

The Representation of Tone and the Parametric Variations of Tonal Systems

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The Representation of Tone and the Parametric Variations of Tonal Systems*

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0. Introduction

This paper is concerned with two closely related topics: the phonological representation of tone, and the parametric differences across tonal systems. The first two sections are devoted to the representation of tone. Section One deals critically with a number of issues central to a model of tonal representation. Section Two presents an approach to tonal representation in which tone, like other "suprasegmentals", is anchored in the prosodic structure. This "prosodic" model is able to relate tone features to other prosodic features (e.g. features for stress, and intonation), and accounts for different types of tones through parameter-setting. Section Three discusses the representation of tones in a number of different types of tone systems, and the implications of the prosodic approach.

1. Issues of Theoretical Importance for a Model of Tonal Representation

Four issues, namely tonal natural classes, number and types of tones predicted by the geometry of tone features, relation of rhyme structure to tonal complexity, and tone-bearing unit (henceforth TBU) in relation to syllable structure, are taken to be central to a model of tonal representation. These four issues will each be discussed in the sections that follow.

1.1. Natural classes of tones:

Shih (1986) has argued that in a number of languages, tone sandhi are most straightforwardly formalized by natural classes based on the shape of the contour tones (Shih 1986:13-20). For example, in Zhangping, a Min dialect, six citation tones exhibit the following tone sandhi alternations (Shih 1986:18):

- (1) a.
- $$\left\{ \begin{array}{l} [24] \\ [11] \\ [21] \\ [55] \end{array} \right\} \quad \text{--->} \quad [33]/__ \left\{ \begin{array}{l} [24] \\ [11] \\ [55] \\ [53] \end{array} \right\}$$
- $$[55]/__ \left\{ \begin{array}{l} [31] \\ [21] \end{array} \right\}$$
- b. $\begin{array}{l} [31] \\ [53] \end{array} \quad \text{--->} \quad [21]/__X \quad (X: \text{any tone})$
- (2) a.
- $$\begin{array}{l} \alpha_{\text{mid}} \\ [-\text{fall}] \end{array} \quad \text{--->} \quad [+level]/__[-\alpha_{\text{mid}}] \\ \text{-low}$$
- b. $[+\text{fall}] \quad \text{--->} \quad [+low] / __X$

The sandhi alternations exhibited in (1) are formulated by Shih into the rules in (2), which adopt the contour feature [fall] from Wang (1967). Tones in each natural class [-fall] and [+fall] then undergo different sandhi alternations accordingly.

The concept of "contour tone unit" (henceforth CTU) proposed by Yip (1989) is in accordance with the idea that contour tones of the Asian type often constitute natural classes based on the shape of the contour; i.e., rising tones (LH) in both upper and lower register ranges form a natural class, as do falling tones (HL). Although great differences exist between Yip's 1989 model and Wang's 1967 feature system in terms of the conceptual frameworks involved in tonal representation, the notion of CTU reflects the insight captured by the features [falling] and [rising] proposed by Wang in 1967. Models following the concept of "contour unit", including Yip (1989), and Bao (1989, 1990), are able to distinguish "contour" tones which are the result of the "clustering" of two tones (e.g. the African type), from those which truly form one unit (e.g. the Asian type) (Yip 1989). In contrast, models which take contour tones to be only the concatenation of two tones generally are incapable of making this distinction and are unable to classify "unitary" contour tones into natural classes.

1.2. Types and number of tones predicted by the geometry of tone features:

Bao's proposal (1989) of a "sister" relation between two tone features, which he called "register" and "contour," is most powerful in predicting the types of tonal assimilation (i.e. spread) which may occur in adjacent syllables. Unfortunately, there has so far been little evidence for the independent spread of contour as a unit. Until evidence comes forward in support of the spread of contour tone without also carrying over the register value, one will have to assume that Bao's model is too powerful.

As to how many tones a model of tonal representation must account for, there is still ongoing debate as to whether redundancy results in an overpowerful and thus less desirable model. Unlike Yip (1980, 1989), and Bao (1989, 1990), Duanmu's model (1990) allows three register heights, within which three-way pitch variations are provided.¹ With this provision, the model allows for 27 tonal contrasts within a tone system.² Hyman (1989) also provides for nine pitch contrasts, although it is not clear whether his model may apply to contour tones of the Asian type. It is obvious that both models permit many more pitch/tone contrasts than are found in attested tone systems and this raises doubts about them. Duanmu argues that only a small number of available segmental features is present in any language's phonology; therefore, the large capacity of his model does not result in any theoretical problems. However, unlike most segmental features, features for pitch (i.e. tone) are relative in nature, resembling features for vowel height. When so perceived, excessive contrasts may be a drawback for the model.

1.3. Rhyme structure and tonal complexity:

Duanmu's model differs from most other autosegmental approaches in that it attempts to relate the complexity of contour tones to rhyme structure, a relationship first advanced by Woo (1969), who proposed a moraic analysis of tone. Duanmu has incorporated Woo's insight and refuted a number of claims

that contour tones are sometimes borne by short vowels, e.g. in languages such as Mende and Igbo. According to Duanmu, short vowels which allegedly bear contour tones in these languages, upon re-examination, are phonetically of a duration much longer than usual, which is just what the moraic analysis of contour tones predicts.³ The relation between rhyme structure and tonal complexity explains why the complexity of contour tones in the world's languages is greatly constrained i.e. the most complex contour tone bears a contour shape consisting of no more than three digits by Chao's tone letters, the concave/convex type. Approaches which take the syllable to be the TBU cannot explain this close relation, and must assume that tonal components are simultaneously associated with the nuclear segment in the rhyme. The drawback of these approaches is that no theoretical constraint is available in the model to explain why extremely complex contour tones (e.g. [3141] falling-rising-falling) are unlikely to exist and are so far unattested

1.4. TBU and syllable structure:

There are two issues under discussion in this section, i.e. the nature of the TBU, and the syllable structure within a language. Following Clements' claim (1983) that TBU in many African languages is the mora, Duanmu (1990) takes this claim a step further and treats the mora as the universal TBU. However, in doing so, one factor, i.e. the syllable structure of the language, has to be taken into consideration in order for the tonal representation to work. Duanmu claims that all syllables in Chinese are bimoraic, and thus all potentially bear contour tones. According to him, the "checked" syllables, i.e. those with -p, t, k, or glottal stop endings, though acoustically shorter in duration than other syllables, are also bimoraic in structure, and may underlyingly bear contour tones. Unfortunately Duanmu cites only one example of the sandhi alternations of a "checked" tone in Taiwanese. More evidence is needed to support (or discredit) his claim that all Chinese syllables are underlyingly bimoraic.

To sum up, a satisfactory account of tonal representation must be able to deal with the four issues pointed out in the preceding sections. That is, a model of tonal representation must account for natural classes of tones, provide a sufficient but not overpowerful account in terms of the number and types of tones within a tone system, explain the close relation between rhyme structure and tonal complexity, and explore the relation between the nature of TBU and the syllable structure of the language. In addition, a satisfactory model also needs to specify the tone features involved, and the overall geometrical relationship of tone features to other features. In the sections which follow, I will attempt to put these issues in perspective, and present a new approach to tonal representation.

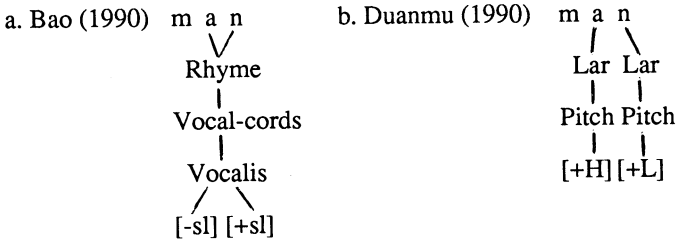
2. A New Approach

2.1. The paradoxical nature of TBU:

It has been proposed that the universal TBU is the mora (Duanmu 1990). In Duanmu's analysis, moras on the core (i.e. skeletal) tier are directly associated in a one-to-one fashion with the segments which carry tones, and no special provisions are needed to avoid violating the association conventions in autosegmental theory.⁴ Moreover, since the relevant tone features are specified under the segments associated directly to moras, there is no need to provide for

any processes which transfer the tone features borne by the entire rhyme into the feature arrays of the segment(s) in the rhyme. This point is illustrated by a comparison offered by Duanmu himself (reproduced from Footnote One on p.152):

(3) Comparison of two representations of the Mandarin word *man* [51] "slow" (with Register omitted):



In Duanmu's analysis, the tones are directly represented under the laryngeal nodes of *a* and *n*. In contrast, TBU in Bao's system is the rhyme as a whole, and the falling tone [51] is considered to be a CTU. It is not immediately clear how the tone may be physically realized on the segments in the rhyme. Bao has suggested a process of "segmentalization" which links the tone features to "the laryngeal node of the head of TBU" (Bao 1990:2). Plausible as it is, such a process is spared by Duanmu's moraic approach to TBU.

However, from a different perspective, it seems that the syllable is indispensable to the representation of tone. From the traditional treatment of tone as a "suprasegmental" property to the treatment of tone in "autosegmental" phonology (such as Goldsmith 1976, Leben 1978, and Yip 1980), there is no disputing that tone differs from segmental phonemes in its domain (i.e. larger-than-segment quality) and its ability to spread to adjacent syllables. The syllable is usually the level to which tonal spread, tonal reduplication, and natural classes of contour tones **must** refer. Even Duanmu, who argues extensively for the moraic TBU, cannot eliminate reference to the syllable.⁵ Moreover, even though Duanmu argues that the analysis of whole tone spread (as in Yip 1989, 1991, and Bao 1989, 1990) may be replaced by tonal copying, this process nevertheless involves the reduplication of tone(s) at the **syllable** level. The pivotal status of the syllable in tonal processes is so compelling that attempts to restrict tonal representation exclusively to the domain of the mora are unlikely to have universal appeal unless the system also refers to the level of the syllable.

However, as noted already, if the TBU is the syllable (as in Yip's and Bao's models), there is no explanation for the close relation between rhyme structure and tonal complexity. It seems, then, that we are presented with a paradox. The resolution of this paradox, I would like to suggest, lies in a new way of perceiving tonal representation. Tone features, similar to other potential prosodic features for stress and intonation, are borne by relevant entities on the prosodic structure, instead of being directly included in the geometrical array of features linked to the laryngeal node of the tone-bearing segment. The following sections will provide details of this new approach.

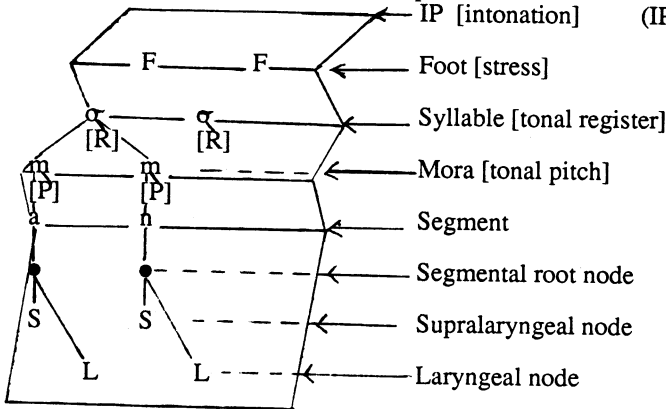
2.2. Tone features as properties of the prosodic structure:

2.2.1. Tone features are prosodic features. We might ask whether tonal representation is simply a matter of the geometrical array of all relevant articulators and features. Although tones **must** be realized through the orchestration of articulators and features, which are in turn part of the feature geometry of the relevant segments, an approach which considers tonal representation to be nothing but a geometrical arrangement of features under the laryngeal nodes of relevant segments, in my opinion, has overlooked an important issue, i.e. the status of tone in the overall picture of phonology. The phonetic property of tone (i.e. "pitch") may be simplistically perceived as the variations of fundamental frequency within a domain (such as a syllable). Although the variations of fundamental frequency are mapped onto the vocalic segments, they are nevertheless not a **property** of the segments.⁶ As a distinct property independent of the segments, tone not only often needs to refer to a higher level of the prosodic structure (e.g. the syllable), but it is also conceptually closer to prosodic elements such as stress, which has been analyzed on the basis of the prosodic (or metrical) structure, not in terms of the geometrical array of segmental features.

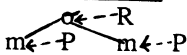
In this section, I will propose that tone is a property of the prosodic structure. Two prosodic levels, namely the syllable and the mora are pertinent to tone; tone features are borne by the entities on these two prosodic levels. This concept is illustrated in (4) and (5) below:

(4) Tonal representation in the prosodic structure:

(IP: intonation phrase)



(5)



(R: register; P: pitch)

2.2.2. The relation of tone features to other prosodic features. In the prosodic structure, all features relevant to the prosody of the language are present. In addition to features relevant to tone, prosodic features relevant to other traditionally-called "suprasegmentals" such as stress and intonation are also anchored at relevant prosodic levels. Although stress has long been analyzed on the basis of the metrical (i.e. prosodic) structure, the discussion of its **features** is almost nonexistent so far. Despite lingering uncertainty about the nature of the features involved in stress (e.g. loudness, pitch), one must assume the **existence**

of such features if prosodic contrasts are to be realized in articulation. Furthermore, to some extent, prosodic features for intonation and stress may be similar (or the same in some cases) to those for tone. The difference lies mainly in the level at which the feature is anchored, and the process by which the prosodic units are realized. In this conceptual framework all potential prosodic features originate in their relevant levels within the prosodic structure, and are borne by elements on these levels such as syllable, mora, and foot.

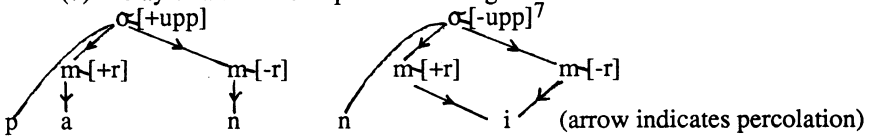
2.2.3. The principle of percolation. In the approach proposed here, tonal representation consists of three inter-related processes. Structurally, tone has its root in the prosodic structure. Tone features, which are referred to as register and pitch features for the purpose of discussion here, are borne by syllables and moras on the relevant prosodic tiers. They then undergo the process of "percolation", which facilitates the coordination of all features into articulatory reality. In the execution of articulation, tone features must be geometrically arranged in the overall array of features. In this section, we propose a principle by which the percolation of prosodic features can be carried out. It is stated in (6) below:

(6) Principle of Percolation:

Prosodic features (e.g. tone features) at a certain level in the prosodic structure must percolate through elements on each subsequent level until they reach the laryngeal node under a segmental root node.

As stated in (6), percolation can be carried out only if a legitimate element is present at each subsequent level. I will henceforth refer to this prerequisite as a "relay" in percolation.

(7) Relay of a successful percolation: e.g.



In the example above, the register feature can percolate down to the moraic segments in the syllable but not to the onset, because no element is available at the mora level to carry out the percolation for the onset segment. Note that the requirement of relay in percolation also applies to the percolation of any potential features for stress and/or intonation, in which the percolation process must abide by language-specific rule(s) regarding how stress (or intonation) is assigned.

2.3. Tone features and the realization of tone:

2.3.1. How many tones should tone features provide? The two features Register (i.e. [upper]) and Tone (i.e. [raised]) proposed by Yip (1980) are perhaps the most widely adopted system of tone features to date. Feature systems consisting of two features along the line of Yip's are not only able to capture the register split which occurred historically in many Asian tone languages, but are also able to provide a highly plausible tonal inventory with only four level tones, two rising, and two falling tones. Except for a small number of languages which are reported to have five level tonal contrasts (Maddieson 1978:338), Yip's feature system seems to suffice to account for the great majority of the world's tonal systems.

However, these exceptions must be dealt with, because at least a few are not readily subject to alternative analyses which may reduce the number of contrasts (e.g. Black Miao and Tahua Yao). One candidate capable of accounting for five-level contrasts is the system proposed by Duanmu (1990). However, as mentioned in 1.2., Duanmu's system raises some question as to whether it is too powerful.

Yip (1980) suggested that a third feature such as Woo's [+/- modify] may be used to account for a tone system with five level contrasts. No detail, however, was given as to how the third feature could be added. In pre-autosegmental analyses, Woo's system (1969) accounts for five level tones by means of three features, i.e. [high], [low], and [modify]. By the feature [modify], she assumed that the frequency range of each tone is narrower in a five level tonal system than that in a three level tonal system. However, Maddieson (1978) showed that as the number of level pitch contrasts increases, so does the entire frequency range utilized by the language. Instead of [modify], Maddieson suggested a feature such as [extreme]; thus in Maddieson's view, a system of five pitch contrasts consists of the more common high, mid, and low tones, plus two more, the extremely high, and the extremely low tones.

I agree with Maddieson on the phonetic reality of the feature [+/- extreme]. However, I also accept Yip's feature Register, which nicely recapitulates the historical development of register split in Asian tonal systems. Moreover, Maddieson's feature system does not readily account for tonal systems with four level contrasts. That is, in a rather common system which contrasts four level tones, one of the tones has to be specified with [+extreme]; it is not clear as to how the feature values of these tones are determined.⁸

I believe that Yip's original feature system is basically on the right track, but it must also provide for five-level contrasts with the addition of a feature along the line of Maddieson's [extreme]. A tone feature system, I suggest, may include a feature for the binary distinction of register, a feature fine-tuning the register range, and a highly marked feature which allows for the extremity of either high or low pitch. I will return to discuss the exact nature of these features after examining the articulators involved in the realization of tone.

2.3.2. The physiology of tone. One of the recent concerns in proposals of tonal models is the phonetic reality of tonal representation. In order to develop a model which reflects the articulatory reality of tone features, a better understanding of the physiological aspect of tone is crucial.

Ohala (1973) has attempted to point out a number of physiological factors involved in achieving variation of pitch (i.e. fundamental frequency). In his words, "the F_0 [i.e. the fundamental frequency] of voice is determined basically by two partially independent factors: (a) the state of the vocal cords and (b) the aerodynamic forces driving the vocal cords." He further pinpointed the physiological makeup involved in these two factors. That is, changes of vocal cord tension or glottal configuration are made possible by the muscles attached to the larynx, including the cricothyroid muscles, as well as other muscles of the larynx such as the adductor muscles, and the extrinsic laryngeal muscles (Ohala 1973:4-6). In addition to factors such as the position of the tongue, elevation of the larynx, and voicing, which result in secondary variation of pitch, according to Ohala, most evidence seems to point to "the activity of the laryngeal muscles" to be "the primary force" behind all major linguistic pitch variations (p.5).

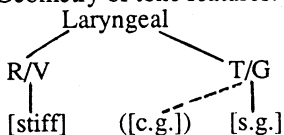
Both Duanmu (1990) and Bao (1990) have developed an articulator-based model. Bao suggests that the articulator for Register is the cricothyroid muscles, and that for Contour it is the vocalis muscle. Duanmu's view, on the other hand, is the opposite: to him, V/R in his system is likely to be related to the vocalis muscle, while Pitch is related to the cricothyroid muscles. In addition, Bao and Duanmu also disagree on the mechanisms involved in tonal variations. Bao considers the vocal cord tension to be the determinant for tonal variations in general. Duanmu considers the articulator V/R to be related to vocal cord tension, but the articulator Pitch to vocal cord thickness. It is not clear to me if their decisions on the articulators were based on precise phonetic evidence, or simply due to a theoretical need to correlate their proposed features to some plausible articulators in the realization of tone.

The physiology of tone appears to be a very complicated matter in reality, a matter perhaps so far not completely understood. It seems quite certain that the variation of pitch (i.e. the production of tone) closely involves the laryngeal muscles. In addition, it could be possible that tonal variations are accomplished through the coordination of a number of muscles intrinsically (and perhaps extrinsically) attached to the larynx such as the vocalis, and the cricothyroid muscles. As our current knowledge stands, the attempts to pinpoint the so-called "articulators" in relation to the tone features proposed for a tonal model are at best no more than speculative in nature. Such attempts serve more of a notational purpose than as a clear explanation of the physiology of tone.

In the discussion which follows, I will therefore consider the articulators in the tonal model as unspecified entities (which, however, are most likely to be related to the larynx. For the purpose of exposition, I will adopt some of the articulatory terms proposed by Duanmu; however, I basically take no position on the exact nature of the articulators involved in the tonal realization and leave this issue open for future investigation.

2.3.3. The geometry of tone features. In 2.3.1., I have pointed out that a tone model should provide for the rare cases of five-level contrasts, and at the same time, account for the register split so commonly seen in Asian tone systems. To facilitate this, I propose the following geometrical relation of tone features at the level of feature geometry:

(8) Geometry of tone features:⁹



R/V: register/voicing
 T/G: tone/glottis
 s.g.: spread glottis
 c.g.: constricted glottis

The laryngeal features adopted here are used somewhat differently from Halle and Stevens' original proposal. For instance, Halle and Stevens used [spread glottis] and [constricted glottis] mainly for representing *h* and *ʔ*; however, these features are used here for the purpose of representing pitch distinctions. The reason for adopting these features (instead of creating a set of new features) is due to the close relationship between "phonation types" of segments (e.g. creaky voice vs. breathy voice), which are closely related to laryngeal states, and registral/tonal distinctions, as exhibited in many Southeast Asian languages (e.g. Mon-Khmer languages). The articulators in (8) are intended to indicate such a close relationship by correlating tonal register with voicing, and pitch with the

glottal state of a segment, both of which are well documented by studies of tonogenesis in some Asian tone languages (e.g. Vietnamese and Chinese)¹⁰.

Under normal circumstances, dominated by R/V and T/G are specifications of features [stiff vocal cords] and [spread glottis] respectively. In rare exceptional cases, a tier usually unspecified under T/G for the feature [constricted glottis] may be specified, provided that the feature [stiff] is also specified with the same value as that of [c.g.]. The close relation between [c.g.] and [stiff] may be captured by the concept of "enhancement" in feature geometry. The feature [stiff] under R/V **enhances** the feature [c.g.]; that is, [c.g.], which, under normal circumstances, is unspecified under the articulator T/G, is restricted by the cooccurrence of the feature [stiff] with the same value specification. Specifications of [c.g.] indicate a highly marked case, with extremely high or extremely low tone. (9) below illustrates how tones are represented by the features in this alternative:

- (9) [+stiff]/[-spread glottis] Hh
 [+stiff]/[+spread glottis] Hl
 [-stiff]/[-spread glottis] Lh
 [-stiff]/[+spread glottis] Ll
- [stiff]/[c.g.] [-s.g.] Hh↑/Ll↓ (marked)

Until a better physiological understanding of tone is available I will consider (8) an adequate model for tonal representation at the feature level, but underline the continuing uncertainty concerning the nature of articulators and features involved in the model.

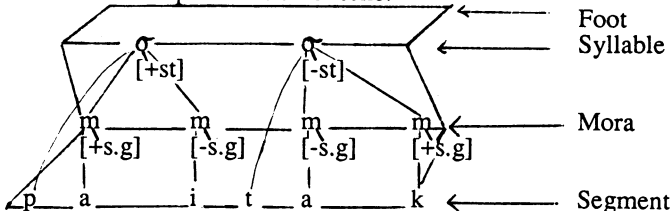
2.4. Summary of the new approach:

I have argued in this paper that tonal representation should be considered a part of the prosodic representation in phonology. In this global model of prosodic representation, all prosodic features originate at the relevant levels of the prosodic plane, and are borne by elements on these levels. Tone features, i.e. [+/- stiff] for register distinctions, and [+/- s.g.] for finer pitch distinctions, are borne by syllables and moras respectively. In the process of speech realization, prosodic features (e.g. tone features) percolate down to the segmental level according to the principle of percolation. The percolation process results in the geometrical arrangement of prosodic features under the laryngeal nodes of relevant segments; the geometrical array of all features then facilitates articulation.

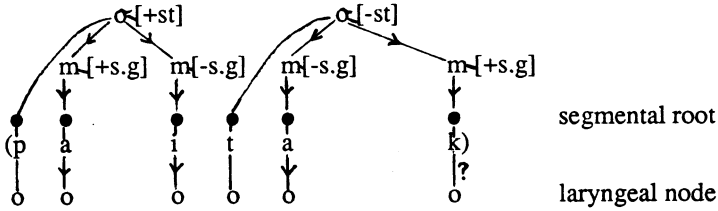
The three major stages regarding tonal representation are illustrated by the following example:

(10) A hypothetical example *pai*³⁵-*tak*³:

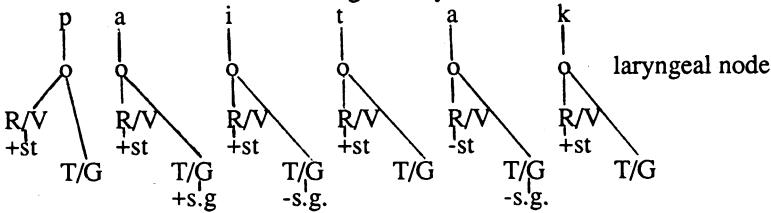
a. Prosodic representation of tone:



b. Percolation of tone features:



c. Tone features in feature geometry:¹¹



In (10c) above, tone features are relayed by elements at each subsequent level; therefore, syllable onsets are unaffected by the percolation, since there is no element at the mora level to relay the register feature. In the case of the syllable coda in *tak*, although the percolation can be relayed by *k*, tone cannot be realized since the syllable coda is voiceless and unreleased. When percolation does not apply, the specifications (and un specifications) of features depend on the voicing and the glottal states exhibited by the consonants.

3. Parametric Differences Across Tone Systems

3.1. Parameters for variation:

In the current approach, TBUs may consist of two levels: at a higher level, the feature for register distinction is borne by the syllables, while at a lower level, moras are the pitch-bearing units. Contour tones in Chinese languages are thus represented by a register specification at the syllable level and two pitch specifications at the mora level. The level(s) at which tonal representation occurs vary parametrically on the basis of the complexity of the tonal system and the syllable structure of the language. In systems where there are only two pitch contrasts, tonal specifications may occur at either the syllable or the mora level, resulting in different surface forms: specifications at the syllable level (i.e. H/L) result in only high/low pitch contrast among the syllables, while specifications at the mora level (i.e. h/l) may give rise to surface "contour" contrasts, depending on the syllable structure of the language. Tone systems which distinguish three-level pitch contrasts are trickier. The representation of the mid tone has two possibilities (i.e. Hl and Lh), and needs to be determined on the basis of the tone's behavior in the language; e.g., in Sicitte (or Tagba), a Senufo language of Burkina Faso, although there are three surface level tones, the patterns of alternation of the mid tone suggest that it may be underlyingly represented by both possible configurations, i.e. Hl and Lh (Garber 1988). Tone systems which consist of four

level pitch contrasts must be fully specified at both the syllable and the mora levels.

The current approach allows the spread of feature values at both the syllable and mora levels without interference between levels. In other words, register assimilation, pitch assimilation, and both register and pitch assimilations are predicted, but the spread of the entire contour tone (of the Asian type) is not.¹²

3.2. Implications of the Parametric Differences:

This approach provides a "parameterized" account of the differences which exist among tone languages in terms of the level(s) of tonal representation and the types of tonal spread. Moreover, the difference between nontonal and tonal languages is also captured by the proposed model of prosodic representation. That is, the difference between a nontonal language (such as English) and a tonal language (such as Luganda) does not necessarily lie in the absence/presence of tone feature(s), but in the level(s) (or prosodic planes) at which the relevant features are anchored.

To conclude, I have in this paper presented a view of tonal representation quite different in concept from most other previous proposals. The difference mainly lies in the following respect: tonal representation is considered to be part of the bigger scene of prosodic structure, but the realization of tone, nevertheless, must involve the geometrical arrangement of tone features at the segmental level. Future endeavors will have to work out some of the formal aspects of this model.

* I am grateful to Duanmu San and Bao Zhiming for discussing many issues with me. Thanks also go to Moira Yip for useful comments. I am solely responsible for any remaining errors.

1. Duanmu (p. c.) is now inclined to recognize only six level contrasts, which are marked by two register distinctions each with three pitch heights.

2. That is, if contour tones occur only in bimoraic syllables, as he claims. Moreover, this number is based on the assumption that contour tones do not cross register ranges. If there is no such constraint, the number is much larger (viz. 81).

3. The analysis of these vowels as short is due to either (1) a lack of contrastive vowel length in the language, or (2) the occurrence of contour tones pre-pausally.

4. Pulleyblank (1986) has formalized the Association Conventions governing the tone-mapping procedure as follows (1986:11):

"Map a sequence of tones onto a sequence of tone-bearing units,

(a) from left to right

(b) in a one-to-one relation."

5. To constrain his model of tonal representation, Duanmu has proposed two universal constraints as follows (1990:122):

a. Only segments in the rhyme (bearing a mora) can be assigned Pitch.

b. One Register per syllable (the emphasis is mine).

6. Except for some rare cases, tones are not determined by the quality of their bearers (i.e. vowels). This sets tone features apart from other features which also exhibit assimilation processes, such as nasal harmony and rounding harmony. In the latter cases, the features have their origins in the relevant segments (e.g.

[+nasal] is a property of a nasal segment); in contrast, tonal assignment in most cases is arbitrary and not related to vocalic qualities.

7. For convenience of discussion, I have adopted Yip's features for register and pitch: [+/-upp(er)] for the binary distinction of register range, and [+/-r(aised)] for the finer distinction of pitch heights within a register range.

8. The same criticism also applies to Woo's use of the three features [high], [low], and [modify].

9. For the phonetic definitions of the features [stiff vocal cords], [slack vocal cords], [spread glottis], and [constricted glottis], see Halle and Stevens (1971:201-2).

10. For a few representative works on tonogenesis, and discussion of "phonation" types in relation to tonogenesis, see Haudricourt (1954a and b), Mei (1970), Matisoff (1973), Thurgood (1980), and Diffloth (1989).

11. Note in (10c) that although the relay is successful in the case of the syllable coda of *tak* (i.e. following Duanmu who considers these "checked" syllables to be also bimoraic), there is some question as to whether tone features should be specified at the feature level, because the unreleased consonant coda is unable to realize the tone.

12. An argument for "whole tone" is presented by Yip on the basis of some data from Changzhi (see Yip's paper in this volume). However, a number of problems remain in the analysis of tone sandhi in Changzhi, and a discussion of these will have to wait for a different forum. More evidence of a less controversial nature is needed before any argument for "whole tone" spread can be established.

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