Automatic Syllabification of Bengali in SPPAS

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***Abstract*—This paper describes the automatic syllabification process of Bengali speech in SPPAS software. The process of detecting syllable boundaries has been carried out using a rule-based system applied to the permissible syllable structures of Bengali. Syllable structures of Bengali has undergone a fair amount of research. In this paper, we verify the existing syllabification rules of Bengali through a speech corpus and then describe its implementation through the resource toolkit of SPPAS software. Finally, by evaluating the automated syllabification system with the manually aligned syllables of the corpus, we have successfully implemented this automatization task, which can significantly help to syllabify large scale speech and text databases in Bengali.**

***Index Terms*—automatic annotation systems, syllabification, Bengali syllable, syllable boundary detection, speech technology**

I. Introduction

This paper describes the implementation of automatic syllabification system in Bengali language. This automated system has been based on a rule-based approach, that defines the rules of segmenting the constituting syllables within a word in Bengali. Automatic syllabification is the final step in the multi-platform software SPPAS which carries out speech segmentation, phonetization and alignment of speech data. We have already created the linguistic resources necessary for implementing segmentation, phonetization and alignment of Bengali speech and its corresponding orthographic text in SPPAS. The analysis of Bengali syllable patterns in a speech corpus and addition of its syllabification rules within the resource module of this annotation software helps us achieve automated linguistic annotations that might be primarily required by a linguist to analyse a large-scale speech corpus in Bengali.

A syllable despite being a foundational unit in the linguistic analysis of speech, does not have a universally agreed upon definition. It is a unit of sound in spoken language that typically consists of a vowel nucleus, along with optional preceding and/or following consonants. Additionally, it serves as a crucial unit of rhythm, stress, and intonation for understanding the phonological structure of speech (Crystal, 2003; Ladd, 2008). But the syllable has been defined with varying perspectives ranging from phonetic to phonological, and even psycholinguistic interpretations. While Ladefoged (2001) defines a syllable as a unit of sound characterized by a single peak of sonority (loudness) focusing purely on the physical properties of speech sounds; linguists such as Chomsky and Halle (1968), define syllables in terms of abstract phonological units. In contrast from the psycholinguistic perspective, syllables are not just phonetic or phonological units but also cognitive units that play a role in language comprehension and production (Levelt, 1999). Nonetheless, syllables have been used as the basic units for building TTS systems in Bengali.

The structure of a syllable is often delineated using the consonant-vowel (C-V) framework, with different languages exhibiting unique syllabic structures, from simple vowel-only syllables in Hawaiian to complex consonant clusters in languages like Russian and Arabic (Elbert & Pukui, 1979; Kenstowicz, 1994; Watson, 2002). Syllabification of a string of phonemes is governed by a set of principles and constraints, such as the Maximal Onset Principle and the Sonority Sequencing Principle, which dictate the division of phonemes into onset, nucleus, and coda within a syllable (Kahn, 1976; Clements, 1990). Then there is the legality principle (Goslin and Frauenfelder, 2001) that validates the legality of the syllable structures in the onset and coda positions.

Automatic syllabification is a crucial component in various Natural Language Processing (NLP) applications like Text-to-Speech (TTS) systems, ASR systems, machine translation, language modeling and such. Being a prerequisite in these application domains, automatic syllabification processes help in increasing the naturalness and intelligibility of the synthesized speech (Krishnan et al., 2019); segmentation of continuous speech into smaller units, which facilitates the recognition process (Rao et al., 2016). Also syllable-based language models have been shown to outperform character-based models in some languages (Sproat, 2001).

Bengali is one of the languages spoken in the Indian subcontinent that historically belongs to the Indo-Aryan (IA) family of languages. Spoken by almost 230 million people as their native language and 37 million as their second-language (Ethnologue, 2021), it currently holds the seventh position among the world's languages2. Bengali is one of the official languages of India and the national language of Bangladesh. It is spoken primarily in Bangladesh and the Eastern Indian states of West Bengal, Tripura, parts of Assam. In this paper, we deal with the Standard Colloquial Bengali (SCB) variety which is spoken mostly in and around Kolkata. Bengali syllable structures have been thoroughly studied for almost a century, in the works of Chatterji (1926b, 1986);

Ray et al. (1966); Sarkar (1986); Dan (1992); Sen (1993); Bhattacharya (2000); Dasgupta (2003); Kar (2010). But the adaptation of automatic syllabification systems has been very negligible in Bengali. As far as our knowledge, there are no current phonetic and speech analysis software available that performs automatic syllabification of Bengali speech data. Our rule-based syllabification approach based on the Bengali syllable patterns can be considered a preliminary approach in the development of such necessary systems for the language.

II. RULE BASED SYLLABIFICATION SYSTEM

A. Bengali Corpus Description

For the purpose of creating a set of syllabification rules in a language one needs to have a good quality speech corpus or text corpus along with a phoneme list, a vocabulary list sufficiently representative of the language and a pronunciation dictionary.

In order to use standardized speech data of Bengali for creating necessary linguistic resources, we have used an open-source speech database created by Google to develop Text to Speech (TTS) systems. The data consists of audio recordings of short phrases/sentences, a pronunciation lexicon, a vocabular list and a phonology definition of Bengali3. All the data have been released under the Creative Commons Attribution 4.0 international license (CC-By-NC-4.0).

The vocabulary list contained approximately 65000 lexical entries of Bengali, including many loan words. The dictionary entries provide a broad phonemic transcription of colloquial Bengali in the Bangladeshi Standard variety. Therefore we manually corrected each of the lexical items in the list to suit our required Standard Indian variety of Bengali speech. Moreover, the transcription was carried out in SAMPA notations to suit our application needs in SPPAS. We have manually carried out the syllabification of this entire vocabulary list in order to gain a clear knowledge of Bengali phonotactics. The distribution patterns of the phoneme sequences in a language are an essential prerequisite in applying the rule-based syllabification approach to the speech corpus.

B. Rule Based Syllabification approach

Rule-based approach and Data-driven approach are the two primary approaches for implementation of automatic syllabification of a language. SPPAS software requires the use of the rule-based approach to define the syllable patterns that exist in a language. This system of syllabification was initially integrated in SPPAS for French (Bigi et al., 2010) and then adapted for Italian (Bigi and Petrone, 2014) and Polish.

Since rule-based method are highly language-specific, they require concise phonological descriptions of the syllable structure in that language. As mentioned earlier, Bengali syllable structure is a very well-researched linguistic unit. Therefore, the application of rule-based approach for executing automatic syllabification in Bengali is quite evident in this respect. Some recent studies (Marchand and Damper, 2007; Marchand et al., 2009) show that rule-based methods perform poorly compared to the data-driven. Yet as preliminary approach to the syllabification task suitable for the requirements of the software, we have adopted this rule-based approach for segmenting syllables in Bengali.

Nonetheless, this approach is constrained by some phonological principles that guide the placement of a syllable boundary within a phoneme sequence. One such widely discussed is the Sonority Sequencing Principle which explains that the sonority of segments rises towards the nucleus and falls towards the coda, where the nucleus is the most sonorous element in a syllable. (Selkirk, 1984). Then there is the Maximal Onset Principle, according to which consonants are syllabified as the onset of the following syllable whenever possible unless it contradicts the sonority principle (Kahn, 1976). Bengali syllables are known to closely follow these two principles (Dasgupta, 2008). But the Principle of Maximum Open Syllabicity (Pulgram, 1970) suggests that languages prefer open syllables (syllables that end in a vowel) over closed syllables (syllables that end in a consonant), emphasizing the preference for onsets over codas. This is clearly not the case in Bengali that is characterized by a lot more complex syllable structures with closed syllables and even consonant clusters.

III. SPPAS SYLLABIFICATION SYSTEM

In this section, we report on the adaptation of a rule-based system for automatic syllabification of phoneme strings of the size greater than a graphic word. SPPAS is a multi-platform speech annotation toolkit, that requires some bare minimum linguistic resources for incorporating a new language that can be easily handled by linguists (Bigi, 2015). Among other functions, SPPAS offers an automatic speech segmentation, phonetization, annotation in multiple formats (such as X-SAMPA, IPA), alignment and prosodic analysis of utterances using the Momel-INTSINT algorithm (Hirst and Espesser, 1993; Hirst, 2011) incorporated within the software itself. Furthermore, various statistical analyses can also be done on the annotated speech data. Linguistic resources of languages such as French, English, Spanish, Italian, Catalan, Polish, Mandarin Chinese, Cantonese, Taiwanese and Japanese have already been implemented in SPPAS.

A. Bengali Syllabification Structure

Before delving into the syllable structures of Bengali here is a brief glimpse into the phonological units of this Indo Aryan language. Phonemically, Bengali features 30 consonants along with 7 oral and 7 nasal vowels. Below is a list of the consonants written in SAMPA notation:

- the 30 consonants /k, $k\_h, g, g\_h, p, p\_h, b, b\_h, t, t\_h, d, d\_h, t`, t`\_h, d`, d`\_h, c, c\_h, dZ, dZ\_h, s, S, h, l, r, r`, r`\_h, m, n, N/$
- the two glides /j, w/
- the 14 vowels $/a, \{, e, i, O, o, u, a\sim\ , \{\sim\ , e\sim\ , i\sim\ , O\sim\ , o\sim\ , u\sim\ /$

Along with these phonemes, some more phonemes were added to the phoneme list for defining some sounds in loan words of Bengali. One of them is the consonant /f/ and the schwa vowel /@/, which is often deleted in Indian languages.

TABLE I
POSITION DISTRIBUTION OF BENGALI SYLLABLE PATTERNS

Position Distribution of Bengali Syllable Patterns					
	Syllable Pattern	Beginning	Middle	End	Total
1	V	9.72	6.58	5.79	22.09
2	VV	1.06	0.36	0.03	1.45
3	VC	5.31	1.48	1.84	8.63
4	CV	46.1	56.15	41.72	143.97
5	CVC	25.35	20.37	42.25	87.97
6	CVV	4.62	7.39	0.72	12.73
7	CCV	4.69	5.6	3.42	13.71
8	VCC	0.11	0.01	0.23	0.35
9	CVCC	0.58	0.03	1.16	1.77
10	CCVC	1.86	1.19	2.34	5.39
11	CCVV	0.25	0.52	0.07	0.84
12	CCCV	0.06	0.28	0.12	0.46
13	VCCC	0.02	0	0	0.02
14	CCVCC	0.13	0	0.16	0.29
15	CCCVC	0.06	0.03	0.08	0.17
16	CVCCC	0.04	0	0.05	0.09
17	CCCVV	0.02	0.01	0	0.03
18	CCVCCC	0.01	0	0	0.01
19	CCCVCC	0	0	0.01	0.01
20	CCCVCCC	0	0	0	0

The phonemes were then categorized into classes based on their place of articulation to determine the contents of the syllable patterns. The phoneme classes are:

V - Vowels: a { e i O o u $a\sim$ {$\sim$ $e\sim$ $i\sim$ $O\sim$ $o\sim$ $u\sim$ @

G - Glides: j w

L - Liquids: l r r' r'_h

P - Plosives: k k_h g g_h p p_h b b_h t t_h d d_h t' t'$\_h$ d' d'$\_h$

F - Fricatives: s S h f

A - Affricates: c c_h dZ dZ_h

N - Nasals: m n N

The manual syllabification of almost 65000 lexicon entries in the vocabulary list of the Google corpus helped us to identify the syllable patterns found in Bengali speech. As seen in Table I, the most common syllable patterns of Bengali are CV and CVC which confirmed earlier studies. Dipthongs (VV) along with Vowels (V) are also considered to be the peak of the syllable. Bengali vocabulary consisting of both Sanskrit and other foreign language borrowed words apart from its native words exhibit different syllable patterns in each of its lexicon strata. Onsets are completely optional, but they might as well be complex but only for borrowed words. There are complex codas in other language borrowed words but not Native and Sanskrit derived words (Kar, 2010). There is no onset- maximization in the language, so word medial clusters as well as geminates become hetero-syllabic (Dan 1992). The only exception to this scenario is when the final consonant is a liquid (r/l) within a cluster. Although a debatable scenario, an intervocalic glide becomes the onset of the next syllable (Kar, 2010).

Figures 1 and 2 show distribution of different phoneme classes in the beginning, middle and end positions of a word and gives an in-depth view of Bengali syllable structure. While

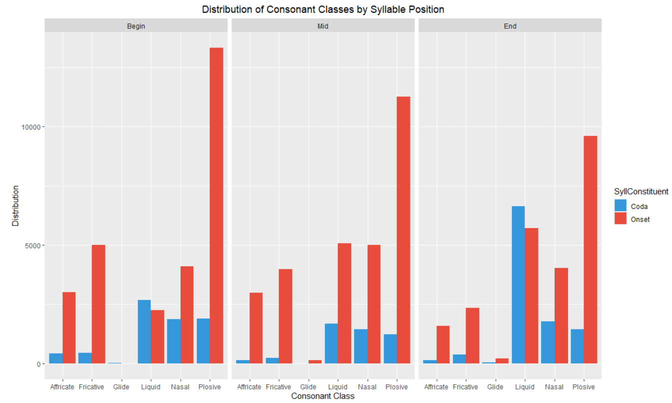

Fig. 1. Distribution of Consonant Classes by Syllable Positions

the occurrence of plosives is much higher in the beginning position than the middle and end, glides and nasals show quite the opposite scenario with more appearance in the middle and end positions.

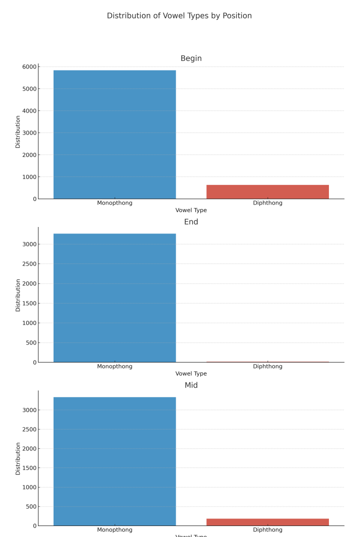

Fig. 2. Distribution of Vowel Types by Position

B. Syllabification Rules

In dealing with the automatic syllabification of a phoneme sequence in SPPAS, the proposed phoneme-to-syllable segmentation system is based on 2 main principles:

1. a syllable contains a vowel, and only one;
2. a pause is a syllable boundary.

These two principles focus the problem on the task of finding a syllabic boundary between two vowels in each Inter-Pausal Unit (IPU). By grouping of phonemes into classes as mentioned in the previous section, we establish language-specific rules dealing with these classes. The identification of relevant classes is therefore very important.

The rule-based syllabification rules are specified for Bengali in two categories as seen in Table II and III. Table II shows

TABLE II

General Rules			
	Observed sequence	Segmentation rules	Examples
1	VV	VV	moria [mo.ria] 'desperate'
2	VXV	V.XV	OboSeSe [O.bo.Se.Se]'finally'
3	VXXV	VX.XV	amra [am.ra] 'we'
4	VXXXV	VX.XXV	apluto [ap.pluto] 'elated'
5	VXXXXV	VXX.XXV	SONSkriti [SON.Skri.ti]'culture'

TABLE III

Exception RUles			
	Observed sequence	Segmentation rules	Examples
1	VGV	V.GV	atulonijo [a.tu.lo.ni.jo] 'incomparable'
2	VPLV	V.PLV	aklanto [a.klan.to] 'immensly tiring'
3	VFPLV	V.FPLV	strit [strit] 'street'

the General rules defining the generic rules of segmenting syllables within a word. And the Exception rules in Table III mention the cases of phoneme patterns that should not follow the above general rules. Every lexical item first runs through the exception rules first and if none of the criteria fits, they follow the general rule to mark the syllable boundary.

C. Implementation in Configuration file

The General and Exception rules are specified within a simple ASCII text file named as 'syllConfig-ben.txt'. The file starts with the list of phonemes and their respective class symbols as:

PHONCLASS i V

PHONCLASS r L

The second part of the file contains the syllabification rules are made as:

GENRULE VXV 0

EXCRULE VGV 0

Here the first column is a rule-type, second column is the classes between two vowels; using the letter X to mention a non-vowel phoneme such as G, F, P, L, A only in case of General rules. In case of Exception rule we mention the phoneme class as G, F, P, L, A to illustrate the phoneme sequence. The final third column specifies the boundary location; where 0 means the boundary is after the first vowel, 1 means the boundary is one phoneme after the first vowel, etc.

IV. EVALUATION OF SPPAS SYLLABIFICATION

The implementation of syllabification rules in SPPAS is very easy and quick. We need to place the configuration file created by following the above-mentioned guidelines and place it inside the subfolder named 'syll' within the resources folder. With that building our linguistic resources' package for the language is complete. Along with the already trained acoustic model, pronunciation dictionary, vocabulary list and some other files containing the transcription of the numerals and other symbols that may be found in the language corpus, we can now begin to segment and annotate our speech corpus. Starting with segmenting of Inter-pausal units (IPU) and silences, phonetization, alignment and finally syllabification of an utterance can now be carried out.

A. Test Corpus

While applying the syllabification module of Bengali in SPPAS, we have used a prosodically enriched data set of Bengali language, developed by C-DAC (Centre for Development of Advanced Computing) Kolkata. This seech data has been recorded of both male and female informants (5 each) belonging to the age group 20 to above 40, who speak Standard Colloquial Bengali (SCB). Both reading and conversational speech of varied prosodic patterns have been represented in this data. The data speech has been manually annotated for syllables by an experienced linguist, who is also a native speaker of Bengali. We have also verified the syllable markings in the tagged files corresponding to the speech files.

We selected speech belonging to both the categories of single sentence/utterance and conversation dialogue passages. The single utterances have different syntactic and intonation patterns of simple affirmative and simple negative, Passive, Imperative, Exclamatory, Interrogative (Yes/No and Wh-questions). The speech data was of 1 male and 1 female speaker. The total duration of the data was of 22.74 minutes approximately. The reason behind implementing these syllabification rules on such a prosodically representative dataset being that rule-based systems can perform well in the context of singular words and even text corpus, but not so much in continuous speech. In continuous speech the rapidly changing intonation and stress patterns falling on the syllables creates ambiguity for the system to segment syllables from the string of phonemes.

B. Automatic syllabification evaluation

The rule-based syllabification system of SPPAS performed quite well with respect to Bengali speech corpus. An example sentence of a Bengali sentence can be seen in Figure 3. Out of the 1634 syllables that were manually marked in the selected utterances of the corpus, the automatic syllabifier algorithm marked about 1528 syllables correctly. Therefore

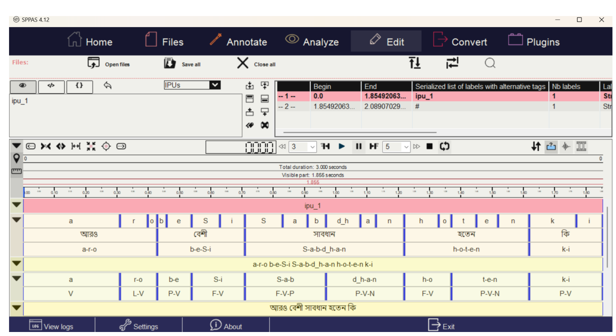

Fig. 3. SPPAS output example of a Bengali sentence

achieving an accuracy of about 93.512%, with an error rate of approximately 6.47%.

C. Results and Discussion

The major problem faced by the automatic syllabification system is in identifying final syllable boundaries when the word ends in a dipthong. Some sporadic problems were also present while segmenting cluster consonants especially geminates. One advantage of SPPAS syllabification system is that even when it encounters unknown words that was not present in the pronunciation dictionary, it is able to predict its phonetization and syllable patterns quite efficiently.

V. Conclusion

This attempt at enforcing automatic syllabification in Bengali speech will enable carrying out basic phonetic and phonological analysis of large-scale speech databases, which otherwise becomes very laborious and subjective. The annotation files generated within SPPAS for each level of segmentation including syllabification can be converted to Praat textgrid files for further analysis. These annotations can also be statistically analysed within SPPAS itself. Further improvement of the efficiency of the current syllabification system will remain as a future scope of this work.

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