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 – tones on final syllables remain unchanged while those on initial syllables change (e.g., word-initial contour tones neutralize to mid-pitch tones). However, exceptions include left-dominance (only final tones changes), both-change (both initial and final tones change), and no-change cases. Further analyses suggest the need for incorporating slope of contour [±smooth] into the internal structure of tone to capture both the tonal inventory in this language and the contextual tone sandhi rules. Taken together, these suggest that while positional restriction (i.e., right-dominance) explains regular sandhi cases, exceptions can be attributed to additional contour constraints that further shape the output tonal sequences.

Keywords: tone sandhi, right-dominance, contour slope, contour constraints

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 position where 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’[1] (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’ (Kuo, 2013)

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 and shows that it involves mixed dominance patterns. Further analyses suggest the need for incorporating slope of contour [±smooth] into the internal structure of tone to capture both the tonal inventory in this language and the contextual tone sandhi rules.

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

[1] 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}].

characterizing regular sandhi rules and discusses whether contour specification using high-low notations is sufficient for capturing tonal behaviors in Huangyan. Section 5 expands on exceptional sandhi processes and explains how they can be rationalized as special repairs to resolve contour clashes. Finally, section 6 discusses the broader 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.

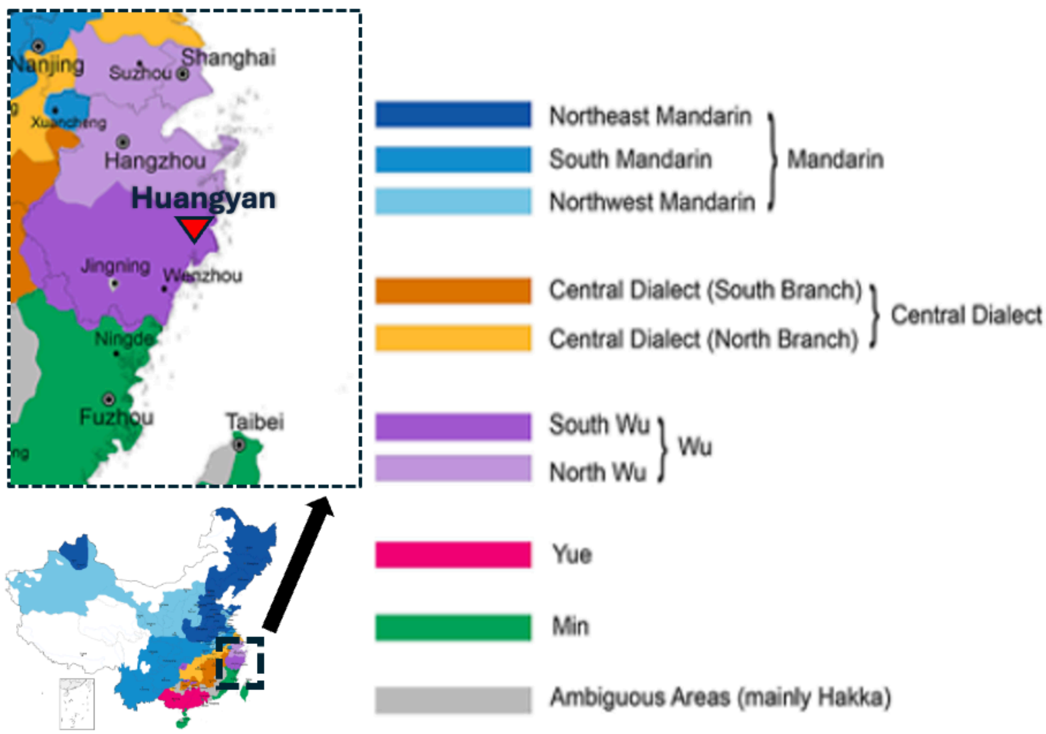


Figure 1. Location of Huangyan Wu: Southern Wu bordering Northern Wu (modified from Huang et al., 2024)

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 sandhi data Qian reported 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)

place / manner		labial	labiodental	dental	alveolo-palatal	palatal	velar	glottal
nasal		m, m̥		n, n̥	ȵ, ȵ̊		ŋ, ŋ̊	
plosive	voiceless	p, pʰ		t, tʰ			k, kʰ	
	voiced	b		d			g	ʔ
fricative	voiceless		f	s	ɕ			h
	voiced		v	z	ʑ			ɦ
affricate	voiceless			ts, tsʰ	tɕ, tɕʰ			
	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

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’

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

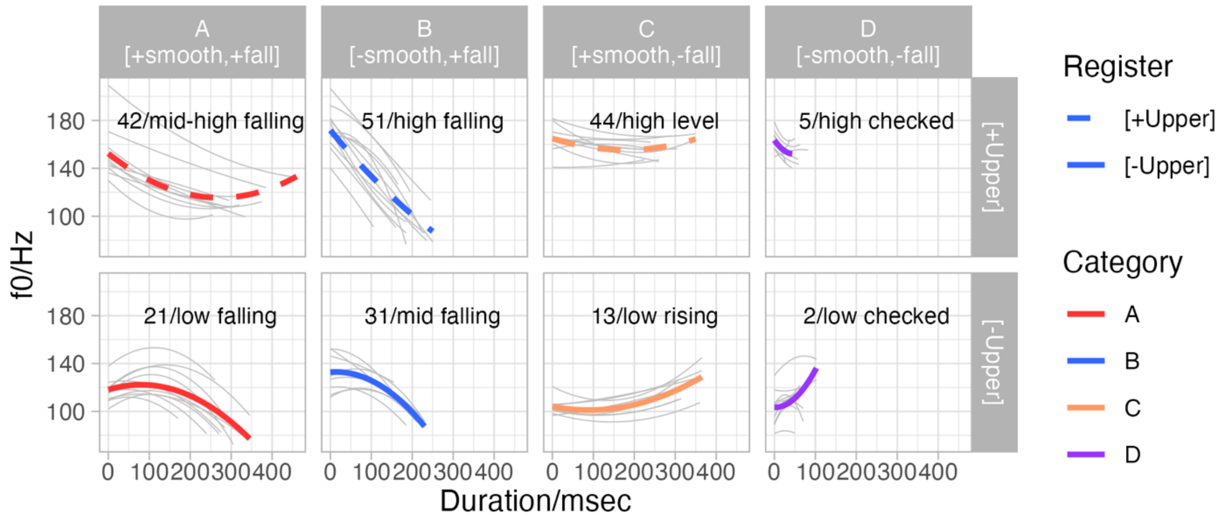
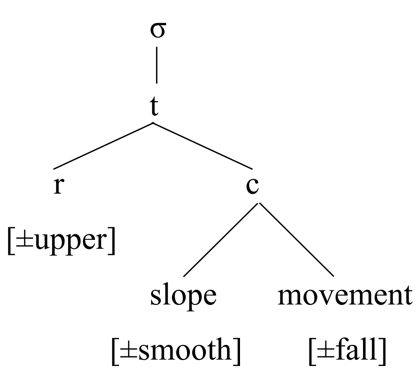


Figure 2. Tonal inventory of Huangyan Wu based on a native speaker over 60 years of age

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) Feature matrices for base tones in Huangyan Wu

A1^{42}: [+upper, +smooth, +fall] C1^{44}: [+upper, +smooth, -fall]

A2^{21}: [-upper, +smooth, +fall] C2^{13}: [-upper, +smooth, -fall]

B1^{51}: [+upper, -smooth, +fall] D1^{5}: [+upper, -smooth, -fall]

B2^{31}: [-upper, -smooth, +fall] D2^{2}: [-upper, -smooth, -fall]

There is evidence from another language that we can better capture sandhi behaviors by treating smooth and sharp tones as natural classes. The importance of slope in characterizing tones and their phonological behavior has been noted by Hsieh (2007). In the Northern Wu dialect of Hangzhou, two rising tones – 23 (*yang ping*; Ib) and 13 (*yang qu*; IIIb) – behave differently in the word-initial positions, as shown in (5). The smooth rise 23 flattens, while the sharp rise 13, being more marked, is preserved.

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

23 → 22 / __ T

13: preserved in __ T

Hsieh (2007) argues that this 'faithfulness to the marked' phenomenon can be explained through slope correspondence (MATCH-SLOPE). What happens in Hangzhou Wu is that a smooth tone is flattened in word-initial positions, while a sharp tone maintains its contour. We will see in the next section that this general pattern holds in Huangyan Wu as well, which suggests that slope or smoothness as a feature is cross-linguistically predictive of sandhi behaviors.

The proposal here, using slope and movement for specifying contour, differs from the traditional tonal transcription using h (high) and l (low).[2] 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), if we use an additional m for specifying a middle pitch.

(6) Contour specifications for base tones in Huangyan Wu (h=high, m=mid, l=low)[3]

A1^{42}: hm A2^{21}: l B1^{51}: hl B2^{31}: ml

[2] 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.

[3] This was suggested by Nicholas Rolle at 2024 Annual Meeting on Phonology.

$C1^{44}$: 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. Table 3 summarizes the statistics of sandhi patterns, and Table 4 presents the output tones for all 64 combinations (8*8) of citation tones.

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]	de̤ʔ sɐʔ 'trait' /2 5/ [**2 5**]	
Count	32 (50%)	3 (4.7%)	23 (35.9%)	6 (9.4%)	64

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**]	[55-31]	[42-31]	[42-**31**]	[21-**44**]	[21-**13**]	[21-**5**]	[21-**2**]
	B2 /31/	[42-**42**]	[55-31]	[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. For tones undergoing sandhi in initial syllables, they mostly neutralize to mid tones (marked in different tints of blue), as in Table 5. However, these are exceptions (marked in purple) to regular sandhi processes, 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 (45/25$^{\uparrow}$, 44$^{\uparrow}$)

The first pattern seen in Table 5 is that A tones and C tones behave alike in their output sandhi tones for initial syllables, neutralizing to mid tones (33 or 23). 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^{42}-B2^{31}. /goŋ^{42}-dɒ^{31}/ 'common-path' → [goŋ^{33}-dɒ^{31}] 'justice' (R1a)

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

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

When we focus on the type of sandhi, C tones always undergo positional sandhi, where the sandhi is conditioned by the position of the tone (i.e., when it's word-initial). For A tones, if we set aside the exceptional sandhi cases when they're followed by another A1 (marked in purple), A1 undergoes positional sandhi, while A2 undergoes contextual sandhi, where the sandhi is conditioned by the neighboring tone.[4]

Checked tones in category D differ from smooth tones in categories A and C in that only the upper register tone D1^{5} shows sandhi, where it lowers to a mid-tone 3, as in (8), but the lower register tone D2^{2} never undergoes sandhi.

(8) R2. **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$^{\mathbf{5}}$-C2^{13}. /tʰiɐʔ^{5}-ləu^{13}/ 'steel-road' → [tʰiɐʔ$^{\mathbf{3}}$-ləu^{13}] 'railway'

Another noticeable pattern is that unlike smooth tones, sharp tones in category B neutralize to 42 before falling tones (A and B tones) but to 21 elsewhere, i.e., before non-falling tones (C and D tones), as in (9).

(9) R3. **Neutralization of sharp falling tones** (B1/B2). B1^{51}/B2^{31} neutralize to 42 before A1/B (R3a) and 21 before C/D (R3b).

Example: B1$^{\mathbf{51}}$-A1^{42}. /hu^{51}-tsʰo^{42}/ 'fire-car' → [hu$^{\mathbf{42}}$-tsʰo^{42}] 'train' (R3a)

B1$^{\mathbf{51}}$-C1^{44}. /ɕəu^{51}-tʰɒ^{44}/ 'hand-cover' → [ɕəu$^{\mathbf{21}}$-tʰɒ^{44}] 'glove' (R3b)

Crucially, in the output sandhi tones, the contour of sharp falling tones in category B is preserved (i.e., sandhi tones are still falling tones), whereas the contour of smooth falling tones in category A is lost (i.e., sandhi tones are flattened). This presents a striking parallel to the Northern Wu variety of Hangzhou with slope contrasts in the tonal inventory, where the sharp rising tone 13 does not undergo sandhi and preserves its contour, while the smooth rising tone 23 undergoes sandhi and is flattened to 22. This lends cross-linguistic support to the treatment of smooth and

[4] 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).

sharp tones as two natural classes differing in slope, as it makes precise predictions about their different behaviors in sandhi processes.

For tones undergoing sandhi in final syllables, they undergo sandhi that often leads to idiosyncratic modfications 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)

In general, tones in final positions don't undergo sandhi, which is consistent with the finding that Huangyan Wu has a mostly right-dominant system, where base tones in final positions tend to remain intact. However, it can be hard for final tones to remain intact in some tonal contexts.

For one thing, tones in the lower register tend to lose their breathy phonation and become modal in final positions. This loss of breathiness can lead to the raising of some lower-register tones in final positions. For instance, non-falling 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}-di^{13}/ 'mountain-ground' → [sɛ^{33}-di^{44}] 'hilly area' (R4a)

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

Similarly, smooth falling tone in the lower register, A2^{21}, is 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).[5]

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

C2^{13}-A2^{21}. /di^{13}-tɕəu$^{\mathbf{21}}$/ '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.

For another, sharp falling tone in the upper register, B1^{51}, 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'

To summarize, tone sandhi in Huangyan Wu involves positional sandhi and contextual sandhi for both initial syllables and final syllables, as shown in Table 7. Positional sandhi always leads to tonal shifts to new tones that don't occur in isolation, so it's non-structure-preserving, whereas contextual sandhi can result in a tonal shift to either a new tone or an existing tone.

Table 7. Classification of 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$^{13\to\mathbf{23}}$, D1$^{5\to\mathbf{3}}$	B1$^{51\to\mathbf{31}\text{(non-breathy)}}$
Contextual sandhi	A2$^{21\to\mathbf{22/23}}$, B1$^{51\to42/21}$, B2$^{31\to42/21}$	A2$^{21\to51/31}$, C2$^{13\to44}$, D2$^{2\to\mathbf{3}}$

The general observations are as follows. In initial positions, smooth tones in A and C undergo a similar type of neutralization to mid-tones, sharp falling tones in B preserve their falling contour despite being context-sensitive, and upper register checked tone D become a mid-tone. In final positions, low register tones become modal, which mostly leads to pitch raising, as with A2, C2, and D2, whereas sharp falling upper tone B1 consistently undergoes pitch lowering.

4. Comparing different approaches to characterizing sandhi in Huangyan Wu

[5] 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.

4.1 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. While these falling tones (in A and B) can theoretically be distinguished by register (H/[+upper] vs. L/[-upper]) and contour, as in (6), there are several issues with this approach.

First, contour specification using high-low notations does not explain why smoothness seems to define natural classes for sandhi rules. On the one hand, smoothness is targeted by sandhi rules, as A and C tones behave alike in their output sandhi tones shown in (13).

(13) **Sandhi rules targeting upper smooth tones**

R1a: upper smooth tones A1^{42} and C1^{44} neutralize to 33 word-initially

a. A1^{42}-B1^{51}: /tɕʰiŋ$^{\mathbf{42}}$-tsʰɒ^{51}/ ‘green-grass’ → [tɕʰiŋ$^{\mathbf{33}}$-tsʰɒ^{31}] ‘green grass’

b. C1^{44}-B1^{51}: /pɒ$^{\mathbf{44}}$-dzɿ^{51}/ ‘report-paper’ → [pɒ$^{\mathbf{33}}$-dzɿ^{31}] ‘newspaper’

On the other hand, smoothness can also condition sandhi rules, as shown in (14).

(14) **Sandhi rules targeting lower smooth tones and conditioned by non-smooth tones**

R1b: lower smooth tones A2^{21} and C2^{13} neutralize to 23 before B/D

a. A2^{21}-B1^{51}: /bi$^{\mathbf{21}}$-tɕəu^{51}/ ‘beer-alcohol’ → [bi$^{\mathbf{23}}$-tɕəu^{31}] ‘beer’

b. C2^{13}-B1^{51}: /zɿ$^{\mathbf{13}}$-ti^{51}/ ‘character-body’ → [zɿ$^{\mathbf{23}}$-ti^{31}] ‘font’

Second, contour specification using high-low notations makes wrong predictions about sandhi rules in Huangyan Wu. For instance, under contour specification, C1^{44} and D1^{5} are both analyzed as h (high), so they should behave alike in conditioning sandhi rules. This is, however, not the case in the language. We would get (15) if the sandhi rule in (14) is represented using high-low annotations.

(15) R1b: l → m / __ hl/**h**/ml/l #

Yet, while the rule is conditioned by D1 (h), it is not conditioned by C1 (h), so using contour specification does not capture how sandhi rules are conditioned. Likewise, A2^{21} and D2^{2} are both analyzed as l (low) under contour specification, but they behave quite differently in final positions. While A2^{21} always undergoes sandhi, D2^{2} only undergoes sandhi when it's preceded by A and C tones, i.e., the smooth tones.

Given these observations, contour specification using high-low annotations is insufficient to capture sandhi behaviors. To fully understand the tonal system in Huangyan Wu, we need to incorporate slope or smoothness to derive smooth and sharp tones as two natural classes to account for tonal interactions.

4.2 Charactering sandhi using smoothness

By incorporating slope into the feature geometry of tones for Huangyan Wu, we can define sandhi rules using natural classes of smooth and sharp tones and understand the nature of different sandhi rules.

First, word-initial neutralization of smooth tones (A and C) results 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 (16).

(16) 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] #

In contrast, word-initial neutralization of sharp falling tones (B1/B2) involves smoothing (changing from [-smooth] to [+smooth]), with the register feature ([α upper]) evaluated to agree with the contour movement feature ([α fall]) on the final syllable, as shown in (18).

(18) R3. **Neutralization of sharp falling tones**. B1^{51}/B2^{31} neutralize to 42 before A1/B (R4a) and 21 before C/D (R4b).
[±upper, **-smooth**, +fall]$^{51/31}$ → [**α upper**, **+smooth**] / __ [**α 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]).

Second, word-initial lowering of upper checked tone (D1) can be seen as the deletion of register feature [+upper], as shown in (17).

(17) R2. **Lowering of upper checked tone**. D1^{5} lowers to 3 before all Ts.

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

In contrast, word-final lowering of sharp falling upper tone (B1) presents a register shift from upper to lower, as in (18).

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

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

This may suggest that sharp contour tone in the upper register is more marked word-finally.

Third, word-final raising of lower tones can 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 (19).

(19) 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)

It could also be due to the possibility that smooth slopes are hard to maintain word-finally for a falling tone in the lower register (R5a), which can in some cases necessitate a further register shift (R5b), as shown in (20).

(20) 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).

[**-upper**, **+smooth**, +fall]^{21} → [**-smooth**]^{31} / [+/-smooth, -/+fall] __ # (R5a)

↘ [**+upper**, **-smooth**]^{51} / [+/-smooth, +/-fall] __ # (R5b)

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.

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 exceptions to regular sandhi, here summarized as X1 and X2 in (21).

(21) Exceptional 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 $55^{\uparrow}$ before $A2^{21}$.

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

The up-pointing notation ($^{\uparrow}$) 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 exceptional 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 exceptional cases can also be better explained if we observe them 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 (22).

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

$[+\text{smooth}, +\text{fall}]^{42/21} \rightarrow [-\text{smooth}, -\text{fall}]^{45^{\uparrow}/25^{\uparrow}}$ / __ $[+\text{upper}, +\text{smooth}, +\text{fall}]^{42}$ #

Viewing from a featural perspective, notably, the sandhi tones $45^{\uparrow}$ and $25^{\uparrow}$ 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 exception to regular sandhi – 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 (23).

(23) X2: **Rising of sharp falling tone** (B1/B2). $B1^{51}/B2^{31}$ become high rise $55^{\uparrow}$ before $A2^{21}$.

$[-\text{smooth}, +\text{fall}]^{51/31} \rightarrow [+\text{upper}, +\text{smooth}, -\text{fall}]^{55^{\uparrow}}$ / __ $[-\text{upper}, +\text{smooth}, +\text{fall}]^{21}$ #

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

In short, exceptional sandhi in Huangyan Wu can be seen as a special repair 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. In non-final positions, 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 tones generally preserve their contours but may undergo idiosyncratic modifications, 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-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 non-final 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 positional 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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