Morphological Analysis for Statistical Machine Translation

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Abstract

We present a novel morphological analysis technique which induces a morphological and syntactic symmetry between two languages with highly asymmetrical morphological structures to improve statistical machine translation qualities. The technique pre-supposes fine-grained segmentation of a word in the morphologically rich language into the sequence of prefix(es)-stem-suffix(es) and part-of-speech tagging of the parallel corpus. The algorithm identifies morphemes to be merged or deleted in the morphologically rich language to induce the desired morphological and syntactic symmetry. The technique improves Arabic-to-English translation qualities significantly when applied to IBM Model 1 and Phrase Translation Models trained on the training corpus size ranging from 3,500 to 3.3 million sentence pairs.

1. Introduction

Translation of two languages with highly different morphological structures as exemplified by Arabic and English poses a challenge to successful implementation of statistical machine translation models (Brown et al. 1993). Rarely occurring inflected forms of a stem in Arabic often do not accurately translate due to the frequency imbalance with the corresponding translation word in English. So called a word (separated by a white space) in Arabic often corresponds to more than one independent word in English, posing a technical problem to the source channel models. In the English-Arabic sentence alignment shown in Figure 1, Arabic word AlAHmr (written in Buckwalter transliteration) is aligned to two English words ‘the red’, and ImEArdp to three English words ‘of the opposition.’ In this paper, we present a technique to induce a morphological and syntactic symmetry between two languages with different morphological structures for statistical translation quality improvement.

The technique is implemented as a two-step morphological processing for word-based translation models. We first apply word segmentation to Arabic, segmenting a word into prefix(es)-stem-suffix(es). Arabic-English sentence alignment after Arabic word segmentation is illustrated in Figure 2, where one Arabic morpheme is aligned to one or zero English word. We then apply the proposed technique to the word segmented Arabic corpus to identify prefixes/suffixes to be merged into their stems or deleted to induce a symmetrical morphological structure. Arabic-English sentence alignment after Arabic morphological analysis is shown in Figure 3, where the suffix p is merged into their stems mWajh and mEArd.

2. Word Segmentation

We pre-suppose segmentation of a word into prefix(es)-stem-suffix(es), as described in (Lee et al. 2003). The category prefix and suffix encompasses function words such as conjunction markers, prepositions, pronouns, determiners and all inflectional morphemes of the language. If a word token contains more than one prefix and/or suffix, we posit multiple prefixes/suffixes per stem. A sample word segmented Arabic text is given below, where prefixes are marked with #, and suffixes with +.

w# s# x# Hl sA}q Al# tj Arb fy jAgwAr Al# brAzyly lw syAnw bwrt y mk An AyrfAyn fy Al# sbAq gdA Al# AHd Al*y s# x# kwn Awly xTw +At +h fy EAlm sbAq +At AlfwrmwlA

3. Morphological Analysis

Morphological analysis identifies functional morphemes to be merged into meaning-bearing stems or to be deleted. In Arabic, functional morphemes typically belong to prefixes or suffixes.
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The original document contains color images.
Sample Arabic texts before and after morphological analysis is shown below.

Mwskw 51-7 (Af b) - Elm An Al# qSf Al# mdfEy Al*y Ady Aly ASAb +_jndy +yn rwsy +yn Avn +yn b# jrwH Tfyf +p q*Aj f Al# jmE +p fy mTAr xAn qIE +p …

In the morphologically analyzed Arabic (bottom), the feminine singular suffix +p and the masculine plural suffix +yn are merged into the preceding stems analogous to singular/plural noun distinction in English, e.g. girl vs. girls.

3.1 Method

We apply part-speech tagging to a symbol tokenized and word segmented Arabic and symbol-tokenized English parallel corpus. We then viterbi-align the part-of-speech tagged parallel corpus, using translation parameters obtained via Model 1 training of word segmented Arabic and symbol-tokenized English, to derive the conditional probability of an English part-of-speech tag given the combination of an Arabic prefix and its part-of-speech or an Arabic suffix and its part-of-speech.1

3.2 Algorithm

The algorithm utilizes two sets of translation probabilities to determine merge/deletion analysis of a morpheme. We obtain tag-to-tag translation probabilities according to (1), which identifies the most probable part-of-speech correspondences between Arabic (tagA) and English (tagE).

(1) Pr(tagE | tagA)

We also obtain translation probabilities of an English part-of-speech tag given each Arabic prefix/suffix and its part-of-speech according to (2) and (3):

(2) Pr(tagE | stemtagA, suffixj_tagjk)

(2) computes the translation probability of an Arabic suffix and its part-of-speech into an English part-of-speech tag in the Arabic stem tag context, stemtagA. StemtagA is one of the major stem parts-of-speech with which the specified prefix or suffix co-occurs, i.e. ADV, ADJ, NOUN, NOUN_PROP, VERB_IMPERFECT, VERB_PERFECT.2

J in suffixj ranges from 1 to M, M = number of distinct suffixes co-occurring with stemtagA. suffixj_tagjk is the part-of-speech of suffixj, where k ranges from 1 to L, L = number of

1 We have used an Arabic part-of-speech tagger with around 120 tags, and an English part-of-speech tagger with around 55 tags.

2 All Arabic part-of-speech tags are adopted from LDC-distributed Arabic Treebank and English tags are adopted from Penn Treebank.
distinct tags assigned to the suffix in the training corpus.

(3) Pr(tag | prefix, stemtag)

(3) computes the translation probability of an Arabic prefix and its part-of-speech into an English part-of-speech in the Arabic stem tag context, stemtag. Prefix and tag in prefix, stemtag may be interpreted in a manner analogous to suffix, tag of suffix, stemtag in (2).

3.2.1 IBM Model 1

The algorithm for word-based translation model, e.g., IBM Model 1, implements the idea that if a morpheme in one language is robustly translated into a distinct part-of-speech in the other language, the morpheme is very likely to have its independent counterpart in the other language. Therefore, a robust overlap of tags given tag between Pr(tag , tag) and Pr(tag , stemtag, suffix) for a suffix and Pr(tag , tag) and Pr(tag , prefix, stemtag) for a prefix is a positive indicator that the Arabic prefix/suffix has an independent counterpart in English. If the overlap is weak or doesn’t exist, the prefix/suffix is unlikely to have an independent counterpart and is subject to merge/deletion analysis.3

**Step 1:** For each tag, select the top 3 most probable tag from Pr(tag, tag).

**Step 2:** Partition all prefix and suffix into two groups in each stemtag context.

**Group I:** At least one of ‘tag’ or ‘tag’ occurs as one of the top 3 most probable translation pairs in Pr(tag, tag). Prefixes and suffixes in this group are likely to have their independent counterparts in English.

**Group II:** None of ‘tag’ or ‘tag’ occurs as one of the top 3 most probable translation pairs in Pr(tag, tag). Prefixes and suffixes in this group are unlikely to have their independent counterparts in English.

**Step 3:** Determine the merge/deletion analysis of the prefixes/suffixes in Group II as follows: If prefix or suffix occurs in more than one stemtag context, and its translation probability into NULL tag is not the highest, delete the prefix/suffix into NULL tag in its stemtag context.

Merge/deletion analysis is applied to all prefix/suffix occurring in the appropriate stem tag contexts in the training corpus (for translation model training) and a new input text (for decoding).

3.2.2 Phrase Translation Model

For phrase translation models (Och and Ney 2002), we induce additional merge/deletion analysis on the basis of base noun phrase parsing of Arabic. One major asymmetry between Arabic and English is caused by more frequent use of the determiner Al# in Arabic compared with its counterpart the in English. We apply Al#-deletion to Arabic noun phrases so that only the first occurrence of Al# in a noun phrase is retained. All instances of Al# occurring before a proper noun – as in Al# qds, whose literal translation is the Jerusalem – are also deleted. Unlike the automatic induction of morphological analysis described in 3.2.1, Al#-deletion analysis is manually induced.

4. Performance Evaluations

System performances are evaluated on LDC-distributed Multiple Translation Arabic Part I consisting of 1,043 segments derived from AFP and Xinhua newswires. Translation qualities are measured by uncased BLEU (Papineni et al. 2002) with 4 reference translations, sysids: ahb, ahe, ahc, ahd.

Systems are developed from 4 different sizes of training corpora, 3.5K, 35K, 350K and 3.3M sentence pairs, as in Table 1. The number in each cell indicates the number of sentence pairs in each genre (newswires, ummah, UN corpus).4

<table>
<thead>
<tr>
<th>Genre</th>
<th>3.5K</th>
<th>35K</th>
<th>350K</th>
<th>3.3M</th>
</tr>
</thead>
<tbody>
<tr>
<td>News</td>
<td>1,000</td>
<td>1,000</td>
<td>9,238</td>
<td>12,002</td>
</tr>
<tr>
<td>Ummah</td>
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<td>1,000</td>
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<tr>
<td>UN</td>
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<td>33,000</td>
<td>327,735</td>
<td>3,270,200</td>
</tr>
</tbody>
</table>

Table 1. Training Corpora Specifications

4 We have used the same language model for all evaluations.

4.1 IBM Model 1

Impact of morphological analysis on IBM Model 1 is shown in Table 2.
Table 2. Impact of morphological analysis on IBM Model 1

Baseline performances are obtained by Model 1 training and decoding without any segmentation or morphological analysis on Arabic. BLEU scores under ‘morph analysis’ is obtained by Model 1 training on Arabic morphologically analyzed and English symbol-tokenized parallel corpus and Model 1 decoding on the Arabic morphologically analyzed input text.  

<table>
<thead>
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<th>corpus size</th>
<th>baseline</th>
<th>morph analysis</th>
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</thead>
<tbody>
<tr>
<td>3.5K</td>
<td>0.10</td>
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<tr>
<td>35K</td>
<td>0.14</td>
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<tr>
<td>350K</td>
<td>0.18</td>
<td>0.31</td>
</tr>
<tr>
<td>3.3M</td>
<td>0.18</td>
<td>0.32</td>
</tr>
</tbody>
</table>

Table 3. Impact of morphological analysis on Phrase Translation Model

BLEU scores under baseline and morph analysis are obtained in a manner analogous to Model 1 except that the morphological analysis for the phrase translation model is a combination of the automatically induced analysis for Model 1 plus the manually induced Al#-deletion in 3.2.2. The scores with only automatically induced morphological analysis are 0.21, 0.25, 0.33 and 0.36 for 3.5K, 35K, 350K and 3.3M sentence pair training corpora, respectively.

<table>
<thead>
<tr>
<th>corpus size</th>
<th>baseline</th>
<th>morph analysis</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>3.3M</td>
<td>0.36</td>
<td>0.39</td>
</tr>
</tbody>
</table>

4.2 Phrase Translation Model

Impact of Arabic morphological analysis on a phrase translation model with monotone decoding (Tillmann 2003), is shown in Table 3.

5. Related Work

Automatic induction of the desired linguistic knowledge from a word/morpheme-aligned parallel corpus is analogous to (Yarowsky et al. 2001). Word segmentation and merge/deletion analysis in morphology is similar to parsing and insertion operation in syntax by (Yamada and Knight 2001). Symmetrization of linguistic structures can also be found in (Niessen and Ney 2000).

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6. References


