The Geometry of Phonological Features
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Source: *Phonology Yearbook*, Vol. 2 (1985), pp. 225-252
Published by: Cambridge University Press
Stable URL: http://www.jstor.org/stable/4419958
Accessed: 30/12/2014 12:01

Phonology Yearbook 2 (1985) 225-252
Printed in Great Britain

*The geometry of phonological features**

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1 On the notion 'feature bundle'

The study of the phonological aspect of human speech has advanced greatly over the past decades as a result of one of the fundamental discoveries of modern linguistics – the fact that phonological segments, or phonemes, are not the ultimate constituents of phonological analysis, but factor into smaller, simultaneous properties or *features*. The apparently vast number of speech sounds found in the languages of the world turn out to be surface-level realisations of a limited number of combinations of a very small set of such features – some twenty or so, in current analyses. This conclusion is strongly supported by the similar patterning of speech sounds in language after language, and by many extragrammatical features of language use, such as patterns of acquisition, language disablement and language change.

What is less clear is the manner in which these ultimate constituents of speech are organised. Bloomfield's well-known characterisation of phonemes as 'bundles of features' suggests inherent disorganisation and lack of structure. One might make this view more explicit by proposing that feature bundles have no internal organisation at all, but that any two features characterising a phoneme are as closely (or as distantly) related as any two others. It is exactly this conception that is incorporated into the familiar view of phonemes as 'feature columns', that is, single-column feature matrices. The attractiveness and wide acceptance of this view owes much to the fact that it provides phonological representations with a simple mathematical structure easily susceptible to analytical and computational manipulation, and permits an extremely elegant formalisation of phonological rules (see Chomsky & Halle 1968, as well as Hertz 1982 for an application to speech synthesis).

It is less apparent, but nevertheless true, that the feature-matrix formalism incorporates certain implications for feature organisation that do not follow from the vaguer notion of 'bundle'. For example, a strict interpretation of the matrix formalism excludes the possibility that features may overlap at a pre-phonetic level of description, or that feature specifications (matrix entries) might have an internal hierarchical organisation of some sort. The very success of the matrix model in providing a simple, explicit view of feature representation has lent tacit support to the view that phonological features are simultaneous and unstructured at the phonological level, and that all instances of surface-level feature overlap must be analysed as an effect of phonetic implementation.

Exactly why this should be so will be clear if we consider the normal interpretation of a two-dimensional feature matrix such as the following:

(1)

	p	i	n
syllabic	−	+	−
sonorant	−	+	+
continuant	−	+	−
high	−	−	−
back	−	−	−
voiced	−	+	+
⋮			

Each phoneme in this matrix is defined by the set of feature values occurring in its column. More exactly, in the conception of Chomsky & Halle (1968: 164–165), a feature column is a function assigning a certain entity, a phoneme, to a set of phonetic categories which determine its physical properties. We see clearly that the notion of 'feature overlap' makes no sense within such a view; features are not entities, with the ability to expand or contract along a given row, but categories to which entities are assigned. Thus it makes no sense, for example, to ask whether the phonemes /p/ and /i/ in (1) share the same instance of the feature [−high], or two different instances of it.

Much work in recent years has suggested that some sort of hierarchical organisation must be attributed to feature representation. Such organisation is required in two senses: that of the *sequential* ordering of features into higher-level units, as proposed in autosegmental and metrical phonology, and that of the *simultaneous* grouping of features into functionally independent sets, as shown by the more recent results of autosegmental and dependency phonology. These two observations are interdependent in a very interesting way. As several writers have shown, most explicitly Thráinsson (1978), Goldsmith (1981), Mohanan (1983), and Mascaró (1983, forthcoming), the study of the interaction among various sets of features, as observed (for example) in the study of assimilation rules, provides prime evidence for the nature of simultaneous feature groupings. If we find that certain sets of features consistently behave as a unit with respect to certain types of rules of assimilation or resequencing, we have good reason to suppose that they constitute a unit in phonological representation, independently of the actual operation of the rules themselves. There is a useful analogy here to syntax: many of the most enduring results of syntactic analysis have been made possible by the recognition that word-groups functioning as single units with respect to syntactic rules form hierarchical constituents in phrase-structure analysis.

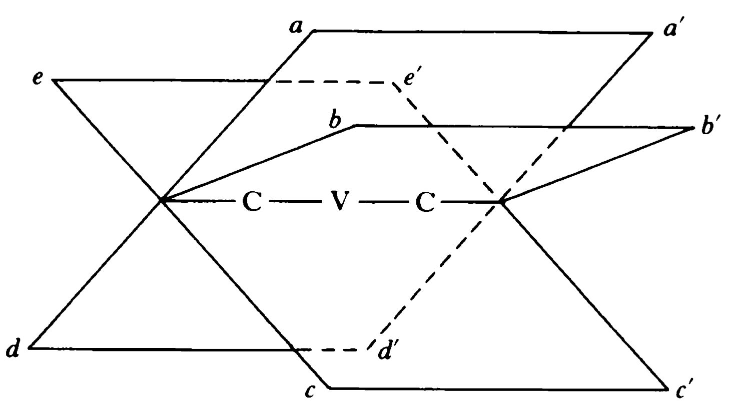
A natural way of expressing these relationships in phonology is in terms of multi-tiered representations, in which individual features and groups of features are assigned to separate tiers. As we know from the study of tone, vowel harmony, nasality and the like, rules may affect segments on one tier without affecting segments on other tiers. By grouping together entire sets of features on single tiers, we in effect make it possible for them to behave as a functional unit with regard to rules of deletion, assimilation, and so forth. Multi-tiered representation, as proposed in autosegmental phonology (Goldsmith 1976), provides a solution to the conceptual problems raised by feature asynchrony within a matrix formalism. If we regard features not as matrix entries but as independent units or segments in their own right, defined by specific sets of gestures and acoustic effects, then it is quite natural to suppose that they may display the behaviour of real entities, and engage in such processes as extension, contraction, deletion and insertion.

The theory developed in this paper is an extension of the work cited above, and develops an approach to the representation of co-occurrent feature hierarchy based upon the evidence provided by sequential feature hierarchy. We attempt to determine the hierarchical structure of a feature representation by examining processes that reveal the independence of certain features with respect to others. To the extent that our observations prove consistent across languages, they converge on a quite specific model of feature organisation, and (as we shall see) provide us with a new criterion for phonological analysis.

2 Two models of feature organisation

To clarify our ideas, it would be useful to contrast two possible models of multi-tiered feature representation, representing opposed views of hierarchical organisation. According to the first of these, phonological representations involve multi-tiered structures in which all features are assigned to their own tiers, and are linked to a common core or 'skeleton'. Such a view can be schematised as in (2):

(2)



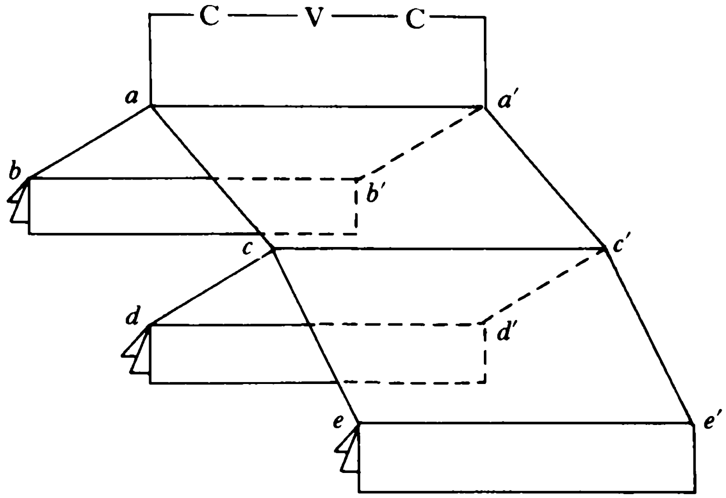
aa′ = sonorant tier, *bb′* = continuant tier, *cc′* = high tier, *dd′* = back tier, *ee′* = voiced tier

In such a conception, a phonological representation resembles an open book, suspended horizontally from its ends and spread open so that its pages flop freely around its spine. The outer edge of each page defines a *tier*; the page itself defines a *plane*, and the spine corresponds to the *skeleton*. Imagine that the feature specifications '+' and '−' are sequenced along the outer edge of each page, and connected to points on the spine (C, V, C) by lines. Such *association lines* define sets of simultaneous features. If the first of these points is associated with all the features of [p] (each on its corresponding tier), the second with all the features of [i], and the third with all the features of [n], we have a representation of [pin].

(2) offers us several of the advantages of autosegmental representation by providing for processes that affect features on one tier while not affecting features on the others. Yet (2), just like (1), fails to impose any organisation on the features, and is therefore equally inadequate. Given a model like (2) we have no way of expressing the fact that certain sets of features consistently behave like functional units, while other imaginable sets do not. Just as significantly, representations like (2) fail to characterise the phoneme as a unit in its own right. It has long been recognised that phonological representations are to a large extent segmentable into phonemes that behave as single units with respect to rules; indeed, this is one of the primary motivations for recognising the phoneme as a category of linguistic theory. Rules must have access to phoneme-sized units in autosegmental theory as well. For example, they must be able to delete consonants and vowels, or spread all the feature of a consonant or vowel on to a neighbouring position in the skeleton, as in the case of compensatory lengthening processes. However, rules affecting phonemes as a unit will have a highly marked status within theories postulating representations like (2), since they have to refer to features arrayed on more than one tier. There is a very real sense in which phonemes, although analysable into individual, autonomous features, are integral units in their own right, and an adequate model of feature representation must be consistent with this observation.

Let us consider, as an alternative, a model developing recent proposals of Mascaró (1983, forthcoming) and Mohanan (1983). In this conception, individual features are organised under hierarchically superordinate nodes, which I will term CLASS NODES. The class nodes themselves are dominated by a yet higher-level class node, which (following Mohanan) I will term the ROOT NODE. The root node, in turn, is directly linked to the CV tier. Under this conception, the phonetic content of a segment is arrayed on two different types of tiers, the feature tiers and the class tiers (including the root tier). As a preliminary proposal, suppose we take the view that the class tiers are exactly the following: the root tier, the laryngeal tier, the supralaryngeal tier, the 'place' tier, and the 'manner' tier (a further tier, the tonal tier, will not figure in the present discussion). These are organised as in (3):

(3)



aa′ = root tier, *bb′* = laryngeal tier, *cc′* = supralaryngeal tier, *dd′* = manner tier, *ee′* = place tier

This conception resembles a construction of cut and glued paper, such that each fold is a class tier (labelled *aa′*, etc.), the lower edges are feature tiers, and the upper edge is the CV tier. Imagine now that each element of the CV tier is individually linked by an association line to a corresponding node on the root tier, and that the first such node is linked to all the features of [p], the second to all the features of [i], and the third to all the features of [n], all placed on the appropriate tiers. We then have a representation of the word [pin].

A model of this sort corresponds to a fundamental observation regarding the structure of the human speech-producing apparatus. The essential characteristic of speech production is that it is COMPONENTIAL in nature, involving the coordination of simultaneous and partly overlapping gestures (cf. Halle & Clements 1983). These gestures show varying degrees of mutual independence. For example, one can maintain a certain oral tract configuration constant, say the one appropriate for producing the vowel [a], while varying the type of laryngeal configuration, or the position of the velum. Or one can hold the laryngeal configuration constant while varying the internal geometry of the oral tract. Following this line of thought, we can identify at least the following articulatory parameters, each of which shows a high degree of independence from the others:

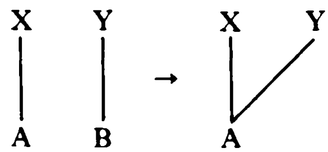
(4) a. laryngeal configuration
b. degree of nasal cavity stricture (open/closed)
c. degree and type of oral cavity stricture
d. a pairing of an active and a passive articulator

Within each of these categories, on the other hand, it is difficult, and sometimes impossible, to maintain one gesture while varying another freely. For example, it is relatively difficult (though not impossible) to combine a spread glottal configuration with voicing; these two features of category (4a) tend to be interdependent in most classes of sounds in most languages. The various categories of (4) are not equally independent of each other, however. While the category of laryngeal configuration is quite freely variable with respect to the other three categories, the latter three show some degree of mutual independence. For example, nasality is not contrastive in pharyngeal sounds, lateral release is not contrastive in labial sounds, low front tongue body position is limited to vowels, and so forth.

The model in (3) embodies this view of speech production. It claims that the varying degrees of independence among phonetic features can be expressed by a hierarchical grouping such that higher-branching categories tend to be more independent than lower-branching categories. More exactly, the relative independence of any two features or feature classes is correlated with the number of nodes that separate them. The geometry of (3) reflects the classification of (4) quite closely, postulating the highest degree of independence between the laryngeal features and all others, and the next highest between the manner and place features. The model in (3) differs from the classification in (4) in one respect, however, in not recognising a hierarchical distinction between nasality and the other manner features. Since such a distinction might be expected on the basis of articulatory and acoustic considerations, one might ask whether such criteria should play a greater role in our formal model.

The ultimate justification for a model of phonological features must be drawn from the study of phonological and phonetic processes, and not from *a priori* considerations of vocal tract anatomy or the like. In this respect we follow the general principle that the justification for the categories and principles proposed for any linguistic level must be supported entirely by evidence pertaining to that level (cf. the 'separation of levels' in structuralist linguistics, or the 'autonomy of syntax' in current formal linguistics). Following this principle each level seeks its own principles of analysis, and the categories appropriate to any one level may prove to be partly distinct from those appropriate to another level. Accordingly our justification for the structure of (3) will be sought entirely in the study of crosslinguistic generalisations concerning common types of phonological and phonetic processes. From this perspective, the model in (3) appears to represent a correct reflection of the types and degrees of *phonological* independence found among phonetic features. For example, it is well known that phonological processes may involve laryngeal features without affecting supralaryngeal features: relevant examples include rules of voicing assimilation, aspiration and deaspiration. Similarly (though less frequently commented on), processes may affect supralaryngeal features while not affecting laryngeal features. The lower-level branching into 'place' and 'manner' features has a similar crosslinguistic justification, deriving from processes that affect categories of one type while not affecting those of the other. Examples justifying these statements will be given below.

More specific evidence bearing upon models such as (3) can be drawn from the study of assimilation processes. It has been suggested by a number of writers (Halle & Vergnaud 1980; Goldsmith 1981; Steriade 1982; McCarthy 1984) that assimilation can be described as the spreading of an element of one tier to a new position on an adjacent tier. In this view, assimilation has the following schematic character, where A is the spreading feature:

(5) 

In the output structure, A is associated with two positions on the related tier, and B has been eliminated from the representation. Now as Mohanan (1983) has pointed out, the view of assimilation characterised in (5) combined with a fairly straightforward criterion of simplicity leads us to the view that there should be three common types of assimilation processes in the world's languages: TOTAL assimilation processes in which the spreading element A is a root node, PARTIAL assimilation processes in which A is a class node, and SINGLE-FEATURE assimilation processes in which A is a single feature. More complex types of assimilation, in which more than one node spreads at once, can be described by this model, but at greater cost.

Such a view of assimilation is strongly supported by many recent studies of assimilation processes. Let us consider total assimilation first. As first pointed out by Kenstowicz (1970), long segments characteristically show the property of behaving like one unit as far as quality-sensitive rules are concerned, and like two units as far as quantity-sensitive rules are concerned. This property extends to long segments derived by rules of total assimilation as well. For example, in Luganda all geminate consonants, whether underlying or derived through a rule of total assimilation, behave as single units with respect to such quality-sensitive rules as palatalisation, and as two units with respect to such quantity-sensitive rules as tone assignment. This result can be explained under the assumption that geminate consonants of both types are represented as single-feature columns (in the present theory, root nodes) linked to two positions on the CV tier (see Clements forthcoming for detailed discussion). A further characteristic of geminate consonants in many languages is that they fail to be broken up by otherwise applicable epenthesis processes (Guerssel 1978). More exactly, geminate consonants appear to be impervious to epenthesis rules if they are tautomorphemic, or created by assimilation rules. This disjunction of properties can be explained under the same assumption as was made above: if underlying tautomorphemic geminates, as well as geminates created by assimilation rules, are single segments linked to two timing tier positions, then epenthesis rules will be unable to insert a vowel between them as a result of the universal prohibition against crossing association lines (see Schein 1981, Kenstowicz 1982, Steriade 1982, McCarthy 1985 for examination of cases and further discussion).

There is also considerable evidence that rules of partial assimilation create linked structure, as predicted by our theory. A closer examination of constraints on epenthesis rules shows that not only geminate consonants, but also consonant clusters that have undergone partial assimilation, are impervious to epenthesis. Thus Steriade (1982) shows that in Kolami, a Dravidian language, consonant clusters are normally broken up by an epenthetic vowel when occurring before another consonant or word-finally, with two exceptions: the rule does not apply between the two members of a geminate consonant, or between a nasal–stop sequence in which the nasal has undergone a rule assimilating it to the place features of the following stop. As Steriade points out, we can explain this pattern of exceptions on the assumption that rules of partial assimilation create partly linked structure; we thus account for the failure of epenthesis to break up geminates and assimilated nasal–stop sequences in a uniform way, in terms of the universal prohibition against crossing association lines. Further evidence for such a treatment of partial assimilation from constraints on epenthesis rules can be found in Tamil (Christdas to appear) and Tangale (Kidda 1984). Evidence of a different sort has been presented by Hayes, on the basis of phonological alternations in Toba Batak, an Austronesian language (Hayes 1985). In this language, partially and totally assimilated consonant clusters pattern together with underlying tautomorphemic geminate consonants in failing to undergo an otherwise applicable rule of glottal stop formation, having the general effect $C \rightarrow ʔ/\text{—}C$. All other consonant clusters undergo this rule. Hayes shows that this pattern of exceptionality can be explained by general principles, on the assumption that assimilation rules create linked structures. Similar explanations for the exceptional behaviour of partially assimilated clusters have been offered by Steriade (1982) for the Sanskrit *visarga* rule and by Harris (1982) for a rule of spirantisation in Havana Spanish.

Turning finally to single-feature assimilation, we have strong evidence for the spreading nature of assimilation rules in certain tone languages, whose rules distinguish single instances of H tones spread over several vowels from multiple instances of H tones linked individually to each vowel (Odden 1984; Leung 1985; Clark forthcoming). Evidence relevant to the analysis of nontonal features is not yet as clear, although spreading analyses have been offered for such features as voicing (Hayes 1984) and continuance (Harris 1982).

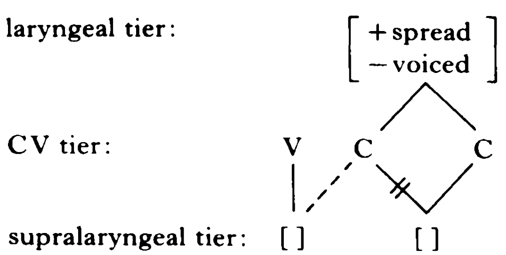
In sum, evidence for the spreading account of assimilation rules seems quite strong, and argues in favour of the multi-tiered view of feature representation proposed here. Other views of assimilation have been suggested in the literature, in particular the view that harmony and assimilation processes involve a combination of autosegmental and metrical formalisms (see Halle & Vergnaud 1981). This view represents a weakening of the present hypothesis, since while it does not exclude the possibility of treating some types of assimilation in terms of spreading rules, it provides other ways of describing assimilation as well. It is possible that such a weakening may be called for, and that assimilation by spreading may turn out to be no more than the unmarked case. In the absence of clear evidence forcing us to such a position, however, it would be desirable to maintain a single, unified formalism for the statement of all assimilation processes. A major goal of the present study is to provide a theory of representation in which all such processes can be stated in the manner shown in (5).

3 The functional unity of the class tiers

A major claim of the structure in (3) is that rules may affect the supralaryngeal features as a unit without affecting the laryngeal features. This claim receives some of its first and strongest motivation in the observations of Lass (1976) regarding the reductions of full consonants to the glottal consonants [ʔ] and [h], occurring commonly throughout the history of English. In Lass's analysis, such reductions are analysed as involving the deletion of the full set of 'oral tract' features, leaving behind the laryngeal features alone which constitute phonetic [ʔ] and [h].

In work drawing upon a similar view of feature organisation, Thráinsson (1978) presents an analysis of the Icelandic preaspiration rule according to which the underlying geminate stops /p^hp^h, t^ht^h, k^hk^h/ are realised as [hp, ht, hk], respectively. Proposing that the laryngeal features and the supralaryngeal features are assigned to separate tiers, Thráinsson argues that preaspiration is most insightfully described in terms of a rule deleting the set of supralaryngeal features of the first member of the geminate, leaving the laryngeal features behind. Thráinsson states the rule as in (6):

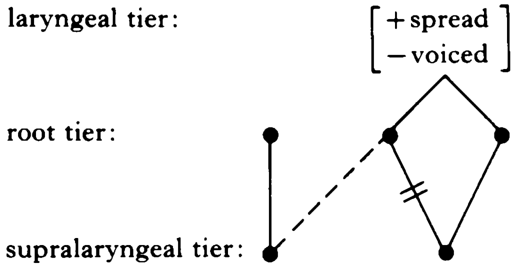
(6)



This rule applies to a CC sequence sharing the laryngeal features [+spread, −voiced] just in case they also share all supralaryngeal tier features; thus it applies to a geminate voiceless aspirated stop. The structural change indicated by the double-crossed line delinks the set of supralaryngeal tier features associated with the first C-element of the geminate, which thus retains only its laryngeal tier specification. The structural change indicated by the dashed line spreads the supralaryngeal tier features of the preceding vowel on to this element, creating an aspirated segment sharing all supralaryngeal features with the preceding vowel: in other words, an [h].

Our analysis is similar to Thráinsson's, except that under the model in

(3) the laryngeal and supralaryngeal features will link to the root tier, rather than the CV tier. We must therefore replace the CV tier with the root tier in our statement of this rule, as shown in (7). In other respects, the two formulations are essentially identical:

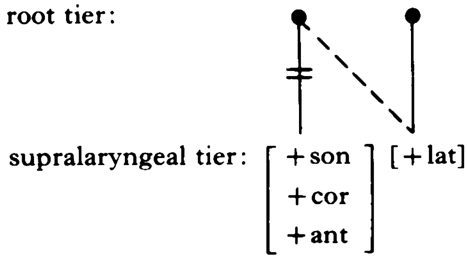
(7) 

In our rules and representations, class nodes are normally represented as single points, since their feature content is entirely determined by the features which they dominate. In rule statements, however, we allow the further option that nodes may be represented by feature sets. These sets are understood as imposing a condition upon the class node they are assigned to, requiring it to dominate the features in question. Thus, the occurrence of the feature set [+spread, −voiced] on the laryngeal tier node in (7) requires that a laryngeal tier node otherwise satisfying this rule must also dominate the features [+spread, −voiced]. As a result of this condition, only voiceless aspirates will undergo the rule. (A fuller account of the formalism assumed in this theory is given in the Appendix.)

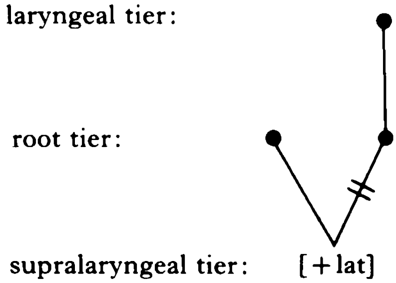
In Klamath, there is a set of phonological processes having the following effect (Barker 1964):

(8) nl → ll
nl̥ → lh
nl' → lʔ
ll̥ → lh
ll' → lʔ

([l̥] is a voiceless [l]; [l'] is a glottalised [l]). If we take the voiceless [l̥] to be an aspirated sound, which is motivated by the phonemic patterning of this language (all obstruent and sonorant consonants then fall into three series: plain, glottalised and aspirated), the rules listed in (8) can all be described in terms of two processes, the first spreading the supralaryngeal features of [l] backward on to [n, l], and the second disassociating the supralaryngeal features of [l̥, l']. These are stated below:

(9) a. 

b.



I assume that only the 'marked' values of the laryngeal features, [+spread glottis] and [+constricted glottis], occur in underlying representations in Klamath. The unmarked values of these feature categories are inserted at the end of the derivation, as they play no active role in the phonology. Since all class nodes meet the condition that they dominate actual phonetic features (see Appendix), (9b) can only be satisfied by a pair of adjacent root nodes, of which the second dominates one of the marked features on the laryngeal tier. Rules (9a, b) apply in succession to provide the derivations in (8).

A second, related (but logically independent) claim entailed by the model in (3) is that laryngeal features may operate as a unit independently of supralaryngeal features. In accordance with this view, we find that laryngeal features undergo rules specific to them in a number of unrelated languages. In Thai, for example, voiced stops, voiceless aspirated stops and voiceless unaspirated stops contrast in syllable-initial position; this contrast is suppressed finally, where only unreleased voiceless stops appear (Noss 1964). In Klamath, a three-way contrast among voiced, voiceless and glottalised obstruents is neutralised immediately preceding another stop, leading in this case to morpheme alternations (Barker 1964). In Proto-Indo-Iranian, a rule of devoicing/deaspiration affected all members of prepausal obstruent sequences, while a mirror image rule of voicing/aspiration (Bartholomae's Law) applied to non-aspirated obstruents adjacent to a voiced aspirate (Schindler 1976); these rules, again, are motivated by alternations. All these rules apply to several members of the set of laryngeal features without affecting any supralaryngeal features.

Let us now consider the independence of the place tier *vis-à-vis* the manner tier. I will examine here some assimilation phenomena in English. Suppose we assume the following partial distinctive feature characterisation of English coronal sounds:

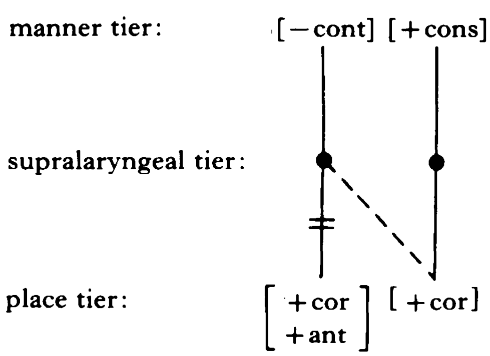
(10)	t, d, n, s, z	θ, ð	š, ž	r
coronal	+	+	+	+
anterior	+	+	−	−
distributed	−	+	+	−

This analysis should be uncontroversial; the characterisation of [t, d, n] as [−distributed] is in accord with Gimson (1970) and my own dialect, although Ladefoged (1982) suggests some variation. The three stops [t, d, n] assimilate to the point of articulation of a following coronal consonant, so that [t, d, n] are interdental before [θ], postalveolar before [š, ž], and retroflex before [r]:

(11)	[t]	[d]	[n]
—θ	eighth	hundredth	tenth, enthuse
—š, ž	each, cheer	edge, gem	inch, hinge, insure, enjoy
—r	tree	dream	enrol

Examples in the third column show that this rule applies across syllable boundaries. This rule is distinct from the rule of nasal assimilation, which applies to the prefix *in-* (*impossible*) but not to the prefix *un-* (*unpublished*); the rule under discussion here applies after *un-* as well (*unthankful*, *unsure*, *unruly*). [l] participates in this assimilation only in part, assimilating to [θ] (*health*) but not, at least not fully, to [č, ǰ] (*filch*, *bilge*). Note finally that this rule applies not only within words, as in the examples above, but also across word boundaries, especially in informal speech; thus the final consonants of *eight*, *ten*, *hundred* assimilate to the initial consonants of *thistles*, *shoes*, *cheeses*, *gems*, *roses*.

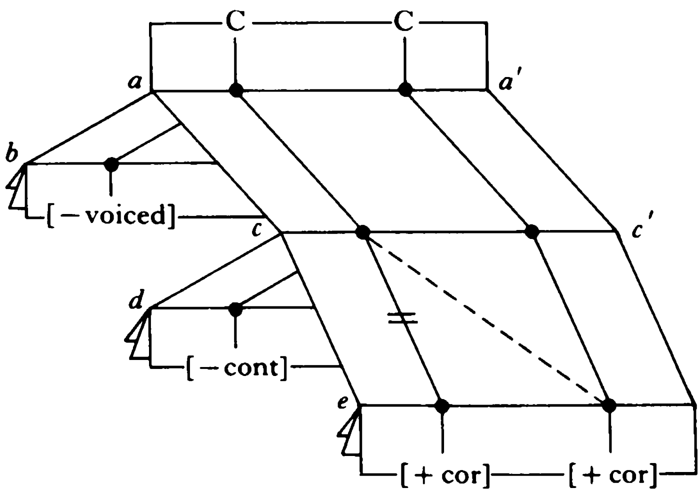
If we ignore the slight complication presented by [l], the rule in question may be expressed as follows:

(12)


(12) applies to a form just in case the supralaryngeal tier node characterising the first segment dominates a manner tier node characterised by the feature [−cont] and a place tier node characterised by the features [+cor, +ant], and the supralaryngeal tier node of the second dominates a manner tier node characterised by the feature [+cons] and a place tier node characterised by the feature [+cor]. If this condition is satisfied, an association is entered between the supralaryngeal tier node of the first segment and the place tier node of the second, as shown by the dashed line.

To aid the reader to see how (12) applies to a representation, I add the following figure, based upon (3):

(13)



This figure is a partial representation of (for example) the segment sequence [t̪θ]. Tiers are organised as in (3), but now association lines are added to show how the lowest tiers (i.e. the feature tiers) are linked to higher-level structure. Since rule (12) is satisfied, it erases the original association line between the leftmost node of the supralaryngeal tier *cc′* and the leftmost node of the place tier *ee′*, as shown by the double-crossed line, and introduces an association between the leftmost node on the supralaryngeal tier and the rightmost node on the place tier, as shown by the dashed line. Henceforth, all disassociated features are phonetically unrealised (I assume that they are deleted by convention), while all features dominated by the rightmost node on the place tier now characterise both nodes on the supralaryngeal tier, and hence both of the C-elements on the CV tier.

It is instructive to compare the formulation in (12) with 'standard theory' statements of a rule of this sort such as the following:

(14) $$\begin{bmatrix} +\text{cor} \\ +\text{ant} \\ -\text{cont} \end{bmatrix} \rightarrow \begin{bmatrix} \alpha\text{ant} \\ \beta\text{distr} \end{bmatrix} / \text{—} \begin{bmatrix} +\text{cor} \\ \alpha\,\text{ant} \\ \beta\ \text{distr} \end{bmatrix}$$

(14) is not just a renotation of (12); as is usually the case, the different notation implies an entirely different set of theoretical assumptions. The theory implied by (14) does not recognise any hierarchical organisation within phonological features, and thus does not provide any principled way of characterising a notion such as 'place of articulation'. For this reason it is unable to characterise rules of assimilation to place of articulation as a favoured rule type in grammars. From the point of view of a non-hierarchical theory of features, (14) is no more and no less ordinary than an equally 'simple' rule in which both occurrences of '[αant]' are replaced with '[αnas]', for example; but we know that rules of the latter type are extremely rare, if not unprecedented. In terms of the framework proposed here, this is explained by the fact that the features '[ant]' and

'[distr]' are grouped together under the place tier, while '[nas]' falls under the manner tier. Under the assumption that only single nodes are affected by ordinary types of assimilation rules, the features [nas] and [distr] could not be affected by such a rule unless *all* the features characterising the supralaryngeal tier were also affected.

We have so far offered evidence demonstrating the phonological independence of each of the class tiers of (3) except for the manner tier. While the individual members of this set of features, particularly [+nasal] and [+continuant], are relatively independent of the features of the other class tiers, there is very little evidence to suggest that the manner tier itself functions as a unit. If this generalisation continues to be sustained, we will have to regard the manner tier as superfluous, and suppose that the so-called manner features link directly to the supralaryngeal tier node. As this issue cannot be resolved for the present, I will leave it for further research.

As a final example bearing upon the organisation of features proposed in (3), let us consider some phonological rules of Sierra Popoluca, a Zoquean language of Veracruz State, Mexico, which has been described by Elson (1947, 1956) and Foster & Foster (1948). In this language, consonant clusters are restricted (with a handful of exceptions) to syllable-final position, where we find the following types: CC, represented by *ps*, *ks*, *ʔC* (*C* = any consonant), and CCC, represented by *ʔps* and *ʔks*. The consonant inventory is /p t t^j k b d d^j g c č s š m n ɲ ŋ l r w j h ʔ/. Of these, /b d d^j g l r/ do not occur in syllable-final position.

There is some reason to think that Sierra Popoluca has a rule merging sequences of identical place nodes. Evidence for this comes from a rule described by Elson as follows: 'when followed by a nasal of the same point of articulation (and not preceded by a glottal stop), voiceless stops p, t, and t^y become a voiceless counterpart of the nasal' (Elson 1947: 15). Some examples are:

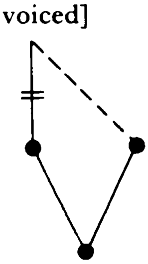
(15)	caM.'mɛ·j.miʔ	/cap.'mɛ·j.mi/	'the ocean'
	pɛN.'nɛʔ	/pɛt.'nɛʔ/	'it is swept'
	wiÑ.'ñɛʔ	/wit^j.'ñɛʔ/	'he has walked'

(capital letters designate voiceless nasals, lowered dots syllable divisions, and raised dots length). The fact that this rule applies only to consonant sequences sharing the same point of articulation suggests that identical place nodes are merged by a principle having an analogous effect to rules merging identical tones, in tonal phonology (cf. Leben 1978). The rule of nasalisation can thus be stated as follows:

(16) root tier: [−constr] [−voiced]

supralaryngeal tier:

place tier:



Comparing this rule with those of (7) and (9), we see that we are on familiar territory. The supralaryngeal tier features characterising the segment on the right spread *en masse* on to the root tier node linked to the supralaryngeal tier node to its left, provided it dominates the feature [−voiced] and is preceded by the feature [−constr], while the leftmost supralaryngeal tier node itself is delinked. The fact that the two supralaryngeal tier nodes must be linked to a single set of place tier features is sufficient to guarantee that the rule will not apply to hetero-organic clusters, and the specification [−voiced] prevents the rule from applying to sequences like /dn/, etc.

Consider now the rule governing transitions between consonants. As Elson states it: 'Both open and closed transition occur between syllables. Open transition has the following forms: (1) the aspiration of voiceless stops when not followed by a consonant phoneme of the same point of articulation ... and (2) the development of a lenis schwa vowel between nasals and certain other sounds. The two members of the cluster are at different points of articulation' (1947: 16). 'Close transition' is described as the lack of development of any type of aspiration or schwa vowel between the two consonants, and characterises the remaining consonant sequences. Examples:

(17) ˈkɛk^{h} . paʔ	/ˈkɛk . pa/	'it flies'
ˈmiñ^{ə} . paʔ	/ˈmiñ . pa/	'he comes'
cf.		
kɛk . ˈgak^{h} . paʔ	/kɛk . ˈgak . pa/	'it flies again'
ˈʔaŋ . kiʔ		'yard'

It is clear from Elson's description that the feature of aspiration and the feature of lenis vocalic release are in complementary distribution, the first occurring after voiceless stops and the second after nasal stops. Since these features appear in otherwise identical environments, it would be desirable to consider the 'open transition' phenomenon to be a single feature, whose variant phonetic realisations are determined by features of the immediately preceding context. Notice first of all that what these two realisations share is the property of oral release of the airflow; we may plausibly assume that when the airflow is not characterised by glottal vibration it will be perceived as aspiration, regardless of whether the glottis is in fact in spread or neutral position, and that if it is accompanied by glottal vibration it will be perceived as a short schwa-like vowel. Let us say, then, that what we are dealing with is a single feature of oral release. Notice second, that such a feature only contrasts with *absence* of oral release when occurring between two stop sounds; in all other circumstances one of the adjacent sounds will be characterised by oral airflow, making a contrast between oral release and its absence impossible.

Given these observations, we may consider the release feature to be simply a 'floating' occurrence of the feature [+continuant], inserted between two stops by the following rule:

(18) $\varnothing \rightarrow [+\text{cont}] / [-\text{cont}] — [-\text{cont}]$

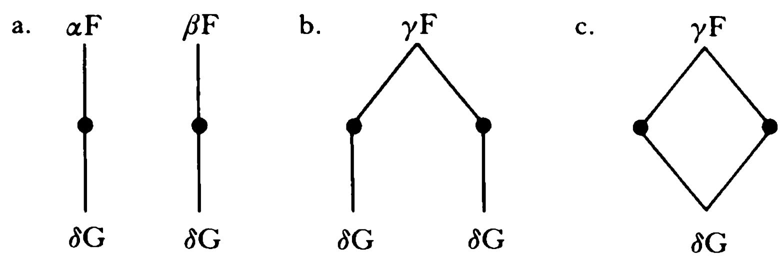
By the operation of this rule, we have the surface forms [kɛk[+cont]paʔ], [miñ[+cont]paʔ], etc., where the specific implementation of the feature [+cont] is determined by speech physiology rather than language-specific rules.

(18) is as yet inadequate, however, since we have not accounted for the condition on its application that the two stops in question should *not* be homorganic. Normally, negative conditions of this type are highly marked in phonology; what is more, this condition is simply the complement to the homorganicity condition involved in the nasalisation rule (16). It is reasonable to think that the formal account we gave of the homorganicity condition in (16) also plays a role in the explanation of the non-homorganicity condition in (18).

The answer is quite simple, if we adopt a proposal by Steriade (1982), called the Shared Features Convention. According to this convention, when the output of a rule creates a configuration in which some feature matrix is shared between two adjacent segments, then all remaining identical features undergo merger. I will here take the liberty of reformulating the convention as in (19), in accordance with the theory of feature geometry assumed in this study:

(19) *Shared Features Convention* (adapted from Steriade 1982)

Given a representation satisfying (b) resulting from a representation satisfying (a) as the result of a rule, where F, G are single features and the dots designate root tier nodes, (b) is converted into (c):



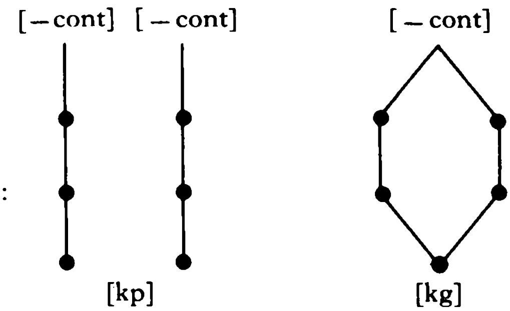
Informally paraphrased, this convention states that if two root nodes should come to dominate a single feature as the result of a rule, then any other identical features that they dominate are immediately merged into one. Let us also assume that when any two class tier nodes come to share all features as a result of (19), they are also merged. Now this convention applies to the output of the rule of Sierra Popoluca merging identical place nodes. As this rule creates partially linked structure, linking of identical features is maximised by the Shared Features Convention. In particular, two adjacent stops sharing the same point of articulation will merge the identical feature sequence [−cont] [−cont] into a single, multi-attached feature. Let us compare the representations of the sequences [kp] and [kg], as they result from the operation of this convention:

(20) [cont] tier:

manner tier:

supralaryngeal tier:

place tier:



It is now apparent why the rule inserting the release feature, (18), applies to sequences like [kp] but not to sequences like [kg]: in the first, the structural description of the rule is satisfied, while in the second it is not.

4 The phonetic content of the class tiers

We have so far said nothing about the phonetic content of the various class tiers, and we turn to this topic now. I assume a standard set of features for the purposes of the present discussion, though with no crucial consequence for the main lines of the discussion.

The class of laryngeal features comprises the set [spread], [constricted], and [voiced]. I assume that tone features are distinct from other laryngeal features, though we find a limited degree of interdependence in some languages, such as Thai (Yip 1982) and Zulu (Laughren 1984).

The manner features are traditionally those concerned with the degree and manner of constriction in the oral tract (regardless of the location of the constriction), and therefore include such features as [consonantal], [sonorant], [continuant], [lateral] and [strident]. The feature [nasal] will be tentatively assigned to the manner tier as well. While it does not fall together with the other members of this set in terms of its aerodynamic properties, this consideration is irrelevant to our analysis, which (as remarked earlier) depends upon phonological, rather than physiological criteria. We will therefore regard the above analysis as provisionally correct, postponing a detailed classification to the time when more decisive evidence becomes available.

Let us turn now to a consideration of the place features. In the classification of Chomsky & Halle (1968), there is a set of features that typically distinguishes place of articulation in consonants but not in vowels, which we will call set P (mnemonic for 'primary'), and a set of features that typically distinguishes place of articulation in vowels, but not consonants, which we will call set S (for 'secondary'). The members of set P include [coronal], [anterior] and [distributed], and the members of set S include [high], [back] and [rounded]. These feature sets are not entirely disjoint, since retroflex vowels take the 'marked' values [+coronal, −distributed] from set P, and consonants with secondary articulation take 'marked' values from set S, such as [+rounded] for rounded consonants, or [+high, −back] for palatalised consonants. I assume that both set P and set S features are members of the class of place features, and leave open the question of whether they form two new class nodes of their own, or directly link to the place tier.

The analysis presented so far, which treats consonants and vowels as largely identical in their feature composition, fails to account for a number of striking asymmetries in the rule-governed behaviour of consonants and vowels.

First, when we consider phonological rules of place assimilation, we find that rules of vowel-to-vowel assimilation frequently include mention of the variable 'C_0', indicating that the assimilation process takes place regardless of the nature or number of intervening consonants. For example, a traditional statement of a rule fronting a vowel before a front vowel in the next syllable would be: $V \rightarrow [-\text{back}]/\text{—}\ C_0\ [-\text{back}]$. On the other hand, rarely if ever do we find any well-justified use of the variable 'V_0' in rules of consonant-to-consonant assimilation: consonants tend to assimilate to adjacent consonants only. I am unaware, for example, of any language in which a nasal becomes homorganic to a consonant across an intervening vowel. This asymmetry between the behaviour of consonants and vowels, which was originally brought to my attention by Morris Halle, calls for an explanation which the present theory does not so far provide.

A further asymmetry involves sequences of the form CV or VC, where the C is a 'plain' consonant, i.e. one having no secondary articulation. We commonly find rules in which the C assimilates to set S features of the V (palatalisation, velarisation, rounding), but rarely if ever do we find rules in which the V assimilates to set S features of the C (e.g. acquiring the features [−high], [−back], [−round], etc.).

We may begin to find our way to an explanation if we consider more closely the way in which redundant place features are assigned to consonants and vowels. In the case of 'plain' consonants (those without secondary articulations), the assignment of redundant class S features is largely context-dependent, depending on the nature of adjacent vowels. Thus consonants are typically rounded before rounded vowels, velarised before back vowels, and so forth. In the case of vowels, however, the assignment of redundant class P features is context-free: thus vowels are normally [−anterior], regardless of the consonantal context.

Given this observation, the consonant/vowel asymmetries noted above can be explained within representational systems that allow three-way distinctions between segments characterised by [+F], [−F] and [øF] (or absence of F), for one or more features F. In the context of autosegmental analyses, we frequently find motivation for recognising such underlying three-way distinctions, such as that between high-toned, low-toned and toneless vowels. Under theories requiring all segments to be fully characterised for all features, there is no straightforward way of representing such a three-way opposition. In autosegmental phonology, which is not subject to such a constraint, such distinctions can be easily captured on the assumption that some segments are 'incompletely characterised' by certain features – that is, not linked to any occurrence of such features on the relevant autosegmental tier.

We may now account for the second of the consonant/vowel asymmetries noted above, the fact that vowels do not assimilate to set S features of (plain) consonants, by assuming that set S features are underlyingly unspecified in such consonants. Only in case of phonemically contrastive 'secondary articulations' will a consonant have an inherent specification for a given class S feature. Vowels, on the other hand, are always specified for set S features, and hence consonants may readily assimilate to these features.

We may easily see that this analysis accounts for the first of the asymmetries noted above as well, the non-occurrence of 'V_0' in rules of place assimilation involving consonants. Such rules may not ignore intervening vowels since vowels are *opaque* with respect to features of set P. I assume that these features are assigned by the following rule, which applies in the unmarked case:

(21)
$$\begin{bmatrix}-\text{cons}\\ \alpha\,\text{back}\end{bmatrix} \rightarrow \begin{bmatrix}-\text{ant}\\ -\alpha\text{cor}\\ +\text{distr}\end{bmatrix}$$

But rules of place assimilation in vowels may ignore intervening consonants, since these elements are normally *transparent* with respect to features of set S, which determine place in vowels. Under this analysis, only consonants bearing secondary articulations (set S features) will have the ability to 'block' vowel-to-vowel assimilations. This is exactly what we observe in Turkish, for example, where the consonants /k, g, l/ block backness (velar) harmony just in case they are opaquely specified for the feature category [back] (Clements & Sezer 1982).

The analysis presented here might appear problematical in the light of the fact that the feature categories [back] and [high] have often been used, in the literature, to characterise place of articulation in consonants. However, these features are not required in a four-place consonant system having the consonants /p t c k/, as (22) shows:

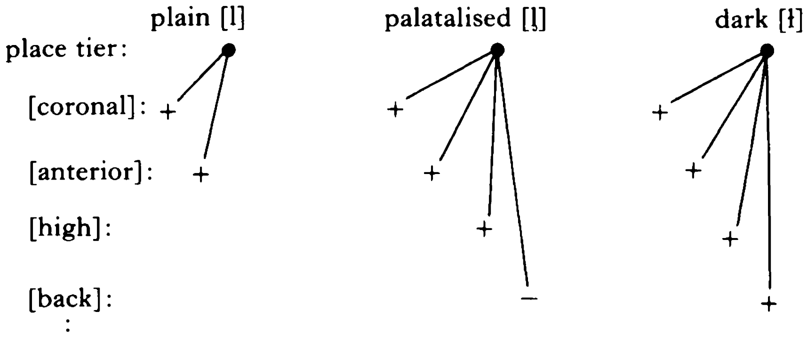
(22)

	p	t	c	k
labial	+	–	–	–
coronal	–	+	+	–
anterior	+	+	–	–

Further distinctions are made available by the feature categories [distributed] and [strident]. Only in the case of languages having consonants with secondary articulations, such as Turkish or Russian, or in the case of languages contrasting two or more consonants in the velar/uvular/pharyngeal region, do the feature categories [back] and [high] have a contrastive value. In other languages, we may consider these features to be either contextually determined through assimilation, or else to have the status of 'enhancement' features, in the sense of Stevens *et al.* (in press).

The distinction between, for example, plain [l], palatalised [l̡] and 'dark' [ɫ] may now be characterised in the following manner:

(23)



It is clear that the principle leading to 'undercharacterised' representations such as the first of those in (23) is of broad application. For example, we may represent [h ʔ] as segments uncharacterised for any place features, acquiring their place features by assimilation to adjacent vowels, as noted by Lass and Thráinsson. Similarly, in many languages we find nasal formatives which always occur adjacent to a consonant, and which always assimilate to the point of articulation of that consonant. We may assume that such nasal elements are characterised only for laryngeal and manner features, acquiring place features by assimilation. In the limit case, all class nodes are absent, in which case we have the so-called 'empty' or 'ghost' consonants and vowels of the CV tier. While segment types such as these were anomalous under previous theories of phonological representation, the present framework provides a principled account of them, relating their apparently 'exotic' characteristics to more familiar phenomena.

5 Residual problems

We have seen that the theory of feature geometry presented in (4), combined with an independent analysis of assimilation processes, offers us a basis for claiming that assimilation processes only involve single nodes in tree structure. At first sight, this claim may appear to be too strong, and we will examine two types of potential problems.

5.1 Redundant feature specification

In Kikuyu, there is an exceptionless process that assigns the features [−cont] and [+voiced] to obstruents occurring after nasal consonants. Some examples follow:

(24) *imperative*	*1st sg. imperfect*	*stem (gloss)*
βur – a	m – bur – eetɛ	'lop off'
tɛm – a	n – dɛm – ɛɛtɛ	'cut'
reh – a	n – deh – eetɛ	'pay'
cin – a	ɲ – jin – eetɛ	'burn'
kom – a	ŋ – gɔm – ɛɛtɛ	'sleep'
ɣor – a	ŋ – gor – eetɛ	'buy'

(see Armstrong 1967). Only [ð] is unaffected by this rule, since an independent rule deletes nasals before this consonant.

Consider now the phonetic nature of the process involved. Here we have an apparent instance of an assimilation process involving two independent nodes: the feature [+voiced] and the feature [−cont]. There is no way to express such a process in terms of the spreading of a single node, under the theory expressed in (3). However, there is good reason to suppose that the feature category [voiced] is redundant in Kikuyu, and unspecified in underlying representation. In Kikuyu, all sonorants are voiced, and voicing is also predictable in obstruents: stops are voiced after nasals, otherwise voiceless; fricatives are voiced. It appears, then, that the assimilation rule in question involves only the feature [−continuant], and that the feature [+voiced] is assigned to segments by a later redundancy rule.

We see from this example that the theory of feature representation and assimilation presented here intersects significantly with the theory of phonological redundancy. We expect that certain apparent exceptions to the view that only single nodes assimilate will be explained by the fact that one or more of the features involved are not yet present in representations, and are added as an effect of late redundancy rules.

5.2 Rule interaction

Another type of apparent counter-evidence to the present theory comes from rules of palatalisation, which typically raise and front the tongue position of a consonant before high vowels and glides. Since a raised, fronted tongue position is an intrinsic characteristic of the following glide or vowel it is reasonable to suppose that we are dealing with an assimilatory process (see Clements 1976 for arguments in favour of this view). Examining the features of palatalised consonants more closely, we see that not just raising and fronting, but *all* the place features of high vowels and glides may be assimilated. The following feature analysis of [i j] is assumed:

(25) i, j = [+cor, −ant, +distr, +high, −back]

Considering now alternations such as *permit/permission*, *decide/decision*, *habit/habitual*, *reside/residual* in English, it might appear that the English palatalisation rule affects not only place of articulation, but also manner, since the affected consonants are not only assigned the place features of the glide *j* but also two of its manner features, [+cont] and [+strident]. As palatalisation rules having this effect are quite common in the languages of the world, this fact might appear to present a serious problem for the analysis.

It is reasonable to suppose, however, that two processes are involved in the English palatalisation rule, not one. The first is a process of spirantisation, which turns *t* to *s* and *d* to *z* before a set of vowel- and glide-initial suffixes (see Chomsky & Halle 1968: 229), and which accounts for the spirants in words like *permissive* and *decisive*. The second is the rule of palatalisation itself, ordered after spirantisation, which changes *s*, *z*, *t*, *d* to *š*, *ž*, *č*, *ǰ* before certain instances of *j*, which are subsequently deleted. The palatalisation rule can be described as one assigning the place node characterising *j* to the preceding stop or fricative, thus recategorising it as [−ant, +distr], etc.; we may then assume that the acoustic properties of this segment are reinforced or enhanced by a subsequent redundancy rule realising it as a strident affricate.

If this account is correct, then we see that rules of palatalisation that apparently affect a subset of place and manner features simultaneously can in some cases be decomposed into independent processes, one of which accounts for spirantisation and the other for place assimilation. This type of analysis is well supported on cross-linguistic grounds, as shown by Bhat (1978), who argues further that the assimilatory component of palatalisation is a composite of the two gestures of fronting and raising.

However, it is unlikely that all palatalisation rules will be susceptible to such an analysis. The endpoint of rule interaction is rule telescoping, by which two or more originally independent rules become synchronically indissociable. Such rules are typically lexicalised and/or grammaticalised, and may show other irregularities. An apparent example of such a rule is the rule of palatalisation in the Chi-Mwi:ni dialect of Swahili, spoken in the city of Brava in Somalia (Kisseberth & Abasheikh 1975). In this language, certain consonants palatalise before the perfect suffix -i:ł-, preserving only their value for the feature [anterior], except for [g], which palatalises idiosyncratically to [z]. The full set of changes is: p t̪ t → s, b d̪ d g → z/[+nasal] —, ł → z, and k → š (t̪, d̪ are dental, t, d alveolar). This rule does not conform to our expectations, and requires a fairly complex statement under the present theory, in keeping with its clearly lexicalised and grammaticalised status: only the perfect formative appears to trigger the rule, and there are numerous lexical exceptions to it. We will not relax the empirical claims of our theory in order to provide simple descriptions of rules such as these, since if we did so we would fail to draw a correct distinction between the common, widely recurrent process types that we take as providing the primary data for our theory, and the sort of idiosyncratic phenomena whose explanation is best left to the domain of historical linguistics.

6 Summary and conclusions

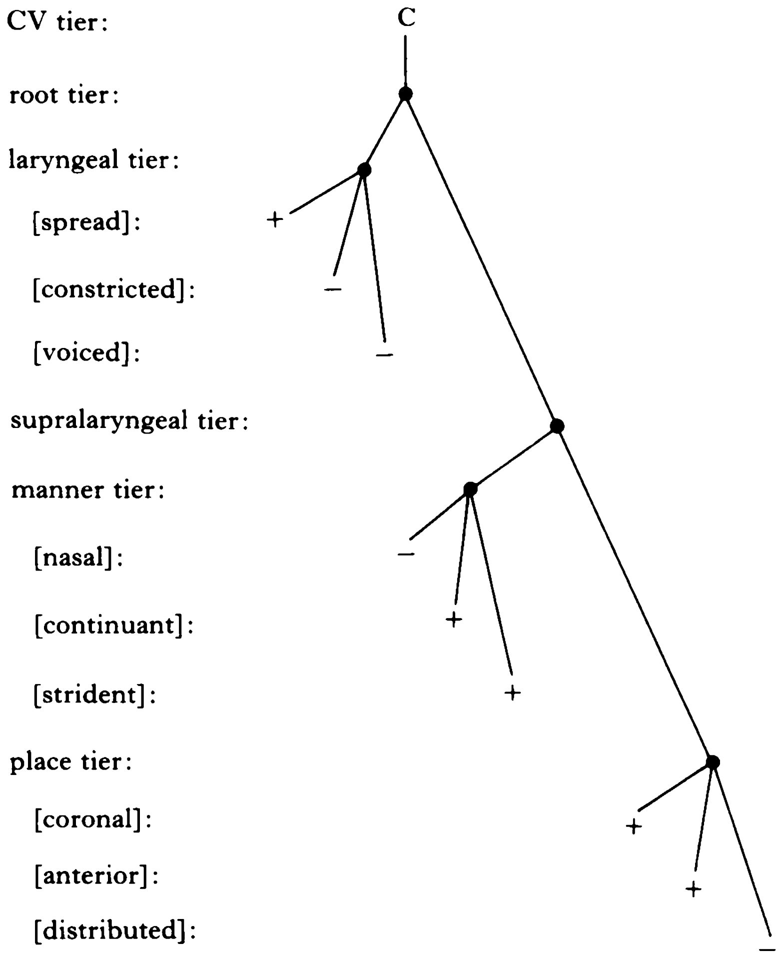
This paper has explored some of the possibilities made available by recent developments in nonlinear phonology, suggesting that feature representation does not involve two-dimensional matrices in the sense of classical Jakobsonian and generative phonology, but rather multi-tiered, hierarchical structures of the type shown in (3). Such a theory of phonological representation offers a constrained theory of assimilation processes, according to which all assimilation rules involve the spreading of a single node: the root node, a class node or a feature node. The study of consonant–vowel asymmetries reveals that the features responsible for distinctions in the location of the primary constriction ('place' features) are subdivided into two sets, of which one is universally present in consonants and vowels, and the other is normally absent in consonants. This theory generalises to the treatment of other 'underspecified' segments, suggesting that class nodes may be absent in certain segment types, such as the laryngeal glides, which lack supralaryngeal features, or the 'always-homorganic' nasals, which lack the place features.

An interesting consequence of this model of feature representation is that many prosodic phenomena that have appeared in the past to require 'autosegmentalised' or 'projected' features, extracted from feature matrices and represented on special tiers, may be treated as cases of ordinary assimilation. For example, it is not necessary to suppose that certain vowel features are placed on special tiers in order to account for vowel harmony phenomena in Turkish (cf. Clements & Sezer 1982); all we need assume is that some formatives (suffixes) are systematically uncharacterised for certain place features in vowels, namely [back] and [round], and that harmony effects result from spreading rules blocked only by segments which are opaquely characterised for the spreading feature. Similarly, the treatment of spirantisation in Spanish proposed by Mascaró (1984) does not require a special tier for the feature [continuant], since we need do no more than assume that certain segment types, in this case voiced non-strident obstruents, are systematically uncharacterised by continuancy.

If these remarks are on the right track, then what distinguishes languages with long-distance assimilation phenomena may be no more than the fact that they systematically omit certain feature specifications that are normally present in other languages. The strongest version of this hypothesis would be the view that there are no special feature tiers or projections at all, and that all cases of harmony and assimilation can be handled within the restrictive theory of representation proposed here, limiting parametric variation to the set of features that can be systematically uncharacterised. Intransigent cases remain, however, and the development of these ideas must await further study.

Appendix

The hierarchical organisation of a segment has the formal structure of a tree diagram rooted in one or more elements of the CV tier, whose terminal symbols are the feature specifications '+' and '−'. Consider the following partial representation of [s]:



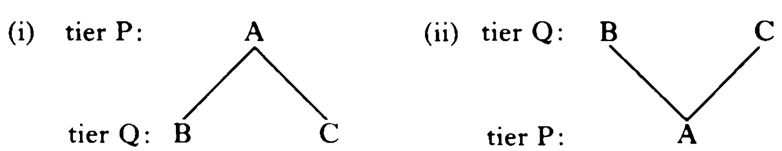
This partial representation consists of fifteen nodes, each arrayed on its own tier. The class nodes are the root tier node, the laryngeal tier node, the supralaryngeal tier node, the manner node and the place node. Given any two nodes M, N such that M lies on the path between N and the root of the tree, M is said to DOMINATE N; if no node intervenes between M and N, M IMMEDIATELY DOMINATES N. Each feature CHARACTERISES every node that dominates it; thus the place node in the diagram above is characterised by the features [+coronal, +anterior, −distributed], and both the root node and the C node are characterised by all the features of the representation. We may define a PHONETIC SEGMENT as any element of the CV tier together with all the features characterising it: thus the diagram above is a representation of the phonetic segment [s].

Nodes of the same class or feature category are ordered under the relation of CONCATENATION and define a TIER. Each tier is one member of an ordered pair of tiers ⟨P, Q⟩ such that nodes arrayed on P immediately dominate nodes arrayed on Q. Given two tiers forming the ordered pair ⟨P, Q⟩, tier P is said to (IMMEDIATELY) DOMINATE tier Q, and P, Q are ADJACENT tiers, and define a PLANE. As the relation of domination is transitive, if tier P dominates Q and Q dominates R, P also dominates R. The relation of adjacency, on the other hand, is non-transitive, symmetrical and irreflexive. Thus if tier R is adjacent to S and S is adjacent to T, R is not adjacent to T; if R is adjacent to S, S is adjacent to R; and no R is adjacent to itself.

Let us designate a node on tier P as n(P), a node on tier Q as n(Q), etc. Branches link nodes only on adjacent tiers. A branch linking n(P) and n(Q) is termed an ASSOCIATION LINE. Representations consisting of several phonetic segments in succession are governed by the well-formedness conventions of autosegmental phonology, which apply individually to each plane. In particular, association lines may intersect only at tiers, i.e. no association lines cross.

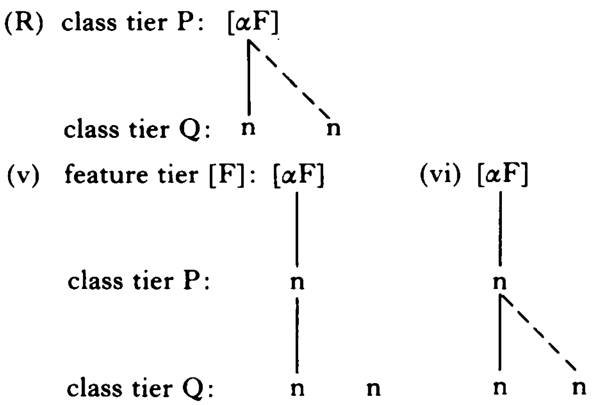
Given a pair of ordered tiers ⟨P, Q⟩, the nodes n(P) are ANCHORS for the nodes n(Q), in the sense of Clements & Keyser (1983). These conventions allow one-to-many and many-to-one associations between nodes of adjacent tiers. It follows from these conventions that representations may contain features that are not dominated by class nodes, and class nodes that are not dominated by other class nodes, but will not contain class nodes that do not dominate features, except in the hypothetical case where a class node does not lie in the domain of a feature (i.e. where there is no accessible feature to link to the class node).

Rule formalism assumed in this work is the same as that assumed elsewhere in autosegmental phonology. For example, just as in the statement of autosegmental tone rules, tier P of the ordered pair ⟨P, Q⟩ may be written above or below tier Q, indifferently; thus statements (i) and (ii) below are equivalent:



In this work, however, a further abbreviatory convention is adopted. Given a configuration of type (iii) occurring as a subpart of a phonological representation K, where S is a class tier, T is any tier adjacent to S, and the *n* are nodes of any appropriate type, (iii) satisfies (iv), a subpart of some structural description SD of a rule R, only if node n(S) in (iii) dominates [αF] in K (where α = + or −):

Under this convention, '[αF]' in (iv) designates a class tier node n(S), not a feature [αF], and is to be understood as a condition placed upon the node n(S) in (iii) being tested as a possible match for n(S) in (iv), requiring it to dominate the feature [αF] in K. Accordingly, a class tier node n(S) in K 'matches' n(S) in (iv) just in case it dominates the feature [αF], and is associated with a node n(T). As an example, rule R below (containing (iv) as a subpart) is applicable to representation (v), since all nodes of R are matched by corresponding nodes of (v), and derives (vi):



This convention gives us the effect of feature percolation.

NOTE

* In preparing this paper I have benefited from discussion with Joan Mascaró, S. J. Keyser, Patricia Keating and Prathima Christdas. Thanks are also due to Kenstowicz & Kisseberth (1979) for problem 2, chapter 2.

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