A Generative Model of a Pronunciation Lexicon for Hindi

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Abstract

Voice browser applications in Text-to-Speech (TTS) and Automatic Speech Recognition (ASR) systems crucially depend on a pronunciation lexicon. The present paper describes the model of pronunciation lexicon of Hindi developed to automatically generate the output forms of Hindi at two levels, the \(<\text{phoneme}\)> and the \(<\text{PS}\>\) (PS, in short for Prosodic Structure). The latter level involves both syllable-division and stress placement. The paper describes the tool developed for generating the two-level outputs of lexica in Hindi.

Index Terms: Hindi PLS, Prosodic Structure, Stress

1. Introduction

Hindi demonstrates considerable regularity in mapping the orthographic representation to pronunciation and is thus very suitable for automatic generation of pronunciation by a programme seeded with hand-written rules. In this paper we describe the model developed to automatically generate output forms at two levels—Phonemic¹ and Prosodic Structure (PS)—from the input forms in the Devanagari script in which Hindi is written. The paper is organized as follows. Section 2 presents the salient points of a pronunciation lexicon relevant to the present work. Section 3 describes the pronunciation lexicon specifications for Hindi. Section 4 briefly describes Devanagari script and the Hindi Writing system. Section 5 gives an account of the rule-based generative model for the generation of Hindi pronunciation lexica being discussed in the present paper. Section 6 reports the results of the evaluation of the programmes and section 7 presents the conclusions.

2. Pronunciation Lexicon

In order for the information on pronunciation in a given language to be easily accessible for voice browser applications, the World Wide Consortium (W3C) Voice Browser Activity Lexicon Standards has recently proposed an advanced set of standards for pronunciation lexicons in the publication entitled Pronunciation Lexicon Specification (PLS) Version 1.0.

2.1. Recommendations of W3C

The specifications of the features of a pronunciation lexicon proposed in the W3C proposals are exhaustive [1]. They can be summed up as follows:

1. PLS is intended to be the standard format of the documents referenced by the \(<\text{lexicon}\)> element of SSML. The lexicon element is an external document that is loaded by the SSML document. There can be more than one PLS document.

- A pronunciation lexicon is referenced by a SRGS grammar in an ASR processor. It can allow multiple pronunciations of a word in the grammar to represent different speaking styles.

- A pronunciation is specified in terms of the "alphabet" attribute of a PLS document. The main valid value of the "alphabet" attribute is the "ipa" or vendor-defined strings of the form "x-organization-alphabet", as for example,"x-SAMPA".

- As a PLS processor must support "ipa" as the value of the "alphabet" attribute, it must support the Unicode representations of the phonetic characters of IPA. These include a set of vowel and consonant symbols, a syllable delimiter, dialetics, symbols for prosodic features of stress, tone and intonation.

- A word in the PLS markup language is described by following elements. The details related to PLS markup language can be found in [1]:

  - The first element is \(<\text{lexicon}\>\). This element has many attributes namely—i. version ii. xml:base iii. xmlns iv. xml:lang v. alphabet

  - The second element is \(<\text{meta}\>\) or \(<\text{metadata}\>\). The meta element is optional and specified by attributes like name, http-equiv and content.

  - Other necessary elements besides \(<\text{lexicon}\>\) are \(<\text{lexeme}\>\), \(<\text{grapheme}\>\) and \(<\text{phoneme}\>\).

  - Other optional elements are \(<\text{alias}\>\) and \(<\text{example}\>\).

2.2. Letter-to-Sound Rules

The term ‘Letter-to-Sound’ (LTS) rules or ‘Grapheme-to-Phoneme’ (G2P) rules refers to rules that change orthography into pronunciation. For the suitability of the term to the Devanagari script, in which Hindi is written, a more specific term, ‘Akshara-to-Sound’ (ATS) rules in place of LTS or G2P rules, has been recently recommended and has come to be in use [2, 3].

Devanagari is a prominent representative of alpha-syllabic scripts derived from Brahmi and used for major Indic languages as well as languages outside India (e.g. Tibetan, Hankan, etc.) [4]. The linguistic level of sounds to which the Devanagari script in Hindi relates is both phonic and phonetic. The main features of A/LTS rules are discussed below.
For languages with irregular relations between orthographic and pronunciation levels, for instance, English, LTS rules can be generated automatically following data-driven approach. For languages with regular relations between orthographic and pronunciation levels, e.g. Hindi and Bangla, A/LTS rules can be generated by hand-written rules.

Some speech synthesis systems such as FESTIVAL [5] have provision for both data-driven and hand-written rules. The basic form of a hand-written rule is the following (see http://festvox.org/bsv/x1429.html):

\[(2) \text{(LC}\alpha\text{RC}=\beta)\]
Where LC is "left context on zero or more input symbols" and RC is "right context on zero or more input symbols".

Writing rules by hand can be very difficult, as it may require a full grasp of the factors involved in determining the pronunciations of words and longer utterances. The following points have to be taken into consideration in writing hand-written A/LTS rules.

(3) • A/LTS rules may refer to word boundary but cannot refer to previous or following words.
• Attention must be given to avoiding conflicting rules.
• The following factors lend complexity to A/LTS rules[6]
  - POS
  - Morphological boundary
  - Stress marks
  - Exceptions due to historical change
  - Borrowings with different A/LTS rules than regular forms
  - The length of LC
  - The length of RC

The A/LTS rules for Hindi, as we shall see below, take these factors into account and give a fairly efficient programme for converting written Hindi words into IPA representations.

For an overview of earlier studies on Letter-to-Sound rules in general as well as Indic languages[3]. It should be pointed out here, however, that attempts at Letter-to-Sound rules for Hindi have been few and far between and have focused on individual aspects, but not all aspects, of the pronunciation of words. For example [7, 8] present comprehensive accounts of the Schwa Deletion process,[9] presents A/LTS rules for segments in Urdu, and [10] proposes the use of the syllable for text-processing in a TTS system for Indian languages. In the model of PLS described here, all the aspects of segmental and prosodic features are included in a single program for a pronunciation lexicon of Hindi.

3. Pronunciation Lexicon Specifications for Hindi

The features included for the pronunciation lexica of Hindi are the following:

(4) • Letter-to-sound conversion using IPA.
• Marking of syllable structures and labeling them as prominent and non-prominent for further TTS and ASR applications.
• Preparation of the systematic variations in the pronunciations of words in Standard Hindi in two lexica, Standard Formal and Standard Colloquial varieties.
• The surface pronunciations of words with stress marks.

The features mentioned above have been taken into account, with multiple uses in mind for the learners of Hindi, TTS and ASR applications, as well as users of screen-reading software in Hindi, among others. Two levels of pronunciations are being produced: the level of segmental IPA symbols with prosodic structure in terms of syllable division and prominence (PS), and the level of segmental IPA symbols with stress marks (phoneme), as illustrated below in the Figures 1 & 2 in the form of screenshots of the input-output generation of two words.

Figure 1: Screenshots of the input-output generation of two words

4. Hindi Writing and Devnagari Script

The official script of Hindi is Devnagari or Devanagari. It belongs to a class of writing systems known as alpha-syllabic, that is, a combination of alphabetic and syllabic systems. Writing systems are alphabetic, if their units stand for phonemic/phonetic vowels and consonants (e.g. English, German). They are syllabic, if each orthographic unit in them represents a syllable (e.g. Hankul for Korean) [3]. Hindi writing encapsulates in it linguistic awareness of its speakers at multiple levels- phonetic, phonological [4, 6, 11] and morphological [12, 13] and lend it the character of a mix of surface and deep orthographic systems, rather than a simple surface orthographic system (see [14], for a discussion of the types of orthographic systems)

The main features of an alpha-syllabic script are the following:

(5) • The consonant letter has an inherent vowel, which is normally the mid central vowel /a/ or its lower counterpart /ā/.
• The inherent vowel can be deleted and the consequent form is represented with a subscript diacritic known as halant. The inherent vowel is assumed to give way to another vowel when added with a diacritic known as matra (mora).
• When not preceded by a consonant, a vowel occurs alone with a full syllabic and vocalic value, e.g. आई /aɪ/ “me-PST-FEM-SING”
• When preceded by a consonant, the vowel is represented as a diacritic (a subscript, a superscript or a lateral script along side a superscript), and is known as a *matra*, as shown in Table 1:

| Vowel Grapheme | IPA Symbol | Unicode Value | With Onset Consonants | Consonant shapes formed (e.g. with the consonant letter k) |
|----------------|------------|----------------|-----------------------|----------------------------------------------------------|
| अ | o | U+0905 | Nil | क + अ = के |
| आ | a | U+0906 | f | क + आ = का |
| इ | i | U+0907 | f | क + इ = कि |
| ई | i: | U+0908 | f | क + ई = की |

Table 1: Examples of four Hindi vowels in isolation and following onsets

• Two or three consonant clusters form ligatures, with one of the consonants (usually the last, except when it is /r/) occurring full but the others occurring half (e.g. लम /kś/, लम /śl/) or occasionally forming a new grapheme, e.g. ध (from त + र) त्रित/.

• In addition, the following superscript "'" called chandrabindu is used for nasal vowels. Another superscript "`" , a bindu (translated as point) has two values- (a) a homorganic nasal consonant, and (b) a nasal vowel. The use of the bindu for both nasal consonants as well as nasal vowels has lent indeterminacy in the orthography phonology conversion. The orthography requires lexical knowledge of its use.

5. Essential background to the Model

5.1. Variety of Hindi

There are two related lexica for two styles of Standard Hindi being described here- Standard Formal Hindi (SFH) and Standard Colloquial Hindi (SCH). They are, however, in a subset relation. SCH is a superset of SFH. SCH contains mainly two points of difference in segmental realization of words from SFH, as stated in (6) below:

(6)

• SFH maintains vowel length distinction between /i i:/ and /u u/ throughout the word; SCH neutralizes it word-finally, e.g.

| SFH | SCH | Gloss |
|-----|-----|-------|
| अटिति | अटिति | guest |
| सौमदिति | सौमदिति | trance/ mausoleum |

• Word-internal /a/ is in general deleted under certain circumstances in SCH (discussed at length in [15, 8, 7]), but is retained in SFH, e.g.

5.2. Rule-based generation of outputs

The central focus of the present programme was the generation rather then listing of the entries of lexemes in the lexicon. In order to achieve this end a well-ordered set of rules was formulated in three separate steps.

The first set of rules was of correspondence between graphemes and their IPA equivalents. All the graphemic shapes were taken into account- as single consonant and vowel letters, and as CV, CCV and CCCV aksharas, e.g., ल /kś/, ल /śl/, ल /tś/.

The second set of rules was regarding the changes in the grapheme- phoneme correspondence on account of segmental processes. These included (a) final vowel lengthening, whereby all short vowel graphemes had to correspond to their long vowel counterparts, e.g., अनलिप्त /without/ → अनलिप्त /without/, (b) word-final schwa deletion , e.g., कमल /kaml/ → कमल /kaml/. The third set of rules consisted of prosodic structure rules. These were mainly rules that involved division of words into syllables and labeling of syllables. The labeling was in two stages, in turn. In the first stage, labeling was based on three degrees of weight [16, 17, 18], namely Light (CV), Heavy (CVV/CVC) and Superheavy (CVCC/ CVVC), which were labeled as oσ, σ and σ respectively.

The second stage, the relabeling stage, was consequent on the following phenomena — (a) word-internal schwa deletion [19], which targeted /a/ in σ syllables, e.g., भान /bān/ → भाण /bān/, (b) Demotion or downgrading of σ syllables into σ syllables on account of stress clash, e.g., एक /a:क/ → एक /a:क/ 'easy'; (c) and promotion or upgrading of σ syllables as σ in disyllabic words as σ syllables, e.g., एक /a:क/ → एक /a:क/ 'how much-fem'. The second stage of rules was ruled by the paradigm — a stay /CV/ a heavy stress /CVV/ a super heavy stress /CVCC/.

An earlier programme of PLS took into account the phenomenon of consonant gemination as part of the second set of rules. Consonants in Hindi are geminated or lengthened when preceding /l/ and /r/, /j/. The rule can be stated as (C+r/l/ → C1C+r/l/), e.g., मार/→ [mār]; 'friendship' and स्वामी /śvāmī/ → and [śvāmī] 'necessary'. This feature is underspecified in the orthography [11]. It has been left out of the final version of the model on the grounds of its suitability to TTS and ASR systems. We find that the duration of geminates /tI/, etc. is not the double of singlets, but of less duration. For example, it was found that the duration of single /tI/ and /lI/ was 0.96 and 0.91 respectively, and of geminates of 1.10 and 1.06 ms. in doublets such as /pota:/ address and /pota:/ leaf, and /holā/ to trouble /holā/ bat(N). In such a case the duration of the geminate consonants can be roughly predicted by rule for the given contexts. Besides, the programme was simpler without the rule of gemination.
The full derivations of four forms kṣaraḥ/कषराः ‘exercise’ and वनस्पतिः/वनस्पतिः ‘prancing’, प्रकृति/प्रकृतिः ‘nature’ and सालमा/सालमा ‘yearly’ by applying the A/LTS rules of Hindi are given in Table-2 below. Gr stands for Grapheme.

5.3. Treatment of exceptions

In order for efficient automatic generation of orthographic forms of Hindi words into prosodic structure and IPA symbols by means of hand-written rules in the model, it was necessary to include an Exceptions component which is fed with the output of given words that are not in conformity with the rest of the outputs (see [20] with a similar suggestion for Tamil). These are the following in the main:

(7)

a. Native vocabulary
i. Limited sets of forms with some prefixes and compounds without internal word-boundaries. For example, /husama/ ‘good time’ and /kusama/ ‘bad time’, in which the schwa in the first syllable will be wrongly deleted. *[susma] and *[kusma] in place of [susma] and [kusma].
ii. Non-honorific Imperative forms of verbs ending in the suffix /-al/. For example, /di khaz/ ‘show-CAUS+IMP+NH’ versus /di khaz/ ‘was seen’.
iii. Complex words with O-O correspondence relation with simple words. For example, the plural forms of feminine nouns /maṭṭi/ ‘fish’ and /tiṭṭi/ ‘butterfly’ as /maṭṭi-ph-PL/ ‘fish-PL’ and /tiṭṭi-ph-PL/ ‘butterfly-PL’. The output forms with stress following the regular A/LTS rules would be *[maṭṭi]-pl/i/ and *[tiṭṭi]-pl/i/ instead. The latter are placed in the Exceptions component.
iv. The use of the diacritics of bindu and chandrabindu in Hindi orthography for two phenomena- vowel nasalization and nasal consonant. Although they are in complementary distribution in general, with the chandrabindu standing for a nasal vowel, and the bindu standing for a nasal consonant, as in /mānta/ /phanda/ ‘trapped (PASS)’ and /kṣara/ ‘noose’, in actual use there is a lot of free variation.
b. Borrowed English vocabulary: words borrowed from English containing short vowels but non-distinctive diacritic (matra) for the vowels [ə e i], e.g. कृति ‘colleague’. The rule-based form here would be *[kṛtii]. The regular pronounced form is *[kṛtii].

6. Evaluation

The PLS programme for Standard Colloquial Hindi was taken for evaluation, as it contained more features for evaluation than the programme for Standard Formal Hindi, as discussed in section 5.1. The data used for evaluation came from a BBC word corpus containing 28731 words. An expert for the pronunciation of the words first annotated the words and then the output of the machine was compared against the annotated list. The following factors were taken into account in evaluating the model:
a. Only the regular features of pronunciation were considered.
b. A transcription was considered correct if it contained one of the main features of akshara-to-sound correspondence in the expected context, as described.
c. In evaluating the model for the regular features of pronunciation, the factors relating to exceptions had to be excluded. Out of the total number of 28731 words tested, the number of words with the diacritics bindu and chandrabindu for the realization of nasal consonants and nasal vowels was 3705 and with deletable schwas 14460. For stress marking as well as for the akshara-to-phoneme correspondence, the entire corpus of 28731 words was considered relevant. For the marking of stress, although only polysyllabic words were relevant, we had to ensure that monosyllabic words were not marked redundantly for stress. Thus the entire corpus of 28731 words was relevant for stress. The result of the analysis of errors is presented in Table 3 below:

7. Conclusion

Developing a programme for generating a pronunciation lexicon for standard Hindi involved coming to terms with several issues described above. The programme began with generating initial grapheme to phoneme correspondences. However, in an attempt to automatically generate the final output at the <phoneme> level it was found that the mixed nature of the Hindi orthography with both surface and deep correspondences made it necessary to automatically generate the internal word-prosodic structure on which the main aspects of segmental realization of forms depended. The present model of pronunciation lexicon for Hindi can be easily applied to other akshara-based orthographic systems with mixed level orthographies. In addition, the contributions extend beyond the scope of a pronunciation lexicon and have general applicability for automating syllable-based processes and stress patterns in South Asian languages.

8. References

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| Rule Applied | Output-1 | Output-2 | Output-3 | Output-4 |
|--------------|----------|----------|----------|----------|
| ATS Rule-1: 1, 2, 3 Akshara-PA Correspondence rules | $\text{kasarota}$ | $\text{manjalatid}$ | $\text{prakritis}$ | $\text{satlanat}$ |
| ATS Rule-4: Final Schwa Deletion | $\text{kasaro}$ | DNA | DNA | DNA |
| ATS Rule-5: Final Vowel Lengthening | DNA | DNA | prakriti: | DNA |
| ATS Rule-6: Syllabification | $\text{kasarot}$ | $\text{sa}$ | $\text{sa}$ | $\text{sa}$ |
| ATS Rule-7: Syllable Labeling by Weight | $\sigma^*$ $\text{maor}$ | $\sigma^*$ | $\sigma^*$ | $\sigma^*$ |
| ATS Rule-8: Syllable Extra-metricality | $\sigma^*$ $\text{maor}$ | $\sigma^*$ | $\sigma^*$ | $\sigma^*$ |
| ATS Rule-9: Syllable Relabeling, Downgrading | DNA | DNA | DNA | DNA |
| ATS Rule-10: Syllable Relabeling, Upgrading | $\sigma^*$ $\text{maor}$ | $\sigma^*$ | $\sigma^*$ | $\sigma^*$ |
| ATS Rule-11: Internal Schwa Deletion | $\sigma^*$ $\text{maor}$ | DNA | DNA | DNA |
| ATS Rule-12: Resyllabification | $\sigma^*$ $\text{maor}$ | DNA | DNA | DNA |
| ATS Rule-14-15: Leveling and Stress Mark Assignment | $\text{kasaro}$ | $\text{lom}$ | prakriti: | $\text{sa}$ |

Table 2: Rule Application and output

| The Phenomena Tested | Words | Wrong Outputs | Percentage Accuracy |
|----------------------|-------|---------------|---------------------|
| Nasal                | 3705  | 82            | 97.79               |
| PS Structure         | 28731 | 254           | 99.12               |
| Schwa Deletion       | 14460 | 116           | 99.20               |
| Anusvara/Anunasika   | 700   | 2             | 99.72               |
| ATS Correspondence   | 28731 | 0             | 100                 |

Table 3: Performance of the proposed system

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