6

An introduction to feature geometry

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6.0 Introduction

This paper provides a short introduction to a theory which has in recent years radically transformed the appearance of phonological representations. The theory, following Clement's seminal (1985) paper, has come to be known as feature geometry.¹ The rapid and widespread adoption of this theory as the standard mode of representation in mainstream generative phonology stems from two main factors. On the one hand, the theory resolved a debate which had been developing within nonlinear phonology over competing modes of phonological representation (and resolved it to the satisfaction of both sets of protagonists), thus unifying the field at a crucial juncture. But simultaneously, the theory corrected certain long-standing and widely acknowledged deficiencies in the standard version of feature theory, which had remained virtually unchanged since The Sound Pattern of English (Chomsky and Halle 1968; hereafter SPE).

The theory of feature geometry is rooted firmly in the tradition of nonlinear phonology — an extension of the principles of autosegmental phonology to the wider phonological domain — and in section 6.1 I review some of this essential background. I then show, in section 6.2, how rival modes of representation developed within this tradition. In section 6.3 I consider a related problem, the question of the proper treatment of assimilation phenomena. These two sections prepare the ground for section 6.4, which

¹ Clements (1985) is the locus classicus for the theory, and the source of the term “feature geometry” itself. Earlier suggestions along similar lines (in unpublished manuscripts) by Mascaro (1983) and Mohanan (1983) are cited by Clements, together with Thainsson (1978) and certain proposals in Lass (1976), which can be seen as an early adumbration of the leading idea. A more detailed survey of the theory may be found in McCarthy (1988), to which I am indebted. Pulleyblank (1989) provides an excellent introduction to nonlinear phonology in general.
Segment

shows how feature geometry successfully resolves the representation problem, and at the same time provides a more adequate treatment of assimilation. I then outline the details of the theory, and in section 6.5 show how the theory removes certain other deficiencies in the standard treatment of phonological features. I close with an example of the theory in operation: a treatment of the Sanskrit rule of n-Retroflexion or Naṭi.

6.1 Nonlinear phonology

Feature geometry can be seen as the latest stage in the extension of principles of autosegmental phonology—originally developed to handle tonal phenomena (Goldsmith 1976)—to the realm of segmental phonology proper. Essential to this extension is the representation of syllabicity on a separate autosegmental tier, the so-called “CV-skeleton” (McCarthy 1979, 1981; Clements and Keyser 1983). Segmental features are then associated with the slots of the CV-tier just as tones and tone-bearing units are associated in autosegmental phonology; and just as in tonal systems, the theory allows for many-to-one and one-to-many associations between the CV-skeleton and the segmental features on the ‘melodic’ tier.

For example, contour segments—affricates, prenasalized stops, short diphthongs, and so on, whose value for some feature changes during the course of articulation—can be given representations analogous to those used for contour tones, with two different values for some feature associated with a single timing slot:

(1) \[ H \rightarrow V \quad [-\text{cont}] \quad [+\text{cont}] \quad [-\text{nas}] \quad [+\text{nas}] \]

Contour tone
Affricate
Prenasalized stop

And conversely, geminate consonants and long vowels can be represented as a single quality associated with two CV-position:

(2) \[ H \rightarrow V \quad i \quad m \]

Tonal spread
Long vowel
Geminate consonant

As Clements (1985) notes, such a representation gives formal expression to the acknowledged ambiguity of such segments/sequences. Kensioicz (1970) has observed that, if rules affecting segmentation are general “a nonlinear frame application on the tier respectively.

Further exception the nonlinear mod the property of gi geminates and rule “within” a geminal structural representation thus impossible to geminate:

(3) \[ ? \quad a \quad C \quad V \]

(4) \[ /rakl/ \quad /rim/ \quad /jst kbiir/ \quad /l-walad/ \]

Here, the starred representations at affairs in which o:

It was quickly t true geminates. I epenthesis failing case of clusters at

Halle and Vergn manipulations of tier and a slot in t
has observed that, for the most part, rules which treat geminates as atoms are rules affecting segment quality; while rules which require a sequence representation are general "prosodic," affecting stress, tone, and length itself. Within a nonlinear framework, the distinction can be captured in terms of rule application on the prosodic (quantitative) tier or the melodic (qualitative) tier respectively.

Further exceptional properties of geminates also find natural expression in the nonlinear mode of representation. One of the most significant of these is the property of geminate integrity: the fact that, in languages with both geminates and rules of epenthesis, epenthetic segments cannot be inserted "within" a geminate cluster. In nonlinear terms, this is due to the fact that the structural representation of a geminate constitutes a "closed domain": it is thus impossible to construct a coherent representation of an epenthesized geminate:

Here, the starred representation contains crossing association lines. Such representations are formally incoherent: they purport to describe a state of affairs in which one segment simultaneously precedes and follows another.

It was quickly noted that assimilated clusters also exhibit the properties of true geminates. The following Palestinian data from Hayes (1986) show epenthesis failing to apply both in the case of underlying geminates and in the case of clusters arising through total assimilation:

Halle and Vergnaud (1980) suggested that assimilation rules be stated as manipulations of the structural relations between an element on the melodic tier and a slot in the CV-skeleton, rather than as a feature changing operation.
on the melodic tier itself. They provide the following formulation of Hausa regressive assimilation:

\[
\text{(5)} \quad \text{/lìttaf}+\text{tasf}+\text{al/} \quad \rightarrow \quad \text{[lìttattaaal]} 
\]

\[
\begin{array}{cccccccc}
\text{C} & \text{V} & \text{C} & \text{C} & \text{V} & \text{C} & \text{C} & \text{V} \\
\text{t} & \text{a} & \text{f} & \text{t} & \text{a} & \text{f} & \text{a} & \text{i} \\
\end{array}
\]

Here – after the regressive spread of the [t] melody and delinking of the [f] – the output of the assimilation process is structurally identical to a geminate consonant, thus accounting for the similarities in their behavior. This in turn opens up the possibility of a generalized account of assimilation phenomena as the autosegmental spreading of a melody to an adjacent CV-slot (see the articles by Hayes, Nolan, and Local this volume).

However, a problem immediately arises when we attempt to extend this spreading account to cases of partial assimilation, as in the following example from Hausa (Halle and Vergnaud 1980):

\[
\text{(6)} \quad \text{/gaddam}+\text{dam}+\text{ii/} \quad \rightarrow \quad \text{[gaddandamii]} 
\]

The example shows that, in their words, “it is possible to break the link between a skeleton slot and some features on the melody tier only while leaving links with other features intact” (p. 92); in this case, to delink place features while leaving nasality and sonority intact. Halle and Vergnaud do not extend their formalism to deal with such cases.

The problem is simply to provide an account of this partial spreading which is both principled and formally adequate. The radical autosegmentalism of phonological properties gives rise to a general problem of organization. As long as there is just one autosegmental tier – the tonal tier – organized in parallel to the basic segmental sequence, the relation between the two is straightforward. But when the segmental material is itself autosegmentalized on a range of tiers – syllability, nasality, voicing, continuancy, tone, vowel-harmony features, place features, all of which have been shown to exhibit autosegmental behavior – then it is no longer clear how the tiers are organized with respect to each other. It is important to notice that this issue is not resolved simply by recourse to a “syllabic core” or CV-skeleton, although the orientation this provides is essential. As Pulleyblank (1986) puts it: “Are there limitations on the relating of tiers? Could a tone tier, for example, link directly to a nasality tier? Or could a tone tier link directly to a vowel harmony tier?”

Steriade (1982) (obstruent follow do, suggesting t linked structure consonant deleti

\[
\text{Steriade sketche: know as multi more extensive (}
\]

\[
\begin{array}{cccc}
\text{p'} & \text{[f]} & \text{[h]} & \text{[n]} \\
\end{array}
\]

These two so make different c multiplanar appi constituted a seq core, ranged abti (Pulleyblank exhibit the com}

\[
\begin{array}{cccc}
\text{[conson} & \\
\end{array}
\]
Steriade (1982) shows that in Kolami, partially assimilated clusters (obstruent followed by homorganic nasal) resist epenthesis just as geminates do, suggesting that the output of the assimilation rule should indeed exhibit linked structure (in the case of geminates, illicit *CC codas are simplified by consonant deletion, rather than epenthesis):

\begin{align*}
\text{(7) Present} & \quad \text{Imperative} & \quad \text{Gloss} \\
\text{melp-atun} & \quad \text{mle} & \quad \text{shake} \\
\text{idg-atun} & \quad \text{id} & \quad \text{tell} \\
\text{pog-atun} & \quad \text{pog} & \quad \text{boil over}
\end{align*}

Steriade sketches two possible formulations of this process, which came to be known as multiplanar and coplanar respectively (see Archanjeli 1985 for more extensive discussion of the two approaches):

\begin{itemize}
\item Multiplanar
\item Coplanar
\end{itemize}

These two solutions induce very different types of representation, and make different empirical predictions. Note first that, in the limiting case, a multiplanar approach would produce a representation in which every feature constituted a separate tier. Elements are associated directly with the skeletal core, ranged about it in a so-called “paddlewheel” or “bottlebrush” formation (Pulleyblank 1986, Sagey 1986b). Here, then, the limiting case would exhibit the complete structural autonomy of every feature:

\begin{itemize}
\item \[\text{coronal}\]
\item \[\text{consoantal}\] \quad \text{C} \quad \[\text{sonorant}\]
\item \[\text{continuant}\]
\end{itemize}
In the coplanar model, on the other hand, tiers are arrayed in parallel, but within the same plane, with certain primary features associated directly with skeletal slots, and secondary or subordinate features associated with a CV-position only indirectly, mediated through association to the primary features. This form of representation, then, exhibits intrinsic featural dependencies. Compare the coplanar representation in (8) above with the following reformulation:

Here, counterfactually, place features have been represented as primary, associated directly to the skeletal tier, while manner features are secondary, linked only indirectly to a structural position. But under this regime of feature organization it would be impossible to represent place assimilation independently of manner assimilation. Example (10) is properly interpreted as total assimilation; any alteration in the association of the place features is necessarily inherited by features subordinate to them. The coplanar model thus predicts that assimilation phenomena will display implicational asymmetries. If place features can spread independently of manner features, then they must be represented as subordinate to them in the tree; but we then predict that it will be impossible to spread manner features independently. The limiting case here, then, would be the complete structural dependency of every feature. In the case of vowel-harmony features, for example, Archangeli (1985: 370) concludes: "The position we are led to, then, is that Universal Grammar provides for vowel features arrayed in tiers on a single plane in the particular fashion illustrated below."

Which model appears to be the one that best explains the data? The coplanar model displays featural asymmetries and modular structure.

To get a sense of the principles governing vowel harmony, consider the following example:

[coronal, anterior, vowel] if there is complete assimilation, the process of picking the features results in a featural taxonomy with possible assimilation.

There is a further point about the coplanar model. Example (11) illustrates a case where features are not directly associated:

\[
V \rightarrow [\text{back}] \\
[\text{round}] \\
[\text{high}] \\
V
\]

The problem is that features involve agreements, so:

\[
V \rightarrow [\text{high}] \\
[\text{round}] \\
[\text{back}] \\
V
\]
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Which model of organization is the correct one? It quickly becomes apparent that both models are too strong: neither complete dependence nor complete independence is correct. The theory of feature geometry brings a complementary perspective to this debate, and provides a solution which displays featural dependence in the right measure.

6.3 The internal structure of the segment

To get a sense of this complementary perspective, we break off from the intellectual history of nonlinear phonology for a moment to consider a related question: what kinds of assimilation process are there in the world's languages? The standard theory of generative phonology provides no answer to this question. The fact that an assimilation process affecting the features, {coronal, anterior, back}, is expected, while one affecting {continuant, anterior, voice} is unattested, is nowhere expressed by the theory. In SPE, there is complete formal independence between features: a feature matrix is simply an unstructured bundle of properties. The class of assimilation processes predicted is simply any combination of values of any combination of features. The constant recurrence of particular clusters of features in assimilation rules is thus purely accidental. What is required is some formal way of picking out natural classes of features (Clements 1987), a "built-in featural taxonomy" (McCarthy 1988), thus making substantive claims about possible assimilation processes in the world's languages.

There is a further problem with the standard account of assimilation, first pointed out by Bach (1968). Consider the following rule:

\[
\begin{align*}
\text{V} & \rightarrow \begin{bmatrix} \alpha \text{ cor} \\ \beta \text{ ant} \\ \gamma \text{ back} \end{bmatrix} / \begin{bmatrix} \alpha \text{ cor} \\ \beta \text{ ant} \\ \gamma \text{ back} \end{bmatrix} \\
\end{align*}
\]

The alpha-notation, which seems at first sight such an elegant way of capturing assimilatory dependencies, also allows us to express such undesirable dependencies as the following:

\[
\begin{align*}
\text{V} & \rightarrow \begin{bmatrix} \alpha \text{ cor} \\ \beta \text{ ant} \\ \gamma \text{ back} \end{bmatrix} / \begin{bmatrix} \beta \text{ cor} \\ \gamma \text{ ant} \\ \alpha \text{ back} \end{bmatrix} \\
\end{align*}
\]

The problem is in fact again due to the complete formal independence of the features involved. This forces us to state assimilation as a set of pairwise agreements, rather than agreement of a set as a whole (Lass 1976: 163).
Segment

A possible solution is to introduce an $n$-ary valued *place* feature, where the variable [r *place*] ranges over places of articulation directly. Apart from giving up binarity, the disadvantage of such a solution is that it loses the cross-classificatory characterization of place: reflex sounds, for example, receiving the description [ret *place*], would no longer be characterized simultaneously in terms of coronality and anteriority, and a process affecting or conditioned by just one of these properties could not be formulated.

Access to a *place* feature is intuitively desirable, however, and a refinement of this idea is able to meet the above criticisms: we introduce a *category-valued* feature. That is, rather than restricting features to atomic values only ("+", "-", "ret"), we allow a feature matrix *itself* to constitute the value for some feature. Thus, rather than a representation such as [ret *place*], we may adopt the following:

\[
\begin{bmatrix}
+ & \text{cor} \\
- & \text{ant}
\end{bmatrix}
\]

Such a move allows us to preserve the fine-grained, multifaceted characterization of place of articulation; the advantage derives from allowing variables to range over these complex values just as they would over atomic ones. Thus the category (13) above is still matched by the variable [r *place*].

Category-valued features have been used extensively in syntactic theories (such as lexical-functional grammar [LFG] and generalized phrase-structure grammar [GPSG]) which adopt some form of unification-based representation (Sheiber 1986), and we will adopt such a representation here (see Local, this volume):

\[
\begin{bmatrix}
\text{cor} = + \\
\text{ant} = -
\end{bmatrix}
\]

Here, values have simply been written to the right of their respective features. We may extend the same principle to manner features, and further, group together place and manner features under a superordinate root node, in order to provide a parallel account of total assimilation (that is, in terms of agreement of root specifications):

\[
\begin{bmatrix}
\text{PLACE} = \begin{bmatrix}
+ & \text{cor} \\
- & \text{ant}
\end{bmatrix} \\
\text{MANNER} = \begin{bmatrix}
- & \text{nas}
\end{bmatrix}
\end{bmatrix}
\]

156
Such a representation has the appearance of a set of equations between features and their subordinate values, nested in a hierarchical structure. This is in fact more than analogy: any such category constitutes a mathematical function in the strict sense, where the domain is the set of feature names, and the range is the set of feature values. Now just as coordinate geometry provides us with a graphical representation of any function, the better to represent certain salient properties, so we may give a graph-theoretic representation of the feature structure above.

![Feature Structure Diagram]

Here, each node represents a feature, and dependent on the feature is its value, be it atomic — as at the leaves of the tree — or category-valued. Formally, then, the unstructured feature matrix of the standard theory has been recast in terms of a hierarchically structured graph, giving direct expression to the built-in feature taxonomy.

### 6.4 Feature geometry

How is this digression through functions and graphs relevant to the notion of feature geometry? Consider the following question: if (16) above is a segment, what is a string? What is the result of concatenating two such complex objects? A major use of the graph-theoretic modeling of functions in coordinate geometry is to display interactions — points of intersection, for example — between functions. The same holds good for the representations we are considering here. Rather than representing our functions on the x/y-axis of coordinate geometry, however, we arrange them on the temporal axis of feature geometry, adding a third dimension to the representation as in figure 6.1. Such is the mode of representation adopted by feature geometry. Historically, the model developed not as a projection of the graph-theoretic model of the segment, but through an elaboration of the theory of planar organization informed by the concerns of featural taxonomy.²

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² As is usual in formal linguistics, various formalizations of the same leading idea, each with subtly different ramifications, are on offer. The fundamental literature (Clements 1985; Sagéy 1986a) is couched in terms of planar geometry; Local (this volume) adopts a rigorous graph-theoretic approach; while work by Hammond (1988), Sagéy (1988), and Bird and Klein (1990) is expressed in terms of algebras of properties and relations.
The essential insight of feature geometry is to see that, in such a representation, "nodes of the same class or feature category are ordered under the relation of concatenation and define a tier" (Clements 1985: 248). With respect to such tiers, the familiar processes of nonlinear phonology such as spreading, delinking, and so on, may be formulated in the usual way. Such a representation thus provides a new basis for autosegmental organization. The rule of place assimilation illustrated in (8) above, for example, receives the formulation in Figure 6.2. Thus whole clusters of properties may be spread at a single stroke, and yet may do so quite independently of features which are represented on a different tier, in some other subfield of the taxonomy.

Clements (1985) helpfully describes these elaborate representations in the following manner: "This conception resembles a construction of cut and glued paper, such that each fold is a class tier, the lower edges are feature tiers, and the upper edge is the CV tier" (p. 229). Feature geometry solves the organization problem mentioned above by adopting a representation in which autosegmental tiers are arranged in a hierarchical structure based on a featural taxonomy. The theory expresses the intimate connection between

Figure 6.1 Geometrical representation of two successive segments in a phonological string. When the figure is viewed "end on," the structure of each segment appears as a tree-like that in example 156. The horizontal dimension represents time.

Figure 6.2 The representation of autosegmental assimilation in a geometrical structure of the sort shown in Figure 6.1.

the internal organ processes such segment point out, the hierarchy with a spreading arc of three common types of assimilation processes, assimilation processes, single-feature assimilation processes (1985: 243) provide relation processes. More greater cost.

While the detail gross architecture idea is that many 1988 and that the executes them, largely root (see Browman and [back], for exa together under the tier "articulator for major class feature about such feature.

In addition, the certain articulator treats them under the sue
In a phonological string, a feature like that in

Figure 6.3 An overview of the hierarchical organization of phonological features, based on Sagey 1986 and others.

... the internal organization of the segment and the kinds of phonological processes such segments support. As Mohanan (1983) and Clements (1985) point out, the hierarchical organization of autosegmental tiers, combined with a spreading account of assimilation, immediately predicts the existence of three common types of assimilation process in the world's languages: total assimilation processes, in which the spreading element is a root node; partial assimilation processes, in which the spreading element is a class node; and single-feature assimilation, in which a single feature is spread. Clements (1985: 231f.) provides exemplification of this three-way typology of assimilation processes. More complex kinds of assimilation can still be stated, but at greater cost.

While the details of the geometry are still under active development, a gross architecture has recently received some consensus. A recurrent shaping idea is that many features are "articulator-bound" (Ladefoged and Halle 1988) and that these should be grouped according to the articulator which executes them: larynx, soft palate, lips, tongue blade, tongue body, tongue root (see Brownman and Goldstein, this volume). The features [high], [low], and [back], for example, are gestures of the tongue body, and are grouped together under the DORSAL node. Controversy still surrounds features which are "articulator free" - such as stricture features - and the more abstract major class features [sonorant] and [consonantal]; we will have little to say about such features here (see McCarthy 1988 for discussion).

In addition, the geometry reflects the proclivity of features associated with certain articulators to pattern together in assimilatory processes, gathering them under the SUPRALARYNGEAL and PLACE nodes. The picture that emerges...
Segment

looks like figure 6.3. At the highest level of branching, the framework is able to express Lass's (1976: 152f.) suggestion that feature matrices can be internally structured into laryngeal and supralaryngeal gestures:

in certain ways [ʔ] is similar to (the closure phase of) a postvocalic voiceless stop. There is a complete cut-off of airflow through the vocal tract; i.e., a configuration that can reasonably be called voiceless, consonantal (if we rescind the ad hoc restriction against glottal strictures being so called), and certainly noncontinuant. In other words, something very like the features of a voiceless stop, but MINUS SUPRALARYNGEAL ARTICULATION... Thus [ʔ] and [h] are DEFECTIVE... they are missing an entire component or parameter that is present in "normal" segments.

Moreover, Lass's suggested formalization of this insight bears a striking resemblance to the approach we have sketched above:

Let us represent any phonological segment, not as a single matrix, but as containing two submatrices, each specifying one of the two basic parameters: the laryngeal gesture and the oral or supralaryngeal gesture. The general format will be:

\[
\begin{bmatrix}
   \text{oral} \\
   \text{laryngeal}
\end{bmatrix}
\]

Lass cites alternations such as the following from Scots:

(17)  kaɾ  cap  kærɪfɛɾɪ  cartridge  oʊn  open
      baɾ  bat  \text{\`wɛn}\text{\`fɛɾɪ}  winter  \text{\`bɛɾn}  button

and notes that the rule neutralizing [p : k] to [ʔ] can now be formulated simply as deletion of the supralaryngeal gesture: in our terms, delinking of the SUPRALARYNGEAL node. The LARYNGEAL node, then, dominates a set of features concerning the state of the glottis and vocal cords in the various phonation-types.

The organization of features below the PLACE node has been greatly influenced by Sagey's (1986a) thesis. This work is largely concerned with complex segments—labiovelars, labio-coronals, clicks, and so on, sounds with more than one place of articulation—and the development of a model which allows the expression of just those combinations which occur in human languages. (These are to be distinguished from the contour segments mentioned above. The articulations within a complex segment are simultaneous—at least as far as the phonology is concerned.) It is to be noted, then, that a simple segment will be characterized by just one of the PLACE articulators, while a complex segment will be characterized by more than one—LABIAL and DORSAL, say.

6.5 M

The hierarchical view long-standing probit places of articulation

\[
\begin{array}{c}
\text{labial} \\
\text{cor} \\
\text{ant}
\end{array}
\]

Such an analysis prt

(19)  [+cor]: \text{\`laɾ} \\
[-cor]: *laɾ

But while the [+cor] class is never embodies an implice class, then so will th impossible to give giving oneself the a

Consider now a t

(20)

\[
\begin{array}{c}
\text{labial} \\
\text{LAB}
\end{array}
\]

Such a theory pred

(21)  [labial]: \text{\`k} \\
[coronal]: \text{\`\text{\`k}} \\
[dorsal]: *\text{\`k}

Under this approach be mentioned—th

Consider now th predict the followi

(22)  [+ant]: *[l] \\
[-ant]: *[l]

Here the problem there seems to be

1 The following discus
6.5 More problems with standard feature theory

The hierarchical view of segment structure also suggests a solution to certain long-standing problems in standard feature theory. Consider the following places of articulation, together with their standard classification:

\[
\begin{array}{ccccccc}
\text{labial} & \text{alveolar} & \text{palatal} & \text{retroflex} & \text{velar} & \text{uvular} \\
\hline
-\text{cor} & +\text{cor} & +\text{cor} & +\text{cor} & -\text{cor} & -\text{cor} \\
+\text{ant} & +\text{ant} & -\text{ant} & -\text{ant} & -\text{ant} & -\text{ant} \\
\end{array}
\]

Such an analysis predicts the following natural classes:

\[
\begin{align*}
\text{[+cor]} & : \{\text{alveolar, palatal, retroflex}\} \\
\text{[−cor]} & : \{\text{labial, velar, uvular}\}
\end{align*}
\]

But while the \text{[+cor]} class is frequently attested in phonological rules, the \text{[−cor]} class is never found. The problem here is that standard feature theory embodies an implicit claim that, if one value of a feature denotes a natural class, then so will the opposite value. This is hard-wired into the theory; it is impossible to give oneself the ability to say \([+F]\) without simultaneously giving oneself the ability to say \([−F]\).

Consider now a classification based on active articulators:

\[
\begin{array}{ccccccc}
\text{labial} & \text{alveolar} & \text{palatal} & \text{retroflex} & \text{velar} & \text{uvular} \\
\hline
\text{LAB} & \text{COR} & \text{COR} & \text{COR} & \text{DOR} & \text{DOR} \\
\end{array}
\]

Such a theory predicts the following classes:

\[
\begin{align*}
[\text{LABIAL}] & : \{\text{labial}\} \\
[\text{CORONAL}] & : \{\text{alveolar, palatal, retroflex}\} \\
[\text{DORSAL}] & : \{\text{velar, uvular}\}
\end{align*}
\]

Under this approach, the problematic class mentioned above simply cannot be mentioned – the desired result.

Consider now the same argument with respect to the feature \text{[anterior]}; we predict the following classes:

\[
\begin{align*}
[+\text{ant}] & : \{\text{labial, alveolar}\} \\
[−\text{ant}] & : \{\text{palatal, retroflex, velar, uvular}\}
\end{align*}
\]

Here the problem is even worse. As commonly remarked in the literature, there seems to be no phonological process for which this feature denotes a
natural class. [anterior] is effectively an ancillary feature, whose function is the subclassification of [+coronal] segments, not the cross-classification of the entire consonant inventory. We can express this ancillary status in a hierarchical model by making the feature [anterior] subordinate to the coronal node:

(23)

<table>
<thead>
<tr>
<th>labial</th>
<th>alveolar</th>
<th>palatal</th>
<th>retroflex</th>
<th>velar</th>
<th>uvular</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAB</td>
<td>COR</td>
<td>COR</td>
<td>COR</td>
<td>DOR</td>
<td>DOR</td>
</tr>
<tr>
<td>+ant</td>
<td></td>
<td>-ant</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Similarly, the feature [distributed] is also represented as a dependent of the coronal node, distinguishing retroflex sounds.

### 6.6 An example

This organization of the place articulators can be seen in action in an account of Sanskrit $n$-Retroflexion or Nati (Schein and Steriade 1986). The rule, simplified, may be quoted direct from Whitney:

189. The dental nasal $n$ ... is turned into the lingual [i.e. retroflex] $n$ if preceded in the same word by ... $s$ or $r$: and this, not only if the altering letter stands immediately before the nasal, but at whatever distance from the latter it may be found: unless, indeed, there intervene (a consonant moving the front of the tongue: namely) a palatal ... a lingual or a dental. (Whitney 1889: 64)

Note Whitney's attention to the active articulator in his formulation of the rule: "a consonant moving the front of the tongue." The rule is exemplified in the data in table 6.1 (Schein and Steriade 1986). We may represent this consonant harmony as the autosegmental spreading of the coronal node, targeting a coronal nasal, as shown in figure 6.4.

![Figure 6.4 Sanskrit n-retroflexion (Nati) expressed as spreading of coronal node](image)

If a labial, velar, and dorsal articulation apply. If, however, only by the standard featural organization coronal harmony applies.

We may thus figure of the language low when once reverted lingual element, ten and does so, unless organ is thrown out assume a different p not move the front.

Note that, with $n$
Table 6.1 Data exemplifying the Sanskrit *n*-Retroflexion rule shown in figure 6.4

<table>
<thead>
<tr>
<th>Base form</th>
<th>Nati form</th>
<th>Gloss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Present</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>mgd-naa-</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>ig-nda-</td>
<td>be gracious</td>
</tr>
<tr>
<td>3</td>
<td>pe-nda-</td>
<td>seek</td>
</tr>
<tr>
<td>Passive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>bhag-na-</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>puur-nda-</td>
<td>bend</td>
</tr>
<tr>
<td>6</td>
<td>vtrk-nda-</td>
<td>fill</td>
</tr>
<tr>
<td>Middle participle 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>maṟṟ-aana-</td>
<td>wipe</td>
</tr>
<tr>
<td>8</td>
<td>kṣved-aana-</td>
<td>hum</td>
</tr>
<tr>
<td>9</td>
<td>puṟ-aana-</td>
<td>fill</td>
</tr>
<tr>
<td>10</td>
<td>kṣubi-aana-</td>
<td>quake</td>
</tr>
<tr>
<td>11</td>
<td>caḷ-kaana-</td>
<td>see</td>
</tr>
<tr>
<td>Middle participle 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>kṛt-a-maana-</td>
<td>cut</td>
</tr>
<tr>
<td>13</td>
<td>kṛp-a-maana-</td>
<td>lament</td>
</tr>
</tbody>
</table>

If a labial, velar, or vowel intervenes — segments characterized by labial and dorsal articulators — no ill-formedness results, and the rule is free to apply. If, however, a coronal intervenes, the resultant structure will be ruled out by the standard no-crossing constraint of autosegmental phonology. The featural organization thus explains why non-coronals are transparent to the coronal harmony (see figure 6.5). This accords nicely with Whitney’s account:

We may thus figure to ourselves the rationale of the process: in the marked proclivity of the language toward lingual utterance, especially of the nasal, the tip of the tongue, when once retracted into the loose lingual position by the utterance of non-contact lingual element, tends to hang there and make its next nasal contact in that position: and does so, unless the proclivity is satisfied by the utterance of a lingual mute, or the organ is thrown out of adjustment by the utterance of an element which causes it to assume a different posture. This is not the case with the gutturals or labials, which do not move the front part of the tongue. (Whitney 1879: 65)

Note that, with respect to the relevant (coronal) tier, target and trigger are
adjacent. This gives rise to the notion that all harmony rules are “local” in an extended sense: adjacent at some level of representation.

It may be helpful to conclude with an analogy from another cognitive faculty, one with a long and sophisticated history of notation: music. The following representation is a perceptually accurate transcription of a piece of musical data:

(24)

\[
\begin{array}{cccccccc}
\text{\textbullet} & \text{\textbullet} & \text{\textbullet} & \text{\textbullet} & \text{\textbullet} & \text{\textbullet} & \text{\textbullet} & \text{\textbullet} \\
\text{x} & \text{y} & \text{z} & \text{w} & \text{v} & \text{u} & \text{t} & \text{s}
\end{array}
\]

In this transcription, x and y are clearly nonadjacent. But now consider this performance score, where the bass line is represented “autosegmentalized” on a separate tier:

(25)

\[
\begin{array}{cccccccc}
\text{\textbullet} & \text{\textbullet} & \text{\textbullet} & \text{\textbullet} & \text{\textbullet} & \text{\textbullet} & \text{\textbullet} & \text{\textbullet} \\
\text{x} & \text{y} & \text{z} & \text{w} & \text{v} & \text{u} & \text{t} & \text{s}
\end{array}
\]

Here, x and y are adjacent, on the relevant tier. Note, too, that there is an articulatory basis to this representation, being a transcription of the gestures of the right and left hands respectively: x and y are adjacent in the left hand. An articulator-bound notion of feature geometry thus lends itself naturally to a conception of phonological representation as gestural score (Browman and Goldstein 1989 and this volume).
Michael Broe

The most notable achievement of feature geometry, then, is the synthesis it achieves between a theory of feature classification and taxonomy, on the one hand, and the theory of autosegmental representation — in its extended application to segmental material — on the other. Now as Chomsky (1965: 172) points out, the notion of the feature matrix as originally conceived gives direct expression to the notion of "paradigm" — the system of oppositions operating at a given place in structure: "The system of paradigms is simply described as a system of features, one (or perhaps some hierarchic configuration) corresponding to each of the dimensions that define the system of paradigms." Feature geometry makes substantive proposals regarding the "hierarchic configuration" of the paradigmatic dimension in phonology. But it goes further, and shows what kind of syntagmatic structure such a hierarchy supports. A new syntagm, a new paradigm.

But now consider this autosegmentalized...