Smooth Tones as a Natural Class:

Explaining Complex Tone Sandhi in the Sinitic Wu Dialect of Huangyan*

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Abstract

This study examines tone sandhi for disyllabic words in the Sinitic Wu dialect of Huangyan. Huangyan typically shows right-dominance – word-final tones remain unchanged while word-initial tones change (e.g., many neutralize to mid-pitch tones). However, other sandhi types are also observed: left-dominance (only final tones changes), both-change (both initial and final tones change), and no-change cases. I propose to incorporate contour slope [±smooth] and movement [±fall] into the feature geometry of tones to capture both the tonal inventory in this language and its sandhi processes. For word-initial sandhi, contour slope (sharp vs. smooth) predicts whether the contour is preserved, while contour movement (fall vs. non-fall) predicts whether sandhi is sensitive to adjacent tones. Unlike word-initial sandhi, word-final sandhi is more structure-preserving, producing tones already in the inventory, and it changes the register but not the contour of tones. Additionally, idiosyncratic sandhi processes serve as special repairs for contour clashes with successive identical contours.

Keywords: tone sandhi, right-dominance, smoothness, contour clashes

1. Introduction

Sinitic tonal languages are known for their tone sandhi, a phenomenon where the base tones of individual syllables can change systematically depending on their position in a phonological word or phrase (Chen, 2000). As sandhi processes often result in neutralization of tones, where tonal contrasts are lost, tone sandhi systems can be classified as being left-dominant or right-dominant, depending on the dominant position where base tones remain intact from neutralization. In left-dominant systems often found in Northern Wu, the tone on the initial (leftmost) syllable remains intact, while tones on non-initial syllables are lost, as in (1) (each tone represented with two endpoints using the incremental five-point pitch scale introduced by Chao, 1930).

(1) Shanghainese (Northern Wu): initial tone is decomposed and extends rightward
/tsʰɔ^{34}-vɛ^{13}/ ‘fry-rice’ → [tsʰɔ^{33}-vɛ^{44}] ‘fried rice’[2] (Xu et al., 1981)

By contrast, in right-dominant systems often found in Southern Min and Southern Wu, the tone on the final (rightmost) syllable remains intact while non-final tones are lost, as in (2).

(2) Taiwanese (Southern Min): final tone is preserved while non-final tone is substituted
/te^{24}-kuan^{51}/ ‘tea-shop’ → [te^{33}-kuan^{51}] ‘teahouse’ (Chien et al., 2017)

Although the left-dominant and right-dominant classification is often used to describe different sandhi systems, both types of dominance patterns can be found within a single language and within a single system of lexical tone sandhi (Rose & Yang, 2024).

This paper examines the lexical tone sandhi system in the Southern Wu variety of Huangyan, focusing on disyllabic words. I argue to introduce contour features of [±smooth] and [±fall] to the feature geometry of tones in capturing the tonal inventory of Huangyan and its mixed sandhi system with both word-initial and word-final sandhi processes. Further analyses show that: (1) unlike initial tones that lose contrastive contours, final tones are less affected by sandhi – they often retain their contours but only shift in register when necessary; (2) the smoothness approach

[2] It should be noted, however, that when /tsʰɔ^{34}-vɛ^{13}/ is used as a verb phrase, it can either undergo extension sandhi or tonal reduction [tsʰɔ^{44}-vɛ^{13}].

using contour features ([±smooth] and [±fall]) outperforms a high-mid-low approach in accounting for sandhi processes; (3) idiosyncratic sandhi processes reflect special repairs to resolve contour clashes of tones with identical contours through heightened dissimilation.

Section 2 introduces the basics of Huangyan Wu, with a focus on its tonal inventory. Section 3 presents the general sandhi patterns observed in Huangyan Wu and analyzes how tones behave in different positions of disyllabic words. Section 4 compares different approaches to characterizing regular sandhi rules and discusses whether contour specification using high-mid-low notations is sufficient for capturing tonal behaviors in Huangyan. Section 5 expands on idiosyncratic sandhi processes and explains how they can be rationalized as special repairs to resolve contour clashes. Section 6 discusses the implications of these findings and concludes.

2. Basics of Huangyan Wu

The Chinese Wu dialect of Huangyan (黄岩话/黃岩話; [wɔ̤ŋjɛ̤̃wa̤]) is a Southern Wu variety spoken in Huangyan, Taizhou in Zhejiang province, the home to Wu dialects. Geographically, it is extremely close to Ningbo, a Northern-Wu-speaking region. Note that different from Northern Wu varieties known for their left-dominant sandhi systems, Southern Wu varieties are typically characterized as having right-dominant systems.

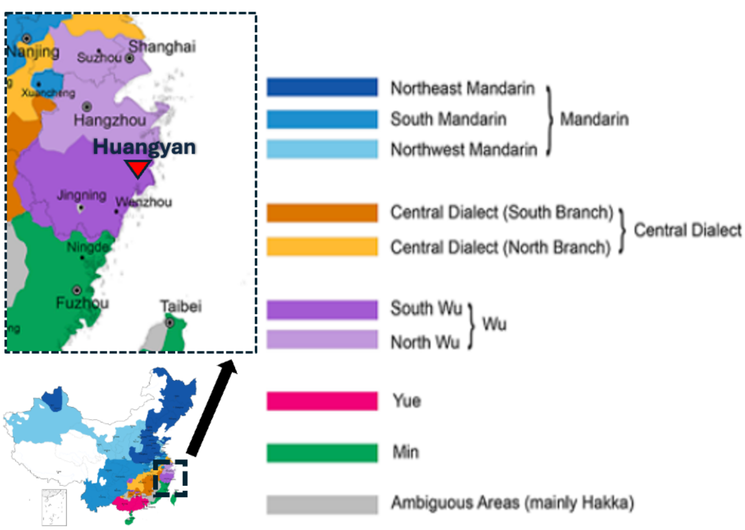


Figure 1. Location of Huangyan Wu: Southern Wu bordering Northern Wu (modified from Huang et al., 2024)

Huangyan Wu is a relatively understudied Southern Wu dialect. To our knowledge, Qian (1992) provided the first sketch of Huangyan in terms of its sound inventory, tonal inventory, and sandhi behaviors. However, the data was not fully sorted out and analyzed. As Huangyan Wu features a *yin*-*yang* register split for voiced and voiceless consonants, the following table organizes the consonantal inventory of Huangyan for reference (cf. Qian, 1992).

Table 1. Consonants of Huangyan Wu (voiceless in upper register; voiced in lower register)[3]

manner \ place		labial	labiodental	dental	alveolo-palatal	palatal	velar	glottal
nasal		m (m̥)		n (n̥)	ȵ (ȵ̥)		ŋ (ŋ̊)	
plosive	voiceless	p, p^h		t, t^h			k, k^h	
	voiced	b		d			g	ʔ
fricative	voiceless		f	s	ɕ			h
	voiced		v	z	ʑ			ɦ
affricate	voiceless			ts, ts^h	tɕ, tɕ^h			
	voiced			dz	dʑ			
lateral				l				

Table 2 describes the tonal inventory of Huangyan Wu. For simplicity, I use upper case letters A, B, C, D to respectively refer to the four tonal categories *ping*, *shang*, *qu*, and *ru* that are marked with Roman numerals in the literature, and I use numbers 1 and 2 for marking the upper and lower register.

Table 2. Tonal inventory of Huangyan Wu: 8 base tones[4]

Register	Tonal categories			
	A (*ping*)	B (*shang*)	C (*qu*)	D (*ru*)
1. upper (*yin*)	A1 /42/ mid-high falling [toŋ^{42}] 'east'	B1 /51/ high falling [toŋ^{51}] 'understand'	C1 /44/ high level [toŋ^{44}] 'freeze'	D1 /5/ short high [toʔ^{5}] 'supervise'
2. lower (*yang*)	A2 /21/ low falling [d̥o̤ŋ^{21}] 'same'	B2 /31/ mid falling [d̥o̤ŋ^{31}] 'move'	C2 /13/ low rising [d̥o̤ŋ^{13}] 'hole'	D2 /2/ short low [d̥o̤ʔ^{2}] 'read'

[3] For nasals, I include devoiced counterparts (noted with a circle below) in parentheses to indicate that syllables with nasal onsets can occur either in the upper register (associated with voiceless onsets) or in the lower register (associated with voiced onsets).

[4] For tone A2, the contour goes slightly upward and then downward for some onsets. For convenience of transcription, I use 21. For tone B2, some monosyllabic words (with voiceless onsets) historically in category B2 are shifting to category B1. For this paper, we focus on monosyllabic words with a voiced onset for category B2.

Figure 2 shows the tonal inventory by an urban Huangyan Wu speaker.

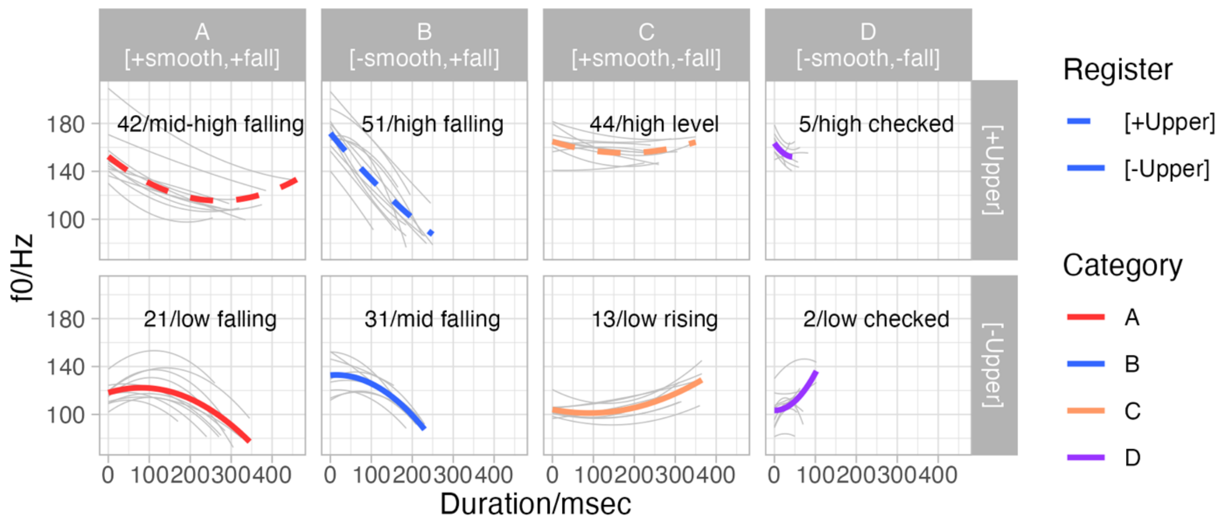
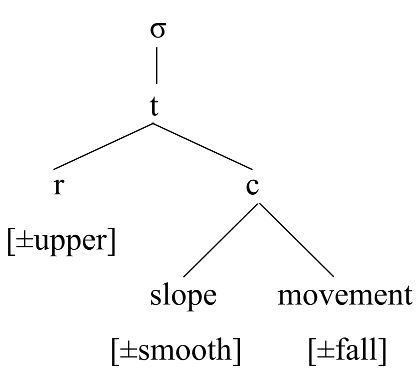


Figure 2. Tonal inventory of Huangyan Wu based on a native speaker over 60 years of age

As can be seen in Figure 2, Huangyan Wu has four falling tones (A1, A2, B1, B2), one level tone (C1), one rising tone (C2), and two checked tones (D1, D2).

To distinguish the four falling tones in Huangyan, this paper proposes to include a new dimension in the feature geometry of tones: *slope*, represented with a [±smooth] feature. This can be seen in Figure 2, where tones in category A ($A1^{42}$, $A2^{21}$) gradually fall, while tones in category B ($B1^{51}$, $B2^{31}$) fall more sharply. (3) illustrates the full feature geometry in Huangyan Wu.

(3) Revised feature geometry of tones (t = tone-bearing unit; r = register; c = contour)



This addition helps differentiate base tones in the inventory of Huangyan Wu, as shown in (4).

(4) Proposed approach: Feature matrices for base tones in Huangyan Wu

Category	Tone	upper	smooth	fall
A	A1^{42}	+	+	+
	A2^{21}	-	+	+
B	B1^{51}	+	-	+
	B2^{31}	-	-	+
C	C1^{44}	+	+	-
	C2^{13}	-	+	-
D	D1^{5}	+	-	-
	D2^{2}	-	-	-

Evidence for [±smooth] contour feature is also found in the Northern Wu dialect of Hangzhou. Hsieh (2007) noted that contour tones of different slopes (smooth vs. sharp) are distinct by their behaviors in word-initial positions. Hangzhou has a left-dominant sandhi system, so the base tones are mostly intact in initial positions. However, two extremely similar rising tones 23 (*yang ping*; Ib or A2) and 13 (*yang qu*; IIIb or C2) behave differently in initial positions. While both tones are in the lower register and share a similar offset pitch, [+smooth] rising tone 23, being longer in duration, is completely flattened and loses its contour, unlike the [-smooth] or more marked rising tone 13 that remains intact, as in (5).

(5) Tone sandhi with 23 (smooth rise) and 13 (sharp rise) in Hangzhou

23 → 22 / __ T

13: preserved in __ T

In Hsieh's (2007) terms, this reflects 'faithfulness to the marked' phenomenon – the more marked tone remains intact from sandhi. This means that the less marked tone, i.e., the smooth tone, tends to change. We will see in the next section that in Huangyan Wu, smooth tones (A and C tones) tend to change more compared to sharp tones as well – they lose their contours as a result.

I will show that the proposal here, using slope and movement for specifying contour, outperforms an alternative approach representing contours using h (high) and l (low) (Bao, 1999;

Chen, 2000).[5] In this alternative approach, falling tones are typically specified as hl, marking a contour tone that transitions from a high onset to a low offset. Following this annotation, we can, to our best, represent falling tones in Huangyan as in (6) (h=high, m=mid, l=low).

(6) Alternative approach[6]: High-low specifications for base tones in Huangyan Wu

$A1^{42}$: hm	$A2^{21}$: l	$B1^{51}$: hl	$B2^{31}$: ml
$C1^{44}$: h	$C2^{13}$: lm	$D1^{5}$: h	$D2^{2}$: l

We'll compare these two different approaches, a contour system featuring slope and movement (4) vs. one featuring high-low distinction (6), in the next section, where we'll look at how these eight citation tones in Huangyan Wu interact in lexical sandhi of disyllabic words.

3. Sandhi patterns

3.1 Sandhi data

The investigation of sandhi patterns in this paper is limited to disyllabic lexical nominals to control for potential morphosyntactic factors on sandhi types in Huangyan Wu.[7] Table 3 summarizes the statistics of sandhi patterns out of all possible combinations (8*8) of base tones, and Table 4 presents the output tones for all these combinations.

Table 3. Sandhi patterns across tonal combinations in Huangyan (unchanged syllable in bold)

Sandhi pattern	right-dominant	left-dominant	both change	no change	Total
Example	xəʔ mi 'black rice' /5 31/ [3 **31**]	ɦo̤ʔ tɔ̃ 'school' /2 21/ [**2** ^{3}51]	sɛ sɥ 'landscape' /42 51/ [33 31]	dɐ̤ʔ sɐʔ 'trait' /2 5/ [**2 5**]	
Count	32 (50%)	3 (4.7%)	23 (35.9%)	6 (9.4%)	64

[5] Here, I follow the conventional annotation of using lower case letters (e.g., h or l) for contour and upper-case letters (e.g., H or L) for register.
[6] The high-low specifications here were suggested by Nicholas Rolle at 2024 Annual Meeting on Phonology.
[7] We suspect that a lack of control on the structure of disyllabic words might be responsible for the unclear sandhi patterns in Qian (1993).

Table 4. Sandhi table: Behaviors of base tones in Huangyan (unchanged syllable in bold)

$T_{\sigma1}$ \ $T_{\sigma2}$		A1 /42/	A2 /21/	B1 /51/	B2 /31/	C1 /44/	C2 /13/	D1 /5/	D2 /2/
A	A1 /42/	[$45^{\uparrow}$-21]	[33-^{3}51]	[33-31]	[33-**31**]	[33-**44**]	[33-44]	[33-**5**]	[33-3]
	A2 /21/	[$25^{\uparrow}$-21]	[22-^{3}51]	[23-31]	[23-**31**]	[22-**44**]	[22-44]	[23-**5**]	[23-3]
B	B1 /51/	[42-**42**]	[$44^{\uparrow}$-31]	[42-31]	[42-**31**]	[21-**44**]	[21-**13**]	[21-**5**]	[21-**2**]
	B2 /31/	[42-**42**]	[$44^{\uparrow}$-31]	[42-31]	[42-**31**]	[21-**44**]	[21-**13**]	[21-**5**]	[21-**2**]
C	C1 /44/	[33-**42**]	[33-31]	[33-31]	[33-**31**]	[33-**44**]	[33-44]	[33-**5**]	[33-3]
	C2 /13/	[23-**42**]	[23-31]	[23-31]	[23-**31**]	[23-**44**]	[23-44]	[23-**5**]	[23-3]
D	D1 /5/	[3-**42**]	[**5**-51]	[3-31]	[3-**31**]	[3-**44**]	[3-**13**]	[3-**5**]	[3-**2**]
	D2 /2/	[**2-42**]	[**2**-^{3}51]	[**2**-31]	[**2-31**]	[**2-44**]	[**2-13**]	[**2-5**]	[**2-2**]

Note: "$45^{\uparrow}$" indicates that it's a falsetto-like rising tone that goes beyond normal pitch range; "^{3}51" refers to a falling tone 51 with a sharp rise from 3 to 5 compressed within the onset.

As Table 3 shows, tone sandhi system in Huangyan Wu is mostly right-dominant. Final tones are stable, whereas non-final tones shift in contour or register. It is notable, however, that there are also exceptions where both tones change (35.9%) or neither changes (9.4%).

3.2 Sandhi tones on initial vs. final syllables

To tease apart the mixed patterns, I investigate tone sandhi in σ1 and σ2 separately.

3.2.1 Sandhi tones on initial syllables

As shown in Table 5, for tones undergoing sandhi in initial syllables (the non-white cells), they mostly neutralize to mid tones (marked in different tints of blue) that are not in the inventory, but there are idiosyncratic sandhi processes (marked in purple), which we will address in section 4.3.

Table 5. Output sandhi tones in initial syllables (σ1)

<table>
<tr><th colspan="2">$T_{\sigma1}$\$T_{\sigma2}$</th><th>A1 /42/</th><th>A2 /21/</th><th>B1 /51/</th><th>B2 /31/</th><th>C1 /44/</th><th>C2 /13/</th><th>D1 /5/</th><th>D2 /2/</th></tr>
<tr><td rowspan="2">A</td><td>A1 /42/</td><td>$45^{\uparrow}$</td><td colspan="7">33</td></tr>
<tr><td>A2 /21/</td><td>$25^{\uparrow}$</td><td>22</td><td colspan="2">23</td><td colspan="2">22</td><td colspan="2">23</td></tr>
<tr><td rowspan="2">B</td><td>B1 /51/</td><td rowspan="2">42</td><td rowspan="2">$44^{\uparrow}$</td><td colspan="2" rowspan="2">42</td><td colspan="4" rowspan="2">21</td></tr>
<tr><td>B2 /31/</td></tr>
<tr><td rowspan="2">C</td><td>C1 /44/</td><td colspan="8">33</td></tr>
<tr><td>C2 /13/</td><td colspan="8">23</td></tr>
<tr><td rowspan="2">D</td><td>D1 /5/</td><td>3</td><td>5</td><td colspan="6">3</td></tr>
<tr><td>D2 /2/</td><td colspan="8">2</td></tr>
</table>

Note: Output sandhi tone targeting low range (42, 21), mid range (33, 23, 22), and high range ($45^{\uparrow}/25^{\uparrow}$, $44^{\uparrow}$)

Moreover, if we focus on each row that shows sandhi behaviors of each base tone, one noticeable observation is that while some tones undergo the same sandhi process (e.g., C1^{44} always changes to mid 33) in initial positions, regardless of the identity of the following (final) tone, other tones undergo different sandhi processes (e.g., A2^{21} changes to 44$^{\uparrow}$ before A2, to 21 before C/D, and to 42 before the rest) depending on the conditioning environment. Hence, Huangyan Wu shows both sandhi processes that are insensitive to adjacent tones, known as *positional sandhi*, and ones that are sensitive to adjacent tones, known as *contextual sandhi*.

Initial tone sandhi appears to be affected by two factors. First, the contour slope ([±smooth]) of the input tone affects the degree to which the contour is preserved during sandhi. Second, the contour movement ([±fall]) of the input tone affects whether sandhi processes are sensitive to adjacent tones. That is, smooth tones and sharp tones differ in how much of their contour remains intact, while falling and non-falling tones differ in how their sandhi behavior depends on the surrounding tones.

The effect of contour slope on initial sandhi is instantiated by the different behaviors of smooth (A/C) vs. sharp (B/D) tones in initial positions. A tones and C tones neutralize to mid tones (33 or 23), which follows naturally from our expectation that both being [+smooth] form a natural class. For those tones in the upper register, i.e. A1^{42} and C1^{44}, they neutralize to 33, whereas for those in the lower register, i.e., A2^{21} and C2^{13}, they neutralize to 23. This is summarized in (7) as the neutralization of smooth tones.

(7) R1. **Neutralization of smooth tones** (A/C). A1^{42}/C1^{44} neutralize to 33 before all Ts (except for A1 before A1) (R1a); A2^{21}/C2^{13} neutralize to 23 before B/D (R1b) and elsewhere, A2^{21} becomes 22 (except for A2 before A1) (R1c) and C2 always becomes 23.

Examples: A1$^{\mathbf{42}}$-B2^{31}. /goŋ^{42}-dɒ^{31}/ 'common-path' → [goŋ$^{\mathbf{33}}$-dɒ^{31}] 'justice' (R1a)

A2$^{\mathbf{21}}$-B1^{51}. /bi^{21}-tɕəu^{51}/ 'beer-alcohol' → [bi$^{\mathbf{23}}$-tɕəu^{31}] 'beer' (R1b)

A2$^{\mathbf{21}}$-C1^{44}. /dʑi^{21}-kuᴀ^{44}/ 'special-weird' → [dʑi$^{\mathbf{22}}$-kuᴀ^{44}] 'strange' (R1c)

Unlike smooth tones, sharp tones B and D, being [-smooth], don't show the cross-category neutralization. B tones, for instance, neutralize to 42 within the category before falling tones (A and B tones) but to 21 elsewhere, i.e., before non-falling tones (C and D tones), as in (8).

(8) R2. **Neutralization of sharp falling tones** (B1/B2). B1^{51}/B2^{31} neutralize to 42 before A1/B (R2a) and 21 before C/D (R2b).

Example: B1$^{\mathbf{51}}$-A1^{42}. /hu^{51}-ts^{h}o^{42}/ 'fire-car' → [hu$^{\mathbf{42}}$-ts^{h}o^{42}] 'train' (R2a)

B1$^{\mathbf{51}}$-C1^{44}. /ɕəu^{51}-t^{h}ɒ^{44}/ 'hand-cover' → [ɕəu$^{\mathbf{21}}$-t^{h}ɒ^{44}] 'glove' (R2b)

Noticeably, in sharp contour tones (category B), the contour is preserved (i.e., sandhi tones remain [+fall]). In contrast, in smooth contour tones (category A/C), the contour tends to be lost (i.e., sandhi tones are typically flattened and, in some cases, raised). This presents a striking parallel to the Northern Wu variety of Hangzhou, where the tonal inventory includes a slope contrast. In Hangzhou, the word-initial sharp rising tone 13 retains its contour, while word-initial smooth rising tone 23 is flattened to 22. What emerges as consistent across Hangzhou (Northern Wu) and Huangyan (Southern Wu) is that sandhi processes target contour tones broadly (whether rising or falling) but affect [+smooth] tones more significantly than [-smooth] tones. This cross-linguistic pattern reinforces the classification of smooth and sharp tones as two natural classes based on slope. Importantly, this distinction provides precise predictions about how these tone classes behave differently in sandhi processes, regardless of what sandhi system (left-dominance for Hangzhou or right-dominance for Huangyan) they instantiate.

The effect of contour movement [±fall] on initial sandhi is instantiated by the conditioning environment of sandhi. Falling tones are more affected by adjacent tones during sandhi than non-falling tones. For instance, A and B tones, being [+fall], are noticeably sensitive to adjacent tones during sandhi, whereas C and D tones, being [-fall], are not. Therefore, A and B tones undergo contextual sandhi, as they can change to different tones depending on the following tone (see Table 5).[8] C and D tones are the opposite – as long as they are in a non-final position, they either always change to the same tone (e.g., 33 for C1^{44} and 23 for C2^{13}) or do not change at all (i.e., D2^{2}), so they do not care about their following tone in sandhi processes.

This effect of contour movement is also found within [-smooth] tones (namely those in categories B and D). Checked (D) tones, being [-fall], preserve within-category pitch distinction after sandhi processes, but sharp falling (B) tones, being [+fall], lose the distinction. That is, the sandhi behaviors of checked tones in category D differ by register. Only the upper register tone

[8] Note that A2^{21} becomes 22 before A and C tones, which is only slightly different from their base tone. Here, we treat 22 as a smoothed allotone of 21, as is often the case across Sinitic dialects (cf. Bao, 2011).

D1^{5} shows sandhi, where it lowers to a mid-tone 3, as in (9), but the lower register tone D2^{2} remains intact.

(9) R3. **Lowering of high checked tone** (D1). D1^{5} lowers to 3 before all Ts (except before A2); D2^{2} is preserved before all Ts.

Example: D1^{5}-C2^{13}. /t^{h}iɐʔ^{5}-ləu^{13}/ 'steel-road' → [t^{h}iɐʔ^{3}-ləu^{13}] 'railway'

This is, however, not the case with tones in category B.

3.2.2 Sandhi tones on final syllables

For tones undergoing sandhi in final syllables, they undergo sandhi that often leads to context-sensitive, idiosyncratic modifications in the output sandhi tones, as shown in Table 6.

Table 6. Output sandhi tones in final syllables (σ2)

<table>
<tr><th colspan="2">$T_{\sigma1}\backslash T_{\sigma2}$</th><th>A1 /42/</th><th>A2 /21/</th><th>B1 /51/</th><th>B2 /31/</th><th>C1 /44/</th><th>C2 /13/</th><th>D1 /5/</th><th>D2 /2/</th></tr>
<tr><td rowspan="2">A</td><td>A1 /42/</td><td rowspan="2">21</td><td rowspan="2">51</td><td rowspan="8">31</td><td rowspan="8">31</td><td rowspan="8">44</td><td rowspan="2">44</td><td rowspan="8">5</td><td rowspan="2">3</td></tr>
<tr><td>A2 /21/</td></tr>
<tr><td rowspan="2">B</td><td>B1 /51/</td><td rowspan="6">42</td><td rowspan="4">31</td><td rowspan="2">13</td><td rowspan="2">2</td></tr>
<tr><td>B2 /31/</td></tr>
<tr><td rowspan="2">C</td><td>C1 /44/</td><td rowspan="2">44</td><td rowspan="2">3</td></tr>
<tr><td>C2 /13/</td></tr>
<tr><td rowspan="2">D</td><td>D1 /5/</td><td rowspan="2">51</td><td rowspan="2">13</td><td rowspan="2">2</td></tr>
<tr><td>D2 /2/</td></tr>
</table>

Note: Output sandhi tone targeting low range (51, 31, 21), mid range (3), and high range (44)

Two observations stand out regarding final positions. First, tones in final positions undergo sandhi less often than those in initial positions (as shown by the greater number of white cells indicating no change), and when they do, sandhi on final syllables is more often structure-preserving than that on initial positions. That is, unlike initial sandhi that mostly outputs tones new to the inventory, final sandhi typically outputs tones already in the inventory.

Second, final tone sandhi typically crosses register boundaries. That is, final sandhi typically targets tones in the lower register, resulting in a raise of tone and a loss of breathy phonation. For instance, [-fall] tones in the lower register, namely C2^{13} and D2^{2}, are raised in final positions when the preceding tone is a smooth tone (an A or C tone), as shown in (10).

(10) R4. **Raising of non-falling low tones** (C2/D2). C2^{13} is raised to 44 after A/C (R4a); D2^{2} is raised to 3 after A/C (R4b).

Example. A1^{42}-C2^{13}. /sɛ^{42}-di̤$^{\mathbf{13}}$/ 'mountain-ground' → [sɛ^{33}-di$^{\mathbf{44}}$] 'hilly area' (R4a)

A2^{21}-D2^{2}. /niŋ^{21}-və̤$^{\mathbf{2}}$/ 'human-object' → [niŋ^{23}-və$^{\mathbf{3}}$] 'character' (R4b)

Similarly, smooth falling tones in the lower register, A2^{21}, are also raised, but to different degrees depending on its preceding tone, as summarized in (11).

(11) R5. **Raising of smooth falling lower tone** (A2). A2^{21} raises to 31 after B and C tones (R5a), but to 51 after A and D tones (R5b).[9]

Example. A1^{42}-A2^{21}. /goŋ^{42}-ni̤ŋ$^{\mathbf{21}}$/ 'work-person' → [goŋ^{33}-niŋ$^{\mathbf{51}}$] 'worker' (R5a)

C2^{13}-A2^{21}. /di^{13}-tɕə̤u$^{\mathbf{21}}$/ 'ground-ball' → [di^{23}-tɕəu$^{\mathbf{31}}$] 'earth' (R5b)

Though B2^{31} doesn't undergo change in contour, it still loses its breathiness and becomes a modal 31, which is not in the tonal inventory.

One caveat is that while lower-register tones are raised to upper through sandhi, the opposite direction is not permitted. That is, breathiness cannot be added to syllables through register-lowering sandhi. B1^{51}, a sharp falling tone in the upper register, tends to be lowered in final positions. It consistently lowers to a modal 31, as does B2^{31}. This is shown in (12).

(12) R6. **Lowering of sharp falling upper tone** (B1). B1^{51} lowers to 31 after all Ts.

Example. A1^{42}-B1^{51}. /tɕʰiŋ^{42}-tsʰɒ$^{\mathbf{51}}$/ 'green-grass' → [tɕʰiŋ^{33}-tsʰɒ$^{\mathbf{31}}$] 'green grass'

3.2.3 Interim summary

To summarize, sandhi processes in disyllabic words of Huangyan Wu affect initial tones more than final tones and in different ways.

Initial tones mostly undergo pitch changes but to different extents depending on their slope-defined natural class – [+smooth] tones tend to lose their contours, while [-smooth] tones do not. Moreover, whether sandhi of the same initial tone has different conditioning environments depends

[9] Here, the output sandhi tone 51 is slightly different from the B1^{51} in the inventory and can be transcribed as ^{3}51, with a sharp rising from 3 to 5 before the falling. The sharp rising may be a result of tonal coarticulation.

on their movement-defined natural class – [+fall] tones tend to be sensitive to adjacent tones during sandhi, while [-fall] tones do not.

Final tone sandhi is more structure-preserving than initial tone sandhi, producing fewer tones new to the inventory. Additionally, unlike initial tones, final tones are less affected by sandhi, often retain their contours. Furthermore, while initial tone sandhi often does not incur a change in register, final tone sandhi does, and typically with lower-register tones, which leads to a raise in pitch and a loss of breathiness. This is reflected in Table 7.[10]

Table 7. Sandhi types in initial and final syllables (bold for sandhi tones not in the inventory)

	σ1	σ2
Positional sandhi	A1$^{42\to\mathbf{33}}$, C1$^{44\to\mathbf{33}}$, C2$^{1̤3̤\to\mathbf{2̤3̤}}$, D1$^{5\to\mathbf{3}}$	B1$^{51\to\mathbf{31}\text{(non-breathy)}}$
Contextual sandhi	A2$^{2̤1̤\to\mathbf{2̤2̤/2̤3̤}}$, B1$^{51\to42/21}$, B2$^{3̤1̤\to4̤2̤/2̤1̤}$	A2$^{2̤1̤\to51/31}$, C2$^{1̤3̤\to44}$, D2$^{2̤\to\mathbf{3}}$

Here, I use the breathy notation under tone values to indicate the breathiness in the input and output syllables, thereby showing whether a change in phonation type is involved.

4. Comparing different approaches to characterizing sandhi in Huangyan Wu

4.1 Charactering sandhi using smoothness

By incorporating slope into the feature geometry of tones for Huangyan Wu, we can capture how sandhi rules are structured with the smooth vs. sharp contrast and understand the nature of two types of sandhi rules – contour-changing sandhi and register-changing sandhi.

4.1.1 Contour-changing sandhi rules

The first case of contour-changing sandhi is exemplified by word-initial neutralization of smooth tones (A and C). This can be seen as a result from the deletion of the contour movement feature [±fall], and the register feature [±upper] further determines the onset of the sandhi tone (3 for upper tones and 2 for lower tones), as shown in (13).

(13) R1a. **Neutralization of upper smooth tones**. A1^{42}/C1^{44} neutralize to 33 before all Ts.

[+upper, +smooth, **±fall**]$^{42/44}$ → [+upper, +smooth, **ø**]^{33} / __ σ #

R1b. **Neutralization of lower smooth tones**. A2^{21}/C2^{13} neutralize to 23 before B/D.

[-upper, +smooth, **±fall**]$^{21/13}$ → [-upper, +smooth, **ø**]^{23} → __ [-smooth] #

[10] While we bold the sandhi tones 22/23 of A2^{21} as being strictly new to the inventory, these sandhi tones can also be treated as contextual allotones of A2 and would not be new to the inventory in a looser sense.

In R1b, sandhi targets smoothness ([+smooth]) and is also conditioned by smoothness ([-smooth]).

In contrast, word-initial neutralization of sharp falling tones (B1/B2) involves smoothing (changing from [-smooth] to [+smooth]), with the register feature evaluated to agree with the contour movement feature on the final syllable, as shown in (14).

(14) R2. **Neutralization of sharp falling tones**. $B1^{51}/B2^{31}$ neutralize to 42 before A1/B (R2a) and 21 before C/D (R2b).

R2a. [±upper, **-smooth**, +fall]$^{51/31}$ → [**+upper**, **+smooth**]^{42} / __ [**+fall**] #

R2b. [±upper, **-smooth**, +fall]$^{51/31}$ → [**-upper**, **+smooth**]^{21} / __ [**-fall**] #

That is, the output sandhi tone becomes [+upper, +smooth, +fall]^{42} when followed by a falling tone ([+fall]), but it turns to [-upper, +smooth, +fall]^{21} when followed by a non-falling tone ([-fall]).

Another case features word-final change of smoothness. This is shown in (15), where smooth tones become sharp tones.

(15) R5a. **Raising of smooth falling lower tone** (A2). $A2^{21}$ raises to 31 after B and C tones.

[**-upper**, **+smooth**, +fall]^{21} → [**-smooth**]^{31} / [+/-smooth, -/+fall] __ #

This suggests that smooth slopes are hard to maintain word-finally for a falling tone in the lower register (R5a).

4.1.2 Register-changing sandhi rules

Word-initial change of register occurs typically in the upper checked tone D1. As shown in (16), word-initial lowering of D1 can be seen as the deletion of register feature [+upper].

(16) R3. **Lowering of upper checked tone**. $D1^{5}$ lowers to 3 before all Ts.

[**+upper**, -smooth, -fall]^{5} → [**ø**, -smooth, -fall]^{3} / __ σ #

For word-final positions, register-changing sandhi rules primarily target lower-register tones, which could be motivated for different reasons. It could be due to the possibility that non-falling lower tones are hard to sustain after smooth tones, which could lead to a register shift (R4a) or a register deletion (R4b), as shown in (17).

(17) R4. **Raising of non-falling lower tones** (C2/D2). $C2^{13}$ is raised to 44 after A/C (R4a); $D2^{2}$ is raised to 3 after A/C (R4b).

[**-upper**, +smooth, -fall]^{13} → [**+upper**]^{44} / [+smooth] __ # (R4a)

[**-upper**, -smooth, -fall]^{2} → [**ø**, -smooth, -fall]^{3} / [+smooth] __ # (R4b)

A register shift also happens when smooth falling lower tones follow another smooth falling tone or non-smooth non-falling tone, as in (18).

(18) R5b. **Raising of smooth falling lower tone** (A2). $A2^{21}$ raises to 51 after A and D tones.

[**-upper**, **+smooth**, +fall]^{21} → [**+upper**, **-smooth**]^{51} / [+/-smooth, +/-fall] __ #

Register-changing sandhi rules can also target word-final upper-register tones like B1 that is sharply falling, as in (19).

(19) R6. **Lowering of sharp falling upper tone** (B1). $B1^{51}$ lowers to 31 after all Ts.

[**+upper**, -smooth, +fall]^{51} → [**-upper**]^{31} / σ __ #

This presents a register shift from upper to lower, which may suggest that sharp contour tone in the upper register is more marked word-finally and needs to be dampened.

4.1.3 Summary of the smoothness account

In sum, the inclusion of smoothness in the feature geometry helps us better understand the nature of sandhi processes in Huangyan Wu.

Word-initial tones in both the upper and the lower registers tend to undergo sandhi, resulting in sandhi tones that are generally centralized around the mid-pitch range to varied degrees, which is dependent on their original register as well as the contour of the following tone. These sandhi processes occur mostly through deleting features (e.g., [±fall] for smooth tones A and C, [+upper] for the checked D1 tone) and occasionally through adjusting features ([-smooth] to [+smooth] for B tones).

In contrast, word-final tones in the lower register tend to undergo sandhi, resulting in raised sandhi tones mostly through adjusting features ([+smooth] to [-smooth] for A2; [-upper] to [+upper] for C2) and occasionally through deleting features ([-upper] for the checked D2 tone). Additionally, sharp contour tone in the upper register (B1) consistently undergoes sandhi word-finally, resulting in a lowered sandhi tone that is less marked.

Moreover, this smoothness account also suggests that initial and final tone sandhi represent sandhi processes that address contour markedness with different priorities, which is summarized in Table 8.

Table 8. Priorities of reducing contour markedness for different tones in different positions (targeted feature in bold)

Tone	Word-initial sandhi	Word-final sandhi
A/C	+smooth > ±**fall** > ±upper	+smooth > ±fall > **-upper**
B	**-smooth** > +fall > ±upper	-smooth > +fall > ±**upper**
D	-smooth > -fall > +**upper**	-smooth > -fall > **-upper**

For word-initial tone sandhi that is less often structure-preserving, it prioritizes radically simplifying contours through tackling the most marked aspect of an word-initial base tone. For initial smooth tones A and C with an unmarked [+smooth], the priority is to address the most marked movement feature [±fall] through deletion. For initial sharp tones B and D with a marked [-smooth], sandhi targets only the most marked [-smooth] if possible, as with B tones, thereby leaving the movement feature untouched and preserved. For initial D tones (i.e., checked tones with a coda), sandhi cannot manipulate [-smooth] and [-fall] features to produce smooth or flattened checked tones. As a result, deleting the register becomes the only option left to reduce markedness in the upper checked tone D1^{5}. In contrast, the lower checked tone D2^{2}, which is unmarked for register, remains unaffected by sandhi.

For word-final tone sandhi that is more structure-preserving, it prioritizes preserving the contour of base tones when further contextual modifications are necessary. This results in the majority of register-changing sandhi rules in word-final tones.

4.2 Issues with using contour specifications

As mentioned in section 2, the presence of four falling tones in Huangyan Wu poses a challenge to the traditional feature geometry of tones assumed in the literature. These falling tones (in A and

B) can theoretically be distinguished by register (H/[+upper] vs. L/[-upper]) and high-low contour specifications (h/high vs. m/mid vs. l/low), as in (6), yet there are several issues with this approach. It overgeneralizes in terms of both the targets and the conditioning environments of sandhi rules, and it requires post-hoc stipulations to avoid overgeneralizations.

Here, we repeat in (20) how the smoothness account explains R1a and R1b in section 4.1.1.

(20) R1a. **Neutralization of upper smooth tones**. $A1^{42}/C1^{44}$ neutralize to 33 before all Ts.
[+upper, +smooth, **±fall**]$^{42/44}$ → [+upper, +smooth, **ø**]^{33} / __ σ #
R1b. **Neutralization of lower smooth tones**. $A2^{21}/C2^{13}$ neutralize to 23 before B/D.
[-upper, +smooth, **±fall**]$^{21/13}$ → [-upper, +smooth, **ø**]^{23} → __ [-smooth] #

As (20) shows, the smoothness account directly defines natural classes for sandhi rules, using [±smooth]. If we were to use high-mid-low (h/m/l) contour specifications for R1a and R1b in (20), we would get the following in (21) and (22) respectively.

(21) Alternative approach: Capturing R1a in (20) with high-mid-low specifications
hm/h → m / __ σ #
(22) Alternative approach: Capturing R1b in (20) with high-mid-low specifications
l/lm → m / __ hl/ml/h/l #

The first issue with a high-mid-low account is that it is subject to overgeneralization regarding the target of sandhi rules. If targets of (21) share a high onset and no low offset, it predicts that $D1^{5}$ (h) should also participate in (21), which is mostly true of the data (except for D1 before $A2^{21}$). Similarly, targets in (22) share a low onset and no high offset, so it predicts that $D2^{2}$ (l) should also participate in (22), which is not true of the data, as D2 never undergoes sandhi.

Therefore, the high-mid-low account overly expects the lower-register checked tones to be targeted by the sandhi rule in (22). In this respect, the smoothness account treats checked tones as [-smooth] and thus avoids the prediction that overgeneralizes, though D1 does behave like A1 and C1 on the surface. Moreover, the high-mid-low account essentially excludes targets with a mid-onset (ml or mh) and those with far-apart onset and offset (hl, lh). This exclusion of unwanted targets appears to a post-hoc stipulation that makes indirect use of slope – less sharp tones with not-so-far-apart onset and offset are targeted by these toward-mid-pitch-range sandhi processes.

The second issue is that the high-mid-low account also overgeneralizes regarding the conditioning environment of sandhi rules. For instance, under contour specification, $C1^{44}$ and $D1^{5}$ are both analyzed as h (high), so they should behave alike in conditioning (22). However, the data suggests that while the rule is conditioned by D1 (h), it is not conditioned by C1 (h), so the high-mid-low account again fails to capture the granularity needed for sandhi rules.

To repair the overgeneralization on both the targets and the conditioning environments in (22), we would have to stipulate that the target l is one with [-constricted glottis], whereas the conditioning h and l are ones with [+constricted glottis], as in (23).

(23) Alternative approach: Capturing R1b in (20) with *revised* high-mid-low specifications

$l_{[\text{-constricted glottis}]}/lm \rightarrow m$ / __ $hl/ml/h_{[\text{+constricted glottis}]}/l_{[\text{+constricted glottis}]}$ #

While this stipulation suffices to capture the rule, one downside to this approach is that we need to appeal to a coda feature [±constricted glottis], whereas in all other tone sandhi, we only need to refer to tonal features. Smoothness, on the other hand, keeps only tonal features relevant for sandhi.

In sum, the high-mid-low account is insufficient to capture the granularity needed for sandhi behaviors. To fully understand tonal interactions in Huangyan Wu, we need to treat smooth and sharp tones as two natural classes to account for tonal interactions.

5. Explaining exceptional sandhi in Huangyan Wu

We have discussed regular sandhi processes up to this point, but as mentioned in section 3.1 on sandhi data, we also see idiosyncratic sandhi rules, here summarized as X1 and X2 in (24).

(24) Idiosyncratic sandhi processes

X1: **Falsetto-like rising of smooth falling tones** (A1/A2). $A1^{42}$ or $A2^{21}$, when followed by $A1^{42}$, becomes sharp rise $45^{\uparrow}/25^{\uparrow}$ with an offset beyond pitch range for speech (thus falsetto-like), while the word-final $A1^{42}$ become 21.

Example: $A1^{42}$-$A1^{42}$. /tʰie^{42}-sy^{42}/ ‘sky-book’ → [tʰie$^{45\uparrow}$-sy^{21}] ‘gibberish’

X2: **Rising of sharp falling tone** (B1/B2). $B1^{51}/B2^{31}$ become high rise $44^{\uparrow}$ before $A2^{21}$.

Example: $B1^{51}$-$A2^{21}$. /tɕiŋ^{51}-diɤ^{21}/ ‘buttress-head’ → [tɕiŋ$^{55\uparrow}$-diɤ^{31}] ‘pillow’

The up-pointing notation (ꜛ) represents tones with an offset that goes beyond pitch range for speech and is often used for *upstep* in languages where there's an upward shift of tone (Hyman & Leben, 2021).

We propose that these idiosyncratic sandhi processes represent an alternative solution Huangyan Wu employs to resolve contour clashes due to successive tones with identical contours. Essentially, both X1 and X2 feature a sequence of falling tones.

This avoidance of successive identical contours in Huangyan can be captured by the Obligatory Contour Principle (OCP) originally proposed for African languages (Goldsmith, 1976). This principle is indeed reflected in Huangyan Wu, where its four falling tones give rise to 16 possible fall-fall combinations. Notably, all 16 combinations undergo some form of sandhi, indicating that fall-fall sequences are generally disfavored for input tones, supporting OCP.

Moreover, these idiosyncratic cases can also be better explained if they are approached from the interaction of features. Assuming smoothness as part of the feature geometry, the sandhi process in X1 can be essentially represented as a smooth falling tone changing to a sharp rising tone, as in (25).

(25) X1: **Falsetto-like rising of smooth falling tones** (A1/A2). A1^{42} or A2^{21}, when followed by A1^{42}, becomes sharp rise 45ꜛ/25ꜛ

[+smooth, +fall]$^{42/21}$ → [-smooth, -fall]$^{45ꜛ/25ꜛ}$ / __ [+upper, +smooth, +fall]^{42} #

Viewing from a featural perspective, notably, the sandhi tones 45ꜛ and 25ꜛ result from change in two features of their base tone, slope and movement, whereas their regular sandhi tones 33 and 23 result from change in only one feature, namely movement. This additional change in slope for A1 and A2 could then clarify why this is an idiosyncratic sandhi rule – this represents a case of heightened contour dissimilation regarding the two dimensions of slope and movement, as opposed to regarding only movement. In a similar vein, X2 also involves change in two features, as in (26).

(26) X2: **Rising of sharp falling tone** (B1/B2). B1^{51}/B2^{31} become high rise 44ꜛ before A2^{21}.

[-smooth, +fall]$^{51/31}$ → [+upper, +smooth, -fall]^{44ꜛ} / __ [-upper, +smooth, +fall]^{21} #

This represents another case of heightened dissimilation in the two dimensions of register and movement.

In short, idiosyncratic sandhi in Huangyan Wu can be seen as special repairs for resolving contour clashes, as it involves dissimilation from a neighboring tone in more than one dimension.

6. Discussion

This paper explores the Sinitic Southern Wu dialect of Huangyan, with a focus on tonal interactions in relation to its tonal inventory. I argue that *slope*, a feature that captures the smoothness of pitch movement, should be incorporated into the feature geometry of tones to account for the four falling tones in the tonal inventory and to explain tonal interactions conditioned by slope features.

Tone sandhi system in Huangyan Wu is mostly right-dominant and involves both *positional* and *contextual* sandhi. Initial tone sandhi is not always structure-preserving and often contour-changing, where tonal contrasts are often neutralized or reduced: sharp falling tones are smoothed, smooth tones are flattened toward the mid-pitch range, and high checked tone are lowered. In contrast, final tone sandhi is more structure-preserving and register-changing, where base tones generally preserve their contours but may undergo idiosyncratic modifications through a shift in register, such as the raising of lower-register tones to facilitate smoother transitions from their preceding tone.

By introducing slope or smoothness as a dimension for analyzing the pitch space, this paper provides a new perspective on the internal structure of tones in Sinitic languages with complex tonal inventories. While traditional models primarily characterize sandhi processes using high-mid-low notations for the pitch movement of contours, this component alone may not fully capture the dynamic and temporal nature of tones. Slope, in contrast, highlights the qualitative nature of tonal transitions and therefore offers a more nuanced understanding of tonal interactions.

This paper demonstrates that the slope of a contour – whether a tone moves smoothly or sharply across pitch space – helps distinguish the four falling tones in Huangyan Wu. It also clarifies why smooth tones behave as a natural class in the sandhi system: these tones not only neutralize to the same sandhi tone in initial positions of disyllabic words but also trigger several contextual sandhi rules.

Furthermore, the interplay of positional and contextual sandhi in Huangyan Wu sheds light on how complex sandhi systems evaluate tonal sequences and resolve contour clashes. Alongside the regular sandhi rules that neutralize non-final tones, the system employs additional repair strategies, such as upstep, to address tonal sequences with identical contour sequences (fall-fall) that would otherwise violate the Obligatory Contour Principle (OCP).

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