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A directional asymmetry in Chinese tone sandhi systems

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Abstract Chinese tone sandhi systems are often classified as left-dominant or right-dominant depending on the position of the syllable retaining the citation tone. An asymmetry exists between the two types of systems: left-dominant sandhi often involves rightward extension of the initial tone to the entire sandhi domain; right-dominant sandhi, however, often involves default insertion and paradigmatic neutralization of nonfinal tones. I argue that the extension of a tone to a larger domain may serve two markedness purposes: the reduction of tonal contours on a syllable and the reduction of pitch differences across syllable boundaries, both of which have a rightward directionality preference. The former is due to the durational advantage afforded by final lengthening; the latter is due to the universal preference for progressive tonal coarticulation. I show that a theory that formally encodes these preferences via intrinsic constraint rankings can predict the directional asymmetry noted above.

Keywords Tone sandhi · Tone spreading · Contour tones · Optimality Theory · Factorial typology · Faithful Alignment

1 Introduction

1.1 Definition

Tone sandhi refers to tonal alternations conditioned by adjacent tones or by the prosodic or morphosyntactic position in which the tone occurs (Yue-Hashimoto (1987), Chen (2000), among others). The sandhi processes involving the Third

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Tone 213[1] in Beijing Mandarin are given in (1) as an illustrative example: the "Third-Tone Sandhi" changes 213 into the Second Tone 35 before another 213, as in (1a); the "Half-Third Sandhi" reduces 213 into its falling portion 21 before any tone other than 213, as in (1b).[2]

(1) Beijing Mandarin tone sandhi involving the Third Tone:

a. 213 → 35 / ___ 213
xaw213-tɕju213 → xaw35-tɕju213 'good wine'
tʂan213-lan213 → tʂan35-lan213 'exhibit'

b. 213 → 21 / ___ {55, 35, 51}
xaw213-ʂu55 → xaw21-ʂu55 'good book'
xaw213-ɻən35 → xaw21-ɻən35 'good person'
xaw213-kʰan55 → xaw21-kʰan51 'good-looking'

1.2 The left-dominant versus right-dominant classification of tone sandhi systems

A considerable amount of work has been devoted to the classification of Chinese sandhi systems into organic groups in the hopes that it will shed light on their complicated patterning. One viable option is to classify the sandhi systems as either "left-dominant" or "right-dominant" (Yue-Hashimoto (1987), Chan and Ren (1989), Chan (1995), Chen (2000)).

In a left-dominant sandhi system, the initial syllable in a sandhi domain preserves its base tone while noninitial syllables undergo sandhi. This is typified by Northern Wu dialects such as Changzhou and Shanghai.

Changzhou's tonal inventory on unchecked syllables, which include open syllables and syllables closed by a sonorant consonant, is 55, 13, 45, 523, and 24 (Wang (1988)).[3] The basic disyllabic and trisyllabic tone sandhi patterns in

[1] Tones here are transcribed in Chao letters (Chao (1948, 1968)), where "5" and "1" indicate the highest and lowest pitches in the speaker's pitch range, respectively. Juxtaposed numbers represent contour tones, e.g., "51" indicates a falling tone from the highest pitch to the lowest pitch.

[2] Another possible analysis of Beijing tone sandhi is that the Third Tone is underlyingly /21/ but becomes [213] in final position (cf. Duanmu (1999)). Though descriptively adequate, this position is difficult to defend from a typological perspective. As discussed in this paper and elsewhere in the literature, Northern Chinese dialects are known to have right-dominant sandhi. It is thus not clear why Beijing Mandarin would be an exception. Moreover, the complication of a tonal contour, even in final position, is much less common cross-linguistically than contour simplication in nonfinal positions. In Yue-Hashimoto's (1987) typology of Chinese tone sandhi, she found nearly a hundred cases of contour leveling or simplification but only three cases of contour complication. Therefore, it is not clear why we would want to entertain a typologically odd description when a cross-linguistically better attested option is available.

[3] We are only concerned with tones on unchecked syllables in this paper. Checked syllables—syllables closed by an obstruent /p/, /t/, /k/, or /ʔ/—are not discussed here as the obstruent codas may influence the behavior of tones independently of the syllable position and tonal features that this paper is concerned with and thus further complicate the already complex data patterns. A complete picture of tone sandhi, of course, must take into account such complications. But I have opted to start with a more modest goal, in the hopes that a complete picture will emerge once we have figured out all its parts.

Changzhou are summarized in (2). We can see that in general, in both disyllables and trisyllables, the tone on the first syllable is extended across the entire sandhi domain, taking over the original tones of the noninitial syllables. For example, if the first syllable has a rising tone 13, then the entire word assumes a rising melody.

(2) Changzhou tone sandhi:

σ_1	$\sigma_1\sigma$	$\sigma_1\sigma\sigma$
55	33-33	33-33-33
13	11-33	11-33-55
45	45-55	45-55-55
523	55-23	52-22-33
24	11-24	11-11-24

The blanket statement above clearly does not account for the nuances of how the initial tone is mapped onto the entire sandhi domain. For example, when the first syllable has an underlying high rising tone 45, the rise surfaces early in the domain, namely, in the first syllable. But when the first syllable has a mid rising tone 24, the rise does not surface until the last syllable. When the first syllable has an underlying tone 55, the tonal melody of the polysyllabic words is a mid level tone, not a high level tone. Wang (1988) also notes exceptional sandhi patterns that relate to whether the last syllable is reduced. Such complications may seem to cast doubt on the generalization that Changzhou tone sandhi involves rightward extension of the initial tone. But the similar behavior of a vast majority of sandhi patterns in not only Changzhou but also many related Northern Wu dialects indicates that this phenomenon is not purely accidental and deserves an analysis. This is also the position endorsed by Wang, the original fieldworker (1988: p. 194).[4]

The tone sandhi behavior of Shanghai is similar to Changzhou with one notable difference. Based on careful acoustic studies, Zee and Maddieson (1979) transcribed unchecked tones in Shanghai as HL, MH, and LH and summarized their sandhi behaviors as in (3). "$L^{\uparrow}$" in (3) indicates a raised Low tone. To remain faithful to the original source, I have opted to keep Zee and Maddieson's notation without adapting it to the five-point scale used elsewhere in the paper. As is evident in (3), the tonal melodies of polysyllabic words in Shanghai consist of two elements: the underlying tone from the initial syllable extended rightward for one or more syllables and a boundary Low tone at the right edge of the word when it can be accommodated. For example, if a tetrasyllabic word has an underlying LH on the initial syllable, then on the surface

[4] Another reason for holding off the analysis for the nuances in the sandhi patterns, not only in Changzhou but possibly in other dialects of Chinese, is that the tonal transcriptions were often based on the original fieldworker's auditory impressions rather than detailed instrumental analyses. I certainly do not wish, nor am I in a position, to impugn anyone's ear, but I do believe that subtle tonal differences are often extremely difficult to hear, even to seasoned field experts, as attested to by the ubiquitous discrepancies in tonal transcriptions among different sources of a single dialect. The caution we should exercise in the interpretation of impressionistic tonal transcriptions has also been emphasized in Chen (2000, pp. 17–19).

the L and the H are realized on the first two syllables, a boundary L is realized on the last syllable, and a Mid tone obtains on the third syllable as the result of interpolation between the second-syllable H and the right-boundary L. The behavior of the HL tone may require extra machinery to account for, as the L from the initial syllable and the boundary L seem to have merged into one and docked onto the right edge. But the difference between H-M-L and H-L-L may be subtle, as other sources of Shanghai tone sandhi, e.g., Duanmu (1996), have transcribed the tones on trisyllables as the latter.

(3) Shanghai tone sandhi:

σ_1	$\sigma_1\sigma$	$\sigma_1\sigma\sigma$	$\sigma_1\sigma\sigma\sigma$
HL	H-L	H-M-L	H-M-L$^{\uparrow}$-L
MH	M-H	M-H-L	M-H-M-L
LH	L-H	L-H-L	L-H-M-L

In a right-dominant sandhi system, on the other hand, it is the final syllable in the sandhi domain that preserves its tone while nonfinal syllables undergo sandhi. This is typical of most of Min, Southern Wu, and Mandarin dialects. The Beijing Mandarin example in (1) above illustrates this right dominance. The four tones in Beijing Mandarin are 55, 35, 213, and 51; the complete disyllabic tonal combinations in Beijing are given in (4). In the table, the first column and first row represent the base tones of the first and second syllables in a disyllabic word; the body of the table represents the surface tonal combinations. From the table we can see that the only sandhis that occur involve the Third Tone in nonfinal positions.

(4) Beijing Mandarin tone sandhi:

<table>
<tr><th>σ_1 \ σ_2</th><th>55</th><th>35</th><th>51</th><th>213</th></tr>
<tr><td>55</td><td colspan="4" rowspan="3">$T_{\sigma1}$-$T_{\sigma2}$</td></tr>
<tr><td>35</td></tr>
<tr><td>51</td></tr>
<tr><td>213</td><td colspan="3">21-$T_{\sigma2}$</td><td>35-$T_{\sigma2}$</td></tr>
</table>

Another example comes from the Southern Wu dialect Wuyi (Fu (1984)). Its tonal inventory has six tones: 24, 213, 53, 31, 55, and 13. The final syllable of a disyllabic word always preserves the original tone; but in nonfinal positions, tone sandhi neutralizes the inventory to two tones 55 and 11, as shown in (5).

(5) Wuyi tone sandhi:

<table>
<tr><th>σ_1 \ σ_2</th><th>24</th><th>213</th><th>53</th><th>31</th><th>55</th><th>13</th></tr>
<tr><td>24</td><td colspan="6" rowspan="3">55-$T_{\sigma2}$</td></tr>
<tr><td>213</td></tr>
<tr><td>53</td></tr>
<tr><td>31</td><td colspan="6" rowspan="3">11-$T_{\sigma2}$</td></tr>
<tr><td>55</td></tr>
<tr><td>13</td></tr>
</table>

It is clear that we are not in a position to predict exactly what the underlying tones neutralize to. One may also notice that the sandhi here involves counterfeeding opacity as 55 changes to 11, but 24, 213, and 53 change to 55 in nonfinal position. But the generalization that the sandhi involves local substitution of nonfinal tones with one of two simpler tones that are perceptually very distinct from each other (level tones 55 and 11) holds true nonetheless.

The Xiamen dialect in (6) (Chen (1987)) furnishes another illustration of right-dominant sandhi. It represents the famous "tone circle" in Southern Min: the tone on a word-final syllable remains unchanged, but the tones on nonfinal syllables undergo paradigmatic changes as indicated by the arrows in (6).

(6) Xiamen tone sandhi on nonfinal syllables:

53 → 44 → 22 ← 24
↖ ↙
21

The synchronic analysis of the "tone circle" pattern in Xiamen or other related dialects such as Taiwanese goes far beyond the scope of this paper. Attempts at such an analysis can be found in Wang (1967), Cheng (1968), Chen (1987), Lin (1994), Hsieh (2005), and Barrie (2006), among others. But we should also note that the tone circle in Taiwanese has been shown to be unproductive when native speakers are tested with novel words (Hsieh (1970, 1975, 1976), Wang (1993), Zhang et al. (2006)). What is relevant to our discussion here is that Xiamen tone sandhi, as a right-dominant system, involves paradigmatic substitution of tones on nonfinal syllables.

1.3 An asymmetry between left-dominant and right-dominant sandhi systems

From the examples in Sect. 1.2, we notice that there seems to be an asymmetry between the left-dominant and right-dominant sandhi systems, in that left-dominant sandhi tends to involve the extension of the initial tone rightward (Changzhou, Shanghai), but right-dominant sandhi tends to involve default tone insertion (Wuyi) or paradigmatic tone change (Beijing, Xiamen), **not** leftward tone extension.

This asymmetry is manifested to a tee in the Wu dialect Tangxi (Tangsic; Kennedy (1953)). In Tangxi, as predicted by the "Nonhead Stress" rule of Cinque (1993) and Duanmu (1990, 2000), modifier-noun compounds have initial stress and left-dominant sandhi while verb-noun phrases have final stress and right-dominant sandhi. Crucially, the left-dominant sandhi is characterized by rightward tone extension as shown in (7a): the entire compound assumes the melody of the first syllable. The right-dominant sandhi, however, is characterized by default insertion as shown in (7b): the final syllable keeps its tone while the initial syllable takes on a low level tone 22, which I consider to be a default tone.

(7) Tangxi tone sandhi:

a. Left-dominant sandhi in modifier-noun compound is characterized by tone extension:

σ_1	$\sigma_1\sigma$	$\sigma_1\sigma\sigma$
33	33-33	33-33-33
51	53-31	55-33-11
24	22-44	22-33-44

b. Right-dominant sandhi in verb-noun phrases is characterized by default insertion:

σ_1 \ σ_2	33	51	24
33	$22\text{-}T_{\sigma 2}$		
51			
24			

Again, there are details of both tone extension and default insertion that fall beyond the scope of this paper. In tone extension, we may notice that the 24 tone extends rightward differently from the 24 tone in Changzhou: the rise is evenly spaced out throughout the sandhi domain here as 22-33-44 but is realized towards the end of the word in Changzhou as 11-11-24. This difference, if significant (see footnote 4), will require machineries beyond the system introduced below to account for. I also hesitate to provide an analysis that predicts the inserted default tone to be exactly 22 beyond noting that the typological literature on tone has a tentative agreement that level tones are less marked than contour tones (Zhang (2002)) and low tones are less marked than high tones (Jiang-King (1996, 1999), de Lacy (2002)).

1.4 The goal of the paper

The goal of this paper is twofold. I first discuss a cross-dialectal typology of the left-dominant and right-dominant sandhi systems, and from it I deduce a precise formal statement of their asymmetry. I then propose a formal model of tone from which this asymmetry emerges as a prediction.

To preview the findings, the dialectal typology shows that the asymmetry is best stated as implicational statements such as "in a language with both left-dominant and right-dominant tone sandhis, if the left-dominant sandhi involves default insertion, then the right-dominant sandhi also involves default insertion; if the right-dominant sandhi involves tone extension, then the left-dominant also involves tone extension."

I argue that the extension of a tone to a larger domain may serve two markedness purposes: the reduction of a pronounced contour tone to lesser contours or level tones on each syllable in the domain and the reduction of pitch differences across syllable boundaries. Both types of extension have a rightward directionality preference, the former due to the durational advantage afforded by final lengthening, which provides a greater incentive for a contour to spread across the sandhi domain from the initial syllable than from the final syllable, and the latter due to the cross-linguistically observed preference for progressive tonal coarticulation over regressive tonal coarticulation. These preferences can be formally encoded in the theory via intrinsic constraint rankings, the former by ranking markedness constraints against contour tones on nonfinal syllables over markedness constraints against the same contour tones on final syllable, and the latter by ranking the faithfulness constraints against leftward tone extension over faithfulness constraints against rightward tone extension. The theory is then motivated by the match between its factorial typology and the dialectal typology and further illustrated with an in-depth analysis of the asymmetrical Tangxi pattern.

It should be noted upfront that there is one important aspect of Chinese phonology that this paper does not attempt to address, namely, whether stress is a relevant concept and, if so, how it should be determined. Duanmu (2000) proposes a collection of diagnostics from word morphology, such as restrictions on word length, word order, and movement within a compound, to argue for nonhead stress and trochaic footing in Mandarin Chinese. Wang and Feng (2006) argue that disyllables in the colloquial Beijing dialect fall under three stress categories—tonal trochees, non-tonal trochees, and tonal iambs—based on evidence from the acoustics of tones and native speakers' minimal pair judgments. Based on the effects of word length, syntactic configuration, and contrastive stress on sandhi domains, Duanmu (1995) argues that both Shanghai and Taiwanese have a metrical system and that compound stress is left-headed in Shanghai and right-headed in Taiwanese. I refer interested readers to these works for arguments for the presence of stress and how it should be determined in Chinese dialects. Crucially, I do not claim that the edge dominance of tone sandhi is either a diagnostic for or a consequence of underlying stress as, although the dominant edge and the location of stress sometimes coincide, as in Tangxi, they often do not. For example, although Mandarin has an invariable right-dominant sandhi pattern as shown above (except with the "neutral tone", see Sect. 2.1), the stress location of a disyllabic compound depends on the syntactic configuration of the compound as Duanmu (2000) has argued.[5] The original fieldworker of Wenzhou (Zheng-Zhang (1964)) has also noted that despite its right-dominance sandhi behavior, its stress falls on the initial syllable (p. 109). Hereafter, I take the edge of sandhi prominence as a given in the analysis, assuming that a language learner will have no trouble making this generalization, and use an undominated constraint

[5] As noted in footnote 2, Duanmu (1999) does not treat Beijing Mandarin tone sandhi as right-dominant. He treats the Third Tone as underlyingly L; its surface rendition for final position is considered to be L followed by an epenthetic H carried by an epenthetic [ʔV] due to a tonal Polarity constraint. The Third Tone sandhi is also partly due to the Polarity constraint, but its directionality has to be stipulated. Therefore, in Duanmu's (1999) conception, there is no mismatch in Beijing Mandarin between stress and the dominant edge of tone sandhi. But as I have argued in footnote 2, this position is difficult to defend on typological and phonetic grounds.

MAX-DOMINANTEDGE(Tone) (abbr. MAX-DOMEDGE(Tone)) to capture it. Stress will be mentioned only if the original fieldworker notes it specifically and will not be assumed to be either the predictor or the consequence of edge dominance in tone sandhi. The separation of edge prominence in tone sandhi and stress prominence in Chinese dialects has been formally recognized in Li (2003).

2 A dialectal typology of the left versus right asymmetry

2.1 The asymmetrical pattern

The asymmetrical pattern that we have seen in Tangxi is in fact more common than initially appears. Even in languages that traditionally fall under either one or the other sandhi direction, one can often find a corner of its sandhi behavior that works in the other direction. For example, as a Southern Wu dialect, Wenzhou tone sandhi is largely right-dominant, with massive tonal neutralization on nonfinal syllables (Zheng-Zhang (1964), Pan (1998)). But certain grammatical categories such as prepositions and some frequent lexical items behave like clitics in Wenzhou. These clitics are prosodically weak and undergo tone sandhi. Interestingly, all proclitics neutralize the tone to 21 as in (8a), but all enclitic tones can be characterized as the extension of the last portion of the tonal contour from the previous syllable as in (8b) (Zheng-Zhang (1964), Pan (1998)).[6] Therefore, the clitic tones in Wenzhou have an asymmetrical behavior: proclitics, which undergo right-dominant sandhi, have default tone insertion; enclitics, which undergo left-dominant sandhi, have rightward tone extension.

(8) Wenzhou tone sandhi in clitics:

a. Tone sandhi for proclitics:

σ	procl.-σ
22	21-22
44	21-44
42	21-42
31	21-31
35	21-35
213	21-213

b. Tone sandhi for enclitics:

σ	σ-encl.
22	22-22
44	44-44
42	42-21
31	31-21
35	35-45
213	213-12

In Beijing Mandarin, although the tone sandhis are also generally right-dominant, certain word-final morphemes are reduced and carry a so-called "neutral tone." The realization of the neutral tone is predictable from the previous tone. Wang (1996)'s study provides the results given in (9). As we can

[6] There is again the issue of nuance: if the "tone extension" statement and the tone transcriptions are taken in their most literal sense, then some of the sandhi patterns in (8) cannot be considered as strictly tone extension, e.g., /35-encl./ → [35-45], /213-encl./ → [213-12]—we would expect perhaps [34-45] and [212-23]. I again hesitate to ascribe significant theoretical status to such subtle differences. Moreover, the original fieldworker, Pan (1998), also considers the tones on the enclitics to be extensions of the stem tones (p. 52).

see, the realization of the neutral tone can be predicted by (a) rightward extension from the preceding lexical tone and (b) a boundary Low tone at the right edge of the word. For example, in a trisyllabic word with two neutral tones at the end, if the initial syllable has an underlying tone 213, then the "3" portion of the initial syllable is realized on the second syllable, and the last syllable has a mid falling tone as the result of a right-boundary Low tone. Therefore Beijing also has the asymmetrical pattern: its final neutral tones are realized with the left-dominant sandhi pattern characterized by rightward tone extension while its lexical tones have right-dominant sandhi with neutralization and simplification.

(9) Beijing Mandarin "neutral tone" realization:

σ	σ-neut.	σ-neut.-neut.
55	55-41	55-42-21
35	35-52	35-53-32
213	21-33	21-33-32
51	51-21	52-21-11

The Shanghai dialect, which we have taken to exemplify left-dominant tone extension in Sect. 1.2, also turns out to have an asymmetrical pattern. Both Xu et al. (1981) and You (1994) documented two types of sandhi in New Shanghai. Type A sandhi, which has the left-dominant tone extension pattern that we have seen, applies to words or phrases that form a tight-knit prosodic unit, and there is no restriction on the grammatical structure of the word. Type B sandhi applies to words or phrases that have a loose internal structure and small pauses between their grammatical components, and its application is primarily limited to the verb-object structure and certain subject-verb, verb-modifier, and coordinated structures (see Xu et al. (1981) for detailed discussions of the two types of sandhi).[7] Crucially, Type B sandhi is right-dominant, and it involves the neutralization and simplification of HL and MH to H and the simplification of LH to M on the first syllable as shown in (10).[8]

(10) Type B sandhi in New Shanghai—right-dominant default insertion:

<table>
<tr><th>σ_1 \ σ_2</th><th>HL</th><th>MH</th><th>LH</th></tr>
<tr><td>HL</td><td colspan="3" rowspan="2">$H\text{-}T_{\sigma2}$</td></tr>
<tr><td>MH</td></tr>
<tr><td>LH</td><td colspan="3">$M\text{-}T_{\sigma2}$</td></tr>
</table>

[7] An anonymous reviewer questioned the theoretical status of statements such as "tight-knit prosodic unit" and "loose internal structure." These are direct translations of the original fieldworkers' statements from Chinese. They may loosely correspond to the "compound" versus "phrase" theoretical distinction, but Xu et al. noted that the definition of "wordhood" is unclear in Chinese and were hesitant to take this position. I share their caution here.

[8] Xu et al. (1981)'s transcriptions in Chao letters have been adapted to H, M, and L to be consistent with the previous discussion of Shanghai in Sect. 1.2.

2.2 The symmetrical pattern

There are also languages with a symmetrical pattern between left-dominant and right-dominant sandhis, i.e., either tone extension in both directions, or default insertion or paradigmatic substitution/neutralization in both directions.

2.2.1 Default insertion in both directions

Huojia (He (1979)) is a dialect spoken in Henan Province that has default insertion in both directions. Its tonal inventory on unchecked syllables is 33, 31, 53, and 13. In disyllabic words, Huojia has four types of tonal combinations, and the type to which a disyllabic word belongs needs to be lexically listed. The four types are: faithful rendition of the two base tones (11a); default insertion of 31 on the first syllable (11b); default insertion of 13 on the second syllable (11c); and default insertion of 31 and 13 on the two syllables, respectively (11d). Therefore, in Huojia, regardless of the direction of the sandhi, the sandhi tone is always a default tone.

(11) Huojia tone sandhi:

a. T_1-T_2 → T_1-T_2
b. T_1-T_2 → 31-T_2
c. T_1-T_2 → T_1-13
d. T_1-T_2 → 31-13

In Chaoyang (Zhang (1979)), there are two types of tone sandhi—initial and final—the choice of which largely depends on the grammatical structure of the word. These two sandhi patterns are summarized in (12).

(12) Chaoyang tone sandhi:

a. Initial sandhi:

<table>
<tr><th>σ_1 \ σ_2</th><th>33</th><th>313</th><th>11</th><th>55</th><th>31</th><th>53</th></tr>
<tr><td>33</td><td colspan="6" rowspan="3">33-$T_{\sigma2}$</td></tr>
<tr><td>313</td></tr>
<tr><td>11</td></tr>
<tr><td>55</td><td colspan="6">11-$T_{\sigma2}$</td></tr>
<tr><td>31</td><td colspan="6">55-$T_{\sigma2}$</td></tr>
<tr><td>53</td><td colspan="6">31-$T_{\sigma2}$</td></tr>
</table>

b. Final sandhi:

<table>
<tr><th>σ_1 \ σ_2</th><th>33</th><th>313</th><th>11</th><th>55</th><th>31</th><th>53</th></tr>
<tr><td>33</td><td colspan="5" rowspan="6">$T_{\sigma1}$-11</td><td rowspan="6">$T_{\sigma1}$-31</td></tr>
<tr><td>313</td></tr>
<tr><td>11</td></tr>
<tr><td>55</td></tr>
<tr><td>31</td></tr>
<tr><td>53</td></tr>
</table>

From the tables in (12), we can see that the tone sandhi in Chaoyang involves default insertion/paradigmatic neutralization in both directions: the initial sandhi represents a synchronic change shift in the tone of the first syllable (53 → 31 → 55 → 11 → 33); the final sandhi involves insertion of default tones 11 and 31. Tone extension is irrelevant.

Zhenhai (Rose (1990), Li (2005)), a Northern Wu dialect spoken in northeast Zhejiang Province, furnishes another example of default insertion in both directions. The tonal inventory on unchecked syllables in Zhenhai is HL, MH, ML, and LM.[9] Disyllabic words in Zhenhai can have either initial or final stress, and the location of stress is determined by both syntactic configuration and tonal identity. The tone sandhi patterns for final-stressed and initial-stressed words are shown in (13a) and (13b), respectively. MH does not occur in an unstressed initial position, and ML does not occur in a stressed initial position.

(13) Zhenhai tone sandhi:

a. Final-stress sandhi:

σ_1 \ σ_2	HL	MH	ML	LM
HL	M-HL			
ML	L-HL			
LM	L-MH			

b. Initial-stress sandhi:

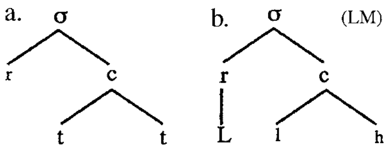
σ_1 \ σ_2	HL	MH	ML	LM
HL	H-HL			
MH	MH-HL			
LM	LM-HL			

Li (2005), following Bao (1990, 1999), assumes the autosegmental tonal representation in (14a): each syllable dominates a register (r) node and a contour (c) node, and the contour node can further branch into tone (t) nodes. For example, a low rising tone LM will be represented with a [Low] feature under the register node and two tone features, [low] and [high], under the contour node as in (14b). The final-stress sandhi in Zhenhai can then be construed as in (15a): the sandhi involves copying the contour node of the initial syllable onto the final syllable and inserting a default [low] under the contour node of the initial syllable and a default [High] under the register node of the final syllable. (15b) illustrates the derivation of surface L-MH when the initial syllable is underlyingly LM: on the surface,

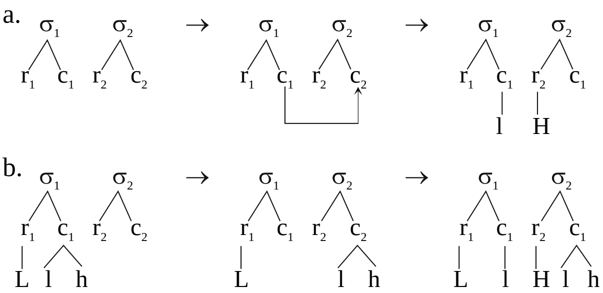
[9] The transcriptions here are from Li (2005), who adapted Rose (1990)'s Chao letters into an H, M, L system.

the initial syllable, with a [L] under the register node and a [l] under the contour node, carries a Low tone, and the final syllable, with a [H] under the register node and two tone features [l] and [h] under the contour node, carries a high rising tone MH.

(14) Representation of contour tone (Bao (1990, 1999), Li (2005))



(15) The autosegmental representation of the final-stress sandhi in Zhenhai:



Although the final-stress tone sandhi in Zhenhai does not neatly fall into either right- or left-dominance, it involves a default-insertion process in the prosodically weak position: the insertion of a low tone under the contour node. The facts that the insertion involves only one tone feature under the contour node, which gives rise to only a level tone, not a contour tone, and that the inserted feature is [l], not [h], indicate that the inserted feature is most likely a default.

The initial-stress sandhi has a more straightforward pattern of default insertion: the unstressed final syllable takes on a default falling tone, and the stressed initial preserves its tone, except when it has an underlying HL, in which case a H obtains on the surface.

Finally, bidirectional paradigmatic tone change/default tone insertion is also found in Lianyungang, a Mandarin dialect spoken in northern Jiangsu. The tonal inventory of Lianyungang is 214, 35, 24, 41, and 55 (Iwata (1982)). Iwata documents four types of lexically determined tone sandhi for Lianyungang as listed in (16).

(16) Lianyungang tone sandhi:

a. Type A:

<table>
<tr><th>σ_1 \ σ_2</th><th>214</th><th>35</th><th>24</th><th>41</th><th>55</th></tr>
<tr><td>214</td><td rowspan="3" colspan="3">21-$T_{\sigma 2}$</td><td rowspan="2" colspan="2">214-$T_{\sigma 2}$</td></tr>
<tr><td>55</td></tr>
<tr><td>24</td><td>21-$T_{\sigma 2}$</td><td rowspan="3">55-$T_{\sigma 2}$</td></tr>
<tr><td>35</td><td rowspan="2" colspan="4">55-$T_{\sigma 2}$</td></tr>
<tr><td>41</td></tr>
</table>

b. Type B:

<table>
<tr><th>σ_1 \ σ_2</th><th>214</th><th>35</th><th>24</th><th>41</th><th>55</th></tr>
<tr><td>214</td><td colspan="5">214-41</td></tr>
<tr><td>35</td><td colspan="5">21-41</td></tr>
<tr><td>24</td><td colspan="5">21-41/55-41</td></tr>
<tr><td>55</td><td colspan="5">44-41</td></tr>
</table>

c. Type C:

<table>
<tr><th>σ_1 \ σ_2</th><th>214</th><th>35</th><th>24</th><th>41</th><th>55</th></tr>
<tr><td>214</td><td rowspan="3" colspan="5">$T_{\sigma 1}$-21</td></tr>
<tr><td>35</td></tr>
<tr><td>55</td></tr>
<tr><td>24</td><td rowspan="2" colspan="5">55-21</td></tr>
<tr><td>41</td></tr>
</table>

d. Type D:

<table>
<tr><th>σ_1 \ σ_2</th><th>214</th><th>35</th><th>24</th><th>41</th><th>55</th></tr>
<tr><td>214</td><td colspan="5">214-55</td></tr>
<tr><td>55</td><td colspan="5">44-55</td></tr>
<tr><td>24</td><td rowspan="2" colspan="5">21-55</td></tr>
<tr><td>35</td></tr>
<tr><td>41</td><td colspan="5">41-11</td></tr>
</table>

According to Iwata (1982), Type A and Type B words have final stress, but only Type A sandhi is right-dominant, and it involves paradigmatic neutralization of the initial tone. Type B sandhi is left-dominant default insertion—the final syllable takes the default tone 41. Type C and Type D words have initial stress, and the final syllable is short. Both types of sandhi are generally left-dominant, with default tones on the final syllable—21 for Type C and 55 and 11 for Type D. But they also involve some neutralization on the initial syllable.

Clearly, the sandhi patterns of Lianyungang involve more than paradigmatic neutralization and default insertion—the choice of surface tones that the underlying tones neutralize to, the partial neutralization and occasional sandhi of the tone at the dominant edge, and the classification of words into different sandhi types all need to be accounted for in a complete analysis. But the generalization that Lianyungang has bidirectional paradigmatic neutralization and default insertion holds true nonetheless and deserves an explanation.

2.2.2 Tone extension in both directions

Tone extension for both left-dominant and right-dominant sandhis is found in Danyang (Lü (1980), Chan (1991, 1995)), a Wu dialect spoken in Jiangsu. There are six tonal melodies in Danyang polysyllabic words with a right-branching structure, as shown in (17) (taken from Chan (1995)). The initial syllable in a right-branching polysyllabic word carries the main stress, and the dominant edge of the tone sandhi coincides with the location of the stress. Danyang is more complex than Changzhou in that the tonal melody of the word is not extended from the initial syllable, but it is generally predictable from the historical tonal category of the initial syllable. Therefore, we can still consider the left-dominant sandhi in Danyang to be tone extension in nature. There is a marked exception to the left-dominant sandhi, however: the application of melody D is not dependent on the tonal category of the initial syllable but largely determined by a 33 tone on the **final** syllable. Chan (1995) in fact takes this melody as the vestige of a right-dominant sandhi system in historical Danyang. Therefore, it seems that Danyang has right-dominant sandhi as well, and it is also characterized by tone extension: the nonfinal 33s are the extension of the final 33. The reason for considering the nonfinal 33s to be extended tones rather than default tones is that if 33 were the default tone, then the identity between the dominant tone and the default tone would be purely accidental, not predicted.[10]

(17) Six tonal melodies in Danyang polysyllabic words with a right-branching structure:

Pattern	σσ	σσσ	σσσσ
A	42-11	42-11-11	42-11-11-11
B	55-55	55-55-55	55-55-55-55
C	24-55	24-55-55	24-55-55-55
D	**33-33**	**33-33-33**	**33-33-33-33**
E	42-24	42-42-24	42-42-42-24
F	11-11	11-11-11	11-11-11-11

[10] The behavior of Pattern E in (17) has been of great theoretical interest to phonologists. Yip (1989) argued that it can be derived by edge associations of 42 and 24 and subsequent spreading of the initial 42 rightward as a unit. Bao (1990) and Chan (1991) both argued that the 42s are derived from 24s that result from the spreading of a unit 24 rightward. All these accounts rely on the theoretical notion of "contour tone unit" in phonological representation. Duanmu (1994a), however, argued that the surface occurrence of [42 … 24] depends on the underlying tones of both initial and noninitial syllables and thus should not be accounted for by contour tone spreading. Consequently, he argued against contour tone units as phonological representations. Bao (1999) questioned the lexical statistics on which Duanmu (1994a) based his argument and maintained that the pattern must be derived by contour tone spreading. I refer interested readers to these works for the debate about contour tone units. For our purposes, it is only important to note that I have sided with Bao, Chan, and Yip in treating this pattern as a spreading pattern; I have not made an attempt to account for why the 42 (or 24) melody extends in a different fashion to the sandhi domain from the other melodies.

2.3 Unidirectional sandhi

Languages in which tone sandhi is only unidirectional are also well attested. I show here that left versus right and tone extension versus default insertion fully cross-classify in the dialectal typology, i.e., the more common left-dominant tone extension and right-dominant default insertion/paradigmatic neutralization coexist with the relatively rare left-dominant default insertion/paradigmatic neutralization and right-dominant tone extension. It is also possible that some of these languages should be more appropriately captured as having symmetrical or asymmetrical bidirectional sandhi if more detailed data are available, as in Wenzhou and Beijing (Sect. 2.1).

2.3.1 Left-dominant tone extension only

As we have mentioned, the "left-dominant tone extension only" pattern is found in many Northern Wu dialects. Changzhou discussed above in Sect. 1.2, exemplifies this pattern.

2.3.2 Right-dominant default insertion/paradigmatic neutralization only

In a language with only right-dominant sandhi, the most common pattern is default insertion or paradigmatic neutralization. This has been exemplified by Wuyi and Beijing in Sect. 1.2. Two more examples come from Yudu (Xie (1992)) and Zhangping (Zhang (1983)).

Yudu is a Hakka dialect spoken in Jiangxi Province of China. Its tonal inventory on unchecked syllables is 31, 35, 44, 22, and 42, and their disyllabic sandhi pattern is summarized in (18) (Xie (1992)). The tone sandhi is right-dominant, as the second syllable always preserves its tone. The initial syllable undergoes a reduction of the tonal inventory: 31 and 35 neutralize to 31, and 44 and 22 neutralize to 44. The right-dominant sandhi here clearly does not involve tone extension but shares great similarity with the right-dominant sandhi in Beijing Mandarin and Wuyi (Sect. 1.2) in having paradigmatic neutralization of the nonfinal tones.

(18) Yudu tone sandhi:

σ_1 \ σ_2	31	35	44	22	42
31	$31\text{-}T_{\sigma 2}$				
35					
44	$44\text{-}T_{\sigma 2}$				
22					
42	$42\text{-}T_{\sigma 2}$				

Zhangping, a Min dialect spoken in Fuzhou Province, has a five-tone inventory on unchecked syllables: 24, 11, 53, 31, and 21. Its disyllabic sandhi pattern is shown in (19) (Zhang (1983)). The pattern is again right-dominant, with preservation of the tone on the final syllable. The initial syllable undergoes massive tonal neutralization: 31 and 53 neutralize to an identical surface tone 21, and 24, 11, and 21 neutralize to either 33 or 55, depending on the tone of the second syllable. Like Yudu, the right-dominant sandhi here does not involve leftward tone extension; the underlying tone on the final syllable stays intact, and the nonfinal syllable undergoes local tone sandhi that results in neutralization.

(19) Zhangping tone sandhi:

<table>
<tr><th>$\sigma_1 \backslash \sigma_2$</th><th>24</th><th>11</th><th>53</th><th>31</th><th>21</th></tr>
<tr><td>24</td><td colspan="3" rowspan="3">33-$T_{\sigma 2}$</td><td colspan="2" rowspan="3">55-$T_{\sigma 2}$</td></tr>
<tr><td>11</td></tr>
<tr><td>21</td></tr>
<tr><td>31</td><td colspan="5" rowspan="2">21-$T_{\sigma 2}$</td></tr>
<tr><td>53</td></tr>
</table>

2.3.3 Left-dominant default insertion only

In a left-dominant-only sandhi system, default insertion, though rare, is also attested. Dongkou (Tang (1960)), a Xiang dialect spoken in Hunan Province, is a case in point. Its tonal inventory is 44, 112, 21, 24, and 13. In disyllabic words, which Tang reports to have initial stress, the second syllable always takes the low falling tone 21 while the first syllable's tone remains intact as shown in (20).

(20) Dongkou tone sandhi:

<table>
<tr><th>$\sigma_1 \backslash \sigma_2$</th><th>44</th><th>112</th><th>21</th><th>24</th><th>13</th></tr>
<tr><td>44</td><td colspan="5" rowspan="5">$T_{\sigma 1}$-21</td></tr>
<tr><td>112</td></tr>
<tr><td>21</td></tr>
<tr><td>24</td></tr>
<tr><td>13</td></tr>
</table>

2.3.4 Right-dominant tone extension only

The "right-dominant tone extension only" pattern is particularly difficult to find in Chinese dialects. I have only found dialects in which a corner of the sandhi behavior can be characterized as leftward spreading (for example, in Wenzhou (Zheng-Zhang (1964)), when the second syllable is 31 or 42, a disyllable sometimes takes tonal shape 42-21) but not dialects whose entire sandhi pattern can be likewise interpreted. However, regressive tonal assimilation is far from unattested in the world's languages. Maddieson (1977), for example, lists Auchi, Chichewa, Villa Alta Zapotec, Mitla Zapotec, and San Esteban Mixtec as having regressive tonal assimilation but notes its rarity compared to progressive tonal assimilation. Therefore, I consider right-dominant tone extension also as an cross-linguistically attested pattern that deserves to be predicted by phonological theory.

2.4 Interim summary

The crucial observation that stems from the dialectal typology is that the pattern in which the left-dominant sandhi is default insertion while the right-dominant sandhi is tone extension is conspicuously missing. Therefore, the asymmetry that we identified at the beginning of the paper should be formally restated as in (21).

(21) The asymmetry between left-dominant and right-dominant tone sandhi restated:
If a language L has both left-dominant and right-dominant tone sandhis,

a. if its left-dominant sandhi involves default insertion/paradigmatic neutralization, then its right-dominant sandhi also involves default insertion/paradigmatic neutralization;
b. if its right-dominant sandhi involves tone extension, then its left-dominant sandhi also involves tone extension.

This, then, should be the prediction that a formal theory of tone and tone sandhi makes. The next section outlines the theoretical machineries necessary for making this prediction. I argue that the asymmetry is the combined result of two factors. First, the extension of a tonal contour over a longer domain helps alleviate violations of markedness constraints against pronounced contours over a short duration, and the initial syllable is under greater pressure to extend its contour than is the final syllable as the latter is subject to pre-boundary lengthening while the former is not. Second, from cross-linguistic phonetic data, we know that tonal coarticulation—the phonetic influence of tone on adjacent tones—is significantly greater in both magnitude and duration progressively than regressively. Therefore, if we consider tone spreading—the phonological process by which a tone takes over the tones of adjacent syllables—to be seeded in coarticulation, then it should also favor the rightward direction.

3 Theoretical apparatus

3.1 The nature of "tone extension"[11]

I have intentionally used a theory-neutral term "tone extension" instead of the more familiar "tone spreading" in the previous sections. The term is used to refer to the extension of either the tonal target at the edge of a syllable or the entire tonal contour on a syllable to a larger domain. For example, the /51/ in an underlying /51-T/, where T refers to any tone, can be rightward extended in any of the following ways: [51-11], [53-31], and [55-11]. The first output reflects the spreading (in a traditional sense) of the tone at the right edge of the first syllable, and the

[11] I am grateful to two anonymous reviewers for raising this issue and helping me clarify the use of terminology and its theoretical consequences.

last two reflect two different ways of extending the falling contour over a two-syllable domain. These different patterns share the characteristics of "extension" and are potentially difficult to differentiate from each other due to necessary effects of tonal coarticulation. Given that the majority of the original sources consulted here provides only the fieldworkers' transcriptions, not acoustic data, I have chosen to collapse these patterns under one blanket term: tone extension.

However, it is necessary to recognize that there are two distinct causes for tone extension. The first cause is that the extension of a tonal contour over a larger domain helps alleviate violations of markedness constraints against pronounced contours over a short duration. In other words, it is motivated by constraints in the form of *CONTOUR$_i$-σ_j (Zhang (2002), among others). For example, the extension of a /51/ contour over two syllables may result in [55-11], [54-21], [53-31], [54-41], or [52-21], among other possibilities. In all these possible outputs, the sharp falling contour is realized over the duration of two syllables. Put differently, on both of the output syllables, only a less pronounced contour tone needs to be realized. This is an improvement in markedness over having to realize the sharp falling contour on only one syllable in the input.

The second cause for tone extension is the spreading of tonal targets at the edges of a syllable, or, when the syllable carries an underlying level tone, the spreading of the tone on the entire syllable, to adjacent syllables. This can be seen as motivated by markedness constraints requiring the agreement of tones on adjacent syllables, similarly to how feature spreading is motivated by AGREE[F] (Lombardi (1999), Baković (2000)).

The two aspects of tone extension are independent of each other and are both necessary. Without the motivation from reducing contour tone markedness, we cannot account for tone extension outputs of /51-T/ as anything other than [51-11], as [55-11], [54-21], [53-31], etc. will always do worse on tonal faithfulness constraint IDENT (Tone), which requires the tonal identity between the input and output syllables, and at most tie with [51-11] on other constraints. Without the motivation from tonal agreement, we cannot account for the canonical spreading behavior of level tones.

The next two subsections (Sects. 3.2–3.3) lay out the formal apparatus that encodes both of these motivations. More importantly, they outline the reasons that both types of tone extension favor the rightward direction, which will serve as the analytical basis for the asymmetry stated in (21). A discussion of the factorial typology (Sect. 4) further motivates the theory by corroborating its cross-linguistic predictions.

3.2 Contour tone markedness hierarchies

3.2.1 The importance of duration in contour tone bearing

Let us first tackle the contour reduction aspect of tone extension. It is important to recognize that tone bearing ability, especially contour tone bearing ability, is crucially dependent on duration. This is determined by both the production and perception of contour tones.

The production of contour tones relies on the contraction and relaxation of laryngeal muscles, which require sufficient duration to be implemented (Ohala (1978)). Specifically, a complicated contour tone, which involves more pitch targets, will involve a more complicated muscle state change and thus will prefer a longer duration; and a contour tone with farther-apart pitch targets will require the muscles to contract or relax to a greater degree and thus also prefer a greater duration of its carrier (Sundberg (1979), Xu and Sun (2002)).

Perceptually, the gradual contraction or relaxation of the laryngeal muscles has a continuous acoustic effect, and the acoustic transition from the beginning to the end of a contour tone carries a significant perceptual weight in the identification of the contour (Gandour (1978), Gandour and Harshman (1978)). Studies have shown that the perception of such gradual pitch change is enhanced when the duration on which the change is realized is longer (e.g., Black (1970), Greenberg and Zee (1979)). This also determines that a longer duration is preferred for contour tones.[12]

3.2.2 Contour tones prefer final syllables, not initial ones

A rich body of cross-linguistic phonetic literature has shown that the final syllable of a prosodic unit is subject to lengthening (Oller (1973), Klatt (1975), Beckman and Edwards (1990), Edwards et al. (1991), Wightman et al. (1992), and Johnson and Martin (2001), among many others). Although it is generally agreed that the utterance-final position induces the greatest lengthening effects (Oller (1973), Klatt (1975), Beckman and Edwards (1990), Wightman et al. (1992), Hofhuis et al. (1995), Byrd (2000), Cho and Keating (2001)), non-prepausal word-final lengthening has also been documented (Lehiste (1960), Lindblom (1968), Oller (1973), Klatt (1975), Beckman and Edwards (1990)). Moreover, unlike non-word-final syllables, a word-final syllable also has opportunities to occur before bigger prosodic boundaries. Therefore, the average duration of a word-final syllable in a connected discourse will be greater than that of the same syllable in non-word-final positions.

Given that contour tones prefer longer duration, it should not be surprising that typological studies on the distribution of contour tones have found that they gravitate to domain-final positions. Clark (1983) identified a number of African languages, such as Ohuhu Igbo, Kikuyu, and Peki Ewe, in which this observation holds. And Zhang (2002), in a larger-scale survey of 187 languages with contour tone restrictions, showed that 47 of them show a preference for prosodic-final syllables as contour bearers. Added to the African languages identified by Clark are many Oto-Manguean languages such as Mitla Zapotec and Sino-Tibetan languages such as Beijing Mandarin. Recall the Beijing pattern that we saw in (1): the complex contour tone 213 is realized as such only word-finally and is simplified to a simple contour 21 or 35 when preceding another syllable.

[12] For more detailed discussions on the importance of duration in contour tone bearing, see Zhang (2002, to appear *a*).

On the other hand, Zhang (2002)'s survey did not find any language in which prosodic-initial positions are independently advantageous in licensing contour tones. This is understandable from the fact that prosodic-initial positions are generally not lengthening positions; and even on the rare occasions when initial lengthening is found, it is to a much smaller degree than final lengthening (Fougeron and Keating (1997), Byrd (2000), Cho and Keating (2001)). Therefore, contour tones, as features that require long duration, do not gravitate to prosodic-initial positions.[13]

The importance of these two typological observations and their phonetic underpinnings is that it is now apparent that when a contour tone is involved, the initial syllable is under a greater pressure to extend it than is the final syllable, as the latter is in a better position to carry the contour due to pre-boundary lengthening. In other words, the first aspect of tone extension—contour tone markedness reduction—implies that it should favor the rightward direction.

3.2.3 Contour tone markedness constraints and their intrinsic rankings

To capture the final advantage in contour tone licensing, we consider a family of markedness constraints in (22a) and their intrinsic ranking in (22b) (Zhang (2002, 2004), also see Zoll (2003)). The constraint family bans a certain contour tone on a certain type of syllable, and the intrinsic ranking ensures that the constraint hierarchy assigns a greater penalty for a contour tone on a nonfinal syllable than the same contour tone on the same syllable in final position. The ranking in (22b) can be generalized as in (22c), i.e., if syllable *j* is shorter than syllable *k*, then the ban on a contour on syllable *j* is ranked higher than the ban on the same contour on syllable *k*.[14]

(22) Contour tone markedness constraints and intrinsic rankings:

a. $*\text{CONTOUR}_i\text{-}\sigma_j$: Contour tone *i* cannot occur on syllable *j*.
b. $*\text{CONTOUR}_i\text{-NONFINAL} \gg *\text{CONTOUR}_i\text{-FINAL}$
c. If σ_j is shorter than σ_k, then $*\text{CONTOUR}_i\text{-}\sigma_j \gg *\text{CONTOUR}_i\text{-}\sigma_k$.

As mentioned in Sect. 3.2.1, another aspect of the contour tone markedness hierarchies is Tonal Complexity (TC), which is defined in (23a). The intuition is that the longer the duration a tone needs for its production and perception, the higher TC the tone has. Particularly relevant for the issue at hand is that a complex contour is of higher TC than a simple contour, which is in turn of higher TC than a level tone; a simple contour with a greater pitch excursion is

[13] For more details of the survey on contour tone distribution and the arguments for the relevance of final lengthening to contour tone bearing, see Zhang (2002, to appear *a*).

[14] Zhang (2002) further argues that the constraints need to refer directly to the durational property of the syllables: if $\text{DURATION}_j \gg \text{DURATION}_k$, then $*\text{CONTOUR}_i\text{-DURATION}_j \gg *\text{CONTOUR}_i\text{-DURATION}_k$. This is crucial in understanding the language-specific behavior of contour tone licensing but is not important to the current discussion. I refer interested readers to this work for more details on the formulation of contour tone markedness constraints.

of higher TC than a simple contour with a small pitch excursion. The relevance of TC to the constraint ranking is that if contour tone *i* is of higher TC than contour tone *j*, then the ban on contour tone *i* on a syllable is more severe than the ban on contour tone *j* on the same syllable as shown in (23b).[15]

(23) Tonal Complexity and its relevance to the contour tone markedness ranking:

a. Definition: For any two tones T_1 and T_2, let D_1 and D_2 be the minimum durations required for the production and perception of T_1 and T_2, respectively. T_1 is of higher Tonal Complexity than T_2 iff $D_1 > D_2$.
b. If contour tone *i* is of higher Tonal Complexity than contour tone *j*, then $*\text{CONTOUR}_i\text{-}\sigma_k \gg *\text{CONTOUR}_j\text{-}\sigma_k$.

To recapitulate, two aspects of these constraint hierarchies help capture the left/right sandhi asymmetry. First, the constraint hierarchy based on Tonal Complexity encourages the extension of contour tones over polysyllabic domains as the extension results in the flattening of contours on each syllable. Second, the initial syllable is under a greater pressure to extend its contour than is the final syllable due to its lower ability to license contour tones; in other words, the grammar encourages rightward contour extension more than leftward contour extension.

3.3 Faithful Alignment

3.3.1 AGREE(T_1-T_2)

As discussed in Sect. 3.1, another aspect of tone extension is the spreading of an edge tone in contour tones or an entire level tone to adjacent syllables, and we have likened this type of tone spreading to the spreading of other phonological features such as [+nasal] or [+round]. It is thus desirable to capture this type of tone spreading in the theory in a similar fashion to general feature spreading. Lombardi (1999) and Baković (2000) have argued that the harmony of features in a domain should be captured by AGREE constraints; Baković (2000) defined AGREE[F] as in (24).

(24) AGREE[F]:
Adjacent segments must have the same value of the feature [F].
(Baković (2000, p. 4))

I propose to capture the spreading of tone by the constraint $*T_1\text{-}T_2$, as defined in (25):

[15] Zhang (2002) argues that the constraints in fact need to directly refer to the TC scale: if Tonal Complexity *j* is greater than Tonal Complexity *k*, then $*\text{CONTOUR}_i\text{-TC}_j \gg *\text{CONTOUR}_i\text{-TC}_k$.

(25) AGREE(T_1-T_2):
If σ_1 and σ_2 are two adjacent syllables and T_1 is the tone at the right edge of σ_1 and T_2 is the tone at the left edge of σ_2, then $T_1 = T_2$.

This constraint has been proposed in earlier works of tone such as Zhang (1999) and Hyman and VanBik (2004). It shares with AGREE[F] the identity requirement between the featural specifications of the two adjacent carriers of the feature, and it can be used to motivate the spreading of both the edge tone of a contour tone and the entirety of a level tone.

3.3.2 Tonal faithfulness constraints

To prevent spreading or other tonal changes from the input to the output, I define two tonal faithfulness constraints MAX(tone) and IDENT(tone) as in (26) (see also Zhang (2000a, 2002, to appear *a*)).

(26) a. MAX(Tone): if T is a tone in the input, then T has an identical correspondent in the output.
b. IDENT(Tone): if α is a TBU in the input and β is a correspondent of α in the output, then the tonal specification of α must be identical to the tonal specification of β.

The evaluation of MAX(tone) and IDENT(tone) differs when the associations of the underlying tones with the Tone-Bearing Units have been altered due to the loss of TBUs or tone spreading. IDENT(tone) will be violated if reassociations such as LH-L to L-HL occur since the tonal specifications for both syllables have been changed; but MAX(tone) is satisfied, as all tonal targets are preserved from the input to the output. The difference between general MAX(F) and IDENT(F) has been argued for at length in Zhang (2000b). The MAX(Tone) versus IDENT(Tone) distinction here shares Zhang (2000b)'s intuition: the preservation of a feature specification **somewhere** in the output should be rewarded, here by not violating MAX(Tone).

3.3.3 Faithful Alignment constraints

With the tonal markedness and faithfulness constraints in place, we can consider the prediction of the theory so far. Let us consider a hypothetical right-dominant sandhi system in which a nonfinal syllable must lose its tonal contrast due to a positional faithfulness ranking MAX-DOMINANTEDGE(Tone) » *TONE » MAX(Tone) (Beckman (1998), Yip (2003)). To keep the scenario simple, let us consider an underlying level tone 55 on the second syllable of a disyllabic compound. The tone sandhi has two distinct possibilities: leftward spreading of the high tone onto the first syllable and default insertion of 22 on the first syllable. The tableau in (27) evaluates these two candidates with respect to the four relevant constraints: MAX(Tone), IDENT(Tone), *TONE, and AGREE(T_1-T_2).

The boldfaced tone in the tableau indicates the tone at the prominent edge. The tableau shows that both candidates violate MAX(Tone) and IDENT(Tone) once due to the loss of tone T on the initial syllable,[16] and both candidates violate *TONE once as they both have one distinct tonal melody associated with them. But only 22-55 violates AGREE(T_1-T_2); 55-55 does not. Consequently, the current prediction is that default insertion should never win a competition as it will always lose to the spreading candidate.

(27) /T-**55**/ → ?

/T-**55**/	MAX(Tone)	IDENT(Tone)	*TONE	AGREE(T_1-T_2)
☞ 55-**55**	*	*	*	
22-**55**	*	*	*	*!

This prediction, however, is problematic—I have shown in a number of examples in Sect. 2 that default insertion does occur in languages. Therefore, there must be constraints in the grammar that specifically ban spreading, but not default insertion, to give default insertion a chance to win. The Faithful Alignment constraints, as defined below, serve this purpose.

I define two families of Faithful Alignment constraints—FAITH-ALIGN-LEFT and FAITH-ALIGN-RIGHT—to ban leftward and rightward spreading, respectively, as in (28a). The intuition is that if, in the output, the left (or right) edge of a tone is spread *n* syllables to the left (or right), then the output violates FAITH-ALIGN-LEFT(*n*) (or FAITH-ALIGN-RIGHT(*n*)). For example, if a trisyllabic word with 51 on the first syllable and any tones on the second and third syllables is realized as [51-11-11] or [53-32-21], then it violates FAITH-ALIGN-RIGHT(2). Intuitively, there is an intrinsic ranking such that for all *i, j*, if *i* is great than *j*, then FAITH-ALIGN(*i*) outranks FAITH-ALIGN(*j*) for both directions as shown in (28b).

(28) Faithful Alignment constraints and intrinsic rankings:

a. For input syllable string $\sigma_1\sigma_2 \ldots \sigma_n$ and input tone T, let their output correspondents be $\sigma_1{'}\sigma_2{'} \ldots \sigma_n{'}$ and T′:
FAITH-ALIGN-LEFT(*i*) (abbr. F-ALIGN-L): If the left edge of T is aligned with the left edge of σ_j in the input and the left edge of T′ is aligned with the left edge of $\sigma_k{'}$ in the output, then $j\text{-}k < i$.

[16] Some may argue that the default insertion candidate does not violate IDENT(Tone) as there is no tonal correspondent to the input tone in σ_1 in the output. This position is untenable. The traditional IDENT(F) is only vacuously satisfied if the segment that carries the feature F is deleted in the output. Given that the carrier of tonal features is the syllable, provided that the syllable is not deleted, an IDENT(Tone) violation must be assessed for any output in which the tone of any syllable does not match the tone of the same syllable in the input, even when the output tone is inserted by default. In other words, given that any output syllable must be realized on **some** pitch, it necessarily sets up a correspondence relation between this pitch and the input tone on this syllable. This is parallel to the assessment of an IDENT(F) violation when an input [+F] or [−F] is mapped onto an output [0F].

FAITH-ALIGN-RIGHT(i) (abbr. F-ALIGN-R): If the right edge of T is aligned with the right edge of σ_j in the input and the right edge of T′ is aligned with the right edge of σ_k' in the output, then $k\text{-}j < i$.

b. $\forall i, j, i > j$, F-ALIGN-EDGE(i) » F-ALIGN-EDGE(j), EDGE = LEFT or RIGHT

We can now look back at the two candidates in (27): the spreading candidate [55-55] now violates F-ALIGN-LEFT(1), and the default insertion candidate [22-55] violates AGREE(T_1-T_2); they tie on all other candidates. Therefore, either candidate has a chance to win the competition depending on the ranking between F-ALIGN-LEFT(1) and AGREE(T_1-T_2).

3.3.4 *F-ALIGN-LEFT(i) » F-ALIGN-RIGHT(i)*

What we have seen so far is that the second cause for tone extension—the spreading of an edge tone in contour tones or an entire level tone to adjacent syllables—motivates an AGREE(T_1-T_2) constraint, which in turn motivates Faithful Alignment constraints, in Optimality Theory.

A shrewd reader may have noticed, however, that the definition of Faithful Alignment is applicable to both types of tone extension: for an input /51-T_1-T_2/, both [53-32-21], as resulted from contour extension, and [51-11-11], as resulted from tone spreading, violate FAITH-ALIGN-RIGHT(2). This is partly due to the intuition of alignment, which mandates only the edge location of a tone, not the specifications of tones elsewhere. But a deeper reason for this particular conception of Faithful Alignment is that it allows us to further restrict the predictive power of the theory by another intrinsic ranking as shown in (29).

(29) $\forall i$, F-ALIGN-LEFT(i) » F-ALIGN-RIGHT(i)

I argue that this intrinsic ranking is projected from scales in phonetics—in this case, tonal coarticulation—*à la* Prince and Smolensky (1993). Tonal coarticulation refers to the contextual influence of one tone on adjacent tones, and both types of tone extension can find their seeds in tonal coarticulation: Xu (1997), for example, documents both the carry-over extension of the high level tone and rising and falling contours into the next syllable in Mandarin. Cross-linguistically, it has been found that the effect of tonal coarticulation is significantly greater in both magnitude and duration progressively than regressively (Vietnamese: Han and Kim (1974); Thai: Gandour et al. (1994); Taiwanese: Peng (1997); Mandarin Xu (1997)). Defining Faithful Alignment in a way that comprehensively includes the effects of tonal coarticulation allows the directional difference in tonal coarticulation to project a ranking among Faithful Alignment constraints in phonology: F-ALIGN-LEFT(i) » F-ALIGN-RIGHT(i). This ranking can be understood from the P-map perspective *à la* Steriade (to appear), which assumes that the perceptual similarity between corresponding forms projects intrinsic rankings among correspondence constraints: an output with rightward spreading will be perceptually more similar to the input than will one with leftward spreading if the speaker knows that the input, if pronounced as is, will have progressive coarticulation.

This intrinsic ranking turns out to be extremely important to the prediction of the factorial typology of our system. Without the intrinsic ranking, a highly ranked F-ALIGN-R and a lowly ranked F-ALIGN-L will undo the desirable effect of the contour tone markedness rankings, which preferentially encourage tone extension from the initial syllable. This can be demonstrated from a schematized example: the constraint ranking F-ALIGN-R » *CONTOUR-NONFINAL » *CONTOUR-FINAL » F-ALIGN-L predicts a sandhi system with left-dominant default insertion and right-dominant spreading, as illustrated by the tableaux in (30a) and (30b). The intuition is that although *CONTOUR-NONFINAL » *CONTOUR-FINAL encourages rightward spreading, a highly ranked F-ALIGN-R prevents rightward spreading from occurring, and a lowly ranked F-ALIGN-L encourages leftward spreading to satisfy *CONTOUR-FINAL.

(30) The undesirable effect of F-ALIGN-R » *CNTR-NONFIN » *CNTR-FIN » F-ALIGN-L

a. **51**-T → **51**-22 (Left-dominant default insertion)

/**51**-T/	F-ALIGN-R	*CNTR-NONFIN	*CNTR-FIN	F-ALIGN-L
☞**51**-22		*		
55-11	*!			

b. T-**51**→ 55-**11** (Right-dominant spreading)

/T-**51**/	F-ALIGN-R	*CNTR-NONFIN	*CNTR-FIN	F-ALIGN-L
☞55-**11**				*
22-**51**			*!	

3.5 Interim summary

With the necessary theoretical apparatus in place, the next section lays out the predictions of the theory by calculating its factorial typology and further argues for the theory by showing that its prediction fully matches the findings of the dialectal typology in Sect. 2.

4 Factorial typology

4.1 Bidirectional sandhi

Let us first consider the prediction of the theory regarding bidirectional sandhi; namely, the prominent syllable can be either initial or final. The two inputs we will consider are /**51**-24/ with initial prominence and /24-**51**/ with final prominence. For each input, the complete set of output candidates should include the faithful candidate, the candidate with default insertion, in which the default tone is assumed to be 22, and various candidates with tone extension. These candidates are laid out in (31), which includes three representative patterns of tone extension for each direction. Prominence is again indicated by boldface.

(31) Inputs and output candidates for the factorial typology:

/**51**-24/ →	**51**-24 (faithful)	/24-**51**/ →	24-**51** (faithful)
	51-22 (default insertion)		22-**51** (default insertion)
	55-11 (tone extension)		55-**11** (tone extension)
	53-31 (tone extension)		53-**31** (tone extension)
	51-11 (tone extension)		55-**51** (tone extension)

The constraints and their intrinsic rankings relevant for the calculation of the factorial typology are given in (32): (32a) lays out the relevant contour tone markedness hierarchies, which make a distinction between a big fall (51) and a small fall (53 or 31); (32b) is the Faithful Alignment hierarchy; (32c) is the positional faithfulness ranking that forces sandhi in non-prominent positions; (32d) includes two IDENT constraints on tone; and (32e) shows the constraint that encourages spreading.

(32) Relevant constraints for the factorial typology and their intrinsic rankings:

a. *BIGFALL-NONFINAL » *SMALLFALL-NONFINAL
    »   »
*BIGFALL-FINAL » *SMALLFALL-FINAL
b. F-ALIGN-L » F-ALIGN-R
c. MAX-DOMEDGE(Tone) » *TONE » MAX(Tone)
d. IDENT-DOMEDGE(Tone), IDENT(Tone)
e. AGREE(T_1-T_2)

However, as we have discussed in Sect. 3.1, the different patterns of tone extension may be difficult to differentiate from each other due to necessary effects of tonal coarticulation. Without extensive acoustic data from the language in question, it would be premature to categorize it as having one or the other extension pattern. Lacking such acoustic data from most of the Chinese dialects under investigation here, I have opted to collapse the tone extension patterns into one, namely the extension of the contour into two level tones, i.e., /**51**-24/ → [**55**-11] and /24-**51**/ → [55-**11**]. The factorial typology, therefore, will only make predictions on the general sandhi pattern type—default insertion or tone extension—but not on the exact rendition of tone extension. The constraints used to calculate the factorial typology have also been simplified accordingly: the difference between big falls and small falls has become irrelevant; so has AGREE(T_1-T_2), which, for an underlying contour tone, is useful only for distinguishing different types of tone extension, e.g., [55-11] versus [53-31]. The IDENT(Tone) constraints are also useful only to distinguish the output tones resulting from different types of tone extension such as [**53**-31] and [**51**-11] and hence are also unnecessary now. The relevant constraints now are shown in (33). The complete factorial typology using the outputs and constraints in (31) and (32) is given in the Appendix.

(33) Relevant constraints for the factorial typology and their intrinsic rankings:

a. *CONTOUR-NONFINAL » *CONTOUR-NONFINAL
b. F-ALIGN-L » F-ALIGN-R
c. MAX-DOMEDGE(Tone) » *TONE » MAX(Tone)

The factorial typology of the constraints in (33) was calculated by *OTSoft* (Hayes et al. (2003)). Rather than computing the output combinations of the two input forms /**51**-24/ and /24-**51**/ for all possible rankings of the constraints, *OTSoft* considers each logically possible output pattern and determines whether there is a constraint ranking that generates it. The result shows that only three types of languages are predicted by the constraint set: the asymmetrical pattern that has left-dominant tone extension and right-dominant default insertion, and two symmetrical patterns in which both left-dominant and right-dominant sandhis involve either tone extension or default insertion. These patterns, along with sufficient rankings that derive them, are given in (34). They match the Tangxi, Danyang, and Huojia patterns in the dialectal typology, respectively. Crucially, the factorial typology does not predict the opposite of the asymmetrical pattern—left-dominant default insertion and right-dominant tone extension: this pattern is unattested in the dialectal typology.

(34) Factorial typology of bidirectional sandhi with inputs /**51**-24/ and /24-**51**/:

Pattern	a. L-dom. extension R-dom. default	b. L-dom. extension R-dom. extension	c. L-dom. default R-dom. default
	/**51**-24/ → [**55**-11] /24-**51**/ → [22-**51**]	/**51**-24/ → [**55**-11] /24-**51**/ → [55-**11**]	/**51**-24/ → [**51**-22] /24-**51**/ → [22-**51**]
Ranking	F-ALIGN-L, *CNTR-NONFIN » F-ALIGN-R, *CNTR-FIN	*CNTR-NONFIN » *CNTR-FIN » F-ALIGN-L » F-ALIGN-R	F-ALIGN-L » F-ALIGN-R » *CNTR-NONFIN » *CNTR-FIN
Language	Tangxi	Danyang	Huojia

4.2 Unidirectional sandhi

For languages with a fixed prominent edge, we can easily deduce from (34) that the factorial typology predicts the full cross-classification of left versus right and tone extension versus default insertion. The rankings in (34a) and (34b) can predict left-dominant tone extension only; the rankings in (34a) and (34c) can predict right-dominant default insertion only; the ranking in (34c) can predict left-dominant default insertion only; and the ranking in (34b) can predict right-dominant tone extension only. As we have shown in Sect. 2.3, all four patterns are attested.

We have noted in Sect. 2.3 that the left-dominant default insertion and right-dominant tone extension patterns are relatively rare and difficult to instantiate in Chinese dialects. This cross-linguistic rarity may be correlated with the fewer number of constraint rankings that can generate these patterns: as the discussion above indicates, the rankings that generate left-dominant default insertion and right-dominant tone extension are proper subsets of the rankings that generate right-dominant default insertion and left-dominant tone extension, respectively.

4.3 Lack of sandhi

Finally, let us consider the theory's prediction for languages in which there is no tone sandhi in one or both directions. To allow the lack of sandhi to occur, we need to forgo the positional faithfulness ranking in (32c) and allow Max(Tone) to outrank *Tone. This produces two extra patterns in the factorial typology, shown in (35). The first pattern represents a language with no tone sandhi in general and is attested in Min dialects Jian'ou (Lin and Pan (1998)) and Haiko (Chen (1997)). The second pattern is the lack of sandhi for initial prominence and default insertion for final prominence. Regarding the patterning of contour tones, it represents a language in which a contour tone can surface on a nonfinal prominent syllable and a final syllable regardless of prominence. I do not know a case in Chinese that clearly instantiates this pattern. But given that its markedness generalizations conform well to our understanding of how contour tones generally behave, this gap is likely not a principled gap but an accidental one.

(35) Patterns involving lack of sandhi predicted by the factorial typology:

Excluded Pattern	a. L-dom. no sandhi R-dom. no sandhi	b. L-dom. no sandhi R-dom. default
	/**51**-24/ → [**51**-24] /24-**51**/ → [24-**51**]	/**51**-24/ → [**51**-24] /24-**51**/ → [22-**51**]
Ranking	Max(Tone) outranks everything	Max-DomEdge(Tone), F-Align-L » F-Align-R » *Cntr-Nonfin » Max(Tone) » *Cntr-Fin, *Tone
Language	Jian'ou	?

Interestingly, the factorial typology excludes some obvious possibilities, which are listed in (36). All of these patterns violate known markedness generalizations about contour tones (Gordon (1999), Zhang (2002)): the left-dominant tone extension and right-dominant no-sandhi pattern in (36a) forces a nonfinal contour tone to flatten when it is prominent but allows it surface when it is not; the left-dominant no-sandhi and right-dominant tone extension pattern in (36b) forces a prominent contour tone to flatten finally but allows it nonfinally; and the left-dominant default insertion and right-dominant no-sandhi pattern in (36c) forces a non-prominent contour tone to flatten finally but allows it nonfinally. To the best of my knowledge, these patterns do not exist.

(36) Patterns involving lack of sandhi *excluded* by the factorial typology:

Pattern	a. L-dom. extension R-dom. no sandhi	b. L-dom. no sandhi R-dom. extension	c. L-dom. default R-dom. no sandhi
	/**51**-24/ → [**55**-11] /24-**51**/ → [24-**51**]	/**51**-24/ → [**51**-24] /24-**51**/ → [55-**11**]	/**51**-24/ → [**51**-22] /24-**51**/ → [24-**51**]

4.4 Interim summary

I have shown in this section that the factorial typology of the proposed constraint set makes predictions that are well matched with language typology. In particular, the factorial typology agrees with the implicational statements in (21): it predicts the non-existence of left-dominant default insertion cooccurring with right-dominant tone extension but the existence of all other combinations. Furthermore, it makes desirable predictions with respect to tonal systems that involve the lack of sandhi in either one or both directions. Although we do not have enough languages with detailed descriptions to fully test these predictions, I am relatively confident that once we do, these predictions will be borne out. The confidence stems from the fact that the predictions are in accord with contour tone markedness generalizations established by large scale language surveys such as Gordon (1999) and Zhang (2002).

5 Case study—Tangxi

As a case study, I show in this section that the asymmetrical Tangxi disyllabic sandhi can be accounted for by the theoretical apparatus proposed. The pattern is recapitulated in (37): there are three underlying tones: 33, 51, and 24; modifier-noun compounds have initial stress and left-dominant tone extension; verb-noun phrases have final stress and right-dominant default insertion.

(37) Tangxi tone sandhi recapitulated:

Left-dominant tone extension	Right-dominant default insertion
/**33**-T/ → [**33**-33]	/T-**33**/ → [22-**33**]
/**51**-T/ → [**53**-31]	/T-**51**/ → [22-**51**]
/**24**-T/ → [**22**-44]	/T-**24**/ → [22-**24**]

Let us first consider the necessary contour tone markedness constraints and their intrinsic rankings. The fact that an initial /51/ is extended onto two syllables as [53-31] shows that for Tangxi, the Tonal Complexity difference between a pronounced falling tone 51 and a less pronounced falling tone 53 or 31 is relevant for the output of the grammar. But for a rising tone, given that an initial /24/ is spread as [22-44], not [23-34], it indicates that the Tonal Complexity difference based on the degree of rising does not matter for Tangxi as a rise is either tolerated or obliterated.[17] Taken together with the final versus nonfinal distinction in contour tone licensing, these observations point to the relevance of the constraints and rankings in (38). Note that the simpler rising tone hierarchy in (38b) does not entail that this hierarchy is intrinsically simpler than the falling tone hierarchy—I have simply conglomerated irrelevant constraints into one for the Tangxi analysis. For example, *RISE-NONFINAL can be seen as the combination of *BIGRISE-NONFINAL » *SMALLRISE-NONFINAL.

(38) Relevant contour tone markedness constraints and intrinsic rankings for Tangxi:

a. *BIGFALL-NONFINAL » *SMALLFALL-NONFINAL
   » »
   *BIGFALL-FINAL » *SMALLFALL-FINAL

b. *RISE-NONFINAL » *RISE-FINAL

The rest of the relevant constraints are listed in (39). (39a) is the Faithful Alignment ranking that we argued for in Sect. 3; (39b) is the positional faithfulness ranking that forces tone sandhi on non-prominent syllables; (39c) includes two IDENT constraints on tone; and (39d) is the constraint that bans the change of pitch across a syllable boundary.

(39) Other relevant constraints and rankings for Tangxi:

a. FAITH-ALIGN-LEFT(1) » FAITH-ALIGN-RIGHT(1)
b. MAX-DOMEDGE(Tone) » *TONE » MAX(Tone)
c. IDENT-DOMEDGE(Tone), IDENT(Tone)
d. AGREE(T_1-T_2)

[17] For concreteness, I have taken the original fieldworker's transcriptions literally. However, we should be open to the possibility that when acoustic data are available for our examination, the exact tone extension patterns may turn out to differ somewhat from the transcriptions and that there may not be a difference between how the falling tone and the rising tone are extended to the disyllabic domain.

To distinguish among different types of output candidates for /51/—pronounced fall [51], partially flattened falls such as [53], and completely level tones such as [55]—we must define IDENT(Tone) gradiently so that for an input /51/, a less pronounced fall better satisfies IDENT(Tone) than a level tone. For our purposes, it suffices to designate the following IDENT(Tone) violations:[18]

(40) IDENT(Tone):

/51/	IDENT(Tone)
51	•
53	*
31	*
55	**
11	**

Let us tackle left-dominant sandhi first. The general tone extension pattern is derived by the low ranking of FAITH-ALIGN-R(1) as compared to the relevant contour tone markedness constraints. For a /**51**-T/ input, the rival candidates for the output [**53**-31] include different ways of extending the initial /51/—[**55**-11], [**55**-51], and [**51**-11]—and default insertion in the final syllable—[**51**-22]—as shown in the tableau in (41). Any candidate with [55] on the first syllable will lose because it is a worse violation of IDENT-DOMEDGE (Tone) than the winning [**53**-31]. Any candidate with [51] on the first syllable, including the one with default insertion, loses due to *BIGFALL-NONFINAL, which crucially outranks IDENT-DOMEDGE(Tone). I did not include candidates that do not fully preserve the tone on the initial syllable, e.g., [**53**-22], as they will clearly lose due to violations of MAX-DOMEDGE(Tone), which is undominated.[19]

[18] More formal definitions of tonal faithfulness constraints or faithfulness constraints in general based on gradient perceptual scales can be found in Zhang (2002, to appear *b*). In these definitions, faithfulness is defined as constraint families, with each member in the family representing one point on the perceptual scale away from the input; they hence heed McCarthy (2003)'s warning that "OT constraints are categorical." I refer interested readers to these works for such definitions. The form of the definition of IDENT(Tone), however, does not affect the crux of the analysis being offered here.

[19] An anonymous reviewer correctly pointed out that the analysis presented here makes the wrong prediction for the trisyllabic pattern /51-T-T/ → [55-33-11] as the high ranking of IDENT-DOMEDGE(Tone) would also prefer [53] on the first syllable. This pattern can be accommodated if we take into consideration that syllables in polysyllabic words are shorter in duration than syllables in mono- or disyllabic words (Lehiste (1972), Klatt (1976), Lindblom and Rapp (1973), Lindblom et al. (1981), Lyberg (1977), Strangert (1985)). Therefore, if we further split the contour tone markedness hierarchies to incorporate this durational difference, we can predict that nonfinal syllables in polysyllabic words cannot have contour tones at all even though nonfinal syllables in disyllabic words can. See Zhang (2000a, 2002, to appear *a*) for further discussions of the effect of syllable count on the distribution of contour tones and OT implementations of this effect.

(41) /**51**-T/ → [**53**-31]

/**51**-T/	*BigF-Nonfin	Id-Dom Edge(T)	*BigF-Final	*SmallF-Nonfin	*SmallF-Final	F-Align-R
☞ **53**-31		*		*	*	*
55-11		**!				*
55-51		**!	*			*
51-11	*!					*
51-22	*!					

The analysis for /**24**-T/ → [**22**-44] is given in (42). The rival candidates again include different ways of extending the initial tone—[**22**-24], [**24**-44], and [**23**-34]—and default insertion in the final syllable—[**24**-22]. All rivals lose due to violations of *Rise constraints. In particular, candidates with a rising tone on the initial syllable loses due to *Rise-Nonfinal, which crucially outranks Ident-DomEdge(Tone). [**22**-24] loses because it violates *Rise-Final, which crucially outranks Agree(T_1-T_2).

(42) /**24**-T/ → [**22**-44]

/**24**-T/	*Rise-Nonfin	Id-Dom Edge(T)	*Rise-Final	Agree (T_1-T_2)	F-Align-R
☞ **22**-44		**		*	*
22-24		**	*!		*
24-44	*!				*
23-34	*!	*	*		*
24-22	*!			*	

The analysis for /**33**-T/ → [**33**-33] is straightforward. None of the contour tone markedness constraints is relevant. The only viable rival is [**33**-22], the default insertion candidate. The tableau in (43) shows that the ranking Agree(T_1-T_2) » Faith-Align-Right(1) suffices to exclude this rival.

(43) /**33**-T/ → [**33**-33]

/**33**-T/	Agree(T_1-T_2)	F-Align-R
☞ **33**-33		*
33-22	*!	

Let us now consider the right-dominant cases. For a /T-**51**/ input, the rivals for the winner [22-**51**] are various tone extension candidates—[53-**31**], [55-**11**], [55-**51**], and [51-**11**]—all of which lose due to Faith-Align-Left(1), which crucially outranks *BigFall-Final and Agree(T_1-T_2). This is shown in the tableau in (44).

(44) /T-**51**/ → [22-**51**]

/T-**51**/	F-ALIGN-L	ID-DOMEDGE(T)	*BIGF-FINAL	AGREE(T_1-T_2)
☞22-**51**			*	*
53-**31**	*!	*		
55-**11**	*!	**		*
55-**51**	*!		*	
51-**11**	*!	**		

For /T-**24**/, the rivals for the winner [22-**24**] are also various tone extension candidates: [22-**44**], [23-**34**], and [24-**44**]. They again all lose due to FAITH-ALIGN-LEFT(1), which crucially outranks *RISE-FINAL. This is shown in the tableau in (45).

(45) /T-**24**/ → [22-**24**]

/T-**24**/	F-ALIGN-L	ID-DOMEDGE(T)	*RISE-FINAL	AGREE(T_1-T_2)
☞22-**24**			*	
22-**44**	*!	**		*
23-**34**	*!	*	*	
24-**44**	*!			

Finally, the analysis for /T-**33**/ → [22-**33**] is given in the tableau in (46). The only viable rival is the candidate with leftward tone extension, and it is again excluded by FAITH-ALIGN-LEFT(1), which crucially outranks AGREE(T_1-T_2).

(46) /T-**33**/ → [22-**33**]

/T-**33**/	F-ALIGN-L	AGREE(T_1-T_2)
☞22-**33**		*
33-**33**	*!	

The discussion above has helped us identify a sufficient ranking that can account for the entire Tangxi pattern. This is shown in (47).

(47) A sufficient ranking for Tangxi:

MAX-DOMEDGE(Tone), *BIGFALL-NONFINAL, *RISE-NONFINAL,
FAITH-ALIGN-LEFT(1)
»
*TONE
»
MAX(Tone), IDENT-DOMEDGE(Tone), *BIGFALL-FINAL, *RISE-FINAL
»
IDENT(Tone), *SMALLFALL-NONFINAL, AGREE(T_1-T_2)
»
*SMALLFALL-FINAL, FAITH-ALIGN-RIGHT(1)

6 Previous analyses

6.1 Chen (2000)'s analysis of Tangxi

The most notable earlier analysis of the asymmetrical Tangxi pattern appeared in Chen (2000). His analysis is as follows. For left-dominant sandhi, the compound first undergoes Tone Deletion on unstressed syllables and then Edge-in Association of the initial tone; as in (48a). For right-dominant sandhi, Tone Deletion still applies to unstressed syllables, but "since tones only associate rightwards, the initial syllables remain toneless, and carry a default pitch level." (p. 298) This is shown in (48b).

(48) Chen (2000)'s account of Tangxi:

a. Left-dominant sandhi:

(x	.	.	.)	
pao	*hyie*	*kong*	*sɨ*	'insurance company'
HL	HL	HL	HL	UR
HL	ø	ø	ø	Tone Deletion
H	ø	ø	L	Edge-in Association

b. Right-dominant sandhi:

(.	x)	
ma	*tsø*	'sell wine'
LH	HL	UR
ø	HL	Tone Deletion

Couched in a serial-derivation framework, this analysis may be subject to the criticisms that Optimality Theory has outlined for ordered rules (Prince and Smolensky (1993)). In addition, there are problems to the analysis independent of the nature of derivation. First, the generalization that "tones only associate rightwards," when stated in prose, does not make accurate predictions. As the cross-linguistic typology in Sect. 2 has shown, languages in which tones associate leftward do exist; the directional asymmetry is manifested as implicational statements, not a hard universal banning leftward association of tones. Second, the mechanism of "Edge-in Association," when translated into constraints implementable in OT, makes wrong predictions for the theory. Let me lay out this argument in detail.

The procedural "Edge-in Association" can be enforced by the high ranking of Alignment constraints in (49) in Optimality Theory.

(49) Edge-in Association's OT translation:

a. ALIGN(Tone, Left, PrWd, Left) (abbr. ALIGN-L):
The left edge of a tone must align with the left edge of a prosodic word.

b. ALIGN(Tone, Right, PrWd, Right) (abbr. ALIGN-R):
The right edge of a tone must align with the right edge of a prosodic word.

However, the addition of these constraints to our system is neither necessary nor sufficient. Their lack of necessity is shown by the successful derivations of all relevant types of tone extension patterns without them. This is shown in (50). For a /**51**-T/ input, the initial /**51**/ will extend as [**55**-11] if the general *CONTOUR outranks FAITH-ALIGN-RIGHT and IDENT(Tone); it will extend as [**53**-31] with the Tangxi ranking in Sect. 5; and it will spread only the low target rightward if IDENT-DOMEDGE(Tone) and AGREE(T_1-T_2) outrank *BIGFALL, *TONE, and FAITH-ALIGN-RIGHT. Put differently, the various ways of extending a tone to a larger domain result from the desire to avoid either a marked contour tone or a pitch change across a syllable boundary. Edge-in Association, or its OT translation, Alignment, is unnecessary to capture these patterns.

(50) Deriving spreading patterns without Alignment:

Pattern	No-Alignment account
/**51**-24/ → [**55**-11]	*CONTOUR » F-ALIGN-R, IDENT(Tone)
/**51**-24/ → [**53**-31]	*BIGFALL » IDENT-DOMEDGE(Tone) » F-ALIGN-R, *SMALLFALL
/**51**-24/ → [**51**-11]	IDENT-DOMEDGE(Tone), AGREE(T_1-T_2) » *BIGFALL, *TONE, F-ALIGN-R

The insufficiency of the Alignment constraints can be demonstrated by the loss of the asymmetry in the factorial typology. Given that both the contour tone markedness hierarchies and Faithful Alignment are independently needed, the Alignment constraints that enforce Edge-in Association cannot replace any part of the current system and thus must be added to the system. But once the Alignment constraints are included, the pattern in which the left-dominant sandhi is default insertion and right-dominant sandhi is tone extension (e.g., /**51**-24/ → [**51**-22], /24-**51**/ → [55-**11**]) can be predicted by the ranking ALIGN-L » F-ALIGN-L » F-ALIGN-R » *CONTOUR: essentially, the asymmetrical prediction enabled by the contour tone markedness and Faithful Alignment hierarchies is completely undone by the high ranking of ALIGN-L.

One may argue that the "tones only associate rightwards" generalization may project an intrinsic ranking F-ALIGN-L » ALIGN-L in the grammar, and this will resolve the overgeneration problem stated above. But this move presents both theoretical and empirical problems. The theoretical problem is in duplication: we now have two mechanisms in the theory to discourage leftward extension of a tone: F-ALIGN-L » F-ALIGN-R and F-ALIGN-L » ALIGN-L. This is undesirable for a theory. The empirical problem is that, with F-ALIGN-L » ALIGN-L, leftward tone extension cannot occur at all, and we know this prediction is false cross-linguistically.[20]

6.2 Duanmu (1993)

The observation that there are two different types of tone sandhi behavior in Chinese dialects was made by Duanmu (1993). He noted that in one type of languages, which he termed M-languages (short for Mandarin-type languages), the underlying tones of full syllables are either kept intact or contribute to the output sandhi tones; but in the other type of languages, which he termed S-languages (short for Shanghai-type languages), only the underlying tone of the initial syllable contributes to the output tones in the sandhi domain, often in the form of reassociating the tonal targets of the initial syllable to the polysyllabic domain. This is a similar observation to the one made here in that it also acknowledges the difference between two types of sandhi—tone extension and paradigmatic tone change—but it attributes the difference to a difference in language type, not initial versus final position, as in the current paper.

Duanmu (1993) went on to argue that the sandhi difference between M-languages and S-languages is due to the fact that the full rimes are underlyingly bimoraic in M-languages but monomoraic in S-languages. Being heavy, the bimoraic rimes in M-languages are inherently stressed and can either keep their underlying tones or carry other contour tones. Being light, the monomoraic rimes in S-languages do not carry inherent stress, and only syllables that are assigned stress by rule, such as the initial syllable, can keep their underlying tones; moreover, the monomoraic status of the rimes prevents them from carrying contour tones, which then forces the tonal targets of the stressed syllable to be extended to the polysyllabic sandhi domain it heads.

The difference in mora count between rimes of M-languages and rimes of S-languages is argued on the basis of phonetic duration and segmental composition of the rimes. Phonetic studies reported in Duanmu (1993, 1994b) showed that the average syllable durations of Mandarin and Shanghai are 215 ms and 162 ms, respectively, and he argued that this supports the position that Mandarin syllables have one extra X slot than Shanghai syllables. In terms of rime complexity, Duanmu (1993, 1994a) argued that M-languages such as Mandarin and Cantonese have coda contrasts and diphthongs while S-languages like Shanghai and Suzhou have no coda contrasts or diphthongs, and all their rimes are in the form of CV, where the vowel is either oral,

[20] An anonymous reviewer questioned whether the analysis provided here can truly be considered an improvement over Chen's elegant statements as it requires 14 ranked constraints and unconventional definitions of faithfulness constraints. I believe that the validity of a theory depends not on its internal complexity but on how well its predictions fit with data. I have tried to justify each component of the theory on phonetic and typological grounds, and I have made an attempt to show that the theory not only provides an analysis for Tangxi but also makes predictions that agree relatively well with language typology. In this light, even if the current analysis did not compare favorably to Chen's in simplicity, it should still be considered a methodological progress.

nasalized, or glottalized. This also supports the bimoraic versus monomoraic distinction between the two types of languages.

Therefore, according to Duanmu (1993), the difference between tone extension and paradigmatic substitution also receives a durational account, but the account is couched in the bimoraic versus monomoraic distinction between the rimes of two types of languages, not the initial versus final difference reflected in the directionalities of the two types of processes. In other words, the relation between the sandhi behavior and the durational property incurred by the position of the prominent syllable is entirely accidental in the Duanmu (1993) account: it just so happens that S-languages like Shanghai have initial prominence and M-languages like Mandarin have final prominence; the fact that tone extension occurs in S-languages and paradigmatic tone change occurs in M-languages is due to the monomoracity of S-language rimes and the bimoraicity of M-language rimes, not the durational difference between initial and final syllables.[21]

A more comprehensive study of cross-dialectal typology, however, has shown us that the M-language versus S-language distinction is possibly inaccurate. We have seen that many languages have dual prominence and an asymmetrical sandhi pattern, with left-dominant tone extension as in Shanghai and right-dominant paradigmatic tone change as in Mandarin. Although in some cases the asymmetry can be accounted for by the Mandarin versus Shanghai difference that Duanmu (1993) has envisioned—for example, the rightward tone extension to "neutral tone" syllables in Mandarin can be attributed to the lack of inherent stress on such syllables—most asymmetrical cases cannot be similarly analyzed. Tangxi, in which the asymmetry is based on the syntactic configuration of the compound, and Wenzhou, in which the asymmetry is manifested in the comparison between proclitics and enclitics, are cases in point. Therefore, it is much more likely that the sandhi difference is caused by the consistent durational difference between initial and final syllables, not by the difference in mora count of the syllables, which may not exist for syllables in the same languages.

[21] Duanmu (1999) revised his earlier position that Shanghai rimes are monomoraic and claimed that they are underlyingly unspecified for weight; the initial syllable is bimoraic on the surface and attracts stress, but it does not carry contour tones, due to a general dispreference for contour tones. This position was defended on the basis of phonetic data from Zhu (1999) as well as on theoretical grounds that relate to cross-linguistic metrical structures. However, with this position, the tone sandhi difference between Mandarin and Shanghai has now become an idiosyncratic ranking difference among constraints such as T-DISTINCTION, POLARITY, and SIMPLE TONE (see Duanmu (1999) for details), which do not directly relate to their syllabic or metrical structures, and it is not clear whether these constraints can be extended to other M- and S-languages to capture their difference. The theoretical gain at one place, therefore, comes with the loss of generality at another.

7 Conclusion

In this paper, I have identified a formal asymmetry between left-dominant and right-dominant tone sandhi systems in Chinese. The asymmetry is best stated in terms of implicational statements: in a language with both left-dominant and right-dominant tone sandhis, if the left-dominant sandhi involves default insertion/paradigmatic neutralization, then the right-dominant sandhi also involves default insertion/paradigmatic neutralization; if the right-dominant sandhi involves tone extension, then the left-dominant also involves tone extension. To capture this asymmetry, I have shown that a theory of tone and tone sandhi must include the following elements: (a) contour tone markedness hierarchies that penalize time-consuming contour tones on syllables with short duration and (b) Faithful Alignment constraints, with the intrinsic ranking FAITH-ALIGN-LEFT » FAITH-ALIGN-RIGHT. The theory is motivated from both the empirical adequacy of its predictions via factorial typology and the phonetic underpinnings of its intrinsic rankings. A case study shows that the theory can indeed account for a real language pattern that manifests the left/right sandhi asymmetry. A by-product of the analysis is that Edge-in Association, or its OT translation in Alignment constraints, should play no role in a theory of tonal melody mapping.

As I have freely admitted throughout the paper and in various footnotes, there are many unresolved issues in this proposal. For example, I have not made an attempt to address the thorny issue of stress in Chinese dialects; I have not investigated the sandhi behavior of checked syllables in dialects that have them; I have not proposed an explicit account for the surface forms of default tones; and I have in places glossed over nuances in tonal transcriptions provided that they do not affect the crux of the analysis to the best of my judgment. Some of these issues can be resolved by careful acoustic studies of the dialects in question, and some simply require a study that is much bigger in scope than can be afforded in this paper. However, I believe that for a large problem like Chinese tone sandhi, careful compartmentalization is a good thing. Provided that the compartmentalization is not done at the risk of either distorting the data or losing the forest for the tree, we may be able to make more efficient progress if we start with relatively modest goals, in the hopes that a complete picture will emerge once we have figured out all the parts to the puzzle.

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Appendix: factorial typology with different tone extension patterns

This appendix lays out the prediction of the theory when different patterns of tone extension are considered. We again assume a system in which the prominent syllable can be either initial or final and the sandhi is bidirectional. The sets of output candidates for the two inputs /**51**-24/ and /24-**51**/ (boldface indicates prominence) are given in (1), repeated from (31) in Sect. 4.1.

(1) Inputs and output candidates for the factorial typology:

/**51**-24/ →	**51**-24 (faithful)	/24-**51**/ →	24-**51** (faithful)
	51-22 (default insertion)		22-**51** (default insertion)
	55-11 (tone extension)		55-**11** (tone extension)
	53-31 (tone extension)		53-**31** (tone extension)
	51-11 (tone extension)		55-**51** (tone extension)

The constraints and their intrinsic rankings relevant for the calculation of the factorial typology are given in (2), repeated from (32).

(2) Relevant constraints for the factorial typology and their intrinsic rankings:

a. *BIGFALL-NONFINAL » *SMALLFALL-NONFINAL
» »
*BIGFALL-FINAL » *SMALLFALL-FINAL

b. F-ALIGN-L » F-ALIGN-R

c. MAX-DOMEDGE(Tone) » *TONE » MAX(Tone)

d. IDENT-DOMEDGE(Tone), IDENT(Tone)

e. AGREE(T_1-T_2)

The factorial typology calculated by *OTSoft* (Hayes et al. (2003)) returns nine patterns, which are shown in (3) along with the crucial rankings that derive them. "BIGFALL" and "SMALLFALL" are abbreviated to "51" and "53", respectively. Of the nine patterns, three represent the asymmetrical left-dominant tone extension and right-dominant default insertion, five represent tone extension in both directions, and one represents default insertion in both directions. The opposite of the asymmetrical pattern—left-dominant default insertion and right-dominant tone extension—is still not predicted.

(3) Factorial typology of bidirectional sandhi with inputs /**51**-24/ and /**24**-51/:

Pattern		Ranking
a. L-dom. extension R-dom. default	/**51**-24/ → [**55**-11] /24-**51**/ → [22-**51**]	*51-NonFin, F-Align-L » *53-NonFin, *51-Fin, F-Align-R » Id-DomEdge(T), *53-Fin, Agree(T_1-T_2)
	/**51**-24/ → [**53**-31] /24-**51**/ → [22-**51**]	*51-NonFin, F-Align-L » Id-DomEdge(T), *51-Fin, F-Align-R, Agree(T_1-T_2) » *53-NonFin » *53-Fin
	/**51**-24/ → [**51**-11] /24-**51**/ → [22-**51**]	Id-DomEdge(T), F-Align-L » *51-NonFin, Agree(T_1-T_2) » *53-NonFin, *51-Fin, F-Align-R » *53-Fin
b. L-dom. extension R-dom. extension	/**51**-24/ → [**53**-31] /24-**51**/ → [55-**51**]	*51-NonFin, Agree(T_1-T_2) » Id-DomEdge(T), F-Align-L » *53-NonFin, *51-Fin, F-Align-R » *53-Fin
	/**51**-24/ → [**53**-31] /24-**51**/ → [53-**31**]	*51-NonFin, Agree(T_1-T_2) » *51-Fin, F-Align-L » Id-DomEdge(T), *53-NonFin, F-Align-R » *53-Fin
	/**51**-24/ → [**51**-11] /24-**51**/ → [55-**51**]	Id-DomEdge(T), Agree(T_1-T_2) » *51-NonFin, F-Align-L » *53-NonFin, *51-Fin, F-Align-R » *53-Fin
	/**51**-24/ → [**55**-11] /24-**51**/ → [55-**51**]	*51-NonFin » *53-NonFin » Id-DomEdge(T) » *51-Fin » *53-Fin, Agree(T_1-T_2) » F-Align-L » F-Align-R
	/**51**-24/ → [**55**-11] /24-**51**/ → [55-**11**]	*51-NonFin » *53-NonFin, *51-Fin » Id-DomEdge(T), *53-Fin, F-Align-L, Agree(T_1-T_2) » F-Align-R
c. L-dom. default R-dom. default	/**51**-24/ → [**51**-22] /24-**51**/ → [22-**51**]	Id-DomEdge(T), F-Align-L » *51-NonFin, F-Align-R » *53-NonFin, *51-Fin, Agree(T_1-T_2) » *53-Fin

References

Baković, E. (2000). *Harmony, dominance, and control*. Ph.D. dissertation, Rutgers University.

Bao, Z.-M. (1990). *On the nature of tone*. Ph.D. dissertation, MIT.

Bao, Z.-M. (1999). *The structure of tone*. New York and Oxford: Oxford University Press.

Barrie, M. (2006). Tone circles and contrast preservation. *Linguistic Inquiry, 37*, 131–141.

Beckman, J. N. (1998). *Positional faithfulness*. Ph.D. dissertation, University of Massachusetts, Amherst.

Beckman, M. E., & Edwards, J. (1990). Lengthening and shortening and the nature of prosodic constituency. In J. Kingston & M. E. Beckman (Eds.), *Papers in the laboratory phonology I: Between the grammar and the physics of speech* (pp. 152–178). Cambridge, UK: Cambridge University Press.
Black, J. W. (1970). The magnitude of pitch inflection. In *Proceedings of the 6th International Congress of Phonetic Sciences* (pp. 177–181). Prague: Academia.
Byrd, D. (2000). Articulatory vowel lengthening and coordination at phrasal junctures. *Phonetica, 57*, 3–16.
Chan, M. K. M. (1991). Contour-tone spreading and tone sandhi in Danyang Chinese. *Phonology, 8*, 237–259.
Chan, M. K. M. (1995). An autosegmental analysis of Danyang tone sandhi: Some historical and theoretical issues. In E. Zee (Ed.), *Wuyu yanjiu* [*Studies of the Wu dialects*] (pp. 145–184). Hong Kong: New Asia Academic Publishing.
Chan, M. K. M., & Ren, H.-M. (1989). Wuxi tone sandhi. *Acta Linguistica Hafniensia, 21.2*, 35–64.
Chao, Y.-R. (1948). *Mandarin primer: An intensive course in spoken Chinese*. Cambridge, MA: Harvard University Press.
Chao, Y.-R. (1968). *A grammar of spoken Chinese*. Berkeley and Los Angeles: University of California Press.
Chen, H.-M. (1997). *Haikouhua yindang* [The sound archive of Haikou]. In Jingyi Hou (Ed.), *Xiandai hanyu fangyan yinku* [The sound archives of modern Chinese dialects]. Shanghai: Shanghai Jiaoyu Chubanshe [Shanghai Education Press].
Chen, M. Y. (1987). The syntax of Xiamen tone sandhi. *Phonology Yearbook, 4*, 109–150.
Chen, M. Y. (2000). *Tone sandhi: Patterns across Chinese dialects*. Cambridge, UK: Cambridge University Press.
Cheng, R. L. (1968). Tone sandhi in Taiwanese. *Linguistics, 41*, 19–42.
Cho, T.-H., & Keating, P. (2001). Articulatory and acoustic studies on domain-initial strengthening in Korean. *Journal of Phonetics, 29.2*, 155–190.
Cinque, G. (1993). A null theory of phrase and compound stress. *Linguistic Inquiry, 24*, 239–297.
Clark, M. M. (1983). On the distribution of contour tones. In M. Barlow et al. (Eds.), *Proceedings of WCCFL 2* (pp. 44–55). Stanford, CA: Stanford Linguistics Association, Stanford University.
de Lacy, P. (2002). The interaction of tone and stress in Optimality Theory. *Phonology, 19*, 1–32.
Duanmu, S. (1990). *A formal study of syllable, tone, stress and domain in Chinese languages*. Ph.D. dissertation, MIT.
Duanmu, S. (1993). Rime length, stress, and association domains. *Journal of East Asian Linguistics, 2*, 1–44.
Duanmu, S. (1994a). Against contour tone units. *Linguistic Inquiry, 25.4*, 555–608.
Duanmu, S. (1994b). Syllabic weight and syllabic duration: A correlation between phonology and phonetics. *Phonology, 11*, 1–24.
Duanmu, S. (1995). Metrical and tonal phonology of compounds in two Chinese dialects. *Language, 71.2*, 225–259.
Duanmu, S. (1996). Tone: An overview. *Glot International, 2.4*, 3–10.
Duanmu, S. (1999). Metrical structure and tone: Evidence from Mandarin and Shanghai. *Journal of East Asian Linguistics, 8*, 1–38.
Duanmu, S. (2000). *The phonology of Standard Chinese*. Oxford: Oxford University Press.
Edwards, J., Beckman, M. E., & Fletcher, J. (1991). The articulatory kinematics of final lengthening. *Journal of the Acoustical Society of America, 89*, 369–382.
Fougeron, C., & Keating, P. (1997). Articulatory strengthening at the edges of prosodic domains. *Journal of the Acoustical Society of America, 101*, 3728–3740.
Fu, G.-T. (1984). Wuyi fangyan de liandu biandiao [Tone sandhi in the Wuyi dialect]. *Fangyan* [*Dialects*], *1984.2*, 109–127.
Gandour, J. T. (1978). The perception of tone. In Victoria A. Fromkin (Ed.), *Tone: A linguistic survey* (pp. 41–76). New York: Academic Press.
Gandour, J., Potisuk, S., & Dechongkit, S. (1994). Tonal coarticulation in Thai. *Journal of Phonetics, 22*, 474–492.
Gandour, J. T., & Harshman, R. A. (1978). Crosslanguage differences in tone perception: A multidimensional scaling investigation. *Language and Speech, 21*, 1–33.
Gordon, M. (1999). *Syllable weight: Phonetics, phonology, and typology*. Ph.D. dissertation, UCLA.

Greenberg, S., & Zee, E. (1979). On the perception of contour tones. *UCLA Working Papers in Phonetics, 45*, 150–164.
Han, M. S., & Kim, K.-O. (1974). Phonetic variation of Vietnamese tones in disyllabic utterances. *Journal of Phonetics, 2*, 223–232.
Hayes, B., Tesar, B., & Zuraw, K. (2003). *OTSoft 2.1*, software package, http://www.linguistics.ucla.edu/people/hayes/otsoft
He, W. (1979). Huojia fangyan de liandu biandiao [Tone sandhi in the Huojia dialect]. *Fangyan* [*Dialects*], *1979.2*, 122–136.
Hofhuis, E., Gussenhoven, C., & Rietveld, A. (1995). Final lengthening at prosodic boundaries in Dutch. In *Proceedings of the International Congress of Phonetic Sciences '95, Vol. 1* (pp. 154–157). Stockholm: KTH and Department of Linguistics, University of Stockholm.
Hsieh, F.-F. (2005). Tonal chain-shifts as anti-neutralization-induced tone sandhi. In S. Arunachalam, T. Scheffler, S. Sundaresan, & J. Tauberer (Eds.), *Proceedings of the 28th Annual Penn Linguistics Colloquium, University of Pennsylvania Working Papers in Linguistics 11.1* (pp. 99–112). Philadelphia: Penn Linguistics Circle.
Hsieh, H.-I. (1970). The psychological reality of tone sandhi rules in Taiwanese. In *Papers from the 6th Meeting of the Chicago Linguistic Society* (pp. 489–503). Chicago: Chicago Linguistic Society.
Hsieh, H.-I. (1975). How generative is phonology? In E. F. Koerner (Ed.), *The transformational-generative paradigm and modern linguistic theory* (pp.109–144). Amsterdam: John Benjamins.
Hsieh, H.-I. (1976). On the unreality of some phonological rules. *Lingua, 38*, 1–19.
Hyman, L. M., & VanBik, K. (2004). Directional rule application and output problems in Hakha Lai tone. *Language and Linguistics*, *5.4*, 821–861.
Iwata, R. (1982). Lianyungangshi fangyan de liandu biandiao [Tone sandhi in the dialect of Lianyungang City]. *Fangyan* [*Dialects*], *1982.4*, 285–296.
Jiang-King, P. (1996). *An optimality account of tone-vowel interaction in Northern Min*. Ph.D. dissertation, University of British Columbia, Vancouver, Canada.
Jiang-King, P. (1999). Sonority constraints on tonal distributions across Chinese dialects. In K. N. Shahin et al. (Eds.), *Proceedings of WCCFL 17* (pp. 332–346). Stanford University: CSLI Publication.
Johnson, K., & Martin, J. (2001). Acoustic vowel reduction in Creek: Effects of distinctive length and position in the word. *Phonetica, 58*, 81–102.
Kennedy, G. A. (1953). Two tone patterns in Tangsic. *Language, 29*, 367–373.
Klatt, D. H. (1975). Vowel lengthening is syntactically determined in connected discourse. *Journal of Phonetics, 3*, 129–140.
Klatt, D. H. (1976). Linguistic uses of segmental duration in English: Acoustic and perceptional evidence. *Journal of the Acoustical Society of America, 59*, 1208–1221.
Lehiste, I. (1960). An acoustic phonetic study of internal open juncture. Supplement to *Phonetica*, *5*.
Lehiste, I. (1972). Timing of utterances and linguistic boundaries. *Journal of the Acoustical Society of America, 51*, 2108–2124.
Li, Z.-Q. (2003). *The phonetics and phonology of tone mapping in a constraint-based approach*. Ph. D. dissertation, MIT.
Li, Z.-Q. (2005). *Dual prominence in tone mapping: A case of tone movement*. Paper presented at WCCFL 24, Simon Fraser University, Vancouver, Canada.
Lin, J.-W. (1994). Lexical government and tone group formation in Xiamen Chinese. *Phonology, 11*, 237–275.
Lin, L.-T., & Pan, W.-S. (1998). *Jian'ouhua yindang* [The sound archive of Jian'ou]. In Jingyi Hou (Ed.), *Xiandai hanyu fangyan yinku* [The sound archives of modern Chinese dialects]. Shanghai: Shanghai Jiaoyu Chubanshe [Shanghai Education Press].
Lindblom, B. (1968). Temporal organization of syllable production. *Speech Transmission Laboratory Quarterly Progress and Status Report, 2–3*, 1–5.
Lindblom, B., & Rapp, K. (1973). Some temporal regularities of spoken Swedish. In *Papers from the Institute of Linguistics (PILUS), 21*. University of Stockholm, Sweden.
Lindblom, B., Lyberg, B., & Holmgren, K. (1981). *Durational patterns of Swedish phonology: Do they reflect short-term motor memory processes?* Bloomington: Indiana University Linguistics Club.
Lombardi, L. (1999). Positional faithfulness and voicing assimilation in Optimality Theory. *Natural Language and Linguistic Theory*, *17*, 267–302.

Lü, S.-X. (1980). Danyang fangyan de shengdiao xitong [The tonal system of the Danyang dialect]. *Fangyan* [*Dialects*], *1980.2*, 85–122.
Lyberg, B. (1977). Some observations on the timing of Swedish utterances. *Journal of Phonetics*, *5*, 49–59.
Maddieson, I. (1977). *Universals of tone: Six studies*. Ph.D. dissertation, UCLA.
McCarthy, J. (2003). OT constraints are categorical. *Phonology*, *20*, 75–138.
Ohala, J. J. (1978). Production of tone. In Victoria A. Fromkin (Ed.), *Tone: A linguistic survey* (pp. 5–39). New York: Academic Press.
Oller, D. K. (1973). The effect of position in utterance on speech segment duration in English. *Journal of the Acoustical Society of America, 54*, 1235–1247.
Pan, W.-Y. (1998). *Wenzhouhua yindang* (The sound archive of Wenzhou). In Jingyi Hou (Ed.), *Xiandai hanyu fangyan yinku* [The sound archives of modern Chinese dialects]. Shanghai: Shanghai Jiaoyu Chubanshe [Shanghai Education Press].
Peng, S.-H. (1997). Production and perception of Taiwanese tones in different tonal and prosodic contexts. *Journal of Phonetics, 25*, 371–400.
Prince, A., & Smolensky, P. (1993). *Optimality Theory: Constraint interaction in generative grammar*. Ms., Rutgers University & University of Colorado, Boulder. Revised version published in 2004 by Malden, MA/Oxford, UK/Carlton, Australia: Blackwell Publishers.
Rose, P. (1990). Acoustics and phonology of complex tone sandhi. *Phonetica, 47*, 1–35.
Steriade, D. (to appear). The phonology of perceptibility effects: The P-map and its consequences for constraint organization. To appear in S. Inkelas, & K. Hanson (Eds.), *The nature of the word: Essays in honor of Paul Kiparsky*. Cambridge, MA: MIT Press.
Strangert, E. (1985). Swedish speech rhythm in a cross-language perspective. *Acta Universitatis Umensis, Umeå Studies in the Humanities, 69*. Stockholm: Almqvist and Wiksell International.
Sundberg, J. (1979). Maximum speed of pitch changes in singers and untrained subjects. *Journal of Phonetics, 7*, 71–79.
Tang, Z.-F. (1960). Hunan Dongkouxian Huangqiaozhen fangyan [The dialect of Huangqiao, Dongkou County, Hunan Province]. *Yuyanxue Luncong* [Forum in Linguistics], *4*, 83–133.
Wang, H. S. (1993). Taiyu biandiao de xinli texing [On the psychological status of Taiwanese tone sandhi]. *Tsinghua Xuebao* [*Tsinghua Journal of Chinese Studies*], *23*, 175–192.
Wang, P. (1988). Changzhou fangyan de liandu biandiao [Tone sandhi in the Changzhou dialect]. *Fangyan* [*Dialects*], *1988.3*, 177–194.
Wang, W. (1967). Phonological features of tone. *International Journal of American Linguistics, 33*, 93–105.
Wang, Y.-J. (1996). Qingsheng yingao suoyi [Pitch qualities of the neutral tone]. *Shijie Hanyu Jiaoxue* [*International Journal of Chinese Pedagogy*], *37.3*, 50–53.
Wang, Z.-J., & Feng, S.-L. (2006). Shengdiao duibifa yu Beijinghua shuangyinzu leixing [Tonal contrast and disyllabic stress patterns in Beijing Mandarin]. *Yuyan Kexue* [Linguistic Sciences], *5.1*, 3–22.
Wightman, C. W., Shattuck-Hufnagel, S., Ostendorf, M., & Price, P. J. (1992). Segmental durations in the vicinity of prosodic phrase boundaries. *Journal of the Acoustical Society of America, 91*, 1707–1717.
Xie, L.-W. (1992). Jiangxisheng Yudu fangyan liangzizu liandu biandiao [Disyllabic tone sandhi in the Yudu dialect of Jiangxi Province]. *Fangyan* [*Dialects*], *1992.3*, 222–227.
Xu, B.-H., Tang, Z.-Z., & Qian, N.-R. (1981). Xinpai Shanghai fangyan de liandu biandiao [Tone sandhi in the New Shanghai dialect]. *Fangyan* [*Dialects*], *1981.2*, 145–155.
Xu, Y. (1997). Contextual tonal variations in Mandarin. *Journal of Phonetics, 25*, 61–83.
Xu, Y., & Sun, X.-J. (2002). Maximum pitch change and how it may relate to speech. *Journal of the Acoustical Society of America, 111*, 1399–1413.
Yip, M. (1989). Contour tones. *Phonology, 6*, 149–174.
Yip, M. (2003). Feet and tonal reduction at the word and phrase level in Chinese. In J. McCarthy (Ed.), *Optimality Theory in phonology: A reader* (pp. 228–245). Oxford: Blackwell.
You, R.-J. (1994). *Shanghaihua yindang* [The sound archive of Shanghai]. In Jingyi Hou (Ed.), *Xiandai hanyu fangyan yinku* [The sound archives of modern Chinese dialects]. Shanghai: Shanghai Jiaoyu Chubanshe [Shanghai Education Press].
Yue-Hashimoto, A. O. (1987). Tone sandhi across Chinese dialects. In Chinese Language Society of Hong Kong (Ed.), *Wang Li memorial volumes, English volume* (pp. 445–474). Hong Kong: Joint Publishing Co.

Zee, E., & Maddieson, I. (1979). Tone and tone sandhi in Shanghai: Phonetic evidence and phonological analysis. *UCLA Working Papers in Phonetics, 45*, 93–129.
Zhang, J. (1999). Duration in the tonal phonology of Pingyao Chinese. In M. K. Gordon (Ed.), *UCLA Working Papers in Linguistics, Papers in Phonology 3*, 147–206.
Zhang, J. (2000a). The phonetic basis for tonal melody mapping in Mende and elsewhere. In R. Billerey & B. Lillehaugen (Eds.), *Proceedings of WCCFL 19* (pp. 603–616). Somerville, MA: Cascadilla Press.
Zhang, J. (2000b). Non-contrastive features and categorical patterning in Chinese diminutive suffixation—MAX[F] or IDENT[F]? *Phonology, 17*, 427–478.
Zhang, J. (2002). *The effects of duration and sonority on contour tone distribution—A typological survey and formal analysis*. New York: Routledge.
Zhang, J. (2004). Contour tone licensing and contour tone representation. *Language and Linguistics, 5.4*, 926–968.
Zhang, J., Lai, Y.-W., & Turnbull-Sailor, C. (2006). Wug-testing the "tone circle" in Taiwanese. In D. Baumer, D. Montero, & M. Scanlon (Eds.), *Proceedings of WCCFL 25*, 453–461. Somerville, MA: Cascadilla Press.
Zhang, J. (to appear *a*). Contour tone distribution is not an artifact of tonal melody mapping. *Studies in the Linguistic Sciences, 33.1*.
Zhang, J. (to appear *b*). The formal comparison between constraint weighting and constraint domination. To appear in *Phonology, 24*.
Zhang, S.-Y. (1979). Chaoyang fangyan de liandu biandiao [Tone sandhi in the Chaoyang dialect]. *Fangyan* [*Dialects*], *1979.2*, 93–121.
Zhang, Z.-X. (1983). Zhangping (Yongfu) fangyan de liandu biandiao [Tone sandhi in the Zhangping (Yongfu) dialect]. *Fangyan* [*Dialects*], *1983.3*, 175–196.
Zheng-Zhang, S.-F. (1964). Wenzhou fangyan de liandu biandiao [Tone sandhi in the Wenzhou dialect]. *Zhongguo Yuwen* [*Chinese Philology*], *129*, 106–152.
Zhu, X.-N. S. (1999). *Shanghai tonetics*. München and Newcastle: Lincom Europa.
Zoll, C. (2003). Optimal tone mapping. *Linguistic Inquiry, 34.2*, 225–268.