Hierarchical Classes of Features in Binary-Feature Phonology

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1. Introduction

Many attempts have been made in Phonology to show that the restriction on features being binary must be removed. Processes dealing with vowel height, for which a ternary feature has been proposed, constitute an example. In a recent paper in this direction,[1] dealing with a sonority hierarchy in Pāli, it has been proposed that Chomsky & Halle's Major-Class features[2] be abolished, and replaced by a multi-valued feature called sonority.

This paper shows that these steps are not necessary. Furthermore, the arbitrariness of creating certain multi-valued features and not others, and the arbitrariness of the values they take on, are both predicted by the theory proposed in this paper.

2. Data

Four examples will be considered. Two examples deal with vowel height, and the other two deal with a sonority hierarchy.

2.1 Sequence of Vowels in Spanish

In Spanish, when two vowels occur in sequence, they constitute either one syllable or two syllables. If the two vowels constitute one syllable, one of the vowels becomes a glide. This will be indicated with $V \rightarrow \underline{V}$. Word boundaries are irrelevant to this process. There are four cases to consider:

1. Both vowels have stress.
2. Only the first vowel has stress.
3. Only the second vowel has stress.
4. Both vowels are unstressed.

In case 1, the two vowels remain as full vowels. In cases 2, 3 and 4, the following tables indicate whether both vowels remain as full vowels or one vowel becomes a glide.[3]

á a á e á o á i á u	é a é e ó i é u	e a e e o i e u
é a é e é o é i é u	é e é e ó i é u	e a e e o i e u
ó a ó e ó o ó i ó u	ó e ó e ó i ó u	o a o e o i o u
í a í e í o í i í u	í e í e í o í i í u	i a i e i o i i i u
ú a ú e ú o ú i ú u	ú e ú e ú o ú i ú u	u a u e u o u i u u
case 2	case 3	case 4

The following sentences support the tables.[4]

aa	papá alaba	la ama	la amaba
ae	papá evita	la era	la heroica
ao	mamá otorga	la oca	la ocasión
ai	papá imita	la hija	la hijita
au	mamá uniforma	la uva	la uvita
ea	pagué ayer	la habla	la hablaba
ee	pagué enojado	la entra	la entraba
eo	pagué ochenta	pague ocho	pague ochenta
ei	sé ideneo	come higos	come hinojo
eu	sé humilde	come uvas	come uvitas
oa	habló Alicia	lo habla	lo hablaba
oe	habló Evita	como Eva	como Evita
oo	habló Horacio	lo oda	lo odiaba
oi	tomó hinojos	como higos	como hinojos
ou	tomó uvitas	como uvas	como uvitas
ia	ví azucenas	mi amo	mi amiga
ie	ví helechos	mi eco	mi helecho
io	comí ochenta	mi oso	mi osito
ii	comí hinojo	mi hijo	mi hijito
iu	comí uvitas	mi uva	mi uvita
ua	tú acusas	su amo	su amigo
ue	tú evitas	su Eva	su Evita
uo	tú opinas	su oso	su osito
ui	tú imitas	su hijo	su hijito
uu	tú ululas	su uva	su uvita

The results condensed in the tables for cases 2, 3 and 4 can be expressed with the following rules:[5]

1.a) [V,-low,-stress] → [-syll] / [+low] — (iueo → Y / a —)
b) [V,+high,-stress] → [-syll] / [-high]— (iu → Y / eoa —)

c) [V,-stress] → [-syll / — [+low] (iueoa → Y / — a)
d) [V,-low,-stress] → [-syll] / — [-high] (iueo → Y / — eoa)
e) [V,+high,-stress] → [-syll] / — V (iu → Y / — iueoa)

These rules express a complicated relationship between the features high and low, but they do not express the process that is really taking place. If we look at the tables that represent cases 2, 3 and 4, we see that

for case 2, "the second vowel becomes a glide if its height is higher than the height of the first vowel",
for case 3, "the first vowel becomes a glide if its height is higher than or equal to the height of the second vowel",

and case 4 is a combination of case 2 and case 3. The generalization involved in this process is the fact that, in principle, "a higher unstressed vowel becomes a glide when in contact with a lower vowel". This generalization is not expressed by rule (1).

2.2 Vowel Shift in English

Chomsky & Halle (1968:pp187), considering pairs like profanity/profane, serenity/serene, derivative/derive, etc., proposed a series of vowel transitions that produce the following results:

$$\bar{\text{æ}} \rightarrow \bar{\text{e}} \qquad \bar{\text{e}} \rightarrow \bar{\text{I}} \qquad \bar{\text{I}} \rightarrow \bar{\text{æ}}$$
$$\bar{\text{ɔ}} \rightarrow \bar{\text{o}} \qquad \bar{\text{o}} \rightarrow \bar{\text{u}} \qquad \bar{\text{u}} \rightarrow \bar{\text{ɔ}}$$

In order to account for these transitions they proposed the following Vowel Shift rule:

2) $$[\text{V}, +\text{tense}] \rightarrow \begin{cases} [-\alpha\text{high}] \,/\, [\alpha\overline{\text{high}}_{-\text{low}}] & \text{(a)} \\ [-\beta\text{low}] \,/\, [\beta\overline{\text{low}}_{\text{high}}] & \text{(b)} \end{cases}$$

This rule is called Vowel Shift because it produces a shift in the front and back tense vowels as follows:

æ → e → i → æ
ɔ → o → u → ɔ

In terms of vowel height, this shift can be expressed as:

low → mid → high → low

There is a generalization, then, that says that for tense vowels "the height of the vowel is shifted one level in a circular scale given by low - mid - high - low". What the Vowel Shift rule says, however, is that for tense vowels, if the vowel is not low, reverse its highness; and if the vowel is not high, reverse its lowness. Even though as a product of these two parts of the rule a vowel shift occurs, the rule does not express this generalization.

2.3 Structure of the Syllable

The Major-Class features have been defined by Chomsky & Halle (1968:pp301) as being syllabic, consonantal and sonorant. With these features, phonological segments can be classified into the following classes:

stop and fricative consonants:	[-syll, +cons, -sonor]
nasal and liquid consonants:	[-syll, +cons, +sonor]
glides:	[-syll, -cons, +sonor]

fricative vowels:	[+syll, +cons, -sonor]
nasal and liquid vowels:	[+syll, +cons, +sonor]
pure vowels:	[+syll, -cons, +sonor]

If we analyse the segments that constitute a syllable, according to their classification with respect to the Major-Class features, we find that the sequence of segments in a syllable is, in general, the following:[6]

stops fricatives	nasals liquids	glides	vowels	glides	nasals liquids	stops fricatives

This general pattern for syllable structure suggests the idea that there is a hierarchy among the classes of segments that result from the Major-Class features, namely, stops and fricatives, nasals and liquids, glides, vowels. The features syll, cons and sonor do not express this hierarchy.

2.4 Sonority Hierarchy in Pāli

Aissen & Hankamer (1974), studying consonant assimilation in Pāli, proposed a sonority hierarchy to account for the assimilation rules. These rules can be sketched as follows:[7]

> If segments are ordered according to the following sequence: stops, fricatives, nasals, liquids, glides, then, whenever two consonants are adjacent, the consonant to the right of the sequence assimilates to the consonant to the left of the sequence.[8]

This assimilation process cannot be expressed in any satisfactory way using Chomsky & Halle's Major-Class features. A sonority hierarchy which would assign numerical values to the sonority of each class of segments could be invoked in the assimilation rule with explanatory power, as follows:

class:	stops	fricatives	nasals	liquids	glides
sonority:	1	2	3	4	5

This rule, then, would say "when two consonants are adjacent, the consonant with the higher sonority assimilates to the consonant with the lower sonority".

3. The Theory

A binary feature divides phonological segments into two classes. Let F be a feature, and let aF and bF be the two values that F takes on. Segments are then divided into two classes: the segments whose phonological matrix has the feature value aF, and the segments whose phonological matrix has the feature value bF. Let F^a be the set of segments that are aF, and let F^b be the set of segments that are bF. Since a segment has to be either aF or bF, the sets F^a and F^b are complementary. Furthermore,

since a feature has two complementary values, if one value is aF, we will also call the other value $\tilde{a}F$.

Two binary features divide segments into four possible classes. Let F and G be features with values aF, bF and xG, yG, respectively. Let K^{ax}, K^{ay}, K^{bx} and K^{by} be the four classes that F and G define, that is,

$$K^{ax} = F^{a} \wedge G^{x}, \qquad K^{ay} = F^{a} \wedge G^{y},$$
$$K^{bx} = F^{b} \wedge G^{x}, \qquad K^{by} = F^{b} \wedge G^{y}.$$

In general, for any pair of features, the four classes that they define are non-empty. However, there exist certain combinations of features for which one of the four classes is empty by the nature of the features. Let F and G, with values aF, bF and xG, yG respectively, be two such features; that is, they define an empty class of segments. Let $K^{ax} = F^{a} \wedge G^{x}$ be the empty class.

Then this theory predicts that there will be a hierarchy among the three non-empty classes; that is, among K^{ay}, K^{bx} and K^{by}.

In order to define a hierarchy, we have to specify which class is in the middle of the hierarchy. This is done as follows:

If the empty class is K^{ax}, then the class in the middle of the hierarchy will be $K^{\tilde{a}\tilde{x}} = F^{\tilde{a}} \wedge G^{\tilde{x}}$. In this example this class is $K^{\tilde{a}\tilde{x}} = K^{by}$. The hierarchy is then:

$$\{ K^{ay}, K^{by}, K^{bx} \} \quad \text{or} \quad \{ K^{bx}, K^{by}, K^{ay} \}.$$

Notice that we are not concerned here about any numerical values that we may want to assign to these classes, so that it does not matter what class comes first, and what class comes last.

To summarize this definition, we can say that the class in the middle of the hierarchy is the class defined by the complementary values of the empty class.

4. Application of the Theory

We can now proceed to apply the theory to the cases considered in 2.

4.1 Vowel Height

The features high and low define an empty class, namely, [+high, +low]. Therefore the hierarchy that we can define among the other three classes will be a hierarchy in which the class [-high,-low] is in the middle. The hierarchy will be:

{ [-high,+low], [-high,-low], [+high,-low] }
or { [+high,-low], [-high,-low], [-high,+low] } .

This fact correlates with the fact that certain phonological rules refer to vowel height as a classification of vowels in three levels: high, mid and low, in which the mid vowels are between the high vowels and the low vowels. That is, low vowels are [-high,+low], mid vowels are [-high,-low], and high vowels are [+high,-low].

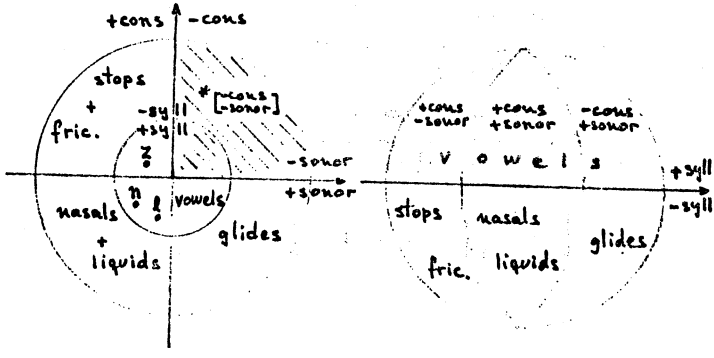
4.2 Sonority Hierarchy

The features cons and sonor define an empty class, namely, [-cons, -sonor]. Therefore we can define a hierarchy among the other three classes in which the class [+cons,+sonor] is in the middle. The hierarchy will be:

{ [+cons,-sonor], [+cons,+sonor], [-cons,+sonor] }
or { [-cons,+sonor], [+cons,+sonor], [+cons,-sonor] } .

This fact correlates with the fact that there is a hierarchy among consonants with respect to the Major-Class features. Since this hierarchy orders consonants according to their sonority, we call it a sonority hierarchy. The three classes are: low-sonority consonants - stops and fricatives - are [+cons,-sonor]; mid-sonority consonants - nasals and liquids - are [+cons,+sonor]; and high-sonority consonants - glides - are [-cons,+sonor].

This classification applies to the vowels as well as to the consonants, and the following picture shows the different classes in the two-feature system and in the hierarchical system:



5. Notation

In order to be able to write a phonological rule that uses the hierarchy, it is necessary to devise a way of defining a ternary feature as a function of the two binary features that define the hierarchy. A simple way of doing that is to assign a numerical value to each non-empty class, from 1 to 3, so that the class in the middle takes the value 2.

Therefore, we can define a ternary feature height with the values: 1 height for low vowels, 2 height for mid vowels, and 3 height for high vowels; and a ternary feature sonority with the values: 1 sonority for low-sonority consonants, 2 sonority for mid-sonority consonants, and 3 sonority for high-sonority consonants.

This definition can be done as follows:

For any feature F with values +F and -F, let us assign the numerical value 1 to +F, and -1 to -F. Let F_1 and F_2 be two features that define a hierarchy. Let $*a_1F_1$ and $*a_2F_2$ be the two values that define the forbidden class.

Then a ternary feature H is defined with the values:

3.a) $$H = \tfrac{1}{2}(F_1 - (*a_1F_1 \times *a_2F_2) \times F_2)$$

This formula will give H the values -1, 0, and 1. If we want to give H the values 1, 2, and 3, we simply use the formula:

3.b) $$H = \tfrac{1}{2}(F_1 - (*a_1F_1 \times *a_2F_2) \times F_2) + 2$$

An example using this last formula follows.

$$\underline{\text{height}} = \tfrac{1}{2}(\underline{\text{high}} - ([+\text{high}] \times [+\text{low}]) \times \underline{\text{low}}) + 2$$

for [-high,+low]: $1/2(-1 - (+1 \times +1) \times +1) + 2 = 1$
for [-high,-low]: $1/2(-1 - (+1 \times +1) \times -1) + 2 = 2$
for [+high,-low]: $1/2(+1 - (+1 \times +1) \times -1) + 2 = 3$

Now we can proceed to write the rules for the cases considered in 2, according to the hierarchies defined in 4.

5.1 Sequence of Vowels in Spanish

The set of rules (1) for sequences of vowels in Spanish can now be rewritten as follows:

4) $$\begin{bmatrix} V \\ -\text{stress} \\ \alpha\text{height} \end{bmatrix} \rightarrow [\text{-syll}] \; / \begin{cases} \left[{}^{V}_{\beta\text{height}}\right] \text{—} & \text{if } \beta < \alpha \\ \text{—} \left[{}^{V}_{\beta\text{height}}\right] & \text{if } \beta \leq \alpha \end{cases}$$

In the same way as the notation $-\alpha F$ has been employed to represent βF such that $\beta = -\alpha$, we can introduce the notation $<\alpha F$ to represent βF such that $\beta < \alpha$; and similarly $\leq \alpha F$, $> \alpha F$, and $\geq \alpha F$. Rule (4) can now be rewritten as:

5) $$\begin{bmatrix} V \\ -\text{stress} \\ \alpha\text{height} \end{bmatrix} \rightarrow [\text{-syll}] \; / \left\{ \begin{matrix} \begin{bmatrix} V \\ <\alpha\text{height} \end{bmatrix} \_\_ \\ \_\_ \begin{bmatrix} V \\ \leq\alpha\text{height} \end{bmatrix} \end{matrix} \right.$$

5.2 Vowel Shift in English

Rule (2) for the Vowel Shift in English can now be rewritten as follows:

6) $$\begin{bmatrix} V \\ +\text{tense} \\ \alpha\text{height} \end{bmatrix} \rightarrow [\alpha +1 \text{ height}]$$

where the operation $+$ should be interpreted Modulo 3, that is, each level of vowel height is raised to the next higher level, if there is one; and the highest level is converted into the lowest level. According to Formula (3.a) $\underline{-1} + 1 = \underline{0}$, $\underline{0} + 1 = \underline{1}$, and $\underline{1} + 1 = \underline{-1}$. According to Formula (3.b) $\underline{1} + 1 = \underline{2}$, $\underline{2} + 1 = \underline{3}$, and $\underline{3} + 1 = \underline{1}$.

5.3 Structure of the Syllable

The structure of the syllable given in 2.3 can now be described in the following way.

The syllable has a nucleus with a [+syll] segment. [-syll] segments can appear to the left and to the right of the nucleus, as long as their sonority increases from the boundaries of the syllable towards the nucleus of the syllable. This can be represented schematically as follows:

7) $$\left[\begin{matrix} \text{-syll} \\ \alpha_i \text{sonority} \end{matrix} \right]^*_i - [\text{+syll}] - \left[\begin{matrix} \text{-syll} \\ \beta_i \text{sonority} \end{matrix} \right]^*_i$$

such that $\alpha_i \leq \alpha_j$ if $i \leq j$, and $\beta_i \geq \beta_j$ if $i \leq j$.

5.4 Sonority hierarchy in Pāli

In order to write the assimilation rules in Pāli, we still have to distinguish between the classes stops and fricatives, and between the classes nasals and liquids. This can be done using the feature continuant, according to the following diagram:

sonority	1	1	2	2	3
continuant	-	-	-	-	-
	stops	fricatives	nasals	liquids	glides

The assimilation rule can now be written as follows:[9]

8.a) $$\begin{bmatrix} C \\ \rangle\alpha\text{sonority} \end{bmatrix} \rightarrow \begin{bmatrix} \alpha\text{sonority} \\ \beta\text{cont} \end{bmatrix} \,//\, \begin{bmatrix} C \\ \alpha\text{sonority} \\ \beta\text{cont} \end{bmatrix} \_\_$$

.b) $$\begin{bmatrix} C \\ \alpha\text{sonority} \\ -\beta\text{cont} \end{bmatrix} \rightarrow [\text{-cont}] \,//\, \begin{bmatrix} C \\ \alpha\text{sonority} \\ \beta\text{cont} \end{bmatrix} \_\_$$

Rule (8.a) assimilates sonority and continuantness in case one consonant has higher sonority than or equal sonority to the other. Rule (8.b) assimilates continuantness if both consonants have the same sonority. The (b) part of the rule is necessary only for the case in which both consonants have the same sonority and opposite continuantness. In this case both should become [-cont].

If we want to write rules (8.a & b) as one rule, we should devise a procedure to define a multi-valued feature in terms of two existing features. For this case, let sonority have the values 1, 2 and 3; and let cont have the values 0 and 1, that is, 0 for [-cont] and 1 for [-cont]. Then the feature

$$\underline{\text{sonority}}' = 2 \times \underline{\text{sonority}} + \underline{\text{cont}} - 2$$

will assign the sonority' values 1, 2, 3, 4 and 6 to the classes stops, fricatives, nasals, liquids and glides, respectively. This allows us to write rule (8) as follows:

9) $$\begin{bmatrix} C \\ \rangle\alpha\text{sonority}' \end{bmatrix} \rightarrow [\alpha\text{sonority}'] \,//\, \begin{bmatrix} C \\ \alpha\text{sonority}' \end{bmatrix} \_\_$$

This, of course, is a phonological excursus that has not been justified at all.

6. Independence of Feature Values

A hierarchy defined by this theory is independent of the actual values assigned to the features that define the hierarchy. Let F and G be features with values +F, -F and +G, -G, respectively. Let us suppose that the empty class is $K^{++} = F^{+} \cap G^{+}$. The hierarchy will have then the class K^{--} in the middle, that is, it will be $\{K^{+-}, K^{--}, K^{-+}\}$.

Let us now change the values of one of the features; for example, let the new values of G be -'G, +'G, in such a way that -'G = +G and +'G = -G. The empty class will then be $K^{+-'} = K^{++}$, and the class in the middle will be $K^{-+'} = K^{--}$; giving the hierarchy $\{K^{++'}, K^{-+'}, K^{--'}\}$. This hierarchy is the same hierarchy obtained before, since $K^{++'} = K^{+-}$, $K^{-+'} = K^{--}$, and $K^{--'} = K^{-+}$.

A hierarchy is then an intrinsic property of the classes defined by a pair of features, independent of the actual feature values.

FOOTNOTES

[1] See Aissen & Hankamer (1974). This approach will be discussed in 2.4.

[2] See Chomsky & Halle (1968). The Major-Class features are syllabic, consonated and sonorant. This classification of segments will be discussed in 2.3.

[3] These tables represent the situation in most dialects of Spanish. There are some variations in some dialects. Fast speech always produces more glidification. When both vowels are the same vowel, vv is sometimes realized as a long vowel, or, in fast speech, as a regular vowel.

[4] Regular Spanish orthography has been used, except to show stress and glitification when two vowels are adjacent.

[5] Rules (1.a & b) represent case 2. Rules (1.c, d &b) represent case 3. If we apply these rules in order when both vowels are unstressed, case 4 follows automatically.

[6] There are exceptions to this general sequence. They are, however, very rare, and they tend to disappear. The most common exception is nasal & stop. This pair is treated in many cases as one prenasalized stop segment. See Rivas (1974). Cf. Fn. 8.

[7] Not all possible combinations of consonants occur. Furthermore, while most of them have synchronic evidence, others have only diachronic evidence.

[8] There is one exception to the description of the assimilation rules presented here; it is the pair nasal & stop, that remains as such. Cf. Fn. 6.

[9] The notation // indicates that the rule is a minor rule, that is, the environment // A- represents / $\begin{bmatrix} A & - \\ - & A \end{bmatrix}$.

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