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VOWEL FEATURES

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The two most obvious functions of features are their classificatory function and phonetic function. Features classify the distinctive sounds of a language by specifying the contrasts between them. The phonetic quality of a sound is specified by assigning an intrinsic phonetic quality to the features. Another use of features in generative phonology is to make possible the definition of a natural class. A fourth function is the specification of sound patterns and sound changes in such a way that expected natural patterns and changes are formally distinguished from "unnatural" ones. A sound change, or alternation, is natural when some physical reason can be found as its underlying cause, as opposed to such sound changes that happen for reasons that have not apparent relation to the sounds. A phonological process described in terms of features should make its degree of naturalness explicit as a function of the formalism. Ideally, a description of a phonological process in terms of features should permit an explanation as well. The very least we expect from a formalised description is that it provide an accurate statement of the process involved. In order to accomplish this, features must be related to the correct physical parameters that control the speech mechanism. If one significant difference between the American English vowel in bird [bɚd] and the vowel in cut [kət] is in the lowering of the third and fourth formants in bird, as opposed to no such lowering in cut, then the distinctive feature may best be labelled [Lowered frequency of the third and fourth formants] or [Lowered F_3, F_4]. As usual, the first second and third formants are written F1, F2, F3, respectively. The frequency of the first, second, and third

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formants are written F_1, F_2, and F_3, respectively. The feature could of course be labelled [Rhotacized] after the perceptual effect of the lowered third and fourth formants, but then we must also include a convention [Rhotacized] --→ [Lowered F_3, F_4] to apply in all environments for the correct phonetic specification. In any case it would be inappropriate to label the distinctive feature with the articulatory term [Retroflex] as that is not even factually correct. The labelling refers to formal specification. Informally we may prefer to refer to the more familiar labels of "retroflex". I will for example continue to use "height" and "back" in the informal discussion.

The search for "true" correlates of features over the years has demonstrated that it is not possible to relate all features to acoustic parameters, as was attempted by Jakobson, Fant, and Halle (1951), nor to exclusively articulatory parameters as was done by the International Phonetic Association (1949), or by Chomsky and Halle (1968). Some features may best be described as articulatory scales, others as acoustic or perceptual, some perhaps as combinations. Moreover, it is suggested that if variations occur as points along one continuous parameter it is more explanatory to describe that variation as a change of values along a single multivalued feature rather than in terms of switching between binary features (Ladefoged 1971). Our primary goal as phonologists-phoneticians is to come up with an accurate description and an explanation of phonological processes.

This chapter is an attempt to provide a first approximation to a set of features that are required to specify contrasts, and phonological processes that involve vowels. The proposed set of vowel features is exhaustive as far as I know. I have attempted to relate each feature to its physical correlate, and to specify the number of phonological values necessary for each feature. The problem of how to deal with cross-language comparisons of the values of a multivalued feature at the lexical level has not been sorted out at this stage. This problem will for example occur when one wants to compare a language with two values of feature to a language with four values of feature, where the lowest vowel in both languages functions in the same way as in rules. As I have concentrated on classificatory features of vowels, problems with features involved in interactions between consonants and vowels have not been considered here.

The basic vowel parameters

The most basic vowel parameter is vowel height. There is no language that does not contrast vowels along a vertical scale. Another basic contrast occurs along a horizontal scale. There are very few languages that do not contrast front and back vowels. Vowel height and backness then form a basic two dimensional vowel space that is required for almost all languages of the world. Additional contrasts, like lip rounding, pharyngal size, nasality can be considered to be superimposed on this basic vowel space.

"Height"

What is the physical correlate of vowel height? There is abundant evidence against the traditional concept of vowel height as the height of the highest point of the tongue. Using X-ray data from Ngwe vowels and cardinal vowels, Ladefoged (1964, 1975) demonstrated that particularly the tongue height of back vowels bears very little relation to vowel height. Figure 1 is a plot of the highest points of the tongue of the cardinal vowels. The tongue height is approximately the same for [o] and [ɔ]. In addition the distance between the tongue heights of [i] and [a] is considerably smaller than that between [u] and [ɑ], which is contrary to how the vowels are heard (Ladefoged, 1967).

X-ray data from vowel production of one speaker each of Akan, Dho Luo, Ateso, and German were analysed by Lindau

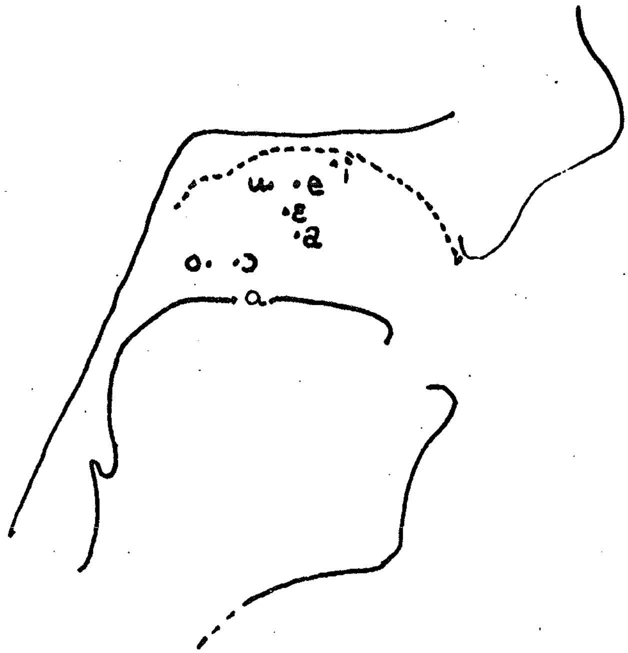


Figure 1. The highest points of the tongue as shown in a published set of x-rays of cardinal vowels. The outline of the upper surface of the vocal tract is not clear on the x-rays, and it is estimated. (From Ladefoged 1975:198.)

et al. (1972). The vowels were [i ɩ e ɛ u ɷ o ɔ]. Figure 2 is a plot of the relative tongue height of these eight vowels in the four languages. The Ateso speaker is the only case where tongue height is related to vowel height; the speakers of the other languages do not use tongue height to produce different vowel heights. Thus tongue height cannot be the primary underlying mechanism of variation in vowel "height".

Lindblom and Sundberg (1969, 1971) proposed relative jaw opening as the main difference between high, mid and low vowels. If this were correct, then the tongue-shapes ought to stay the same within the jaw, and the jaw opening vary with vowel height (provided of course front and back vowels are regarded separately). Lindblom and Sundberg showed that for their single Swedish subject the tongue shapes did remain constant with respect to the jaw.

Ladefoged et al. (1972) studied vowel productions of six American English speakers by use of cineradiography. Figure 3 is from this study. It shows the front lax vowels /ɩ ɛ æ/ - as in bit, bet, bat - superimposed onto a fixed jaw for each of the six subjects so as to show only the movement of the tongue (if any) with respect to the jaw. It is clear that even when we confine the discussion to /ɩ ɛ æ/, we find that only subject 2 behaves as predicted by Lindblom and Sundberg. Subject 1 has similar tongue shapes for /ɛ/ and /æ/ and uses jaw opening to distinguish between two out of three vowels. None of the others have similar tongue shapes in any of the three vowels. They cannot then be using primarily different degrees of jaw opening to control vowel height.

Figure 4 is a plot of relative jaw opening in the eight vowels in Akan, Dho Luo, Ateso, and German. Jaw opening in Dho Luo, at least in this speaker, shows a good ordering relationship to vowel height but the distances between the vowel points do not correspond very well to how they are heard. The vowel points of the other languages show a

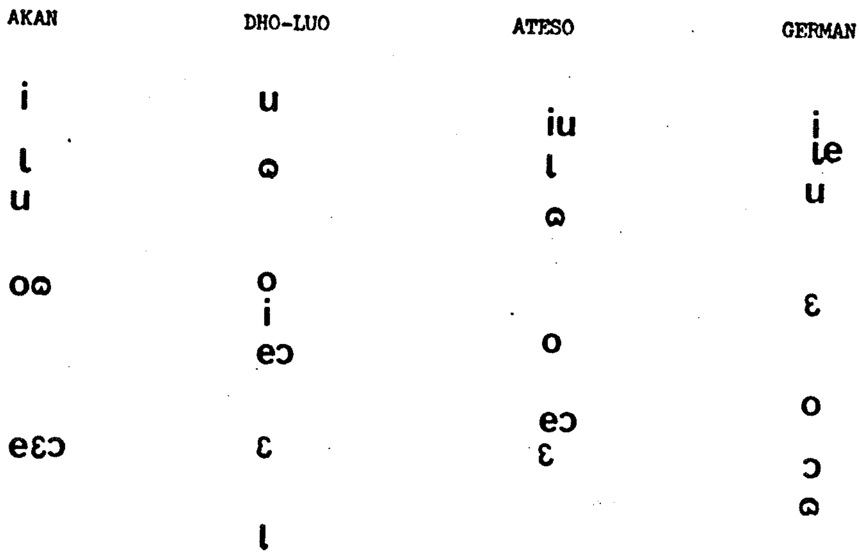


Figure 2. Vertical positions of the highest points of the tongue in eight vowels of the speakers of Akan, Dho-Luo, Ateso, and German.

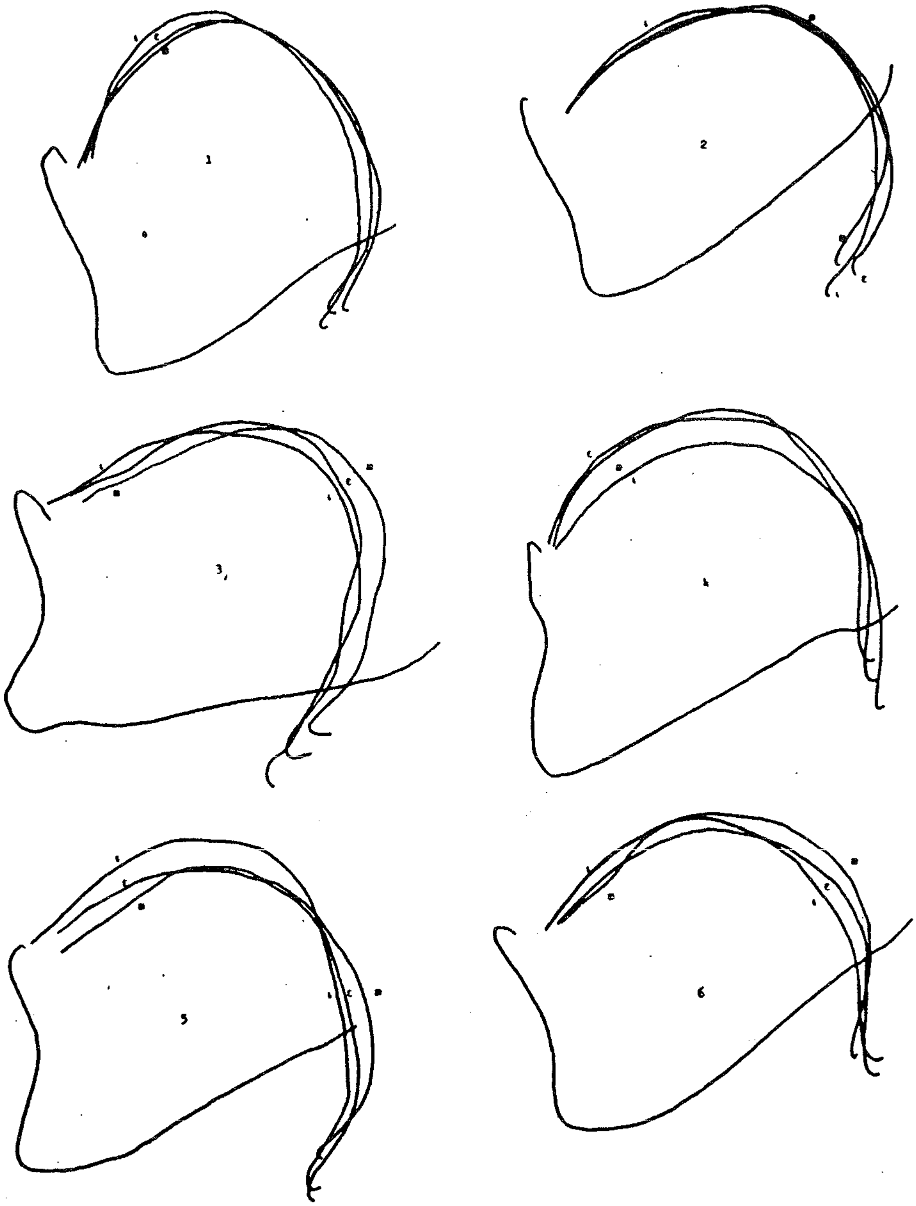


Figure 3. The lax vowels /ɪ ɛ æ/ in English superimposed onto a fixed mandible for each of six subjects so as to show only the movement of the tongue (if any) with respect to the mandible. (Ladefoged, DeClerk, Lindau, and Papçun 1972.)

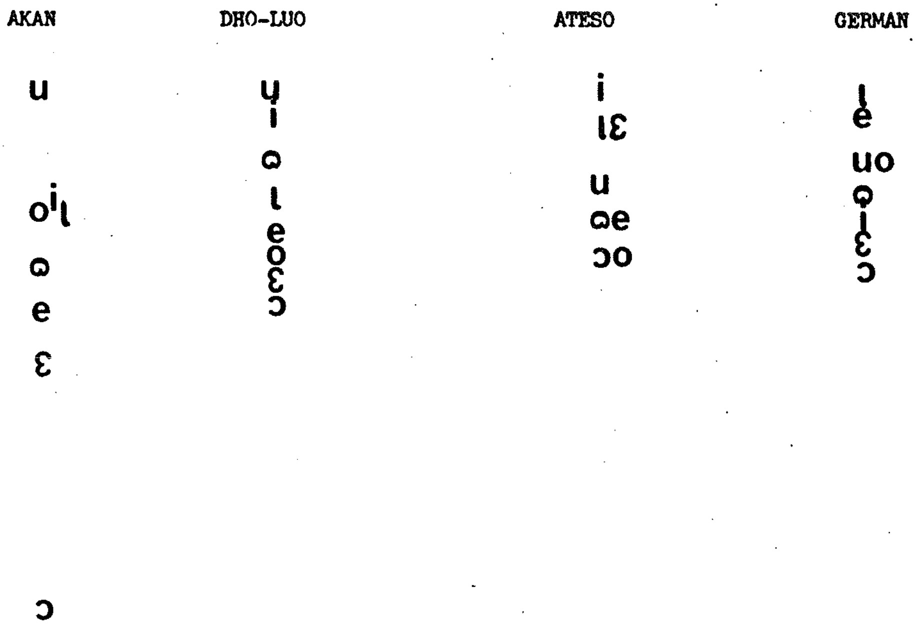


Figure 4. Vertical positions of the jaw opening in eight vowels of the speakers of Akan, Dho-Luo, Ateso, and German.

better relation between jaw opening and vowel height than was the case when tongue height and vowel height were compared, but the relationship is not good enough to support Lindblom and Sundberg's claim about the jaw opening as the universal phonetic correlate of vowel height. The use of jaw opening to distinguish between high, mid, and low vowels by some speakers only shows that this is one possible way of achieving vowel height. It does not justify postulating jaw opening as a necessary correlate of vowel height.

In summary, all available evidence points to the fact that a speaker has several possible gestures available for producing a certain point in the basic vowel space, and that different speakers also do make use of all available mechanisms to achieve the same acoustic result. The invariance in vowel height is not of any articulatory kind but rather acoustic. Formant frequencies plotted on a formant chart usually show a much better relation to how the vowels are perceived (Ladefoged 1964, 1971, 1975). The cardinal vowels as spoken by Daniel Jones were plotted on the formant chart in Figure 5. The formant frequencies were inferred from a formant chart in Lindblom and Sundberg (1969), and plotted on a formant chart with F_1 against the difference between F_2 and F_1. The resulting figure is much closer to the traditional quadrilateral than the figure described by the highest point of the tongue (Figure 1). Vowel height is related in a straight-forward way to the frequency of the first formant (F_1). High vowels have relatively low F_1, and low vowels have relatively high F_1. Articulatorily based features like Tongue Height, Jaw opening, Stricture (Williamson 1974)[1] are less appropriate for vowels. With the correlate of vowel height being F_1 the most appropriate features label of vowel height is of course [F_1].

The feature [F_1] is multivalued because vowels may contrast more than two values along this single scale. Phonological processes involving this feature shifts the vowels up and

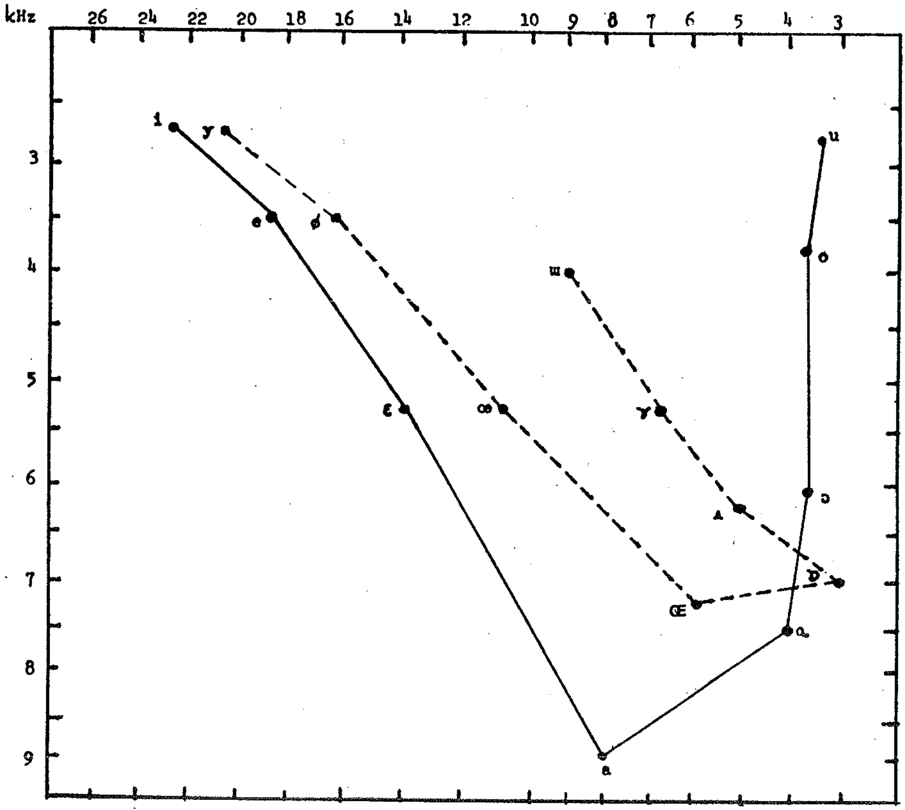


Figure 5. Formant chart with the frequency of the first formant on the vertical axis and the distance between the frequencies of the first and second formants on the horizontal axis for the cardinal vowels. The formant frequencies are from Lindblom and Sundberg (1969).

down one scale. The use of binary features to express movements along one physical scale would make a wrong claim about the relationship between the vowels. There are values of [F_1] that simply cannot be expressed correctly with two binary features. A Swedish dialect, Scanian, (as spoken in Malmö) diphthongizes long vowels as below (Bruce 1970):

/i:/ → [ei]	/y:/ → [øy]	/u:/ → [eu]
/e:/ → [εe]	/ʉ:/ → [øu]	/o:/ → [εo]
/ε:/ → [æε]	/ø:/ → [œ ø]	/ɑ:/ → [æɑ]

A vowel insertion rule must specify a vowel one step lower than the underlying vowel. As four heights are involved, Chomsky and Halle's [High] and [Low] cannot be used but we can try Wang's [High] and [Mid] with the use of paired variables (Wang 1968).

$$\emptyset \rightarrow \begin{bmatrix} V \\ \alpha\text{high} \\ \beta\text{mid} \end{bmatrix} \Big/ \_\_ \begin{bmatrix} \beta\text{ high} \\ -\alpha\text{mid} \end{bmatrix}$$

(The rounding variation has been ignored, since it is not pertinent to the point). This rule generates the desired output, [ei], [εe], [æε], etc. but because of the switching nature of the rule it also generates a fourth type of diphthong [æ i], [œ y], and [æ u] that is not only not desired but makes the wrong claim that this would be the most likely extension of diphthongization in Scanian. The only way to avoid it is by the use of n-ary values. This also makes the rule formally simpler.

$$\emptyset \rightarrow \begin{bmatrix} V \\ n + 1\ F_1 \end{bmatrix} \Big/ \_\_ \begin{bmatrix} n\ F_1 \end{bmatrix}$$

How many values are needed for F_1 ? Some languages contrast only two values of vowel height, e.g. Kabardian (Halle 1970) with the vowel system

ɵ
a

or Turkish with a system of eight vowels on two heights:

i y ɯu
e ø ɑo

Sedlak (1969) lists some twenty languages with two vowel heights. The maximum number of values for this vowel feature seems to be four. Ladefoged (1971) reports Danish and English, and Hockett (1955) two Polish dialects with four heights. Dan has a system with at least four central vowels:

i	ɨ	u
e	ɘ	o
	ɵ	
(æ)	a	(ɒ)

(/æ/ and /ɒ/ are included by Bearth and Zemp (1967) but not by Welmers (1973).[2]

Five vowel heights have been reported for Ngemba by Eastlack (1968);

i	ɨ	u
I		
e	ë	o
	ɘ	
	a	

The vowel /I/ could easily be distinguished from the others by some other feature than height. Moreover, the maximal contrast at any value of Backness is still only four heights. So Ngemba has at least no more than four contrastive heights. Even so, this analysis makes the system look suspiciously inefficient with respect to the use of available acoustic space.

For contrastive purposes we thus need four values of $[F_1]$. If the glides /j ʋ w ɥ / are regarded as end points of the vowel height continuum, they can be included at one end of this scale as $[0\ F_1]$.

"<u>Back</u>"

The second basic vowel dimension places vowels as points along a horizontal scale, usually called Backness. Backness has traditionally been regarded as an articulatory dimension. While it is true that the tongue is further back in back vowels than in front vowels, there is, however, not a good correspondence between the highest points of the tongue on the horizontal dimension and the way in which corresponding vowels are located on a vowel chart. Compare the positions of [o] and [ɔ] in Figure 1. Again, we look to acoustic dimensions for a better correlate of Backness. The obvious candidate is the frequency of the second formant, F_2. F_2 is relatively low for back vowels, relatively high for front vowels, and in between for central vowels. When F_2 is plotted against F_1 on the ordinary type of formant chart the resulting figure forms a traditional vowel triangle. Acoustically and perceptually, however, back vowels are usually not on a slope like the right hand side of a triangle, but distributed more on a straight vertical line. The acoustic, and probably the perceptual vowel space, is in fact more like the Jonesian quadrilateral than a triangle. If we plot F_1 against the difference between F_2 and F_1, instead of against F_2, a quadrilateral vowel figure is obtained. The slope of the front vowels also improves in relation to the auditory chart. Backness is thus better related to the difference between F_2 and F_1 than simply to F_2, and the feature will be labelled $[F_2-F_1]$.

Some real evidence for $[F_2-F_1]$ comes from studies of acoustic and perceptual vowel spaces using a type of factor analysis, PARAFAC, which "incorporates, <u>within the factor model</u>, certain basic tests for determining the explanatory factors" (Harshman 1971:14). This procedure of factor analysis provides a unique, "true" solution for a set of adequate data. Three factors were extracted from a data set of formant frequencies of Swedish vowels of several speakers. The vowels along the factor corresponding to the "back" dimension were distributed in such a way that they are much better related to $F_2 - F_1$ than to F_2 (Lindau et al. 1971).

There are languages that do not contrast vowels along the horizontal dimension. When there thus is only one value of $[F_2 - F_1]$ that value refers to central vowels. These systems occur in some Caucasian languages, e.g. Kabardian. Hockett (1955) mentions Adyge, possibly Abkhaz, and Udykh with a system of

ɨ
ə
a

Mohrlang (1971) analyses Higi as a system of three central phonemes.[3] The occurrence of such vowel systems constitutes a violation of Sedlak's proposed universal no. 4:

"All languages have a high or lower high front vowel." Of course, both Kabardian and Abkhaz have extremely rich inventories of <u>phonetic</u> vowels that are derived from assimilations to features of surrounding consonants - including [i]s - but I presume Sedlak refers to vowel systems on the phonological level. These facts further imply the nonexistence of any universal to the effect that there is at least one particular vowel such that it occurs in all languages of the world. There simply is not. Another universal suggests itself, and I propose it here:

"If a language has no horizontal contrast, all the vowels will be central."

I do not know of any language with only back or only front vowels.

The majority of languages contrasts two horizontal values. In the vowel systems I have looked at, these two values equal front and back, i.e. the maximum and minimum values of the feature [$F_2 - F_1$]. I propose a second universal of this feature to complement the first one.

"If a language has horizontal contrasts, then it has front and back vowels."

The feature [Back] in the SPE system has a maximum of two values. This excludes the possibility of specifying central vowels on the systematic phonemic level. Consequently, in languages with three heights, as in the very common seven vowel system of /i e ɛ a ɔ o u/, the vowel /a/ is forced into a [+Back] classification, and it is distinguished from /ɔ/ by the feature [Round] . This implies a very curious claim that the third vowel height somehow "causes" /a/ to be [+Back] , when really the way in which /a/ functions as front, central, or back in different languages does not have any obvious relation to the number of heights or rounding there are. Moreover, many languages have other central vowels that function as vowels between front and back vowels, and not as unrounded back ones.

There are also languages that contrast three horizontal values with the same value of rounding. Norwegian has four high vowels, out of which three are rounded (Vanvik 1972), namely /i y ʉ u/. The vowels /ʉ/ and /u/ could conceivably be derived from underlying /u/ and /o/ respectively, but I do not consider a neater system and a reduplication of historical process justification enough for this in present day Norwegian, where the alternation patterns do not support this "solution". There is no alternation [ʉ]~[u] nor [u]~[o]. Norwegian contrasts three rounded horizontal values. Another language with three horizontal contrasts is Brôu (Miller 1967). This language has 41 vowels, including short and long vowels, and diphthongs, It seems the system can be reduced to 17 long and short vowels, or to the following ten or eleven basic vowels.

i	ɨ	u
e	ə	(ʌ)o
	a	ɑ ɔ

I have retranscribed Miller's transcription into that of IPA for easier reference. My symbols are chosen from studying Miller's detailed phonetic descriptions and acoustic charts.

On the acoustic charts /a/ is clearly central, right between front and back vowels. The system is symmetric with /ɨ ə a/ as central vowels. From the literature I do not know of any strong evidence that /a/ behaves as a phonological front vowel. There is thus no reason to postulate /a/ as front and low rather than central. Thus Brôu contrasts four low vowels, three of which are unrounded; so also here three values of $[F_2 - F_1]$ are essential.

As three contrasts constitute the maximum number of horizontal contrasts, another universal suggests itself:

"No language contrasts more than three horizontal values."

<u>Features of the lips</u>

The feature $[F_2 - F_1]$ is not quite independent. A constriction at the front of the vocal tract results in a larger distance between F_2 and F_1 than a constriction in the middle (where back vowels are). When we add variation at the ends of the vocal tract this affects F_3 and F_2, and thus also the distance between F_2 and F_1. A decrease of the size of either end of the vocal tract will lower F_3 and F_2. Thus the relatively small difference $F_2 - F_1$ that results from a constriction in the middle of the vocal tract is made even smaller by decreasing the mouth opening. Front vowels will have a larger distance between F_2 and F_1 if pronounced with spread lips (and wide low pharynx). The maximal horizontal distance is obtained by maximising the mouth opening for front vowels and decreasing it for back vowels - which is why front vowels are basically unrounded, and back vowels basically rounded. Variation of the size of the mouth opening may be used to create more vowels. Decreasing the lip opening for front vowels, and increasing it for back will add sets of vowels inside the "basic" maximal vowel space.

The lip opening can be decreased in two days: by protruding the lips or by compressing them by vertical forces so that the lip opening becomes a narrow slit. These two possibilities have been recognized since Sweet (1877). Both mechanisms involve lip action, or labiality, but only the first type is protruded. Labial consonants are produced by lip compression, and protrusion may be superimposed. Protrusion implies labiality, but not vice versa. Many phonological rules also apply to rounded vowels and labial consonants, so a feature is needed to cover both types of lip action - [Labial]. Protrusion is as usual specified with Round . Both lip features have invariant articulatory correlates, and complex acoustic ones.

Round

The feature [Round] may serve to contrast two types of front vowels and two types of back vowels. I have not come across any language with a rounding contrast for central vowels. [Round] is a binary feature. Phonetic degrees of lip protrusion are predictable from the value of F_1 (vowel height).

Systems with a single front rounded vowel are rare. Chacobo, Basque, Mandarin Chinese are reported by Sedlak. Two front rounded vowels occur in a substantial number of languages e.g. German, Icelandic, Faroese, Norwegian, Swedish, French, Albanian, Turkish, Hungarian, Estonian, Tibetan, Akha. No language has more than three contrastive front rounded vowels. Systems with three rounded vowels are not very common. Sedlak lists Icelandic with three front rounded vowels. But most analyses come up with one or two front vowels (Einarsson 1928, Haugen 1958, Benediktsson 1959). They occur in those versions of French that distinguish for example jeûne [ʒø:n] 'fast' and jeune [ʒœn] 'young'.

Systems with one back unrounded vowel occur in Chinese.

iy ɯu
ə
a

Two back unrounded vowels occur in Turkish for example:

iy ɯu
eø ɑo

Akha (Lewis 1968)[4] i y ɯ u
e ø ɤ o
ɛ a ɔ

As for front rounded vowels, the maximum number of back unrounded vowels is three, as in Vietnamese:

i ɯ u
e ɤ o
æ ʌ ɔ
a

or in Fe' Fe' (Hyman 1972):

i ɯ u
e ɤ o
a ɑ

The above languages also demonstrate that front rounded and back unrounded vowels may co-occur in a system.

Central vowels are mostly unrounded. Rounded ones occur in for example Norwegian (p. 15). There is no language that contrasts rounded and unrounded central vowels at the same height. In languages with a single central unrounded vowel, that vowel is usually /a/. Sedlak lists a number of languages with two central unrounded vowels. Three central unrounded vowels are not very common but occur for example in Brôu (p. 16), Ngwe, and Kashmiri:

Ngwe (Dunstan 1966):

i	ɨ	u
e	ə	o
ɛ		ɔ
	a	

Kashmiri (Kelkar 1964):

i	ɨ	u	
e	ə	o	(+/:/)
	a		

Four central unrounded vowels occur in Dan (p. 12).

There is a problem with assessing systems with reported central or back unrounded vowels. Linguists do not consistently use the same symbols for these vowel classes. As it turns out it may be a pseudoproblem: these two vowel classes never contrast for non-low vowels. The low /a/ and /ɑ/ may contrast as in Brôu, though this is very rare.

The non-contrastiveness of unrounded high central and unrounded high back vowels seems to have an acoustic reason. Apparently it has to do with non-linear relationships between articulation and acoustic effects. Consider Figure 5. Rounding non-low front vowels lowers F_2 some 200 Hz, while unrounding back vowels has a much larger effect on F_2, which increases by about 700 Hz. This relatively large increase of F_2 will place the "back" unrounded vowels acuostically very close to a central position. Vowels in this acoustic area are notoriously unstable. This is the most difficult area for a speaker in which to produce constant and stable vowel qualities, and for a listener to distinguish between vowel qualities. The instability of the central unrounded and back unrounded vowels is predictable from Fant's Maxima Theory (Fant 1960, Gunnilstam 1973). Vowels are more stable at those areas in the vocal tract where a constriction produces formant curves (as on logograms) where two formant curves have their respective maximum and minimum simultaneously. At these places a small articulatory movement causes no acoustic change. But where formant curves have a steep slope, a small articulatory change will have large acoustic effects. A study of Fant's logogram of the effect on formants as a function of the place of constriction with various degree of lip rounding shows that at 10 cm from the glottis (approximately [u]) unrounding will cause a considerable upward slope of F_2 (Fant 1960, p. 82). Very small articulatory displacements in the back to central area will cause relatively large shifts of F_2 as long as the lips are not rounded.

Labial

Vertical lip compression is a much less usual way of decreasing the lip opening for vowels than lip protrusion. In fact, the only language I am aware where this occurs, is Swedish. Swedish contrasts lip protrusion, [Round] , and lip compression, [Labial] , for high vowels:

i	y ʉ	u
e	ø	o
		ɑ

/y/ and /ʉ/ are both non-back with decreased lip opening. The vowel /y/ is produced with lip protrusion, /ʉ/ with the gesture for [Labial] . A second reason for classifying /ʉ/ as [Labial] is in the nature of its offglide. In Swedish long high vowels have an approximant offglide at the same place of articulation as the vowel. The offglide after [ʉ:] is a labial [β]. The others are [ij, yɥ, uw].

Urhobo approximants supply another example of a Round-Labial contrast. Urhobo has a round /w/ and a labial /ʋ/. Before high back vowels both are also velar. Before rounded vowels both /w/ and /ʋ/ are influenced by the rounding -

but not in the same way. In producing /w/ in /ṹwúro/ 'bend in the knee' and /owɔ/ 'leg' my informant's lips are quite strongly protruded, but while producing /ʋ/ in /òdù:ʋù/ 'a kind of animal trap' and /ʋurɛ/ 'sever' the lip opening is decreased but not by protrusion (cf. Kelly 1966).

Both in Swedish and Urhobo the vowels and approximants differ by the use of two separate lip gestures, not by different degrees of the same gesture, so they should be characterized by separate features.

Expanded

In many Niger-Congo languages of West Africa and in Nilo-Saharan languages of East Africa vowels may be distinguished by a mechanism involving the size of the pharynx, as controlled by variation in the positions of the root of the tongue and the larynx (Ladefoged 1964; Pike 1967; Stewart 1967; Lindau et al. 1972; Antell et al. 1974; Lindau 1975). This mechanism consistently underlies one phonological process only: vowel harmony. On the basis of evidence from the same speaker Halle and Stevens (1969) and Perkell (1971) suggest that the root of the tongue distinguishes the "tense" and "lax" vowels in English in the same way as harmonizing sets are distinguished in the African languages. But it is quite clear that, when more speakers are considered, not all speakers of English separate "tense" and "lax" vowels using the tongue-root (Ladefoged et al. 1972). In the African languages the size of the pharynx separates two harmonizing sets of vowels. The maximal system is 5 + 5 vowels: five vowels /i e з o u/ with a large pharynx and five vowels /ɩ ɛ a ɔ ɷ/ with a small pharynx. The ten-vowel systems are relatively rare. They have been reported for some Kwa languages, namely Sele (Allen 1974), Abe (Stewart 1971), Igede (Bergman 1971), and Engenni (Thomas 1969), for some Benue-Congo languages, namely Ọgbia (Williamson 1972), Abuan (Wolff 1969), and Kohumono (Cook 1969), and for some Gur languages: Kasem, Sisala, Mianka (Bendor-Samuel 1971). Among Nilo-Saharan languages ten vowel systems are found in Kalenjin, Päkot, Acholi, Lotuko (Antell et al. 1974). Nine vowel systems where /ɜ/ has merged with some other low vowel are fairly common. They occur for example in Akan languages, Delta Ịjọ, and some Central Delta languages. The vowel /a/ tends to be neutral to vowel harmony and the 4 + 4 + /a/ system patterns like below:

1.		2.	
i	u	ɩ	ʊ
e	o	ɛ	ɔ
	a		

Many languages have reduced the nine vowel system to a partially harmonizing seven vowel system. By the time the system has reduced to a five vowel system the vowel harmony will be lost (Williamson 1974).

Over the years many features have been proposed for African vowel harmony: Tense, Raised Height, Breathy, Covered - just to mention a few. There is now substantial evidence that the main phonetic control of the vowel harmony is the movement of the tongue root (Lindau et al. 1972; Retard 1973; Painter 1973). The tongue root mechanism is mostly - but not always - combined with vertical larynx displacements, and sometimes with movements ofthe back pharyngal wall. It thus seems that what a speaker tries to accomplish is variation of the pharyngal size. As illustrated in Figure 6 the Akan speaker produces the set 1 vowels /i e/ with a relatively large pharynx by advancing the root of the tongue beyond a "normal" position for that vowel, and by lowering the larynx. The relatively small pharynx of the set 2 vowels /ɩ ɛ/ is produced by retracting the root of the tongue beyond its "normal" position, and by a relatively high larynx.

Figure 7 functions as a summary statement of the formant space in Akan. A comparison of Figure 6 and Figure 7 will give some idea of articulatory-acoustic relationships.

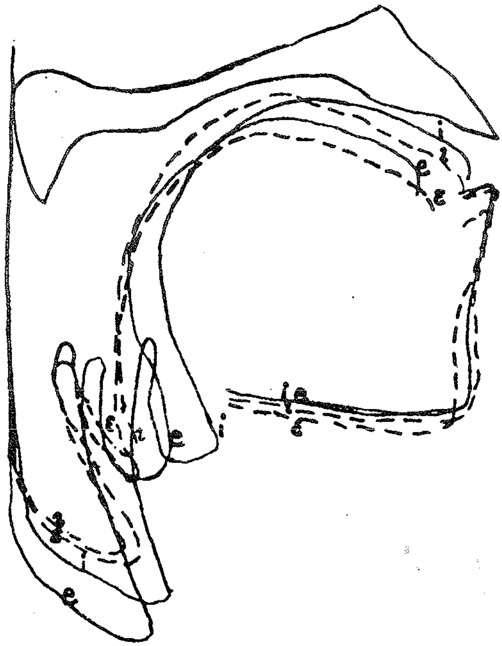


Figure 6. Selected tracings of /i e / of one speaker of Akan.

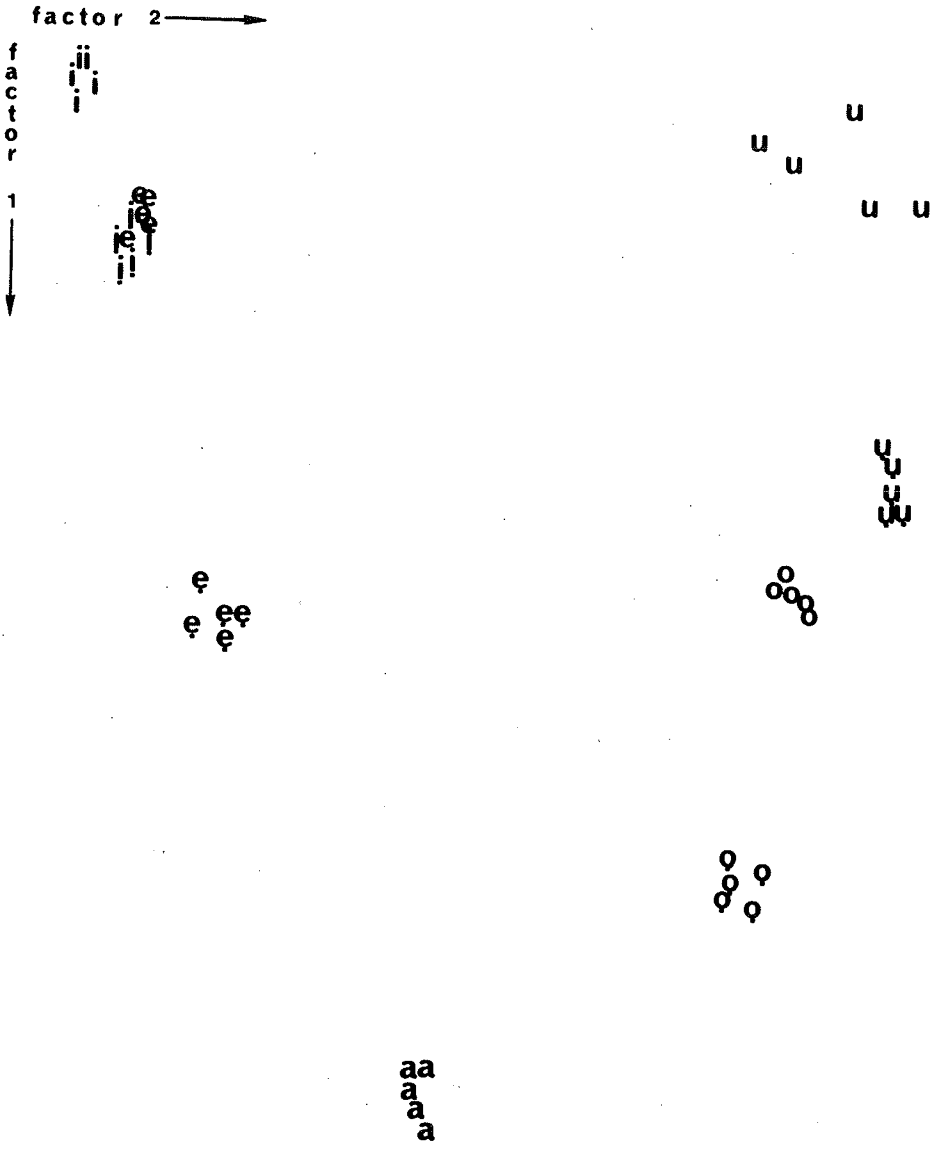


Figure 7. Two factor solutions of factor analysis of two formant frequencies of five tokens each of nine vowels of four speakers, using the Parafac-procedure (Harshman 1970). Language: Akan. The dotted vowels represent set 2 vowels. Factor 1 = F_1, factor 2 = inverse of F_2, correlation = 993, mean square error = 1016.7 (or 31.5 mel). The factor solution is here used as a normalization procedure for formant frequencies.

Varying the size of the pharynx, as between /i/ and /ɩ/, and /e/ and /ɛ/ affects F_1: that is, it has the same general acoustic effect as varying the size of a constriction in the front of the mouth. Decreasing the pharynx size (by retracting the tongue root) increases F_1 in the same way as apening up a constriction of the mouth does (by lowering the body of the tongue). That is, going from [i] to [e] by mainly increasing the size of the mouth constriction, and going from [i] to [ɩ] by decreasing the pharyngal size will have very much the same acoustic effect. For an attempt to explain this, see Lindau (1973). This is clearly shown by the acoustic merging of /ɩ/ and /e/ in Figure 7.

While there is more than one articulatory way of varying vowel height ([i] → [e]), the difference between [i] and [ɩ],and between the other harmonizing pairs has a consistent articulatory correlate. This is not just variation of the tongue root. The larynx and the back pharyngal wall are also involved. What is consistent is the variation of pharyngal size. So the corresponding feature will not be labelled [Advanced Tongue Root] but [Expanded], referring to pharyngal expansion.

When there is no contrast, the tongue root is not especially advanced or retracted. This state is regarded as a zero value of the feature [Expanded]. In the African languages the contrast is achieved by deviating in opposite directions from that zero value. So the feature values are:

[1 Expanded] = Wide pharynx
[0 Expanded] = Neutral pharynx
[-1 Expanded] = Narrow pharynx

It is conceivable that the same mechanism is involved in distinguishing between emphatic and non-emphatic consonants. If that is so, both [0 Expanded] and [-1 Expanded] occur in languages with pharyngalized consonants, like Arabic. It is evident from the cineradiographic data presented by Ali and Daniloff (1970) that vowels in the environment of pharyngealized consonants are all produced with a retracted tongue root, very similar to that in the vowel harmony languages. Some speakers of English seem to produce the so called tense vowels with an advanced tongue root and the lax vowels with a neutral tongue root, so here the difference is between [1 Expanded] and [0 Expanded]. But it is obvious from our data in Ladefoged et al. (1972) that speakers are not consistent in distinguishing tense and lax in this way, so the feature [Expanded] cannot be used to distinguish English vowels.

Vowel systems in many Mon Khmer languages are characterized by so called <u>voice registers</u>, where the vowels fall into two sets called First and Second Register. K. Gregersen (1973) summarized a good number of impressionistic phonetic descriptions of the two registers. On the basis of this he proposes that the Mon Khmer registers are really controlled by the same mechanism as vowel harmony in African languages. There are striking similarities in these impressionistic descriptions to the earlier descriptions of the African vowels. No conclusive evidence in terms of x-ray data occurs as yet that I am aware of, but Gregersen's hypothesis sounds very likely. If he is correct, then some Mon Khmer languages contrast [-1 Expanded] and [0 Expanded], others contrast [0 Expanded] and [1 Expanded]. Gregersen points out that one set is "normal" and the other set may deviate in either direction.

<u>"Retroflex"</u>

So called "retroflex" vowels have been reported for Badaga, a Dravidian language. Emeneau (1939) analyses the Badaga vowel system into 30 contrastive vowels:

i u i̚ u̚ i̋ ű

e o e̚ o̚ e̋ ő

a a̚ a̋

V̚ = slightly retroflex vowel.

V̋ = strongly retroflex vowel.

Each vowel occurs long and short as well. The Badaga contrasts call for a ternary feature of retroflexion. It is worthwhile to point out that these threeway contrasts have not been noticed elsewhere.

Emeneau described the retroflex vowels as being produced with the tip of the tongue curled upwards and backwards to a smaller or greater extent. Ladefoged (1975) points to the vowel in American English sir, cur, bird and he notes that although these vowels are strongly r-coloured, they are nevertheless not always retroflex. Some speakers produce the r-colouring with the tip of the tongue down. There is also a constriction in the pharynx below the epiglottis.

The acoustic effect of both gestures for r-colouring is a lowered third and fourth formant. It seems that again we have a feature where the invariant physical reality lies in the acoustic domain rather than in the articulatory domain. The articulatory term "retroflex" is therefore inappropriate as label for the feature. Ladefoged labels the [ɚ] vowels with an auditorily based term "rhotacized". I suggest that as we already have acoustic features [F_1] and [$F_2 - F_1$] and this correlate is also acoustic, the most appropriate label is acoustic, [Lowered F_3, F_4]. The three contrastive values 0, 1, and 2 of [Lowered F_3, F_4] refer to plain vowels, slightly "retroflex" vowels and strongly "retroflex" vowels, respectively.

Nasal

Properties and processes involving nasalization in vowels have been discussed extensively by Ferguson (1963), Ladefoged (1971), Ruhlen (1973) among others. Nasalized vowels occur frequently phonetically in the environment of nasal consonants. But many languages show a true contrast between oral and nasalized vowels, e.g. many Kwa languages in West Africa. The feature is [Nasal] with an obvious articulatory correlate: the state of the velum. The acoustic effects of lowering the velum are very complex. They include an increase of F_1 (House and Stevens 1956, Ohala 1971), as well as increases in the bandwidths of the formants. Nasalized vowels will thus sound "lowered" without changing the rest of the vocal tract which is why nasal vowels tend to lower systematically (Ohala 1971, Hombert 1974). The feature [Nasal] is probably binary, although several degrees of nasality occur phonetically.

Long

Long and short vowels occur in many languages. The durational differences are, however, not always interpretable as contrastive length. The domain of a length feature may be the syllable in which case vowel duration is predictable from the syllable structure. This is the case in for example Icelandic, Norwegian, and Swedish. In Swedish closed long syllables may end in V:C, or VCC. In other languages, where long vowels function alike to diphthongs, long vowels may be derived from VV-sequences, as in Finnish (Lehiste 1970). The interpretation of [V:] as /VV/ is also standard in such tone languages as have tonal glides or double tone over a long vowel, as happens in many Niger-Congo languages.

Vowel length is accompanied by qualitative differences in many languages. Problems arise in the interpretation when trying to decide on which is significant. The vowel quality differences manifest themselves in centralization of short vowels. This is the case in German, Swedish, English, Czech, Serbocroatian, where the two sets of vowel qualities are referred to as "tense" in long vowels and "lax" in short vowels. A listening experiment conducted by Hadding and Abramson (1964) showed that in Swedish the durational differences became less important when a vowel pair differed substantially in quality. It thus seems that when vowels differ in both respects, quality differences are a primary cue provided these differences are large enough.

There are undoubtably also languages like Luganda, Estonian, Mixe, where vowels differ solely as to segmental quality, so a feature [Long] must be included in a universal inventory. Probably only two values are contrastive: short and long. Ladefoged (1974) reports four values in Kamba, but some are grammatically conditioned. The question of two or three contrastive lengths in Estonian has been debated for years (Lehiste 1970). Lehiste demonstrates that Estonian has unquestionable three ranges of durational vowel differences - short, long, overlong - but there are alternative interpretations of the overlong vowel. Hoogshagen (1959) reports three vowels lengths in Mixe (Mexico) V, V˙ and V:, interpreting them as /V/, /V˙/ and /V·h/, respectively. More than two lexically contrastive lengths have not been demonstrated unambiguously - yet. Length is therefore a binary feature. Short vowels are [-Long], long vowels are [+Long].

"Tense"

The tense/lax distinction has been extensively discussed since the time of Melville Bell (1867). A feature like Tense is clearly needed in many phonological rules. Whether this feature is truly also needed for contrastive purposes is not that obvious, and what phonetic mechanism controls the feature seems to be a wide open question, judging from the literature. The range of proposed correlates covers most conceivable parameters from "muscular energy" to perceptual "colour" dimensions. For a discussion of the literature the reader is referred to Miller (1974). What is meant by a tense/lax distinction is usually the kind of vowel quality differences that accompany long and short vowels in European languages like English, German, Swedish, Czech and in some languages spoken in India, e.g. Kannada. The long vowels here are perceptually more peripheral and the corresponding short vowels more centralized towards a schwa. In English tense vowels are also diphthongized.

When tenseness could be predicted from length in these languages the feature [Tense] may not be needed on the systematic phonemic level. But because the vowel quality sometimes is the primary one (p. 28), we might want to keep Tense as a contrastive feature for phonetic reasons.

There are also languages where Tense apparently is independent of length. Hindi-Urdu apparently has tense-lax contrastive differences without length differences (Sedlak). So does Friulian, also according to Sedlak. As [Tense] can be independent from [Long] it must be included as a separate feature.

The qualitative difference between Tense and Lax is described as peripheral vs. central. There is no consistent articulatory mechanism corresponding to this (Ladefoged et al. 1972). Perceptual and acoustic relations correspond quite well. On an acoustic chart the lax vowels are inside the tense vowels, on an axis towards a [ə]. Although the feature is better regarded as acoustic rather than articulatory, there is no obvious single acoustic parameter that exactly corresponds to that axis. For laxing, we could use something like "formant frequencies approaching $F_1 = 500$, $F_2 = 1500$, $F_3 = 2500$ Hz". It is worth stressing again here that also from an acoustic point of view Tense is not the same as the feature Expanded. Tenseness is on a central - peripheral acoustic axis, while Expanded is on a vertical (F_1) axis.

The feature of tenseness will be labelled [Peripheral]. It is a binary feature. So called tense vowels are [+Peripheral]. [-Peripheral] vowels are inside their [+Peripheral] counterparts approaching formant frequencies of 500, 1500 and 2500 Hz.

Welmers (1973) reports a remarkable vowel system for Dinka with three phonetic degrees of centralization. But the three degrees of [Peripheral] are also accompanied by differences in length and phonation types, so it seems unlikely that the peripheral - central differences are contrastive. Besides, as some of the central - peripheral vowels in Dinka are controlled by differences in pharyngal size (L. Jacobson, personal communication) it is apparently not the feature [Peripheral] that is involved but the feature [Expanded].

Phonation types

Differences in phonation types among vowels are usually non-contrastive. Voiceless vowels occur in many languages, but always conditioned by surrounding voiceless consonants. Hindi vowels may be somewhat breathy voiced from preceding breathy voiced consonants. There are a few languages where different states of the glottis are contrastive. Ladefoged (1971) reports Gujerati contrasts between voiced and breathy voiced vowels, at least on the systematic phonetic level. Lango contrasts voiced and laryngealized vowels. Ladefoged's feature is [Glottal Stricture] with nine possible categories. Only two of these may contrast for vowels.

\+ + + + +

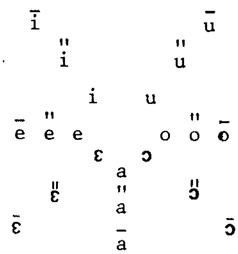
It remains to mention two features apart from [Peripheral], that do not seem to function to classify sounds into contrastive categories, but that are needed for correct specification of phonological processes. The feature [Grave] is not contrastive independently of other features. Grave vowels are always back, and grave consonants are all classified after their place of articulation. But labial and velar consonants often function together as a class, and interact with back vowels. The common property of grave sounds is an acoustic one: low spectral energy.

As an example of this feature in phonological rules let us take a comparison between British and American English. Both dialects have a vowel /ju:/ and a vowel /u:/, but the British /ju:/ has become /u:/ in some varieties of American English in stressed syllables in the environment after dental and alveolar consonants, but not after labial and velar consonants. Cf. the American pronunciation of <u>pew</u>, <u>spew</u>, <u>beauty</u>, <u>few</u>, <u>view</u>, <u>mute</u>, <u>cute</u>, <u>gules</u>; but <u>enthuse</u>, <u>tune</u>, <u>stew</u>, <u>dune</u>, <u>lute</u>, <u>nude</u>, <u>rude</u>, <u>sue</u>, <u>presume</u>. This historical sound change is best described in terms of the feature Grave . The nongrave /j/ may disappear after a nongrave segment, but not after a grave segment:

$$\begin{bmatrix}\text{-vocalic}\\ \text{-consonantal}\\ \text{-grave}\end{bmatrix} \rightarrow \emptyset \;/\; [\text{-grave}] \;---$$

Other examples of the use of this feature can be found in Hyman (1972).

The second "rule" feature occurs in Dinka. Welmers (1973) arranges the Dinka vowels in a system like an eight spoke wheel with the top spoke missing:



V̄ = long brassy peripheral
V̈ = medium long, breathy, somewhat centralized
V = very short, very centralized

Morphophonemic alternations take place as follows according to Welmers (1973:29):

> "Alternations between noun singulars and plurals appear to involve most commonly a movement clockwise to the next spoke but in the same position on the spoke; that is if the singular has /ü/, the plural has /ö/; if the singular has /ö/, the plural has /ɔ̈/, and so on until if the singular has /ë/ the plural has /ï/; but if the singular has /ï/ there is no change in the plural (since there is no spoke in the next position clockwise). A less common pattern is precisely the reverse, with the alternation in the plural one spoke counter-clockwise from the vowel of the singular; if the singular is on the /u/ spoke there is no change in the plural. Still other alternations are one step in or out on the same spoke: /ō/ to /ö/, /a/ to /ä/, and the like."

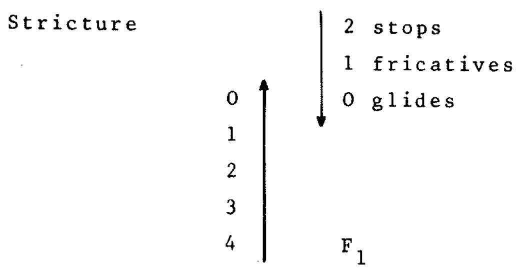
Alternations one step in or out on the same spoke could be accounted for by the n-ary feature [Glottal Stricture]. But there is no feature that could do the "around the clock" patterns. The underlying mechanism must be acoustic, in fact it corresponds very well to the frequency of the second formant, F_2. From any position on the spokes, going clockwise or counterclockwise there is a continuous change of F_2. Thus we need a multivalued feature [F_2]. For Dinka there are seven values. The feature [F_2] is associated with this "around the clock" variation, and it is different from variation in "backness" in our framework.

List of features	Maximum contrasts
F_1	4 (5, if 0 = glide, fn. 1)
$F_2 - F_1$	3
Round	2
Labial	2
Expanded	2 (3 values)
Lowered F_3, F_4	3
Nasal	2
Long	2
Peripheral	2
Glottal Stricture	2 (7)

"Rule features"	Number of values
Grave	2
F_2	n

Footnotes

1. In K. Williamson's framework [Stricture] is an n-ary feature referring to the size of the passage between two articulators, ranging from complete closure to wide open (for low vowels). Including consonants and vowels in a single feature is probably not correct. At the point where the stricture changes from obstruent to sonorant (i.e. to a glide) the phonetic correlate changes from a basically articulatory to an acoustic mechanism. As both stricture rules and vowel rules may involve glides, what we have is perhaps two features that overlap at the point of glides. If we regard glides as the zero value for each feature, we could also describe how, when a weakening process results in glides, the next step is deletion of the whole segment. Glides are also regarded as end points of the vowel space.



2. The Dan vowels occur long and short. /æ:/ and /ɒ:/ occur only as long vowels in the data from Bearth and Zemp (1967).

dɨ spear	fi: unpleasant odour	bu rotte
dɩ tree	we: salt	bo: beetle
dɵ father	wɛ: sleeping place	dɔ: termite
za judgment	wæ: to collect	bɒ: helper

3. According to Mohrlang (1971) Higi contrasts /i e ə a/ word finally and /ə e a/ word medially. As the phonetic values of /ə e a/ are determined by the surrounding consonants, Mohrlang analyses them all as phonemically central. It must also be pointed out here that the analysis of Higi vowels is by no means clearcut. Wolff (1959) analyses Higi as a six vowel system:

i	ɨ	u
e		o
	a	

4. Lewis' transcription has been converted into that of IPA.

Languages mentioned

Language	Classification
Abe	Kwa/Niger-Congo
Abkhaz	Caucasian
Abuan	Benue-Congo/niger-Congo
Acholi	Eastern Sudanic/Nilo-Saharan
Adyge	Caucasian
Agwagwune	Benue-Congo/Niger-Congo
Akha	Burmese-Lolo/Sino-Tibetan
Albanian	Indo-European
Arabic	Semitic/Afro-Asiatic
Ateso	Eastern Sudanic/Nilo-Saharan
Badaga	Dravidian
Basque	undetermined
Brôu	Mon-Khmer/Austro-Asiatic
Chacobo	Tacana-Pano/Ge-Pano-Carib
Chinese	Han-Chinese/Sino-Tibetan
Czech	Slavic/Indo-European
Dan	Mande/Niger-Congo
Danish	Germanic/Indo-European
Dho Luo	Eastern Sudanic/Nilo-Saharan
Dinka	Eastern Sudanic/Nilo-Saharan
Engenni	Kwa/Niger-Congo
English	Germanic/Indo-European
Estonian	Uralic/Altaic
Faroese	Germanic/Indo-European
Fe'fe'	Benue-Congo/Niger-Congo
Finnish	Uralic/Altaic
French	Italic/Indo-European
Friulian	Italic/Indo-European
German	Germanic/Indo-European
Gujerati	Indic/Indo-European
Higi	Chadic/Afro-Asiatic
Hindi	Indic/Indo-European
Hungarian	Uralic/Altaic
Icelandic	Germanic/Indo-European
Igede	Kwa/Niger-Congo
Ịjọ	Kwa/Niger-Congo
Japanese	Japanese-Ryukyuan/Altaic
Kabardian	Caucasian
Kalenjin	Eastern Sudanic/Nilo-Saharan
Kannada	Dravidian
Kasem	Gur/Niger-Congo
Kashmiri	Indo-Iranian/Indo-European
Kohumono	Benue-Congo/Niger-Congo
Lango	Eastern Sudanic/Nilo-Saharan
Lotuko	Eastern Sudanic/Nilo-Saharan
Luganda	Bantu/Niger-Congo
Mianka	Gur/Niger-Congo
Mixe	no information - spoken in Mexico
Ngemba	Benue-Congo/Niger-Congo
Ngwe	Benue-Congo/Niger-Congo

Norwegian	Germanic/Indo-European
Ọgbia	Benue-Congo/Niger-Congo
Päkot	Eastern Sudanic/Nilo-Saharan
Polish	Slavic/Indo-European
Sele	Kwa/Niger-Congo
Serbocroatian	Slavic/Indo-European
Sisala	Gur/Niger-Congo
Swedish	Germanic/Indo-European
Tibetan	Sino-Tibetan
Turkish	Turkic/Altaic
Twi/Akan	Kwa/Niger-Congo
Udykh	Caucasian
Urhobo	Kwa/Niger-Congo
Vietnamese	Austro-Asiatic

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