A SYLLABIFICATION ALGORITHM FOR STANDARD SWEDISH

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ABSTRACT

The syllable as a linguistic unit has been the object of much dispute. Even when there is agreement about the number of syllables in a linguistic word, or string of words, spoken distinctly and in isolation, a great number of diverse algorithms has been proposed for syllabification in different languages. A phonetically oriented investigation has started in order to study, from a cross-language perspective, syllabification in spoken Standard Swedish, Greek and French. After having tested six different syllabification algorithms for Standard Swedish in a pilot study, a speech sample of 2001 syllables from two speakers was analysed into syllables by applying the principles of Maximal Onset, Phonotactic Syllable Constraints within the domain of prosodic phrases. This was done independently of morphological boundaries or any sonority hierarchy.

1. INTRODUCTION AND AIM

It is currently understood that prosodic features have a very high significance for the listener. They are fundamental to fast lexical access [1]. One important aspect of identifying elements of meaning (be it root morphemes, derivational or inflectional morphemes, words of various kinds or phrases) is their coding into segments, syllables and larger linguistic units like prosodic phrases. In the bottom-up process, acoustic cues in the speech signal are used by the listener in order to decode words.

The aim of this study is twofold: First, in an exploratory investigation, to test various rules for syllabification in Swedish which have been posited in the litterature, and second to apply a new syllabification algorithm, determined as a result of the test procedure, to a sample of spoken Standard Swedish and to analyse the results thoroughly. The analysis will include distributional data and duration measurements. Due to the contrastive frame work of the project, the investigation is carried out with a view to a larger cross-language study including Greek and French.

2. SOME REMARKS ON THE NOTION ”SYLLABLE”

The starting point chosen for this investigation is the fact that Swedish learners of French as a foreign language have demonstrably greater difficulties in understanding spoken French than spoken English or German. When trying to find an explanation for this imbalance of linguistic behaviour, the way of coding words into the speech wave provides a useful point of departure. There is a remarkable difference in syllabification of words into syllables between French, on the one hand, and the Germanic languages English and German, on the other. The most striking difference is the presence of the two phonological processes ”enchaînement” and ”liaison” in French resulting in a form of resyllabfication not to be found in the Germanic languages. It is generally assumed that the domain for syllabification in French is the rhythmical group (groupe rythmique) whereas in the Germanic languages the word is used as the domain.

Contrary to the general opinion in the literature, it could be asked if the phenomenon of enchaînement, e.g. the syllabification of segments into syllables starting with a consonant, typical of French, exists in Germanic languages, too. This seems to be the case in Swedish when the word beginning with a vowel appears unstressed in a sentence context. For instance:

(1a) ”Karl **vill ära** en ‘hjälte ...
(Karl wants to honour a hero ...)

(1b) ”Karl **vill lära** en ‘hjälte ...
(Karl wants to teach a hero ...)

(1a’) karl - **vi- lä - ra**- en - hjäl- te

(1b’) karl - **vi - lä**- **ra** - en - hjäl- te ...

The first word has focus accent marked ”, the last one has only word accent marked ‘. The syllables in between are unstressed.

3. SWEDISH SYLLABLES

Swedish, as a Germanic language, has a rather complex syllable structure, although there are languages with an even more complex structure. It is necessary to make a distinction between syllables that are morphemes by themselves and syllables that are part of polysyllabic morphemes or words. A review of different syllabification principles for Swedish is to be found in [2].

It is not surprising to find that, in Swedish, as in other languages, there is no generally agreed upon principle for syllablification. In Swedish, the matter is more complicated than, for example, in French because Swedish has the prosodic features of quantity (phonologically distinct segment length with its characteristic temporal pattern of complementary length) and accent (word stress).

4. THE INVESTIGATION

As has been shown, there is no unanimous principle for syllabification in Swedish to be found in the literature. Therefore, before analysing a larger corpus, it was felt necessary to systematically study the effect of various syllabification algorithms. This was done in a methodological study using a small part of the total corpus [3]. The results of the pilot study constituted the basis for determining a satisfying syllabification algorithm for Swedish to be applied to the large corpus. The

expectation was not to find a perfect algorithm but rather to gain new and deeper insights in the problem of syllabification, especially from a contrastive persepctive. A comprehensive description of the investigation is to be found in [2]. Taking all this into consideration, the following algorihtm was chosen for the analysis fo the larger corpus in the main study:

Maximal Onset
Phonotactic Constraints
Splitting of Long Consonant (following stressed short vowel)

The main study contained 2,001 syllables, 999 for the female and 1002 for the male speaker. The total duration of the speech samples was 9 minutes and 19 seconds.

5. RESULTS

All results are presented for each speaker individually and pooled for both speakers as well. This is done in order to show the individual behaviour. The following aspects are dealt with: the occurrences of the two syllable types open vs closed, the various syllable structures, and the duration of syllables according to syllable type, syllable structure, effect of stress and phrase boundaries.

5.1. Occurrences/number of syllables

The female speaker had 62% open and 38% closed syllables, the male speaker had 56% open and 44% closed syllables, respectively. Pooled there were 59% open and 41% closed syllables in the Swedish material. The different syllable structures and their distribution for each speaker individually and the percentage pooled for both speakers are shown in Table 1.

Table 1 shows very clearly that in this corpus two syllable structures dominate (indicated in bold face). Among the open syllables (59% in total), the structure /CV/ accounts for 40%, among the closed syllables (41% in total), the structure /CVC/ accounts for 23% of all syllables. The rest of the syllable structures amount to a few percent only. Many structures appear only a few times in the material. this is, of course, a consequence of the relatively small corpus analysed.

Table 1. The different syllable structures and their distribution for each speaker individually and the percentage pooled for both speakers.

Syllable structure	Speaker					
	Male (n=1002)		Female (n=999)		Pooled (n=2001)	
	number n	%	number n	%	number n	%
OPEN:	563	56.2	620	62.1	1183	59.1
V	55	5.5	64	6.4	119	6
VV	10	1.0	21	2.1	31	2
CV	**383**	**38.2**	**424**	**42.4**	**807**	**40**
CVV	50	5.0	59	5.9	109	5
CCV	50	5.0	34	3.4	84	4
CCVV	14	1.4	18	1.8	32	2
CCCV	1	0.1	0	0	1	0
CLOSED:	439	43.8	379	37.9	818	40.9
VC	53	5.3	30	3.0	83	4
VCC	5	0.5	1	0.1	6	0
VCCC	0	0	1	0.1	1	0
VVC	2	0.2	3	0.3	5	0
VVCC	1	0.1	1	0.1	2	0
CVC	**243**	**24.3**	**226**	**22.6**	**469**	**23**
CVCC	35	3.5	39	3.9	74	4
CVCCC	1	0.1	1	0.1	2	0
CVVC	31	3.1	29	2.9	60	3
CVVCC	4	0.4	3	0.3	7	0
CCVC	30	3.0	32	3.2	62	3
CCVCC	10	1.0	3	0.3	13	1
CCCVC	0	0	1	0.1	1	0
CCCVCC	1	0.1	0	0	1	0
CCVVC	13	1.3	5	0.5	18	1
C	7	0.7	4	0.4	11	1
CC	3	0.3	0	0	3	0

5.2. Durations

Means and standard deviations of syllables durations for each speaker and pooled for both speakers are calculated. Durations of syllable types and syllable structures are given for different aspects: syllable type (open/closed), syllable structure, effect of different levels of stress and of phrase boundaries (see [3].

6. SYLLABIFICATION ALGORITHM (CONVENTIONS AND RULES)

Based on the results of the pilot study, and the results of the main study, a new test algorithm is defined. It is based on the principle of Maximal Onset favouring open syllabels, the Splitting of long consonants and on Phontocatic Syllable Constraints within the domain of the prosodic phrase. It differs only in one rule from the algorithm applied in the main study in that it takes care of the remaining elements /C/ and /CC/. They are to be found before a phrase boundary, the limit of the domain of the syllabification algorithm. It consists of two parts: the pre-conditions (input string and conventions) and the syllabification rules. They, in turn, consist of the basic syllabification rule proper and three admjustment rules.

6.1. Pre-conditions

Input structure: string of phonological symbols (segmental and prosodic):

V, C	two segmental categories: V = vowel, C = consonant
|	minor (weak) phrase boundary
||	major (strong) phrase boundary

Direction of application: left-to-right (parallel to production)

Knowledge of phonotactic constraints

6.2. Syllabification rules

Rule 1. Insert a syllable boundary (**.**): after each vowel.

Rule 2. Adjust to the following structural conditions:

2.1 Long consonants: split the long /C:/ into two C, the first one becomes coda.

2.2 Consonant cluster: move syllable boundary to the right as phonotactic constraints permit.

2.3 Isolated consonants or clusters (left overs): adjoin to the left (delete syllable boundary inserted according to Rule 1).

The working of the algorithm is illustrated in two examples below (| denotes phrase boundary, SAMPA transcription)).

Example 1

orthography	genom engelsmännen (by the Englishmen)
labelling (phonetic transcription)	[j en Om E N: El s mEn:En]
CV -layer	| CVCVC VCCVCCCVCCVC |
Rule 1 (insertion of syllable boundary)	| CV.CV.C V.CCV.CCCV.CCV.C |
	| CV.CV.C V.C**C**V.CCCV.C**C**V.C |
Adjustments:	| CV.CV.C VC.**C**VCC.CVC.**C**V.C |
Rule 2.1 (Long C)	| CV.CV.C VC.**C**VCC.CVC.**C**VC |
Rule 2.2 (Phonotactics)	[je. nO. m EN.NEl s. mEn. nE n]
Rule 2.3 (Left overs)	
Syllabification	

Example 2:

orthography	det är en ganska traditionsrik sport (this is a rather traditional sport)
labelling (phonetic transcription)	[de: Eng a~s k athr a d i ɧu:n s r i: ks p O ʈ]
CV -layer (input structure)	| CVVVCCVCCVCCVCVCVVCCCVVCCCVC |
Rule 1 (insertion of syllable boundary)	| CVV.V.CCV.CCV.CCV.CV.CVV.CCCV V.CCCV.C |
Adjustments:	
Rule 2.1 (Long C)	
Rule 2.2 (Phonotactics)	(void)
Rule 2.3 (Left overs)	| CVV.VC.CV.CCV.CCV.CV.CVVCC.CV VC.CCV.C |
Syllabification	| CVV.VC.CV.CCV.CCV.CV.CVVCC.CV VC.CCVC |
	[de: .EN. ga~.**s** ka .thra .d i .ɧu:n s .r i: k.s p O ʈ]

It should be noted that no word boundaries nor a (phonetically motivated) sonority hierarchy are needed.

7. DISCUSSION

According to the algorithm applied, on the average, 59% of the total number of syllables were categorized as open and 41% as closed syllables. This is clearly a different finding compared to the percentages given in the literature. [4] gives 37% for open syllables in German and 40% in English. In spite of this, there seems to exist a clear difference with respect to the distribution of open and closed syllables in these Germanic languages and French. In the calculation by [5] where word boundaries and the sonority hierarchy are ignored, the percentages are 82% open and 18% closed syllables. In her study, the domain for syllabification was also the prosodic phrase and not the word.

This investigation has shown that a clear distinction has to be made between phonological syllables on the word level, i.e. in the lexical domain, and phonetic syllables in running speech, unscripted as in the present investigation or read aloud. If a universal stand point is taken, syllabification algorithms can be described as follows: There is a fundamental part that applies to all languages, namely the Maximal Onset Principle which operates in the domain of prosodic phrases. It results in open syllables only . Such an algorithm works very well if the language does not have any aggravating or intervening phonological features. Those can be the special status of a segment, e.g. the /s/ in French in relation to other consonants, or prosodic features like stress and quantity. Upon this basic part of the syllabification algorithm, language specific rules are added that take into consideration the special features of the language in question. For Swedish, for instance, the quantity pattern of complementary length in the sequences of stressed vowel and following consonant /'V:C/ vs /'VC:/ calls for a special rule. The solution chosen in this investigation is to split the long consonant into two single ones.

However, this algorithm still contains some problems. An old problem concerns the treatment of long consonants. The velar nasal (in medial and final morpheme position only and always long), when it becomes the onset consonant after splitting a long /C:/, is not accepted as onset. It violates the phonotactic rules according to which the velar nasal is only allowed following a stressed short vowel. Splitting a long voiceless stop in word medial position where it, contrary to its pre-stress position, is unaspirated leads to an onset with an unaspirated stop. However, in the absence of any better solution at the moment, we have to accept these problems for the time being. At the same time, we have to continue our work for better solutions and, hopefully, this report will contribute to a vivid discussion.

Where the prosodic decoding of words/lexical elements in fluent speech is concerned, two hypotheses can be put forward which may reflect the fundamental differences between languages like French, on the one hand, and Germanic languages like Swedish, English or German, on the other: Speech recognition in the Germanic languages relies more on acoustic (word) cues. Preference is given to the bottom-up processing. In French (and other Romance languages, maybe except e.g. Italian) speech recognition, due to the lack of acoustic word cues, relies more on the linguistic/pragmatic context. Preference is given to top-down processing.

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