Parallel Texts: Data Driven Machine Translation and Beyond*. pages 88–95.
- Dinh Dien, Hoang Kiem, and Nguyen Van Toan. 2001. Vietnamese Word Segmentation. In *Proceedings of the Sixth Natural Language Processing Pacific Rim Symposium*. pages 749–756.
- Dien Dinh and Thuy Vu. 2006. A Maximum Entropy Approach for Vietnamese Word Segmentation. In *Proceedings of the 2006 International Conference on Research, Innovation and Vision for the Future*. pages 248–253.
- Timothy Dozat. 2016. Incorporating Nesterov Momentum into Adam. In *Proceedings of the ICLR 2016 Workshop Track*.
- Zhiheng Huang, Wei Xu, and Kai Yu. 2015. Bidirectional LSTM-CRF models for sequence tagging. *arXiv preprint arXiv:1508.01991*.
- Canasai Kruengkrai, Kiyotaka Uchimoto, Jun'ichi Kazama, Yiou Wang, Kentaro Torisawa, and Hitoshi Isahara. 2009. An Error-Driven Word-Character Hybrid Model for Joint Chinese Word Segmentation and POS Tagging. In *Proceedings of the 47th Annual Meeting of the ACL and the 4th IJCNLP of the AFNLP*. pages 513–521.
- Guillaume Lample, Miguel Ballesteros, Sandeep Subramanian, Kazuya Kawakami, and Chris Dyer. 2016. Neural Architectures for Named Entity Recognition. In *Proceedings of the 2016 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies*. pages 260–270.
- Hong Phuong Le, Thi Minh Huyen Nguyen, Azim Roussanaly, and Tuong Vinh Ho. 2008. A hybrid approach to word segmentation of Vietnamese texts. In *Proceedings of the 2nd International Conference on Language and Automata Theory and Applications*. pages 240–249.
- Phuong Le-Hong, Azim Roussanaly, Thi Minh Huyen Nguyen, and Mathias Rossignol. 2010. An empirical study of maximum entropy approach for part-of-speech tagging of Vietnamese texts. In *Proceedings of the Traitement Automatique des Langues Naturelles*.
- Wuying Liu and Li Lin. 2014. Probabilistic Ensemble Learning for Vietnamese Word Segmentation. In *Proceedings of the 37th International ACM SIGIR Conference on Research & Development in Information Retrieval*. pages 931–934.
- Xuezhe Ma and Eduard Hovy. 2016. End-to-end Sequence Labeling via Bi-directional LSTM-CNNs-CRF. In *Proceedings of the 54th Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)*. pages 1064–1074.
- Tomas Mikolov, Ilya Sutskever, Kai Chen, Greg S Corrado, and Jeff Dean. 2013. Distributed Representations of Words and Phrases and their Compositionality. In *Advances in Neural Information Processing Systems* 26. pages 3111–3119.
- Thomas Mueller, Helmut Schmid, and Hinrich Schütze. 2013. Efficient Higher-Order CRFs for Morphological Tagging. In *Proceedings of the 2013 Conference on Empirical Methods on Natural Language Processing*. pages 322–332.
- Liang NanYuan and Zheng YanBin. 1991. A Chinese word segmentation model and a Chinese word segmentation system PC-CWSS. *Journal of Chinese Language and Computing* 1(1).
- Minh Nghiem, Dien Dinh, and Mai Nguyen. 2008. Improving Vietnamese POS tagging by integrating a rich feature set and Support Vector Machines. In *Proceedings of the 2008 IEEE International Conference on Research, Innovation and Vision for the Future in Computing and Communication Technologies*. pages 128–133.
- Cam-Tu Nguyen, Trung-Kien Nguyen, Xuan-Hieu Phan, Le-Minh Nguyen, and Quang-Thuy Ha. 2006. Vietnamese Word Segmentation with CRFs and SVMs: An Investigation. In *Proceedings of the 20th Pacific Asia Conference on Language, Information and Computation*. pages 215–222.
- Dat Quoc Nguyen, Mark Dras, and Mark Johnson. 2017a. A Novel Neural Network Model for Joint POS Tagging and Graph-based Dependency Parsing. In *Proceedings of the CoNLL 2017 Shared Task: Multilingual Parsing from Raw Text to Universal Dependencies*. pages 134–142.
- Dat Quoc Nguyen, Dai Quoc Nguyen, Dang Duc Pham, and Son Bao Pham. 2014a. RDRPOSTagger: A Ripple Down Rules-based Part-Of-Speech Tagger. In *Proceedings of the Demonstrations at the 14th Conference of the European Chapter of the Association for Computational Linguistics*. pages 17–20.
- Dat Quoc Nguyen, Dai Quoc Nguyen, Dang Duc Pham, and Son Bao Pham. 2016a. A Robust Transformation-Based Learning Approach Using Ripple Down Rules for Part-of-Speech Tagging. *AI Communications* 29(3):409–422.

- Dat Quoc Nguyen, Dai Quoc Nguyen, Son Bao Pham, Phuong-Thai Nguyen, and Minh Le Nguyen. 2014b. From Treebank Conversion to Automatic Dependency Parsing for Vietnamese. In *Proceedings of 19th International Conference on Application of Natural Language to Information Systems*. pages 196–207.
- Dat Quoc Nguyen, Dai Quoc Nguyen, Son Bao Pham, and Dang Duc Pham. 2011. Ripple Down Rules for Part-of-Speech Tagging. In *Proceedings of the 12th International Conference on Intelligent Text Processing and Computational Linguistics - Volume Part I*. pages 190–201.
- Dat Quoc Nguyen, Dai Quoc Nguyen, Thanh Vu, Mark Dras, and Mark Johnson. 2017b. A Fast and Accurate Vietnamese Word Segmenter. *arXiv preprint arXiv:1709.06307*.
- Le Minh Nguyen, Xuan Bach Ngo, Viet Cuong Nguyen, Quang Nhat Minh Pham, and Akira Shimazu. 2010. A Semi-supervised Learning Method for Vietnamese Part-of-Speech Tagging. In *Proceedings of the International Conference on Knowledge and Systems Engineering*. pages 141–146.
- Phuong Thai Nguyen, Xuan Luong Vu, Thi Minh Huyen Nguyen, Van Hiep Nguyen, and Hong Phuong Le. 2009. Building a Large Syntactically-Annotated Corpus of Vietnamese. In *Proceedings of the Third Linguistic Annotation Workshop*. pages 182–185.
- Tuan-Phong Nguyen and Anh-Cuong Le. 2016. A Hybrid Approach to Vietnamese Word Segmentation. In *Proceedings of the 2016 IEEE RIVF International Conference on Computing and Communication Technologies: Research, Innovation, and Vision for the Future*. pages 114–119.
- Tuan Phong Nguyen, Quoc Tuan Truong, Xuan Nam Nguyen, and Anh Cuong Le. 2016b. An Experimental Investigation of Part-Of-Speech Taggers for Vietnamese. *VNU Journal of Science: Computer Science and Communication Engineering* 32(3):11–25.
- Dang Duc Pham, Giang Binh Tran, and Son Bao Pham. 2009. A Hybrid Approach to Vietnamese Word Segmentation using Part of Speech tags. In *Proceedings of the 2009 International Conference on Knowledge and Systems Engineering*. pages 154–161.
- Thai-Hoang Pham, Xuan-Khoai Pham, Tuan-Anh Nguyen, and Phuong Le-Hong. 2017. NNVLP: A Neural Network-Based Vietnamese Language Processing Toolkit. In *Proceedings of the IJCNLP 2017 System Demonstrations*. page to appear.
- Nils Reimers and Iryna Gurevych. 2017. Reporting Score Distributions Makes a Difference: Performance Study of LSTM-networks for Sequence Tagging. In *Proceedings of the 2017 Conference on Empirical Methods in Natural Language Processing*. pages 338–348.
- Yan Shao, Christian Hardmeier, Jörg Tiedemann, and Joakim Nivre. 2017. Character-based Joint Segmentation and POS Tagging for Chinese using Bidirectional RNN-CRF. In *Proceedings of the 8th International Joint Conference on Natural Language Processing*. page to appear.
- Kanji Takahashi and Kazuhide Yamamoto. 2016. Fundamental tools and resource are available for Vietnamese analysis. In *Proceedings of the 2016 International Conference on Asian Language Processing*. pages 246–249.
- Kristina Toutanova, Dan Klein, Christopher D. Manning, and Yoram Singer. 2003. Feature-rich Part-of-speech Tagging with a Cyclic Dependency Network. In *Proceedings of the 2003 Conference of the North American Chapter of the Association for Computational Linguistics on Human Language Technology - Volume 1*. pages 173–180.
- Ngoc Anh Tran, Thanh Tinh Dao, and Phuong Thai Nguyen. 2012. An effective context-based method for Vietnamese-word segmentation. In *Proceedings of First International Workshop on Vietnamese Language and Speech Processing*. pages 34–40.
- Oanh Thi Tran, Cuong Anh Le, Thuy Quang Ha, and Quynh Hoang Le. 2009. An Experimental Study on Vietnamese POS Tagging. In *Proceedings of the 2009 International Conference on Asian Language Processing*. pages 23–27.
- Thi Oanh Tran, Anh Cuong Le, and Quang Thuy Ha. 2010. Improving Vietnamese Word Segmentation and POS Tagging using MEM with Various Kinds of Resources. *Journal of Natural Language Processing* 17(3):41–60.
- Daniel Zeman, Martin Popel, Milan Straka, Jan Hajič, Joakim Nivre, et al. 2017. CoNLL 2017 Shared Task: Multilingual Parsing from Raw Text to Universal Dependencies. In *Proceedings of the CoNLL 2017 Shared Task: Multilingual Parsing from Raw Text to Universal Dependencies*. pages 1–19.
- Yue Zhang and Stephen Clark. 2008. Joint Word Segmentation and POS Tagging Using a Single Perceptron. In *Proceedings of the 46th Annual Meeting of the Association for Computational Linguistics: Human Language Technologies*. pages 888–896.