Phonological modeling for continuous speech recognition in Korean

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Abstract
A new scheme to represent phonological changes during continuous speech recognition is suggested. A phonological tag coupled with its morphological tag is designed to represent the conditions of Korean phonological changes. A pairwise language model of these morphological and phonological tags is implemented in Korean speech recognition system. Performance of the model is verified through the TDNN-based speech recognition experiments.

1 Introduction
The most widely used language models in speech recognition are word-level models, such as word-pairs and word-bigrams (Lee, 1989)(Bates et al., 1993)(Agnas et al., 1994). However, these models take too much space and need large corpus to be correctly trained. Also they are domain dependent, so it is hard to add new vocabularies. To cope with these problems, several category-level language models are suggested (Jardino, 1994)(Yang et al., 1994). These models include word-category models based on the first and last syllables of the words, and models using an automatic categorization technique to reduce the perplexity. The category-level language models showed a reduction in space requirements and better domain independence. For the agglutinative languages, several morpheme category/tag-level models are also suggested (Sakai, 1993)(Nakata, 1994). These models are basically the same as the ones used in text tagging systems, and use bigram/trigram statistics between tags.

However, Korean has many phonological changes which happen in a morpheme and between morphemes, and those changes result in the disparity between phonetic and orthographic descriptions of the morphemes. To cope with the phonological changes during Korean speech recognition, we suggest a representation scheme for the phonological changes, and a morphological and phonological tag pair language model (we call it pairwise language model). A hierarchical morphological tag set derived from the one used in written text analysis (Lee and Lee, 1992) is used and a phonological tag set is constructed from the Korean standard pronunciation rules (of Education, 1991). Performance of the model is tested through an experimental TDNN(time-delayed neural network) speech recognition system. The proposed model is quite extensible to new vocabularies and new domains by adding new dictionary entries for the necessary morphemes, and can be refined to bigram or trigram probabilistic models to give better recognition results.

2 Declaritive modeling of Korean phonological rules
Phonological changes during speech recognition in Korean are modeled with phoneme-sequence-to-morpheme dictionary entries and a binary connectivity matrix.

Phoneme-sequence-to-morpheme dictionary
Figure 1 shows a sample entry of the phoneme-sequence-to-morpheme dictionary. For a phoneme sequence [n u n], two morphemes are in the dictionary: one is an adnominal verb-ending and the other is a noun-ending. The figure shows a left and right morphological tag, and a left and right phonological tag for the adnominal verb-ending case.

The morphological tag “eCNMG” says that the

1A phoneme sequence can be a sequence of morphemes due to contraction, especially in spontaneous dialogues, and can have different left and right morphological categories.
morpheme is a verb-ending(e), makes a complex sentence(C), especially a inner sentence(N), through a noun phrase construction(M) and it is an adnominal verb-ending(G). The phonological tag "P-n" says that the morpheme is not changed at all(−) and the first(and the last for the right phonological tag) phoneme is [n]. "P" in "P-n" says that it is a phonological tag. A phonological tag of the form "Pa=b" (see figure 2 and 4) means that ‘a’ is pronounced as [b] and "Pa2b" (see figure 3 and 4) means ‘a’ is pronounced as [b] by the neutralization phenomenon.

Binary connectivity matrix While the dictionary keeps the information about how a single morpheme is changed phonologically, the phonological binary connectivity matrix keeps the collocational information of two morphemes' pronunciations.

Figure 2 shows the connectivity matrix entries for consonant assimilation. These entries say that a morpheme whose last consonant ‘t s ss’ are changed into [n], can be followed by a morpheme whose first phoneme is [n] or [m]. Wild characters(*, ?) can be used to reduce the number of entries in the matrix.

Generally, we apply the following two guidelines for the phonological rule modeling.

- Make a new dictionary entry for each morphologically conditioned phonological changes: Some phonological changes, such as vowel contraction and neutralization, happen only in the specific morphemes in a specific collocational relation. In these cases, registering all the phonologically changed morphemes or morpheme-sequences is preferred.

- Represent the final changes when more than one changes occur: When more than one phonological changes occur for a morpheme or between morphemes, register only the final form of each morpheme rather than all the intermediate forms. This strategy increases the number of dictionary entries but eliminates the successive rule application.

3 Representative phonological modeling examples

In this section, major Korean pronunciation rules (text-to-speech rules) (of Education, 1991) are explained and their modeling (for speech-to-text conversion) using the dictionary and the connectivity matrix is described.

Yale romanization is adopted to represent the Korean phonemes.

Neutralization In Korean, only 7 consonants are pronounced as syllable coda. This is called neutralization or consonant cluster simplification and happens when the morpheme is followed by a pause or a consonant.

The followings are some examples:

"takk+ta" \(\rightarrow\) [tak-tta] (clean)

"pwu-ekh" \(\rightarrow\) [pwu-ek] (kitchen)

"talk+kwa" \(\rightarrow\) [tak-kkwa] (chicken and)

"os+kwa" \(\rightarrow\) [ot-kkwa] (clothes and)

"nelp+ko" \(\rightarrow\) [nel-kko] (wide and)

"celn+ko" \(\rightarrow\) [cem-kko] (young and)

Figure 3 shows the dictionary entry for the neutralized “talk” (chicken) and the corresponding connectivity matrix entry. "PEND" is a special tag for the pause. For each “Pa2b” tag, a connectivity with "PEND" is added in the matrix.

Glottalization First consonants ‘k t p s c’ after last consonants ‘k(kk, kh, ks, lk) t(s, ss, c, ch, th) p(ph, lp, lph, ps)’ are pronounced as [kk tt pp ss cc] respectively. Verb-ending’s first consonants

\(^2^\)We will use ’t s ss’ notation to mean ’t’, ’s’, or ’ss’ through out in this paper.

\(^3^\)The pronunciation rules cover intra-word and inter-word phonological changes.
Figure 3: Dictionary entry for [t a k] and the corresponding connectivity matrix entry

Figure 4: Dictionary entry for [kk wa], and the corresponding connectivity matrix entry

'k t s c' after a verb-stem with 'u(nc) m(lm) lp lth' as its last consonants, are pronounced as [kk tt ss cc].

Here are some examples:

"ppet+ta" [ppet-tta] (stretch) 't' ⇒ [tt]
"iss+ten" [it-tten] (have existed) 't' ⇒ [tt]
"talk+kwa" [tak-kkwa] (chicken and) 'k' ⇒ [kk]
"ulp+ta" [up-tta] (recite) 't' ⇒ [tt]

Figure 5 shows an example of "talk-kwa" which is pronounced as [tak-kkwa]. The connectivity matrix says that a morpheme with first consonant changed from 'k' into [kk] can follow a morpheme with last consonant 'lk' neutralized as [k].

Assimilation Last consonants 'k(kk, kh, ks, lk) t(s, ss, c, ch, th, h) p(php, lp, lph)' followed by 'n m' are pronounced as [ng n m]. First consonant 'l' following the last consonants 'm ng' is pronounced as [n]. First consonant 'l' following the last consonants 'k p' is also pronounced as [n]. 'n' following or followed by 'l' is pronounced as [l]. The first consonant 'n' following 'lh lth' is also pronounced as [l].

Consonant contraction 'h(nh, lh)' followed by 'k t c', are combined with those 'k t c' and pronounced as [kh th ch]. Final consonants 'k(lk) t(p lp) c(nc)' followed by 'h' are merged with that 'h' and pronounced as [kh th ph ch]. The followings are some examples:

"noh+ko" [no-kho] (put down) 'h'+[k] ⇒ [kh]
"manh+ko" [man-kho] (many) 'h'+[k] ⇒ [kh]
"talh+ci" [tal-chi] (wear out) 'h’+c' ⇒ [ch]
"palk+hi+ta" [pal-khi-ta] (lighten) 'k’+h' ⇒ [kh]

Figure 6 shows the case of "noh-ko". The ’h’ and ’k’ are merged to [kh]. The phonological tag "Ph=X" means that "h" is disappeared.
Figure 6: Dictionary entries for [n o] and [kh o], and the corresponding connectivity matrix entry

(changed to X(nothing)).

Others "cye ccy e chye" in a word’s conjugational form, are pronounced as [ce cce che]. For example,

"ka-ci+e" ⇒ "ka-cye"
[k a c e] (have)
'cye' ⇒ [ce]

"cci+e" ⇒ "ccye"
[c c e] (cook)
'ccye' ⇒ [c c e]

Since the desyllabification is morphologically conditioned, the dictionary entries model the phenomenon according to our general guidelines. So, [k a c e] have the following many morphological forms in the dictionary:

[k a c e] "ka-ci"
(morpheme root form)
"ka-ci+e"
(root+sentential ending)
"ka-ci+e"
(root+connective verb-ending)
"ka-ci+e"
(root+aux. connective verb-ending)

However, 'yey' not in syllables "yey lyey" can be pronounced as [ey]. In these cases, two distinct entries are made in the dictionary for each morpheme.

In this way, we modeled all the Korean pronunciation rules in about 1000 entries of phoneme-sequence-to-morpheme dictionary and more than 500 lines of binary phonological connectivity matrix.

4 Pair-wise language model

The phonological connectivity matrix developed in the previous section, coupled with the morphological connectivity matrix is used as a pair-wise language model for continuous Korean speech recognizer. The morphological connectivity matrix is constructed similarly to model the Korean morphotactics using the morphological tags in the dictionary (Lee and Lee, 1992).

Figure 7 shows the architecture of the TDNN-based continuous speech recognizer. The TDNN-based phoneme recognizer gives a sequence of phoneme vectors for the input speech, and this phoneme sequence is decoded by the Viterbi lexical decoder. Tree-structured phoneme-sequence-to-morpheme dictionary is used in the lexical decoding phase and a morpheme graph is extracted after the pair-wise language model is applied. The language model checks each adjacent pair of morphemes in the graph whether they are connectable morphologically and phonologically.

The suggested model using the connectivity matrices for the phonological tags and the morphological tags is easy to construct, easy to maintain, and domain independent. A new morpheme can be added by coding one or more dictionary entries corresponding to its phonological variations.

5 Experiments

Performance of the pairwise language model is tested using the TDNN-based phoneme recognizer. Input speech is sampled at 16KHz and the mel-scaled filterbank output is used as the recognizer’s input. The TDNN phoneme recognizer is trained for all 39 Korean phonemes from the carefully selected 75 sentences (phone-balanced corpus). Using this recognizer, we do the Viterbi lexical decoding by em-
| Morphs | Targets | Correct | Deletion | Insertion | Substitution |
|--------|---------|---------|----------|-----------|-------------|
|        | 2380    | 2204    | 26       | 415       | 139         |

(92.6 %)

Figure 8: Morpheme recognition results for new 321 sentences

ploying the tree-structured phoneme-sequence-to-morpheme dictionary, and apply the proposed pairwise language model. For new 321 sentences, applying the language model produces 92.6% correct morphemes under the 70% correct phoneme recognition performance (figure 8). The evaluation is based on the DP best matching of the morpheme graphs with the correct morpheme sequences.

### 6 Conclusion

In this paper, a new scheme to represent phonological changes in Korean is suggested. A pair-wise language model of morphological and phonological tags is proposed for continuous Korean speech recognition. The proposed model has the following advantages in phonological modeling for Korean speech recognition:

- domain independent,
- easy to construct,
- easy to maintain,
- easy to add a new vocabulary.

The pairwise language model integrates speech recognition and natural language processing at the morpheme-level, and the morpheme-level integration provides the full-fledged morphological/phonological processing which is essential for agglutinative and morphologically complex languages, such as Korean and Japanese. The model can be extended to categorial bigram models which are widely used in Korean text tagging systems.

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