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# THREE DIMENSIONAL PHONOLOGY*

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The purpose of this paper is to sketch the logical and formal structure of a theory of phonology that is currently being developed by the authors, on the basis of previous work in the field, and, in particular, of their own research (that is, in this case, Vergnaud and Halle 1979, essentially). The fundamental features of this new theory will be best understood when we compare it to the theory of SPE, henceforth the "Standard Theory" (Chomsky and Halle 1968). Within the Standard Theory, there are two levels of representation: the level of SYSTEMATIC PHONEMICS and the level of SYSTEMATIC PHONETICS. A representation at either one of these levels is a linear sequence of units (junctures and segments in the case of systematic phonemics), and representations at systematic phonemics are mapped onto representations at systematic phonetics through the application of phonological rules, which are essentially context-sensitive rules (in the technical sense); some of these rules apply cyclically (cf. Halle 1959, 1962, 1964; Chomsky 1951, 1955, 1964, SPE). In the early seventies, it was pointed out that this model of phonological competence was in principle incapable of handling tonal phenomena commonly found in various African languages (see Leben 1971, Williams 1971). Williams 1971 and Goldsmith 1973, 1974, 1976a, 1976b proposed to overcome these difficulties by introducing into the theory what turned out to be essentially an elaboration of Z. Harris's long components (Z. Harris, 1944, 1951). (Some of Harris's ideas appear to resemble thoughts put forward at about the same time by J. R. Firth (1948), because of Firth's elliptical presentation, however, the exact nature of the resemblances is difficult to pin down.) According to Williams and Goldsmith, each representation is to be analyzed as a pair of autonomous sub-representations spliced together by simple principles. These two sub-representations can be called the "tone tier" and the "segment tier", respectively. Each tier is a linear sequence of units (tones in the case of the tone tier and junctures and segments unspecified for tone in the case of the segment tier) and can be affected independently by rules specific to it. This extension of the standard model has been elaborated and refined in the work by Goldsmith and others, and the set of principles that were developed there has come to be known under the name "Autosegmental Phonology". In provocative contributions, McCarthy (1976, 1979) showed that the language and the concepts of autosegmental phonology could help solve some outstanding problems in Semitic phonology and morphology. McCarthy proposed that new autonomous tiers be introduced, beside the tone tier. In particular, he demonstrated that, by splitting the segment tier of "standard" autosegmental phonology into three separate and autonomous tiers, the vowel tier, the consonant tier, and the "syllabic skeleton", the basic structure of the paradigm of Semitic verbal stems could be accounted for in a simple and natural fashion. In addition, he suggested that each one of the previously defined tiers should be split in its turn into subtiers, corresponding to the different morphological units.

The autosegmental approach has been extremely successful, and fruitful. In particular, it has led to significant discoveries in several subdomains of phonology (see in particular the work by Clements 1976 and the work by McCarthy cited above). On the other hand, it is clear that there are some difficulties with this model, of a formal and conceptual kind, as well as of an empirical kind (see Sportiche 1977 and Zubizarreta 1980a, for example). It was the recognition of this fact that led the authors to propose and develop a different kind of extension of the Standard Theory, based essentially on work by Liberman (1975, 1977), Prince (1975, 1976, 1977a, b), and Selkirk (1978a, b, 1979, forthcoming); and also Vergnaud 1975, Halle and Vergnaud 1976, Vergnaud 1977, and Sportiche 1977. The authors extended the "metrical treatment" beyond its original domain of definition by introducing an abstract notion of binary branching tree and by showing that the basic concepts of metrical theory could be elaborated and generalized, and at the same time combined with the models sketched in Halle and Vergnaud 1976, for example, in such a way as to yield illuminating accounts of such diverse phenomena as harmony, stress, or syllabic structure (Vergnaud and Halle 1979). A corollary result of this paper was to show that the metrical formalism allowed for an adequate characterization of these various areas in terms of separate and autonomous "modes of representation". This (unforeseen) consequence of the analysis must be taken as an indication of its--at least, partial--correctness, since the various domains that happen to fall under metrical theory are actually independent from each other. In this sense, Vergnaud and Halle (1979) points to a more radical revision of the SPE theory than was explicitly recognized there. The recent work on "autosegmental representation" to which we referred above can also be best understood in this perspective.

We take as our starting point the last chapter of John McCarthy's (1979) dissertation *Formal Problems in Semitic Phonology and Morphology* where the morphophonemics of the Arabic verb are investigated. As is well known, Arabic verb form consists of a stem to which may be adjoined a number of affixes. Following McCarthy we shall refer to the stem by the term traditional in Hebrew grammar <u>binyan</u> (pl. <u>binyanim</u>). In Table 1, reproduced from McCarthy's dissertation, there are illustrated the 15 tri-consonantal and 4 quadri-consonantal binyanim recognized in the classical Arabic grammatical tradition. When we examine these forms, we notice that they all share the stem consonants--k t b in the tri-consonantal case, and d ḥ r j in the quadri-consonantal case-- but differ from one another in the vowels and in some other consonants that they contain, as well as in what we shall call here the SYLLABIC SKELETON, i.e., in the sequential arrangement of consonants and vowels in each form. Specifically, in the first column of Table 1 we find the eight skeleta in (2):

| | | | |
|---|---|---|---|
| (2) a. | C V C V C (I) | C C V C V C (VII) | |
| | C V C C V C (II) | C C V C C V C (X) | C V C V C C V C (V) |
| | C V V C V C (III) | C C V V C V C (XI) | C V C V V C V C (VI) |

| | Perfective Active | Perfective Passive | Imperfective Active | Imperfective Passive | Active Participle | Passive Participle |
|---|---|---|---|---|---|---|
| Triliterals | | | | | | |
| I | katab | kutib | aktub | uktab | kaatib | maktuub |
| II | kattab | kuttib | ukattib | ukattab | mukattib | mukattab |
| III | kaatab | kuutib | ukaatib | ukaatab | mukaatib | mukaatab |
| IV | ʔaktab | ʔuktib | uʔaktib | uʔaktab | muʔaktib | muʔaktab |
| V | takattab | tukuttib | atakattab | utakattab | mutakattib | mutakattab |
| VI | takaatab | tukuutib | atakaatab | utakaatab | mutakaatib | mutakaatab |
| VII | nkatab | nkutib | ankatib | unkatab | munkatib | munkatab |
| VIII | ktatab | ktutib | aktatib | uktatab | muktatib | muktatab |
| IX | ktabab | | aktabib | | muktabib | |
| X | staktab | stuktib | astaktib | ustaktab | mustaktib | mustaktab |
| XI | ktaabab | | aktaabib | | muktaabib | |
| XII | ktawtab | | aktawtib | | muktawtib | |
| XIII | ktawwab | | aktawwib | | muktawwib | |
| XIV | ktanbab | | aktanbib | | muktanbib | |
| XV | ktanbay | | aktanbiy | | muktanbiy | |
| Quadriliterals | | | | | | |
| QI | daḥraj | duḥrij | udaḥrij | udaḥraj | mudaḥrij | mudaḥraj |
| QII | tadaḥraj | tuduḥrij | atadaḥraj | utadaḥraj | mutadaḥrij | mutadaḥraj |
| QIII | dḥanraj | dḥunrij | adḥanrij | udḥanraj | mudḥanrij | mudḥanraj |
| QIV | dḥarjaj | dḥurjij | adḥarjij | udḥarjaj | mudḥarjij | mudḥarjaj |

Table I

The number of consonantal slots in the skeleta varies from a minimum of three to a maximum of five. When the number of consonantal slots equals the number of consonants in the stem there is a straightforward left-to-right, one-one linking up much as that found by Leben, Goldsmith, etc. in various tone languages. Thus, we find:

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(2)  b.  I   katab      III   kataab      QI   daḥraj
             | | |            | |  |           | || |
             CVCVC            CVCVVC           CVCCVC
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In the light of this parallel with tonal phenomena McCarthy makes the ingenious suggestion that the consonantal stems be regarded on a par with the tonal melodies and that the same principles of linking as found in tonal grammars are observed here. In particular the following conditions of well-formedness are observed:

(3) a. i) unless otherwise stipulated, segments in the melody and slots in the skeleton are linked one-one from left to right;

ii) each slot in the skeleton must be linked with at least one segment in the melody;

iii) linking lines must never cross.

These well-formedness conditions immediately account for the form of certain of the binyanim in (1), in particular, for many of those where the number of consonantal slots in the skeleton exceeds the number of segments in the melody; e.g.,

(3) b. k t a b a b IX      d ḥ a r j a j QIV


The situation is somewhat more complicated when the form takes a prefix (e.g., IV, VII, X, and QIII). The prefix then occupies the first (and if applicable, the second) slot, whereas the stem melody fills the rest of the slots, in conformity with (3a ii).

Infixes such as the /n/ in XIV and QII present still more complex conceptual problems. If they are not to violate the prohibition against crossing of linking lines, the infixes will have to be inserted into the stem melody; i.e. we should need a rule that inserts /n/ into the stem melody after the second consonant of the stem; i.e.,

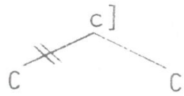
(4) a. $\emptyset \rightarrow n \; / \; _{stem}[CC \_\_\_$      in XIV, QIII

McCarthy proposes a rather different solution. He suggests that the infix be represented on a separate autosegmental tier from that of the stem, as illustrated in (4b):

(4) b. XIV

It is not difficult to show that McCarthy's suggestion is superior to the infixation rule (4a). To see it consider the Class II binyan *kattab* or the Class V binyan *takattab*. Given the Well-formedness Conditions (3a), we should have expected **katbab* and **takatbab* in their stead. Since we saw that the proposed conditions yield such correct forms as IX *ktabab* or XI *ktaabab*, it is clear that we are not dealing with a malfunctioning of the well-formedness condition but rather with the effects of a special rule. McCarthy proposes that the requisite rule applies to certain binyanim only and cuts one of the two links between the last consonant of the melody and the skeleton (4c):

(4) c.




in II, V, XII, XIII

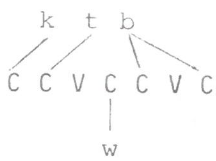
As a result we obtain derivations such as (4d):

(4) d.


Since the well-formedness condition (3a ii) requires that every slot in the skeleton be linked to a segment in the melody, we have the choice of linking the empty C slot in the skeleton with either /t/ or /b/. Since the purpose of the rule (4c) was to eliminate the link between the slot and the segment /b/, we shall assume that this type of relinking is excluded by convention. We, therefore, link the empty slot in the skeleton to /t/ and obtain the correct output.

Consider now the other two binyanim where (4c) applies, i.e., XII, XIII. We shall assume that these two binyanim have the infix /w/ linked to $C_3$.

(4) e.

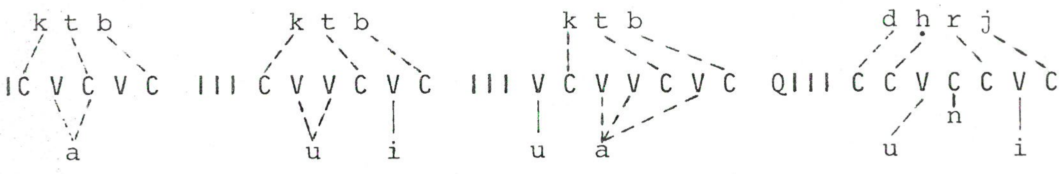



When these forms undergo rule (4c) there are two available candidates for filling the empty slot without violating the prohibitions against the crossing of links: we can link the empty slot either to /t/ of the stem, or to the /w/ of the infix. In fact, both alternatives are made use of by the language; the first alternative generates XII; the second, XIII. It hardly needs saying that this result does not follow in any natural fashion from the alternative solution (4a), where the infix is inserted into the stem melody. The result just sketched must, therefore, be regarded as evidence in favor of the proposal that stem melodies and affix melodies are represented on separate tiers.

The vowels in Semitic words, as is well known, play a role that is analogous to affixes in other languages. Thus in the first column of

Table (I) all forms have the vowel /a/; in column 2 the vowel melody is /u-i/; and in column 4, /u-a/. We can obtain these results by the simple assumption that the vowels constitute a separate tier, as illustrated in (5a):

(5) a.

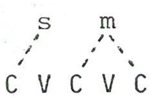



katab kuutib ukaatab dhunrij

In (5a) we have represented with a solid line those links between melody unit and skeleton slot that must be stipulated in the rule generating the binyan in question; whereas all links that are the consequence of the well-formedness conditions in (3a) are represented by broken lines. We follow the convention that when a melody contains both units that are linked by rule and units that are unlinked, it is the latter that are spread to unfilled slots (from left to right). Observe that no violations of the prohibition against the crossing of linking lines result from this in (5a) because the stem melodies and the affix melodies are represented on separate tiers. Notice, in particular that in QIII there are in effect three separate melody tiers: the consonantal stem, the infix /n/, and the vowel pattern /u...i/.

In addition to tri- and quadri-consonantal stems, Arabic possesses also bi-consonantal stems; e.g., sm "poison". When such a stem is mapped onto the skeleton CVCVC of the first binyan we get, as expected,

(5) b.




samam

In Hebrew, the same constructive principles obtain as those in Arabic and we get first binyan stems such as:

(5) c. galal "he rolled" (intr.)

bazaz "he plundered"

However, when these bi-consonantal stems are mapped onto a quadri-consonantal skeleton--e.g., II CVCCVC--we do not get the expected

gillel bizzez[1]

but rather

gilgel bizbez

To generate the latter forms we must presuppose that the stem melody is reduplicated, i.e.,

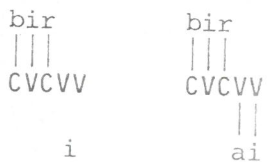
(5) d.


Since the melody tier is autonomous of the skeleton--though not unrelated to it--the facts just discussed would appear to be perfectly plausible: it is to be expected that rules that affect one tier would leave the other unchanged. Nothing that has been said above should lead us to expect that the two tiers will always undergo a change simultaneously, and, in fact, the extremely widespread phenomenon of reduplication which we briefly discuss below is precisely an instance of this type.

A striking illustration of the independent behavior of the two tiers is provided by the plural formation in Hausa which was the subject of two recent articles by W. Leben (1977a, b).

In (6a) we exhibit nouns which form their singulars and plurals with identical skeleta but different melodies in the suffix. (We disregard all tonal phenomena in the present discussion.)

(6) a. bír+ìi    bìr+ái "monkey"    bàak+óo    bàak+íi "guest"

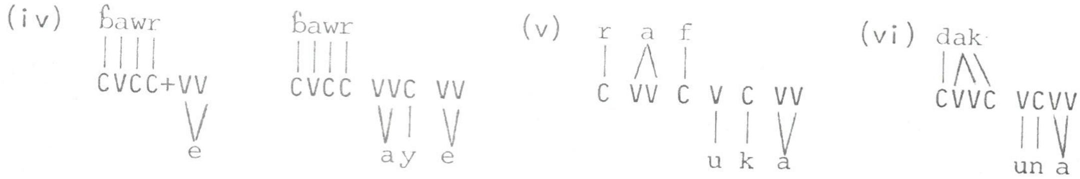



In (6b), the plural forms differ from the singular not only in affix melody but also in skeleton shape:

(6) b. (i) ràaf+íi    ráaf+úkàa "stream"

(ii) ɓáwr+ée    ɓáwr+àayée "fig tree"

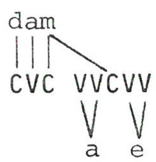
(iii) dáak+ìi    dáak+únàa "hut"




There is a large class of nouns which form their plural by copying the final stem consonant. As illustrated in (6c iii), these nouns differ from those in (6b) in that their plural suffix melody contains no consonant. By virtue of Condition (3a ii), unfilled slots in the skeleton must be linked to some segment in the melody. The only segment capable of filling the empty consonantal slot here is the last consonant of the stem melody.

(6) c. (i) dámóo dámàamée "land monitor"

(ii) báràa báróoríi "servant"

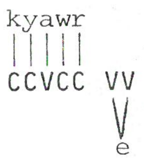
(iii) 

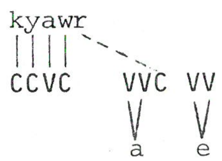

(iv) 


Newman (1972) has observed that stems with long vowels normally choose the suffix melody -aayee while stems with short vowels choose the suffix melody without the glide. He also notes that some stems with the skeleton of the form CVCC use the plural suffix with /y/, while others use the plural suffix without /y/. Thus, in contrast with ɓáwrée - ɓáwràayée "fig tree" quoted in (6b) we have also

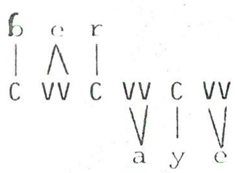
kyáwrée - kyáwàarée "door covering"

In the framework developed here the latter type of plurals are accounted for by saying that in the plural the stem skeleton must end with a single C, but the melody remains intact.

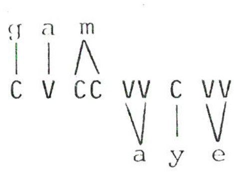



It was pointed out that stems with long vowels form their plural on the model of ɓáwràayée. They share this property with stems that end in geminate consonants. In our framework these two types of stems share also the property of having a single melody segment linked to two consecutive skeleton slots:

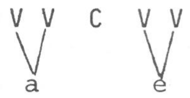



"rats"




"head pain"

Hausa is subject to a rule inserting the glide [y] between two adjoining long vowels or diphthongs. In terms of the framework presented this means that in the word skeleton there must be C slot between any consecutive VV slots, and moreover, that any such C slot, if not otherwise filled, will be linked to a [y] segment by a special rule. The plural suffix for the class under discussion is therefore:

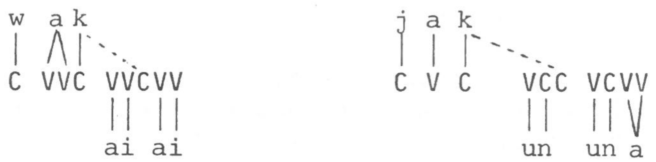



In conformity with the Well-formedness Condition (3a) the empty C slot in the suffix will be linked to the last stem consonant, as illustrated in (6c iii). In the case of stems with branching melody segments, the forms are subject to a special rule which severs the link between the last stem consonant and C slot of the suffix. This empty C slot is then linked to a [y] segment by the special rule mentioned in the preceding paragraph.

A further class of nouns forms the plural by reduplicating the plural suffix melody. The examples in (6d) should be compared with those in (6a) and (6b), where the same plural affixes appear unreduplicated.

(6) d. waakee  waakaikai  "beans"

jakaa  jakunkunaa  "bag"

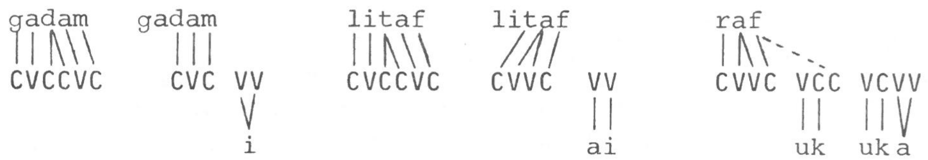



The most interesting cases of reduplication are those where the stem melody is copied. We illustrate these in (6f):

(6) f. gáddám+àa  gáddándám+íi  "dispute"

líttáaf+íi  lìttàt+tàaf+ái  "book"

ráafúffúkàa  "streams"




The reduplication process in Hausa has two parts. It extends the skeleton by copying the last syllable of the stem. In the case of gaddam the skeleton is extended by CVC, and in the case of littaaf the skeleton is extended by CVVC.[2] Concomitantly with the extension of the skeleton the stem melody is copied. We shall assume that the two copying processes--that of the skeleton extension and the stem melody reduplication--add material on the right of the base stem. As we shall see below, in such cases the linking of the slots in the skeleton extension to the segments of the stem melody proceeds from right to left. While there are numerous examples--especially in the case of tonal melodies--in which consecutive melody segments are linked to a single slot in the skeleton, normally only a single melody can be linked with a given skeleton slot. This restriction holds in Hausa reduplication (as well as in other reduplication processes) and as a result some stem melody segments will remain unlinked. Such unlinked segments are deleted by a general convention to be added to the Well-formedness Condition.

Secondly, Hausa consonant sequences are subject to regressive assimilation. This assimilation is total in the case of obstruent clusters, but affects only the point of articulation of the first consonant in the case of sonorant-obstruent clusters:

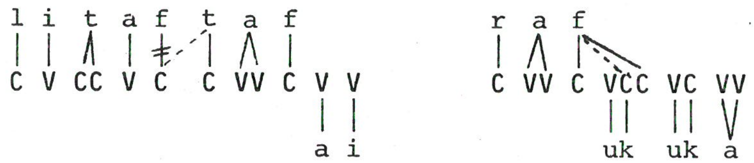
littaf+taaf+ai → littattaafai

raaf+ukfuk+aa → raafuffukaa

gaddam+dam+i → gaddandamii

Formally total assimilation consists of a rule like (4c) that breaks the link between the first of two C slots and the segment in the melody with which the slot was associated, as shown in (6g):

(6) g.




The Well-formedness Condition (3a) then establishes a link between the now empty C slot and the nearest consonant in the melody tier. Ultimately the unlinked segment in the melody tier is deleted.

Examples such as gaddandamii "dispute" show that it is possible to break the link between a skeleton slot and some features on the melody tier only while leaving links with other features intact. At this point, however, we are not prepared to extend our formalization to these cases as well.

We must finally return to the fact that in linking the reduplicated melody to the skeleton we proceeded from right to left. A. Marantz (1980) has studied the reduplication process in a variety of languages and has shown that the linking of slots and melody units proceeds from right to left when the skeleton is extended to the right hand side, whereas the melody is linked to the skeleton slots from left ro right when the skeleton is extended to the left. We illustrate the latter case in (7a) with examples from Sanskrit:

(7) a. tanóti "stretches" tatā́na "stretched"

drúhyati "strives to harm" dudróha "strove to harm"

To form the perfect stem, CV is prefixed to the skeleton and a V slot linked to /a/ is inserted before the stem vowel. Finally, the stem melody is reduplicated and linked to the prefix skeleton from left to right:

(7) b.

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tan  tan               druh  druh
||   /||               \|    ||\\
CV   CVVC              CV    CCVVC
      |                        |
      a                        a
```

It hardly needs saying that the preceding sketch of reduplication was, of necessity, very schematic and touched upon only a few aspects of this rich topic. To mention just one of the aspects that has been overlooked here, in Sanskrit when the basic stem begins with a continuant-stop cluster it is the stop rather than continuant that is reduplicated.

(7) c. stabhnā́ti tastámbha "prop"

stuté tuṣṭuve "praise"

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stambʰ   stambʰ   stu   stu
 ||      |||||    ||    |||
 CV      CCVCC    CV    CCV
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We now turn to the question as to where syllables belong in the scheme of things that has been outlined here. Our proposal is that skeleta in all languages are subdivided into subsequences to which the term SYLLABLE has traditionally been attached. Furthermore we wish to argue that the syllables themselves possess internal constituent structure. Specifically, we believe that each syllable consists of one obligatory and two optional constituents. The obligatory constituent, which we shall call RIME, dominates at least one V slot in the skeleton. The rime may be flanked on its left by a subsequence of C slots, which we designate by the traditional term ONSET. In some languages the RIME may be followed by a subsequence of C slots, which shall be termed APPENDIX. Our studies have uncovered many phonological processes where the constituents of the syllable--in particular, the onset and rimes--function independently of one another. In fact, it appears to us that the superordinate unit, the syllable, plays a much more marginal role in phonology than do its constituents.

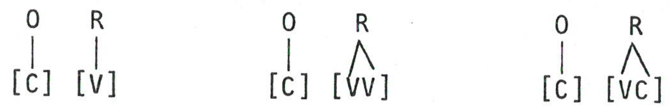
Linguists familiar with the literature on metrical phonology will no doubt recall the important result that in all languages known to us, stress assignment rules are sensitive to the structure of the syllable rime, but disregard completely the character of the onset. To cite but one example:

in the English stress rules the crucial property of syllables is whether or not they end with a short vowel ("weak cluster"); properties of the onset play no role here. Stress rules thus provide good motivation for analyzing syllables into onsets and rimes.

When we examine the skeleta in the first column of (2) we see at once that these share a final CVC sequence, which is preceded by the sub-sequences CV, CVV, or CVC. The skeleta in the second and third columns of (2) can be generated from those in the first column by prefixing the subsequences C and CV respectively.

We propose to take literally the remark that onsets and rimes are constituents of the syllable and impose an appropriate tree structure or bracketing on the sequence of segments that make up a syllable; i.e., we represent the canonical syllables of Arabic as in (8a):

(8) a.




Consider now the skeleta in terms of onsets and rimes. The difference between the skeleta in each column of (2) lies in the penultimate rime: it is V in the first row, VV in the second row, and VC in the third. There is, however, a gap in (2): in the third column the expected CVCVCVC skeleton is missing. This gap is related to yet another peculiarity of the Arabic binyanim in (1). We note that the difference between the binyanim in columns 1 and 2 of (1) resides solely in their respective vowel melodies. The binyanim in columns 3-6 differ from those in columns 1-2 also in their vowels but in addition they have different skeleta than those in 1-2. With the exception of the binyanim in Class I, columns 3-4 (the Imperfectives) are generated by prefixing a V slot to the 1-2 skeleton, while the skeleta of columns 5-6 are generated by prefixing a CV-sequence to the 1-2 skeleton. This simple procedure breaks down in case of binyanim of Class I. Here in place of a skeleton of the form VCVCVC we find one of the form VCCVC, for which, moreover, no provision is made by the formula for generating the skeleta that we have stated above. We can account for this gap if we assume that the skeleta are subject to the deletion rule (8b):

(8) b. Delete a penultimate nonbranching rime if preceded by a nonbranching rime.

The deletion rule (8b) accounts also for the gap in (2), for it converts the expected sequence CVCVCVC to CVCCVC, which happens to be identical with a skeleton already generated by our formula.

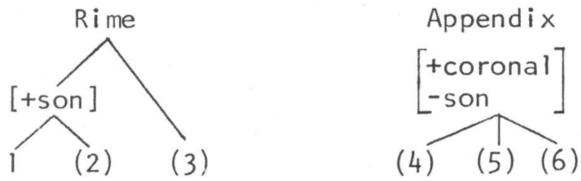
It has been recognized for well over a quarter of a century that the syllable is the domain over which the sequential constraints on phonemes are best defined. Benjamin Lee Whorf presented a formula for English monosyllabic words which made a considerable impression when it became known to wide circles of linguists in the early 1950's. Influenced by Whorf, Einar

Haugen in his contribution to the 1956 volume honoring Roman Jakobson proposed "that the syllable be defined as the smallest unit of recurrent phonemic sequences" (p. 216) and showed that sequential constraints of a number of languages could be captured in a natural fashion if approached from this perspective.

Haugen also proposed an internal structure for the syllable. Haugen's structure, which was adapted from a proposal by Hockett, differs from the one sketched above by us. For Hockett and Haugen the syllable consists of a "nucleus" and two "margins", one "pre-nuclear" and the other "post-nuclear".

In an article that appeared in the same volume as that of Haugen, Moulton studied in detail the sequential constraints of modern German. His main result was to show that there is an intimate relationship between the syllabic nucleus and post-nuclear margin. Moulton wrote: "If we examine the clusters which occur after short vowel... we shall find (1) that all consonants other than /š, s, t/ are limited to positions 1 and 2 after the syllable nucleus; and (2) that no more than five consonants occur after the syllable nucleus; e.g.,... (des) Herbsts... If we then examine the clusters which occur after long vowels... and diphthongs... we shall find (1) that all consonants other than /š, s, t/ are limited to position 1 after the syllable nucleus; and (2) that no more than four consonants occur after the syllable nucleus; ...e.g.,... (des) Obsts..." (p. 374). Although Moulton does not mention this specifically, his data (see especially Table 1 on p. 375) show that the constraints he cites for position after long vowels and diphthongs obtain also for rimes where a short vowel is followed by a liquid or a nasal. Thus the syllable final sequences of German contain at most six slots: an initial vowel slot followed by a sonorant slot, followed by an unrestricted consonantal slot, plus a three slot appendix limited to coronal obstruents. Of these six slots only the first is obligatory; slots 2-6 are all optional. We propose to capture these restrictions by postulating the structure illustrated in (9a):[3]

(9) a.




It can readily be seen that (9a) captures the restrictions just mentioned: since noncoronal obstruents can occupy only slot 3, a cluster such as /mf/ may be preceded by a short vowel, but not by a diphthong or vowel + sonorant sequence. (The same is true of long vowels if long vowels are represented by a branching rime.) The cluster /ns/, on the other hand, may appear both after short vowels as well as after long vowels and vowel + sonorant sequences:

(9) b.

| | | | |
|---|---|---|---|
| Kampf | Sumpf | *keimpf | *garmpf |
| Hans | uns | eins | Herrns |

We observe that the left branching structure of the rime in (8a) allows us to express the restriction that slots 1 and 2 are limited to sonorants. Implicit in our procedure is the so-called "feature percolation convention" (Vergnaud 1977), which states that segments dominated by a given node must possess the features specified at the node in question. This convention is made use of in expressing the restrictions on the appendix and on the first two slots of the rime.

Additional evidence for treating the appendix as a separate extra-metrical constituent of the syllable rather than integrating these nodes into the rime comes from the fact that in the three languages that we have had an opportunity to examine in some detail, appendices do not appear freely in all positions of the word but are limited to word final syllables. This is true of Arabic, of English and, as we explain below, also of Malayalam.

A new example demonstrating the autonomy of the different constituents of the syllable is taken from the East African language, Luganda. We are indebted for the facts as well as for the most essential aspects of the solution to an unpublished paper by G. N. Clements, "Syllable and Mora in Luganda". Clements notes that in Luganda "sequences of unlike vowels are not permitted within the phonological phrase. When such sequences would otherwise arise through morphophonemic combinations they are reduced by (special--MH/JRV) rules". We illustrate this in (9a):

(9) a. zi+a+ni → zaani "whose"

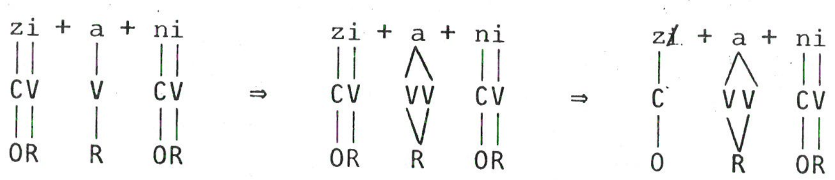
o+mu+kazi#o+no → omukazoono "this woman"

βa+e+βak+a → βeeβaka "they sleep"

N+βogo#e+no → mbogeeno "this is a buffalo"

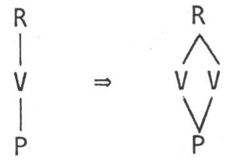
We propose that the process which produces this result consists of two parts. In the first of these, a non-branching rime becomes branching if it follows directly another rime. The second part of the process deletes all but the last of a sequence of consecutive rimes. Phonemes in the melody tier that remain unlinked to the skeleton are deleted by a convention. We illustrate this in (9b):

(9) b.




The rules that are required for the derivations in (9b) are given in (9c):

(9) c. (i)

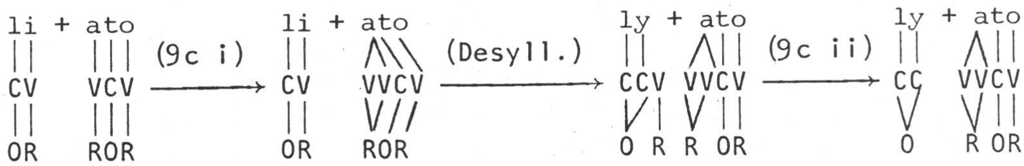


in env. R ___

(ii) R → Ø / ___ R

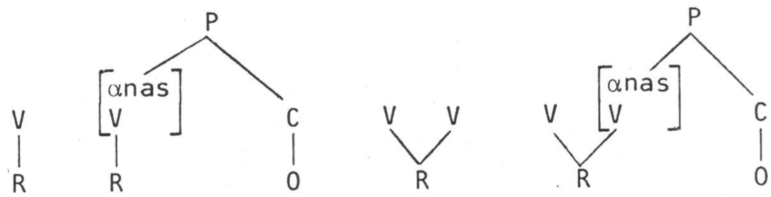
Certain other rules interact with the rime fusion rules (9c). In position after certain consonants, high vowels become glides if followed by nonhigh vowels. We assume that the desyllabification of high vowels takes place after (9c i) but before (9c ii) because this order allows for the simplest form of the rules. We thus obtain derivations such as those in (9d)

(9) d.

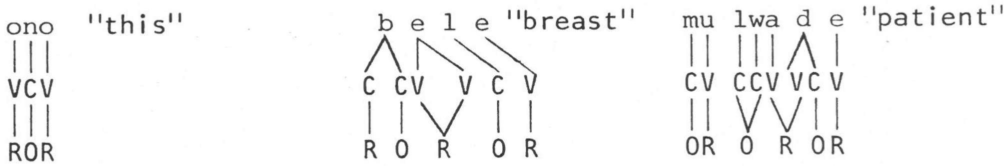


Clements notes two further peculiarities of Luganda words. On the one hand, vowels are always short before geminate (long) consonants, whereas they are always long before nasal clusters (with the exception of a readily specified class of cases). In order to understand these distributions we need to examine briefly the structure of rimes of Luganda. In underlying representation the kinds of rimes illustrated in (9e i) are found: (The capital P in the top line of the examples below stands for a distinctive feature complex on the melody tier.)

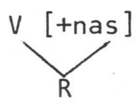
(9) e. (i)



(ii) Examples

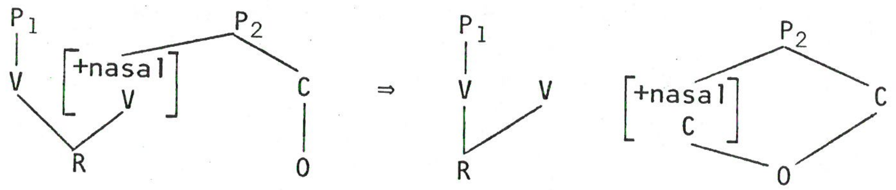


As shown in (9e ii) all these except



appear on the surface. The gap is due to a special rule which links a word-medial nasal to the following onset, converting the latter into a prenasalized stop:

(9) f.

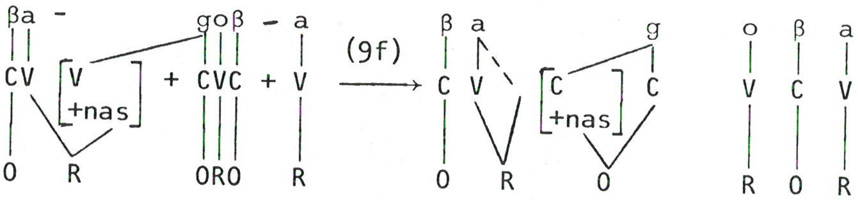



The Well-formedness Condition will then apply and link $P_1$ to the now empty right branch of R. Hence, before stops, the vowel is always long:

(9) g. (i) βa + goβ + a "they chase"

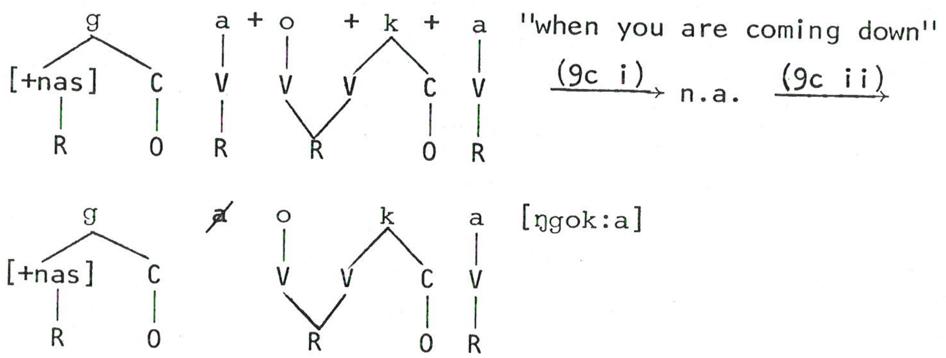
(ii) βa + N + goβ + a "they chase me" → βaa ŋgoβa

(iii)




This lengthening does not happen before geminate obstruents because rule (9f) affects only nasals:

(9) h.

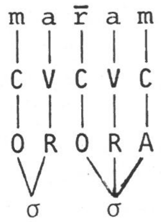



The Luganda examples just examined clearly require for their description explicit reference to rime structure. Without the availability of this device any plausible treatment of the facts becomes all but unformulable. We take this to be additional evidence for our suggestion that the syllable constituents--onset and rime--function as independent phonological entities.

Additional evidence for treating the appendix as a separate extrametrical constituent of the syllable rather than integrating these nodes comes from an unpublished manuscript by K. P. Mohanan, "Syllable Structure in Malayalam". Malayalam syllables have a complex onset which may consist of as many as three consonants and the onsets are subject to all sorts of restrictions. By contrast, Malayalam rimes are of a very simple kind: vowels and syllabic /r/ are the only phonemes that may appear there. As a consequence one would expect to find that Malayalam words all end with vowels or reflexes of syllabic /r/. This expectation, however, is violated by the appearance of words ending with /m/ and /n/; e.g., /mar̄am/ "tree" /baalan/ "boy". At first sight this would seem to be a violation of the restriction of rime structure just proposed. We shall, however, see directly that the violation is more apparent than real.

It is noted by Mohanan that as regards stress assignment, "syllables such as r̄am in mar̄am ("tree") behave as if they have nonbranching rimes." Since stress assignment in Malayalam (as in many other languages, e.g., English) is determined purely by the rimes of the word (and disregards all onset properties), the stress facts just mentioned constitute evidence for limiting the rime-core of a syllable such as r̄am to the vowel and for treating the word final /m/ as an Appendix.

(10) a.




As noted above in Malayalam appendixes may occur (as extra-metrical elements) in word final syllables only. The presence of an appendix does not alter the rime structure, and for this reason, to quote Mohanan, "syllables such as r̄am in mar̄am behave as if they have non-branching rimes."

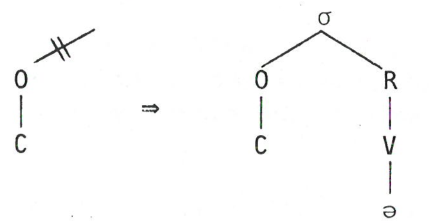
On the surface, Malayalam phrases end with a vowel except when the phrase final word ends with /m/ or /n/. In underlying representations, however, words may end with consonants. However, such consonant final words surface unmodified only before vowel initial words; elsewhere they are subject to schwa insertion as illustrated in (10b):

(10) b.

| | | | | | |
|---|---|---|---|---|---|
| paal ewite | "where is the milk?" | paalə ṯaru | "give me milk" | paalə | "milk" |
| waal ewite | "where is the sword?" | waalə ṯaru | "give me the sword" | waalə | "sword" |
| mar̄am ewite | "where is the tree?" | mar̄am n̲asiccu | "the tree was destroyed" | | |
| | | mar̄am | "tree" | | |

The schwa insertion rule supplies a schwa rime to any onset not integrated into a syllable:

(10) c.




Since as illustrated in (10a) word final /m/ and /n/ are appendixes not onsets, words ending with /m/ or /n/ are not subject to schwa insertion.

To sum up, Malayalam syllables ending with /m/ and /n/ behave as though the syllable final consonants are not part of the rime constituent. This fact provides further plausibility to the suggestion we made above that in some languages it is necessary to recognize the appendix as a third constituent of the syllable in addition to the onset and rime.

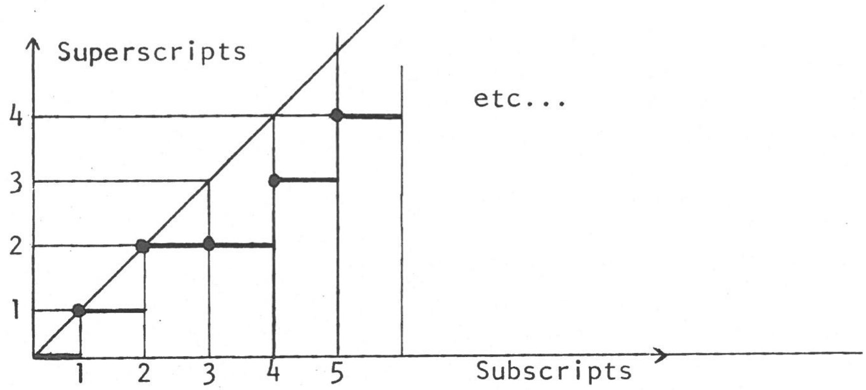
The treatment of the facts discussed above requires an elaboration of the formalism. We would like to argue that the required elaboration involves indexing of the elements that constitute each morpheme. Specifically, the general well-formedness condition on linking units in different tiers can be formalized quite simply as an invariance principle, i.e., most associations between morpheme melodies and the slots in the skeleton that have been encountered above can be characterized as preserving the CANONICAL INDEXING of each morpheme, where the term canonical indexing refers to the left-to-right counting of the units within the morpheme.

Canonical indexing is invariant in the unmarked case. In more complex cases, like those, e.g., of the Arabic binyanim II, V, XII, and XIII, some distortion is introduced in the correspondence between the canonical indexings of the two tiers--the morpheme melody and the skeleton slots. These cases can be clarified formally once it is realized that the splicing together of the two sequences of elements--the segments of the morpheme and the slots of the skeleton--can be represented as a step function in which each jump corresponds to a unit step in the "scanning" of the melody line. In these terms the linking lines in such examples as the binyan II form kattab illustrated in (4b) can be formalized as in (11a):

(11) a. $C^{1}_{1}$ $C^{2}_{2}$ $C^{2}_{3}$ $C^{3 \rightarrow \infty}_{4 \rightarrow \infty}$

where the step function involved is the one in (11b).

(11) b.




We stop at this point in order to survey the broad outlines of the picture that emerges from the discussion above. We have attempted to present here a variety of facts which cannot be readily dealt with in terms of the traditional one- (or two-) dimensional phonological representation where words are pictured as linear sequences of distinctive feature complexes. In place of this traditional framework we proposed that the phonological representation is a three dimensional object. Its core is constituted by a linear sequence of slots--the skeleton. Each morpheme of the word is represented by a sequence of distinctive feature complexes, which we have called the MELODY. The phonetic content of each skeleton slot is specified by means of lines that link the slot to a distinctive feature complex in one or more morphemes. The Well-formedness Condition (3a) defines what constitutes a proper link between a slot in the skeleton and a segment in a morpheme melody. The lines that link the melody with skeleton define a plane. Thus, the phonological representation of a word contains as many planes as there are morphemes in the word. In the least marked case, the segments of the different morphemes constituting a word are linked to consecutive blocks of segments in a unique left-to-right order. This type of linking, which was illustrated by the Hausa forms in (6a) and (6b), is also found in most of the phonological phenomena that have been subject to detailed linguistic investigation.

The examples we have focused on here have been of a rather different sort: they have been mainly instances where segments of one morpheme melody are linked both to slots that precede as well as to slots that follow the slots linked to a second morpheme. As we have seen, examples of this latter type are all but the standard case in the Semitic languages and are far from uncommon in Hausa. It was also noted that in languages with distinctive tone melodies, each melody is treated as a separate morpheme linked to the V slots in the skeleton generally without regard to links with any other morpheme.

In this paper we have examined certain other aspects of the proposed three-dimensional phonological representation. In particular, we have noted that skeleton slots do not simply succeed one another in linear order but have a special organization of their own. The most basic of these is the organization into syllables. We have presented evidence that the syllable consists of three distinct constituents--onset, rime and appendix--of which only the rime is obligatory. The constituent organization of the syllable is expressed not by means of boundary markers, but rather by means of trees on a separate plane anchored in the C and V slots of the skeleton. These trees provide a natural way for capturing the oft-noted equivalence between closed syllables and syllables with long vowels. The distinction between rime and appendix explains certain peculiarities in the sequential constraints on phoneme sequences as well as the differential treatment of certain closed syllables. Finally, the tree structures that express the constituent structure of syllables are formally identical with the tree structures encountered in the "metrical" treatment of other prosodic phenomena, most notably stress and vowel harmony (see Vergnaud and Halle (1979)). Moreover, constituents of the syllable--specifically rimes--are the terminal elements in which the stress trees are anchored. Thus, in some languages, a word may exhibit a number of independent constituent organizations, each of which is anchored in the C V skeleton.

Since the facts that we have investigated so far are rather limited, we are not in a position to make extensive claims about the validity of what we have proposed here. We expect to continue our investigations along the lines sketched above for some time into the future, and it is our hope that what we have presented here is sufficiently intriguing to induce colleagues to explore some of the problems in this domain where there is still so much to be learned.

FOOTNOTES

*This paper is a slightly edited version of the communication we presented at the GLOW symposium at Nijmegen in April, 1980. The material presented here is part of a longer work on metrical phonology which is now in preparation. We are grateful to W. R. Leben for comments on the Hausa section. This work was supported in part by National Institutes of Mental Health Grant #5 P01 MH 13990-13.

[1]Forms parallel to *gillel, *bizzez, do, in fact exist; e.g., pizzez "leap, prance", millel "utter".

[2]Shortening of the second syllable in littattaafai is due to a special rule which shortens a vowel in closed syllable (Leben, personal communication).

[3]The formula disregards the rimes /Vsp/ as in Lisplaut "hissing sound" and /Vsk/ as in Kiosk "kiosk", for which special provisions will have to be made.

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