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Feature Organization*

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Abstract

Feature organization involves the study of the internal composition of` speech sounds. This article reviews linguistic approaches to this topic dating from the mid-20th century with a special emphasis on the theory known as Feature Geometry. This theory, in its simplest and most general form, characterizes segment-internal feature structure in terms of a feature tree whose terminal nodes are features, whose intermediate nodes are feature classes, and whose root node groups all features defining the segment. The principle objective of this approach is to provide a formal characterization of the class of possible phonological processes. More recent developments and extensions of this approach are examined, with special emphasis on applications to phonetics, such as Articulatory Phonology.

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1. Early views

What are speech sounds composed of? An early answer to this question was that speech sounds are definable as "bundles" of simultaneous features, having no internal organization (Bloomfield 1933). However, a number of observations beginning in the mid-20th century called this view into question. A first discovery, stemming from such work as Hockett (1942), Harris (1944), Firth (1957), and others, was that features may have different scope across the segments of which a word or phrase is composed. A "long component" (Harris) or "prosody" (Firth) such as emphasis in Arabic, or vowel harmony in Turkish, typically extends over many segments. Even more strikingly, perhaps, the study of the tone languages of Africa and elsewhere has shown that tones are typically asynchronic with segments in the sense that several tones can be sequenced on a single syllable, giving rise to contour tones, while single tones can extend across several syllables. Some morphemes have been found to consist of tones alone, and most spectacularly, tones can "float", exerting a decisive influence on the tone contour of an utterance even though having no segmental realization themselves. (See Goldsmith 1990, Yip 2002 for reviews of these and other "nonlinear" properties of tone systems.) Work in autosegmental phonology and related frameworks has brought to light many analogues to these properties among segmental features.

If features are not organized into unstructured "bundles", what is their organization? Earlier work in phonology gave scant attention to this question, though there were suggestions, from time to time, that features could be classified into related classes or families, and that such families could behave as units in regard to phonological processes (see e.g. Trubetzkoy 1969, Lass 1975). The view which has gained most currency in recent work, from Clements (1985) to Padgett (2002), is that features are structured into

feature classes which combine in various ways to form higher-level units -- notably the familiar consonant and vowel segments, but also incompletely specified subsegments. If features play a role in modern phonological theory similar to that of the atom in physics, feature classes play a role similar to that of the molecule: thus, segments are assigned a quasi-molecular structure in which each "molecule" corresponds to an independent articulator of the vocal tract (the tongue, the lips, the velum, the glottis, etc.). A further level of organization groups these smaller classes into larger classes corresponding to composite articulatory structures such as the oral cavity, or the larynx. The resulting structure forms a comprehensive hierarchy of features.

2. Feature geometry

This conception can be formalized in different ways. One well-known approach is that called **feature geometry**. This approach proposes to characterize feature structure within the general framework of autosegmental phonology. It addresses questions such as the following:

- what is the internal structure of speech sounds?
- how do speech sounds interact in phonological systems?
- what are possible and impossible phonological processes?

In its earliest and simplest form (Clements 1985, drawing upon earlier suggestions by Mascaró and Mohanan), the basic premises of feature geometry are the following:

(1) a. features may be grouped into feature classes,

b. classes form a strict hierarchy which can be represented as a rooted tree,

c. this hierarchy is universal (identical in all languages),

d. each feature and feature class is represented as a node on a separate autosegmental tier, and

e. each such node links to elements of just one higher-level tier.

This conception of feature organization can be illustrated by the tree structure in (2), showing the (highly simplified) representation of the doubly-articulated labial velar stop [kp], found in many African languages. (The English speaker can approximate this sound by attempting to pronounce the word *backpack* without the initial *ba*).

<Figure (2) near here>

In this diagram, the Root node dominates all features. The Laryngeal, Oral Cavity, and Place nodes are intermediate class nodes, and [-spread glottis], [-voiced], etc. are the features themselves, constituting terminal nodes of the tree. Each node (including the features) is placed on a separate line, representing an independent autosegmental tier. Note that features on different tiers are not ordered with respect to each other; for instance, [labial] neither "precedes" nor "follows" [dorsal]. This figure illustrates the various properties in (1): features are grouped into classes (1a), classes form a strict heirarchy (1b), the hierarchy is universal by hypothesis (1c), each feature and class is represented as a separate node on a separate tier (1d), and each node links to the elements of just one higher-level tier (1e). It follows from the latter assumption that features belong to (at most) one immediately superior class; for example, no feature can link to both the Laryngeal node and the Place node.

How is the membership of feature classes determined? In feature geometry, classes are determined *functionally* rather than phonetically. A set of features forms a class just in case it behaves as a cohesive unit with regard to phonological statements and processes. As an example, let us consider NC (nasal + consonant) clusters in Spanish. The phoneme /n/ of the article *un* has several realizations, depending on the sound that follows. Examples are shown in (3).

(3)	u[m] pato	'a duck'	(labial)
	u[N] gato	'a cat'	(velar)
	u[n] topo	‘a mole'	(dental)
	u[n̲] choco	'a cuttlefish'	(post-alveolar)
	u[n] oso	'a bear'	(dental)

If the following sound is a vowel or glide, as in the last example in (3), /n/ is realized as a dental sound. But if it is a consonant, /n/ acquires its place of articulation, being realized as labial before the /p/ of *pulpo*, velar before the /g/ of *gato*, and so forth. The same preconsonantal distribution is found within words, as shown by the examples in (4):

(4)	ca[m]po	'field’	(labial)
	ca[n]to	'chant’	(dental)
	ca[n̲]cho	'rock'	(post-alveolar)
	ca[N]co	'flower pot'	(velar)

These examples show that the various features which define the property "place of articulation" behave as a single unit in Spanish. Rather than stating the assimilation rule in terms of each individual place feature ("/n/ is realized as [labial] before labial sounds, [dorsal] before dorsal sounds," etc.), it may be stated once and for all by making reference to the Place node, which groups all oral cavity place features together: "nasal consonants share the Place node with a following consonant." The NC cluster is accordingly treated as a linked sequence comprising internally sequenced manner features ([+nasal] followed by [-nasal], etc.) but a single Place specification, as shown by the representation of relevant features of *ninfa* [niMfa] 'nymph' in (5).

<figure (5) near here>

Each segment is said to be "characterized" by the features it dominates in the tree. Thus [M] is characterized as [labial], [+nasal], and [-continuant], while [f] is characterized as [labial], [-nasal] and [+continuant]. The fact that the nasal acquires a labiodental, rather than bilabial realization can be explained on the assumption that the Place node receives a uniform articulatory interpretation at the phonetic level.

As this example illustrates, the Place node has been determined on purely phonological grounds, following the observation that in Spanish, as in many other languages, all place features constitute a functional unit. As place features tend to behave as a single group across languages, they are gathered into a single Place class. Though phonetic considerations were not used as a criterion in setting up this class, it is not a phonetically arbitrary one, but comprises the set of features that define the location of the primary constriction of a segment in the oral cavity. In this case (and others), the feature classes brought to light by the study of phonological patterns prove to have certain phonetic properties in common. This is surely not an accident, but shows that the feature hierarchy has its phonetic basis in speech articulation. The complete feature hierarchy resembles a simplified image of the vocal tract, in which each class represents a functionally independent articulator or articulator set.

Given these various observations, we may formulate the following claim:

(6) Phonological statements (rules, constraints) take single nodes as arguments.

This means that phonological statements may operate only on single nodes in the tree. Place of articulation assimilation in Spanish provides a good illustration; this rule targets a single node (the Place node), requiring that nasal consonants must share this node with the following consonant in the word or phrase. The empirical interest of (6) in crosslinguistic perspective is that it heavily constrains the set of imaginable phonological rules, dividing them into two classes: 1) possible rules, 2) impossible rules. Spanish nasal assimilation is a possible rule, as it conforms to (6); but a similar rule requiring a nasal consonant to assimilate to a following consonant in terms of an arbitrary set of features such as [labial], [voiced], and [lateral] would not meet this criterion, as no single node groups just these features and no others. A great deal of research has tended to corroborate this claim, at least for the better-understood features; for example, the arbitrary rule just stated is unattested across languages, as far as we know. One of the major results of work in feature geometry has been its ability to provide a much narrower characterization of the notion "possible rule", and hence "possible process", than has been achieved in other approaches.

3. Later developments of feature geometry

The rather simple conception outlined above has been modified and elaborated in later work. A first development came from the work of McCarthy (1988). McCarthy reviewed the various properties that have traditionally been seen as diagnostics of autosegmental representation, including:

(7) a. assimilation
  b. dissimilation
  c. floating features
  d. contour features
  e. single-feature morphemes

and pointed out that while some features (e.g. those characterizing tone, place of articulation, voicing) satisfy some or all of these diagnostics across languages, at least two apparently do not: the major class features [±sonorant] and [±consonantal]. If we place these features on separate autosegmental tiers, we will incorrectly predict that they will exhibit some or all of the properties listed in (7). In order to exclude this possibility, McCarthy proposed that [±sonorant] and [±obstruent] are features of the root node, rather than autonomous features in the autosegmental sense. While this proposal has been contested (see especially Kaisse 1992 for discussion of [±consonantal]), counterexamples have proven scarce, and it has tended to be widely accepted. However, this result requires a modification of statement (1d), restricting it only to those features which exhibit autosegmental properties such as those listed in (7).

A second important development comes from Articulator Theory, as developed by Sagey (1990) and Halle (1995). These writers noted that autosegmentally-represented features can be divided into two types, those that depend for their execution on one or another of the articulators ([labial] = lips, [coronal] = tongue front, [dorsal] = tongue body, etc.), which they term **articulator-dependent**, and those that are not, which they term **articulator-free**. Examples of articulator-dependent features are [±anterior] and [±distributed], which are executed exclusively by the tongue-front articulator [coronal], and examples of articulator-free features include [±continuant] and [±consonantal], which can be executed by any of several articulators. Regarding the first, Sagey observed that whenever one segment assimilates to another in coronality, its dependent features of [±anterior] and [±distributed] always spread along with it. For example, if a labial sound such as *m* assimilates to a nonanterior coronal sound such as [tS], it will not only become coronal (for this, a shift to [n] would suffice), but also nonanterior (post-alveolar). This regularity can be expressed by placing [±anterior] and [±distributed] under [coronal] as **dependents**, as shown in (8):

<figure 8 near here>

Given this representation, the spread of [coronal] to a preceding segment, as indicated by the dashed line, will entail the spread of its dependent features as well. In contrast, the higher-level features [±continuant] and [±nasal] are unaffected. In general, as this example illustrates, higher-level structure tends to remain stable under processes that affect lower-level structure – another strong and apparently correct claim of feature geometry.

A further innovation in Sagey's work is the classification of speech sounds into three types: **complex segments**, containing two unordered place specifications, **contour segments**, containing two internally sequenced features, and 3) **simple segments**, comprising all others. Complex segments include the labial-velar stops *kp*, *gb* of many sub-Saharan African languages (as shown in (2)) or the clicks of many South African languages, both of which combine a velar closure with another closure located further forward in the mouth, as well as consonants with minor (or secondary) articulations, such as labialized k^w. Contour segments include affricates such as t^s, containing successive [-continuant] and [+continuant] components, and prenasalized stops such as nd, containing successive [+nasal] and [-nasal] components. The recognition of contour segments greatly extends the expressive power of the theory, and for this reason they have come under close scrutiny; it now appears, for example, that affricates can be reanalyzed as simple stops with no [+continuant] component (see Kehrein 2002 and references therein).

A third development in feature geometry is Unified Place Theory as summarized in Hume (1994), Clements and Hume (1995) and references therein. The basic innovation of this approach is its use of a single set of articulator features to express related places of articulation in vowels and consonants:

(9)	feature:	in consonants:	in vowels:
	[labial]	labials, labialized consonants	rounded vowels
	[coronal]	coronals, palatalized consonants	front and retroflex vowels

[dorsal]	velar and uvular consonants, velarized and emphatic consonants	back vowels
[pharyngeal]	uvular and pharyngeal consonants, pharyngealized and emphatic consonants	pharyngealized vowels

(Note that uvulars are characterized as both [dorsal] and [pharyngeal].) This approach captures the close phonological relationship between homorganic consonants and vowels by assigning them the same features. Thus, rounded vowels share the feature [labial] with labial consonants, front vowels share the features [coronal] and [-anterior] with palatal consonants, back vowels share [dorsal] with velar and uvular consonants, and so forth. This analysis allows common processes of consonant/vowel place assimilation to be expressed as the spreading of Place features. For example, the shift of /pi/ to [pu] is characterized as the spread of [labial] from the consonant to the vowel, while velar palatalizations such as /ki/ > [ci] are characterized as the spread of [coronal,-anterior] from the vowel to the consonant. A formal consequence of this approach with respect to earlier work is that features such as [labial] and [coronal] must be allowed to link to two different tiers of structure (C-place in the case of consonants and V-place in the case of vowels and secondary articulations), requiring a weakening of principle (1e). This innovation is needed to express the transparency of consonants to many types of vowel spreading; for example, rounding harmony in Turkish vowels is not blocked by labial consonants like *p*, as would be predicted under the No Line-Crossing constraint of autosegmental phonology if [labial] were linked to the same tier in consonants and vowels.

Two attempts have been made to express the consonant/vowel relations in (9) while maintaining principle (1e) as well as the traditional vowel features [±back, ±round]. In the model proposed by Ní Chiosáin and Padgett (1993), consonant place features are represented twice, once on a consonantal tier of structure where they constitute primary place features and again on a vocalic tier where they act as "virtual" secondary place features. A basic claim of this model is that only the latter interact directly with vowels; thus the shift of /pi/ to [pu] represents the spread of the secondary labial feature [+round] from the consonant to the vowel. Velar palatalizations such as /ki/ > [ci] are handled by a separate mechanism of restructuring. In a proposal by Halle et al. (2000), developing earlier work by Halle (1995), the shift of /pi/ to [pu] involves the spread of the terminal feature [labial], as in the Clements/Hume model, but the output is subjected to restructuring by a set of Equivalency Relations so that the resulting [u] bears the feature [+round] instead of [labial]. Palatalizations are handled analogously. As the restructuring conventions required in both models carry out rather substantial surgery on feature trees, both require at least a limited violation of constraint (6).

A closely related and equally controversial question in feature organization concerns the correct expression of the close relations between certain consonant types and tones. Observations from a number of tone languages in Asia and Africa have brought to light the common (though not universal) relationships between consonants and tones shown in the first two columns in (10):

(10)	consonants	tones	Halle/Stevens features
	voiced obstruents	low (or extra-low) tones	[+slack vocal cords]
	voiceless obstruents	high tones	[+stiff vocal cords]

For example, in many tone languages, voiced obstruents are found to trigger low tones on following vowels or to block the spread of high tones across them (just as they would do if they bore low tones). For example, in the African language Ewe high tones are realized as rising after noun-initial voiced obstruents: /ví/ > [vǐ] 'child'. To express such facts, Halle and Stevens (2001), drawing on their own earlier research as well as work summarized in Bao (1999), propose a feature-geometrical account in which consonants and tones share the features in the third column in (10). In this model, the feature [+slack vocal cords] is interpreted phonetically as voicing in obstruents and low tone in vowels, while [+stiff vocal cords] is interpreted as voicelessness in obstruents and high tone in vowels. Halle and Stevens propose that both of these features link directly to the Glottal tier (analogous to the Laryngeal tier in (2)), in conformity with (1e).

However, many linguists have noted that not all tone languages exhibit the relations in (10). Not only are these relations sometimes broken by historical change, but many, perhaps most tone languages do not exhibit any phonological consonant/tone interactions at all. For example, in many tone languages, such as Mende or Kikuyu, high tones spread freely across all obstruents, both voiceless and voiced. In order to render the Halle/Stevens model compatible with such facts, it appears that a feature-geometric model must be enriched in one of at least two ways. One solution would allow tonal geometry to be parameterized across languages, requiring a relaxation of (1c). In this approach, tone features would dock to the Glottal node in languages which, like Ewe, exhibit the consonant/tone interactions in (10), while in languages lacking such interactions, such as Mende and Kikuyu, tone features would dock to a higher-level node, such as the Syllable or Mora. Another solution would maintain a universal tonal geometry but would allow tone features in consonants to dock to a different node from tone features in vowels. In this approach, Ewe, Mende and Kikuyu would all have the same representations, and what would differ would be the level of structure accessed by the tone rules. This solution, like the Clements/Hume proposal for place features, would require a weakening of principle (1e). At the present time both of these approaches, and variants of them, are undergoing active research (see Yip 2002, 56-61 for related discussion and further references).

One more recent proposal may be noted. In early work on feature geometry, Hayes (1986) had suggested that feature classes are built up derivationally, introduced only when they are triggered by rules. Developing this suggestion within a constraint-based framework, Clements (2001) proposes that though the feature hierarchy is universal (cf. (1c)), not all languages make use of all structure. Rather, structure is present just to the extent that it is activated in a particular language. For example, French, with no place assimilation, does not activate the Place node. In the limit case, a language with no phonology whatsoever – that is, in which underlying and surface representations are identical – would have no tier structure at all. Clements shows that this approach can provide a solution to several traditional problems involving long-distance harmony and assimilation.

4. Phonetic extensions of feature geometry

Feature geometry drew much attention in the late 1980s and 1990s, leading to the development of many further proposals within the general framework of autosegmental phonology. Related models have been developed in other nonlinear phonological frameworks such as Dependency Phonology (e.g. Smith 1989, van der Hulst 1989) and Government Phonology (e.g. Harris 1994, Scheer 1998). Given limits of space, we will be able to discuss just one other important development here, involving the extension of feature-geometrical approaches to phonetics. This development aims to achieve a full integration, as opposed to ad hoc "interface", of phonetics and phonology. Three proposals will be reviewed here.

First, from the point of view of precedence and influence, the framework of Articulatory Phonology as developed by Browman and Goldstein (1989, 1992, etc.) deserves special attention. The hypothesis underlying this framework is that the basic principles underlying spoken language are best understood in viewed as patterns of coordinated articulatory gestures. Articulatory Phonology proposes to model phonetic and phonological patterns in terms of "articulatory scores", that is, formal representations consisting of abstract gestures and their patterns of coordination. Given that feature-geometrical representations have already brought to light structures that resemble abstract "maps" of the vocal tract, it is not surprising to find that there is a close resemblance between gestural scores and feature-geometrical representations. Gestures are defined in terms of articulator sets whose content is similar to that of the Oral Cavity node in some feature geometry models (Clements and Hume 1995) or to the Place node in others (Padgett 1995). Each articulator set includes specifications for constriction degree, constriction location, constriction shape, and stiffness for a particular articulator (Lips, Tongue Tip, Tongue Body, etc.). These components closely parallel the features of feature geometry, as shown in (11):

(11)	<u>Articulatory Phonology</u>	<u>Feature Geometry</u>
	LIPS	[labial]
	Tongue Tip (TT)	[coronal]
	Tongue body (TB)	[dorsal]
	closed	[-continuant]

critical	[+continuant] in [-sonorant]
dental	[+distributed]
etc.	

Nevertheless, Articulatory Phonology differs from Feature Geometry in several important respects. First, gestures have temporal duration while features do not. Second, while features are categorical (typically one-valued, or two-valued at most), the components of gestures are quantitatively specified. Third, while features are defined in terms of quantal articulatory-acoustic relationships (Stevens 1989), gestures are defined in terms of an articulatory task-dynamic model (Salzman and Kelso 1987). Again, while most features are represented on separate tiers in feature-geometrical representations, the components of gestures (such as constriction location, constriction degree, etc.) are bundled together with an articulator on the same "tier" of the gestural score. Still another difference is that while Feature Geometry places class nodes directly in the feature representation, Articulatory Phonology locates them outside the articulatory score.

All these differences make precise predictions which help to distinguish the relative sphere of application of each theory. It does not appear at present that either theory fully covers the empirical domain of the other; thus, Feature Geometry is too coarse-grained to capture a great many articulatory regularities at the phonetic level, as Browman and Goldstein have amply shown, while Articulatory Phonology is too fine-grained to capture important generalizations at the phonological level, such as feature economy (Clements 2003). It may be that in spite of their close resemblance, the two theories must still be viewed as interfaced, rather than truly fused (Zsiga 1997). Nevertheless, Articulatory

Phonology has taken a major step toward bringing phonology and phonetics closer together.

Two other approaches have attempted to achieve similar goals. Keyser and Stevens (1994) propose a theory of feature geometry based largely on phonetic criteria. Drawing almost exclusively on articulatory and acoustic considerations, they attempt to bring the phonological tree into closer agreement with known facts about the control of articulatory processes and their corresponding acoustic correlates. In another direction of research, Clements and Hertz (1996) propose an integrated representational system (IRS) for expressing phonology-acoustic relations, providing a formal theory of acoustic scores comparable to the articulatory scores of Browman and Goldstein. Their approach, like Browman and Goldstein's, must be considered an interface model in the sense that phonological structure and acoustic scores constitute separate but related planes within a complex representational space.

5. Current trends and perspectives

This article has reviewed a number of proposals to explain the behavior of speech sounds in terms of models of segment-internal feature structure. These proposals have been developed within the broader framework of nonlinear phonology. An underlying assumption has been that well-elaborated models of representation can go a long way toward constraining phonological structure, allowing the expressive power of rules to be severely limited. As McCarthy has put it (1988, 84), "if representations are right, the rules will follow".

In formulating strict, testable predictions about a wide range of phonological processes, feature geometry and related approaches have provided a powerful engine for research and have brought to light a great many discoveries that would hardly have been conceivable in their absence. They continue to raise substantive questions concerning segmental interactions, several of which, as noted above, remain essentially unsolved at the present time. Multi-tiered feature representations are compatible in principle with constraint-based approaches (e.g. Zoll 1998) and can be defined in terms of constraints on feature configurations (e.g. Uffmann, 2005). Perhaps most importantly, by invoking the abstract, higher-level cognitive organization of speech, feature representations provide a necessary counterpart to phonetically-driven approaches, providing explanation in areas where phonetics does not reach (Clements, in press). The study of feature organization can be expected to continue to play a central role in future work, though perhaps in a somewhat different form.

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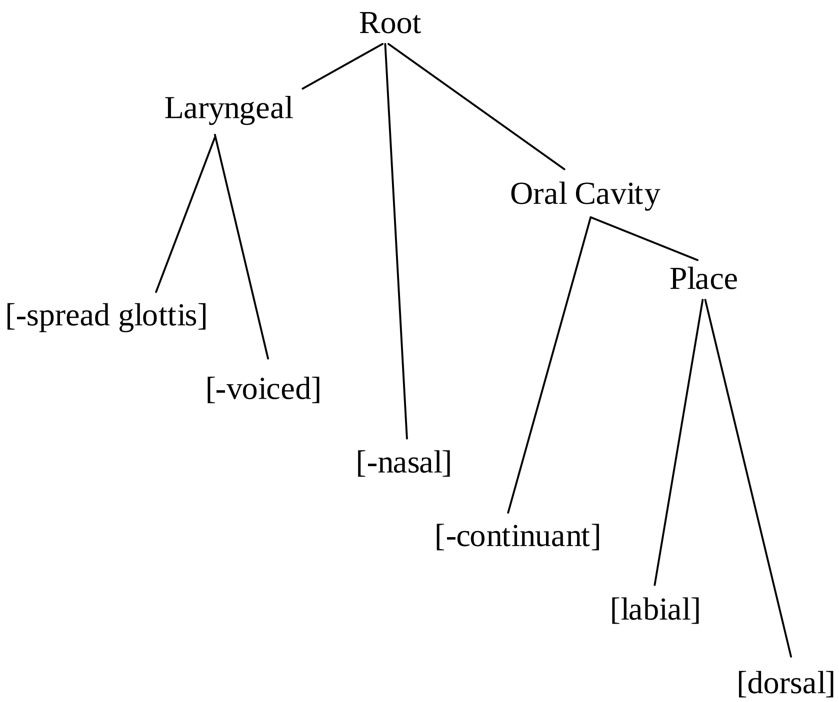
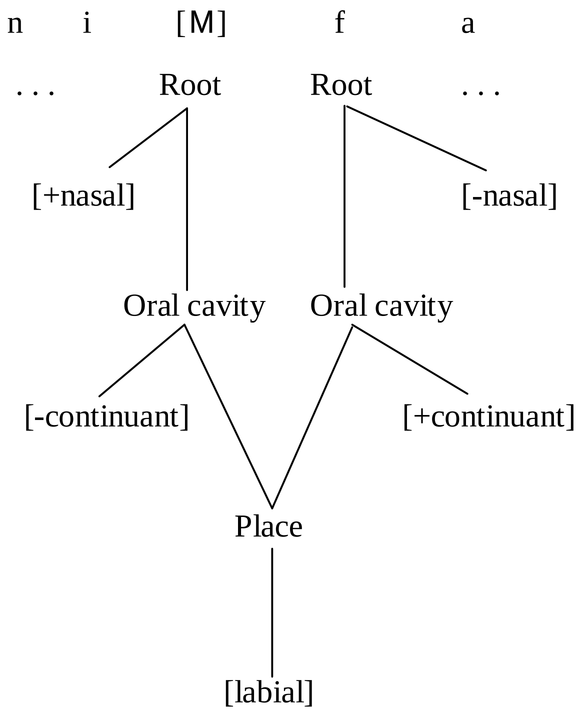
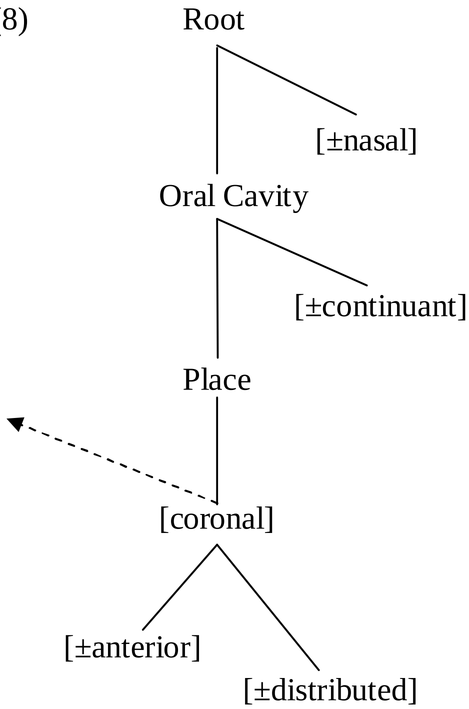
(2)


Root
Laryngeal
Oral Cavity
Place
[-spread glottis]
[-voiced]
[-nasal]
[-continuant]
[labial]
[dorsal]

(5)


n i [M] f a
. . . Root Root . . .
[+nasal]
[-nasal]
Oral cavity
Oral cavity
[-continuant]
[+continuant]
Place
[labial]

(8)


Root
[±nasal]
Oral Cavity
[±continuant]
Place
[coronal]
[±anterior]
[±distributed]