

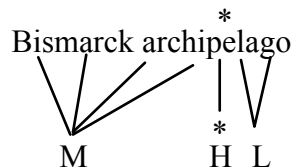
## *What is a starred tone? Evidence from Greek*

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### X.1 Starred and unstarred tones

The theoretical construct “starred tone” is assumed without comment in virtually all autosegmental analyses of intonation. The notation on which this idea is based—the asterisk or star to indicate accent—appears to have been introduced by Goldsmith in his early discussions of English intonation (1976, 1981). Goldsmith suggested that one syllable in the syllabic tier and one tone in the melodic tier are assigned an accent, “written with an asterisk” (1981:288). The fact that both the tone—e.g. the H tone of the basic declarative contour of American English, HL or MHL, shown in (1)—and the syllable are marked with a star ensures their autosegmental association and, the theory predicts, their phonetic co-occurrence. In addition, the accentual association makes the starred syllable “prominent or ‘distinguished’” (1976:117).

(1)



The star notation, with some modifications, was adopted by Janet Pierrehumbert in her 1980 dissertation which combines elements of the early work on intonation and tone by Goldsmith, Liberman (1975), Leben (1976) and Bruce (1977). Pierrehumbert’s original analysis was further refined and developed in Beckman & Pierrehumbert (1986) and Pierrehumbert & Beckman (1988). In Pierrehumbert’s analysis, the English intonation system involves an inventory of *pitch accents*, each consisting of one or two tones, High and Low. The monotonal H and L pitch accents are marked with a star (H\*, L\*), which indicates their association to metrically strong syllables. The star also distinguishes monotonal pitch accents from unstarred “phrase accents”, which (simplifying somewhat) are associated not with strong syllables but with the ends of phrases. In all of this,

Pierrehumbert's use of the star does not deviate from Goldsmith's.

Complications arise with the bitonal pitch accents. Pierrehumbert argues that in English there are four bitonal accents, which she writes as  $H^*+L$ ,  $H+L^*$ ,  $L^*+H$ , and  $L+H^*$ <sup>1</sup>. This means that an accent consisting of a sequence of two tones can be aligned with the accented syllable in either of two contrasting ways, and this contrast is indicated by starring one of the two tones. Phonetically, this use of the star is to be interpreted as signifying that the starred tone is aligned in time with the accented syllable, while the unstarred tone leads or trails the starred tone "by a given time interval" (Pierrehumbert, 1980:77). One observable consequence of the alignment difference between the two tones is that unstarred tones are subject to spreading in certain circumstances—Pierrehumbert (1980:221ff.) suggests that tone-spreading is the basis of stretches of level pitch that span several syllables in English—while starred tones are not expected to spread, precisely because they are already associated to a particular syllable. Finally, Pierrehumbert notes that phonologically the use of the star reflects a strength relationship between the two tones, such that "the starred tone is the stronger one, and the unstarred one is the weaker one" (Pierrehumbert, 1980:25).

Many aspects of the Pierrehumbert-Beckman approach—including the star notation—have been adopted without comment in subsequent work on the intonation of other languages (among others, Hayes & Lahiri, 1991, for Bengali; Féry, 1993, for German; Prieto, van Santen & Hirschberg, 1995, for Spanish). One can identify two main assumptions underlying the way in which the star is used in bitonal accents in this subsequent work. The first assumption is that association can be defined phonetically in terms of temporal alignment: a tone  $T$  associated with a segmental domain  $S$  will "occur" during the temporal interval spanned by  $S$ . As Silverman & Pierrehumbert put it "[autosegmental] links between elements constrain them to overlap, as they are produced in time" (1990:72). The second assumption is that the two tones in a bitonal accent are in a metrical relation which entails that one will necessarily be the stronger, i.e., that there will always be exactly one starred tone. Together these assumptions predict that phonetically (a) one tone in a pitch accent is aligned in time with the accented syllable; (b) unstarred tones are aligned relative to another tone rather than the segmental string; and (c) bitonal accents have "a fairly invariant time course" (Pierrehumbert & Beckman, 1988:123).

Although the assumptions just sketched seem quite widespread, in discussion of the present paper at the conference, both Pierrehumbert and Beckman insisted that the essential meaning of the star in bitonal accents is phonological, conveying above all the fact that *in English* there is a *categorical distinction* between two possible ways of aligning the tones of a bitonal accent with an accented syllable. While this may have been the original intention, we think that the two assumptions spelled out in the preceding paragraph are a fair summary of the way in which the Pierrehumbert-Beckman approach has been applied by others to other languages. Consequently, we think that examining these assumptions, and the phonetic predictions based on them, is a worthwhile undertaking, even if it is not strictly justified by a close reading of Pierrehumbert's and Beckman's original writings.

We may begin by noting that there are already some data that contradict the predictions mentioned above. For example, Silverman & Pierrehumbert (1990) present extensive evidence that phonetically, the  $F_0$  peak corresponding to the  $H^*$  prenuclear accent in English is often aligned with the onset consonant of the following unstressed syllable. Results of a similar nature on the late alignment of  $H^*$  accents in Spanish are also reported by Prieto *et al.* (1995) without comment. Furthermore, to our knowledge, there are no detailed empirical studies of how leading and trailing tones are aligned, except that it is generally assumed that “the position of the unstarred tone with respect to the segmental material ... varies considerably depending on the speech rate and the intrinsic length of the segments” (Pierrehumbert & Steele, 1989:183). To our knowledge the only author to go beyond such generalities is Grice (1995:215ff.), who proposes two different representations for leading and trailing tones arguing that leading tones are associated with the syllable preceding the accented syllable (if there is one available), while trailing tones occur a fixed interval in “normalized time” after the starred tone. However, no quantitative data are presented in support of this claim, nor is the notion of “normalized time” elaborated on.

Evidently, the slightly “skewed” alignment of accentual peaks (or valleys) that correspond to monotonal accents is not a serious problem for the theory. It could, for

example, be attributed to low-level phonetic factors, such as a sluggish response of the vocal folds to an “F<sub>0</sub> rise” command (c.f., for example, Anderson, Pierrehumbert & Liberman, 1984). As Pierrehumbert & Beckman note “tone durations are at least somewhat independent of the durations of the minimal tone-bearing units (1988:119-120). Thus, it can be argued that although phonological association is “digital”, phonetic alignment is “analog”, and hence prone to both language specific variation and universal traits, possibly of a psychoacoustic nature<sup>2</sup>.

However, if alignment is the sole exponent of the association of tones to segments, phonetic variability in this domain becomes a crucial issue when the phonological structure of a bitonal accent is in question. In the remainder of this paper we present evidence that such problems do arise. In particular we show that there exist pitch accents that are clearly bitonal but in which neither tone is, strictly speaking, aligned with the accented syllable. We argue from this fact that association cannot be based on phonetic alignment in any straightforward way and that a more abstract and rigorously defined notion of starredness is required.

## X.2 Greek prenuclear accents

The case we wish to discuss in detail is the prenuclear accent in Modern Greek. One striking feature of Greek intonation is that in a wide range of declarative utterances, all accents but the final accent of each intonational phrase can be of the same type. A few examples are shown in Figure X.1.

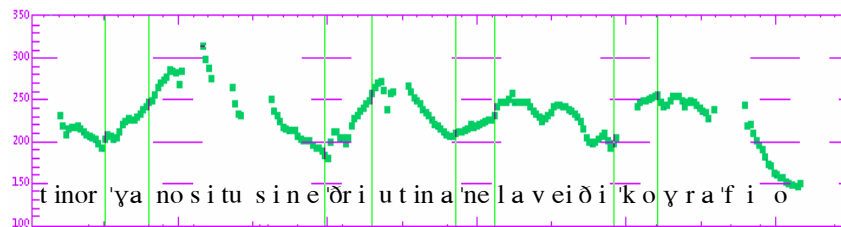


Figure X.1. F<sub>0</sub> trace of the sentence [tin or'yanosi tu sineðriu tin a'nelave iði'ko ɣra'fio] lit. “the organization the conference-GEN it undertook specialized company” “the organization of the

conference was undertaken by a specialized company.” Vertical lines mark the edges of the prenuclear accented syllables.

### X.2.1 Evidence for a bitonal representation

As is clearly shown in Figure X.1., these prenuclear accents involve a fairly sharp rise in  $F_0$  followed by a more gradual fall back to the baseline level. That is, they seem to consist of a tonal sequence LH, with the L and the H defining the beginning and ending points of the sharp rise.

This bitonal analysis of the pattern in Figure X.1 is borne out by experimental evidence. Concretely, the results of an experiment reported in Arvaniti and Ladd (1995) (henceforth AL95) seem to rule out an analysis in which the valleys in the contour reflect a “sagging”  $F_0$  transition between two  $H^*$  tones. The idea of the sagging transition was first proposed by Pierrehumbert (1980), who argued that the interpolation between two  $H^*$  accents in English is not monotonic; rather,  $F_0$  sags in such a way that the depth of the resulting valley increases with increased distance between the two  $H^*$  tones. This is clearly not the case in Greek. AL95 measured the  $F_0$  scaling of the valleys between prenuclear accents with from one to five unstressed syllables intervening, and found no effect of the number of intervening syllables at all. This suggests strongly that the prenuclear accent patterns reflect the occurrence of distinct L and H targets, and appears to rule out a single-tone,  $H^*$  representation.

### X.2.2 Is the L or the H the starred tone?

Given that Greek, like English, has dynamic stress and an inventory of pitch accents from which speakers can choose the one appropriate for the meaning they wish to convey, our assumption was that the LH sequence associated with metrically strong prenuclear syllables in Greek is a bitonal accent. Furthermore we assumed that one of its constituents would normally be aligned with the accented syllable, and thus be the starred tone of the accent, while the other would probably show some evidence of spreading or of being aligned relative to the starred tone.

Instrumental inspection, however, revealed that both the L and the H involve local

maxima and minima (i.e., there is no evidence of tone-spreading), and, more importantly, neither is aligned with the stressed syllable: the rise defined by the LH sequence in most cases begins before the accented syllable and ends after it (see Figure X.1. for an illustration of this pattern).

On the other hand, AL95 found that the L tone, in addition to the invariant scaling discussed in X.2.1, shows invariant alignment as well: the L is consistently aligned just before the beginning of the accented syllable—specifically 5 ms, on average, before the beginning of the accented syllable’s consonantal onset. The alignment of the H tone, in contrast, showed both individual and context-dependent variability, which resembles the behavior expected from a trailing tone (e.g. Pierrehumbert & Steele, 1989). On the basis of these findings, AL95 (following Arvaniti, 1994) concluded that the L tone is the starred tone of the accent: while neither tone is normally aligned with the accented syllable itself, L appears more invariant than H, suggesting phonological association.

Yet there are reasons to doubt that L\*+H is the correct representation. Two possible, and somewhat contradictory, alternative analyses suggest themselves. One is L+H\*, a representation that is consistent with the fact that Greek prenuclear accents sound *high* not *low*. If starredness is at all related to strength, intuitively one would expect the perceptually more salient tone to be the starred one. More substantively, recent evidence suggest that the stability of the L tone’s alignment may be unrelated to starredness. In particular, Prieto *et al.* (1995) found that while the alignment of H\* peaks in Spanish is extremely variable, the start of the rise for the accent is always located “precisely at the syllabic onset or just a few milliseconds into the onset [...] between 0.8 and 12 ms” (1995:446). Yet, the start of the rise, though low, does not involve a L target: Prieto, Nibert & Shih (in prep.) show that, in contrast to the Greek data of AL95, “the larger the distance [between accents], the lower the L value is” (quoted in Prieto *et al.*, 1995:446). Similar stability in the alignment of valleys which are not considered to be L targets is reported in Caspers & van Heuven (1993) for Dutch, suggesting that there may be a universal tendency for valleys to be stable, and for peaks to show variability in alignment. This suggests that stability of the alignment of the L may not be a safe criterion for representing the Greek accent as L\*+H.

On the other hand, there are also arguments for analyzing the LH configuration not as a bitonal accent at all, but as a sequence of a L\* accent and a H edge tone of some sort. This analysis is motivated by the observation that in the data of AL95 the alignment of

the H seems to be sensitive to the location of the word boundary: for two of the three speakers in that study, the H is aligned later if there are more unstressed syllables following the accent, but this effect does not extend past three such syllables. As it happens, in the corpus of AL95 intervals with one, two and three unaccented syllables correspond to words with final, penultimate and antepenultimate stress respectively; thus, it seems plausible that the alignment of the H is related not only to the number of following unstressed syllables, but also to the position of the accent relative to the end of the word: the further the accent is from the boundary, the later the alignment of the H tone. That is, the H may be an edge tone *for the word*, which would tend to move to the right of the stressed syllable until it meets a word boundary.

Neither of these alternative analyses (L+H\* or L\* H sequence) is well enough supported on its own to cause us to reject our original L\*+H analysis, but the fact that we can find evidence for three contradictory conclusions suggests that it might be worth reexamining the entire problem on the basis of new phonetic data. This reexamination is discussed in the next subsections.

### X.2.3 Could the H be a word-edge tone?

We first consider evidence relevant to the analysis with a L\* accent and a H edge tone. To test the idea that the alignment of the H is sensitive to the distance between the accented syllable and the edge of the word, we performed an experiment (henceforth Experiment 1), in which we manipulated the segmental composition (and hence the actual duration) of the constant two-syllable post-stress interval of proparoxytones (words with antepenultimate stress). For example, we compared the alignment of the H in the sequence [tiko] in the (underlined) test word of (2) with the alignment of the H in the corresponding sequence [makra] in (3)<sup>3</sup>.

(2) [to ro'ðitiko to'pio 'ine apo ta ore'otera tis e'laðas]

lit. “the rhodian landscape is from the more-beautiful the Greece-GEN”

“The landscape of Rhodes is among the most beautiful of Greece.”

(3) [ta a'pomakra vra'xaca 'isa pu ðia'krinondan 'mesa stin o'mixli]

lit. “the distant rocks(dim.) just that be-distinguished in the fog”

“The distant rocks could just be seen in the fog.”

This approach was based on the idea that, if the H is an edge tone, then the “distance between the accented syllable and the edge of the word” should be a matter of actual duration considered as a continuous phonetic variable, rather than some “phonological distance” that increases in syllable-sized steps. (This summary simplifies the rationale behind this experiment; for more detail on it and the other experiments discussed here the reader is referred to Arvaniti, Ladd & Mennen, 1998.) However, our initial hypothesis was not borne out. What we found instead was that, under these experimental conditions, the alignment of the H is as invariant as that of the L. Specifically, the H in proparoxytones is aligned on average 10.6 ms (s.d. = 14.1) after the onset of the first postaccentual vowel.

As this result was rather unexpected, we decided to try to replicate it in a second experiment (henceforth Experiment 2). In Experiment 2 we more systematically manipulated the duration of the interval between the onset of the accented syllable and the beginning of the following unaccented vowel, by varying the segmental composition of the syllables involved. This variation is illustrated in examples (4) and (5), two sample sentences from our materials, in which the relevant interval is long in (4), [vjen], and much shorter in (5), [lem]<sup>4</sup>.

(4) [ˈama ˈvjenume ˈekso to ˈvraði ta peˈðja ta kraˈtai i miˈtera mu]

lit. “when we-go out the evening the children them keeps the mother my”

“When we go out in the evening, my mother looks after the kids.”

(5) [ta ɣlikoˈlemona pu aˈɣorasēs ðen ˈitan ˈfreska]

lit. “the limes that you-bought NEG were fresh”

“The limes you bought were not fresh.”

Our hypothesis was that the distance in ms between the L and H tones of the accent would be proportional to the combined duration of the accented syllable and the first postaccentual consonant, while the distance of the H tone from the onset of the first postaccentual vowel would not correlate with that vowel’s duration.

The results confirmed our hypotheses and clearly replicated the finding of Experiment 1: in the case of proparoxytones at least, the H tone of a prenuclear accent is aligned just after the onset of the first postaccentual vowel (mean = 17 ms; s.d. = 31.9), irrespective



of the vowel's duration. This suggests that we are not dealing with a word-edge tone, since the alignment of H in proparoxytones appears to be governed relative to the accented syllable and not relative to the following word-edge. Moreover, the results are not consistent with analysing the H as a trailing tone either, since it is aligned relative to a fixed segmental landmark rather than a stable distance from the L tone of the accent; recall the claims of Pierrehumbert (1980) and Grice (1995), quoted earlier, that trailing tones would be expected to follow the starred tone by a fixed temporal interval.

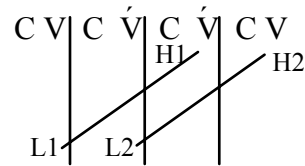
This conclusion was largely supported by the results of a further experiment (Experiment 3). For Experiment 3 we created a set of sentences in which we manipulated both the position of the prenuclear accent under investigation relative to the right word-edge and, separately, the number of unaccented syllables following the accent; thus the experiment included proparoxytones, paroxytones (words with penultimate stress) and oxytones (words with final stress), while the number of unaccented syllables following the prenuclear accent under investigation ranged from zero to three. The results (based on the data elicited from three speakers who had taken part in the previous experiments and analysed following the same procedure as before) show that the alignment of the H is relatively stable in paroxytones and oxytones, though it exhibits greater variability and between-speaker variation than in proparoxytones. These results recall some of the effects demonstrated by Silverman & Pierrehumbert (1990) for prenuclear H\* in English, and by Prieto *et al.* (1995) for H\* in Spanish, and indicate that both tonal crowding and word edges may be relevant to tonal alignment in Greek, as they are in Spanish and English. At the same time, our results by and large support the conclusion of Experiments 1 and 2 that the H of the prenuclear accent is not a word-edge tone.

#### X.2.4 H vs. L in stress clash

As mentioned, in Experiment 3 we also looked at clash cases, i.e., cases in which prenuclear accents appeared on adjacent syllables. As has often been noted in the literature, such cases create pressure both metrically (e.g. Nespor & Vogel, 1989; Vogel, Bunnell & Hoskins, 1995) and tonally (Bruce, 1977; Silverman & Pierrehumbert, 1990;

Prieto *et al.*, 1995) and require some kind of resolution. The clash cases of Experiment 3 are particularly interesting, since in these cases two tones—the H tone of the first accent (henceforth H1) and the L tone of the second accent (henceforth L2)—are both competing for alignment with the same string, as shown in (6).

(6)



Our data show that in such cases the speakers have three distinct strategies for resolving the competing alignment requirements of the tones<sup>5</sup>. The first, which is relatively rare, is to deaccent the first word. The second, which is rather more common, is to use an accent that sounds impressionistically *low* for the second word in the clash, a strategy that has also been reported by Prieto *et al.* (1995) for Spanish. Our original analysis of this configuration was that it involved the replacement of the second LH accent by a different accent type, but Prieto *et al.*, who deal with similar data in Spanish, attribute it instead to an overlap of “two underlying gestures, resulting in a rising-falling gesture” in which “the rise [corresponds] to the first accent and the fall to the second accent” (1995:442).

By far the most common strategy for dealing with clashes, used in more than half of the cases in our data, is to undershoot or eliminate L2 and leave H1 and H2 fully realized. Specifically, our results show that for two of our three speakers the interval in Hz between L1 and H1 remains unaffected in the clash condition, though the alignment of H1 is earlier; in contrast, the scaling of L2 is clearly higher than normal, i.e., L2 is “undershot”. (The third speaker also showed a statistically non-significant trend for L2 undershoot but mostly aligned L2 later than normal.) The pitch trace of a typical clash case resolved in this way is shown in Figure X.2. In short, then, our data suggest that H1, as a tonal target, takes precedence over L2. The primacy of the H tone is all the more significant if one considers that a H will be perceived as such even if it is marginally higher than a preceding L, while it is more difficult for a L to be perceived if it is undershot (see Grice, 1995:189-90 for a discussion).

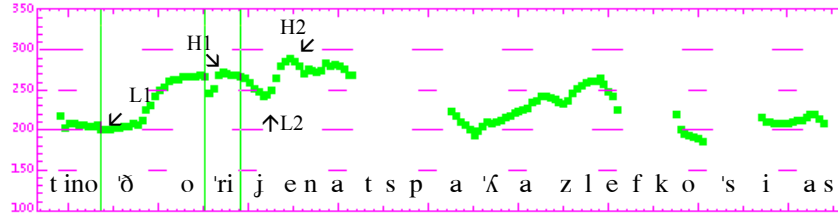


Figure X.2. Example of clash resolution in which the L of the second accent [L2] is undershot. The phrase reads [tin oðo 'rijenas ts pa'λaz lefko'sias] lit. “the street Rigenas of old Nicosia” and forms the first part of the sentence “Rigenas Street in old Nicosia, I know [it] very well.” Vertical lines mark the edges of the syllables in the clash, and arrows the position of the tonal targets.

### X.3 Discussion and conclusion

We may summarize our findings about the phonetic realization of the L and H tones in the Greek prenuclear accent as follows. When there is at least one unaccented syllable on both sides of the accented one—what we can term canonical conditions—both the L and the H tone show stable alignment *outside the temporal extent* of the accented syllable. Importantly, both tones are aligned with reference to the accented syllable, and there is no evidence that one of them aligns with reference to the other. In contexts of pressure due to tonal crowding, and particularly when there is a stress clash, the realization of H1 takes precedence over that of L2, though there is a trade-off in that H1 retains its scaling while L2 is more likely to retain its alignment.

These findings provide little evidence for choosing between the H or the L as the starred tone. Our original analysis of the accent as L\*+H seems to be the least well supported by the data. One argument against it is that the H does not exhibit the predicted alignment of a trailing tone. A second argument could be the relative instability of the L tone in clashes, which makes the L the less robust of the two tones, though this argument is weakened somewhat by Pierrehumbert’s (1980:75) observation that H tones raise L tones, even when the H in question is a leading tone in a H+L\* pitch accent.

The alternative analysis, namely that the accent is a L+H\*, is supported mainly by the clash data, which show the H to be more resilient under pressure. The problem posed by the fact that the L does not exhibit the predicted alignment of a leading tone (i.e., it does not precede the H by a fixed interval) could perhaps be avoided if one adopted Grice’s

(1995) proposal that leading tones are associated to the unaccented syllable preceding the accent, if one is available. This would account for the fact that the L tone of Greek prenuclear accents is normally aligned with the preaccentual syllable, and also for the observation that utterance initial accents do not start with as deep a valley as phrase internal ones (similar arguments for L+H\* accents in English are discussed by Grice, 1995:226ff.).

Yet there is a more general argument against starring *one* of the two tones in the Greek LH pitch accents, namely the fact that in Greek no contrast depends on the alignment of the bitonal accent, i.e., there is no contrast between L\*+H and L+H\* as there is in English (see also section X.2). As far as we can tell from our work on various aspects of Greek intonation, *prenuclear* accents take the form LH (though *nuclear* accents vary; e.g. in yes-no questions the nucleus is L\*, while in emphatic statements it is H\*). Thus, it has been suggested to us by Beckman and Pierrehumbert respectively that the accent should be represented without a star—i.e., as LH—or starred as a whole—i.e., as [LH]\*. We examine each of these alternatives in turn and discuss another solution that is perhaps marginally more satisfactory.

Not starring any of the tones is the solution chosen by Beckman & Pierrehumbert (1986) and Pierrehumbert & Beckman (1988) for the representation of the HL pitch accent of Japanese. We believe there are two problems with adopting this solution for Greek. First, Pierrehumbert & Beckman (1988) seem to define starless accents in such a way that they are really equivalent to accents with a star: they label the nodes of the Japanese HL accent as *s* and *w* respectively on the basis that the H tone is always aligned with the mora that is lexically specified to carry the accent. In our view this *s/w* labeling is for all intents and purposes equivalent to starring one of the tones. Therefore, representing the LH accent of Greek without a star would not obviate the problem. Secondly, even if it could be shown that Pierrehumbert & Beckman's notation for Japanese means something different from the star notation, it is probably inappropriate to treat Greek as being similar to Japanese. The position of the accent in Japanese is lexically defined and the accent as such does not enter into contrast with other accentual morphemes (only with the lack of accent). This is obviously not the case in Greek, which has dynamic stress and an intonationally meaningful inventory of possible pitch accents (though, as mentioned, Greek does not seem to us to have a contrast between L\*+H and L+H\*). Thus, if we adopt a starless LH representation we will be faced with one of the following: all pitch accents will have to be represented without a star, in which case it will be cumbersome, if

not impossible, to make a clear distinction between pitch accents and other types of intonational morphemes in Greek, such as phrase accents; alternatively, bitonal accents will have a different representation (e.g. LH) from one-tone accents (H\* and L\*). Neither solution seems satisfactory to us, and both suggest that the role of the star is different in bitonal and monotonal accents.

The alternative that avoids the problem of some pitch accents being starred while others are not is to adopt Pierrehumbert's suggestion of starring the whole sequence, i.e., to represent the accent as [LH]\*. We foresee one particular danger with this solution. Concretely, we believe that this notation could easily be interpreted as showing a *movement* rather than a sequence of independent tonal targets, when one of the fundamental tenets of the theory is precisely that intonational structure is based on tones *not* configurations. Apart from the general theoretical considerations in the "levels-*vs.*-configurations" debate, we feel that the data presented in Arvaniti *et al.* (1998) provide strong motivation for treating the L and the H as independent tonal targets.

Another solution, that in our view presents fewer problems than either the LH or [LH]\* representations, is to star both tones, i.e., to represent the accent as L\*H\*. This analysis can be argued for on the basis that both the L and the H tones are in fact aligned relative to the stressed syllable albeit outside its boundaries. If starredness equals association and association equals alignment *relative to* the metrically strong syllable (rather than *with* the metrically strong syllable), while lack of a star means alignment relative to another tone, then this conclusion follows naturally from the theory's predictions on alignment. Furthermore, this analysis has the advantage of keeping the star as a notation that distinguishes pitch accents from other intonational morphemes, and of showing that *both* tones are aligned with respect of a metrically strong syllable without suggesting that the tones underlyingly form a movement. The details of this association, which are only hinted at in the L\*H\* shorthand, would possibly be worth looking into.

It is at present rather difficult to decide among the five solutions presented here, and it is difficult to avoid the feeling that in some cases we have a distinction without a difference. To be sure, some of the five possibilities seem more promising than others, but the fact remains that the data are compatible with all five representations, and therefore the choice among them is not based on solid principles. This conclusion cannot but expose a weakness in the phonological basis of starredness and the definition of its phonetic exponents. The fact that our data do not allow us to reach a firm conclusion

suggests that not only can we not infer phonetic alignment from phonological association, but—more importantly—we cannot use phonetic alignment with the stressed syllable as the defining characteristic of starred tones, i.e., of their phonological association. Thus, it seems to us that the task for the future is, on the one hand, to refine the notion of the phonological association of tones in *intonational* systems, and on the other, to define with greater rigor and precision the phonetic exponents of association, so that empirical testing is both viable and fruitful. With respect to the latter task, we believe that an area deserving particular attention is what Pierrehumbert & Beckman (1988) term “the temporal location of tones”, a topic also discussed by Cole (this volume). The meaning of the term *tone* or *tonal target* is still quite unclear: do targets have duration as Pierrehumbert & Beckman and Cole suggest? If so, how is target duration to be defined and how does it relate to pitch perception? We believe that these are issues worth addressing not only because their investigation can shed light on matters intonational but also because it will lead to a better understanding of the interplay between phonetics and phonology.

### Notes

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<sup>1</sup> A fifth bitonal accent, H\*+H, was reanalyzed and dropped from the inventory of accents by Beckman & Pierrehumbert (1986), and is not considered further here; see Ladd (1996:273-77) for a brief discussion of the fate of H\*+H.

<sup>2</sup> A case in point may be Rossi’s (1971) finding, quoted in Beckman (1986), that the perceived pitch of a vowel with moving  $F_0$  corresponds to the frequency value reached roughly two thirds through the  $F_0$  excursion. Rossi’s results suggest that in order for the tonal target to be perceived as occurring on the accented syllable, the  $F_0$  peak has to be reached towards or after the end of this syllable, which is exactly the situation observed in the American English and Spanish data of Silverman & Pierrehumbert (1990) and Prieto *et al.* (1995) respectively. Such psychoacoustic evidence casts doubt on the validity of the assumption that  $F_0$  minima and maxima are to be equated with tonal targets.

<sup>3</sup> The experimental materials consisted of 22 sentences like (2) and (3), in which proparoxytone test words were set into natural sounding sentences and bore the prenuclear accent under investigation. The materials were recorded by five native speakers of Greek who read each test sentence eight times from a randomized list typed in Greek. The six most fluent and natural tokens were selected for analysis using standard ESPS Waves<sup>+</sup> facilities. The H was measured at the highest  $F_0$  point around the end of the accented syllable. As in some test words the accented syllable began with a voiceless obstruent, we considered the onset of the accented syllable as equivalent to the L and measured the distance of the H from that point.

<sup>4</sup> The speakers who participated in Experiment 1 read the 25 test sentences of the new corpus twice from a randomized list, and the more natural rendition of each sentence was selected for measurement. The same measurements as for Experiment 1 were made, except that in Experiment 2 the L target was taken to be the absolute  $F_0$  minimum in the vicinity of the accented syllable’s onset. This was possible because, unlike Experiment 1, in the materials for Experiment 2 the accented syllables had only sonorants and voiced fricatives as onsets.

<sup>5</sup> The data discussed in Arvaniti (1994) suggest different strategies for clash resolution. This discrepancy is most probably due to the fact that the majority of the sentences used in that study did not involve

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sequences of LH accents: either a prenuclear LH accent was followed by a nuclear H\*, i.e., the tones were not clashing, or the clashing syllables were separated by a H% intermediate phrase boundary.

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