Kalabari tonotactics require Forbidden Substructure Constraints stated over substrings not autosegmental representations

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- Renewed interest in **phonological representations**
  - What are the '**atoms**' of representation? E.g. features, moras, gestures, formants, ...
  - Are they universal? And are they 'substance-free' without direct reference to phonetics?
  - How are these elements organized internally (e.g. feature geometry), and how are do they relate to other elements (i.e. **precedence** within a tier, **association** across tiers)?
  - What kinds of prosodic **constituents** do these elements form, and what governs this? E.g. syllables, feet, prosodic words, the prosodic hierarchy, ...
- Most interest in representations has focused on phonological **inputs** (crudely, the contents of the **lexicon**) and phonological **outputs** (their form after **phonological operations**)
- Today: What are the computational properties of representations in phonological **constraints**, which dictate well-formed outputs (and perhaps inputs *à la* Morpheme Structure Constraints)?
  - To use one recent example, consider the constraint in Figure 1 proposed in Bermúdez-Otero (2025) to account for /aɪ/ raising (i.e. "Canadian Raising")
    - Voiced coda: *ride* /ɹaɪd/ → [ɹaɪd]
    - Voiceless coda: *write* /ɹaɪt/ → [ɹəɪt]
  - Constraint is a prosodic tree (the minimal word), with a strong/weak branch (s/w) distinction, and allowance for potential transparent intermediate structure ('...' in the tree)

phonological representations
atoms
precedence
association
constituents
inputs
lexicon
outputs
phonological operations
constraints

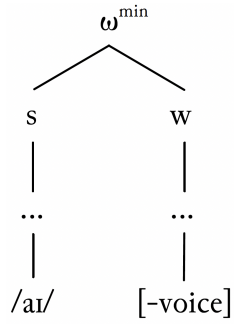

Figure 1: Constraint to capture /aɪ/ raising (Bermúdez-Otero, 2025)

- *What are the constraints on constraints?*
  - What kind(s) of representations do constraints have?
  - What computational properties do such representations have compared to the phonological content they evaluate?
- We present data from **Kalabari** tone which shows a conspiracy to avoid tone sequences of low-high-high, which we call ***LHH** — **Kalabari** ***LHH**
- We formalize *LHH **tonotactics** as a **forbidden substructure constraint** — **tonotactics** **forbidden substructure constraint**
  - Crucially, we argue that it is best described by a **forbidden substring** grammar rather than a more elaborated forbidden substructure grammar over autosegmental representations — **forbidden substring**
- Roadmap
  - Relevant Kalabari data (§1)
  - The problem (§2)
  - Our solution (§3)
  - Summary (§4)

1 Data

- Kalabari language (ISO 639-3 [ijn])
  - Part of **Ijoid** family of extreme south of **Nigeria** (Niger Delta region) — **Ijoid** **Nigeria**
  - Highly analytic, head-final language (unlike all non-Ijoid neighbors)
  - Basic clause-level word order: [S] [ADJUNCT] [O] [V] [INFL]
- Kalabari **tone system** — **tone system**
  - Relatively well-described (Jenewari, 1977, 1980; Harry, 2004; Anonymous and Blench, 2008; Harry and Hyman, 2014; Rolle and Harry, 2025).
  - H vs. L tone distinction (e.g. sò 'sky' vs. só 'go'), plus contrastive downstepped highs transcribed as ↓H (e.g. ɔ́lɔ́ 'cough' vs. ɔ́↓lɔ́ 'hold')
  - Tone is fully contrastive on both nouns and verbs

Table 1: Tone contrasts on two-syllable words

LL	ìkè	'hunchback'
LH	òkí	'sawfish'
HL	íkù	'cocoyam'
HH	íkú	'louse'
H↓H	á↓kɔ́	'bitter'

- The ***LHH conspiracy** (Rolle and Harry, 2025) — ***LHH conspiracy**
  - Systematic gap of LHH words in (native) vocabulary (§1.1)
  - A LHH output conspicuously avoided in grammatical tone (§1.2)
  - Downstep insertion with derived LH#H sequences across words (§1.3)
  - (Exceptional lowering operations in certain noun phrases – §1.4)
  - (Low-toned clitics spread their tone to avoid phrase-level LHH – §1.5)

1.1 Underlying *LHH gap

- Gaps in underlying tone patterns with three-syllable words (Table 2)
  - Downstep – Must be on final vowel (three native exceptions in Harry 2004: á↓ɗúá 'defense', í↓rúá 'sun', íŋ↓góló 'limpet')
  - *HLL – A few exceptions from loanwords/*wanderwörter* (e.g. ɔ́kòrò 'okra', íŋkòrò '*tom-tom* menthol candy', ábìlì 'draughts board game')
  - **Underlying *LHH gap** (Two known exceptions – Loanwords/*wanderwörter* ègúsí 'melon' and àkótó 'small container') **Underlying *LHH gap**

Table 2: Tone contrasts on three-syllable words

LLL	àkàkà	'edge'	HLL	*		-	-	-
LLH	ìkìká	'biscuit'	HLH	íkàrí	'thorn'	-	-	-
LHL	ɔ̀kíkɔ̀	'spoon'	HHL	íkpápʊ̀	'pen knife'	H↓HL	*	
LHH	*		HHH	ékékɛ́	'pebbles'	H↓HH	*	
LH↓H	ɔ̀kɔ́↓kɔ́	'skull'	HH↓H	ísá↓ká	'eyelash'	H↓H↓H	*	

- Such restrictions equally hold of larger mono-morphemic words of four or five syllables (e.g. *LLHH, *LHHL, *LHHH, *LHH↓H, *HLHH, *etc.*)

1.2 No LHH in grammatical tone

- Kalabari **grammatical tone** **grammatical tone**
  - In noun phrases, pre-nominal modifiers replace underlying tone of noun with a dedicated grammatical tone melody ("construction tonology" – Harry and Hyman 2014)
- Grammatical tone melodies (circled in Table 3)
  - Associative constructions (e.g. compounds, possessor nouns) assign a ⒽⓁ melody
  - Possessive pronouns as a class assign a ⒽⓁⒽ melody (often realized with downstep)
  - Demonstratives and pre-nominal determiners assign a ⓁⒽ melody
  - Quantifiers and most numerals assign a Ⓛ melody

Table 3: Grammatical tone avoids creating phrase-level LHH pattern (Harry and Hyman, 2014)

		Noun:	HH	LL	HL	LH	H↓H
			námá	pùlò	bélè	gàrí	ɓá↓rá
Modifier:			'meat'	'oil'	'light'	'flour'	'hand'
Associative	tʊ̀ɓɔ̀ 'a child's ...'	ⒽⓁ	tʊ̀ɓɔ̀ námà	tʊ̀ɓɔ̀ púlò	tʊ̀ɓɔ̀ bélè	tʊ̀ɓɔ̀ gárì	tʊ̀ɓɔ̀ ɓárà
Poss. pronoun	ìnà 'their ...'	ⒽⓁⒽ	ìnà ná↓má	ìnà pú↓ló	ìnà bé↓lé	ìnà gá↓rí	ìnà ɓá↓rá
Demonstrative	tɔ̀ 'which ...'	ⓁⒽ	tɔ̀ nàmá	tɔ̀ pùló	tɔ̀ bèlé	tɔ̀ gàrí	tɔ̀ ɓàrá
Quantifier	jà 'some ...'	Ⓛ	jà nàmà	jà pùlò	jà bèlè	jà gàrì	jà ɓàrà
*	tà	Ⓗ	*tà námá	*tà púló	*tà bélé	*tà gárí	*tà ɓárá

- Conspicuously absent are cases with only a Ⓗ melody
  - If modifier is low-toned, this would result in a derived phrase-level L#HH pattern

1.3 Downstep insertion with LH#H

- When LHH sequences are incidentally produced, repaired by the insertion of a **downstep** **downstep**
  - This happens in LH#H contexts, but *not* in L#HH contexts for which we assume some restriction on inserting downsteps within a word (as opposed to before it)
- Contexts include between a noun and a post-nominal modifier (1a), a verb and an inflectional marker (1b), two verbs in a serial verb construction (1c), and the subject and the predicate (1d)

(1) Downstep insertion (in red): ...LH#H... → ...LH#↓H... (Rolle and Harry, 2025)

a. [gàrí ↓mámgbà]
gàrí mámgbà
garri.flour all
'all *garri* flour'

b. [námá sèlé ↓té↓é]
námá sèlé té↓é
meat be.chosen PERF
'the meat has been chosen'

c. [ɓìlà má dìsɛ́ ↓sáɓá árì]
ɓìlà má dìsɛ́ sáɓá árì
elephant DEF.PL sneeze cross CONT
'the elephants are sneezing over'

d. [òdòdó ↓fɔ̃́ sélɛ́ té↓é]
òdòdó fɔ̃́ sélɛ́ té↓é
snake salt choose PERF
'the snake has chosen salt'

- Crucially, downstep is specifically *not* inserted in a simple H#H sequence

1.4 Exceptional lowering operations

- While downstep insertion is the most robust response to incidental phrase-level LHH sequences, there are two other construction-specific responses, both only in noun phrases
- First, the modifier òpù 'big' is one of very few pre-nominal modifiers which does *not* assign grammatical tone (Table 4; cf. Table 3)
  - The only tone change happens with all-high nouns (e.g. fénı́ 'bird'), which may optionally be pronounced all-low – no other tone type shows such variation
- Tone-lowering in this (and only this) context avoids a L#HH sequence

Table 4: Lack of grammatical tone with òpù 'big' (Harry and Hyman, 2014)

Noun:	HH	LL	HL	LH	H↓H
Modifier:	fénı́ 'bird'	fìnì 'fire'	sírì 'leopard'	èkpé 'he-goat'	wá↓rí 'house'
òpù 'big ...'	òpù fénı́ ~ òpù fènì	òpù fìnì	òpù sírì	òpù èkpé	òpù wá↓rí (Cf. *òpù wàrì)

- Second, associative constructions (Table 3) can create a LHH sequence if the modifying noun is underlying LH, and it assigns a ⒽⓁ melody to the following head noun
  - In this context, the modifying noun itself can optionally undergo lowering (2)

– Downstep insertion (the usual repair) is not possible (2c)

(2) a. [èkpé námà]
èkpé ⒽⓁ námá
he.goat ASSOC meat
'he-goat meat, the he-goat's meat'

b. [èkpè námà]
(also acceptable)

c. Cf. *[èkpè ↓námà]

1.5 Clitic-triggered low tone spreading

- Low-toned pronominal clitics in subject position are special: Condition three tonal variants
  - The clitic's low tone spreads to a contiguous string of high-toned syllables to its right (the most natural pronunciation – 3a)
  - The clitic's low tone spreads to all high tones but one (less natural – 3b)
  - The clitic's low tone does not spread (the least natural – 3c)

(3) Clitic-triggered low tone spread (Rolle and Harry, 2025)

a. [à fèkèfèkè tɛ́↓ɛ́]
à fékéféké tɛ́↓ɛ́
I be.light PERF
'I have become light (in weight)'

b. [à fèkèfèké ↓tɛ́↓ɛ́]
(less natural)

c. [à fékéféké tɛ́↓ɛ́]
(least natural)

- Only the prosodically-weakest clitics trigger this: low-toned, monosyllabic, onsetless
  - The exhaustive list is à 'I', ɔ̀ 'he', ǹ 'they' (not a morphological natural class)
- Low tone spread is restricted to the phonological phrase but is otherwise phonologically **unbounded**, and only stops at a low tone (or downstepped high), in (4)

unbounded

(4) a. [ò ɓùrùmà sèlɛ̀ tɛ́↓ɛ́]
ɔ̀ ɓúrúmá sélɛ́ tɛ́↓ɛ́
he indigo choose PERF
'he has chosen indigo'

b. [à dʒɛ̀̀ fènì̀ fɛ̀ tɛ́↓ɛ́]
à dʒɛ́́ fénί́ fɛ́ tɛ́↓ɛ́
I another bird buy PERF
'I have bought another bird'

- Why do clitics spread here? An appeal to *LHH
  - These clitics are prosodically deficient, and one repair is to incorporate them into the following prosodic domain by spreading their low tone (lefthand side in Figure 2 – Rolle and Harry 2025)
  - This alleviates deficiency, but it creates a new problem: a newly derived LHH sequence
  - To repair this, the low tone spreads unboundedly to all (or all-but-one) contiguous high-toned syllables within the phrase (righthand side in Figure 2)

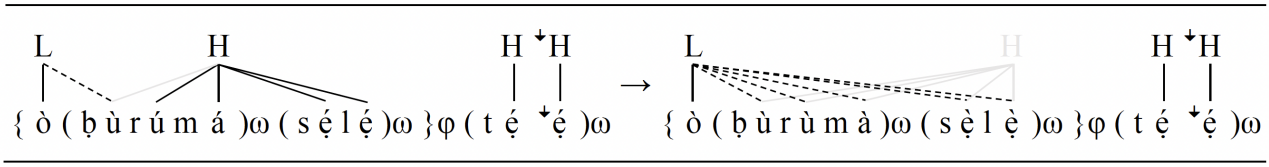

Figure 2: Incorporation of prosodically deficient clitic leads to unbounded low tone spreading

2 The problem

- LH#H sequences are repaired even when they are created by **H tone spread** **H tone spread**
- In transitive verb phrases, an *in situ* object conditions deletion of verb tone (neutralizing any contrast), after which the final tone of the object spreads onto the verb (Tables 5 and 6)
  - Underlying LH objects are most telling (e.g. gàrí at the bottom of these tables)
  - Object-to-verb tone spreading creates derived LH#H sequences, and these are then repaired *via* insertion of a downstep

Table 5: Deletion of verb tone with tone spread from object (L-toned verb sèlè 'to choose')

LL	bìtè 'cloth'	à bìtè sèlè téꜜé	→	à bìtè sɛlɛ téꜜé	→	à bìtè sèlè téꜜé	'I have chosen cloth'
HL	sírì 'leopard'	à sírì sèlè téꜜé	→	à sírì sɛlɛ téꜜé	→	à sírì sèlè téꜜé	'I have chosen a leopard'
HH	ígbé 'box'	àrì ígbé sèlè téꜜé	→	àrì ígbé sɛlɛ téꜜé	→	àrì ígbé sélé téꜜé	'I have chosen a box'
HꜜH	wáꜜrí 'house'	à wáꜜrí sèlè téꜜé	→	à wáꜜrí sɛlɛ téꜜé	→	à wáꜜrí sélé téꜜé	'I have chosen a house'
LH	gàrí 'flour'	ɔ̀ gàrí sèlè téꜜé	→	ɔ̀ gàrí sɛlɛ téꜜé	→	ɔ̀ gàrí sélé téꜜé (→ ɔ̀ gàrí ꜜsélé téꜜé)	'he has chosen flour'

Table 6: Deletion of verb tone with tone spread from object (H-toned verb érí 'to see')

LL	pùlò 'oil'	féní pùlò érí téꜜé	→	féní pùlò ɛrɪ téꜜé	→	féní pùlò èrì téꜜé	'the bird has seen the oil'
HL	bélè 'light'	ɔ̀ bélè érí téꜜé	→	ò bélè ɛrɪ téꜜé	→	ò bélè èrì téꜜé	'he has seen the light'
HH	námá 'meat'	á námá érí téꜜé	→	á námá ɛrɪ téꜜé	→	á námá érí téꜜé	'she has seen the meat'
HꜜH	wáꜜrí 'house'	à wáꜜrí érí téꜜé	→	à wáꜜrí ɛrɪ téꜜé	→	à wáꜜrí érí téꜜé	'I have seen the house'
LH	gàrí 'flour'	ɔ̀ gàrí érí téꜜé	→	ɔ̀ gàrí ɛrɪ téꜜé	→	ɔ̀ gàrí érí téꜜé (→ ɔ̀ gàrí ꜜérí téꜜé)	'he has seen the flour'

- *LHH tonotactics thus disallow such sequences from a number of origins (represented autosegmentally in Table 7)
  - When the high tone sequence belongs to the same word (Presumably a single H toneme, but perhaps two tonemes – Table 7a-b)
  - When the high tone sequence is derived with incidentally-adjacent words (Presumably multiple H tonemes – Table 7c)
  - When the high tone sequence is derived from grammatical tone (Again, presumably multiple H tonemes – Table 7d)
  - When the high tone sequence is derived through spreading in verb phrases (Presumably a single H toneme – Table 7e)

Table 7: Total inventory of banned *LHH structures

a.	*	#	L		H		#	b.	*	#	L	H	H	#												
			|	/	\						|	|	|											
		#	μ́	μ́	μ́	#				#	μ́	μ́	μ́	#												
c.	*	L	H	#	H		d.	*	L	H	#	Ⓗ		e.	*	L	H	#								
		|	|		|				|	|		|												
		μ́	μ́	#	μ́				μ́	μ́	#	μ́				μ́	μ́	#	μ́							

- If we want to capture the range of *LHH prohibitions, how do we formalize this constraint?
- Much work in computational phonology has shown the utility of **Forbidden Substructure Constraints** (FSCs) (Rogers et al., 2013; Jardine, 2016, 2017a, *inter alia*)

Forbidden Substructure Constraints

  - Potential FSCs are in Table 8, where we use the negative symbol '¬' to denote a forbidden substructure
  - The arrows denote **precedence** relations, and the solid lines **association** lines between structure on separate **tiers**

precedence

association

tiers

Table 8: Potential Forbidden Substructure Constraints to capture *LHH

a.	¬	L	→	H	→	H	b.	¬	L	→	H	→	H	c.	¬	L	→	H								
									|		|		|												
									μ́	→	μ́	→	μ́			μ́	→	μ́	→	μ́						

- Herein lies the problem (see also commentary in Hyman 2014, 'How Autosegmental is Phonology?'):
  - The FSC in Table 8a refers only to the **tonal tier**

tonal tier

    - This rules out those structures with two separate H tonemes (i.e. Table 7b,c,d), but not those with only one toneme which spreads across two moras (Table 7a,e)
  - The FSC of Table 8b fares no better, which references both the tonal tier and **mora tier**

mora tier

    - This, too, does not rule out the one-toneme structure (again, Table 7a,e)
  - At the same time, the FSC in Table 8c is insufficient the other way
    - It does not rule out the two-toneme structures (Table 7b,c,d)
- A grammar requiring multiple FSCs misses an important generalization in unifying *LHH

3 Solution

- The problem stems from formalizing *LHH as an FSC over an autosegmental representation
  - I.e. over multiple tiers simultaneously
- Instead, with a string of high-toned moras *μ́μ́*, what is required is *insensitivity* to whether there are one or two H tonemes on the tonal tier
- Our solution is a FSC as a **forbidden substring** rather than a **forbidden autosegmental representation** (i.e. a FSC referencing only one tier, here the mora tier)

forbidden substring

forbidden autosegmental representation

- This is reminiscent of the **Melody-Local** analyses of Jardine (2020) **Melody-Local**
  - Bifurcates constraints into operating either on a tonal tier or a 'surface' tier which includes information about the properties of each TBU
  - That is, *different parts of the grammar run in parallel on different representations*
  - Here, the *LHH constraint operates on this surface tier — a 'flattened' string that represents the properties of each mora
- In more detail:
  - Each individual piece of phonological structure on a tier is an '**element**' (Table 9) **element**
  - Elements have precedence relations with other elements on the same tier
  - We can 'flatten' autosegmental representations to a string-based representation where **associations** are instead represented as **properties** of TBUs, in this case moras (see Jardine and Heinz 2015; Jardine 2017b, 2020 for various procedures for doing this) **associations** **properties**
    - Formally, properties are **unary relations** on the set of elements in the structure (e.g., the set of elements that are $\acute{\mu}$ moras) **unary relations**

Table 9: Associated elements across tiers acquire a 'property' of the other element

(a high tone element)	H			
	|			
(a moraic element)	μ	$\Rightarrow$	$\acute{\mu}$	(a moraic element with a high tone property)

- With this in mind, let us reexamine potential FSCs (in Table 10, where each element in each tier is boxed)
  - In Table 10a, the FSC references only a substring (i.e. a single tier), and thus is only sensitive to moras and their associated properties
  - Crucially, *these properties themselves have no precedence or identity relations because they are not distinct elements*
  - Therefore, in the string representation, there is no way to detect whether identical properties of two elements stem from the same source or not (i.e. whether they come from one H toneme or two)

Table 10: Forbidden substring (cf. forbidden autosegmental representations)

a. Our proposal	Cf.	b. Dismissed alternative 1	c. Dismissed alternative 2
$\neg$		$\neg$	$\neg$
$\boxed{\grave{\mu}} \rightarrow \boxed{\acute{\mu}} \rightarrow \boxed{\acute{\mu}}$		$\boxed{\text{L}} \rightarrow \boxed{\text{H}} \rightarrow \boxed{\text{H}}$ $\boxed{\grave{\mu}} \rightarrow \boxed{\acute{\mu}} \rightarrow \boxed{\acute{\mu}}$	$\boxed{\text{L}} \rightarrow \boxed{\text{H}}$ $\boxed{\grave{\mu}} \rightarrow \boxed{\acute{\mu}} \rightarrow \boxed{\acute{\mu}}$

- In total, an FSC referencing a forbidden substring on a single tier (i.e. Table 10a) correctly rules out all the ungrammatical structures in Table 7 (cf. 10b-c)

4 Summary

- This talk has examined phonological representations within formal constraints governing well-formed outputs (constraints of the types used in both traditional and computational phonology)

- Our focus was on a conspiracy to avoid LHH sequences in the Nigerian language Kalabari, what we called *LHH tonotactics
  - Observation: LHH sequences are banned regardles of whether they come from two separate H tonemes or one H toneme spread across two moras
  - Problem: A single forbidden substructure constraint (FSC) over an autosegmental representation cannot capture both contexts
  - Solution: A FSC stated over a single-tier substring of moras endowed with tonal 'properties' (reminiscent of 'Melody-Local' analyses *à la* Jardine 2020)
- We leave with two questions
  - To what extent are FSCs over full autosegmental representations ever necessary?
    - More pointedly, what limits are there on the types of autosegmental substructures which a constraint can refer to?
  - And is a simpler solution lurking in the data, which involves decomposing tonemes and downstep into tonal features? (Snider 1999; Yip 2001; Lionnet 2025, *inter alia*)
    - Perhaps in the end, all one needs is a single constraint referencing only **register features** on a **register tier** (i.e. **lhh*, rather than *LHH)

register features
register tier

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