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SPREADING IN FUNCTIONAL PHONOLOGY*

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Abstract

The occurrence of and the restrictions on the temporal spreading of phonological feature values (assimilation, harmony) are the results of interactions between the functional principles of minimizing articulatory effort and minimizing perceptual confusion. This proposal is tested on the typology of opacity to nasal spreading. While the sonority approach of Gnanadesikan (1995) meets with insuperable problems with regard to the position of /h/ in the hierarchy, and the feature-geometric representational approach of Piggott (1992) needs to take recourse to ad-hoc conditions in UG in order to get the hierarchy right, the functional approach accurately predicts the attested typology.

1. The functional approach to spreading

We can distinguish several fundamental functional principles, all of which can lead to the phenomenon of feature or gesture spreading.

1.1. Limiting the perceptual loss of an articulatory deletion

The Dutch words[1] |aːn| 'on' and |pasə| 'fit' concatenate as [aːmpasə] 'adapt'. Compared to the alternative [aːnpasə], the assimilated form saves us a complete closing-and-opening gesture of the tongue blade. Apparently, Dutch language users value this gain higher than the perceptual loss of replacing the perceptual [place: coronal] specification of |aːn| with a surfacing [place: labial] feature in /aːmpasə/, at least for a nasal consonant in the first position of a consonant cluster. In constraint language, the ranking of *GESTURE (tongue blade: close & open) above *REPLACE (place: coronal, labial / nasal / _ C) forces the deletion of the tongue-blade gesture.

The labiality of /m/ in /aːmpasə/ must have come about by the ***spreading*** (in this case, lengthening) of the closing-and-opening gesture of the lips: while the hold phase (closed lips) would be short in [aːnpasə], as in [pasə], it must be somewhat longer in [aːmpasə], approximately adding the durations of the lip closures of a [m] in coda and a [p] in onset. This spreading is forced by a perceptual requirement, namely the perceptual specification of simultaneous nasality and consonantality (or non-orality). After all, if we just leave out the tongue-blade gesture without adjusting the lip gesture, the result would be /aãpasə/, with a vocalic (or oral) nasal. Apparently, a

* This paper is chapter 19 of Boersma (1998), which is available from the author (http://www.fon.hum.uva.nl /paul/) or from the publisher (http://www.hagpub.com).

[1] I write underlying perceptual specifications between pipes, articulatory implementations between square brackets, and perceptual results between slashes.

path constraint like *REPLACE (nasal × oral: +nasal & –oral, +nasal & +oral) is undominated.[2] In a short notation, the relevant evaluation reads:

|an+p|	*GESTURE (blade)	*DELETE (coronal)	*INSERT (nasal & oral)	*INSERT (nasal & labial)
[anp] /anp/	*!			
[aãp] /aãp/		*	*!	
[an͡mp] /amp/	*!	(*)		(*)
☞ [amp] /amp/		*		*

(1)

Note that the process /an+p/ → [amp] crucially involves *both* spreading and deletion: if we spread without deletion, we incur a perceptual loss without any articulatory gain; if we delete without spreading, the perceptual loss will not outweigh the articulatory gain. The Optimality-Theoretic approach serves us well in the evaluation of this kind of tunnelling processes.

The general function of this kind of spreading is that it limits the perceptual loss associated with the deletion of an articulatory gesture: in itself, the spreading gesture (lip closure) is unrelated to the lost gesture (tongue blade). This phenomenon of the correlation between labial spreading and coronal deletion is one of the reasons why the concept of ***place node*** has been advanced in theories of feature geometry (Clements 1985, Sagey 1986, McCarthy 1988, Clements & Hume 1995): the process described here would then be "explained" as "spreading of the place node".

But there is no articulatory reason why the three articulators should act as a group: they can be moved independently from each other. The attested common behaviour must be caused by the perceptual specification of a nasal consonant: the only thing common to the lip, blade, and body closures, is that we can use any of them to implement faithfully the perceptual feature combination [nasal & not oral]: as long as there is a constriction anywhere in the mouth, the listener will hear the acoustic characteristics of an airstream that travels exclusively through the nose.

So **there is no place node**: the learner does not need such an innate feature grouping to learn that to realize a nasal consonant, she can choose any articulatory gestures [lips: closed], [blade: closed], and [body: closed].

1.2. Reducing articulatory synchronization

The perceptual specification |an| is a shorthand for:

[2] I would like to use terminology that is unbiassed with respect to the oral/nasal distinction, i.e., I would regard [p] and [a] as oral and non-nasal, [m] as nasal and non-oral, and [ã] as oral *and* nasal. The traditional term for this interpretation of 'oral' is 'continuant': an unfortunate leftover from the age of binarism, when it had to perform the multiple roles of distinguishing fricatives from plosives, and nasal consonants from nasalized vowels.

Specify:	|a|	|n|
coronal		+
voice	voiced	voiced
noise	–	–
F1	max	
round	–	–
nasal	–	+
oral	+	–

(2)

An isolated |a| can fairly easily be realized as [a] (closed velum, wide tongue), and heard faithfully as /a/; an isolated |n| can equally easily be pronounced as [n] and heard as /n/. A faithful implementation of the concatenated |an|, however, requires two articulatory contours at the transition between the two sounds: an opening of the velopharyngeal port and an alveolar closing of the tongue blade. There are three possibilities for the relative timing of these contours. First, the nasal gesture may occur before the coronal gesture:

Articulate:

velum	closed	open	
tongue	wide		closed

Perceive:

coronal	trans		side
voice	voiced		
nasal	–	+	
oral	+		–
	a	ã	n

(3)

The value *side* for the feature [coronal] refers to the oral side branch between the velum and the coronal constriction; this branch causes a *zero* (depression) in the frequency spectrum, and the length of this branch puts a minor cue to the place of constriction into the location of this zero (which the visual cue of closed lips can easily override: a stationary nasal sound pronounced with closed tongue tip and closed lips will sound like /n/ only in the dark).

The output /aãn/ is quite faithful to the input: all specified features appear, and nothing is heard that was not in the input. Autosegmentally, the correspondence is perfect. Segmentally, of course, there is the misalignment of the left edges of [+nasal] and [–oral]. We can solve this problem by synchronizing the two gestures:

Articulate:

velum	closed	open
tongue	wide	closed

Perceive:

coronal	tr	side
voice	voiced	
nasal	–	+
oral	+	–
	a	n

(4)

Perfectly faithful this time, but it violates a synchronization constraint. The third possibility is to put the coronal gesture before the nasal gesture:

Articulate:

velum	closed		open
tongue	wide	closed	

Perceive:

coronal	tr		side
voice	voiced	unvoiced	voiced
nasal	–		bu +
oral	+	–	
	a $t^{\urcorner}$	_	q^{N} n

(5)

This produces the terrible /$at^{\urcorner}$_$q^{N}n$/ (for want of a better notation, I represent the nasal release burst by /q^{N}/; /_ / means silence). Apart from the intrusion of a nasal burst, there may be a voiceless silence in the middle, though the result /$ad^{\urcorner}$ ‿$G^{N}n$/ (broadly /$a^{d}n$/) is, depending on the glottal configuration, also a possible, though hardly less problematic, output (/‿/ stands for the sound of the vocal-fold vibrations radiated out through the vocal-tract walls).

The cross-linguistically favoured candidate will come as no surprise:

|an|	*DELETE (anything)	*INSERT (nasal burst)	*SYNC (velum: close, blade: close)	*INSERT (nasal & oral)
☞ aãn				*
an			*!	
$at^{\urcorner}$ _ $q^{N}n$		*!		

(6)

Most languages seem quite willing to incur this minor violation of segmental integrity. The low ranking of the path constraint expresses the importance of the autosegmental approach.

To find out how far nasality spreads into the vowel (§1.8), we must first know with what precision the velar and coronal gestures are synchronized. The ranking of the synchronization constraint depends on this precision: synchronizing the two gestures within 20 milliseconds is more difficult than synchronizing them within 40 ms. If we can describe the realized timing difference with a Gaussian distribution, we can represent the imprecision as a standard deviation σ, expressed in seconds, and the universal ranking is

$$\text{*SYNC (velum, blade / } \sigma < x_1) >> \text{*SYNC (velum, blade / } \sigma < x_2) \Leftrightarrow x_1 < x_2 \tag{7}$$

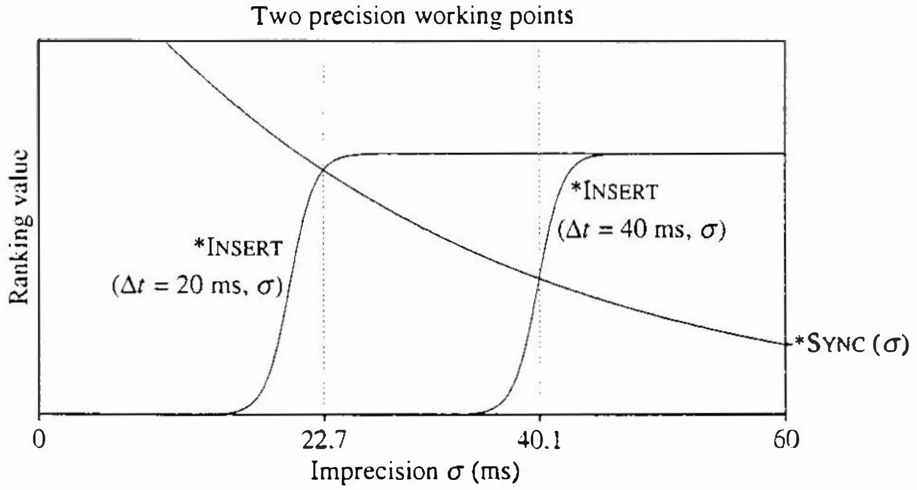
Likewise, the ranking of *INSERT (nasal burst) depends on the probability that a nasal burst is generated. This probability depends on the intended timing difference Δt between the velar and coronal gestures and on the imprecision σ with which this timing difference is implemented:

$$probability(\Delta t, \sigma) = \frac{1}{\sigma\sqrt{2\pi}} \int_{\Delta t}^{\infty} e^{-y^2/2\sigma^2} dy \tag{8}$$

This leads to the universal local rankings

$$\begin{gathered}\text{*INSERT (nas bu / } \Delta t' / \sigma = x_1) >> \text{*INSERT (nas bu / } \Delta t / \sigma = x_2) \Leftrightarrow x_1 > x_2 \\ \text{*INSERT (nas bu / } \Delta t = x_1 / \sigma) >> \text{*INSERT (nas bu / } \Delta t = x_2 / \sigma) \Leftrightarrow x_1 < x_2\end{gathered} \tag{9}$$

The rankings of *SYNC and *INSERT are monotonically decreasing and increasing functions of the imprecision, respectively. For a given timing difference, this leads to the emergence of a working point (cf. figure 10.3):



(10)

In this example, a timing difference of 20 or 40 ms leads to a working point of 22.7 or 40.1 ms, respectively. We can see all three local rankings in the figure.

In reality, the ranking of *INSERT will not depend on any probabilities. Instead, its ranking will be determined by the number of times it is violated or not during the learning process (Boersma 1998: chapter 15).

1.3. Strong specifications spill over to weakly specified segments

The [+front] (i.e. maximum F_2) specification of |ɛ| in the English word |tɛns| 'tense' is implemented by keeping both the tongue body and the lips in non-neutral positions (fronted and spread, respectively) throughout the duration of [ɛ]. In constraint language, the faithfulness constraint *DELETE (+front / vowel) must dominate an articulatory constraint like *GESTURE (lips: spread). This *DELETE constraint is indeed expected to be ranked high, since the replacement of a high F_2 by a low F_2

would make a large acoustic difference for a vowel, and this would be expected to give a large *perceptual* difference as well. In fact, the perceptual difference between a front and a back vowel is large enough that English uses it to support meaning contrasts; in constraint language, the faithfulness constraints for the perceptual feature [front] are ranked so high (for stressed vowels) that any underlying [front] contrast reaches the surface.

The faithful implementation of [front] for a vowel comes with a cost. If lip spreading is fully realized during all of the vocalic opening phase, the gesture of returning the lips to their neutral position must occur after the vowel, i.e. during [n] or [s]. This will have an acoustic effect on the consonant. For instance, at least the first part of the /s/ in /maus/ 'mouse' will sound differently from the first part of the /mais/ 'mice'. However, the acoustic difference between a rounded [s̹] and a spread [s̜] is much smaller than that between [ɛ] and [ɔ], so that the speaker will be understood much easier if she varies the lip shape of a sibilant fricative than if she varies the lip shape of a mid vowel. In constraint language, *INSERT (+front / sibilant) is ranked so low that the lip spreading needed to implement the perceptual place of a neighbouring vowel is allowed to extend well into the fricative; the general lowness of rounding faithfulness for consonants also leads English to not lexically contrasting rounded and spread fricatives.

1.4. Limiting the duration of an articulatory gesture

In English, the articulatory realization of a vowel seems to be governed by a scheme of "there and back again": the [ɛ] in [tʰɛɛ̃n_ᵗs] 'tense' tends to be realized as movements away from the neutral tongue-body and lip positions during the closure of [t], and as movements back to the neutral position during [s] or so. Apparently, this language likes to spend an articulatory gesture in order to return to the less fatiguing neutral position. In constraint language, we start from the four-parameter constraint family *GESTURE (lips: spread / *duration* / *precision* / *distance* / *velocity*), isolate the duration parameter, rename the resulting family for clarity to *HOLD, and realize that we must have a universal ranking within this continuous family exemplified by *HOLD (lips: spread / long) >> *HOLD (lips: spread / short).

If, as seems the case in English, duration is a strong determinant of articulatory effort, the *HOLD family will limit the amount of the spreading of the lip gestures that help implementing the place specifications of the neighbouring vowels. Now, vowel specifications are universally weaker in unstressed than in stressed syllables, since confusion probabilities are greater in unstressed syllables. If vowel faithfulness is *very* weak in unstressed syllables, and duration is a strong effort cue, unstressed vowels will tend to have a neutral position of the articulators. For instance, adding the unstressed comparative morpheme to |tɛns| yields [tʰɛɛ̃n_ᵗsə] 'tenser'.

For the comparative morpheme, of course, we cannot reconstruct any underlying non-neutral vowel quality. But English shows alternations between full vowels and /ə/, as in /prˈoutɛst/ 'protest (noun)' versus /prətˈɛst/ 'protest (verb)', from which we can posit a common underlying form |proutɛst|. The two surface forms prove the strong specification of vowel quality in stressed syllables, and its weak specification in pre-stress position:[3]

[3] An alternative analysis would have that the effort needed to produce place information is greater in pre-stress than in stressed position, because pre-stress syllables are much shorter. The dependence of *GESTURE on the resulting velocity differences would be able to produce the attested asymmetry. However, a still more realistic account would describe the interplay between two continuous families: *GESTURE as a function of velocity, and MINIMUM (F_2) as a function of the realized F_2. The result would be the intersections of these two functions (see Boersma 1998: ch. 10); however, if the two

|proutɛst| + initial stress	PARSE (place / stress)	*GESTURE (lips: round)	PARSE (place / pre-stress)
☞ pr'outɛst		*	
pr'ətɛst	*!		

(11)

|proutɛst| + final stress	PARSE (place / stress)	*GESTURE (lips: round)	PARSE (place / pre-stress)
prout'ɛst		*!	
☞ prət'ɛst			*

(12)

Most crucially, however, the constraint *GESTURE (lips: round) depends on the duration of the lip closure, as we can see in the evaluation of /prəl'ɔŋ/ 'prolong':

|proulɔŋ| + final stress	PARSE (place / stress)	*GESTURE (lips: round / long)	*GESTURE (lips: round / short)	PARSE (place / pre-stress)
proul'ɔŋ		*!		
☞ prəl'ɔŋ			*	*
prəl'əŋ	*!			

(13)

If the constraint *GESTURE (lips: round) had not depended on duration, the result would have been */proul'ɔŋ/.

1.5. Reducing the number of articulatory contours

We could imagine languages where the lip closing-and-opening gesture is divided into two separate gestures: a closing and an opening gesture. Constraints for such gestures have no *duration* parameter, so their general form is something like *MOVE (*articulator*: from *a* to *b* / *precision* / *velocity*). For lip rounding, we would have *MOVE (lips: from neutral to round) and *MOVE (lips: from round to neutral).

If the *MOVE constraints are separate, there must also be a separate *HOLD (*articulator*: *position* / *duration*) constraint, for instance *HOLD (lips: round / long). Note that this is different from our earlier *GESTURE (lips: round / long), which includes the actual closing and opening movements.

If *HOLD dominates *MOVE, we tend to have short combinations of closing and opening gestures, and these are likely to be incorporated organizationally into a single gesture, as described earlier. If *MOVE dominates *HOLD, however, the articulator tends to stay in its position until stronger constraints force it to move.

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functions do not intersect, i.e., if the minimum effort of lip spreading (namely, the organizational effort of the neural command) is greater than the maximum acoustic loss of place information (namely, the replacement of a full [ɔ] with a completely neutral [ə]) in unstressed position, the result would plainly be [ə].

For instance, consider the Hungarian dative suffix |nɛk|. Its |ɛ| may be specified as [front], judging from the form /nɛkɛm/ 'to me'. But since affixes are usually less strongly specified for their features than stems, beause of their lesser semantic content, the [front] specification of |ɛ| is weaker than that of the stem that it is added to. If *MOVE is highly ranked, the form |fɔl+nɛk| 'wall+DAT' will surface as /fɔlnɔk/:

|fɔl+nɛk|	*MOVE (tongue)	*REPLACE (place / stem)	*REPLACE (place / suffix)	*HOLD (tongue)
fɔlnɛk	*!			*
☞ fɔlnɔk			*	*
fɛlnɛk		*!		*

(14)

Thus, the principle of the minimization of effort lets us either limit or spread articulatory gestures. The limitation comes from high *HOLD constraints or from the universal dependence of *GESTURE on duration, which minimize energy expenditure; the spreading comes from high *MOVE constraints, which minimize the organizational effort, i.e. the number of muscle contours.

1.6. Limiting harmony

The spreading of an articulatory gesture, forced by *MOVE, can only extend so far until it reaches a perceptual specification that is stronger than the *MOVE constraint. For instance, leftward spreading of the articulatory gesture of velum lowering (a form of ***nasal harmony***) is blocked in some languages by the first obstruent encountered. This is not because obstruents are specified as [–nasal] in these languages, but because they are specified for the perceptual feature [plosive] or [fricative], which means that a release burst or friction noise should be audible during these segments. The high pressure drop across the constriction, needed for release bursts or friction noise to arise, is hard to attain if the velopharyngeal port is open. So, strong perceptual specifications can block spreading.

For instance, consider the rightward spreading of the velum-lowering gesture in Warao (Osborn 1966):

|mojo| 'cormorant'	*MOVE (velum)	*INSERT (nasal / j)	*INSERT (nasal / o)
mojo	*!		
mõjo	*!		*
☞ mõj̃õ		*!	**

(15)

Apparently, Warao does not consider it very (perceptually) offensive to nasalize a glide or a vowel. This is relatively natural: under nasalization, a glide is still a glide, and a vowel is still a vowel, so that their main perceptual specifications are honoured in the output. On the other hand, Warao spreading is blocked by a plosive:

|mehokohi| 'shadow'	*DELETE (plosive)	*MOVE (velum / σ _)	*MOVE (velum / σσ _)	*MOVE (velum / σσσ _)	*INSERT (nasal / h)	*INSERT (nasal / V)
mẽhokohi		*!				*
☞ mẽh̃õkohi			*		*	**
mẽh̃õŋõhi	*!			*	*	***
mẽh̃õŋõh̃ĩ	*!				**	****
mẽh̃õkõh̃ĩ			**!		**	****

(16)

Apparently, Warao does consider it quite offensive to nasalize a plosive. Again, this is relatively natural: under nasalization, a plosive becomes a nasal stop, so that its main perceptual specifications (silence and release burst) are violated. Note that the spreading must be implemented with a ***family*** of *MOVE constraints, crucially ranked by the moment of the gesture, thus expressing the strategy "move the velum up as late as possible", which is one of the possible local strategies for globally minimizing the number of gestures (on the utterance level); if there had been a single *MOVE constraint, the candidate /mehokohi/ would have been the best candidate (of those shown here), and the plosive would throw its shadow leftward all the way to /m/.

Thus, perceptual features can block the spreading of an articulatory gesture. The spreading will not proceed beyond the block, because that would require a second articulatory gesture. In tableau (16), this is shown (schematically) by the double violation at the candidate /mẽh̃õkõh̃ĩ/. Thus, this kind of articulatory spreading often shows *opacity* effects.

1.7. Spreading of perceptual features

The spreading of ***perceptual*** features would reduce the perceptual salience within the utterance (if this were defined as the number of perceptual contours) and the perceptual contrast between utterances, without decreasing articulatory effort. So there are a lot of arguments against it, and languages use it much less than articulatory spreading. For instance, it is not probable that [ps] will become [fs] (the feature *fricative*), or that [ɔti] will become [oti] (the feature *vowel height*). We expect spreading of degree-of-constriction features only if the participants use the same articulator, i.e., we do expect [zn] to become [dn] and [ɛti] to become [eti].

However, there is also one argument in favour of perceptually motivated 'spreading': it could improve the probability of recognition of the feature, as hinted at in §1.3. This phenomenon would be associated with stem-affix vowel harmony, whole-word domains, etc. (the F-domain of Cole & Kisseberth 1994). The acoustic-faithfulness constraint MAXIMUM (x) which says that a feature specified for its maximum value should be realized with a value greater than x, has an analogue in LONG (*feature*: *value*, t): "a feature specified for the value v is heard at least as long as the period t", with a universal ranking of LONG (f: v, t) >> LONG (f: v, u) $\Leftrightarrow t < u$. For Hungarian (14), the result would be the same as with articulatory spreading:

|fɔl+nɛk|	LONG (place: back, σ)	LONG (place: back, σσ)	*REPLACE (place / stem)	*REPLACE (place / suffix)
fɔlnɛk		*!		
☞ fɔlnɔk				*
fɛlnɛk			*!	

(17)

But it is not spreading (as Cole & Kisseberth note). 'Transparent' segments with incompatible articulations are expected, not 'opaque' ones, as we see from an example of Guarani (Rivas 1974):

|tupa [nas]|	*DELETE (plosive)	LONG (place: back, σ)	LONG (place: back, σσ)	*MOVE (velum)
tupã			*!	*
tũpa			*!	**
☞ tũpã				***
tũmã	*!			*

(18)

We see that \|p\| is transparent to nasal 'spreading'; the winning candidate has the most velar movements of all, quite contrary to the winners in articulatory spreading sytems like Warao. Plosives are transparent to the spreading of [+nasal] but are still pronounced as plosives. Analogously to the situation in most other languages, where nasality can be seen as superposed on an oral string and implemented with a [lowered velum] gesture, these harmony systems may consider orality (in half of their morphemes) as being superposed on a nasal string and implemented with a [raised velum] gesture, i.e. /tũpã/ is the mirror image of /muna/.

1.8. Coarticulation

There has been some controversy about the strategies that speakers use for the timing of articulatory gestures (Kent & Minifie 1977, Fowler 1980).

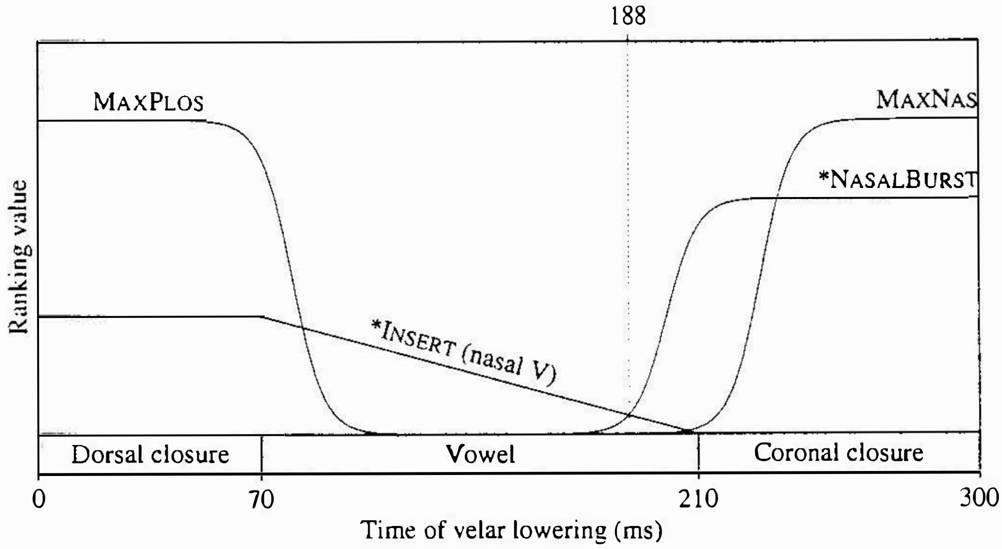
For instance, Benguerel & Cowan (1974) found that some speakers of French, when asked to pronounce a phrase containing /istʀstʀy/, started the lip rounding for /y/ during the first [s] or even during [i], which suggests the strategy "as early as allowed", i.e. as soon as the gesture does not conflict with the specifications of the current segment. Most of the authors cited in this section refer to ***articulatory*** specifications: since rounding does not conflict with the articulatory specifications for [s], but does conflict with those for [i], the rounding will start in [s]. As far as motor planning is concerned, such descriptions may be realistic, but for purposes of explanation, I would rather talk about the linguistically more relevant ***perceptual*** specifications: rounding hardly conflicts with the perceptual specifications of \|s\| (sibilant noise), but does conflict with those of \|i\| (maximum F_2). In this respect, I would like to quote the pre-OT account by Perkell & Matthies (1992: 2911), who propose that the /iC(C)(C)u/ phenomena show the "simultaneous and variable expression of three competing constraints", among which a constraint to "begin the /u/-related protrusion movement when permitted by relaxation of the perceptually motivated constraint that the preceding /i/ be unrounded." In the current section, I show how we can formalize such accounts.

In contradiction with this *feature-spreading* model, Bell-Berti & Harris (1979) found that lip rounding started at a fixed time before the coronal release in sequences as [patup] and [pastup] (in their own speech). Bell-Berti & Krakow (1991) found a comparable result for the timing of the velar gesture in |an|: the timing difference between velum lowering and the coronal closure did not depend on the material that preceded [an].

I will now show that these conflicting *feature-spreading* and ***coproduction*** models both turn out to be expected in a typology of strictly ranked phonetic-implementation constraints. Consider the specification |kan|. The plosive is strongly specified for being plosive, because that is its primary specification; I will express this circular statement tautologically as a high-ranked MAXPLOS. The vowel is weakly specified for being non-nasal, because its primary specifications are sonorance and lowness, both of which are not seriously injured by nasalization; I will express this as a constraint family *INSERT (nasal / V / duration), in which I make explicit the dependence of its ranking on the degree of overlap between the lowered velum and the vowel. The nasal specification of |n| wants to make itself heard as early as possible; the ranking of the MAXNAS constraint depends on the duration of nasality: the shorter its duration, the stronger the violation of MAXNAS. Finally, we have a synchronization-and-precision constraint, whose ranking is determined by the working point established in §1.2; for a given timing difference Δt, the ranking of this *NASALBURST constraint is the minimum of the rankings of *INSERT (nasal burst / Δt / $\sigma = x$) and *SYNC (velum, blade / $\sigma < x$) as functions of x. For instance, for Δt = 20 ms, it is the ranking value associated with the leftmost cutting point in figure 10. We can now make the continuous tableau (19) of the violated constraints as a function of the moment of velum lowering in [kan].

Optimality Theory is about minimizing the maximum problem. The 188-ms candidate in (19) is the most harmonic: this working point is determined by the interaction of the synchronization constraint *NASALBURST and the orality specification for the vowel. If we lengthen the vowel, giving |ka:n|, the curve of *INSERT (nasal V) may lower somewhat (because most of the vowel will be oral), so that the working point will shift a little bit to the left; if we replace the plosive with a glide, however, giving |ja:n|, the working point will not change. Basically, therefore, the constraint rankings in (19) are compatible with the coproduction hypothesis.

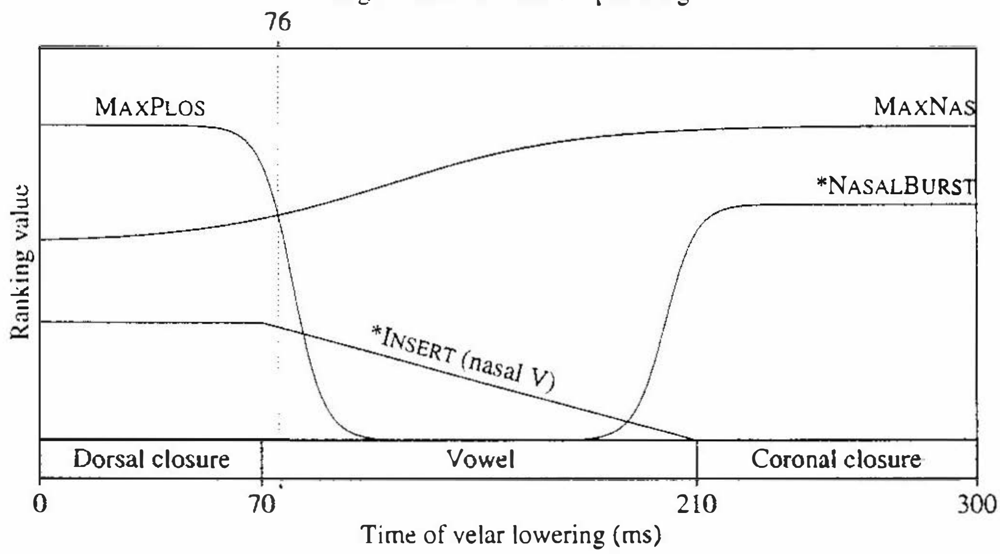
Low MAXNAS: coproduction



(19)

But we have the freedom of ranking the MAXNAS constraint higher than in (19):

High MAXNAS: feature spreading



(20)

The working point has shifted to 76 milliseconds, which is where we find the minimal maximum problem. If we lengthen the utterance to |kajan|, the MAXNAS constraint will dominate the non-nasal specifications of the complete |aja| sequence, and the working point will again be determined by the interaction of MAXNAS with the plosive specification. The rankings in (20), therefore, are compatible with the feature-spreading hypothesis.

2. An example: nasal harmony

To show that the above account is not a mere restatement of the facts, we must first note that it actually makes predictions about possible languages, and then that these predictions are borne out by the facts.

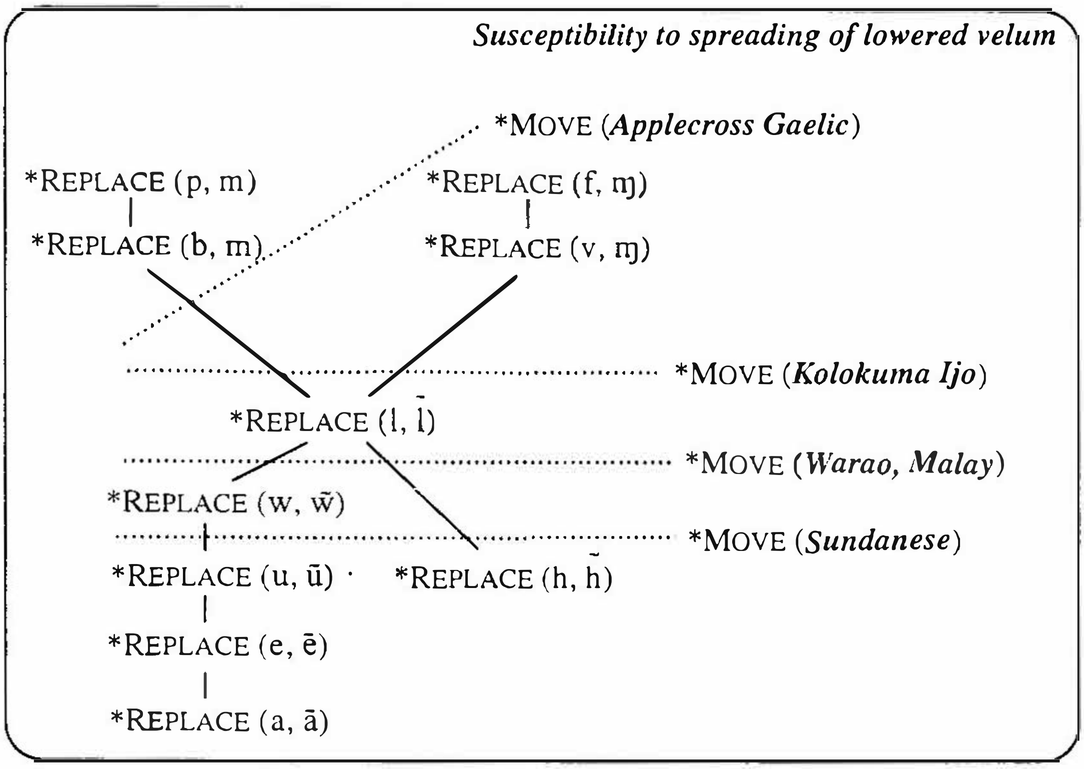
The proposal that articulatory spreading can be blocked by perceptual specifications, i.e. by protesting *REPLACE constraints, predicts that the degree of opaqueness of the specified segment to spreading must depend on the height of the *REPLACE constraint, and, therefore, on the perceptual difference between the specified and the assimilated segment. We will see that the resulting universal *REPLACE hierarchy accurately predicts the typology of opaqueness to nasal spreading.

The second prediction is that in so-called perceptual spreading, segments are more transparent as their perceptual specifications are more different from their assimilated counterparts. We will see that this is also borne out for nasal harmony systems.

2.1. Functional explanation and description

In nasal-harmony systems, the [lowered velum] gesture is incompatible with the perceptual specifications of most consonants: in decreasing order of perceptual incompatibility, we find plosives, fricatives, liquids, oral glides, and laryngeal glides; this order reflects implicational universals of transparency of consonants to nasal harmony.

For instance, nasality spreads rightward through a glide in Malay [mãȷ̃ãn] 'stalk' but not through a plosive in [mãkan] 'eat' (Piggott 1992). The phonetic explanation is obvious again. In [mãȷ̃ãn], the glide becomes nasalized, which hardly makes it less



(21)

of a glide; for [mākan], by contrast, spreading would give *[māŋān], which replaces an underlying plosive with a nasal, clearly a perceptually much more drastic perturbation. We can rank the offensiveness of nasalization for any segment in the *REPLACE constraint family (21), noting that lowering the velum on a fricative will almost certainly produce a plain nasal, though a nasal fricative in Applecross Gaelic is reported not to lose its frication (Van der Hulst & Smith 1982).

The hierarchy is mainly based on the degree of constriction of the oral cavity: the narrower this constriction, the more the sound will be influenced by a lowering of the velum. The location of the constraint for /h/ is based on the perceptual distance between [h] and [h̃], which will also depend on the degree of mouth opening; the difference between a non-nasal and a nasal [h] will not be much different from the difference between a non-nasal and a nasal vowel with the same degree of oral constriction. As for plosives and fricatives, it is hard to say a priori which of these groups will suffer the most from nasality, i.e. whether it is worse to lose plosiveness or to lose frication.

The typological predictions from (21) follow when we cross the *REPLACE hierarchy with the appropriate family of *MOVE (velum) constraints. All replacements whose offensiveness lies below *MOVE, will be implemented, and all those above will not. This will lead to the following implicational universals:

1. If glides can be nasalized, so can vowels and laryngeals.
2. If liquids can be nasalized, so can glides.
3. If plosives or fricatives can be nasalized, so can liquids.

(22)

These predicted universals produce exactly the possible sets of nasalization targets identified in Piggott (1992:62) for "Type A" nasal-harmony systems, except that Piggott says that plosives never join in. Five of Piggott's nasal-spreading systems are shown in (21): they all fit into the functional hierarchy that we derived.

2.2. Nasal spreading and the sonority hierarchy?

While our functional account may be descriptively adequate, its acceptance in the linguistic community will depend on how its results compare to traditional generative accounts of the same phenomena. I will discuss two previous accounts of nasal spreading. In this section, I will discuss Gnanadesikan's (1995) idea of coupling the attested hierarchy of susceptibility of nasalization to the ***sonority hierarchy***.

The sonority hierarchy ranks speech sounds according to their suitability to form syllable margins (onsets and codas) and nuclei. Prince & Smolensky's (1993) account of syllabification in Imdlawn Tashlhiyt Berber, which allows any segment in nucleus position and any segment except /a/ in onset position, provides the following universal hierarchies for margin avoidance and peak (nucleus) avoidance:

Sonority scales

*peak/ptk	*margin/a
*peak/bdg	*margin/eo
*peak/fsx	*margin/iujw
*peak/vzɣ	*margin/lr
*peak/mnŋ	*margin/mnŋ
*peak/lr	*margin/vzɣ
*peak/iujw	*margin/fsx
*peak/eo	*margin/bdg
*peak/a	*margin/ptk

(23)

The rankings within these two families are thought to be universal, but the two families can be ranked with respect to one another in a language-specific way: Imdlawn Tashlhiyt chooses the wild ranking *margin/ptk >> *peak/ptk (with undominated PARSE and FILL, and ONSET just above *margin/iujw), while in Dutch the two families are joined somewhere between lr and iu.

Apparently, the rankings in (23) are based on several requirements for nuclei. Nuclei like to be continuous sounds, so that they can be lengthened; this moves the plosives /ptkbdg/ in (23) to the bottom of the nucleus-affinity hierarchy. Nuclei like to be voiced, so that they can bear tone; this leads to the subdisions of the fricatives and the plosives. And nuclei like to be loud, so that they contribute to the rhythm of the utterance; this leads to the subhierarchy based on the degree of supralaryngeal opening: a > e > i > l > m > v. Now, these phonetic explanations are admittedly *post hoc*, but a similar explanation would even be needed to explain the sonority hierarchy if it were an innate device. After all, natural selection tends to have the effect of improving the fitness of the organism to its environment (Darwin 1859), which in our case would mean that an innate sonority hierarchy would contribute to efficient communication.

But there are ways to determine whether a human property is innate or not. Humans have flexible fingers. We know that these were a result of natural selection (the races who could not make tools, produced fewer grandchildren), because the properties of fingers are hereditary: no infant swimming practice will create webs between the fingers. Now, we can still swim more or less with our innate maladapted peripherals, and the description of the use of the fingers in the art of swimming does not have to refer at all to their original function. If the sonority hierarchy were an innate device as well, likewise separated from its origin, we would expect it, too, to be used unchanged for things other than syllable structure. If, however, the sonority hierarchy is the result of language-specific learning, we expect that there can be hierarchies that look like sonority hierarchies but are just that little different, in line with their current function (they may have webs). We will see that the latter seems to be the case.

First, we note that the subhierarchy that tells us that voiceless fricatives are better nuclei than voiced plosives (used productively in Imdlawn Tashlhiyt), is based on the primacy of the continuity of the sound. If we steer away from syllable positions, and consider the suitability of segments to bear tone, we must conclude that the primary condition for tone is voicing, not continuity. The hierarchy for tone faithfulness can be expressed as the family *REPLACE (tone: H, L / *env*) etc, or loosely as PARSE (tone / *env*), with a fixed ranking by degree of voicing:

Tone scale

PARSE (tone / aeo)
|
PARSE (tone / iu)
|
PARSE (tone / lmnr)
|
PARSE (tone / vzɣ)
|
PARSE (tone / bdg)
|
PARSE (tone / fsx)
|
PARSE (tone / ptk)

(24)

This ranking tells us that the higher we are in this scale, the lower we expect the perceptual confusion between high and low tones to be. The hierarchy is supported by some facts: Limburgian and Lithuanian sequences of a short vowel and a consonant can only exhibit a tone contrast if that consonant is a sonorant (lmnr); Limburgian (except Venlo) allows more tone contrasts in /aC/ sequences than in /iC/. The difference between (23) and (24) is the ranking of voiced plosives and voiceless fricatives. It predicts that there could be languages with voicing contrasts on /bdg/ but not on /fsx/, and no languages with the reverse. Unfortunately, I know of no data that bear on this matter.

More promising would be an investigation into the hierarchies of the susceptibility of segments to perturbations, as long as these hierarchies are expected to be close, though not equal, to the sonority scale. As an example, take the behaviour of [ɦ] in syllabification and in harmony processes. Gnanadesikan (1995: 21) reports on a child that replaces unstressed initial syllables with [fi]: [fimawo] 'tomorrow', [fitero] 'potato', [fimon] 'Simone'; however, if the initial consonant of the final, stressed, syllable is a glide or liquid, the child replaces it by the initial consonant of the initial syllable, if that is less sonorous: [fibun] 'balloon', [fipis] 'police'. Gnanadesikan rightly concludes that the sonority scale is involved, though she sees a problem in the behaviour of /h/, which patterns with the less sonorous segments: [fihajn] 'behind'. However, this is exactly as we would expect in (23): [h] is voiceless and, therefore, not very suitable for a nucleus; phonetically, it is a voiceless fricative whose noise stems from the glottal constriction and from any other places in the vocal tract that happen to be narrowed; though its spectral properties depend strongly on the shape of the supralaryngeal cavities, we would be inclined to classify it with the low-sonority voiceless fricatives /fsx/ in the hierarchy (23). Gnanadesikan, however, states that "*h* is arguably more sonorous than liquids since it patterns with the more sonorous glides in processes such as nasal harmony".

The special place of /h/ in (21) as compared to (23) is completely due to the fact that [h] is the only sound (of the ones considered) that gets it voicelessness from a glottal gesture instead of from an oral constriction: it violates the complementarity of sonorants and obstruents, since it is not a sonorant (i.e., there is no perception of voicing) and it is not an obstruent either (i.e., there is no strong supralaryngeal constriction). Thus, the hierarchy of transparency to nasal spreading follows the appropriate phonetic principle of perceptual contrast, not the allegedly innate sonority scale.

We must conclude that there is no evidence for the innateness of the sonority scale, and that the scales are equal to what they would look like if they were invented afresh by every language learner. What can be considered innate, is the ability to rank faithfulness constraints by degree of contrastivity, i.e. to rank highly what is useful and lowly what is superfluous; this ability may well have had an influence on the number of grandchildren that our forbears managed to put on the earth.

2.3. Nasal spreading in feature geometry?

The second generative account of nasal spreading that we will discuss is Piggott (1992). He casts the problem in feature-geometric terms, proposing that "the feature [nasal] is organized as a dependent of the Soft Palate node" (p. 34). Any interpretation of this in functional terms (the perceptual feature [nasal] depends on a soft-palate gesture for its implemantation) is ruled out by Piggott's subsequent statement that "[s]preading is blocked in this pattern by segments specified for the Soft Palate node". As we now know, it is the perceptual feature [nasal], not the soft-palate gesture, that is specified, and it is this perceptual specification that blocks the spreading.

Piggott's basic idea is that segments that are opaque to nasal spreading have an underlying nasal specification, i.e. instead of the functional hierarchy of varying ***degrees*** of specification, Piggott subscribes to an all-or-none representational solution. In Malay, for instance, glides are targets for nasalization, so that they must be underlyingly unspecified for nasality. In Sundanese, glides are opaque to nasal spreading, which Piggott ascribes to a language-specific specification of these glides as [+consonantal]. The difference between Malay and Sundanese follows, then, from Piggott's following assumption for Universal Grammar (my numbering):

(UG3819a) "If [+nasal] is an underlying property of [+consonantal] segments, then other segments specified underlying [sic] for a Soft Palate node must also be [+consonantal]."

This assumption refers to glides and laryngeals: if glides are [–consonantal], they cannot be opaque to nasal spreading; laryngeals (/h/ and /ʔ/) are assumed to be always [–consonantal], hence not opaque.

Piggott thus considers the laryngeal segments /h/ and /ʔ/ targets for nasal spreading, because they cannot be specified for the Soft Palate node. Now, nasalizing /h/ gives an articulatory coordination that we can describe as [h̃], which results in an auditory perception that we can describe as /h̃/, because some nasality will be heard in the friction noise; but nasalizing /ʔ/ gives an articulation that we can describe with the shorthand [$\tilde{ʔ}$], which will be perceived as /ʔ/, because no nasality will be heard during the closure (though perhaps it will during the glottal burst). Piggott goes into some lengths explaining that *phonologically*, the glottal stop is nasalized, though *phonetically*, it isn't. This is another example of the confusion of articulation and perception, which follows automatically from forcing phonology into the straightjacket of a hybrid feature system.

Note that Piggott's account does not yet predict that in Sundanese all non-glide, non-laryngeal consonants must be opaque, like the glides. In Kolokuma Ijo, the liquid /r/ is subject to nasalization. According to Piggott, /r/ must be unspecified for nasality in this language. Again, this account does not yet predict that the glides /w/ and /j/ are also subject to nasal spreading. In Applecross Gaelic, fricatives are targets of nasal spreading, and must be unspecified for nasality. Again, this does not predict the fact that liquids and glides are also subject to nasalization. To account for the hierarchies not explained by the representations, Piggott introduces a second assumption into Universal Grammar:

(UG3819b) "The segments specified for the Soft Palate node must otherwise constitute a natural class that is not limited to sonorants."

This statement probably requires some exegesis. The class of "segments specified for the Soft Palate node" always includes the nasal stops (/m/ and /n/); any other segments in this class must be opaque to nasal spreading, since they are specified for [–nasal]. Now let's see to what natural classes the nasal stops can belong.

- First, there is the class of stops ([–continuant] segments); this class contains the nasals plus the plosives, so that the plosives must form a possible class of opaque segments.
- Then there is the class of all [+consonantal] segments. This predicts that the set of all non-nasal consonants (with the glides optionally included) can be opaque to nasal spreading.
- The nasals also belong to the class of [+sonorant] segments. This set is ruled out from relevance by the ad-hoc condition "not limited to sonorants" in (UG3819b).
- Piggott comes up with the 'natural class' of ***non-approximant consonants***. Besides the nasals, this class comprises the fricatives and plosives, so that the fricatives and plosives together must form a possible class of opaque segments.

The attested typology, now, can be generated by two parameters: a binary parameter that determines whether glides are consonantal, and a ternary parameter that determines whether the set of segments specified for the Soft Palate node comprises all consonants, or just the non-approximants, or only the stops.

The problem with Piggott's approach is that his assumptions are completely arbitrary and ad hoc, especially the "limitation to sonorants". Without this last condition, only liquids (and sometimes glides) would be opaque, and fricatives and plosives would be targets for nasal spreading, clearly an impossible situation on simple functional grounds. This move makes Piggott's account hardly acceptable even for a large part of the generative community, but it is hard to see what could be done to save the feature-geometric approach with its hybrid representations of phonological features. The reader is invited to compare this to the functional account, which makes no assumptions beyond the one that phonology adheres to common principles of human motor behaviour and perception.

2.4. An empirical difference: nasalization of plosives

In Piggott's account, it is impossible that plosives are targets for nasal spreading: the class of segments specified for the Soft Palate node would have to consist of the set of nasal stops alone, and this is ruled out by the famous condition in (UG3819b). The functionally derived hierarchy (21), on the other hand, would predict that plosives can also be nasalized, namely, if the *MOVE family is ranked high enough. Of course, the position of *MOVE becomes more rare as it is farther away from the crosslinguistically average position, but a small amount of plosive nasalization should be expected.

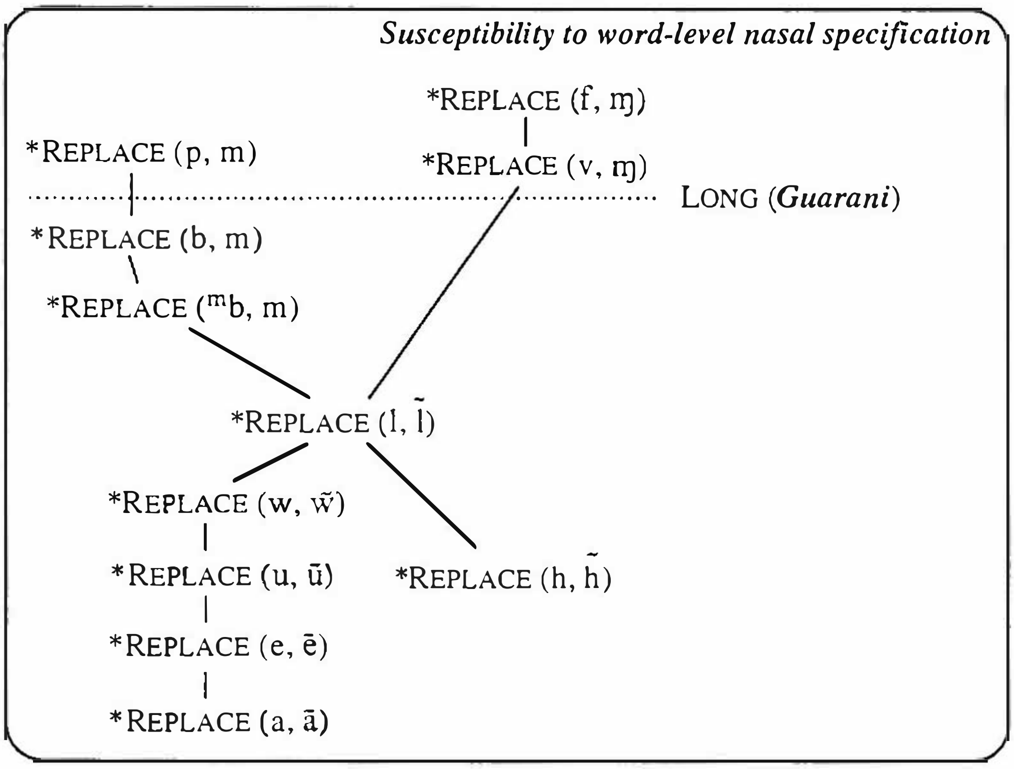
While I know of no systematic harmony-like spreading involving plosives, we find a relevant example of sandhi in Sanskrit, where every word-final plosive becomes a nasal if the following word starts with a nasal; unfortunately, we cannot tell what word-final fricatives would do, since these do not exist in Sanskrit. In the Dutch dialect of Bemmel, the nasal sandhi in |ɑ̈k| 'if I' + |min| 'my', which may surface as /ɑ̃ŋmin/ 'if I my', may extend to a prepended |ɔ̈k| 'also', giving /ɔ̃ŋɑ̃ŋmin/ 'even if I my' (with nasalized vowels); however, this process seems not to be allowed to occur even in a sequence like |ɔ̈k+ɑ̈j+min| 'even if you me', which is realized as /ɔ̈kɑ̈jmin/, so we may not be able to draw any conclusions from these data.

2.5. Morpheme-level nasal specifcations

The other type of nasal harmony, coined "type B" by Piggott (1992), shows ***transparency*** of obstruents, as in the Guarani example of §1.7. Functionally, we expect exactly the same hierarchy as in (21), as is shown in (25). The *REPLACE constraints have to compete with constraints that try to make every segment in the word nasal. Only those segments that would not lose their main perceptual specifications, are allowed to become nasalized. Fricatives and voiceless plosives generally seem to be belong to the transparent class. Voiced plosives, however, may become nasals: surely the perceptual distance between /b/ and /m/ is less than the distance between /p/ and /m/, because /b/ and /m/ share at least their specification for voicedness.

The fact that the voiced plosives are often /^{m}b/ instead of /b/, leads Piggott to the proposal that voiced stops are specified for the ***Spontaneous Voicing node***. Piggott's generalization is that only segments specified for Spontaneous Voicing are targets for nasalization. There is, however, an interesting move that Piggott has to make in order to defend his Spontaneous Voicing hypothesis. In his discussion of Type A nasal harmony, Piggott considered the laryngeal segments /h/ and /ʔ/ targets for nasal spreading; in his discussion of Type B harmony, these laryngeal segments suddenly turn up as *transparent*. This is necessary because according to theories of feature geometry, laryngeal consonants cannot be specified for Spontaneous Voicing. This means that Piggott holds that /h/ is not nasalized in Type B nasal harmony, and that /ʔ/ is not even just "phonologically" nasalized. This is a clear prediction, and it is completely contrary to the 'functional' prediction from (25), which must hold that |h| and |ʔ| are nasalized.

Thus, we are left with an empirical question: are the laryngeals in Guarani-type nasal-harmony systems pronounced with a lowered velum or not? Contra Piggott, I predict that they are.



(25)

3. Conclusion

In this paper, I argued that in articulatory spreading, strong perceptual specifications may produce opacity, and that in perceptual 'spreading', strong perceptual specifications may produce transparency.

From the functional standpoint, it is difficult to share Gnanadesikan's surprise that /h/ turns up in two different places in the two otherwise similar hierarchies (21) and (23); we should be surprised if it didn't.

Compared with Piggott's carefully contrived representational solution, the functional approach needs no recourse to far-fetched assumptions for accurately predicting the attested typology of opacity to nasal spreading.

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