Improving Part-of-Speech Tagging Accuracy for Croatian by Morphological Analysis

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This paper investigates several methods of combining a second order hidden Markov model part-of-speech (morphosyntactic) tagger and a high-coverage inflectional lexicon for Croatian. Our primary motivation was to improve tagging accuracy of Croatian texts by using our newly-developed tagger CroTag, currently in beta-version. We also wanted to compare its tagging results – both standalone and utilizing the morphological lexicon – to the ones previously described in (Agić and Tadić 2006), provided by the TnT statistical tagger which we used as a reference point having in mind that both implement the same tagging procedure. At the beginning we explain the basic idea behind the experiment, its motivation and importance from the perspective of processing the Croatian language. We also describe tools – namely tagger and lexicon – and language resources used in the experiment, including their implementation method and input/output format details that were of importance. With the basics presented, we describe in theory four possible methods of combining these resources and tools with respect to their operating paradigm, input and production capabilities and then put these ideas to test using the F-measure evaluation framework. Results are then discussed in detail and conclusions and future work plans are presented.

Povzetek: Opisana je nova metoda označevanja hrvaških besedil.

1 Introduction

After obtaining satisfactory results of the preliminary experiment with applying a second order hidden Markov model part-of-speech/morphosyntactic tagging paradigm by using TnT tagger on Croatian texts, we decided to attempt reaching a higher level of accuracy based on these results. Detailed description of the previous experiment is given in (Agić and Tadić 2006) and TnT tagger is described in (Brants 2000). Please note that abbreviation HMM is used instead hidden Markov model and PoS (MSD) tagging instead part-of-speech (morphosyntactic) tagging further in the text.

In the section about our future work plans in (Agić and Tadić 2006), we provided two main directions for further enhancements:

a. Producing new, larger and more comprehensive language resources, i.e. larger, more precisely annotated and systematically compiled corpora of Croatian texts, maybe with special emphasis on genre diversity and
b. Developing our own stochastic tagger based on HMMs (being that TnT is available to public only as a black-box module) and then altering it by adding morphological cues about Croatian language or other rule-based modules.

We considered both courses of action as being equally important. HMM PoS/MSD trigram taggers make very few mistakes when trained on large and diverse corpora encompassing most of morphosyntactic descriptions for a language and, on the other hand, they rarely seem to surpass 98% accuracy on PoS/MSD, excluding the tiered tagging approach by (Tufis 1999.) and (Tufis and Dragomirescu 2004), not without help of rule-based modules, cues from morphological lexica or other enhancements which in fact turn stochastic tagging systems into hybrid ones. We have therefore chosen to undertake both courses of action in order to create a robust version of Croatian PoS/MSD tagger that would be able to provide us with high-quality MSD-annotated Croatian language resources automatically.

However, knowing that manual production of MSD-tagged corpora takes substantial amounts of time and human resources, we put an emphasis on developing and fine-tuning the trigram tagger in this experiment. Here we describe what is probably the most straightforward of currently available fine-tuning options for Croatian –

combining CroTag tagger and Croatian morphological lexicon. The lexicon itself is described in (Tadić and Fulgosi 2003) and implemented in form of Croatian lemmatization server, described in (Tadić 2006) and available online at http://hml.ffzg.hr. Our notion of tagger-lexicon combination in this paper refers to several possibilities of utilizing high coverage of the lexicon on Croatian texts in order to assist CroTag where it makes most errors, namely while tagging tokens that were not encountered by its training procedure.

Section 2 of the paper describes all the tools, language resources, annotation standards, input and output formats used in the experiment, while section 3 deals in theory with four conceptually different but functionally similar methods of pairing CroTag tagger and Croatian morphological lexicon. Section 4 defines the evaluation framework that would finally provide us with results. Discussion and conclusions along with future plans are given in sections 5 and 6.

2 Resources and tools

In this section, we give detailed insight on tools and resources used in the experiment, along with other facts of interest – basic characteristics of available annotated corpora and input-output file format standard used.

2.1 Inflectional lexicon

At the first stage of the experiment, we had available the Croatian morphological lexicon in two forms – one was the generator of Croatian inflectional word forms, described in (Tadić 1994) and another was the Croatian lemmatization server, detailed in (Tadić 2006). As it can be verified at http://hml.ffzg.hr, the server takes as input a UTF-8 encoded verticalized file. File verticalization is required because the server reads each file line as a single token which is used as a query in lemma and MSD lookup. Output is provided in form of a text file and an equivalent HTML browser output. Figure 2.1 represents a simplified illustration of this output: first token is the word form given at input and it is followed by pairs of lemmas and corresponding morphosyntactic descriptors compliant to MULTEXT-East v3 specification, given by e.g. (Erjavec 2004).

```
da [da2 Qr] [dati Vmia2s] [dati Vmia3s]
        [dati Vmip3s] [da1 Css]
```

Figure 2.1 Output of inflectional lexicon (illustration)

Therefore, a text document was extracted from the server containing all (lemma, token, MSD) triples and any computer program or a programming library implementing fast search capability over this document could be utilized in our experiment as a black-box module. For this purpose, we used the Text Mining Tools library (TMT), described in (Šilić et al. 2007), that had implemented a very fast and efficient dictionary module based on finite state automata, storing triples of word forms, lemmas and tags into an incrementally constructed deterministic automaton data structure. This TMT dictionary module has thus provided us with the needed object-oriented interface (conveniently developed in C++, same as CroTag) that we could use to get e.g. all lemmas and MSDs for a token, all MSDs for a (token, lemma) pair etc. By utilizing this library, a working inflectional lexicon interface was at our disposal to be used both as an input-output black-box and rule-based module for integration with CroTag at runtime.

2.2 Stochastic tagger

Stochastic PoS/MSD trigram tagger for Croatian (or just CroTag from this point on) was developed and made available in form of an early beta-version for purposes of validation in this experiment, enabling us to envision future improvement directions and implementation efforts. Although many stochastic taggers have been made available to the community for scientific purposes during the years – for example, the TnT tagger (Brants 2000) and its open source reimplementation made in OCaml programming language, named HunPos (Halacsy et al. 2007) – and could be utilized in research scheme of our experiment, we still chose to develop our own trigram HMM tagger. This enabled us to alter its operation methods whenever required and also allowed us to integrate it with larger natural language processing systems that are currently under development for Croatian, such as the named entity recognition and document classification libraries. CroTag is developed using standard C++ with some helpful advice from the HunPos development team and additional interpretation of the OCaml source of HunPos tagger itself.

At this moment, the tagger implements only a second order hidden Markov model tagging paradigm (trigram tagging), utilizing a modified version of the Viterbi algorithm (Thede and Harper 1999), linear interpolation, successive abstraction and deleted interpolation as smoothing and default unknown word handling paradigms. These are de facto standard methods, also found in both TnT and HunPos. CroTag presumes token emission upon reached state and is trained as a visible Markov model, i.e. on pre-tagged corpora, from which it acquires transition and emission probability matrices, as described in e.g. (Manning and Schütze 1999).

Input and output formats of CroTag are once again virtually identical to ones of TnT and HunPos The training procedure takes a verticalized, sentence delimited corpus and creates the language model – i.e. tag transition and token emission probability matrices – while the tagging procedure takes as input a verticalized, sentence delimited, non-tagged text and utilizes the language model matrices to provide an output formatted identical to that required for training input: verticalized text containing a token and MSD per line.

Since CroTag is still under heavy development taking several different implementation directions, tagging procedures do not offer any possibility of setting the parameters to the user at the moment, although implementation of these options is placed on our to-do list. Once we develop a final version of CroTag, it will be made available to the community as a web service and possibly as an open source project as well. Additional work planned for CroTag beta is discussed in section 6 together with other possible research directions.

2.3 Annotated corpus

The Croatia Weekly 100 kw newspaper corpus (CW100 corpus further in the text) consists of articles extracted from seven issues of the Croatia Weekly newspaper, which has been published from 1998 to 2000 by the Croatian Institute for Information and Culture. This 100 kw corpus is a part of Croatian side of the Croatian-English parallel corpus, as described by (Tadić 2000).

PoS	Corpus %	Different MSD
Noun	30.45	119
Verb	14.53	62
Adjective	12.06	284
Adposition	09.55	9
Conjunction	06.98	3
Pronoun	06.16	312
Other	20.27	107

Table 2.1 PoS distribution on the CW100 corpus

The CW100 corpus was manually tagged using the MULTEXT-East version 3 morphosyntactic descriptors specification, detailed in (Erjavec 2004) and encoded using XCES encoding standard (Ide et al. 2000). The corpus consists of 118529 tokens, 103161 of them being actual wordforms in 4626 different sentences, tagged by 896 different MSD tags. Nouns make for a majority of corpus wordforms (30.45%), followed by verbs (14.53%) and adjectives (12.06%), which is in fact a predictable distribution for a newspaper corpus.

Some details are provided in Table 2.1. Please note that PoS category Other includes acronyms, punctuation, numerals, etc. A more detailed insight on the CW100 corpus stats and pre-processing methods can be found in (Agić and Tadić 2006).

3 Combining lexicon and tagger

Four different methods were considered while planning this experiment. They all shared the same preconditions for input and output file processing, as described in the previous section. We now describe in theory these methods of pairing our trigram tagger and morphological lexicon.

3.1 Tagger resolving lexicon output

The first idea is based on very high text coverage displayed by the inflectional lexicon (more than 96.5% for contemporary newspaper texts documented). The text, consisting of one token per line to be tagged, could serve as input to the lexicon, providing all known MSDs given a wordform in each output line. The tagger would then be used only in context of tag sequence probabilities obtained by the training procedure and stored in the transition probability data structure. Namely, a program module could be derived from basic tagger function set, using tagger's tag transition probabilities matrix to find the optimal tag sequence in the search space, narrowed by using output of the inflectional lexicon instead of a generally poor lexical database stored in the emission probability matrix acquired at training.

3.2 Lexicon handling unknown words

A second-order HMM tagger such as CroTag is largely (almost exclusively) dependent of matrices of transition and emission probabilities, both of which are usually obtained from previously annotated corpora by a training procedure. As mentioned before, both CroTag and TnT (and HunPos, for that matter) use visible Markov model training procedures. It is well-known that it this case a large gap occurs when comparing PoS/MSD tagging accuracies on tokens known and unknown to the tagger in terms of the training procedure. If the training procedure encounters wordforms and discovers their respective tag distributions at training, error rates for tagging these words decrease substantially compared to tagging words that were not encountered at training. Improving trigram tagger accuracy therefore often means implementing an advanced method of guessing distributions of tags for unknown wordforms based on transition probabilities and other statistical methods, e.g. deleted interpolation, suffix tries and successive abstraction. Namely, TnT tagger implements all the methods listed above. However, most of these heuristic procedures frequently assign MSD tag distributions containing morphosyntactic descriptions having no linguistic sense for given unknown wordforms. We based our second method of pairing CroTag and inflectional lexicon on that fact alone; it would be worth investigating whether lexicon – as a large, high-coverage database of wordforms and associated lemmas and MSDs – could serve as unknown word handling module for the tagger at runtime. As it is expected that in most cases lexicon would recognize more word forms than tagger, implementation of this setting seemed to us as a logical and feasible course of action.

Suffix trie	Lexicon	Distribution
$p(tag_{i1} \mid suff_i)$	$(w_i\ l_1\ tag_1)$	
...	...	$p'(tag_{ii} \mid w_i)$
$p(\boxed{tag_{ii}} \mid suff_i)$	$(w_i\ l_1\ \boxed{tag_{ii}})$	$p'(tag_{ij} \mid w_i)$
$p(\boxed{tag_{ij}} \mid suff_i)$	$(w_i\ l_1\ \boxed{tag_{ij}})$	$p'(tag_{ik} \mid w_i)$
$p(\boxed{tag_{ik}} \mid suff_i)$	$(w_i\ l_2\ \boxed{tag_{ik}})$	
...	...	$\sum p' = \sum p$
$p(tag_{in} \mid suff_i)$	$(w_i\ l_m\ tag_1)$	

Table 3.1 Lexicon improving the suffix trie

In more detail, the idea builds on (Halacsy et al. 2006) and (Halacsy et al. 2007) and is basically a simple extension of the unknown word handling paradigm using suffix tries and successive abstraction (Samuelsson 1993). Trigram tagger such as TnT uses algorithms to disambiguate between tags in tag lists provided by emission probability matrix for a known wordform. Upon encountering an unseen wordform, such a list cannot be found in the matrix and must be constructed from another distribution, e.g. based on wordform suffixes acquired from specific types of encountered wordforms and implemented in the suffix trie data structure. Successive abstraction module contributes by iteratively choosing a more general distribution, i.e. distribution for shorter suffixes, shortening until a distribution of tags for a matching is finally assigned to the unknown token. This results in large and consequently low-quality distributions of MSD tag probabilities for unknown word forms, resulting in lower tagging accuracy. Taking high coverage of the inflectional lexicon into consideration, our idea was to choose from the suffix trie distribution only those MSDs on which both lexicon and suffix trie intersect, falling back to suffix tries and successive abstraction alone when both lexicon and tagger fail to recognize the wordform. By this proposition, we utilize wordform and tag probabilities as given by the suffix trie and yet choose only meaningful wordform and tag pairs, i.e. pairs confirmed by reading the lexicon. Probabilities of tags that remain in distributions after the selection are recalculated, increasing and thus becoming more reliable for calculating the optimal tag sequence. Table 3.1 illustrates this principle: if suffix trie tag and lexicon tag for an unknown token match, this tag is chosen for the new emission distribution of the previously unknown wordform and emission probability is recalculated.

3.3 Lexicon as pre-processing module

In this method, we train CroTag and obtain matrices containing transition and emission probabilities. The latter one, emission probability matrix, links each of the tokens found in the training corpus to its associated tags and counts, i.e. probabilities as is shown in Figure 3.1. The figure provides an insight on similarities and differences of storing language specific knowledge of tagger and inflectional lexicon.

```
%% ...
ime 26 Ncnsa 24 Ncnsn 2
imena 8 Ncnpa 1 Ncnpg 1 Ncnpn 3 Ncnsg 3
imenima 2 Ncnpd 1 Ncnpi 1
imenom 3 Ncnsi 3
imenovan 2 Vmps-smp 2
imenovana 1 Vmps-sfp 1
imenovanja 3 Ncnpg 2 Ncnsg 1
imenovanje 1 Ncnsv 1
imenovanjem 1 Ncnsi 1
imenovanju 4 Ncnsl 4
   %% ...
```

```
%% ...
ime ime Ncnsa ime Ncnsn ime Ncnsv
imenima ime Ncnpd ime Ncnpi ime Ncnpl
imenom ime Ncnsi
%% ...
```

Figure 3.1 Emission probability matrix file and lexicon output file comparison

It was obvious that inflectional lexicon and tagger lexicon acquired by training have common properties, making it possible to create a lexicon-derived module for error detection and correction on the acquired lexicon used internally by the tagger. From another perspective, inflectional lexicon and tagger lexicon could also be merged into a single resource by some well-defined merging procedure.

3.4 Lexicon as post-processing module

Similar to using language knowledge of the inflectional lexicon before tagging, it could also be used afterwards. Output of the tagger could then be examined in the following manner:

1. Input is provided both to tagger and inflectional lexicon, each of them giving an output.
2. The two outputs are then compared, leading to several possibilities and corresponding actions:
   a. Both tagger and lexicon give an answer. Lexicon gives an unambiguous answer identical to the one provided by the tagger. No action is required.
   b. Both tagger and lexicon give an answer. Lexicon gives an unambiguous answer and it is different from the one provided by the tagger. Action is required and we choose to believe the lexicon as a manually assembled and thus preferred source of language specifics.
   c. Both tagger and lexicon give an answer. Lexicon gives an ambiguous answer, i.e. a sequence of tags. One of the tags in the sequence is identical to taggers answer. We keep the tagger's answer, being now confirmed by the lexicon.
   d. Both tagger and lexicon give an answer. Lexicon gives an ambiguous answer and none of the tags in the sequence matches the one provided by the tagger. A module should be written that takes into account the sequence provided by the lexicon and does re-tagging in a limited window of tokens in order to provide the correct answer. Basically, we define a window sized 3 tokens/tags and centred on the ambiguous token, lookup the most frequent of various trigram combinations available for the window (these are given by the lexicon!) in transition probability matrix of the tagger and assign this trigram to the window, disambiguating the output. By this we bypass tagger knowledge and once again choose to prefer lexicon output, unfortunately disregarding the fact that Viterbi algorithm outperforms this simple heuristic disambiguation.
   e. Tagger provides an answer, but token is unknown to the lexicon. We keep the tagger's answer, this being the only possible course of action.
   f. Tagger does not provide an answer and lexicon does. If its answer is unambiguous, we assign it

to the token. If it is ambiguous, we apply the procedure described in option 2d.

3. Final output produced by the merge is then investigated by the evaluation framework.

It should by all means be noted that each of the presented paradigms had to undergo a theoretical debate and possibly – if considered to be a reasonable course of action – a full sequence of tests described in section 4 in order to be accepted or rejected for introducing overall improvement of tagging accuracy or creating additional noise, respectively. Details are given in the following sections.

4 Evaluation method

As a testing paradigm, we chose the F-measure framework for evaluation on specific PoS and general accuracy for overall tagging performance. Firstly, we provide a comparison of CroTag beta and TnT: overall PoS vs. MSD accuracy and also F-measures on nouns, pronouns and adjectives, proven to be the most difficult categories in (Agić and Tadić 2006). We then discuss the proposed tagger-lexicon combinations and provide the measures – overall accuracy and F1-scores for those methods judged as suitable and meaningful at the time of conducting the investigation.

Each test consists of two parts: the worst-case scenario and the default scenario. Worst-case is a standard tagging accuracy measure scenario created by taking 90% of the CW100 corpus sentences for training and leaving the other 10% for testing. Therefore, in a way, this scenario guarantees the highest number of unknown words to be found at runtime given the corpus. The default scenario chooses 90% of sentences from the CW100 pool for training and then 10% for testing from the same pool, making it possible for sentences to overlap in these sets. The default scenario is by definition not a standard measure scenario and was introduced in order to respect the nature of random occurrences in languages, leaving a possibility (highly improbable) of tagger encountering identical sentences at training and at runtime. Also, we argue that investigating properties of errors occurring on highest accuracy scores, derived by the default testing scenario, provides additional insight on properties of trigram tagging in general.

Note that we do not include testing scenarios debating on training set size as a variable: in this test, we consider improving overall tagging accuracy and not investigating HMM tagging paradigm specifics as in (Agić and Tadić 2006), being that conclusions on this specific topic were already provided there.

5 Results

The first set of results we present is from the set of tests evaluating overall tagging accuracy of CroTag on full MULTEXT East v3 MSD and on PoS information only (by PoS we imply the first letter of the MSD tag – not comparable to English PoS of e.g. English Penn Treebank). Acquired results are displayed in Table 5.1.

It could be stated from this table that results on TnT and CroTag are virtually identical and the differences exist merely because testing environment – mainly the number of unknown words – was variable. It is however quite apparent that CroTag outperformed TnT on part-of-speech, especially regarding unknown tokens, but this should be taken with caution as well, being that CroTag dealt with fewer unknowns in that specific test.

Second testing case considers combining CroTag and the inflectional lexicon. Before presenting the results and in order to interpret them correctly, it should be stated that only two of the four initially proposed merging methods were chosen to proceed to the practical testing session: method (3.2) using the inflectional lexicon as an unknown world handler (3.4) using the inflectional lexicon as a postprocessing module to resolve potential errors produced by the tagger. We rejected applying (3.1) tagger as a disambiguation module for inflectional lexicon output because it would be costly to develop yet another tagger-derived procedure to handle transition probabilities only. This procedure would, in fact, do nothing different than a common HMM-based tagger does with its own acquired lexicon: disambiguates its ambiguous entries upon encountering them in the text and applying the transition probability matrix and handling procedures on unknown words.

		TnT		**CroTag**	
		MSD	**PoS**	**MSD**	**PoS**
Worst case	Overall	86.05	96.53	86.05	96.84
	Known	89.05	98.29	89.26	98.42
	Unknown	66.04	86.02	65.95	87.29
	Corp. unk.	13.07	14.40	13.77	14.11
Default case	Overall	97.54	98.51	97.51	99.31
	Known	98.04	98.74	98.05	99.43
	Unknown	62.21	83.11	63.75	88.39
	Corp. unk.	01.42	01.51	01.59	01.13

Table 5.1 Overall tagging accuracy on MSD and PoS

The idea of inflectional lexicon as preprocessing module (3.3) was also rejected, mainly because we were unable to define precisely how to merge its database to the one acquired by tagger at training procedure. Being that tagger training procedure assigns each entry with a number of its occurrences overall and number of occurrences under various MSDs, in order to apply the inflectional lexicon as proposed by (3.3), we would have to assign these numbers so the tagger could understand the new entries. If we assign all to 1, it does not contribute and is redundant and if we assign any other number, we are in fact altering the tagging procedure outcome in such a manner that is not in any way bound by the language model, i.e. the training corpus. Therefore, we proceed with considering proposed cases (3.2) and (3.4) only.

We have also omitted PoS results from this testing case because TnT and CroTag are both able to achieve an accuracy over 95% without additional modules so we were focused in investigating MSD accuracy, keeping in mind that most errors do not occur on PoS but on sub-PoS levels resolvable by the lexicon. Details are provided by Table 5.2.

The first apparent conclusion is that method (3.4) that cleans up the errors on tagger output has failed and that it has failed on unknown words – where we may have expected it (or hoped for it) to perform better. The reason is, on the other hand and second thought, quite obvious: the tagger applies a tag to an unknown word using transition probabilities and smoothing procedures that are proven to operate quite satisfactory in TnT, HunPos and CroTag. When the postprocessing lexicon-based module encounters a word tagged as unknown, this word is rarely unambiguous in the inflectional lexicon. Therefore, a resolution module using transition probabilities has to be applied quite frequently and this module clearly and expectedly does not outperform default unknown word handling procedures.

		TnT	CroTag +3.2	CroTag +3.4
Worst case	Overall	86.05	85.58	83.94
	Known	89.05	88.84	88.18
	Unknown	66.04	65.13	57.38
	Corp. unk.	13.07	13.77	13.77
Default case	Overall	97.54	97.97	97.88
	Known	98.04	98.53	98.51
	Unknown	62.21	63.49	59.40
	Corp. unk.	01.42	01.59	01.59

Table 5.2 Tagging accuracy with (3.2) unknown word handler and (3.4) postprocessing

Based on other stats in Table 5.2, we could end the section by stating that CroTag, when combined with the inflectional lexicon in such a manner that the lexicon provides morphological cues to the tagger upon encountering unknown words, outperforms TnT by a narrow margin on the default MSD test case. However, a more sincere and exact statement – taking in regard all section 5 tables – would be that both TnT and CroTag share the same functional dependency regarding the number of unknown words they encounter in the tagging procedure. That is, CroTag outperforms TnT when less unknown tokens occur for him at runtime and vice versa, the inflectional lexicon contributing for around 1.3% improvement on unknown words. We can thus argue that our beta-version of CroTag tagger performs as well as TnT tagger and that we succeeded in implementing a state-of-the-art solution for tagging large-scale corpora of Croatian, given the test environment we had at hands, its drawbacks noted and hereby included.

In Table 5.3 we present results of evaluation broken down by three most difficult PoS categories: adjectives, nouns and pronouns. Data and analysis is given for PoS information only, as mentioned before.

		Adjective	Noun	Pronoun
TnT	Worst case	64.56	81.63	75.42
	Default case	94.79	96.75	96.94
CroTag	Worst case	65.31	80.85	74.62
	Default case	95.86	97.40	95.88
CroTag +3.2	Worst case	66.72	82.61	77.32
	Default case	95.06	96.79	95.82

Table 5.3 Tagging accuracy with adjectives, nouns and pronouns

It can be clearly noticed that suggested combination mode (3.2) outperforms both TnT and CroTag in the worst case scenario on all parts of speech since it has the support of HML when handling unknown words, that obviously do occur somewhat more frequently in this scenario. In the default case scenario, results are expectedly more even and inconclusive – default CroTag actually outperforms lexicon combination (3.2) because unknown tokens were found in small numbers in the test sets, much too small for the inflectional lexicon to contribute significantly to overall tagging accuracy.

6 Conclusion

In this contribution we have presented CroTag – an early beta-version of statistical PoS/MSD tagger for Croatian and proposed combining it with a large scale inflectional lexicon of Croatian, creating a hybrid system for high-precision tagging of Croatian corpora. We have presented several possible types of combinations, tested and evaluated two of them using the F-measure evaluation framework. CroTag provided results virtually identical to TnT, differing only in fractions of percentage in both directions in different evaluating conditions. This way we have shown that CroTag functions at the level of state-of-the-art regarding HMM-based trigram tagging and PoS/MSD-tagging in general.

Our future directions for improvement of this system could and probably can and probably will fall into several different research pathways.

The first of them should be analyzing tagging accuracy on morphological (sub-part-of-speech) features in more detail and fine-tuning the tagger accordingly.

Various parameterization options could also be provided at tagger runtime. Such options could include parameters for unigram, bigram and trigram preference or implementing token emissions depending on previously encountered sequences (multiword unit dependencies). As was previously mentioned, once we remove the beta-version appendix from CroTag by implementing these features and optimizing and tidying its source code, it will firstly be made available as a web service and then most probably as a freely-downloadable open source project on the web.

Fine-tuned rule-based modules for Croatian language specifics could also be considered and applied before or after the statistical procedure. Another option would be integration of inflectional lexicon into tagger as they have been programmed as separate modules, inducing some overhead to execution speed.

The next direction would be to build a full lemmatizer which, unlike inflectional lexicon presented in this paper, gives fully disambiguated lemmas as output relying on the results of the tagger. Selection of proper lemmas from sets of possible ones would be done on the basis of tagger output, once again fine-tuning levels of confidence between tagger and lemmatizer similar to section 3 of the paper.

It should also be noted that (Agić and Tadić 2008) takes into account an entirely different approach, putting an emphasis on corpora development. Namely, all the methods presented in previous sections are made exclusively for handling unknown word occurrences and all of them required lots of time and human effort to be implemented. On the other hand, manual corpora development – although obviously also requiring time and effort – is by definition a less demanding and at the same time reasonable course of action: larger, better and more diverse corpora are always a necessity for any language, necessity that implicitly resolves many unknown wordform issues as well. Courses of action could therefore be argued; we decided to take most of them throughout our future work in order to additionally improve tagging accuracy on Croatian texts.

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