LETTER-TO-SOUND CONVERSION FOR GALICIAN TTS SYSTEMS

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ABSTRACT

In this paper, a linguistically rule-based letter-to-sound (LTS) conversion algorithm is described for Galician language. A complete set of phonological transcription rules regarding the Galician standard variety is presented. A SAMPA computer readable phonetic alphabet for Galician is also proposed. The algorithm was implemented and tested by using CORGA text materials. The obtained experimental results gave rise to 98.5% of accuracy rate. The main errors were identified and possible solutions are discussed in order to increase this value. It is also demonstrated in our work that there is a very good matching between Galician, European Portuguese and Brazilian Portuguese LTS conversion algorithms. Our purpose with this work is to develop a module that can improve synthetic speech naturalness in Galician. Other applications of this system can be expected like language teaching/learning. These results, have proved the dramatic importance of linguistic knowledge on the development of Text-to-Speech systems (TTS).

1. INTRODUCTION

Several frameworks have been proposed to tackle the grapheme-to-phone transcription module of a Text-to-Speech system, among which it can be mentioned: information theoretic systems such as decision trees [1], automatically-trained decision trees [2], table look-up models [3], dictionary-based approaches [4], linguistically rule-based modules [5], hybrid systems [6], neural networks approaches [7] Finite State Transducers (FST) [8] statistical approaches [9] and HMMs [10]. A comparison of different techniques and results is made by Damper et al [11].

One of the most preferred approaches is dictionary-based, which uses a large dictionary containing the phonetic transcription of a given number of words. This technique has been widely applied to languages whose orthography is roughly phonetically-based, such as English or French. But this approach fails when new words that are not in the dictionary come up.

For European Portuguese language (EP), some synthesizers have been proposed since the early 90's, based on different synthesis techniques, such as the formant-based synthesizer DIXI [12] and the Multivox [13], the articulatory-based synthesizer [14], or the concatenative-based synthesizer [15]. In every case, the LTS is an independent module of the TTS architecture and it is mostly built by using a rule-based approach [13], [16] and a Finite State Transducers approach [17].

For Galician, as far as we know, there is *Cotovía* [18], a bilingual concatenative TTS system for Spanish and Galician. However, regarding the rule-based approaches, there seem to be no publication of the complete set of rules for Galician available

Symbol	Meaning
...	Any grapheme
< x >	Grapheme or set of graphemes x
[y]	Phone or set of phones y
,	Separates options
{ x_1, x_2, x_3 }	Set of graphemes
< x_1 {x_2, x_3} >	< x_1 x_2 > or < x_1 x_3 >
< C / y >	Consonant except <y>
< C / {w, z} >	Consonant except < w> and < z>
V	Any graphic vowel (e.g. a, e, i, o, u)
C	Any graphic consonant (e.g. p, t, k, b, d, g...)
Pont	Punctuation mark (e.g. , . ! ? () - ; sp)
Ltr	Characters that are letters (e.g. a, b, c, …)
SP	Space between words
Hf	Hyphen
<(case) x >	Certain case that modifies the grapheme <x>
<(C) x>	<x> is a consonant
<(V) x>	<x> is a vowel
<(UV) x>	<x> is unvoiced
<(VO) x>	<x> is voiced
<(US) x>	<x> is an unstressed vowel
<(S) x>	<x> is a stressed vowel
<(W_bgn) x>	<x> is in word beginning
<(Prn_D) x>	Grapheme <x> in Demonstrative Pronoun (e.g. este(s), ese(s), aquel(s))

Table 1. Annotation symbols and conventions used in the LTS algorithm for Galician.

There is a large tradition of phonological and phonetic studies in Galician with recognized theoretical and experimental results [19], [20], [21]. However, when regarding the application of this knowledge to TTS systems in Galician, a big gap remains to be filled, specifically in what concerns practical rules that allow building a LTS module.

As far as we know through publications, this phonological knowledge is only being applied to EP and BP TTS systems [22], [23] respectively.

We justify our rule-based approach mainly because: we consider Galician as a variety of Portuguese, (together with a large list of authors); Galician, like EP and BP varieties, has a good phonological regularity; Galician, unlike Portuguese, has less orthographic deviation, due to the late orthography fixation and ongoing normalization; a rule approach is more economic than a phonetic dictionary in terms of space required to store the function; a rule approach is always able to read a new word; a good set of rules based in a linguistic description can cover almost any transcription problem; our rule approach proved to have a good rate of accuracy in EP (98.80%) [22] and BP (97.44%) [23] and most of the rules can be adapted to Galician and other varieties of Portuguese..

For our algorithm construction, studies on recent Galician phonology and phonetics were considered [19], [20], [21] and some sandhi phenomena were already included.

2. LETTER-TO-SOUND ALGORITHM

2.1. Annotation Conventions

In Table 1, the writing conventions used in the LTS algorithm proposed in section 2.2. are presented.

phoneme class	symbol	example
Vowels	/a/	casa, cama, cal, acto
	/i/	río, fío, ir, digo
	/u/	xunta, último
	/E/	ferro, almacén, mel, exame,
	/e/	rochedo, ver, vello
	/O/	voz, caracol
	/o/	curioso, don
Semivowels	/j/	queixo, loita, piano, fiestra
	/w/	louvar, mouro, ruela, suor
Plosive consonants	/p/	pé, campo
	/t/	trato
	/k/	carpa, aqui, kantiano
	/b/	bebo,
	/d/	caldo, morder
	/g/	gato, figo
Affricate c.	/tS/	chamar, achar
Fricate consonants	/f/	faro, feliz, café
	/T/	fácil, zarzallo, macio, luz
	/s/	selo, cousa, cuspir
	/S/	xa, xente, muxica
Nasal consonants	/m/	memoria, campo
	/n/	nada, onte
	/J/	brasña
	/N/	unha, algunha
Liquid consonants	/l/	lúa, álxebra, colgar
	/L/	valla, muller
	/r/	coro, carta
	/rr/	rato, melro, aforrar

Table 2. SAMPA for Galician.

Some cases were previously defined in the system, such as Vowels, Consonants, Voiced and Unvoiced Consonants, Stressed and Unstressed Vowels/Syllables and Demonstrative Adjectives.

For phonetic annotation, we proposed a SAMPA transcription set of symbols for Galician (Table 2), based on SAMPA alphabets [21] for Portuguese and Spanish, with some phonetic extensions: [l*] to represent the velar lateral consonant <sal>, "*salt*"; /~/, a diacritic to represent the vowel nasalization caused by the proximity of nasal consonants; /z/ and /T*/ to assign voicing to fricatives /s/ and /T/ respectively.

The Galician SAMPA we proposed was mainly phonological-based, differently from what we previously used for EP and BP which was more phonetic-based, due to the great number of allophones considered in standard Galician [19]. This allophonic variation was eliminated because these context dependent parameters are automatically extracted by the voice font unit selection training system that will feed our synthesis engine.

2.2. Transcription Rules

In the following Tables 3 to 10 a complete set of transcription rules for every grapheme used in Galician is proposed and some examples of occurrence are given.

#	graphical pattern <a>	phon	example
1	... < a, á, à >...	/a/	casa, cama, cal, pau, acto, cá
#	**graphical pattern <b>**	**phon**	**example**
1	... <b>...	/b/	ben, pobre
#	**graphical pattern <c>**	**phon**	**example**
1	...<ch>...	/tS/	chuvia, achar, che
2	... < c > < e, i >...	/T/	certo, cinco
3	... <c>...	/k/	cando, caeu, actos, dialectal
#	**graphical pattern <d>**	**phon**	**example**
1	... <d>...	/d/	despois, caldo, vida

Table 3. Transcription rules for <a>, <b>, <c>, <d>.

The Galician alphabet is composed of 23 graphemes and 6 digraphs (<<ch>, <gu>, <ll>, <nh>, <qu>, <rr>), which were included in the single grapheme patterns. All graphical patterns were considered, including graphemes that are likely to occur in foreign words (such as <j>, <k>, <y>, <w>, cfr. Table 10).

Raising and falling diphthongs were also beard in mind, although some of them are incorporated in the rules of graphemes <i> and <u>. Most of the rules presented are stated in literature [22] for the Galician standard variety. Every phonetic output was confirmed by a native Galician linguist, this way assuring the correct transcription of all graphic patterns.

#	graphical pattern <e>	phon	Example
1	... <SP, Pont> <e> <SP>...	/E/	ti e eu
2	...<(Prn_D), (S) e>...	/e/	este, ese
3	...<(W_bgn) e><x>...	/E/	extra, exame
4	...<(S) e><C>< i,u><V/ {i,u}><Pont>...	/E/	seria, recua,
5	...<(S) e><C><C/ {m,n}>< i,u><V/i,u><Pont>...	/E/	modestia, controversia
6	...<e>< n><C, Pont>...	/e/	meten, cóllenno
7	...<é>< n><Pont>...	/E/	tamén, vén
8	... <e> <n> < za, cio, cia><s, Pont>...	/E/	ciencia, pertenza
9	... < é > <s><Pont>...	/e/	lugués
10	... < e > <s, z> <a><s, Pont.>...	/e/	luguesa, avareza
11	... < e > <do><s, Pont.>...	/e/	penedo,
12	...<e><m,n><e><Pont>. .	/E/	gene, leme
13	...<(S) e><r><Pont>...	/e/	ver, saber
14	...<(S) e><u, o><Pont>....	/e/	seo, freo, temeu
15	...< (S) e ><la><Pont>...	/E/	vela, cadela, aquela
16	...<e><l><C, Pont>...	/E/	papel, pel, felpa
17	...<i><e>...	/E/	fiestra
18	...<(S) e><i>...	/e/	cheira, queira
19	... < é >...	/E/	léxico, vixésimo
20	...<é, e><(ct, cn,)>...	/E/	dialecto, técnica
21	...<(US) e><o, a>...	/e/	aldea, real, feo
23	...<(S) e><ll, ñ, ch, x>...	/e/	vello, pecho
24	... < (US) e >...	/e/	despois, español
25	... < (US) e ><Ltr, Pont>...	/e/	chocolate

Table 4. Transcription rules for <e>.

When conceiving these rules, we tried to design them, as much as possible, according to graphic patterns, this way reducing their dependence from other modules of text processing we are developing, such as the tonic syllable marker and the syllable divisor. Main exceptions to some of the rules are also presented.

The transcription of the 27 graphemes and 6 digraphs that are likely to appear in Galician texts is performed by a total amount of 93 rules.

Most of the problems in Galician LTS algorithm, similarly to what happens in Portuguese language, have to do with the vocalic alternations between /e/ and /E/ and /o/ and /O/.

#	graphical pattern <f>	phon	Example
1	... < f >...	/f/	fai, café, flor, naíf
#	**graphical pattern <g>**	**phon**	**Example**
1	... < g u > < e, i >...	/g/	guerra, guindaste
2	... < g >...	/g/	figo, Galiza, fungo
#	**graphical pattern <h>**	**phon**	**Example**
1	... < h >...	/ /	hoxe, haber
#	**graphical pattern <i>**	**phon**	**Example**
1	...<i><ño, ña>...	/i~/	padriño, morriña
2	... <V/{i, u}> <i>...	/j/	caixa, papeis, loita
3	...<i> <V/{i, u}>...	/j/	fiestra, liorta, canción
4	... < i, í >...	/i/	río, fío, ir, digo

Table 5. Transcription rules for <f>, <g>, <h>,<i>.

#	graphical pattern <l>	phon	Example
1	... < l > <C/h, Pont>...	/l*/	calma, último, alzar, colgar
2	... < ll >...	/L/	muller, mollado, vello
3	...<l>...	/l/	lúa, valado, vela
#	**graphical pattern <m>**	**phon**	**Example**
1	...<V><m><C>...	/~m/	cumprido, importante, tempo, ambos
2	... < m >...	/m/	memoria, campo
#	**graphical pattern <n>**	**phon**	**Example**
1	... <u><nh><a>...	/N~/	unha, algunha
2	...<V><n><C, Pont>...	/~n/	onte, antes, unha, don,
3	... <n>...	/n/	nai, neno, onte, once, onda
#	**graphical pattern <ñ>**	**phon**	**Example**
1	...<ñ>...	/~J/	braña, niño, mariñeiro

Table 6. Transcription rules for <l>, <m>, <n>, <ñ>.

They may occur for the following four reasons: 1) verbal morphology (e.g. <meto> /e/ vs <metes> /E/; <acordo> /o/ vs <acordo> /O/); 2) disambiguation of pairs of homographs either with a different grammatical category (noun/verb: <comezo> /e/ vs <comezo> /E/, <acordo> /o/ vs <acordo> /O/) or with the same grammatical category (noun/noun: <besta> /e/ vs <besta> /E/; 3) etymological reasons that can not be ruled (e.g. the tonic vowel in <ferro> is /E/ while in <negro> is /e/); 4) metaphony, a phonetic phenomenon widely spread in Galician and Portuguese, that consists in the regressive and assimilative influence performed by the final unstressed word vowel over the opened tonic vowel. The final closed vowel closes the tonic

vowel a little bit /E/>/e/ (e.g. <medo>) and /O/>/o/ (e.g. novo).

#	graphical pattern <o>	phon	Example
1	....<ó>...	/O/[1]	código, só, lóxico
2	…< (W_bgn) h> <o> <r, s, t>…	/O/[2]	horario, hora, hotel
3	...<o, ó><n>><es, C, Pont>...	[o]	don, acción, papón
4	…<(S) o><r><es, Pont>…	/o/	cor, dor, mellor, mellores
5	…<o><z>< Pont>…	/O/	voz, atroz
6	…<o><ces>< Pont>…	/O/	voces, noces
7	…<o><so><s, Pont>…	/o/	curioso, desexoso
8	…<o><sa> <s, Pont>…	/O/	desexosa, xeitosa
9	…<o><l, la><C, Pont>…	/O/	caracol, mol, farola
10	…<o><i><s><Pont>…	/O/	caracois
11	.. ..<(S) o><C>< i ><V/ {i,u}><Pont>...	/O/	ocio, odio, serodio
12	...<o><u>...	/o/	mouro, ouro
13	...<o><i>...	/o/	loita, coitado
14	…<Ltr><o><l><C/h> …	/o/	soltar, volver
15	...<(S) o><a>...	/o/	coroa, boa
16	...<(S) o><a>...	/o/	coroa, boa
17	...<o><(pt, bt, bx, ct, cl, gn)>...	/O/	optar, obter, obxectar,
18	... <(US) o > <s, Ltr, Pont, SP>...	/o/	veciño, carro, europeo
19	... <(US) o >...	/o/	asobío, polir
#	graphical pattern <p>	phon	Example
1	... < p >...	/p/	pato, polo, carpa

Table 7. Transcription rules for <o>, <p>.

#	graphical pattern <q>	phon	Example
1	...<qu><e,i>...	/k/	esquina, quen, queixo
2	... < q >...	/k/	quorum
#	graphical pattern <r>	phon	Example
1	... < r r > ...	/rr/	aforrar, curro
2	...<(W_bgn) r>...	/rr/	rúa, ría
3	... <l,n><r>…	/rr/	honra, melro
4	... < r >...	/r/	mar, cara, fraco
#	graphical pattern <s>	phon	Example
1	…<s><C_VO>…	/z/[3]	prosma, fasllo
2	…<s><SP><C_VO>…	/z/	estás desperto
3	...<s>...	/s/	selo, cousa, cuspir
#	graphical pattern <t>	phon	Example
1	… <t>…	/t/	corte, tamén

Table 8. Transcription rules for <q>, <r>, <s>, <t>.

[1] Exception to this rule: infinitive forms of <pór> /o/.
[2] Exception to this rule: <hoxe> /o/.
[3] SAMPA extension for the voiced alveolar fricative.

#	graphical pattern <u>	phon	Example
1	... < ü > ...	/w/	lingüista, pingüe
2	... <V/u>< u >...	/w/	cauto, ceu, pouco, fuxiu
3	...<u><V/u>	/w/	minguar, ruela, tenue, suor, frecuente
4	... < ú, u >...	/u/	túa, rúa, pulo, miúdo
#	graphical pattern <v>	phon	Example
1	... < v >...	/b/	avogado, volveu, vostede
#	graphical pattern <x>	phon	Example
1	List of exceptions	/ks/	axila
2	...<(W_bgn) ex, exo, extra, taxi, xeno, xilo>...	/ks/	extra, exame, excedente, xenofobia, xilófono
3	...< (W_bgn) ex><V><x>...	/ks/	exaxerar, exixir, exexese, exixencia
4	...< x>...	/S/	xamón, xente, obxecto, relox
#	graphical pattern <z>	phon	Example
1	... < z SP> <C_VO>...	/T*/[4]	cruz verde, cruz branca
2	... <z>...	/T/	zunir, prezo, luz

Table 9. Transcription rules for <u>, <v>, <x>, <z>.

#	graphical pattern <j>	phon	Example
1	... <j>...	/dZ/	jeep, jazz, judo
#	graphical pattern <k>	phon	Example
1	... < k>...	/k/	karate, kamikaze
#	graphical pattern <y>	phon	Example
1	….<(W_bgn) y>…	/jj/	yen, yang
2	...<y>...	/i/	baby, bodyboard
#	graphical pattern <w>	phon	Example
1	…<w>…	/w/	walkie-talkie, whisky

Table 10. Transcription rules for foreign graphemes <j>, <j>, <y>, <w>.

Grapheme <x> is also of difficult transcription because of etymological reasons. The following list of exceptions and their morphological variations was created in which <x> is pronounced /ks/: *anglosaxón,*

[4] SAMPA extension for the voiced dental fricative.

aproximar, asfixia, axila, axilar,axioma, bórax, clímax, complexo, convexo, crucifixo, elixir, exacto, exame, exaxerar, exceder, excelente, excepto, exclamar, exilio, eximir, éxodo, exótico, explosión, expurgar, extenso, extensión, extensor, extra, fax, galaxia, hexágono, laxo, léxico, maxilar, nexo, reflexionar, prefixo, reflexo, saxón, sexo, sexual, sílex, sintaxe, sufixo, taxi, texto, textual, tórax, tóxico.

2.3. Algorithm Implementation

The time needed to generate an acoustic utterance from a text input should be as short as possible. In order to achieve the best performance in the implementation process, we tried to group the rules/patterns according to the type of logical test and common characters. In our system, an average of three tree nodes evaluations is needed for reaching the output pattern.

As much as possible, the rules that were leading to the default output were not implemented. The default output is chosen to be the most frequent among the total outputs for a given grapheme. With this procedure, from the total 93 rules presented rules only nearly 75 are needed. Temporal performance tests with other LTS systems are foreseen.

Compared with the dictionary based approach, our system requires less memory space and can cope with any new word which makes it a better option for large vocabulary Galician TTS systems. Statistical approaches devise transcription rules from a given set of training utterances, but this usually leads to scattered and complex conditions that should be re-organized. This is a good and universal option when little or no knowledge of the language exists.

3. RESULTS AND DISCUSSION

The proposed algorithm was implemented and tested using texts from the CORGA (Corpus de Referencia do Galego Actual) [25]. This corpus is composed by several types of texts, extracted from newspapers, books magazines, journals and transcriptions of oral data, covering different areas from politics to technology or fiction. A training text containing a total number of 10289 characters distributed among 2121 words was used as the text input of our system. The phones originated by our system were manually checked and 98.50% were correctly converted.

The errors were marked and classified as shown on Table 11. From a total of 1.50% of errors (182 wrongly transcribed graphemes), 0.21% are exceptions that were still not implemented for lack of time. Most of the errors come from <e> and <o> grapheme transcription, since these graphemes have a high variability in Galician, as in Portuguese. Many of them occur in homographs (e.g. noun <selo> e/ vs verb <selo> /E/) and words with sub-morphemic alternation caused by metaphony (e.g. <sogro> /o/ vs <sogros> /O/).

Other mistakes in <e> and <o> grapheme's transcription are due to vocalic alternations which occur along the conjugation of the verbs (e.g. <eu bebo> /e/, <ti bebes> /E/, <el bebe> /E/). This alternation is well known and can also be predicted by using linguistic information. Foreign words also represent a problem to be considered in Galician LTS conversion. However, Galician seems to admit less foreign words than EP and BP.

Type of error	# occur.	% occur.
Homographs with <e>	26	0.21
Mistakes in <e> along verbal conjugation	15	0.12
Mistakes in <o> along verbal conjugation	18	0.15
Mistake in <e> transcription	32	0.26
Mistake in <o> transcription	32	0.26
Mistake in <u> transcription?	10	0.08
Foreign words	12	0.10
Non implemented exceptions	26	0.21
Acronyms	11	0.09
Total	**182**	**98.50**

Table 11. Errors in absolute frequency and percentage relative to total grapheme nr.

Comparisons with other LTS modules for Portuguese TTS systems seem to confirm the good performance of our rule-based approach. Besides, our system is more optimized when compared with other similar frameworks, since we only deal with 93 rules, when others need around 600 rules, as stated in [13].

Our good results are very comparable to the LTS for EP [22], with an accuracy rate of 98.80%. The LTS system [23] has an accuracy rate of 97.44%. Other rule-based frameworks don't mention accuracy rates [12], [13], [26].

4. CONCLUSIONS

In this paper, we described a LTS transcriber linguistically rule-based that is perfectly able to be applied to any Galician TTS system. The proposed rules were implemented and tested using texts from CORGA corpus. Evaluation of our system resulted in 98.50% of correct transcribed graphemes. Most of the errors were found in homographs, verbal conjugations, metaphony affected words and foreign words.

From the obtained results, it is our belief that morphological decision in terms of verb/noun will drastically improve the efficiency of our LTS system. This study is already ongoing. Phonological information regarding the verbal flexion of the verbs can also be included in future developments. These problems are

fully shared by EP, BP and Galician. A careful research on the phonological behavior of the foreign words in Galician is also foreseen. Although some sandhi phenomena occurring between consonants in word boundaries were included, other phenomena regarding vocalic neighboring are soon expected to be implemented

The proposed algorithm is an adaptation of the LTS for EP proposed elsewhere [22]. From the overall set of rules presented, 80.2% are fully applicable, 19.1% have the same input pattern but a different output. This means that we have 95.3% of pattern compatibility. We also intend to evaluate the compatibility of our patterns with other varieties of Portuguese.

A comparison of our system with another one using automatically-generated rules obtained by decision trees, for instance, is foreseen.

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