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DECLARATIVE SYLLABIFICATION IN TASHLHIT BERBER

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1. Introduction

Syllabification in Tashlhit Berber is taken by various phonologists, including Prince and Smolensky (ms), Scobbie (1993a,b) and Zec (1995) as a challenging test case for any theory of syllabification because, according to Dell and Elmedlaoui (1985, 1988), Tashlhit has a multiplicity of syllabic consonants, and numerous consonant-only words. For example, the following transcriptions from Dell and Elmedlaoui (1985) exemplify syllabic stops, fricatives and sonorants. (I shall use IPA notation throughout this paper. In particular, the diacritic [̩] marks syllabic consonants, where Dell and Elmedlaoui employ capital letters or an apostrophe.)

(1)	tf̩tk̩ts̩tt	you sprained it
	tl̩di	she pulls
	ts̩kr̩t	you did
	tn̩ʃ̩ft	you grazed the skin
	tx̩zn̩t	you stored

Data such as that in (1) is grist to the mill of theoretical phonology, yet there is an important sense in which it is not raw data at all. The transcriptions in (1) are the product of an analysis arising from the selective observation of the original authors, according to their training and, to a certain extent, their theoretical predisposition. Yet the transcriptions of descriptive studies such as those in (1) are often employed in theoretical phonological studies as if they were data to be explained by a theory. Faced with the speech data that led Dell and Elmedlaoui to the representations in (1), another researcher might make different observations, leading to a different analysis. In the first part of this paper I shall argue for a different view of Tashlhit syllable structure, in which phonetic syllabic consonants are phonologically analyzed as a coproduced vowel and consonant.

There is a theoretical debate in Berber studies as to whether or not syllabic obstruents are to be analyzed phonologically as VC sequences (such as ə + Consonant). Dell and Elmedlaoui's papers, which have attracted most attention from contemporary phonologists, argue against phonological schwas. Other authors argue for the presence of phonological schwas in other Berber dialects (e.g. Saib, 1978 for Tamazight; Chtatou ,1982 and Dell and Tangi, 1992 for Tarifit), and it is natural to enquire whether a more unified account of Berber phonology might be arrived at if Tashlhit were to be treated likewise. Theoretical phonologists should be aware of this debate in approaching a controversy about data such as that discussed here. Many phonologists (e.g. Larson, 1992; Prince and Smolensky ms, and Zec, 1995) take Dell and Elmedlaoui's view as uncontroversial, yet, as we shall see, it is only one particular analysis of some Berber data. It is not the only (nor necessarily even the best) analysis, though it is coherent view.

There is no debate that schwas occur at the surface, however, in some Tashlhit words – the only questions are as to their lexical status and whether they should be accommodated in syllable structure or regarded as a purely phonetic-level phenomenon of no phonotactic relevance. Consequently, as well as the question of the nature of syllable structure in Tashlhit and the affiliation of syllabic consonants to syllable positions, an adequate theory of syllabic consonants must also include an account of the relationship between the phonological representation of syllabic consonants and their phonetic interpretation.

In order to evaluate the adequacy of a particular view of Tashlhit syllable structure (to be developed below), I shall present a computationally implemented grammar of syllable structure which can be used for syllabification, and/or to explain the distribution of schwas or syllabic obstruents.

Since I have raised a question over the status of second-hand data in the phonology literature, it is incumbent on me to make my own sources explicit. The data given in this paper is drawn from several sources:

i) Published transcriptions. In particular, in the absence of a machine-readable dictionary of Tashlhit order, I have been collecting lists of words in phonemic transcriptions from the Berber phonological literature (see Table 1). These records are simple surface phonemic transcriptions (sometimes with a few allophonic details.) The word list in Bouzida *et al.* (1993) is in fact a Tamazight lexicon, but I have obtained translations and audio recordings of all the words in that list in Tashlhit and Tarifit. For about 1/3 of these transcriptions, therefore, we have cognate forms in the three principal varieties of Berber. These word lists are in ASCII files in a format which can be submitted to the phonological parser I describe below in order to evaluate it, and to investigate the analyses it yields for any desired dataset.

Bouzida *et al.* (1993)	215 words
Damiri (1993)	392 words
Dell and Elmedlaoui (1985)	179 words
Dell and Elmedlaoui (1988), Appendix	110 words
Total	896 words
In preparation for future parsing tests:	
Elmedlaoui (1992)	895 examples
Boukous (1987)	1458 examples

Table 1: Sources of published transcriptions

ii) Detailed, impressionistic IPA transcriptions of 70 short sentences or phrases made in a graduate class in practical face-to-face phonetic transcription.

iii) Continuous physical measurements i.e. 240 labial electromyographic records, 240 simultaneous audio recordings (10 repetitions of 12 minimal pairs) and 1616 other audio recordings, containing at least two readings of all the word-lists in Table 1. Although the 240 EMG and simultaneous audio recordings were made for a separate study, an experimental investigation of the extent of labialization in labialized and non-labialized consonants, this data sometimes includes items relevant to the question of syllabicity.

iv) Theory laden notes e.g. surface phonemic transcriptions with selective attention to features of interest in the current study.

The shape of this paper will be as follows. In sections 1–3 I shall present various arguments and pieces of data that cast doubt on the standard analysis of Tashlhit, in which surface syllabic consonants are phonologically associated to syllable nuclei. I propose an alternative analysis in which schwas are licensed by a nuclear V slot, as in English, and that surface syllabic consonants are phonologically a combination of schwa and a consonant, the syllabicity of the consonant arising through the phonetic interpretation of nuclear schwa + marginal consonant as *coproduced* consonantal and vocalic components. The vocalic component of a consonant is its secondary articulation, on which Dell and Elmedlaoui (forthcoming) are silent.

In section 4 and the Appendix I present a complete phonological grammar of Tashlhit syllable structure in a form that is suitable for use in an automatic parsing program. This parser is applied to the analysis of the 607 words in Bouzida *et al.* (1993) and Damiri (1993), in order to evaluate the coverage of the grammar. The parses produced by the program were scored by a native speaker. The 289 words from Dell and Elmedlaoui (1985, 1988) were also submitted to the parser for cross-theoretical comparison. These evaluation experiments are briefly discussed in section 5.

2. Phonological and phonetic views on syllabic consonants

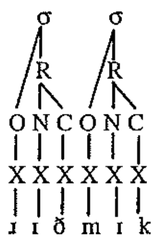
According to the most common view of syllabic consonants, as taught in contemporary phonology textbooks such as Kenstowicz (1994) and assumed in current publications (e.g. Zec, 1995), surface syllabic consonants are represented in nonlinear phonological representations as a consonant associated to a nuclear position. For example, the English words *rhythm* and *rhythmic* may be represented as in (2):

This example also illustrates the commonly accepted view that the position of a segment is not fixed in syllable structure, but may vary from one syllable to another, e.g. in different forms of a paradigm, or in different lexical environments. For example, /m/ is nuclear in (2a) but is an onset in (2b).

This view may be contrasted with an alternative proposal regarding the nature of syllabic consonants in English, which holds that they derive postlexically from fast or casual speech fusions of vowels and consonants (Trnka ,1935; O'Connor and Trim, 1953; Catford, 1977; Browman and Goldstein, 1990; Coleman, 1994). The consonant may be prevocalic, as in (3a), or postvocalic, as in (3b).

(2a)

b)



(3a) /səpəuz/ → [s̩pəuz] 'suppose'
/pɹɪpəuz/ → [pɹ̩pəuz] 'prepose'
/pɹəpəuz/ → [pɹ̩pəuz] 'propose'

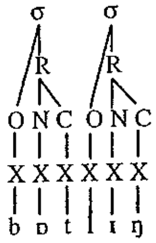
(3b) /bʌtən/ → [bʌtn̩] 'button'
/kʌzən/ → [kʌzn̩] 'cousin'
/bɒtəl/ → [bɒtl̩] 'bottle'
/ɹɪðəm/ → [ɹɪðm̩] 'rhythm'

Evidence for this view comes from the observation that the vowel reduction and syllabicity of the consonant are in a complementary, variable and gradient relationship. That is, if the vowel is unreduced, the consonant will not be syllabic, whereas when the consonant is syllabic, the vowel is always reduced. The degree of vowel reduction is a continuous scale, as is the complementary percept of degree of syllabicity.

According to this view, in English syllable structure consonants are only associated to non-nuclear positions, as in (4):

(4a)

b)



In order to put flesh on the bones of this proposal, I must address the question of how syllabic alternants of marginal consonants come about. For example, how is the reduction of /ə/ and concomitant development of the syllabicity of /l/ in (4a) accounted for? I shall consider two proposals: first, a phonological account involving reorganisation of the syllable structure in (4a); second, a phonetic account in which (4a) is not altered.

2.1 A phonological account of syllabic consonants

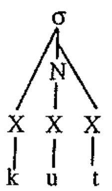
A simple account of the deletion (though not reduction) of /ə/ and assignment of syllabicity to /l/ in (4a) is available using the notation and rules of nonlinear phonology. The deletion is determined by a rule such as (5), accompanied by spreading (or possibly movement) of the /l/ into the empty nucleus position which results. Such spreading need not be determined by a rule, but might be regarded as the consequence of a repair strategy which intervenes to make sure that the obligatory nucleus of the second syllable is filled with the nearest sonorant segment available to it. This spreading is formally similar to several accounts of compensatory lengthening in the nonlinear phonology literature.

(5)

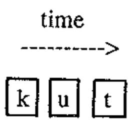
2.2 A phonetic model of syllabic consonants

Before developing a phonetic alternative to the account presented in the preceding section, it is necessary to make explicit the standard view of segmental temporal arrangement that is generally supposed in nonlinear phonology (e.g. Sagey, 1986; Bromberger and Halle, 1989). According to this view, the linear sequence of segments in phonological representations corresponds straightforwardly to the temporal sequence of segments in the phonetic realization of such representations, with maybe some allowance for coarticulation between adjacent segments. For example, in the phonological representation in (6a), the linear sequence of segments /k/ < /u/ < /t/ is taken to correspond to the temporal sequence of (possibly partly overlapping) phonetic segments [k] < [u] < [t] in (6b), as illustrated in Clements and Hertz (forthcoming).

(6a)

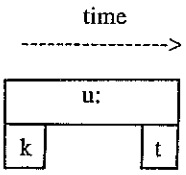


b)



This view of phonetic interpretation can be set against an alternative in which phonetic consonants and vowels are not held to lie in a sequence; instead, vowels are coproduced with and overlapped by adjacent consonants Öhman (1966), Fowler (1980), Liberman (1970) and Browman and Goldstein (1986), Perkell (1969), Griffen (1985), Löfqvist (1990), de Jong (1991). For example, the temporal arrangement of the segments in (6a) is held to be that in (7).

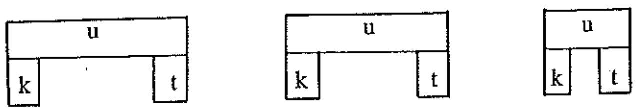
(7)



This view may strike some phonologists as somewhat nonstandard, but that impression will not be shared by many phoneticians. Although this view of temporal organisation is not universally accepted in phonetics, it is a very common view of segmental temporal arrangement, and may even prove to be the most popular view among phoneticians, if a survey were to be taken. According to this view, the extent or duration of the vowel is longer than that of the inter-consonant duration: owing to the overlap of consonants on vowels, the duration of the vowel is commensurate with the whole syllable (Coleman, 1992, 1994).

According to the coproduction hypothesis, when a syllable is spoken faster, it is the vowel in particular which is compressed. The consonants may be compressed somewhat also, but because their duration is typically much less than that of vowels, the main consequence of syllable compression is that the interval between the onset consonant(s) and coda consonant(s) is shortened. As a result, less of the vowel will be audible. These compression effects are gradient; three points on the continuum are illustrated in (8).

(8a) b) c)



full vowel | reduced somewhat | very reduced

As the interval between the consonants is shortened, the articulatory or acoustic targets for the vowel may not be reached. This proposal was employed by Stevens and House (1963) in a numerical model of consonant-vowel-consonant transitions and proposed as the basis of a theory of unstressed vowel reduction by Lindblom (1963). (Lindblom has modified this theory in the light of evidence presented by Harris (1978) that in careful speech, such as that employed by professional speakers, it is possible to reach articulatory targets even in shortened syllables. Lindblom views such behaviour as special cases in which the speaker makes a special effort to move their articulators faster in order to counteract the vowel quality reduction which would otherwise be expected to take place.)

The coproduction model offers a straightforward account of the gradient and complementary relationship between vowel reduction and syllabic consonant formation, even for syllabic obstruents. As a vowel is shortened, the duration between the consonants is reduced, until a point is reached at which the coda consonant begins as soon as the onset consonant is released. In English, this gives rise to unstressed syllabic sonorants as in *bottle*, *cousin* and *rhythm*, as well as fast-speech syllabic obstruents as in e.g. *Bob'd̩ buy it* (< Bob would buy it), *g̩'day* (< good-day), *'k̩you* (< thank you), *s̩'ppose* (< suppose), *tʰ̩'night* (< tonight), etc.

As well as numerous analyses of phonetic data in support of this model, several computational implementations of the coproduction theory of vowel quality reduction and syllabic consonant formation may be cited in support of this view, especially the speech synthesis models developed by Browman and Goldstein (1986) (Articulatory Phonology), Coleman (1992b) and Local (1992) (the YorkTalk system) and Dirksen and Coleman (forthcoming) (the IPOX system). Such implementations enable us to explore the acoustic consequences of varying the model parameters, in particular syllable duration or the degree of syllable compression which conditions vowel reduction and syllabic consonant formation (Coleman, 1995).

Note that in the coproduction model the vowel is not deleted, only reduced and possibly eclipsed by a neighbouring consonant. We do not expect to find absolute neutralization of the distinction between the reduced forms of minimal pairs such as *prepose* vs. *propose*, as an analysis employing a vowel deletion rule such as (5) would predict. Instead, the coproduction model predicts that perception of the distinction between *prepose* and *propose* will be gradually compromised the more the unstressed vowel is reduced, leading eventually to complete neutralization. Evidence that this prediction is correct can be seen from the spectrograms in Fig. 1. The spectrograms in panels (a) and (c) of Fig. 1 are of utterances of *prepose* and *propose* spoken at a moderate rate, in which the vowels of the first syllable, though short and unstressed, have distinctive spectral signatures ([ɪ] vs. [ə]). The principal difference is F2([ɪ]) ≈ 1580 Hz, whereas F2([ə]) ≈ 1225 Hz. These vowels are voiced, though there are only a few pitch periods, due to their shortness. The [ɹ] in the initial consonant cluster is devoiced ([ɹ̥]) and covered in aspiration noise in both words, as it is overlapped by the aspiration phase of the preceding voiceless aspirated stop. F2([ɹ̥]) is different in *prepose* than in *propose*, due to the distinction between the vowels [ɪ] and [ə]. In particular, F2 is the same for [ɹ̥] as for the vowel which follows, i.e. F2([ɹ̥]) ≈ 1580 Hz in *prepose* and F2([ɹ̥]) ≈ 1225 Hz in *propose*. This pattern of coarticulation of the spectrum of [ɹ] with the spectrum of the following vowel and the over-writing of [ɹ] with the voicelessness and aspiration of the preceding [p^h] is entirely consistent with the patterns of overlap in the coproduction model described in Coleman (1993).

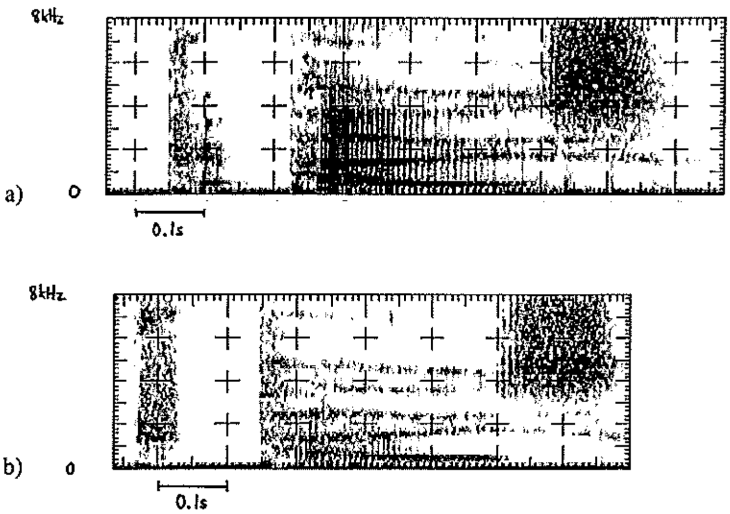


Figure 1: Spectrograms of *prepose* **(continued on p. 8)**

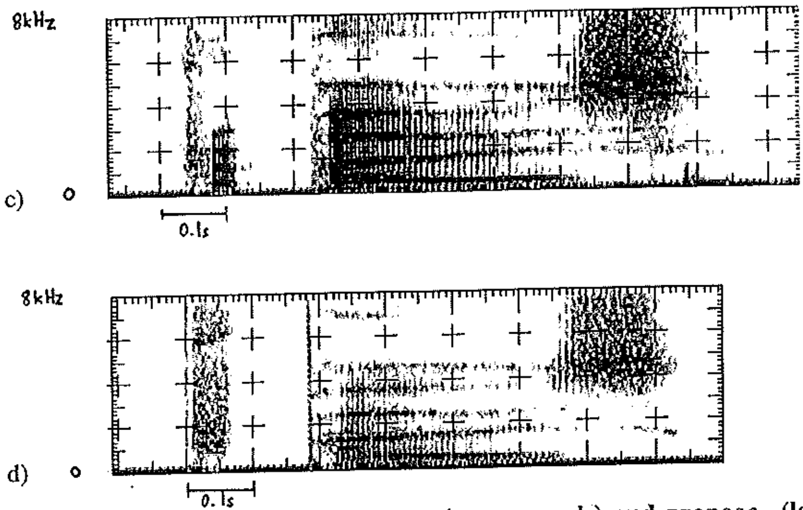


Figure 1: Spectrograms of *prepose* (upper panels) and *propose* (lower panels) spoken at a moderate rate (a and c) and faster rate (b and d).

Panels (b) and (d) of Fig. 1 show the same words spoken at a faster rate. Note that F2([ɹ̥]) remains distinctive in the lower spectrograms, even though the vowel has become totally eclipsed. F2([ɹ̥]) ≈ 1460 Hz in the reduced version of *prepose*, (suggestive of a more centralized articulation of [ɪ] i.e. a slightly less palatalized secondary articulation of [ɹ̥]) whereas F2([ɹ̥]) ≈ 1225 Hz in the reduced version of *propose*, as in the unreduced version, suggesting no difference of tongue body position. The difference in F2 between the [ɹ̥] of *prepose* and *propose* is not as large in the reduced pair (Δ ≈ 235 Hz) as in the unreduced pair (Δ ≈ 355 Hz), showing that the distinction is acoustically somewhat neutralized, in that the reduced tokens are less different from one another than are the unreduced tokens. Nevertheless, an F2 difference of 235 Hz is easy to perceive, so that the neutralization is not absolute.

The retention of the distinction in the fast speech pair is consistent with at least two phonological analyses. First, a vowel deletion analyses could still be made to work provided that (some of) the vowel features that distinguish [ɪ] from [ə] were to be copied onto the preceding [ɹ] before vowel deletion. This would require a phonological spreading or copying rule, which would in effect model some aspects of phonetic coarticulation in the phonological component. Alternatively, it is possible to dispense with both vowel deletion and phonological spreading or copying and employ the same phonological representation for the reduced and unreduced tokens; that is, to model vowel reduction, eclipse and coarticulation in the phonetic interpretation component. The coproduction analysis sketched out here and described more fully in Coleman (1992a,b) spells out this proposal. My own preference is for this second analysis, as I favour a minimal phonological component and an empirically well-founded theory of phonetic interpretation.

Having established a phonetic model of syllabic consonant formation in English, I shall now examine whether the same kind of analysis can be put forward for Tashlhit.

3. Syllabic consonants in Agadir Tashlhit

My principal Tashlhit informant, Mr. Lahcen Damiri, is from Agadir, a seaport city in Southern Morocco. The phonology and phonetics of Agadir Tashlhit is similar to that of Imdlawn Tashlhit, the variety studied by Dell and Elmedlaoui (1985, 1988). The main differences are in the lexicon: Agadir is an urban centre, and the lexicon contains many more nativized loans from Moroccan Arabic than in neighbouring rural dialects of Tashlhit. Nevertheless, Agadir and Imdlawn are said to be in the same Tashlhit dialect region. Mr. Damiri is, at the time of writing, a graduate student in linguistics at the University of Oxford. He has been living outside Morocco for less than nine months. He is not a linguistically naïve subject; on the contrary, he has a special interest in phonology, and is well acquainted with the literature on syllable theory and syllabification in generative phonology. In his unpublished Master's thesis, he advocates Dell and Elmedlaoui's theory of syllabification for Tashlhit, with a few modifications of his own, which are not germane to the present study. As well as acting as an informant, he also scored the parses produced by my syllabification algorithm, as described in section 5 below. The segment inventory of Agadir Tashlhit is presented in Table 2.

The transcriptions in Table 2 are mostly in accordance with I.P.A. conventions, except where established practise in the Berber literature varies. In those cases, I.P.A. equivalents are given in square brackets. I have included [ə], marked with a question mark to indicate its disputed status.

According to the generally accepted theory of Tashlhit syllable structure (i.e. Dell and Elmedlaoui 1985), syllabification is based on the association of nuclei with sonority peaks and syllable margins with sonority troughs (as many phonologists have proposed to be the case more generally, as we have seen). This sonority-based approach has the merit that syllabification of consonant-only words is not problematic. Even in words without vowels, some consonants are more sonorous than others. For example, in the Tashlhit words /txznt/ 'you stored' and /txzntnt/ 'and store them', the /n/'s are analyzed as syllable nuclei, because they are more sonorous than the obstruents which precede and follow them. However, sonority is not a sufficient criterion by which to determine the syllable positions of every segment in such words. /txznt/ has only a single sonority crest, the /n/. /z/ is less sonorous than /n/ because it is a fricative, /x/ is less sonorous than /z/ because it is voiceless, and /t/ is less sonorous than /x/ because it is a stop. If sonority were the only factor in determining syllable structure, /txznt/ would be analyzed as a single syllable with the shape MMMNM, and /txzntnt/ as a disyllabic word with the shape MMMNMNM (where N = nuclear segment and M = marginal segment). The sonority sequencing principle alone is not even sufficient to determine whether the /t/ between the two /n/'s in /txzntnt/ is a coda or an onset. But worse, native-speaker judgements have determined that /txznt/ is a disyllabic word ([tx̣zṇt] or [txẓṇt]) and /txzntnt/ a trisyllabic word ([tx̣zṇtṇt] or [txẓṇtṇt]) in Tashlhit. It is necessary to impose a limit on the length of non-nuclear consonant sequences (or equivalently, on the size of non-nuclear constituents) in order to derive parses which contain the right number of syllables. Furthermore, in order to determine the syllable affiliation of marginal consonants between nuclei, it is necessary to add a theoretical constraint such as the Maximal Onset Principle to the sonority cycle. (For example, every Berber syllable has a filled onset in Dell and Elmedlaoui's 1985 analysis.) This in turn presupposes that "maximal onset" is a well-defined construct, a requirement that is independently called for in order to explain why /txznt/ is not a single syllable (i.e. why /txz/ is not a single onset).

Labial	Coronal		Dorsal: Velar	Dorsal: Uvular	Pharyngeal	Laryngeal	
							Stops
	t	ṭ [tˤ]	k kʷ	q qʷ			[-voice]
b	d	ḍ [dˤ]	g gʷ				[+voice]
m	n	[n] [nˤ]					Nasals
							Fricatives
f	s	ṣ [sˤ] š [ʃ] [ṣ̌][ʃˤ]		x [χ] xʷ [χʷ]	ħ	h	[-voice]
	z	ẓ [zˤ] ž [ʒ] ẓ̌ [ʒˤ]		ɣ [ʁ] ɣʷ [ʁʷ]	ʕ		[+voice]
	l	[ḷ] [lˤ]					Lateral
		[ṛ] [rˤ]		r [r], [ɾ] or [ʀ]			Trill or tap
							Vowels
		i/y [j]	u/w				high
			ə?				
			a				low

Table 2: Agadir Tashlhit segment inventory

An alternative analysis of consonant-only words in Tashlhit employs the coproduction analysis of syllabic consonants set out in the preceding section. According to this view, a disyllabic consonant sequence such as [tẓẓ̩nt] would be analyzed as having vocalic nuclei in its phonological representation e.g. /təxzənt/. (The pronunciation [txẓ̩nt] could, in similar fashion, be phonologically represented as /txəzənt/, although since consonant + vowel and vowel + consonant fusions may both yield syllabic consonants, the placement of eclipsed vowels in phonological representations is not a clear-cut matter.) I shall use the symbol /ə/ in these representations as a place-holder denoting a V-slot, without taking a stand on whether it is an independent member of the vowel system, or an allophone of one of the three undisputed vowels /i/, /u/ and /a/, or as a place-holder which may be filled by more than one possible vowel category.

There are, then, two different views to be considered: Dell and Elmedlaoui's sonority-based theory, consistent with the view in nonlinear phonology that syllabic consonants are nuclear, and the version of the coproduction model set out above, in which syllabic consonants are non-nuclear, and the nucleus has vocalic content manifest as secondary articulation of consonants. How shall I choose between the two views? No amount of formal argumentation will settle the issue. On the one hand, advocates of the "nuclear consonant" hypothesis might regard /ə/ as an abstract diacritic denoting syllabicity, predictable by their syllabification procedure and therefore, by Occam's razor, eliminable. From the other side, advocates of the vowel+consonant fusion hypothesis might claim greater simplicity and regularity in their view of syllable structure (every nucleus contains a vowel and every consonant is marginal, even in Tashlhit), and greater explanatory power in predicting the placement of surface [ə]'s where they do occur. Although I shall present a computational implementation of my view of syllable structure below, I do not claim that a similar implementation of sonority-based syllabification could not easily be developed: either theory of syllabification can easily be implemented computationally and shown to be workable, debugged, and improved. What is required in order to resolve the analysis of syllabic consonants is better phonetic data than the literature so far provides, as well as specific phonological evidence. I shall now present a number of arguments in support of my view that syllabic consonants in Tashlhit are the coproduced realization of a phonological vowel and consonant.

3.1 Phonetic variability

The data in this subsection relates to the status of apparent CC-initial words such as /kdu/ 'smell', /gbu/ 'pierce' etc. These are analyzed as complex onsets according to the syllabification procedure in Dell and Elmedlaoui (1985). In the phonological grammar described below, I analyse them as CəC-, so that e.g. [kdu] is phonologically disyllabic /kədu/. The motivation for this comes from two directions: first, phonological simplicity (i.e. a grammar which lacks complex onsets is simpler than one which allows them). Second, phonetic variability: in a number of Tashlhit examples of this kind in our small collection of audio recordings, there is evidence of variability in the presence or absence of a vocalic segment. For example:

(9a) /k^{w}ḍih/ is realised as
[kŭḍih] (with 2 voicing intervals, [ŭ] and [i]) in 9/10 tokens and as
[k^{w}ḍih] (with only [i] voiced) in 1/10 tokens.

b) /ik^{w}bar/ is realised as
[ikŭbar] (with 3 voicing intervals, [i], [ŭ] and [a]) in 8/10 tokens and as
[ik^{w}bar] (with 2 voicing intervals, [i] and [a]) in 2/10 tokens.

c) /kḍu/ is realised as
[kəḍu] in 8/10 tokens and as [kḍu] in 2/10 tokens.

Such variability is highly suggestive of differential phasing of a (possibly hidden) vocalic nucleus and a neighbouring consonant, certainly a simpler explanation than resyllabification or an optional epenthesis rule.

3.2 Impressionistic records

Other examples of optional or intrusive schwa sometimes breaking up consonant clusters and alternations were found during practical phonetic transcription classes with graduate students, in which I made the following observations:

(10a) [tigː(ə)mi] 'house' (/ti-gmmi/)
b) [tigʷma] 'houses' (/ti-gʷma/)

c) [tigːəni] 'sewing (n.)'
d) [gʷno] 'sew!'

The related forms in (10a,b) have the same phonotactic structure: /tigvmV/, where **v** denotes a nonprominent vowel, which is often manifested as a short phonetic vocoid between the release of [g] and the closure of [m]. Sometimes, however, the [ʷ] in [tigʷma] is completely coproduced with the [g] and [m], and there is no vocoid between them. In (10a), the [ə] may be completely coproduced with the [g], especially when [g] is long. A variant realization has the nuclear quantity of [ə] realized on the following [m], which might be considered syllabic in consequence. These cases are parallel to those in (9).

Note that there are some cases of intrusive schwa which seem to be entirely phonetic (i.e. not the realization of a phonological nucleus), as Dell and Elmedlaoui (1985: 116) noted. For example, the words in (11) are typically pronounced with [ə] before the [r] or [ɾ]. Native speakers agree that these words are phonological disyllables, although the effect of the intrusive schwa is to render them phonetically trisyllabic.

(11) /afrux/ [af(ə)rux] 'boy' (optional ə)
/tafruxt/[tɐfərʊxt] 'girl'

A second set of impressionistic records is more directly related to the question of syllabic consonants and the coproduction hypothesis. In the transcriptions in (12), various secondary articulations were noted on some syllabic and non-syllabic consonants. [ʂ] in (12a) denotes a palatalized [s] (i.e. an [s] with coproduced [i]-like resonance). Superscript [ᴵ] and [ᵊ] denote clear and central vocal tract resonance respectively (see Kelly and Local 1989: 72–4).

(12a) [ʂɾ̩ᴵstn̩ᵊt] 'put them down'

b) [t̩ᴵklit] 'you spend the day'

c) [ʃᵊfᵊtᵊ] 'fishing net' (/ššfkt/, nativized loan from Arabic)

d) [lᴵmᴵnᵊdɪl] 'tablecloth' (nativized loan from Arabic)

Note that [t] is clear in (12b) but central in (12c). In (12d), [l] and [m] are clear, whereas [n] is not especially clear, but more central. If the coproduction analysis is correct, and such secondary articulation distinctions reflect phonemic distinctions between eclipsed vowels, the secondary articulation observations in (12d) are suggestive of the possible phonological analyses /l(ɪ)m(ə)ndil/ or /(ɪ)lm(ə)ndil/, where (V) denotes an overlapped vowel (unlike in example 12).

Vowels come in at least three kinds of variants. In (13a) I indicate the range of variation in vowel quality conditioned by segmental environment, including pharyngealization of the word and whether the syllable is open or closed. In (13b) I show the non-nuclear, glide variants of vowels in (13b), according to the orthodox view that glides are featurally identical to vowels, but differ by virtue of their syllable position. The coproduction model proposes the group of vowel realizations in (13c), though it remains to be established whether the secondary articulations $C^{\text{ə}}$, $C^{\text{ʕ}}$ or $C^{\text{ɣ}}$ are all instances of /a/, since I have not yet established whether or not [ə] is distinct from /a/.

(13a) <u>Nuclear, unreduced</u>   b) <u>Non-nuclear</u>

/i/	[i], [ɨ], [ɪ], [ɪ-]	[j]
/u/	[u], [o], [ʊ], [ŏ]	[w]
/a/	[ɛ], [a], [ɑ], [ɐ], [ə]?	[ʕ]

c) <u>Secondary articulation</u>

/i/	C^{j} i.e. C̡
/u/	C^{w}
/a/	$C^{\text{ə}}$, $C^{\text{ʕ}}$ or $C^{\text{ɣ}}$

I shall examine some relationships between secondary articulation and vowel qualities more fully in the next section, starting with the least controversial case.

3.3 Syllabic and non-syllabic variants of /u/ and /i/

In this section, I shall first present evidence that /u/ and /w/ as well as /i/ and /y/ are morphophonologically related. Then I shall give some instances which suggest that /u/ and /^{w}/ are morphophonologically related. Finally, I shall give some examples in which [u] and [^{w}] are in free variation.

3.3.1 Alternations between imperatives and agentive nouns

The imperative is the base form of the verb in Tashlhit. Bensoukas (1994: Appendix A) gives a short but representative list. Most of the imperative forms are triconsonantal (e.g. /bdg/ 'become wet', /hlb/ 'eat something with milk'), but there are biconsonantal and quadriconsonantal forms too (e.g. /anf/ 'move aside', /rzzf/ 'visit'). (The two quadriconsonantal forms listed by Bensoukas both have medial geminates.) There are also, apparently, some uniconsonantal imperatives: I shall argue below, however, that these pattern as biconsonantal forms in which one of the consonants is a glide /y/ or /w/.

The majority of biconsonantal forms take the vowel /a/ in initial position, e.g. /ag^{w}m/, /als/, /ars/, /azn/, /anf/, /awz/, /awd/, /aws/, /aḍn/, /ags/. Exceptions to this generalization include [ml], [rg], [gn], [sγ], [ṣd], and [gḍ]. It may be possible to argue that [ml], [rg], and [gn] are de-geminated /mml/, /rrg/ and /ggn/, as their agentive noun forms are /anmmal/, /amrrag/ and /amggan/ respectively. Another group of apparent exceptions to the /a/-initial generalization is: [dru], [kḍu], [zug], [gli], [ħri], [k^wti], [rwi], [ṛmi], [sti], [xlu], [ẓli], [žži] and [lli]. I shall treat these as triliteral, by representing [i] and [u] as /y/ and /w/ in these cases, as well as in the apparently uniconsonantal forms [ak^wi], [asi], [awi], [aru] and [iri]. The first four are thus lexically biliteral /k^wy/, /sy/, /wy/, and /rw/, and the final form is lexically triliteral /yry/, and hence lacks initial /a/. The slight abstraction of this analysis is supported by comparison of imperatives containing high vowels with their corresponding agentive noun forms, tabulated in (14).

(14)

Imperative	Agentive Noun	Gloss
/dru/	/amdraw/	'share a meal'
/kḍu/	/amkḍaw/	'smell'
/zug/	/amzwug/	'roam, elope'
/gli/	/amglay/	'goad'
/ħri/	/amħray/	'scratch'
/k^wti/	/amk^wtay/	'remember'
/rwi/	/amrway/	'mix up'
/ṛmi/	/anṛmay/	'be tired'
/sti/	/amstay/	'choose'
/xlu/	/amxlaw/	'become crazy'
/ẓli/	/amẓlay/	'separate'
/žži/	/amažžay/	'be fat'
/lli/	/amallay/	'roam'
/ak^wi/	/amak^way/	'jump'
/asi/	/amasay/	'take'
/awi/	/amaway/	'carry'
/aru/	/amaraw/	'give birth'
/iri/	/amaray/	'want, love'

In every case except the last, /u/ or /i/ in the imperative corresponds to /w/ or /y/, respectively, in the agentive noun form. Morphophonological alternations such as those in (14) illustrate a pervasive property of Berber phonology, that high vowels and glides are often contextually-determined alternants of a single abstract vocoid in the consonantal melody. I shall now consider how consonantal labiovelarization /^{w}/ fits into the pattern of /u/ ~ /w/ variation.

3.3.2 Alternations between singular and plural nouns

In (15) and (16) I present two kinds of data as evidence that [^{w}] is a nonsyllabic variant of /u/. (15) gives the singular and plural forms of a few nouns. (This data is from Damiri, 1993.) As is typical in Hamito-Semitic languages, the consonantal and vocalic melodies are morphologically separable. The difference between singular and plural is indicated phonologically through the use of different vowel melodies. The consonantal melody is the same in both singular and plural.

(15)

Singular	Plural	Gloss
a) /ašak^{w}š/	/išukaš/	'pile of stones'
b) /agdur/	/ig^{w}dar/	'jar'
c) /akfuf/	/ik^{w}faf/	'roofed passage'

In (15b, c), the vowel melodies are /a–u/ in the singular and /i–a/ in the plural. However, there is also a consonantal difference, in that the velar stops are unrounded in the singular forms but rounded in the plurals in (15b, c). The same relation holds in (15a) except that the velar stop is rounded in the singular form and unrounded in the plural. The vocalic melodies in (15a) are different from (b, c) if we regard [^{w}] as part of the consonantal melody. However, the pattern is greatly simplified if we treat [^{w}] as part of the vocalic melody, and thus part of the singular and plural morphemes in all six cases. The plural melody will then be /i–u–a/, with /u/ realized as [u] in (15a) and as [^{w}] in (15b,c). The singular melody is /a–u/, with /u/ realized as [u] in (15b,c) and as [^{w}] in (15a). I shall treat the duplication of /a/ in the singular of (15a) as following from its template: in both singular and plural forms in (15a), a nucleus intervenes between the first two consonants. (15b, c) are equally regular in their templates, as there is no syllabic vocoid between the first two consonants. This paradigm shows that the morphophonemic analysis of noun stems, number inflection and phonotactic templates is simple and regular if [^{w}] is analysed as a nonsyllabic variant of /u/, not as part of the consonantal melody.

In (16) I list a few examples from Damiri (1993) of free variation between syllabic and non-syllabic /u/ (i.e. [^{w}] and [u]). These lend additional support to the proposal that [^{w}] and [u] are aspects of a single superordinate phonological category, although this free variation is not productive.

(16) [manag^{w}] ~ [managu] 'when'
[agg^{w}rn] ~ [aggurn] 'flour'
[ax^{w}lil] ~ [axlul] 'snot'

The relationship between [w] and [^{w}] may be captured by assigning them the same set of V-place features. The difference between them is that in e.g. [k^{w}], [g^{w}] and so on, the V-place of [^{w}] is combined with the C-place features of a dorsal consonant, whereas in [w], the V-place features completely characterize the place of articulation.

3.4 Is [ə] related to [a]?

In 3.3 I showed that [w] and [^{w}] may be non-syllabic alternants of /u/, and that [y] may be a non-syllabic alternant of /i/. In this section, I return to the question of the status of [ə]. It seems reasonable to conclude at this stage that [ə] is probably not a variant of /u/, though it might be a variant of /i/. (I suggested in (12) that there may be more than one distinctive secondary articulation in syllabic consonants. For example, the contrast between /i/ and /a/ might be preserved in the environment of syllabic consonants.) The remaining question, therefore, is whether [ə] is a variant of /a/, or an independent category of vocoid.

I shall present two sets of evidence which suggest that [ə] is sometimes phonologically related to /a/, though I do not yet have sufficient evidence to settle the question. The data in (17) exemplify morphophonological alternations between [ə] and /a/ (or rather, since they are drawn from Dell and Elmedlaoui 1985, between syllabic C – which I analyze as /əC/ – and /aC/).

(17)	<u>Perfective</u>	<u>Imperfective</u>	<u>Gloss</u>
	/ṣuwr̩/	/ṭṭṣuwar/	'to wait'
	/sx̣xn̩/	/ttsx̣xan/	'dip (in sauce)'
	/bḍdl̩/	/ttbddal/	'exchange'
	/ẓiyr̩/	/ṭṭẓiyar/	'tighten'
	/huwl̩/	/tthuwal/	'to worry'

The perfective forms in (17) end in two consonants, the second of which is syllabic. In the coproduction model of syllabic consonants, I analyse these as $/C_1 əC_2/$. The imperfective forms end with the parallel shape $/C_1 aC_2/$.

The data in (18) concerns [ə] ~ [a] parallels between forms in two major Berber dialects. (The Tamazight data is from Bouzida *et al.*, 1993, and the Tashlhit data is from my own observations.)

(18)	<u>Tashlhit</u>	<u>Tamazight</u>	<u>Gloss</u>
	/aməxxar/	/amakar/	'voleur'
	/aməzwar/	/amazwar/	'premier'
	/ažž/	/əǧǧ/	'laisser, abandonner'
	/izgr/	/əzgər/	'traverser'
	/inxar/	/inzər/	'nez'
	/nəttənti/	/nutənti/	'elles'
	/nəttni/	/nutni/	'ils, eux'
	/aqəmum/	/aqamum/	'bouche/gueule'

The data in (17) and (18) are not sufficient to settle the question of the phonological composition of [ə], i.e. consonantal syllabicity. In particular, it is not yet possible to tell whether [ə] is the "eclipsed" variant of /a/, or whether [ə] is a cover term for more than one category of eclipsed nuclei. If this latter suggestion were the case, we would hope to find minimal pairs as in the English example in Fig. 1. But in the majority of [ə] – vowel correspondences in (17) and (18), the vowel is /a/.

4. A syllabification algorithm

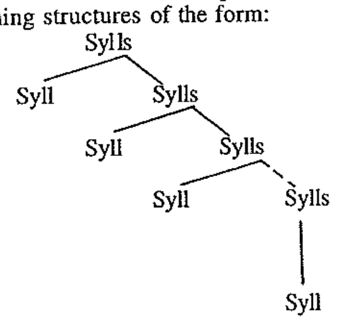
The main difference between the analysis of Tashlhit syllables that I proposed above and that of Dell and Elmedlaoui (1985) is the postulation of phonological vowel in the analysis of syllabic consonants. In other words, I claim that every Tashlhit syllable contains a phonological vowel as its nucleus, with consonants restricted to marginal positions. To see if this view of syllable structure is reasonable when tested against a large body of Tashlhit data, I developed an explicit grammar of Tashlhit syllable sequences which could be employed by a parsing algorithm to automatically compute syllable structures from input text. The complete grammar is listed in full in the Appendix. It is written in the notation of Functional Logic Grammar, a unification-based phrase-structure grammar formalism that will be described in more detail below. I shall describe the context-free backbone of this grammar first, before discussing the particular extensions of the FLG formalism. (Although the rules are context-free, the language defined by them is regular, as there is only one-sided recursion.)

In the absence of a theory of prosodic structure of Tashlhit words, I simply treated words as syllable sequences. These can be defined by two context-free rules:

(19) Sylls → Syll
Sylls → Syll Sylls

which together define the unit sequence and any length sequence of syllables, with right-branching structures of the form:

(20)



The internal structure of each syllable may be defined by the phrase structure rules in (21).

(21) Syll → Onset Rime
Rime → Nucleus Coda
Onset → X
Nucleus → X
Coda → X

I take it as uncontroversial that these rules are cross-linguistically well-attested. (A weakly equivalent analysis into moras is also possible, and may be preferable.) Declarative Phonology was criticised more than once at the Royaumont meeting for being excessively oriented to language-specific descriptions. This criticism is completely fallacious, as the analysis presented here demonstrates. (See also Coleman, 1991.) Practically all of the rules and constraints of this grammar are found cross-linguistically. Some of these general constraints are conjoined with additional language-specific details which refine and restrict them, in a manner which is very close to the proposals of Mohanan (1993) for the decomposition of phonological rules into various interacting subcomponents.

Phonological representations include structures of distinctive features in addition to hierarchically structured parse trees. In order to incorporate complex feature structures and constraints into a context-free grammar, the notation of Functional Logic Grammar (FLG) was employed. A grammar written in this PATR-II like formalism (see Shieber, 1986) may be automatically translated into a Prolog Definite Clause Grammar (DCG), which has a straightforward procedural interpretation as a top-down, depth-first, backtracking parser. Simple descriptions of the operation of a Prolog DCG-based parser may be found in Clocksin and Mellish (1981) or Pereira and Shieber (1987). This is not the appropriate place to write a tutorial on the theory of parsing in computational linguistics. There are many good introductory textbooks to the subject, which phonologists interested in parsing would be advised to consult. The theory of parsing in computer science and computational linguistics is a well-established field of study, with numerous important and useful scientific results, including several provable correct parsing algorithms. It is not necessary for any linguist who is unfamiliar with this literature to spend time reinventing parsing theories.

In the Functional Logic Grammar notation, the simple symbols of context-free rules are each adorned with a variable, which serves as a bearer of a feature structure. For example, the context-free preterminal rule in (22a) is written as (22b) in FLG. (Half of the grammar in the Appendix consists of segmental feature descriptions of this kind.) F is a variable which references the feature structure defined in the second line of rule (22b). Note that the value of each feature in (22b) is written after it, which is the usual practise in unification-based grammars. The reason is that as well as binary features, it is often desirable to employ features whose value is itself a feature structure. For instance, we might want to employ feature structures such as (22c) in some grammar. In this grammar, I shall use such feature structures in order to represent phonological structures such as (22d).

(22a) X → /i/ (where /i/ has the features [+son, -cons, -low, -back, -rnd])

b)
```
x(F) --> "i",
  {F === [son: +, cons: -, low: -, back: -, rnd: -]}.
```

c)
```
[supralaryngeal: [vplace: [low: -, back: -, rnd: -]]]
```

d)
```
[syll: [onset: [x: [...]],
       rime: [nucleus: [x: [...]],
              coda: [x1: [...],
                     x2: [...]]]]]
```

The inventory of segments in the Appendix includes the following accommodations to the ASCII character set: "e" means [ə], "S" means [š], "Z" means [ž], "Y" means [ɣ], "£" means [ʕ], "h." means [ħ], otherwise "." after a letter denotes pharyngealization.

A context-free rule decorated with variables may also be augmented with constraints over those variables. These constraints are typically either a) unification of feature structures, written === in FLG; b) Boolean combination of constraints, such as "A and B" (written A, B), "A or B", "if A then B", "not A"; or c) n-place predicates, such as "more_sonorous(X,Y)" in (24) below.

In addition to the cross-linguistic syllable structure rules in (21), the grammar includes a rule for branching codas, that might be written as a simple context-free rule:

(23) Coda → X X

I shall assume that this rule is also cross-linguistically common, although it is not universal. Thus, I could advance a claim to cross-linguistic generality with as much or as little credence as any other phonological framework.

In the Functional Logic Grammar for Tashlhit, rule (23) is fleshed out as in (24).

```
(24) coda(C) --> x(F1), x(F2),
               {F1 === [cons: +, empty: -],
                F2 === [cons: +, empty: -],
                not(more_sonorous(F2,F1)),
                C === [x1: F1, x2: F2]}.
```

The material in curly brackets on the second to fourth lines of this rule expresses constraints on what kinds of segments can occur in branching codas. Specifically, the second and third lines require that two X-slots may only contain [+consonantal] material, and they must be nonempty. (There is no point allowing one consonant of a branching coda to be empty, because (21) already contains a rule for nonbranching codas. I shall analyse open syllables as containing an empty coda. This makes the grammar shorter.) The fourth line prevents a branching coda from having rising sonority. The fifth line simply puts the feature structures of the two X-slots into a complex feature structure C, which can be made the value of the category-valued feature [coda: C] in the rime rule. Thus, despite its apparent complexity, every line of this rule expresses an aspect of universal grammar. Lines 2–4 express substantive universals of branching coda structures, whereas line 5 is a purely formal construct.

Because I am going to use the grammar to parse surface forms in which /y/ and /w/ are different symbols from /i/ and /u/, not lexical representations in which an archiphonemic notation such as /I/ and /U/ might be considered, both pairs of symbols are listed in the segmental inventory, though they bear the same features, differing only in the value of the diacritic feature [± nuclear], which is adopted solely to differentiate them. Also, because the input strings do not usually contain overt schwas – these are to be predicted on the basis of the computed syllable parses – the empty string "" and the letter "e" (i.e. schwa) are both listed in the segmental inventory, with the same features. The empty string "" may also occur in onset or coda position, in which case it is not parsed as a schwa, but as an empty consonant. (For readability, *all* empty nuclei are written "e" in the output of the parser, and empty consonants are written "_".) Onset, nucleus and coda may each be empty, but we need to ensure that they are not *all* empty. Consequently, the syllable rule in (25) includes a constraint prohibiting empty syllables (the final line).

(25)
```
syllable(S) --> onset(O), rime(R),
        {S === [onset: O, rime: R],
         S === [onset: [x: [empty: E1]],
                rime: [nucleus: [x: [empty: E2]],
                       coda: [x1: [empty: E3],
                              x2: [empty: E4]]]],
   call(not((E1 = '+', E2 = '+', E3 = '+', E4 = '+')))}.
```

4.1 How complex should Onset and Coda be?

The grammar presented so far defines a maximal syllable template (C)V(C(C)). I shall now consider the complexity of the onset, nucleus and coda constituents. In a theory which allows sequentially empty nuclei, the minimal syllable template (C)V alone is sufficient to generate arbitrarily long consonant sequences, if the V may be empty or its phonetic interpretation eclipsed by a neighbouring consonant. But the syllabifications which result may be undesirable, in that the number of syllables predicted by that theory does not accord with native-speaker judgements. For example, the (C)V parse of /txzntnt/ in (26) has seven syllables, though native speakers judge it to have three syllables.

(26)

If the maximal syllable template is (C)V, there must be at least one syllable for each consonant in a word. In consonant-only words in Tashlhit, there are fewer syllables than consonants, entailing the possibility of consonant clusters in onset or coda. In general, however, the bigger the template, the greater the number of possible analyses there will be for any given string. For example, the (C)V syllable grammar has a single parse for any four-consonant string, whereas a (C)V(C) syllable grammar licenses up to five parses for a four-consonant string:

CV.CV.CV.CV
CVC.CV.CV
CV.CVC.CV
CV.CV.CVC
CVC.CVC

Such inherent ambiguity is undesirable and should be minimized. Nevertheless, even a (C)V(C) syllable grammar is too limited for the analysis of /txzntnt/, which would be assigned at least four syllables in the (C)V(C) grammar. Either the onset or the coda node must be allowed to branch – but not both, if that is possible, in order to limit the ambiguity of the grammar. I prefer to allow the coda to branch rather than the onset, for two reasons: first, there are numerous clear cases of CVCC monosyllabic words. In contrast, many instances of candidate CCV words (e.g. /bdu/) may plausibly be analysed as CəCV, as there is often an epenthetic schwa between the two consonants. An alternative logical possibility is əCCV: I do not have any data on which to settle this question. Second, Dell and Elmedlaoui (1988) present data on syllable weight showing that e.g. [ln̩t] is heavy, whereas [dn̩] is light. This distinction is easily stated as a contrast between branching and non-branching codas: /lənt/ *vs.* /dən/.

4.2 Geminates

A superficial problem for the (C)V(C(C)) proposal is posed by the existence of numerous Tashlhit words containing geminates in word-initial position.

(27a)	/ṭṭažin/	'utensil'
b)	/šš/	'eat'
c)	/ṭṭaf/	'hold'
d)	/ṭṭaṣ/	'sleep'
e)	/ttggwa/	'be washing clothes'

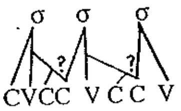
In the (C)V(C(C)) syllable grammar, there are only two ways in which geminates may be parsed: tautosyllabically, in the coda, or transsyllabically, in the coda of one syllable and in the following onset. This predicts that word initial geminates will always have a syllabic beginning i.e. [CC...] must be analyzed as either /əCC.../ or possibly /CəC.../. The plausibility of this prediction is shown by two kinds of data. First, initial geminates *are* syllabic, a fact which has no explanation if syllables may have branching onsets. Second, many cognate words in Tamazight Berber contain [əC] where Tashlhit has syllabic C:

(28)	<u>Tashlhit</u>	<u>Tamazight</u>	
	/imqqur/	/aməqqʷran/	'big'
	/imẓzi/	/amažṭuḥ/	'small'
	/ṭṭažin/	/aṭažin/	'utensil'
	/šš/	/əšš/	'eat'
	/ṭṭaf/	/əṭṭəf/	'hold'
	/ṭṭaṣ/	/əṭṭəs/	'sleep'
	/kʷn̩ni/	/kʷənni/	'you (m. pl.)'
	/nk̩ki/	/nəkki/	'me'
	/tadggʷat/	/tadəgʷat/	'afternoon'

Words containing two apparent initial geminates, as in (27e), also present no problem for the (C)V(C(C)) grammar. For example, in audio recordings of the phrase /ini za ttggʷa yat tklit aḍni/ ('please say "ttggwa" again'), at least the first /t/ of /ttggʷa/ is a coda to the preceding /za/. The second /t/ may be parsed as the second consonant of a branching coda, or as the onset of the following syllable. The (C)V(C(C)) grammar requires that a nucleus intervene between /tt/ and /ggʷ/. The parses my grammar predicts are shown in (29). I do not have data to determine whether the second element of the two geminates is a coda or an onset, so (29) collapses both possibilities into a single diagram.

Support for the prediction of a vowel between the two geminates comes from my recordings. The only two words with double geminates in word-initial position in my data, /ttggʷa/ and /ttgga/, have a short, central, audible vowel separating the two geminates in 9/10 tokens of each word.

(29)



z a t t ə g g^{w} a

4.3 The grammar is not a program

Although the grammar in the Appendix contains rules (e.g. phrase-structure rules), they are not instructions about how to compute the constituent structure of a segmental string. This position may be contrasted with standard theories of syllabification, such as Clements and Keyser (1983), Harris (1983), Levin (1984), and Dell and Elmedlaoui (1985), in which instructions for the construction of syllable structure are regarded as a proper part of the phonological component.

A form like /atta/ is ambiguous in the (C)V(C(C)) grammar, since it has at least the following two parses:

(30a)

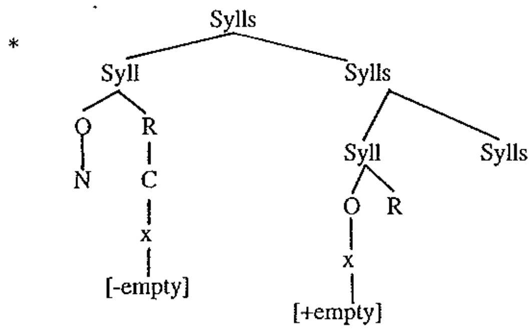
b)

(Parses with an empty nucleus breaking up the geminate are not considered in this example, though they are a logical possibility.) Phonologists generally do not like such ambiguity, and seek empirical evidence for a unique parse of every string in most cases. Adding a maximal onset preference will favour (30b) over a). There are several ways in which such a parsing preference might be achieved. The traditional solution, which builds on the mechanism of rule ordering, places rules that parse consonants into onsets before those that parse consonants into codas. Such rule ordering is not available in declarative phonology, so one of two alternative techniques must be adopted.

i) In the parser: pick minimal coda rules as parse hypotheses before larger coda expansions. This is similar in many ways to the traditional solution just mentioned, in that it employs a control structure based upon the sequential selection of rules. Phrasing the strategy in terms of "small codas" rather than "big onsets" is more conducive to a single-pass, left-to-right parsing strategy, however. (This strategy is also employed to ensure that filled codas are preferred over empty codas.)

ii) In the grammar: add a trans-syllabic constraint that the onset may not be empty if previous coda is filled. To prohibit structures that conform to the partial description in (31a), it is necessary to add a constraint on feature-structures of the form shown in (31b).

(31a)



b) In structures of the form:

```
[sylls:   [syll:    [rime: [coda:       [x1: [empty:  E1] ]]]]
                                        [x2: [empty:  E2] ]]]]
          [sylls:  [syll:  [onset:  [empty:  E3]]]             ]]
```

if (E3=+) then ((E1=E2=+))

The constraint in (31b) is somewhat more verbose than it needs to be, since feature structures are descriptions of structures, rather than strings. It would be convenient to be able to employ structural descriptions of the form (32):

(32) [coda:[x1: [empty: E1]]] [onset: [empty: E3]]
           [x2: [empty: E2]]]

It would be possible to add a facility for incorporating such sequence constraints in FLGs, but at present it is necessary to implement the verbose constraint (31b) directly as a restriction on the "sylls" constituents:

(33)
```
sylls(Ss) --> syllable(S), sylls(Rest),
        {Rest === [syll: [onset: [x: [empty: E3]]]],
            S === [rime: [coda: [x1: [seg: C1, empty: E1],
                                 x2: [seg: C2, empty: E2]]]],
    (call((E3 = '+')) -> call((E1 = E2, E2 = '+')); (E3 = '-'))}
```

(The final statement of this rule in the Appendix is still more verbose, as it factors in a number of other constraints too.)

5. Evaluation

Being a context-free grammar augmented with complex symbols and unification, the syllable sequence grammar is easily evaluated using a variety of parsing algorithms. The Functional Logic Grammar was automatically translated into a Prolog DCG using the algorithm of Boyer (1988), which yields a top-down, left-to-right, backtracking parser. In evaluating this grammar, I had two criteria: i) the account it provides of schwa distribution (i.e. syllabic consonants); ii) broad coverage of the data. A list of 589 Tashlhit words was analysed using this parser, yielding analyses such as the following:

```
Input = SSlaYwm            Number of syllables = 3
Syllabification = [first : SeS, rest : [first : laY, rest : wem ] ]

Input = YwmmS          Number of syllables = 2
Syllabification = [first : Ywem, rest : meS ]

Input = Ywmt          Number of syllables = 1
Syllabification = Ywemt

Input = aSSkwar            Number of syllables = 2
Syllabification = [first : _aSS, rest : kwar ]

Input = aqwrqS          Number of syllables = 3
Syllabification = [first : _aqw, rest : [first : re_, rest : qeS ] ]

Input = ggwd.          Number of syllables = 1
Syllabification = gegwd.

Input = gwdl          Number of syllables = 2
Syllabification = [first : gwe_, rest : del ]

Input = gwmr          Number of syllables = 2
Syllabification = [first : gwe_, rest : mer ]

Input = kSm          Number of syllables = 2
Syllabification = [first : ke_, rest : Sem ]

Input = kd.u          Number of syllables = 2
Syllabification = [first : ke_, rest : d.u_ ]

Input = kks          Number of syllables = 2
Syllabification = [first : ke_, rest : kes ]

Input = kwfs          Number of syllables = 1
Syllabification = kwefs

Input = kwmmS          Number of syllables = 2
Syllabification = [first : kwem, rest : meS ]

Input = kwnkwrri            Number of syllables = 3
Syllabification = [first : kwenkw, rest : [first : re_, rest : ri_ ] ]

Input = kwrkd.          Number of syllables = 2
Syllabification = [first : kwer, rest : ked. ]


Input = lYwnbaz          Number of syllables = 3
Syllabification = [first : leYw, rest : [first : ne_, rest : baz ] ]

Input = lYwr.d.          Number of syllables = 2
Syllabification = [first : leYw, rest : r.ed. ]

Input = lglmun          Number of syllables = 3
Syllabification = [first : leg, rest : [first : le_, rest : mun ] ]

Input = lkrh          Number of syllables = 2
Syllabification = [first : lek, rest : reh ]
```

```
Input = mlk          Number of syllables = 1
Syllabification = melk

Input = nnqqwr.t.          Number of syllables = 2
Syllabification = [first : nenq, rest : qwer.t. ]

Input = qwnt.          Number of syllables = 1
Syllabification = qwent.

Input = ssYwrS          Number of syllables = 2
Syllabification = [first : ses, rest : YwerS ]

Input = taskwflt          Number of syllables = 2
Syllabification = [first : taskw, rest : felt ]

Input = taxwrstt          Number of syllables = 3
Syllabification = [first : taxw, rest : [first : res, rest : tet ] ]
```

The 589 parses were checked by a native speaker (Damiri), a graduate student with extensive education in phonological theory, who is an advocate of Dell and Elmedlaoui's approach to syllabification. He was asked to assess (1) the syllable count, (2) the placement of syllable boundaries, and (3) the distribution of schwas (interpreted as syllabicity of a neighbouring consonant if desired). My expectation was that even if he disagreed with the parser about the placement of syllable boundaries, we might at least test the theory-internal plausibility of the parser in terms of its ability to determine the number of syllables in each word. (It is frequently claimed in the syllabification literature that native speakers are more consistent at counting syllables than determining syllable boundaries.)

The results of this experiment are as follows:

i) The informant marked 12 of our parses as incorrect. By this metric, our parses have the right number of syllables per word in 98% of cases. The 12 errors arose for the following reasons: 2 mistranscriptions in the input; 6 word-initial consonant clusters analyzed by Damiri as branching onsets, and by my grammar as involving an extra word-initial syllable; 1 coda-onset parsing preference disagreement, for which the number of syllables was not disputed, however; and 3 analyses in which Damiri felt unhappy with the coda cluster /$\check{z}\gamma^{w}$/.

ii) In 30 words (c. 5% of the test set) the informant was unsure of his own judgement as to the placement of syllable boundaries or syllable count.

As an additional test of our grammar, it is instructive to compare the several phonetic transcriptions in which Dell and Elmedlaoui (1985) record schwas with the predictions our parser makes concerning their location:

(33)

Dell and Elmedlaoui's transcriptions		Parser input	Parser output
/i.sLm/	[isləm]	islm	is.lem
/txZ.nakkw/	[tx(ə)z̩nakkw]	txznakkw	tex.ze.nakkw
/tbX.lakkw/	[təbx̩lakkw]	tbxlakkw	teb.xe.lakkw
/ma.ra.tGt/	[maratəgt]	maratgt	ma.rat.get
/it.bD.rin/	[it.əb(ə)d̩.rin]	itbdrin	it.bed.rin
/t-!ngd-t/	[!tn̩(ə)gətt]	tngdt	teng.det
		tngtt	teng.tet

/tS.bɣ'ṭ/	[ts(ə)bɣṭ]	tsbYt	tesb.Yet
/R.gLx/	[r̥gl̥əx]	rglx	reg.lex
/ixNg/	[ixn̥əg]	ixng	ix.neg
/ixNgt/	[ixn̥əgət]	ixngt	ix.negt
/iškd/	[iškəd]	iSkd	iS.ked
/i.šNn.qas/	[išn̥nəqas]	iSnnqas	iS.nen.qas
/arista<u>yL</u>qqayd/	[yɪl]	aristlqqayd	a.ris.tay.leq.qayd
/ina<u>wL</u>mas/	[wʊl]	inawlmas	i.nawl.mas

In a third test, the 110 words in the Appendix of Dell and Elmedlaoui (1988) were parsed. This data concerns the formation of imperfectives by gemination of one of the consonants of the basic stem. In some imperfectives (e.g. /mmrz/, /ffrn/ and /xxng/) the first consonant of the basic stem is geminated, whereas in others (e.g. /ɣmml/, /rkkm/ and /kʃʃm/, the second consonant is geminated. According to the grammar presented here, the generalization which predicts which consonant is geminate in the imperfective stem is:

(35) The onset of the final syllable is geminated.

Basic forms such as /ɣml/, /rkm/ and /kʃm/ are parsed as disyllabic /ɣəməl/, /rəkəm/ and /kəʃəm/ by my parser. In these forms, the onset of the final syllable will be the second consonant. In contrast, forms such as /mrz/, /frn/ and /xng/ are parsed as monosyllables i.e. /mərz/, /fərn/ and /xəng/. In these stems, the final syllable is the only syllable, so its onset is the first consonant.

For this experiment, I made a minor alteration to the computation of sonority in coda clusters. The underlying (C)V(C(C)) grammar is unchanged, though. The alteration is as follows:

```
coda(C) --> x(F1), x(F2),
     {F1 === [cons: +, empty: -],
     F2 === [cons: +, empty: -],
     more_sonorous(F1,F2),
     C === [x1: F1, x2: F2]}.
/* Sonority */

more_sonorous(F1,F2):-
     F1 === [son: +],
     F2 === [son: -], !.
more_sonorous(F1,F2):-
     F1 === [cons: -],
     F2 === [cons: +], !.
more_sonorous(F1,F2):-
     F1 === [son: +, nas: -],
     F2 === [son: +, nas: +], !.
more_sonorous(F1,F2):-
     F1 === [cont: X, voi: +],
     F2 === [cont: X, voi: -], !.
more_sonorous(F1,F2):-
     F1 === [cont: +],
     F2 === [cont: -, voi: -], !.
```

The force of these alterations is a) branching codas must have falling sonority. Level sonority is not permitted within a coda; and b) only voiceless stops are permitted after a fricative within a branching coda: /ʃb/, /ʒb/ etc. cannot be tautosyllabic. In addition, the analysis of postvocalic /žɣ^{w}/ is improved, as it must be divided between onset and coda.

Generalization (35) fails in four cases (out of 110 in the test set). I do not have an explanation for two of them (/nʒh/ and /rʃq/).The other two (/rwl/ and /lwr/) are problematic for Dell and Elmedlaoui's analysis too. Both syllabification procedures yield a few problematic cases.

In the same paper, Dell and Elmedlaoui (1988) also present some data on Berber versification, demonstrating a sensitivity to the distinction between heavy and light syllables. This data is entirely unproblematic for my grammar. Naturally, the difference between heavy and light syllables will have to be defined in a slightly different way in my grammar than in Dell and Elmedlaoui's: according to the theory of syllable structure that I employ, a heavy syllable is one with either a full vowel and a coda (e.g. /tas/) or a branching coda (e.g. /lnt/).

6. Discussion

I have presented a grammar of Tashlhit Berber syllable structure in which consonants may only occur in non-nuclear positions, and nuclei may only bear vocalic features. This grammar is almost entirely composed of constraints on syllable structure that are provided by Universal Grammar. I have presented a variety of arguments, from Berber morphophonology, cross-dialect comparisons, phonetic variability and cross-linguistic comparison of syllabic consonants in Berber and English that such a grammar is phonetically and phonologically plausible. The plausibility of the grammar was also formally evaluated by employing it to automatically parse a number of word-lists.

I argued that this evidence strongly supports the coproduction model of syllabic consonants. If that is correct, any grammar of Tashlhit syllable structure must allow for the parsing of non-overt (that is, eclipsed or empty) nuclei, as ours does. I am currently pursuing two lines of research to spell out the phonetic interpretation component more fully. First, in collaboration with Francois Dell and Mohamed Elmedlaoui, I am searching for minimal pairs or near-minimal pairs in Tashlhit differing only in the secondary articulation of syllabic consonants (parallel to the *prepose ~ propose* examples in English). If any such examples can be found, they will show that the nuclei of syllables containing syllabic consonants are vocalic. Second, to demonstrate the reasonableness of the coproduction model, I have employed the IPOX speech synthesis system (Dirksen and Coleman, forthcoming) to produce waveforms sounding like [kzn̩t] from an input in which vowels are specified (e.g. /kazant/), but with the syllables highly compressed, so that the vocalic nucleus is completely eclipsed by the onset and/or coda, in exactly the fashion described in the theoretical presentation in section 2.2 above. Such a demonstration does not settle the nature of syllabic consonants as they are produced by Tashlhit speakers, but it does show that the theory of Tashlhit syllable structure and the coproduction model of phonetic interpretation are mutually consistent.

In conclusion, I have presented data and arguments in support of the following claims:

i) Although Tashlhit has many syllabic consonants at the phonetic level, it is not necessary to treat them as syllable nuclei in the phonology.

ii) Proposing a V slot filled with vocalic features in the phonological analysis of syllabic consonants yields the basis of an account of secondary articulation of those consonants, as well as an account of schwa epenthesis.

iii) This also enables the syllable template to be (C)V(C(C)), a hypothesis which is borne out by the computational evaluation of a small lexicon.

iv) It is not necessary to deal with parsing preferences by tinkering with the parsing algorithm. This can be done by explicit structural constraints in the grammar, which have a declarative interpretation.

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Appendix

```
/* BERBER.G - A Functional Logic Grammar of Tashlhiyt Berber */

/* Vowels */

x(F) --> "i",
      {F === [son: +, cons: -, low: -, back: -, rnd: -, nuclear: '+',
                  empty: -, seg: 'i']}.
x(F) --> "a",
      {F === [son: +, cons: -, low: +, rnd: -, empty: -, seg: 'a']}.
```

```
x(F) --> "u",
      {F === [son: +, cons: -, low: -, back: +, rnd: +, nuclear: '+',
              empty: -, seg: 'u']}.

x(F) --> "e",
      {F === [son: +, cons: -, low: +, empty: +, seg: 'e']}.
      /* Empty vowel - alternative notation */

x(F) --> "",
      {F === [son: +, cons: -, low: +, empty: +, seg: 'e']}.
      /* Invisible empty vowel */


/* Consonants */

x(F) --> "y",
      {F === [son: +, cons: -, low: -, back: -, rnd: -, empty: -,
            nuclear: -, seg: 'y']}.
x(F) --> "w",
      {F === [son: +, cons: -, low: -, back: +, rnd: +, empty: -,
            nuclear: -, seg: 'w']}.

/* y and w are not distinct categories from i and u, differing
only by virtue of position. If distinct symbols are employed in
generation, overgeneration will result. */

x(F) --> "b",
      {F === [son: -, cons: +, cont: -, voi: +, nas: -, place: lab,
            empty: -, seg: 'b']}.
x(F) --> "m",
      {F === [son: +, cons: +, cont: -, voi: +, nas: +, place: lab,
            empty: -, seg: 'm']}.
x(F) --> "f",
      {F === [son: -, cons: +, cont: +, voi: -, nas: -, place: lab,
            empty: -, seg: 'f']}.
x(F) --> "d.",
      {F === [son: -, cons: +, cont: -, voi: +, nas: -,
                  place: cor, ant: +, low: +, empty: -, seg: 'd.']}.
x(F) --> "d",
      {F === [son: -, cons: +, cont: -, voi: +, nas: -,
                  place: cor, ant: +, low: -, empty: -, seg: 'd']}.
x(F) --> "t.",
      {F === [son: -, cons: +, cont: -, voi: -, nas: -,
                  place: cor, ant: +, low: +, empty: -, seg: 't.']}.
x(F) --> "t",
      {F === [son: -, cons: +, cont: -, voi: -, nas: -,
                  place: cor, ant: +, low: -, empty: -, seg: 't']}.
x(F) --> "n.",
      {F === [son: +, cons: +, cont: -, voi: +, nas: +,
                  place: cor, ant: +, low: +, empty: -, seg: 'n.']}.
x(F) --> "n",
      {F === [son: +, cons: +, cont: -, voi: +, nas: +,
                  place: cor, ant: +, low: -, empty: -, seg: 'n']}.
x(F) --> "Z.",
      {F === [son: -, cons: +, cont: +, voi: +, nas: -,
                  place: cor, ant: -, low: +, empty: -, seg: 'Z.']}.
x(F) --> "Z",
      {F === [son: -, cons: +, cont: +, voi: +, nas: -,
                  place: cor, ant: -, low: -, empty: -, seg: 'Z']}.
x(F) --> "S.",
      {F === [son: -, cons: +, cont: +, voi: -, nas: -,
                  place: cor, ant: -, low: +, empty: -, seg: 'S.']}.
x(F) --> "S",
```

```
      {F === [son: -, cons: +, cont: +, voi: -, nas: -,
                place: cor, ant: -, low: -, empty: -, seg: 'S']}.
x(F) --> "r.",
      {F === [son: +, cons: +, cont: +, voi: +, nas: -,
                place: cor, ant: +, low: +, empty: -, seg: 'r.']}.
x(F) --> "r",
      {F === [son: +, cons: +, cont: +, voi: +, nas: -,
                place: cor, ant: +, low: -, empty: -, seg: 'r']}.
x(F) --> "l.",
      {F === [son: +, cons: +, cont: +, voi: +, nas: -,
                place: cor, ant: +, low: +, empty: -, seg: 'l.']}.
x(F) --> "l",
      {F === [son: +, cons: +, cont: +, voi: +, nas: -,
                place: cor, ant: +, low: -, empty: -, seg: 'l']}.
x(F) --> "z.",
      {F === [son: -, cons: +, cont: +, voi: +, nas: -,
          place: cor, ant: +, low: +, empty: -, seg: 'z.']}.
x(F) --> "z",
      {F === [son: -, cons: +, cont: +, voi: +, nas: -,
          place: cor, ant: +, low: -, empty: -, seg: 'z']}.
x(F) --> "s.",
      {F === [son: -, cons: +, cont: +, voi: -, nas: -,
          place: cor, ant: +, low: +, empty: -, seg: 's.']}.
x(F) --> "s",
      {F === [son: -, cons: +, cont: +, voi: -, nas: -,
          place: cor, ant: +, low: -, empty: -, seg: 's']}.
x(F) --> "gw",
      {F === [son: -, cons: +, cont: -, voi: +, nas: -,
                place: dor, high: +, rnd: +, empty: -, seg: 'gw']}.
x(F) --> "g",
      {F === [son: -, cons: +, cont: -, voi: +, nas: -,
                place: dor, high: +, rnd: -, empty: -, seg: 'g']}.
x(F) --> "kw",
      {F === [son: -, cons: +, cont: -, voi: -, nas: -,
                place: dor, high: +, rnd: +, empty: -, seg: 'kw']}.
x(F) --> "k",
      {F === [son: -, cons: +, cont: -, voi: -, nas: -,
                place: dor, high: +, rnd: -, empty: -, seg: 'k']}.
x(F) --> "Yw",
      {F === [son: -, cons: +, cont: +, voi: +, nas: -,
                place: dor, high: -, rnd: +, empty: -, seg: 'Yw']}.
x(F) --> "Y",
      {F === [son: -, cons: +, cont: +, voi: +, nas: -,
                place: dor, high: -, rnd: -, empty: -, seg: 'Y']}.
x(F) --> "xw",
      {F === [son: -, cons: +, cont: +, voi: -, nas: -,
                place: dor, high: -, rnd: +, empty: -, seg: 'xw']}.
x(F) --> "x",
      {F === [son: -, cons: +, cont: +, voi: -, nas: -,
                place: dor, high: -, rnd: -, empty: -, seg: 'x']}.
x(F) --> "qw",
      {F === [son: -, cons: +, cont: -, voi: -, nas: -,
                place: dor, high: -, rnd: +, empty: -, seg: 'qw']}.
x(F) --> "q",
      {F === [son: -, cons: +, cont: -, voi: -, nas: -,
                place: dor, high: -, rnd: -, empty: -, seg: 'q']}.
x(F) --> "h.",
      {F === [son: -, cons: +, cont: +, voi: -, nas: -, place: rad,
          empty: -, seg: 'h.']}.
x(F) --> "h",
      {F === [son: -, cons: +, cont: +, voi: -, nas: -, place: lar,
          empty: -, seg: 'h']}.
x(F) --> "£",
```

```
      {F === [son: -, cons: +, cont: +, voi: +, nas: -, place: rad,
            empty: -, seg: '£']}.
 x(F) --> "", 
      {F === [son: -, cons: +, low : +, empty: +, seg: '_']}.
      /* Empty consonant */
 /* Syllable structure */

 syllable(S) --> onset(O), rime(R),
      {S === [onset: O, rime: R],
       S === [onset: [x: [empty: E1]],
              rime: [nucleus: [x: [empty: E2]],
                     coda: [x1: [empty: E3],
                            x2: [empty: E4]]]],
      call(not((E1 = '+', E2 = '+', E3 = '+', E4 = '+')))}.
      /* Empty syllables are prohibited */

 onset(O) --> x(F),
      {F === [cons: +],
      O === [x: F]}.
 onset(O) --> x(F),
      {F === [cons: -, son: +, low: -,
               nuclear: -],  /* y or w, not i or u */
      O === [x: F]}.
 rime(R) --> nucleus(N), coda(C),
      {R === [nucleus: N, coda: C]}.

 nucleus(N) --> x(F),
      {F === [son: +, cons: -, nuclear: +],
      N === [x: F]}.

 /* [nuclear: +] prevents y and w from occurring as nuclei, so that
 rimes like yy are prohibited */

 coda(C) --> x(F1), x(F2),
      {F1 === [cons: +, empty: -],
      F2 === [cons: +, empty: -],
      not(more_sonorous(F2,F1)),
      C === [x1: F1, x2: F2]}.                          /* CC */

 coda(C) --> x(F1), x(F2),
      {F1 === [cons: -, son: +, low: -, empty: -, nuclear: '-'],
      F2 === [cons: +, empty: -],
      C === [x1: F1, x2: F2]}.                          /* GC */

 /* In branching codas, both elements must be nonempty to avoid
      a vacuous contrast between eC, Ce and C */

 coda(C) --> x(F),
      {F === [cons: +, empty: -],
      C === [x1: F]}.
 coda(C) --> x(F),
      {F === [cons: -, son: +, low: -, empty: -, nuclear: '-'],
      C === [x1: F]}.                                   /* y or w */

 coda(C) --> x(F),
      {F === [cons: +, empty: +],    /* Filled codas are preferred */
      C === [x1: F]}.


 /* Sonority */

 more_sonorous(F1,F2):-
      F1 === [son: +],
```

```
      F2 === [son: -], !.
more_sonorous(F1,F2):-
      F1 === [cons: -],
      F2 === [cons: +], !.
more_sonorous(F1,F2):-
      F1 === [son: +, nas: -],
      F2 === [son: +, nas: +], !.    /* l and r are more
                                        sonorous than n and m */

more_sonorous(F1,F2):-
      F1 === [cont: +],
      F2 === [cont: -], !.
more_sonorous(F1,F2):-
      F1 === [cont: X, voi: +],
      F2 === [cont: X, voi: -], !.

      /* b is not more sonorous than S, even though b is
      voiced and S voiceless */


/* Sequences of syllables */

sylls(Ss) --> syllable(S),
      {S === [onset: [x: [seg: On]],
            rime: [nucleus: [x: [seg: Nu, empty: E1]],
                  coda: [x1: [seg: C1, empty: E2],
                        x2: [seg: C2, empty: E3]]]],
      /* Word-final empty rimes are prohibited */
      call(not((E1 = '+', E2 = '+', E3 = '+'))),
      sstring(On,Nu,C1,C2,Sname),
      Ss === [syll: S, number: 1, string: Sname]}.

sylls(Ss) --> syllable(S), sylls(Rest),
      {Rest === [number: N, string: Reststr,
                syll: [onset: [x: [empty: E3]]]],
      M is N+1,                         /* M counts syllables */
      S === [onset: [x: [seg: On]],
            rime: [nucleus: [x: [seg: Nu]],
                  coda: [x1: [seg: C1, empty: E1],
                        x2: [seg: C2, empty: E2]]]],
      /* Onset may not be empty if previous coda is filled (maximal
      onset) */
      (call((E3 = '+')) -> call((E1 = E2, E2 = '+')); (E3 = '-')),
      sstring(On,Nu,C1,C2,Sname),   /* sstring joins the terminals of
                                       each syllable together into a
                                 string called Sname */
      Ss === [syll: S,
            string: [first: Sname,
                     rest: Reststr],
            rest: Rest, number: M]}.
```

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