Sonority Waves in Syllabification

Caroline Wiltshire

Abstract

The current emphasis on markedness constraints in phonology has deep historical roots in the development of syllable phonotactics, with sonority playing a salient role from the beginning. Goldsmith (2011) points to the use of sonority in syllabification dating back to pre-generativists Panini, Whitney (1874), Jesperson (1904), and Pike (1947) among others. In his review of the concept of "syllable", Goldsmith concludes "Sonority, and the wave-like recurrence of peaks of sonority, seems to me to be the fundamental pattern of syllabification in language" (2011: 29). The use of waves can be compared and contrasted to the use of constituent structure for modelling the role of sonority in phonology, via examples such as syllabification and alternations within L1s, adaptations of words borrowed from L2s, and acquisition of L2s syllables and consonant clusters. While phonotactics in terms of syllable constituents can be developed to account for (most of) these examples, the sonority wave approach provides not only an account, but also a motivation.

Keywords: sonority, syllable, constituent, borrowing, acquisition

1. Introduction

The current emphasis on constraints in phonology has deep historical roots in the development of syllable phonotactics, with sonority playing a salient role from the beginning. Goldsmith (2011) points to the use of sonority in syllabification dating back to pre-generativists, including Panini, Whitney (1874), and Jesperson (1904) among others. Pike and Pike (1947) borrow the formalism of syntactic structure to introduce the syllable as a hierarchical structure dominating sub-constituents, and many modern accounts of sonority focus on its role within syllable constituents such as onset or coda (e.g., Steriade 1982, Selkirk 1984, Gouskova 2001). However, sonority fits uneasily into the standard formalism of generative theory in two main ways: 1) it is not a binary contrast that can be represented in a [$\pm$feature] contrast, but rather a gradient/scalar one with multiple values (Hankamer & Aissen 1974) and 2) what matters often is relative sonority, or the sonority of one segment relative to its neighbors (Goldsmith & Larson 1990).

In opposition to the hierarchical approach to stating sonority constraints within syllable constituents, Goldsmith (2011) also discusses a more "wave-like" understanding of sonority, in which speech consists of rises and falls of sonority, with the peaks defining the number of syllables and the trough marking the beginning of a syllable. This understanding emphasizes the use of both gradience in sonority values and contextual factors in determining sonority, both of which can be lacking in hierarchical approaches. As with wave and particle theories in physics (Pike 1959), Goldsmith suggests that both approaches add to our understanding of sonority and its function in the syllable.

In this paper I will review examples of several of the major applications of sonority in phonological description and analysis, where we find it useful for: a) motivating alternations within languages b) motivating alternations in languages in contact and c) order of acquisition (in first and second language acquisition). In this chapter, I provide examples from my own work which required reference to sonority in: a) alternations within L1s (Spanish, Malayalam), b) adaptations of words borrowed from L2s, in order to meet L1 syllable phonotactics (Indonesian) and c) acquisition of L2s syllables and consonant clusters (Indian Englishes). Where they differ, I compare the use of hierarchical syllable structure vs. sonority waves as explanations for the generalizations and alternations, confirming the importance of the latter. While accounts that restrict sonority based on syllable constituency can be developed to provide a formal account for (most of) the examples, the sonority wave approach provides not only an account, but also a motivation.

2. Background

The *Sound Pattern of English* (Chomsky & Halle 1968) was noted for its avoidance of syllable related phenomena and its insistence that segments are characterized in terms of distinctive features with binary values. There have been several approaches to dealing with the issue of sonority as gradient, rather than an all or nothing feature like [±voice] or [±coronal]. One approach in keeping with the use of binary distinctive features is that of Clements (1990) who proposes combining the plus values of a set of four major class features: sonorant, approximant, vocoid, syllabic (1990:294), to give a relative sonority ranking of

(1) Sonority class rankings in Clements (1990:294)

Obstruents <	Nasals <	Liquids <	Vowels
1	2	3	4

Exactly the opposite of this approach is to use an n-ary sonority feature (Vennemann 1972, Hankamer & Aissen 1974, Hooper 1976, Selkirk 1984), in some cases dispensing with the major class features entirely (Hankamer & Aissen 1974: 142, Selkirk 1984: 110). Segments or segment classes each are indexed with a numerical value to represent sonority levels, and ranked by their sonority index into a hierarchy as in (2).

(2) Sonority index in Selkirk (1984: 112)

p,t,k	b,d,g,	f,θ	v,z,ð	s	m,n	l	r	i,u	e,o	a
.5	1	2	3	4	5	6	7	8	9	10

In Optimality Theory, a set of constraints relate segments to syllable positions, with a fixed ranking ensuring that a segment of higher sonority is preferred as a peak and one of lower sonority is preferred as a margin (Prince & Smolensky 1993). Baertsch (2002) and Baertsch & Davis (2009) extend this approach further towards capturing sonority relationships by proposing a syllable internal segment that allows onsets to consist of two margin segments (M_1 followed by optional M_2) and considering the coda as M2 as well, in order to capture sonority relationships within onsets and between onsets and codas, again using fixed rankings.

(3) Fixed ranking for fixed relative sonority (Prince & Smolensky 1993: 141)

*P/t >> ….*P/l …. >> *P/i >> *P/a

*M/a >> *M/i….>> *M/l ….>> *M/t

(4) Split Margin to handle sonority relationship within and between constituents

(Baertsch 2002, Baertsch & Davis 2009: 303)

*M_1/[+lo] >> *M_1/[+hi] >> *M_1/r >> *M_1/l >> *M_1/Nasal >> *M_1/Obstruent

*M_2/Obstruent >> *M_2/Nasal >> *M_2/l>> *M_2/r >> *M_2/[+hi] >> *M_2/[+lo]

The treatment of classes of sounds as having a numerical sonority is compatible with the wave approach to sonority. For diagramming this approach, I will use a less detailed scale (5) than the index in (2), to map the rise and falls of sonority within words as in (6):

(5) Sonority Hierarchy (a la Selkirk 1984, Steriade 1982)

Obstruent stops < fricatives < nasals < liquids < glides < vowels

Obstruent stops	fricatives	nasals	liquids	glides	vowels
1	2	3	4	5	6

(6)
```
6         *         *     *              *    *    *
5        /\        /\    /\              /\   /\   /\
4       * \      /  \   / \             /  \/    *   \
3      /    \  /     \ /   \           /    *        *
2     *      \/       \/    *         *               \
1             *       *                                *
      f ɹ  ɪ  k ə    t ɪ v            s o n ə ɹ æ n t
```

These waves can be constrained by a minimum value for the peak, a depth requirement for the trough, and an obligatory alternation between the two which requires sonority to fall between peaks and troughs, and rise between troughs and peaks, monotonically. A syllable is well-formed when it meets these requirements, and one syllable is more optimal than another if it has a higher peak, lower trough, greater rise in sonority between neighboring segments in the onsets and lesser fall between neighboring segments in a coda.

The main distinction for hierarchical structures, as Goldsmith (2005/2016) describes it, is that information "does not pass from one terminal element to another, but flows up and down a tree" so that the "link between two adjacent elements is expressible directly iff they are sisters" (2005/2009 slide 9). A more hierarchical approach to syllables is therefore based on constraints within sub-syllabic constituents, especially onset and coda:

```
(7)              σ
               /   \
       Onset        Rhyme
                   /     \
             Nucleus       Coda
```

With the nucleus as a peak of sonority, we generally appeal to three basic principles to deal with the effects of sonority in the context of neighboring segments: sonority sequencing within onsets/codas, sonority distance within onsets/codas, and contact between codas/onsets. Again drawing on a sonority scale as in (2)/(5), these constraints are stated as:

(8) Sonority Sequencing Generalization: consonant clusters in the onset must rise in sonority towards the nucleus, while clusters in the coda fall in sonority (Hooper 1976, Steriade 1982, Selkirk 1984)

(9) Minimal sonority distance requirement: consonants in a cluster in onset or coda differ from each other in sonority to a degree determined language-specifically (Steriade 1982)

(10) Syllable Contact: Sonority falls across a syllable boundary; codas should be more sonorous than following onsets (e.g., Murray & Vennemann 1983)

It is also generally observed that **c**ross-linguistically, less sonorous onset consonants and more sonorous coda consonants are preferred (Clements 1990, Carlisle 2001), and that there may be limits on the number of consonants in coda and or onset (Harris 1983, Itô 1986), although often these limits seem to result from the limits on sonority sequence and distance.

3. Case studies

The following examples illustrate some of the uses of sonority as a factor in phonological analyses, comparing the insights of hierarchical syllable structure vs. sonority waves. I begin with language-internal alternations (3.1), and then move to extensions involving languages in contact, as in borrowing and second language acquisition (3.2-3).

3.1. Alternations within L1s

Two general types of processes are attributed to sonority and its roles in syllabification: a) realization of phonemes differently in different syllable positions, including lenition and fortition, and b) insertion or deletion of segments in order to fit sonority/syllable requirements. I discuss one example of each.

First, an example of fortition from Argentinian Spanish, as discussed in Baker and Wiltshire (2003). High vocoids [i, j] in nucleus or coda position are realized as a fricative [ʒ] in onset, as shown below:

(11) a. *bueyero* ‘ox driver’ [bweˈ**ʒ**ero] *buey* ‘ox’ [bwe**j**]

b.. *yendo* ‘going’ [ˈ**ʒ**en̪do] *ir* ’to go’ [**i**r]

We attributed fortition to a constraint HONSET : Be strong in onsets (Baker & Wiltshire 2003: 37). The term strong is a reference to sonority: “a consonant strength hierarchy is basically an inverted sonority hierarchy” (Lavoie 2000:213), so that fricatives are stronger than approximants or vowels; hence the constraint HONSET favors fortition as seen in the change from a vocoid (indeterminate between a vowel and an approximant) to a fricative in onsets. In Baker & Wiltshire, we assume a gradient HONSET, as not all varieties of Spanish strengthen onsets to the same extent.

The use of a constraint like HONSET fits with the hierarchical view: consonants must be parsed in onsets to be evaluated by this constraint. Under a wave view of sonority peaks and troughs, Goldsmith argues

> we might expect to find a difference in the realization of consonants depending on where in the wave of sonority they appear. On this view, a consonant that appears in a context of *rising* sonority at the beginning of a syllable – that is, before the peak of the syllable—

> is in a qualitatively different environment compared to those that appear in the context of *falling* sonority, at the end of the syllable (2011: 4).

In the sonority profile of a word without fortition, as in (12) on the right, the distinction between onset and peak may be minimal, while fortition in the onset on the left, exaggerates the depths of a trough preceding a peak, providing perhaps a better formed wave in terms of a relationship between two neighboring elements. In the constituent view, the increased strength of an "onset" is relatively unmotivated, a matter of fiat. Constraints like HONSET or fixed rankings like that in (3) can be motivated as functionally grounded, but that grounding is provided in terms of the sonority relationships between neighbors.

(12) Sonority profile with and without fortition

```
6        *       *   *               *    *      *
5       * \     / \ /               *    *   \   /
4      /   \   /   *               /          *
3     /     \ /                   /
2    /       \/                  /
1   *        *                  *
    [b we ˈʒ e   r o]           *[bwe ˈj e r o]
```

A second kind of alternation related to sonority is epenthesis, found cross-linguistically when a cluster of consonants exceeds language-specific limits. Malayalam provides an example of typical epenthesis, despite the fact that K. P. Mohanan (1982, 1986) and T. Mohanan (1989) attracted attention to Malayalam by arguments for an atypical syllabification. K.P. Mohanan (1982) analyzed Malayalam as lacking in codas, so that all consonant clusters had to be syllabified in onsets, while T. Mohanan (1989) argued that codas were allowed in initial lexical syllabification, but that different constraints hold at different lexical levels and post-lexically. Wiltshire (1992) proposes that there are only two levels of syllabification: one with codas and one without. Among the evidence presented in these arguments was data on the distribution of vowel epenthesis. As in many languages, epenthesis is motivated by input consonant clusters that cannot be syllabified within the constraints of the language. In Malayalam, schwa appears in word-final position after clusters such as liquid + stop (ɾp, lt), homorganic nasal + stop (mp, n̪d̪), and geminates (pp, tt, etc.).

(13)	[wijaɾppə]	'sweat'	[bʱɾaʂʈə]	'excommunication'
	[cempə]	'copper'	[pan̪t̪ə]	'ball'

These schwas generally can be understood to repair clusters which cannot fit into codas word-finally without violating sonority sequencing, and statements about possible clusters word-initially, medially, and finally are more complicated if we cannot refer to codas which are required to fall in sonority. In Malayalam, word-initial sequences rise in sonority (stop + glide for example) and we never find the opposite (*glide + stop). Morpheme-final and word-final sequences (preceding the epenthetic schwa above) include clusters that show a fall in sonority (mp) or level sonority (geminates). The same sequences and more are found word-medially; we find both falls in sonority, and falls followed by rises; such clusters are not found word-initially:

(14)	[kalpana]	'king's order'	[wak̪ram]	'fence'
	[swapnam]	'dream'	[can̪d̪ɾan]	'moon'

A coda-less analysis, treating all intervocalic consonant clusters as onsets, would violate sequencing by parsing a fall and rise together into the onset, and we could not explain why such sequences occur medially but not initially. An analysis with codas would describe them as containing up to two consonants, a continuant followed by a stop, while onsets likewise contain maximally two consonants, the second of which is a continuant. By this analysis, the words which end in an epenthetic schwa cannot be syllabified without it.

Arguments in favor of post-lexical syllabifications entirely without codas are generally considered external to the phonology proper (e.g., evidence from language games, native speaker pauses, rhyme and the writing system, see especially Mohanan 1982, 1986), but they may nonetheless refer to some characteristic that is accessible to native speakers. In order to refer to this, previous analyses provided for a distinct syllabification at some level. However, consider the sonority-wave representation for some words in Malayalam:

(15) Sonority representation for some Malayalam words

```
6    *       *           *    *          *     *
5  *  \     / \         * \   / \        /\    /
4      \   *   \        /  \  /  \      /  \  /
3       \ /     *      /    \ *   *    /  *  /
2        \/           *      \/       /    \/
1        **                   *      *      *
     w a k t̪ ɾ a m     s w a p  n a m   p  a n̪  t̪  ə
       'fence'         'dream'         'ball'
```

In the usual interpretation of a sonority wave, Goldsmith writes "Just as a peak of derived sonority corresponds to the nucleus of a syllable, so the local minimum (or trough) of sonority marks the boundary between syllables; in general, syllables are stretches from one trough of derived sonority up to, but not including, the next trough of sonority" (Goldsmith 1993: 53). The wave approach can provide for native speakers to create a new interpretation of a unit, one which runs from the segment immediately after one peak to the end of the next peak, which is independent from the syllable and its constituents.

From the hierarchical point of view, with sonority sequencing invoked to constrain onsets and codas, the epenthesis of Malayalam improves the underlying forms to make syllabifiable surface forms.. From the wave point of view, we can create units from one peak to the next, providing for native speaker behavior. The fortition example is not so clearly motivated in a hierarchical approach, as the syllables may already have respectable onsets, but in a wave approach fortition can be seen to improve the shape of the sonority wave.

3.2 Loanword adaptations

Words borrowed into a language are often adapted to conform to the sound structure of the language; in some cases, borrowed words present a language with challenges which its phonology has never encountered, and thus provide evidence of hidden phonological tendencies. A large body of literature now addresses the factors involved in adapting loanwords (e.g., LaCharité & Paradis. 2005, Peperkamp 2005, Kenstowicz 2006, deJong & Cho 2014) including adaptations of borrowed words in order to meet L1 syllable phonotactics (e.g., Gouskova 2001, Kabak & Idsardi 2007, Batais & Wiltshire 2015).

I illustrate with examples from Indonesian, a language in which 34% of the vocabulary is borrowed (Tadmor 2009); approximately 12% of the vocabulary (or one-third of the borrowings) comes from Arabic and Dutch. Indonesian allows simple syllable structures with only a single consonant at the beginning or end of the syllable/word, and therefore has no strategy for dealing with consonant clusters word-initially or finally. Words from Arabic and Dutch can have such clusters, and as found in Batais (2013) and discussed in Batais & Wiltshire (2015), monosyllabic words with a cluster of consonants at the beginning or end have an epenthetic vowel added, when borrowed into Indonesian. This epenthesis resembles that of Malayalam (Section 3.1), improving the syllabifiability of consonants by providing a nucleus. However, the location of the epenthetic vowel depends on the sonority pattern within the consonant cluster. A word-final sequence of consonants in Arabic can have rising, equal, or falling sonority; epenthesis adds the vowel between the two consonants if the sonority of the cluster rises (a-f) and after the cluster if its two consonants are equal or falling in sonority (g-j):

	Arabic	**Indonesian SR**	**Gloss**
a.	/sˤubħ/	[subuh]	‘dawn prayer’
b.	/fikr/	[pikir]	‘to think’
c.	/fahm/	[paham]	‘to understand’
d.	/siħr/	[sihir]	‘sorcery’
e.	/ʕasˤr/	[ʔasar]	‘late afternoon prayer’
f.	/ʕumr/	[ʔumur]	‘age’
g.	/waqt/	[waktu]	‘time’
h.	/sabt/	[sabtu]	‘Saturday’
i.	/θalʤ/	[salʤu]	‘snow’
j.	/ʕilm/	[ʔilmu]	‘science’

Table 1: Borrowings from Arabic in Indonesian

Two consonant clusters in Dutch monosyllables have rising sonority, and have the epenthetic vowel added between the two consonants (a-c), while three consonant clusters have an initial /s/ and the epenthetic vowel appears immediately after the /s/ (d-e):

	Dutch	**Indonesian SR**	**Gloss**
a.	/krax/	[kərah]	'collar'
b.	/blus/	[bəlus]	'blouse, dress'
c.	/slɔt/	[səlot]	'door lock'
d.	/sxruf /	[səkrup]	'screw driver
e.	/strok/	[sətruk]	'invoice'

Table 2: Borrowings from Dutch in Indonesian

While epenthesis in a single location into the two consonant clusters (always between or after the two consonants word-finally) would provide a form that is syllabifiable in Indonesian, the location reflects an aspect of sonority: a preference for sonority to fall across the intervocalic consonant cluster, known as syllable contact (10). Note that this preference is not necessarily expressed all the time, for example within the three consonant clusters such as /str/, the falling sonority cluster that remains after a single vowel is epenthesized [sətr] does not trigger another epenthesis (*[sətəruk]). However, the preference for a fall in sonority is a factor that can be used to choose between otherwise equally viable options such as [pikir] vs, [pikri].

In Batais & Wiltshire (2015), we analyze this using a constraint based on (10), referring to sonority contact and a preference for more sonorous codas adjacent to less sonorous onsets. Can a wave approach to sonority offer any insights?

(16) Sonority representations for syllable contact

```
6          *     *                    *       *
5         / \   / \                   /\       /
4        /   \ /   *                 / \    *
3       /     \ /                   /   \   /
2      /       \/                  /     \ /
1     *        *                  *       *
      p   i   k   i  r      vs,   *p  i   k   r i
```

Both would seem to be well formed waves, with rises to each peak. Following Indonesian syllabification, which does not allow clusters in onsets or codas, the correct form [pi.kir] benefits from a lower sonority [k] in the onset rather than the higher sonority [r] which would form the onset of the second syllable of *[pik.ri]. Furthermore, interpreting the graphs into syllables defined from trough to trough, as mentioned above, would lead to an incorrect syllabification for the *[pi.kri] case. In terms of sonority waves, the sonority contact preference could be seen as a way to provide for lower sonority onsets and syllabifications compatible with a trough as the beginning of the syllable.

3.3. Second language acquisition

As with borrowing, second language (L2) acquisition can provide a probe into the phonological system of languages. First language acquisition has provided evidence of the importance of sonority (Barlow 2005, Gnanadesikan 2004, Pater & Barlow 2003). Gnanadesikan's L1 English learner shows a preference for less sonorous onsets, and when faced with a complex cluster, deletes the more sonorous consonants, a pattern that can result from the same HONSET constraint in section 3.1. L1 acquisition is understood to provide evidence for universal tendencies, and while L2 acquisition involves transfer as well, acquiring a second language may present learners with structures not present in their first language for which transfer may not be relevant. Instead, how they deal with those structures can reveal relatively hidden aspects of L1 or universal tendencies. The role of syllable structure during the L2 acquisition of consonant clusters in onsets or codas by speakers of L1s which lack those clusters reveals yet again the role of sonority in syllabification (e.g., Hancin-Bhatt & Bhatt 1997, Wiltshire 2005, Wiltshire 2014). One of the earliest papers applying Optimality Theory to this observation was Hancin-Bhatt and Bhatt (1997), who use a combination of universal constraints on sonority and constraint rankings transferred from L1 to predict patterns of L2 learners in producing new clusters for the L2.

A large body of work on the pronunciation of consonant clusters in coda positions by L2 learners who lack codas or coda clusters has provided evidence that the acquisition follows a pattern based on sonority, as discussed in Wiltshire (2014). To illustrate, I draw on an example from Indian English, which is generally learned as a second language by speakers of Indian L1s. In studies of speakers of different L1s (Gujarati, Hindi, Angami, Ao, and Mizo), I find that L2 productions of final consonant clusters also revealed the effects of sonority sequencing (Wiltshire 2005, Wiltshire 2017), but, in addition, suggests that L2 speakers of English treat final clusters ending in /s/ as special, just like L1 speakers.

Of the five Indian languages, the three Tibeto-Burman ones are the simplest in syllable structure: Angami allows no coda consonants at all, while Ao and Mizo allow exactly one consonant in coda. The two Indo-Aryan languages, Hindi and Gujarati, both allow consonant clusters in codas, but only those obeying the Sonority Sequencing Generalization by falling in sonority. The productions of consonant clusters of the target L2 English differs based on the L1 of the speaker, with speakers of languages which do not allow clusters (Angami, Ao, Mizo) deleting consonants more often than speakers of languages which do allow clusters (Gujarati, Hindi), as shown in the table below.

Cluster type (# tokens per L1)	Angami	Ao	Mizo	Gujarati	Hindi
Nasal-stop (30)	6.7%	3.3%	13.3%	6.7%	0
Lat-stop or lat-nas (25)	12%	16%	28%	12%	4%
Fricative-stop (20)	35%	15%	45%	10%	5%
Stop-s (30)	0%	0%	6.7%	6.7%	0%
Stop-stop (20)	45%	45%	65%	10%	5%
CC-s (35)	51.4%	42.8%	57.1	34.3%	14.3%
CC-stop (10)	30%	30%	70%	20%	0
Total tokens altered	42/170	38/170	62/170	25/170	8/170
% altered	24.7%	20.6%	36.5%	14.7%	4.7%

Table 3: Percentages of word-final cluster reductions in Indian English, by L1 groups

Not all types of clusters were treated equally. Nasal-stop clusters and lateral-stop clusters, which follow the sonority sequencing principle, and stop-fricative clusters, which do not, were produced more often by all L1s speakers, while clusters of two stops, with flat sonority, and fricative-stop (surprisingly) were more often reduced by deletion or epenthesis. For example, Tibeto-Burman speakers generally had no systematic problems producing nasal + stop (*stamp*), and liquid + stop (*held*); all speakers more surprisingly produced stop + /s/ (*slabs*) as well. The more problematic clusters included /s/ + stop (*ask*), stop + stop (*project*), and some three consonant clusters (*lifts, asks, sculpt*). Overall, apart from sequences involving stops and fricatives, the clusters that are more frequently produced follow the sonority sequencing generalization (8), and the clusters that are reduced violate it or sonority distance (9).

Wiltshire (2017) analyzes the data in optimality theory, using a constraint against complex consonant clusters in codas, plus constraints that directly translate the sonority related principles from (8)-(9)

(17) Markedness Constraints on coda consonant clusters:

*COMPLEXCODA:	No consonant clusters in Coda.
SONSEQ:	Consonant clusters fall in sonority in the coda.
MSD:	Consonants in the coda differ in sonority by a minimum of 2 steps.

In an OT analysis of L2 acquisition, we begin by considering the results of L1 acquisition, which is assumed to be transferred when beginning L2. In the L1 acquisition, we assume that markedness constraints outrank correspondence constraints initially (Gnanadesikan 2004), and then constraints are reranked based on exposure to the L1 data. In acquiring languages like Ao, Angami, and Mizo, with no coda clusters, the markedness constraints above would remain ranked above correspondence constraints as learners encounter no data causing them to rerank.

To acquire languages like Hindi and Gujarati, which do allow clusters, learners must demote at least *COMPLEXCODA in their L1 grammars. Such a ranking would leave coda clusters subject to constraints on sonority sequencing and distance, but not rule them out altogether.

(18) a. Markedness outranks Correspondence in Angami, Ao, and Mizo L1 grammars

*COMPLEXCODA, SONSEQ, MSD >> MAX(C), DEP(V)

b. Markedness and Correspondence interleaved in Gujarati and Hindi L1 grammars

SONSEQ, MSD >> MAX(C), DEP(V) >> *COMPLEXCODA

Transfer of these L1 rankings predict that Angami, Ao, and Mizo speakers will initially reduce consonant clusters of all kinds, while Hindi and Gujarati speakers will repair only the more marked clusters in their L2 English productions. Once Angami, Ao, and Mizo speakers begin to learn, they will lower *COMPLEXCODA first, as all coda clusters will violate that markedness constraint while only a subset will also violate the SONSEQ and MSD constraints. At that point, they should first produce the less marked clusters, those which satisfy SONSEQ and MSD, thus producing an emergence of the unmarked effect. While the SONSEQ and MSD constraints were obscured in the L1 grammars due to the effect of a constraint eliminating all clusters, once *COMPLEXCODA is lowered they can make their presence known. As in the table above, these speakers of L1s that lack complex codas deleted consonants from a greater number of target clusters, from 20.6% for Ao speakers up to 36.5% for Mizo speakers; Hindi and Gujarati speakers had much lower rates of deletion, at 4.7% and 14.7%, respectively. Furthermore, the clusters which were more marked for sonority sequencing, such as stop + stop, are also the clusters more often reduced, while the well-formed nasal +stop rarely is.

The predictions of sonority sequencing do not perfectly hold, however, as fricatives are considered higher in sonority than stops and should therefore precede them in codas; however, the speakers of Indian English, regardless of their L1, tended to produce stop + fricative clusters correctly more often than fricative + stop.

(19) Markedness of two-consonant clusters by sonority sequencing and the MSD:

Least Marked		Most Marked	
NS, LS	**FS**	**SF**	SS

Two-consonant cluster acquisition order by speakers of Indian English:

First/Best		Last/Worst	
NS, LS	**SF**	**FS**	SS

The fricative in the stop + fricative cluster was generally /s/ or /z/, which leads to two types of explanations: either the sonority sequencing constraint does not count stop + /s/ as a markedness violation, or some other factor outweighs sonority. One such factor could be frequency, which is known to play a role in L1 acquisition (Zamuner *et al*. 2005); it is plausible that the frequency of stop + /s/ clusters in English provided learners with more opportunities to master it. However, applying the Gradual Learning Algorithm (Boersma and Hayes 2001) reveals that the special treatment of /s/ in clusters cannot result from frequency alone, supporting the claim that C + /s/ clusters should be treated as special in L2 as well as L1 phonology (Yildiz 2005).

So we are left with treating stop + /s/ in codas as not counting as a sonority sequencing violation. The finding for the L2 English speakers is similar to Kirk and Demuth (2005), which found two year old children acquiring English as an L1 were more accurate in nasal + /z/ and stop + /s/ clusters, before other clusters. Kirk and Demuth also reject a frequency solution, and attribute their finding to the ease of production for word-final fricatives, even in clusters, relative to other clusters. There are also a variety of representational approaches for making the claim that these sequences are structurally distinct from other clusters. For example, excess consonants word-finally have been treated as being outside of coda position and therefore not subject to the coda sonority sequencing constraints, particularly when they are often morphologically separate. Formalisms along those lines include the use of an appendix or extraprosodic prosition (e.g., Fudge 1969; Goldsmith 1990; Itô 1986) or treating consonants as the onset of an empty headed syllable in government phonology (Kaye *et al*. 1990).

Looking at the sonority waves in (20), examples like *held* and *project* behave as expected, while *slabs* is unexpectedly good and *ask* unexpectedly bad.

(20) Acquired (held, slabs) vs. repaired (ask, project) final clusters

```
6        *              *              *                  *      *
5       / \            / \              \                /\     /\
4      /   *          *   \              \              * \    /  \
3     /     \        /     \              \            /   \  /    \
2    *       \      *       \  *           *          /     \/      \
1             *              *               *       *     *        * *
       h e l d       s l a b s           a s k      p r o j  e     c t
```

This simple representation of sonority sequencing provides no additional explanatory power, based as it is on simple relationships between neighboring segments. A more sophisticated model which allows neighbors to interact and influence each others' sonority value, as discussed next and in Larson (1990) would be required to explain the exceptional behavior of /s/.

4. Discussion and conclusions

One main motivation for sonority hierarchies not yet discussed is the description of syllabification, and the classic case for the use of sonority in syllabification is Berber (Dell & Elmedlaoui 1985). As this is presumably familiar to the reader, I will sketch their analysis only enough to make a comparison between constituents and waves possible. According to Dell & Elmedlaoui, word syllabification precedes by searching left to right for the most sonorous unsyllabified element, setting that element up as a nucleus of a syllable, and taking the segment to its left as its onset. The algorithm begins by looking at elements of the highest sonority ([a]) and proceeding in order up the hierarchy to lower sonority elements ([i], [l], [n] etc) until the entire word is syllabified or until there is no sequence of two unsyllabified elements in a row, in which case the stray segments are joined up into a syllable. The analysis is formalized using a scale of sonority with multiple levels, but otherwise follows a hierarchical approach; once a segment is taken as an onset to an adjacent nucleus, it cannot be syllabified in any other way. The analysis demonstrably works.

However, an alternative in terms of sonority waves has been developed by Goldsmith, in work with Gary Larson (Goldsmith & Larson 1990, Larson 1992, Goldsmith 1993). Using a dynamic computational network which allows each segment to interact with its neighbors, Goldsmith and

Larson create a derived sonority value for each segment in context which can explain syllabification in Berber, among other things.[i] Each segment enters the model with an inherent sonority, but segments affect the sonority of their neighbors on either side, raising or lowering their derived sonority until the model settles into equilibrium. The model sets variables alpha as a factor for the segment's influence on its lefthand neighbor, and beta *mutatis mutandis* to the right; if both values are set at zero, we have the simple sonority waves used in the illustrations above. However, non-zero values allow the model to incorporate both gradience and context in a finer tuned and more interactive model of the calculation of sonority. While the input /tluat/ in Berber would show inherent values of sonority that look like a single peak/syllable, they show that with negative (inhibitory) values for both alpha and beta, the derived sonority creates the two peaks found in the analysis of Dell & Elmedlaoui.

(21) Larson (1992: 62) analysis of Berber in the dynamic computation model

inherent:	0	5	7	8	0		derived values:	-2.6	4.34	1.54	8.38	-.89
	t	l	u	a	t	→		t	L	w	A	t

This model also offers insight into the treatment of /s/ in clusters with other consonants. Larson (1992) provides data from English to a learning algorithm for the model, and it learns to give /s/ a low sonority, negative alpha and positive beta. This means segments to the left of /s/ have lowered sonority while segments to its right increase in sonority, resulting in sonority waves for coda /ts/ clusters that show a sonority fall (1992: 67ff).

Goldsmith (2011) writes that “syllabification is not simply an effect, of which the sounds are the cause” (2011:28), and we have seen that here in examples ranging from the more traditional sources of data, language-internal alternations, to more novel types of data from language borrowing and acquisition.. Syllabification and its relationship with sonority can affect the character of a segment in fortition, determine where epenthesis is required or best-located, and explain which sequences are easier/harder to acquire. While the use of a simple model of sonority waves that incorporates gradience, peaks and trough has enhanced our understanding of these processes, we may need the further sophistication of the dynamic computational model to capture further gradience and the influence of neighboring segments on the evaluation of sonority in sequence.

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[i] The model is discussed in greater detail in Goldstein and Iskarous (this volume).