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FROM FEATURES TO CONTOURS
WHY FORMS, NOT ACOUSTIC SIGNALS, SHOULD BE MODELLED

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RÉSUMÉ – Des traits aux contours. Pourquoi faut-il modéliser des formes, non le signal ?
L'objet de toute modélisation mathématique en phonologie doit consister en des catégories formelles discrètes, non en des paramètres phonétiques. Telle est la thèse soutenue ici, qui s'oppose aux courants inductifs en vogue actuellement. L'existence de "patrons temporels" mise en avant par ces approches ne constitue pas, en tout cas, un argument recevable à l'encontre d'une phonologie formelle: on montrera ici que l'hypothèse de « contours » temporels est nécessaire dans la théorie phonologique. En vérité, la plupart des soi-disant traits phonologiques gagneraient à être définis comme des propriétés émergentes de tels contours, ce qui implique de fonder mathématiquement des notions phonologiques telles que l' « association autosegmentale ». Au total, moins les concepts de la théorie phonologique apparaissent comme des métaphores, plus le contenu de ses primitives paraît abstrait.

MOTS-CLÉS – Contours, Phonologie autosegmentale, Phonologie formelle, Primitives phonologiques, Traits phonologiques, VOT

SUMMARY – *It is argued here that the object of mathematical modelling in phonology should consist of discrete formal categories, not of phonetic parameters, contrary to the claims of current empiricist approaches to phonological knowledge. In any case, the existence of "temporal patterns", emphasized by these approaches, is not an acceptable argument against formal phonology: temporal "contours" are shown to be necessary objects in phonological theory. Indeed, most so-called phonological features should be viewed as emerging from such contours. To what extent this is the case depends on whether phonological notions like "autosegmental association" could actually be mathematically grounded. As a result, the less metaphorical the concepts of phonological theory are, the more abstract the content of its primitives is.*

KEYWORDS – Autosegmental Phonology, Contours, Formal phonology, Phonological features, Phonological primitives, VOT

1. INTRODUCTION

What, in phonology, should be subject to mathematical modelling? Before any attempt to answer this question, some misunderstandings ought to be sorted out. For example, the following text, found by chance on the web, illustrates a typical criticism that is often levelled against phonology by several trends of thought sharing an empiricist and phoneticist approach to phonological categories and regularities.

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> *Chomsky and Halle [1968] and many formal linguists rely on the notion of a universally available phonetic space defined in discrete time. This assumption plays a central role in phonological theory. [...] But decades of phonetics research demonstrate that there exists no universal inventory of phonetic objects. We discuss three kinds of evidence: first, phonologies differ incommensurably. Second, some phonetic characteristics of languages depend on intrinsically temporal patterns, and, third, some linguistic sound categories within a language are different from each other despite a high degree of overlap that precludes distinctness. Linguistics has mistakenly presumed that speech can always be spelled with letter-like tokens.*
> *Robert Port, Against formal phonology*
> *[http://www.cs.indiana.edu/%7Eport/pubs.html]*

This text is also representative of a double (selective?) ignorance. The first, which will not be discussed here (see on this point [Carvalho, Wauquier, 2007]), consists in assigning to phonology as a whole what is a specific feature of Chomsky, Halle's [1968]; henceforth *SPE*) generative framework: the hypothesis that there is a "universal inventory of phonetic objects"; by doing so, empiricist approaches pass over structuralist legacy on the notion of phonemic category. The second characteristic of such theses is that they mistake 'discreteness' for 'linearity', and, thereby, forget one of the major advances of phonological theory in the last thirty years: the distinction between (segmental) 'melodies' and (skeletal) 'positions'; hence, they also pass into silence the claim that the plurilinear structure of representations is compatible with the discreteness traditionally assigned to phonological objects.

In defence of the empiricist trends, it is true that the past decade has seen a focus on constraint-based theories like Optimality theory (OT), and, until very recently, issues concerning representations were largely outside the mainstream of research interests in these frameworks; as a result, for an increasing number of phonologists, the image of the lexical input has remained the same as within the previous rule-based theories. Nevertheless, given the advances allowed by autosegmental phonology from 1975 [Goldsmith, 1976] till the mid nineties, the /xxxx/-type representations that appear in the first cell of OT'ist tableaux should be viewed, at the best, as mere notational shorthands for much more complex structures. As will be seen, far from resembling "letter-like tokens", such representations encode, in a sense, the "temporal patterns" advocated above by Port, though they preserve the discreteness of the earlier phonemes.

Here I would like to suggest a further step towards reduction of the symbolic content of phonological representations, which nevertheless should remain formal objects. Let us suppose that the current phonological primes themselves cannot be reduced to pure symbols, but that they emerge from such plurilinear representations as those mentioned above. One example thereof in recent research is the representation of phonological length in autosegmental phonology. I propose that the same holds for the objects that constitute both formally and historically the foundations of phonology: *features*. It will be shown why and how the laryngeal properties usually encoded by the features 'aspirated' and 'voiced' can and must be represented in terms of discrete *contours* characterizing the transitions between syllabic positions in such a way that these laryngeal qualities appear as the mirror-image of consonantal and vocalic length respectively. Finally, it will be seen how assigning a potential energy to syllabic positions, and, hence, variable flows to association lines, might allow us to convert into contours the majority of the so-called phonological features.

2. TEMPORAL PATTERNS ARE FORMAL OBJECTS: A DIACHRONIC PARADOX

Does phonology really “presume that speech can always be spelled with letter-like tokens”? Before the phoneme ceased to be a matter of discussion with the advent of generative phonology, the answer given by authors like [Ebeling, 1962, p. 79; Fry, 1964; Collinge, 1965, p. 5], and, *contra* Chomsky [1964] and Chomsky, Halle [1965], by Householder [1965, 1966], was positive. However, *the phonemic theory itself* concurs with phonetic and psycholinguistic evidence in demonstrating that phonological representations are not pearl necklaces. This follows from sound change.

Let us examine a typical case of what is commonly called 'transphonologization', 'feature transfer' [Martinet, 1970, § 6.19] or 'secondary split' [Hoenigswald, 1960, p. 93-94]: the one that is caused by contextual change. Old Russian had a short /i/-like vowel (henceforth *i*), which palatalized the preceding consonant (exemplified by *t*). As a result, in linear terms, Old Russian showed the following allophonic rules:

(1) a. /t/ → [tʲ] / __ i

b. /t/ → [t] elsewhere

At this stage, we are told that there was only one /t/-phoneme: the phonetic difference between the allophones [t] and [tʲ] was not perceived as such by the speaker; it was assigned to the presence of /i/ in the second case and to its absence in the first case. Later on, /i/ was deleted; its palatalizing effect remained nevertheless; hence, since /i/-deletion implies the loss of the conditioning context, a /tʲ/ : /t/ contrast emerged from the split of the previously unique */t/.

However, the second stage of this change is absurd in structuralist terms. If the context of an allophone happens to change, then the allophone must also change. Let us imagine a word-game in Spanish consisting in syllable permutation. Given a word like /ˈlago/ 'lake', pronounced as [ˈlaɯo], [unˈlaɯo] 'a lake' will give [uŋˈgola] and not *[uŋˈɯola], /g/ being realized as [ɯ] in intervocalic position but as [g] elsewhere. Accordingly, if the palatality of Old Russian [tʲ] is assigned by the speaker to the /i/-phoneme, the loss of the latter should logically lead to *t*-depalatalization; the preservation of the palatalizing effect is, thus, incomprehensible.

Yet, facts crucially contradict the predictions resulting from structural phonology, and seem to support the unsustainable claim of the 'secondary split'! It is well-known, indeed, that */ti/ gave Modern Russian /tʲ/, or, at the least, that [i] > Ø *did not imply the deletion of t-palatality*. Why is structural phonology unable to explain a change like [tʲi] > [tʲ]? There are three possible answers; one only is satisfactory.

First, according to structuralist principles, and to most scholars who discussed the problem (see references in [Carvalho, 2005]), if this was possible, it ought to be because [tʲ] was *already* a phoneme before [i]-deletion. Now, once again, such a claim would be absurd for both theoretical and empirical reasons. On the one hand, we should have had, given the rules in (1), two (phonetically similar) phonemes (/t/ and /tʲ/) in complementary distribution, which is a contradiction in terms. As pointed out by Janda (2003: 409), analyses assuming such 'marginal', 'quasi-' or 'secondary' phonemes, as they were called, 'provide neither any motivation for *why* nor any mechanism for *how* certain [...] allophones which are in complementary distribution could become phonologized'. On the other hand, if we consider certain varieties of Brazilian Portuguese which undergo coronal palatalization by /i/ and loss of the latter in final unstressed syllables,

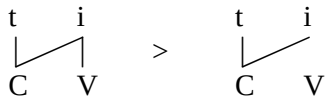
the resulting [tʲ]-like consonants are still perceived as /ti/; interestingly, speakers are unable to pronounce onsets containing *ch*-like affricates in loanwords, and use vowel epenthesis therein (pers. obs.). Thus, the mysterious 'transmutation' of the palatal feature from the vowel to the consonant, which underlies the concept of transphonologization, lacks empirical basis[2].

A second solution, much in the line of Port's previously mentioned phoneticist claims, is brought by Booij [2002] and Janda [2003], where it is argued that allophonic properties must be lexically stored in order to survive after loss of the conditioning context. A rather costly solution, indeed: this amounts to rejecting the concept phoneme in its core sense, that is not only linearity but also invariance, since the underlying representations should contain both allophonic and distinctive features; nevertheless, nothing tells us why the former may also disappear, as in the Spanish example above.

Interestingly (and ironically, given the assumptions of those empiricist trends), *t*-palatality would be viewed in this thesis as an allophonic property of /t/, much in the same way as in the classical linear phoneme theory, where, given the representation /ti/, /t/ is said to be realized as [tʲ] *before* the phoneme /i/, as in (1a). Now, there is a third solution which accounts for the change [tʲi] > [tʲ] as well. This could be glossed as follows: /i/ was first realized as [ʲi] (where [ʲ] stands for the palatal feature of the preceding consonant) whenever it was, say, *combined* with /t/; later on, it was simply realized as [ʲ]; thus, [tʲ] preserved its palatal feature after the loss of the vowel because /i/ *remained despite* [i]-*deletion*. This view, which actually dates back to Baudouin de Courtenay in 1881 (cf. Cao 1985: 165, n. 26), is the one that autosegmental phonology currently expresses by distinguishing between segmental melodies – exemplified by *ti* in (2) – and skeletal positions – *CV* in (2).

The solution in (2a,b) avoids the difficulties met by the other theses. There are no /t/ and /tʲ/ phonemes in complementary distribution since /i/ is still there in (2b). The fact that [tʲ] is perceived as /ti/ naturally follows from (2a,b): *i*-delinking does not imply deletion of the second slot, which remains available for contextual *i*-association (e.g., in glide formation before vowel)[3]. Finally, [tʲ] survived in Russian because the *i*-melody involved a *contour* (= 2a), and the change affected the contour, hence (2b), not the melody itself, which has never fallen. On the contrary, in the Spanish example above, the process consists of *melody* permutation, whence the allophone [ɥ] changes into [g].

(2) a. [tʲi] b. [tʲ]



[2] Diachronic evidence might be seen as problematic when adduced for a certain point about the synchronic working of the phonological component. It may be argued that diachronic changes are quite different from synchronic processes: while the latter can be seen as operations taking one symbolic representation and transforming it into another one, there is no such thing as a copying mechanism which transfers representations from the brains of one generation to the next; thus, different patterns might emerge through some sort of reanalysis. However, sound change is not taken here as a strictly historical phenomenon, but simply as the trace of what was once a synchronic phonological process first involving 'free' variation, and, later on, gradual loss of the conservative variant. Now, as is shown by palatalization processes, this second stage does *not* lead to an automatic reanalysis of the remaining variant.

[3] Hence, phonologization is not an all-or-nothing process: it is only when *t* and *i* are linked to the same C-position, and only to this position, since V has been lost, that a new /tʲ/-phoneme can be said to emerge.

Obviously, this cannot be expressed in linear terms: since classical phonemes lack the distinction between skeletal slots and segmental content, there are no such things as *i*-delinking within structural phonemics, where both (2a) and (2b) should be assigned the same underlying representation: /ti/. Thus, classical phonology, where phonemes are assumed to be underlyingly linear units, cannot account for a basic mechanism of sound change. However, the contours that replace the earlier phonemes are by no means substantive and continuous objects, contrary to Port's claim; they remain formal and discrete components of phonological representations.

3. FEATURES AS CONTOURS

3.1 THE PARALLEL BETWEEN LENGTH AND VOICE

Furthermore, the above explanation for the shift of allophones into phonemes has an interesting consequence for current debates between 'abstractionist' and 'exemplarist' models of phonological knowledge. The supporters of the latter views often focus on the fact that speakers perceive, and should therefore stock, 'language-specific phonetic patterns down to extremely fine levels of detail, most naturally described using continuous mathematics rather than an inventory of phonetic categories such as the IPA' [Pierrehumbert, 1999]. Now, this notion of 'fine phonetic detail' is somewhat misleading, precisely because phonology is no longer based on IPA-like objects. Let us return to the example of /ti/. Following exemplarist theses, *t*-palatality is 'phonetic detail'. As was seen in § 2.1, however, if this phonetic characteristic was perceived by the speakers, and hence survived in Russian, the reason is precisely that it was *not* a 'detail', but the distinctive feature of /i/! Following on from, e.g., Steriade (1987), let us assume that 'assimilatory' phenomena involve propagation of *distinctive* features. The question, then, is: if the advocates of the 'phonetic detail' are right in claiming that, according to psycholinguistic evidence, speakers are sensitive to *all* possible allophonic alternations,

(3) does *any* allophonic alternation[4] result from some sort of 'assimilation', i.e. from a contour, involving propagation of distinctive objects?

This is the kind of challenge phonology should be faced with, and it is by no means a trivial one. As will be seen, a positive answer to (3) should lead us to revisit the content of phonological primitives on the basis of their temporal behaviour. The example of Old Russian /ti/ may seem trivial, and actually it is, since [–back] (or the element 'I', according to Kaye *et al*. [1985]) is a well-known feature of the vowel system. But let us consider the case of a language like Korean where *lenis* obstruents are voiced between vowels but voiceless elsewhere, or that of a number of languages like German, Russian, Turkish, etc. where voiced obstruents are devoiced word-finally, that is when there is no vowel following the consonant. If the answer to (3) is 'yes', such allophonic alternations suggest that voweliness and voice are, say, two 'states' of the same distinctive object, according to the configuration involved. Let X be such an object; 'voweliness' is nothing but a cover-term for the association of X to a V-position, and 'voice' equals association of X to the preceding C-position; in languages having final devoicing, X/C_i-association implies X/V_{i+1}-association. Interestingly, this amounts

[4] I am speaking here of *contextual* alternations only. The sole true 'allophonic' alternations may be those people are aware of, i.e. those that are perceived *as such*, and these are precisely *not* context-dependent. The so-called 'free' variants are, thus, usually assigned to socio-stylistic parameters by the speakers.

to constraining the number of phonological primes, since two distinct primitives (voice and voweliness) become one: X. The question, then, becomes: what is X?

By following the above line of thought, I am actually proposing to generalise a remarkable result of autosegmental phonology, an example of which is the treatment of length. As is well-known, the distinction between long and short vowels or consonants, which relied on a [±long] feature in most works in structural phonemics and, later on, in *SPE*, is now seen as resulting from a contour-based opposition such as the one in (4), where X = S = any segment (i.e. set of features), and • = skeletal slot:

(4) a. /S:/ (long S) b. /S/ (short S)

Hence, one element was eliminated from the inventory of symbolic primes assumed by phonological theory, while the role of configurations became more important. Shortening does not consist in changing the value of a [+long] feature: just as the 'fall' of [i] in (2a,b), it requires contour loss.

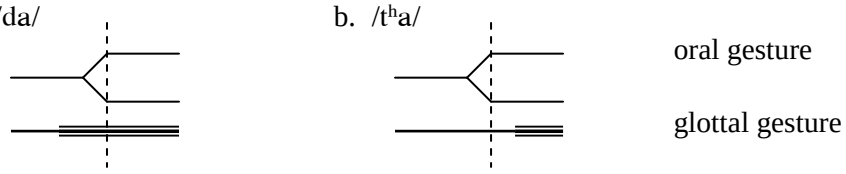
Now, it is worth noting that the parallel drawn between length and laryngeal properties is independently supported by their sharing the characteristics in (5).

(5) a. Phonetic temporal basis

b. Symmetric distribution

If speaking about the temporal dimension of phonological length is a truism, it should be recalled that phoneticians have long defined the notion of 'voice onset *time*' (VOT), according to which consonantal voice results from *anticipation* of glottal vibrations from the syllable peak to the moment preceding the oral closure release, as in (6a) (where *d* = any voiced onset, *a* = any vowel); conversely, 'aspiration' (or [+spread glottis]) follows from the *delayed* onset of glottal vibrations, which occurs after the oral release, as in (6b) (t^h = any aspirated onset).

(6) a. /da/ b. /t^ha/



Accordingly, both aspirated and voiced consonants happen to be marked in word-final position, as if they implied a *following nucleus*. Now, so are geminates in word-initial position, as if consonantal length presupposed a *preceding* nucleus, and, though less frequently noticed, so are long vowels in word-final position (cf. [Myers, Hansen, 2007, p. 157-158]), as if they implied a following *onset*.[5] There seems to be, indeed, a symmetric relationship between VOT and length. Hence, aspiration and voice, as distinctive features, appear as optimally associated with consonants rather than with vowels because they are emerging properties of the 'onset' defined as the *onset-nucleus transition*; likewise, consonantal and vocalic length is a property of the 'rhyme', viz of the *nucleus-onset transition*. In short, occurring in mirror contexts within the syllable,

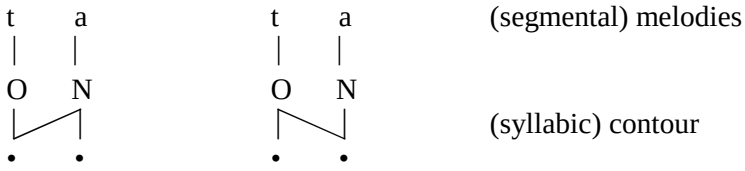
[5] That is: if a language has word-final aspirated and/or voiced consonants, it also has aspirated and/or voiced consonants elsewhere, but the converse is false; likewise, if it has word-initial long consonants or word-final long vowels, it also has long consonants or vowels elsewhere, but the converse is false.

VOT and length are in complementary distribution. Could it, then, be the case that they result from propagation of the same objects? If so, what are those spreading objects?

As is shown by typology, the triplet /t^h/ ~ /t/ ~ /d/ functions as a strength scale: /t^h/ is *fortis* with respect to /t/, while /d/ is *lenis vis-à-vis* /t/. What is interesting about this scale is that it involves two opposite values, 'tension' (the *fortis* term /t^h/) and 'sonority' (the *lenis* term /d/), which are the very same concepts as those that have long been discussed, since Jespersen [1904], regarding the nature of the syllable. In the line of views dating back to van Ginneken [1907], the syllable is something like a vector spreading from a peak of tension and a trough of sonority, which correspond to the onset (O), to a peak of sonority and a trough of tension, which correspond to the nucleus (N) (for a detailed discussion, cf. [Klein, 1993]).

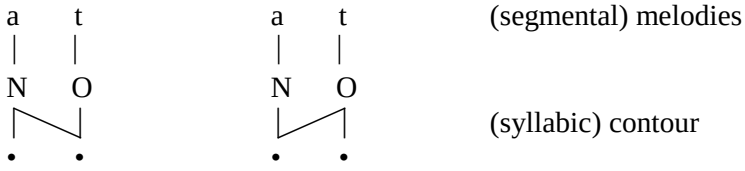
Let us take seriously the idea that the 'tension' and 'sonority' poles of segmental strength scales are the same articulatory and perceptual objects as those involved by syllable structure. The peak of tension, represented by O, can thus be defined, in articulatory terms, as an open (and tense) state of the glottis; sonority, represented by N, is a closed (and lax) state of the glottis. It follows that, given an ON sequence, VOT-values are properties that emerge either from the spreading of the onset to the following N-position (aspiration), or from the spreading of the nucleus to the preceding O-position (voice). The resulting ambiassociation of one slot naturally accounts for the mechanism of voice onset time: N-propagation to O in (7a) formalises voice anticipation in (6a); inversely, O-propagation to N in (7b) stands for voice delayed release in (6b).

(7) a. /da/ b. /t^ha/



Furthermore, the complementarity between VOT and length, (7a,b) entails the NO contours in (8), in which, contrary to all current representations of long vowels and geminates, no additional slot is required.

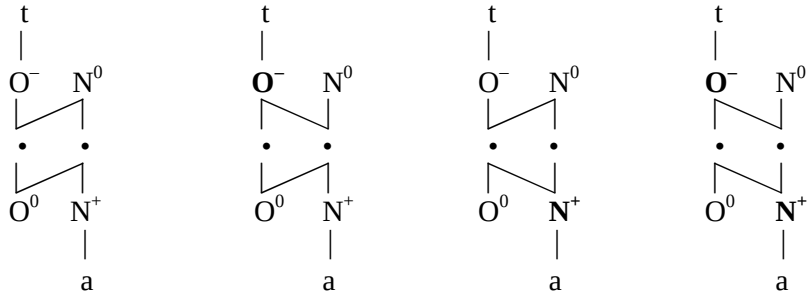
(8) a. /aat/ b. /att/



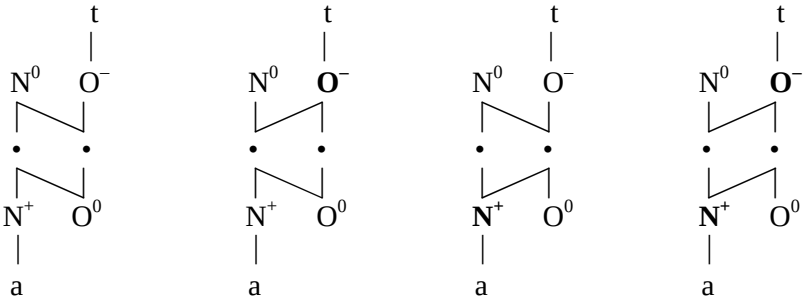
However, an empirical problem arises from (7, 8). If O and N belong to the same tier, then the No Crossing Principle (NCP) disallows simultaneous propagation of O and N; in other words, there can be neither aspirated voiced consonants nor long vowels + geminates. Now, some languages (in particular, many Indian languages) do have the former combination, which is often referred to as 'breathy voice', noted as /d̤^{h}a/ (cf. [Ladefoged, 1993, p. 139-147]); similarly, /aatt/-type rhymes are found in Latin, Finnish, etc. Therefore, syllable components must be assigned to two distinct planes, which will be labeled the 'O-tier' and the 'N-tier', in such a way that aspiration and voice, on the one hand, gemination and vowel length, on the other hand, may combine without

violation of NCP.[6] Furthermore, the assumption that there are, as is shown in (9), N- and O-elements in the O- and N-tiers respectively preserves linearity between O and N, which would not have been the case otherwise in (9d,h).

(9) a. /ta/ b. /t^{h}a/ c. /da/ d. /d̤^{ɦ}a/



e. /at/ f. /att/ g. /aat/ h. /aatt/



In each tier, as is shown in (9), O and N have, say, different and specific values or, as I shall put it, different *markedness states*, which will be discussed in § 4. At this stage, suffice it to say that the contours in (9) provide a built-in representation of the markedness scales characterising VOT and length. Since long segments are marked *vis-à-vis* short segments because they involve two slots *vs* one, as is shown in (4), markedness will be expressed in terms of *elementary weight* (W_X), viz the number of slots an X-element is associated with. It will be assumed that (X/Y = O/N, α = +/–):

(10) A contour is *unmarked* iff $W_{X0} > W_{Y\alpha}$, and *marked* iff $W_{X0} \leq W_{Y\alpha}$ ($\alpha \neq 0$).

Hence the following implicational scales according to the number of marked contours:

(11) a. /d̤^{ɦ}a/ (2) ⇒ /t^{h}a/ (1) *and* /da/ (1)
/t^{h}a/ (1) *or* /da/ (1) ⇒ /ta/ (0) cf. (9a-d)

b. /aatt/ (2) ⇒ /att/ (1) *and* /aat/ (1)
/att/ (1) *or* /aat/ (1) ⇒ /at/ (0) cf. (9e-h)

Indeed, (9d) implies both (9a) and (9b,c) in a given language, whereas either (9b) or (9c) presuppose (9a) only. Likewise, any language having (9h) also has both (9e) and (9f,g), whereas either (9f) or (9g) imply (9e) only. Several other markedness aspects of syllable structure are accounted for by the present approach (cf. [Carvalho, forthcoming]).

[6] O/N segregation is not limited to languages having breathy voice or /aatt/ rhymes, which would be circular: the universality of this segregation can be independently demonstrated (cf. [Carvalho, 2005]).

3.2 A CONTOUR-BASED ACCOUNT OF CONSONANT LENITION

An interesting issue of converting laryngeal features into configurational properties is that the latter provide a non-arbitrary account of consonant *lenition* between vowels. This frequent type of sound change is illustrated by Romance data in (12) (WR = Proto-West Romance, NWR = Proto-Northwest Romance):

(12)

a.	/atta/ > /ata/	Lat. *gatta* > WR **gata*	Port. *gata* 'cat (*f.*)'
b.	/ata/ > /ada/	Lat. *nata* > WR **nada*	Port. *nada* 'nothing'
c.	/ada/ > /aða/	Lat. *vada* > WR **vaða*	Port. *vá* 'go (*subj.*)'
d.	/alla/ > /ala/	Lat. *balla* > NWR **bala*	Fr. *balle* 'ball'
e.	/ala/ > /aala/	Lat. *ala* > NWR **aala*	Fr. *aile* 'wing'

Why is it that a quantitative change like the one in (12a) plays the same role as putatively qualitative changes like those in (12b,c)? Why does the change in VOT in (12b) parallel that in manner features in (12c)? Why does consonant degemination in (12a,d) involve either consonant voicing like in (12b), or vowel lengthening like in (12e), both processes playing once again the same role despite their apparent diversity?

Given the notions in (13), and the condition on contour change in (14),

(13)

a. *Elementary weight* of O^0 (W_O0):
number of skeletal *positions* associated with an O^0-*element* (cf. § 3.1).

b. *Positional weight* of N^0 in O (W_N0/O):
number of N^0-*elements* associated with an O-linked skeletal *position*.

c. *Positional strength* of O (S_O): $W_O0–W_N0/O$.

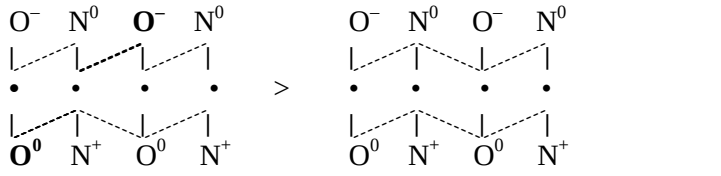
(14) Polarisation:

If X^{α}_{i} spreads to a given slot, then $X^{0}_{i\pm1}$ is also associated with this slot.

lenitive changes can be given the unified and non-arbitrary description in (15), where S_O decreases from one degree at a time.

(15) Loss of O^0/O^- polarisation: cf. (12a,d)

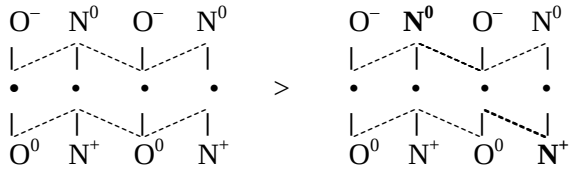
a. /tatta/ b. /tata/



2	3	2	3	= W_{O0}
1	**1**	1	**2**	= W_{N0}/O
1	**2**	1	**1**	= S_O

(16) N^0/N^+ polarisation I: cf. (12b)

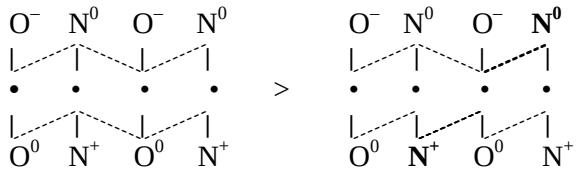
a. /tata/ b. /tada/



2	**3**	2	**2**	$= W_{O^0}$
1	2	1	2	$= W_{N^0}/O$
1	**1**	1	**0**	$= S_O$

(17) N^0/N^+ polarisation II: cf. (12e)

a. /tata/ b. /taata/



2	**3**	2	**2**	$= W_{O^0}$
1	2	1	2	$= W_{N^0}/O$
1	**1**	1	**0**	$= S_O$

Voicing is N^0/N^+ (or N-)polarisation of O_2, intervocalic voiced onsets undergoing both O- and N-polarisations, as is shown in (16b). It follows from (14) that voicing is impossible if N^0 cannot spread to the right, as in (15a), where, O^- spreading to the left, N^0-propagation is disallowed by NCP. Hence /tata/ > /tada/ is not expected to be accompanied by a change like /tatta/ > /tadda/.[7]

Another natural issue of (14) is that voicing is only one possible lenitive evolution. As can be seen, (16) and (17) differ solely in terms of 'axis' of N-polarisation. Thereby, voicing and lengthening appear as formally equivalent lenition strategies, and just as /tt/ > /d/ is impossible, so is compensatory lengthening of the form /atta/ > /aata/ disallowed. Only the contour-based theory is able to capture this equivalence and this impossibility.[8]

In sum, it is no longer surprising that quantitative changes such as those in (15, 17) and 'qualitative' changes such as voicing may pattern and function together: they are all quantitative as far as they emerge from similar contours.

4. EXTENDING THE CONTOUR THEORY: ASSOCIATION LINES AS ENERGY FLOWS?

Should we stop after such a good start? Indeed, two kinds of reasons concur in suggesting that the import of the present contour model goes far beyond length and

[7] Though voiced obstruent geminates may exist (and are, of course, allowed by the contour model), this ban on geminate voicing may explain the relative rarity of voiced (obstruent) geminates.

[8] Indeed, the impossibility of /atta/ > /aːta/ is hardly comprehensible if geminates and long vowels involve an additional specific slot, as is the case in standard autosegmental accounts.

VOT. On the one hand, two empirical facts ought to be pointed out. Firstly, voicing is only one type of lenition, which also comprises spirantization processes, whereby plosives change into fricatives (/ata/ > /aθa/, /ada/ > /aða/). Secondly, VOT is only one type of laryngeal feature classes; there are also ejectives, implosives, etc.. Interestingly, frication and laryngeal properties can be viewed as elements of a general set of 'manner' features, insofar as most consonantal segments result from combination of these with 'place' features (labial, coronal, dorsal, etc.). Now, if VOT can be straightforwardly accounted for in terms of contours, should *all* 'manner' properties be defined in such terms, only place qualities remaining within the domain of (melodic) features?[9]

A second, and complementary, set of reasons for such a generalization is provided by the lack of formal foundations of some phonological notions, regardless of their descriptive power. What exactly does the term 'association line' cover? What really is a 'floating' melody? As will be shown, generalizing contour-based definitions for most of the so-called features necessarily leads to assign a mathematical significance to these basic notions of autosegmental phonology, as well as to the quite impressionistic concept of 'charm'. Interestingly, then, it appears that *the less metaphorical the conceptual tools of phonological theory are, the more abstract the content of its primitives is*, since labels such as 'fricative', 'aspirated', 'ejective', etc. are ruled out from the set of symbolic atoms.

For independent reasons partly related to the 'strict CVCV' approach of government phonology [Lowenstamm, 1996; Scheer, 2004] that will not be discussed here, syllable-based contours will be assumed to be constituted by O- and N-elements only. How, then, can the four ON configurations in (9a-d) generate all the possible 'manner'-features characterizing syllable onsets, and only these features?[10] What follows should be taken as mere suggestions for further research. As will be seen, however, the redefinition of such classical notions as 'sonority' and 'aperture' that these proposals allow, on the one hand, and some empirical predictions they make, on the other hand, show that the track is worth being explored.

Let us first assign the following formal content to three phonological concepts:

(18) a. 'Association lines':
association of a melody *a* with a position *x* is a *flow* $\varphi_{a/x}$ resulting from a *potential energy* π_a.

b. 'Floating/anchored' melody:
a is a floating melody iff any flow $\varphi_{a/x} = 0$; it is an anchored melody iff there is at least one flow $\varphi_{a/x} \neq 0$.

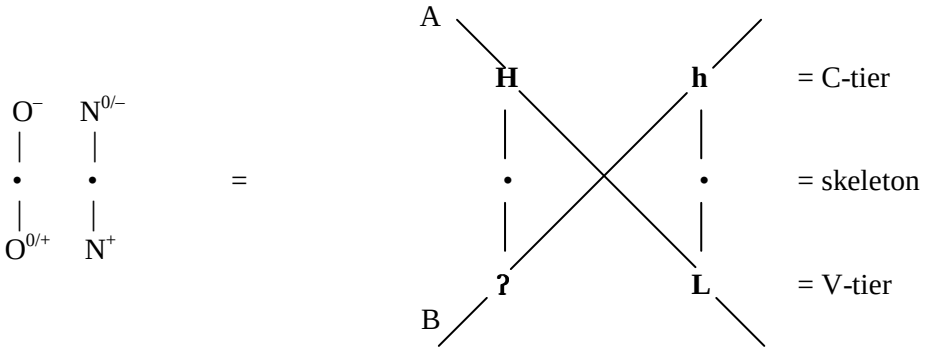
c. 'Charm' values:
by convention, $\pi_{O^-} = -1$, $\pi_{N^+} = +1$, $\pi_{O^0} = \pi_{N^0} = 0$.

It follows from (18) that : (i) for any X^{α}-melody, with $\alpha \neq 0$ and $W_X = 2$, there are two phonologically relevant flows $\varphi_1 = \alpha n$ and $\varphi_2 = -\alpha(n-1)$ for any value of n ; (ii) O^0 and N^0 are floating melodies, unless they spread to more than one position. Let us add that, in certain marked configurations, O^0 and N^0 may take the charge of the adjacent melody, whence O^+ and N^- respectively, and are therefore anchored.

[9] A first step towards integration of fricatives in a contour model is provided by Tifrit's (2005) work.
[10] Likewise, how can the four NO configurations in (9e-h) generate all the possible syllable 'rhymes'?

Let us now assume that our four symbolic primes have, within ON transitions, the substantive content expressed by Kaye et *al.*'s (1990) H/L- and ʔ/h-elements:

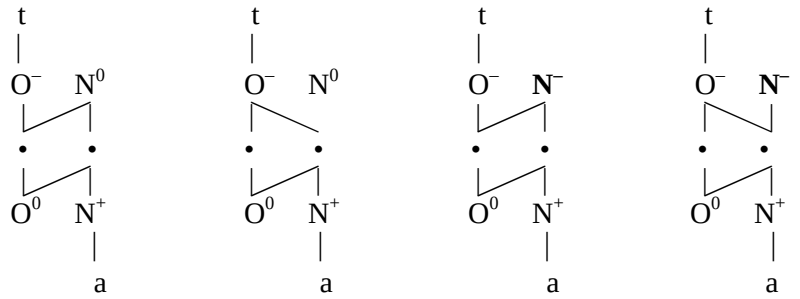
(19)



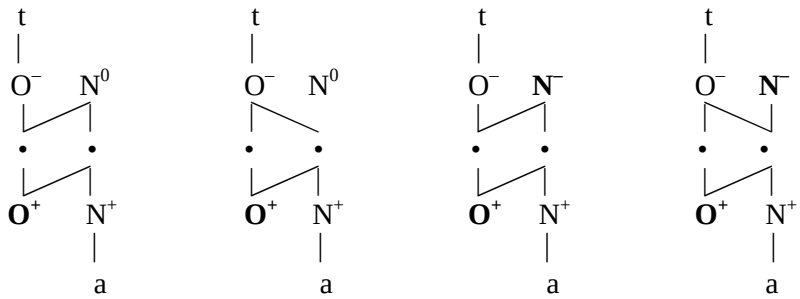
A and B, which could be called the *Jespersen's* and *Saussure's axes*, represent 'sonority'- and 'aperture'-based contrasts respectively. In A, as was seen in § 3, the O^{-}- and N^{+}-melodies are the sites of *obstruents* and *vowels* respectively, i.e. of the less and most sonorant segmental types; if linked with more than one position, they underlie the *laryngeal states* usually expressed by the features [+spread gl] (H) and [+voice] (L). In B, the O^{0}- and N^{0}-melodies (when associated to more than one position) are the sites of *liquids* and *glides* respectively, i.e. of the most open consonants and of the most closed vowels; if $\pi_a \neq 0$, the resulting O^{+}- and N^{-}-melodies will be assumed to underlie 'closing' and 'opening' gestures, i.e. *glottalization* (ʔ) and *frication* (h) respectively.

Given the overall organization of the properties carried by ON transitions, contours are likely to be assigned, for example, the phonetic interpretations in (20) (where /ʦ/ = affricate, /$t^{ʔ}$/ = ejective, and /t*/ = *fortis* obstruent, existing, for example, in Korean).

(20) a. /ta/ b. /t^{h}a/ c. /sa/ d. /ʦa/



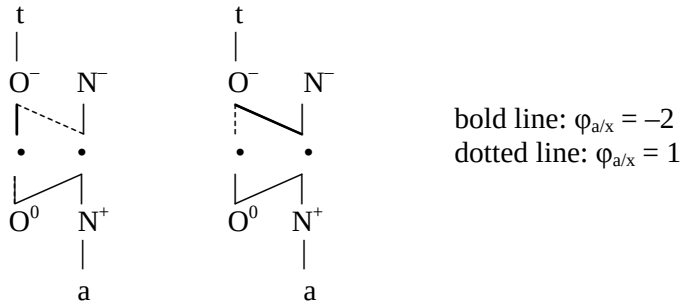
e. /$t^{ʔ}$a/ f. /t*a/ g. /$s^{ʔ}$a/ h. /$ʦ^{ʔ}$a/



It follows from (20a-h) that there can be neither aspirated fricatives (*/s^{h}a/) nor voiced ejectives (*/d^{ʔ}a/), since, given the ban on line crossing, O^{-}-propagation onto the following nucleus, and N^{-}-propagation onto the preceding onset within the C-tier are mutually incompatible, and so are O^{+}- and N^{+}-propagation within the V-tier. Indeed, both aspirated fricatives and voiced ejectives are unattested in the world's languages.

It is worth noting that, as both aspirated (/t^{h}a/) and affricated (/tsa/) consonants suppose the unmarked voiceless type /ta/, and are therefore marked onsets, consonants cumulating aspiration and affrication (/ts^{h}a/), which imply /ta/, /t^{h}a/ and /tsa/, are still less common types, and should accordingly derive from more complex representations. This is allowed by assuming that, whenever $W_a = 2$ and $\pi_a \neq 0$, there are two distinct configurations according to whether $\varphi_{a/x_1} = \alpha n$ and $\varphi_{a/x_2} = -\alpha(n-1)$ or $\varphi_{a/x_2} = \alpha n$ and $\varphi_{a/x_1} = -\alpha(n-1)$. Thus, languages like Chinese, where aspirated affricates contrast with non-aspirated ones, involve finer oppositions, in which *energy distribution* is a relevant phonemic property, as is shown in (21), phonological markedness being, once again (cf. § 3.1), a built-in characteristic of the model:

(21) a. /tsa/ b. /ts^{h}a/



Let us add that the present contour model provides discrete representations for 33 distinct ON-types. *Prima facie*, it avoids both overgeneration and undergeneration, given what we know about the phonological systems of the world's languages.

5. CONCLUSION

Three conclusions can be drawn from the above discussion. Firstly, the existence of 'temporal patterns', as opposed to 'letter-like tokens', is not a crucial argument in favour of empiricist-phoneticist claims; as is shown by diachronic evidence, contours are, indeed, necessary objects in phonological theory (§ 2). Secondly, not only should segmental phonemes be ruled out from phonological representations for theory-internal reasons, and replaced with contour-based configurations, but also a certain number of the so-called features might be seen as emerging from such contours, which is supported by typological and diachronic evidence (§ 3). Finally, to what extent it is actually the case depends on whether notions such as autosegmental association can be mathematically grounded (§ 4).

The author of these lines, as the reader may have guessed, is a phonologist, not a mathematician. What precedes must be taken as a trail for further research suggested by such diverse aspects as diachronic change (§§ 2, 3), and the behaviour and typology of some of the so-called features (§§ 3, 4). However, if phonological notions do require a non-metaphorical significance, this trail should naturally and preferably be pursued through the collaboration of linguists and mathematicians.

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