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Shift is derived[1]

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Shift is an input–output mapping where a feature or autosegment loses its underlying associations and surfaces with different associations. In Harmonic Serialism, shift can either be analyzed as a multi-step process or a single-step process. While Gietz et al. (2023) argue for the latter, this paper refutes their arguments and provides evidence supporting a multi-step analysis of shift. Specifically, it demonstrates that shift in Kibondei and Halkomelem, the languages analyzed by Gietz et al. (2023), does not require a single-step shift operation and that the analyses they present are empirically inadequate. Typological modeling not only reinforces the result that a single-step shift operation is superfluous but demonstrates that grammars with such an operation undergenerate with respect to the attested typology.

KEYWORDS: autosegmental shift, Halkomelem, Harmonic Serialism, Kibondei, Logoori

1. INTRODUCTION

Shift is an input–output mapping where a feature or autosegment loses its underlying associations and surfaces with different associations. For example, Kibondei (Bantu; Kisseberth & Cassimjee 2006) disallows high tones from surfacing phrase-finally. Among other things (see Section 2), this restriction motivates high tones underlyingly associated to the final vowel of verbs to shift onto the penult phrase-finally (1).

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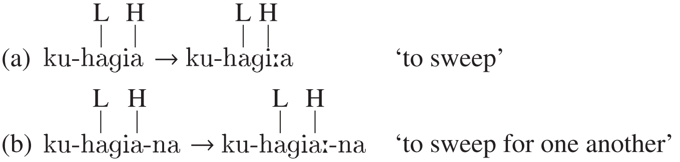
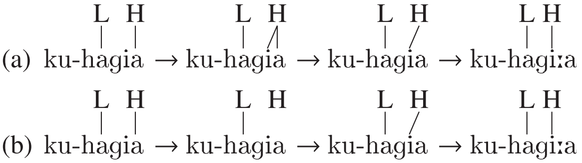
(1) *Phrase-final shift in Kibondei* (Kisseberth & Cassimjee 2006: 84–85)



Serial phonological frameworks, such as Harmonic Serialism (HS; Prince & Smolensky 1993/2004, McCarthy 2000, 2016), explicitly delimit the set of operations available to model input–output mappings. Previous approaches to shift in HS have decomposed it into more basic steps of creating and removing autosegmental links (for tone, see McCarthy 2006, 2008b, McCarthy et al. 2012, Calamaro 2017, Breteler 2018, Lamont 2022a; for moras, see Torres-Tamarit 2012, Lamont 2023; for segmental metathesis, see Takahashi 2019, Mooney 2022). These approaches are illustrated in (2), where the input–output mapping is broken down into two intermediate steps: either the high tone is first linked to the penultimate vowel and then delinked from the final vowel (2a), or the high tone is first delinked from the final vowel and then linked to the penultimate vowel (2b). Hereafter, the derivations exemplified by (2a) and (2b) are referred to as *linking+delinking* and *delinking+linking*, respectively.

(2) *Shift as linking+delinking (a) or delinking+linking (b)*



By contrast, Gietz et al. (2023) identify shift mappings that they argue cannot be modeled by linking+delinking or delinking+linking. On that basis, they conclude that HS cannot adequately model shift unless Gen is equipped with a basic operation that implements shift in one step (hereafter, a SINGLE-STEP SHIFT OPERATION). This paper reexamines their arguments and refutes their claims. Specifically, it demonstrates that shift in Kibondei and Halkomelem, the languages analyzed by Gietz et al. (2023), does not require a single-step shift operation, and that the analyses they present are empirically inadequate. Typological modeling not only reinforces the result that a single-step shift operation is superfluous but demonstrates that grammars with such an operation undergenerate with respect to the attested typology. Sections 2 and 3 provide the analyses of Kibondei and Halkomelem, respectively, and Section 4 provides the typology. Section 5 concludes.

2. High tone shift in Kibondei

In Kibondei (Bantu; Merlevede 1995, Kisseberth & Cassimjee 2006; see also Cassimjee & Kisseberth 1998: 51–53, 66–69, Lee & Lee 2002, Lee 2013), high tones shift to surface as close as possible to the right edge of phonological phrases without actually surfacing phrase-finally. The examples in (3) illustrate the high tone underlyingly associated to the final vowel of the verb /hàgiá/ surfacing on the phrase-penultimate vowel; it shifts regressively in (3a), shifts progressively in (3b), and surfaces in situ in (3c). The analysis in this section derives regressive shift as delinking+linking and progressive shift as linking+delinking. The examples below also illustrate phrase-penultimate vowel lengthening, which independently supports the status of the phonological phrase.

(3) *High tone shift in Kibondei* (Kisseberth & Cassimjee 2006: 84–85)

```
         L  H           L H
         |  |           | |
(a) ku-hagia → ku-hagiːa                    'to sweep'
         L  H                L      H
         |  |                |      |
(b) ka-hagia sakafu → ka-hagia sakaːfu      'cl.1 swept the floor'
         L  H             L  H
         |  |             |  |
(c) ku-hagia-na → ku-hagiaː-na              'to sweep for one another'
```

Kibondei verbs are either underlyingly toneless or have one underlying high tone; of the 451 verbs in Kisseberth & Cassimjee (2006), 277 are toneless and 174 are high-toned (see Merlevede 1995 for discussion of nominal tonology). The table in (4) summarizes the possible underlying forms of verbs up to three moras long; there are no monomoraic toneless verbs. As discussed later in this section, the data on longer verbs are too sparse to precisely characterize their underlying forms. Prefixes are also underlyingly toneless or associated to one high tone.

(4) *Underlying forms of Kibondei verbs*

			/V́/	H | ku-da	‘to eat’
/VV/	ku-senga	‘to cut’	/V̀V́/	L H | | ku-koma	‘to kill’
/VVV/	ku-ambika	‘to cook, boil’	/V̀V́V/	L H | | ku-ombeza	‘to ask for’
			/V̀VV́/	L H | | ku-hagia	‘to sweep’

Toneless verbs surface faithfully with toneless prefixes, such as the infinitive /ku-/ and first person present affirmative /ni-a-/ (5a, b); the high vowel never surfaces in the latter, which is omitted from the analysis as a simplification. With high-toned prefixes, such as the class 1 third person present affirmative /á-/, the high tone shifts onto the verb's penultimate syllable (5c, d).

(5) *Toneless verbs* (Kisseberth & Cassimjee 2006: 11, 37, 50, 58, 127)

(a) (i)	ku-ambika → ku-ambiːka	'to cook, boil'
(ii)	ku-senga → ku-seːnga	'to cut'
(b) (i)	ku-ambika m-t͡ʃuzi → ku-ambika m-t͡ʃuːzi	'to cook, prepare m-chuzi'
(ii)	ni-a-senga ɲama → n-a-senga ɲaːma	'I am cutting meat'
(c) (i)	$\overset{\text{H}}{\overset{\vert}{\text{a}}}$-ambika → a-amb$\overset{\text{H}}{\overset{\vert}{\text{i}}}$ːka	'cl.1 is cooking'
(ii)	$\overset{\text{H}}{\overset{\vert}{\text{a}}}$-senga → a-s$\overset{\text{H}}{\overset{\vert}{\text{e}}}$ːnga	'cl.1 is cutting'
(d) (i)	$\overset{\text{H}}{\overset{\vert}{\text{a}}}$-ambika m-boga → a-amb$\overset{\text{H}}{\overset{\vert}{\text{i}}}$ka m-boːga	'cl.1 is cooking m-boga'
(ii)	$\overset{\text{H}}{\overset{\vert}{\text{a}}}$-senga ɲama → a-s$\overset{\text{H}}{\overset{\vert}{\text{e}}}$nga ɲaːma	'cl.1 is cutting meat'

As the tableaux in (6) illustrate with /á-senga ɲama/ → [a-sénga ɲaːma] 'cl.1 is cutting meat' (5d.ii), progressive shift is modeled as linking+delinking. In these and following tableaux, pairwise relations between constraints reflect the ranking represented in the Hasse diagram (53) in Appendix A, which also provides constraint definitions, discussion of Gen, and the full set of tableaux. In the first step of the derivation, the prefix high tone is linked to the penultimate syllable of the verb (6b). This improves on Align-R, which penalizes syllables that intervene between the rightmost syllable linked to a high tone and the end of the phonological phrase,[2] at the expense of *Link(H), which penalizes syllables linked to high tones. Delinking (6c) or deleting the high tone (6d) satisfies Align-R and *Link(H), but is ruled out by higher ranked constraints. Further improvement on Align-R is blocked in the second step by $*\text{H}]_{\omega}$, which penalizes word-final high tones (6f). Instead, the link to the prefix is lost, improving on *Link(H) (6g). The derivation converges in the third step with the prefix high tone on the penultimate syllable of the verb (6h).

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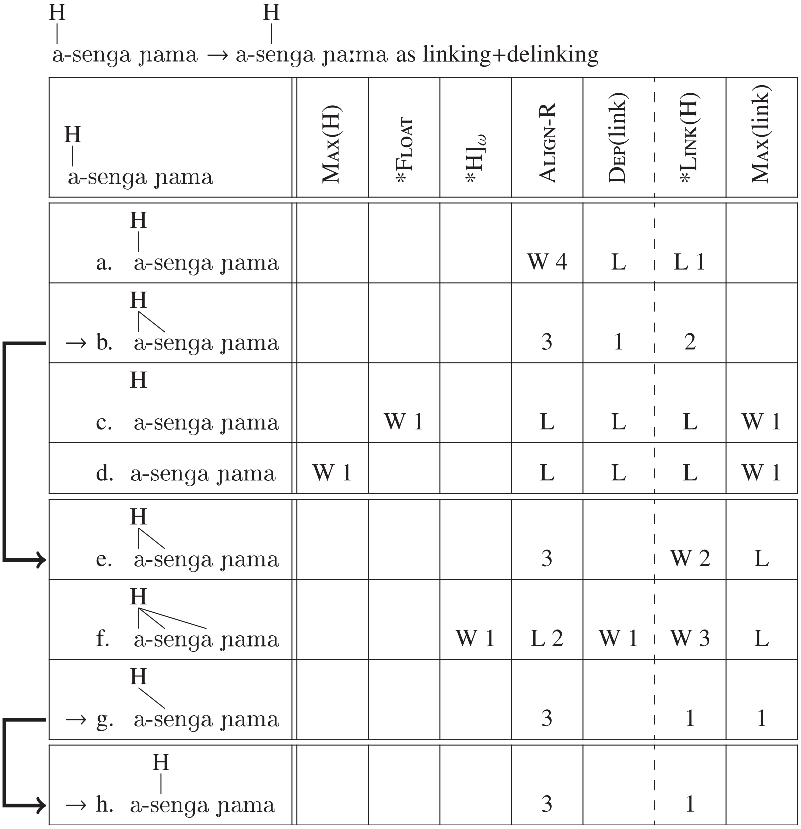
[2] This constraint is consistent with multiple formalizations; all that is required for the analysis is a pressure on all high tones to spread rightwards. I implement this as a Generalized Alignment constraint (McCarthy & Prince 1993, McCarthy 2003) assuming a wider familiarity, but it can also be implemented as Relation-Specific Alignment (Hyde 2012, 2016), Share (McCarthy 2010, Mullin 2011), or a directional constraint (Lamont 2022a, b).

Linking a high tone to a syllable that precedes its leftmost link does not improve on any phonotactic constraint and is excluded from tableaux.

(6)

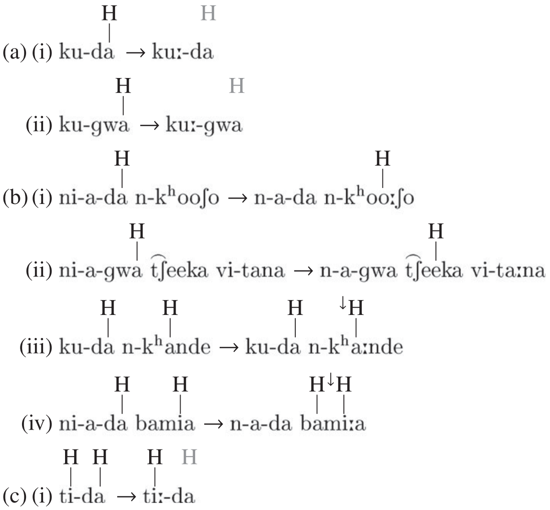


H H
a-senga ɲama → a-senga ɲaːma as linking+delinking

H a-senga ɲama	Max(H)	*Float	$*\mathrm{H}]_{\omega}$	Align-R	Dep(link)	*Link(H)	Max(link)
a. H a-senga ɲama				W 4	L	L 1	
→ b. H a-senga ɲama				3	1	2	
c. H a-senga ɲama		W 1		L	L	L	W 1
d. a-senga ɲama	W 1			L	L	L	W 1
e. H a-senga ɲama				3		W 2	L
f. H a-senga ɲama			W 1	L 2	W 1	W 3	L
→ g. H a-senga ɲama				3		1	1
→ h. H a-senga ɲama				3		1	

Because it is not optimal to link high tones to word-final syllables, prefix high tones cannot shift into following words. However, high tones that are underlyingly word-final can. In addition to other contexts, inter-word shift occurs with monosyllabic verbs; Kisseberth & Cassimjee (2006) give eight such verbs, which are all underlyingly high-toned. Phrase-finally, monosyllabic verbs do not surface with high-toned syllables (7a, c), and phrase-medially, their high tones shift onto the penultimate syllable of a following toneless word (7b.i, ii). When the following word has a high tone, the verb's high tone surfaces in the preceding syllable, triggering downstep (7b.iii, iv). While the high tones in gray do not surface linked to any syllables, it is ambiguous whether they remain floating or are deleted. As a simplification, the analysis in this section assumes they remain floating; Section 3 addresses an unambiguous case of deletion.

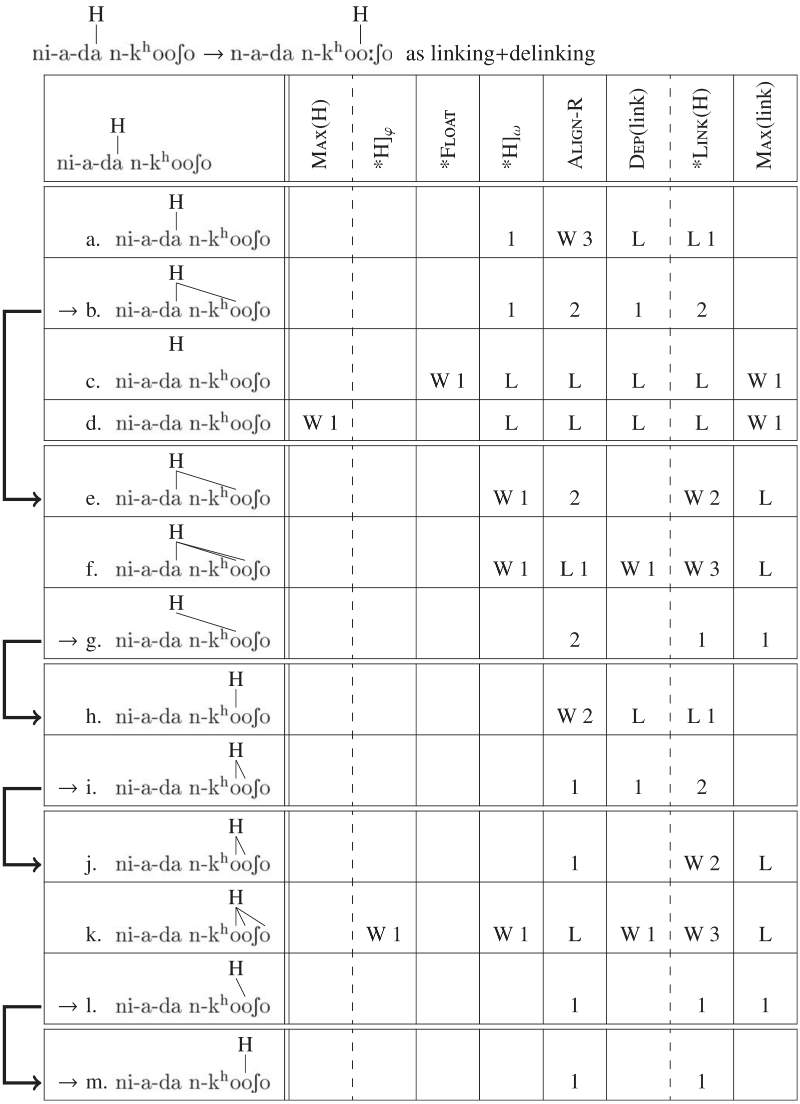
(7) *Monosyllabic high-toned verbs* (Kisseberth & Cassimjee 2006: 46, 56, 58, 83, 103)



(a)	(i) ku-da → kuː-da	‘to eat’
	(ii) ku-gwa → kuː-gwa	‘to fall/drop/trip’
(b)	(i) ni-a-da n-kʰooʃo → n-a-da n-kʰooːʃo	‘I am eating cashew nuts’
	(ii) ni-a-gwa t͡ʃeeka vi-tana → n-a-gwa t͡ʃeeka vi-taːna	‘I am falling down well’
	(iii) ku-da n-kʰande → ku-da n-kʰaːnde	‘to eat food’
	(iv) ni-a-da bamia → n-a-da bamiːa	‘I am eating okra’
(c)	(i) ti-da → tiː-da	‘we ate’

The tableaux in (8) illustrate inter-word shift in /ni-a-dá n-k^{h}ooʃo/ → [n-a-da n-k^{h}oó:ʃo] ‘I am eating cashew nuts’ (7b.i). As before, the derivation begins by linking the high tone to the following word, improving on Align-R (8b). The violation of $*H]_{\omega}$ cannot be removed in this step: delinking the high tone violates *Float (8c) and deletion violates Max(H) (8d), which both dominate $*H]_{\omega}$. However, in the second step, delinking does not create a floating tone, and the high tone loses its link to the verb, satisfying $*H]_{\omega}$ (8g). The remaining derivation is identical to that in (6), with the high tone shifting from the initial syllable of the noun to its penult (8l). Spreading to the final vowel not only violates $*H]_{\omega}$ but also $*H]_{\varphi}$, which penalizes phrase-final high tones (8k).

(8)



ni-a-da n-kʰooʃo → n-a-da n-kʰooːʃo as linking+delinking

ni-a-da n-kʰooʃo	Max(H)	*H]$_\varphi$	*Float	*H]$_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
a. ni-a-da n-kʰooʃo				1	W 3	L	L 1	
→ b. ni-a-da n-kʰooʃo				1	2	1	2	
c. ni-a-da n-kʰooʃo			W 1	L	L	L	L	W 1
d. ni-a-da n-kʰooʃo	W 1			L	L	L	L	W 1
e. ni-a-da n-kʰooʃo				W 1	2		W 2	L
f. ni-a-da n-kʰooʃo				W 1	L 1	W 1	W 3	L
→ g. ni-a-da n-kʰooʃo					2		1	1
h. ni-a-da n-kʰooʃo					W 2	L	L 1	
→ i. ni-a-da n-kʰooʃo					1	1	2	
j. ni-a-da n-kʰooʃo					1		W 2	L
k. ni-a-da n-kʰooʃo		W 1		W 1	L	W 1	W 3	L
→ l. ni-a-da n-kʰooʃo					1		1	1
→ m. ni-a-da n-kʰooʃo					1		1	

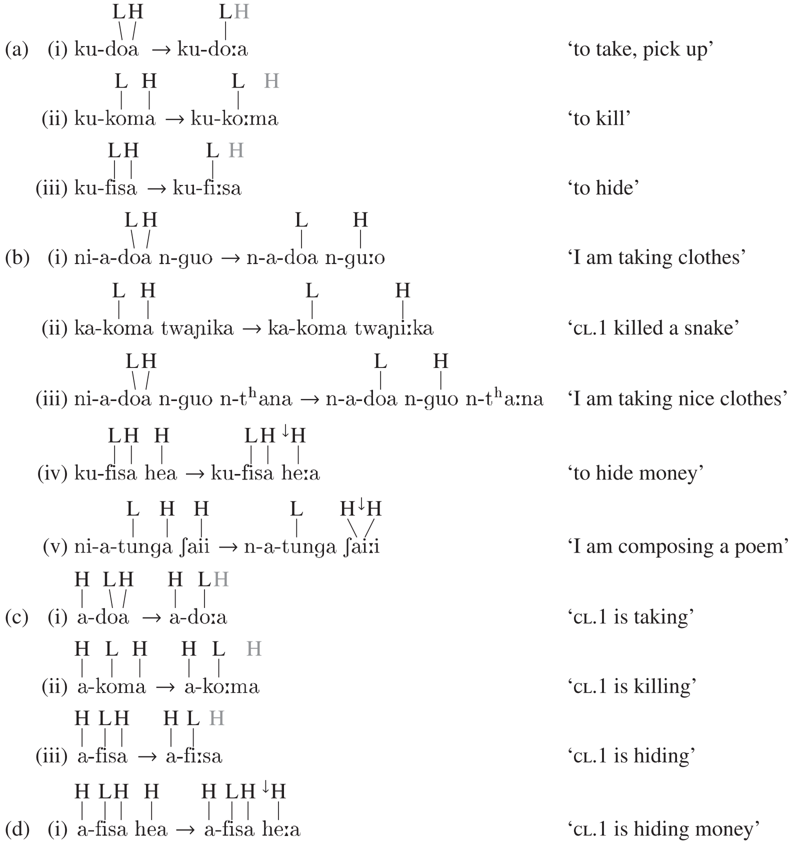
Underlyingly phrase-final high tones delink from their hosts to satisfy *H]$_\varphi$, as the tableaux in (9) illustrate with /ku-dá/ → [ku:-da^{H}] 'to eat' (7a.i). Because Max (H) dominates *Float, floating tones cannot be deleted, and remain floating unless they can optimally be linked to a syllable. In this case, neither syllable is an acceptable host: linking to the verb would violate *H]$_\varphi$ and linking to the prefix fatally violates CrispEdge-L, which penalizes linking high tones to syllables that precede the leftmost syllable associated to the same morpheme (Itô & Mester 1999, Kaplan 2018; see Rolle & Merrill 2022 for an alternative approach). The derivation converges in the second step with the verb's tone floating (9d).

(9)
H H
ku-da → kuː-da

H ku-da	Max(H)	*H]$_\varphi$	CrispEdge-L	*Float	*H]$_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
H a. ku-da		W 1		L	W 1			W 1	L
H → b. ku-da				1					1
c. ku-da	W 1			L					1
H → d. ku-da				1					
H e. ku-da			W 1	L		W 1	W 1	W 1	

Similar effects are observed in disyllabic high-toned verbs; of the 199 disyllabic verbs in Kisseberth & Cassimjee (2006), 69 have underlying high tones. Phrase-finally, disyllabic verbs do not surface associated to their lexical high tones (10a, c). Their high tones shift onto the penult of following toneless words (10b.i–iii) or up to following high tones, triggering downstep (10b.iv, v, d). Unlike toneless verbs, high tones never surface on the initial syllable of disyllabic high-toned verbs, for example, /á-kòmá/ → [á-kòma^{H}] *[a-kóma^{H}] (cf. 5c.ii, d.ii). In general, no high-toned verb with more than one syllable allows high tones to link to its initial syllable. This motivates postulating lexical low tones at the left edge of high-toned verbs (see Marlo 2013: 155 fn. 11 for discussion of similar analyses of Luyia and Hyman & Valinande 1985, Hyman 2018, and Hyman & Katamba 1993 for a diachronic perspective), resulting in three lexical tone melodies: toneless /Ø/, high-toned monosyllabic /H/, and low-high multisyllabic /LH/.

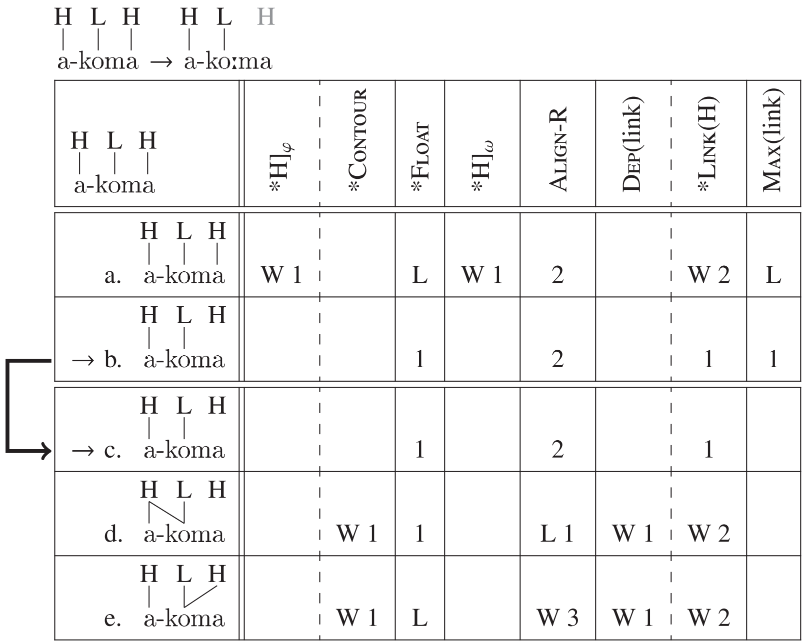
(10) *Disyllabic high-toned verbs* (Kisseberth & Cassimjee 2006: 61, 70, 102, 145, 147)



(a) (i) ku-doa → ku-doːa ‘to take, pick up’
(ii) ku-koma → ku-koːma ‘to kill’
(iii) ku-fisa → ku-fiːsa ‘to hide’
(b) (i) ni-a-doa n-guo → n-a-doa n-guːo ‘I am taking clothes’
(ii) ka-koma twaɲika → ka-koma twaɲiːka ‘CL.1 killed a snake’
(iii) ni-a-doa n-guo n-tʰana → n-a-doa n-guo n-tʰaːna ‘I am taking nice clothes’
(iv) ku-fisa hea → ku-fisa heːa ‘to hide money’
(v) ni-a-tunga ʃaii → n-a-tunga ʃaiːi ‘I am composing a poem’
(c) (i) a-doa → a-doːa ‘CL.1 is taking’
(ii) a-koma → a-koːma ‘CL.1 is killing’
(iii) a-fisa → a-fiːsa ‘CL.1 is hiding’
(d) (i) a-fisa hea → a-fisa heːa ‘CL.1 is hiding money’

The blocking effects of lexical low tones are illustrated in the tableaux in (11) with /á-kòmá/ → [á-kòma$^{\text{H}}$] ‘CL.1 is killing’ (10c.ii). As in (9), the phrase-final high tone is delinked in the first step of the derivation, satisfying $*\text{H}]_{\varphi}$ (11b); the derivation converges in the next step (11c). Linking the prefix high tone to the verb-initial syllable would improve on ALIGN-R (11d) and linking the floating tone to it would satisfy *FLOAT (11e). Both, however, fatally violate *CONTOUR, which penalizes syllables linked to multiple tones. Between the lexical low tones and *CONTOUR, high tones are blocked from linking to initial syllables of multisyllabic high-toned verbs.

(11)



H L H → H L H

a-koma → a-koːma

H L H a-koma	$*\text{H}]_\varphi$	*Contour	*Float	$*\text{H}]_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
a. H L H a-koma	W 1		L	W 1	2		W 2	L
→ b. H L H a-koma			1		2		1	1
→ c. H L H a-koma			1		2		1	
d. H L H a-koma		W 1	1		L 1	W 1	W 2	
e. H L H a-koma		W 1	L		W 3	W 1	W 2	

Like disyllabic high-toned verbs, high-toned verbs with three or four syllables all disallow high tones from linking to their initial syllables (12–13); in Kisseberth & Cassimjee (2006), 75 of the 198 trisyllabic verbs are high-toned, 22 of 45 quadrisyllabic verbs are high-toned, the only verb with five syllables is toneless, and there are no verbs with six or more syllables. In trisyllabic verbs, high tones are either underlyingly associated to the penultimate vowel as in /òmbéza/ or the final vowel as in /hàgiá/. Phrase-finally, these high tones surface on the penultimate vowel (12a), either surfacing in situ (12a.i, iii) or undergoing regressive shift (12a.ii). Phrase-medially, verb-penultimate high tones surface in situ (12b.i), while verb-final high tones shift into the following word (12b.ii), mirroring the behavior of high tones in prefixes and verbs with one or two syllables, respectively. Because there is not enough data in Kisseberth & Cassimjee (2006) to determine the underlying forms of quadrisyllabic verbs, the examples in (13) only present their surface forms with the toneless infinitive prefix /ku-/ (13a) and the high-toned class 1 present affirmative /á-/ (13b).

(12) *Trisyllabic high-toned verbs* (Kisseberth & Cassimjee 2006: 84–85, 119, 125)

L H → L H
(a) (i) ku-ombeza → ku-ombeːza 'to ask for'

L H → L H
(ii) ku-hagia → ku-hagiːa 'to sweep'

L H → L H
(iii) ku-hagia-na → ku-hagiaː-na 'to sweep for one another'

L H → L H
(b) (i) ni-a-ombeza n-guo → n-a-ombeza n-guːo 'I am asking for clothes'

L H → L H
(ii) ka-hagia sakafu → ka-hagia sakaːfu 'CL.1 swept the floor'

H L H → H L H
(c) (i) a-hagia → a-hagiːa 'CL.1 is sweeping'

(13) *Quadrisyllabic high-toned verbs* (Kisseberth & Cassimjee 2006: 34, 43–44, 139, 160)

L H / H L H
(a) (i) ku-aibiːka (b) (i) a-aibiːka 'be ashamed, feel shy'

L H / H L H
(ii) ku-babaiːka (ii) a-babaiːka 'fumble about'

L H / H L H
(iii) ku-babazuːa (iii) a-babazuːa 'remove bark'

L H / H L H
(iv) ku-babatiːza (iv) a-babatiːza 'press down on s.t. with the hand or foot'

L H / H L H
(v) ku-tajaliːʃa (v) a-tajaliːʃa 'prepare, serve (e.g. food)'

L H / H L H
(vi) ku-zizimiːza (vi) a-zizimiːza 'be compelled to be somewhere'

Regressive shift is illustrated in the tableaux in (14) with /ku-hàgiá/ → [ku-hàgí:a] 'to sweep' (12a.ii). The high tone is delinked in the first step, satisfying $*\mathrm{H}]_{\varphi}$ (14b). In the second step, it is linked to the penult, satisfying *FLOAT (14d), and the derivation converges in the third step (14e). The crucial difference between trisyllabic verbs and shorter verbs is that only the former have an acceptable syllable to host floating tones. In monosyllabic verbs, floating tones can only link to prefixes, violating

CrispEdge-L, or the verb itself, violating $*\mathrm{H}]_{\varphi}$ (9). In disyllabic verbs, floating tones can only link to the verb-initial syllable, violating *Contour, or the verb-final syllable, violating $*\mathrm{H}]_{\varphi}$ (11).

(14)

```
  L  H        L H
  |  |        | |
ku-hagia → ku-hagiːa  as delinking+linking
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L H | | ku-hagia	$*\mathrm{H}]_{\varphi}$	*Float	$*\mathrm{H}]_{\omega}$	Align-R	Dep(link)	*Link(H)	Max(link)
L H | | a. ku-hagia	W 1	L	W 1			W 1	L
L H | → b. ku-hagia		1					1
L H | c. ku-hagia		W 1		L	L	L	
L H | / → d. ku-hagia				1	1	1	
L H | | → e. ku-hagia				1		1	

To summarize the analysis, Kibondei verbs are underlyingly specified with one of three tonal melodies: toneless /Ø/, high /H/, or low-high /LH/. All and only monosyllabic verbs take the high melody. Verbs that take the low-high melody have the low tone associated to their initial vowel and the high associated to a following vowel. Verbal prefixes are either underlyingly toneless /Ø/ or associated to a high tone /H/. All high tones are drawn to the right edge of phonological phrases, but cannot link to word-final syllables or syllables already associated to a tone. Underlyingly word-final tones shift onto the penult of following toneless words and other tones shift onto the penult of their host word. Underlyingly phrase-final tones shift onto the penult of their host word if it is at least trisyllabic and fail to surface otherwise.

The analysis derives progressive high tone shift as linking+delinking and regressive high tone shift as delinking+linking. It thus invalidates the claims by Gietz et al. (2023) that Harmonic Serialism cannot model high tone shift in Kibondei or regressive shift from final to penultimate syllables without modeling shift as a single-step operation. Their latter claim is an artifact of their typology not allowing floating features (see Section 4 for discussion).

While the present analysis benefits from a more complete data set, the analysis Gietz et al. (2023) present cannot even account for the data in the sources they cite, Cassimjee & Kisseberth (1998) and Lee & Lee (2002). Specifically, their analysis incorrectly predicts regressive shift whenever word-final high tones cannot shift into the following word, as in [á-fisá h!é:a] 'CL.1 is hiding money' (10d); this specific example is discussed by Lee & Lee (2002: 346).[3] The support in (15) illustrates the ranking paradox that emerges when this example is included in their analysis (see Appendix B for constraint definitions). The winner∼loser pair in (15a) illustrates inter-word shift in /á-tàgá m-p^{h}ombe/ → [á-tàga m-p^{h}ó:mbe] 'CL.1 is selling beer' (Kisseberth & Cassimjee 2006: 136); these candidates come from tableau 16 in Gietz et al. (2023: 33), which does not posit lexical low tones. To rule out the faithful loser, high tones must be worse word-finally than removed from their base position and misaligned from the right edge of a word. This contradicts the ranking required to prevent the verb-final high tone in [á-fisá h!é:a] from shifting regressively (15b). I do not claim that every analysis of Kibondei that assumes a single-step shift operation fails, but the analysis presented by Gietz et al. (2023) does.

(15) *A ranking paradox in the analysis by* Gietz et al. (2023)

	Max(H)	OCP	NonFin	Base-Ident	Align-R	NoLongT
a. H H H H a-taga m-p^{h}ombe ∼ a-taga m-p^{h}ombe			W	L	L	
b. H H H H H H a-fisa hea ∼ a-fisa hea			L	W	W	

Before moving on, it is worth justifying another difference between the present analysis and Gietz et al.'s. Whereas the present analysis penalizes autosegmental linking and delinking with the constraints Dep(link) and Max(link), respectively, Gietz et al. (2023) employ an Ident constraint. This is explicit in sections 4 and 5 of their paper, but not in their analysis of Kibondei; their definition of Base-Ident (p. 32) implies a mix of Max(link) and Ident. In the analysis of Kibondei, the choice of faithfulness constraints is immaterial because Dep(link) and Max(link) are not

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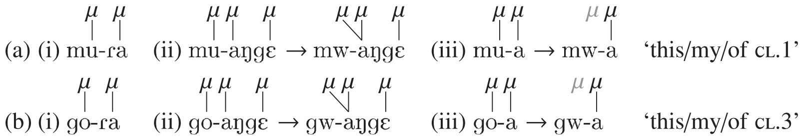
[3] Gietz et al. (2023: 30) incorrectly report that adjacent high tones do not surface in Kibondei despite this example and discussion of downstep by Cassimjee & Kisseberth (1998: 67-69).

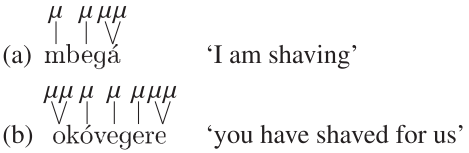
crucially ranked relative to each other. However, other systems provide evidence against using Ident.

For example, one method of avoiding vowel hiatus in Logoori (Bantu; Leung 1991, Zymet 2018, Odden 2021, n.d.) involves glide formation and compensatory lengthening (see Gess 2011, Kiparsky 2011, Borgeson 2022 for overviews of compensatory lengthening, Torres-Tamarit 2012, 2016, Jacobs 2019, Lamont 2023 for analysis in HS, and Shaw 2009 for analysis in a related framework). While word-internal vowels are lengthened (16.ii), word-final vowels are not (16.iii), obeying a phonotactic restriction on word-final long vowels. However, this restriction is not absolute, as underlying word-final long vowels surface faithfully (17). This pattern is straightforwardly modeled assuming Dep(link) and Max(link), but cannot be modeled using Ident. As above, whether the moras in gray remain floating or are deleted is ambiguous (see Section 3 for discussion).

(16) *Compensatory lengthening word-internally (ii) but not word-finally (iii) in Logoori* (Zymet 2018: 305)

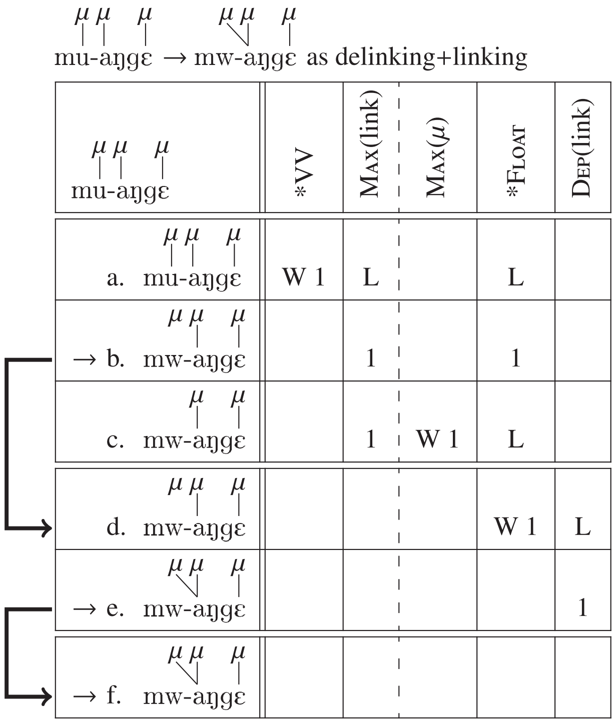


(17) Word-final long vowels in Logoori (Odden n.d.: chapter 3:8, 115)



The difference between derived and underlying word-final long vowels is captured by ranking *Float between Max(link) and Dep(link) (see Lamont (2023) for a full analysis of hiatus resolution that minimally differs in its assumptions). As in the tableaux in (18), which illustrate the mapping /mu-aŋgɛ/ → [mw-aːŋgɛ] 'my cl.1' (16a.ii), compensatory lengthening is modeled as mora delinking+linking. Pairwise relations between constraints reflect the ranking represented in the Hasse diagram in (85) (see Appendix C for the full set of tableaux). The prefix mora is delinked in the first step (18a), satisfying the constraint *VV, which penalizes adjacent vowels. Deleting the mora also satisfies *VV, but is dispreferred because Max(μ) dominates *Float (18c). In the second step, the floating mora is linked to the stem-initial vowel, satisfying *Float (18e). The derivation converges in the third step (18f).

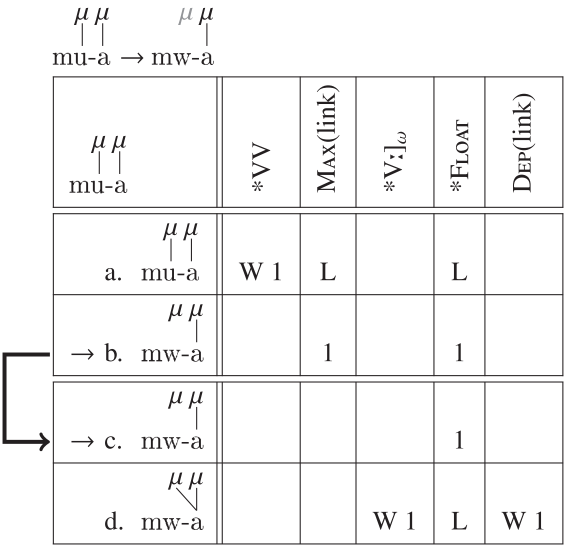
(18) mu-aŋgɛ → mw-aŋgɛ as delinking+linking



mu-aŋgɛ	*VV	Max(link)	Max(μ)	*Float	Dep(link)
a. mu-aŋgɛ	W 1	L		L	
→ b. mw-aŋgɛ		1		1	
c. mw-aŋgɛ		1	W 1	L	
d. mw-aŋgɛ				W 1	L
→ e. mw-aŋgɛ					1
→ f. mw-aŋgɛ					

Delinked moras remain floating to avoid surfacing word-finally, as the tableaux in (19) illustrate with /mu-a/ → [mw-a$^{\mu}$] ‘of CL.1’ (16a.iii). After the prefix mora is delinked (19b), the derivation converges (19c). Linking the floating mora to the vowel fatally violates *V:]$_{\omega}$, which penalizes word-final long vowels (19d).

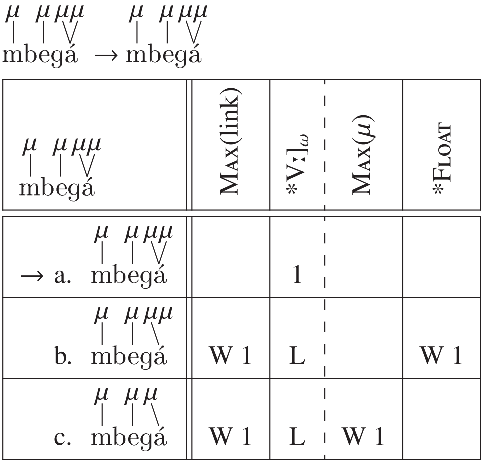
(19)



μ μ mu-a	*VV	Max(link)	*V:]$_\omega$	*Float	Dep(link)
a. μ μ mu-a	W 1	L		L	
→ b. μ μ mw-a		1		1	
→ c. μ μ mw-a				1	
d. μ μ mw-a			W 1	L	W 1

While *V:]$_\omega$ prevents floating moras from linking to word-final vowels, it cannot motivate delinking or deleting underlying word-final long vowels, as the tableau in (20) illustrates with [mbegáː] 'I am shaving' (17a). Delinking (20b) or deleting (20c) one of the moras associated to the word-final vowel would satisfy *V:]$_\omega$, but both violate Max(link), which is ranked higher.

(20)



μ μ μμ mbegá	Max(link)	*V:]$_\omega$	Max(μ)	*Float
→ a. μ μ μμ mbegá		1		
b. μ μ μμ mbegá	W 1	L		W 1
c. μ μμ mbegá	W 1	L	W 1	

Because Max(link) and Dep(link) are crucially ranked, they cannot be combined into a single constraint like Ident. The support in (21) illustrates the resulting ranking paradox.

(21) *Compensatory lengthening in Logoori cannot be modeled with* Ident

	Max(μ)	*VV	*Vː$]_\omega$	*Float	Ident(μ)
 a. mw-aŋgɛ ~ mw-aŋgɛ				W	L
 b. mw-a ~ mw-a			W	L	W
 c. mbegá ~ mbegá			L	W	W

In summary, the distribution of long vowels in Logoori provides empirical evidence that moraic faithfulness must be modeled by two constraints, Max(link) and Dep(link), not a symmetrical faithfulness constraint, Ident(μ), in Harmonic Serialism (see McCarthy 2008a for discussion of this question with respect to place assimilation). Assuming a uniform analysis of autosegments generally, this extends to tones and other features.

3. [low] shift in Halkomelem

In Halkomelem (Salishan; Suttles 2004), the feature [low] must be linked to a stressed vowel. Among other things, this restriction motivates delinking [low] from vowels that are not assigned stress and then either deleting it or linking it to a stressed vowel. The examples in (22) illustrate the basic pattern with the reflexive suffix /-θat/. The suffix vowel surfaces faithfully when it is stressed (22a) and as [ə] otherwise (22b–f). When the mid-vowel /e/ is stressed, the [low] feature shifts onto it, lowering it to [a] (22b, c), and deletes otherwise (22d–f). The analysis in this section models [low] shift as delinking+linking.

(22) *[low] shift and [low] deletion in Halkomelem* (Suttles 2004: 244)

(a) ɬəqʷ-θ$\overset{\text{low}}{\text{a}}$t → ɬəqʷ-ˈθ$\overset{\text{low}}{\text{a}}$t ‘get all wet’

(b) kʷes-θ$\overset{\text{low}}{\text{a}}$t → ˈkʷ$\overset{\text{low}}{\text{a}}$s-θət ‘become hot (weather)’

(c) peθə-θ$\overset{\text{low}}{\text{a}}$t → ˈp$\overset{\text{low}}{\text{a}}$θə-θət ‘spread out (INTR)’

(d) n$\overset{\text{low}}{\text{a}}$s-θ$\overset{\text{low}}{\text{a}}$t → ˈn$\overset{\text{low}}{\text{a}}$s-θət ‘get fat’

(e) hiːl-θ$\overset{\text{low}}{\text{a}}$t → ˈhiːl-θət ‘let oneself fall’

(f) t͡sə-θ$\overset{\text{low}}{\text{a}}$t → ˈt͡sə-θət ‘approach’

Halkomelem has a five vowel system, composed of the high vowels /i(ː), u(ː)/, the mid vowels /e(ː), ə/, and the low vowel /a(ː)/ (Suttles 2004: 9). The distribution of [ə] is largely predictable and typically analyzed as epenthetic (Bianco 1996, Kinkade 1998); as a simplification, I assume schwa is present in the input, either underlying or having been inserted at a previous derivational step. The leftmost full vowel in a word usually attracts primary stress, which is otherwise assigned to the leftmost [ə], but this is complicated by non-trivial interactions with the morphology and lexical specification (Suttles 2004: 13–14; see Bianco 1996, 1998 for thorough description and analysis; see Pruitt 2012, 2019, 2022 for discussion of primary stress in Harmonic Serialism).

Several suffixes with underlying low vowels including the reflexive /-θat/ and the reciprocal /-talˀ/ undergo [low] shift but surface faithfully when stressed (23a). Otherwise, the [low] feature is delinked from the suffix vowel. If a mid vowel /e/ is assigned stress, the [low] feature is linked to it, lowering it to [a] (22b). This occurs even when a vowel intervenes between the stressed vowel and the suffix (22b.ii, iv). While shift between adjacent syllables appears to be exceptionless, there are exceptions when a vowel intervenes, for example, [ˈt’ejəm-təlˀ] ‘stick together’ (Suttles 2004: 246) and [ˈtᶿ’ekʷ’ə-təl] ‘shine light on e.o.’ (Gerdts 2000: 141).

(23) *[low] surfacing on the stressed vowel* (Suttles 2004: 244, 246–247)

(a)	(i)	ɬəqʷ-θ$\overset{\overset{\text{low}}{|}}{\text{a}}$t → ɬəqʷ-ˈθ$\overset{\overset{\text{low}}{|}}{\text{a}}$t	‘get all wet’
	(ii)	θələq-ˈt$\overset{\overset{\text{low}}{|}}{\text{a}}$lˀ-əstəxʷ → θələq-ˈt$\overset{\overset{\text{low}}{|}}{\text{a}}$lˀ-əstəxʷ	‘separate it, divide it’
(b)	(i)	kʷes-θ$\overset{\overset{\text{low}}{|}}{\text{a}}$t → ˈkʷ$\overset{\overset{\text{low}}{|}}{\text{a}}$s-θət	‘become hot (weather)’
	(ii)	peθə-θ$\overset{\overset{\text{low}}{|}}{\text{a}}$t → ˈp$\overset{\overset{\text{low}}{|}}{\text{a}}$θə-θət	‘spread out (INTR)’
	(iii)	xəmen-t$\overset{\overset{\text{low}}{|}}{\text{a}}$lˀ → xəˈm$\overset{\overset{\text{low}}{|}}{\text{a}}$ːn-təlˀ	‘be enemies, be rivals’
	(iv)	t͡s’ewə-t$\overset{\overset{\text{low}}{|}}{\text{a}}$lˀ → ˈt͡s’$\overset{\overset{\text{low}}{|}}{\text{a}}$wə-təlˀ	‘help each other’

The tableaux in (24) illustrate [low] surfacing in situ in [ɬəqʷ-ˈθat] ‘get all wet’ (23a.i). In this and following tableaux, pairwise relations between constraints reflect the ranking represented in the Hasse diagram in Appendix D (94), which also provides constraint definitions and the full set of tableaux. In the first step of the derivation, primary stress is assigned to the suffix (24c), satisfying $*{-}\Delta_{\omega} \geq \{i,u\}$, which penalizes vowels more sonorous than schwa that are not the Designated Terminal Element (DTE; de Lacy 2006: 66–69) of the word. Assigning stress to the root is preferred by ALIGN-L(ˈσ), which penalizes syllables that intervene between the left edge of the word and the stressed syllable, but fails to satisfy $*{-}\Delta_{\omega} \geq \{i,u\}$, which is higher ranked (24b). In addition to motivating stress assignment, $*{-}\Delta_{\omega} \geq \{i,u\}$ also blocks linking the [low] feature to an unstressed vowel (24d). Delinking (24e) or deleting the [low] feature (24f) also satisfies $*{-}\Delta_{\omega} \geq \{i,u\}$, but violates higher ranked constraints, including MAX(link). For reasons to be discussed below, it is necessary to bifurcate MAX(low) into a general MAX(low) constraint and a constraint that specifically penalizes deleting [low] features that are linked to a vowel, MAXLINKED(low).[4] The latter is ranked high enough to rule out all such candidates, which are excluded from the following tableaux. Along with assigning primary stress to the suffix, deleting the [low] feature is the only other way to satisfy [low]→ˈσ, which penalizes [low] features

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[4] Formally, this constraint can be derived by conjoining MAX(low) and MAX(link) (Smolensky 2006). In a weighted, serial framework (Pater 2012), its effects can be derived as a cumulative effect of the two constraints without positing a third constraint per se.

not linked to a stressed syllable (24f). The derivation converges in the next step (24g).

(24)
low low
ɬəqʷ-θat → ɬəqʷ-ˈθat

low ɬəqʷ-θat	MaxLinked(low)	$*-\Delta_\omega \geq \{i,u\}$	*Float	Max(link)	Align-L(ˈσ)	[low]→ˈσ	$*-\Delta_\omega \geq ə$	Max(low)	Dep(link)
low a. ɬəqʷ-θat		W 1			L	W 1	W 2		
low b. ˈɬəqʷ-θat		W 1			L	W 1	1		
low → c. ɬəqʷ-ˈθat					1		1		
low d. ɬaqʷ-θat		W 2			L	W 1	W 2		W 1
low e. ɬəqʷ-θət			W 1	W 1	L	W 1	W 2		
f. ɬəqʷ-θət	W 1			W 1	L		W 2	W 1	
low → g. ɬəqʷ-ˈθat					1		1		

When the root contains a vowel other than schwa, it attracts primary stress, as the tableaux in (25) illustrate with /kʷes-θat/ → [ˈkʷas-θət] 'become hot (weather)' (23b.i). The first two steps improve on $*-\Delta_\omega \geq \{i,u\}$: first, the leftmost vowel is stressed (25b), and then the [low] feature is delinked from the suffix (25f). In the first step, assigning stress to either vowel removes one violation of $*-\Delta_\omega \geq \{i,u\}$, and Align-L(ˈσ) prefers that the root vowel is stressed (25b). Other than deleting the [low] feature in the second step, which is ruled out by MaxLinked(low), only delinking it improves on $*-\Delta_\omega \geq \{i,u\}$. The floating [low] feature is then linked to the root vowel in the third step (25h), satisfying *Float and [low]→ˈσ. Deletion would also satisfy these constraints, but is ruled out because Max(low) dominates Dep(link) (25i). The derivation converges in the fourth step with the [low] feature on the root vowel.

(25)

low low

kʷes-θat → ˈkʷas-θət, as delinking+linking

low kʷes-θat	$*{-}\Delta_\omega \geq \{i,u\}$	*Float	Max(link)	Align-L(ˈσ)	[low]→ˈσ	$*{-}\Delta_\omega \geq ə$	Max(low)	Dep(link)
low a. kʷes-θat	W 2				1	W 2		
low → b. ˈkʷes-θat	1				1	1		
low c. kʷes-ˈθat	1			W 1	L	1		
low d. ˈkʷes-θat	W 1	L	L		1	1		
low e. ˈkʷas-θat	W 1	L	L		L	1		W 1
low → f. ˈkʷes-θət		1	1		1	1		
low g. ˈkʷes-θət		W 1			W 1	1		L
low → h. ˈkʷas-θət						1		1
i. ˈkʷes-θət						1	W 1	L
low → j. ˈkʷas-θət						1		

The feature [low] can only shift onto the mid vowel /e/; it deletes in words with stressed low vowels (26a), high vowels (26b, c), and schwa (26d). Unlike high tones in Kibondei and moras in Logoori, the [low] feature cannot remain floating; it must delete. As discussed below, this motivates the bifurcation of Max(low) into two constraints.

(26) *[low] does not shift onto vowels other than /e/* (Suttles 2004: 244, 246, 382)

(a)	(i)	$\text{n}\overset{\substack{\text{low}\\ \vert}}{\text{a}}\text{s-θ}\overset{\substack{\text{low}\\ \vert}}{\text{a}}\text{t} \rightarrow \text{ˈn}\overset{\substack{\text{low}\\ \vert}}{\text{a}}\text{s-θət}$	‘get fat’
	(ii)	$\text{t}\overset{\substack{\text{low}\\ \vert}}{\text{a}}\text{s-t}\overset{\substack{\text{low}\\ \vert}}{\text{a}}\text{l}^{ʔ} \rightarrow \text{ˈt}\overset{\substack{\text{low}\\ \vert}}{\text{a}}\text{s-təl}^{ʔ}$	‘collide’
(b)	(i)	$\text{hiːl-θ}\overset{\substack{\text{low}\\ \vert}}{\text{a}}\text{t} \rightarrow \text{ˈhiːl-θət}$	‘let oneself fall’
	(ii)	$\text{tiq}^{w}\text{’-t}\overset{\substack{\text{low}\\ \vert}}{\text{a}}\text{l}^{ʔ} \rightarrow \text{ˈtiq}^{w}\text{’-təl}^{ʔ}$	‘collide’
(c)	(i)	$\text{k}^{w}\text{əʃu-θ}\overset{\substack{\text{low}\\ \vert}}{\text{a}}\text{t} \rightarrow \text{k}^{w}\text{əˈʃu-θət}$	‘pig-self’
(d)	(i)	$\text{t͡sə-θ}\overset{\substack{\text{low}\\ \vert}}{\text{a}}\text{t} \rightarrow \text{ˈt͡sə-θət}$	‘approach’
	(ii)	$\text{x}^{w}\text{t͡səməs-t}\overset{\substack{\text{low}\\ \vert}}{\text{a}}\text{l}^{ʔ} \rightarrow \text{ˈx}^{w}\text{t͡səməs-təl}^{ʔ}$	‘meet one another’

The tableaux in (27) illustrate [low] deletion with a stressed high vowel in /hiːl-θat/ → [ˈhiːl-θət] ‘let oneself fall’ (26b.i). The first two steps of the derivation are identical to those in (25): primary stress is assigned to the root (27b) and the [low] feature is delinked from the suffix (27d). In the third step, however, the floating [low] feature is deleted (27g) rather than being linked to the stressed vowel (27f). The latter is ruled out by *[high, low] which penalizes segments that are specified as both high and low. The derivation converges in the fourth step.

(27)

low
│
hiːl-θat → 'hiːl-θət

low │ hiːl-θat	$*{-}\Delta_\omega \geq \{i,u\}$	*Float	Max(link)	[low]→'σ	*[high, low]	$*{-}\Delta_\omega \geq ə$	Max(low)	Dep(link)
low │ a. hiːl-θat	W 2			1		W 2		
low │ → b. 'hiːl-θat	1			1		1		
low │ c. 'hiːl-θat	W 1	L	L	1		1		
low → d. 'hiːl-θət		1	1	1		1		
low e. 'hiːl-θət		W 1		W 1		1	L	
low ╱ f. 'hiːl-θət					W 1	1	L	W 1
→ g. 'hiːl-θət						1	1	
→ h. 'hiːl-θət						1		

To prevent [low] from shifting onto schwa as in /t͡sə-θat/ → ['t͡sə-θət] *['t͡sa-θət] 'approach' (26d.i), it must be deleted before stress is assigned. This is modeled by dividing stress assignment across two steps, one which stresses full vowels and one which stresses schwa, and ordering [low] delinking between them (see Elfner 2016 for discussion of phenomena where stress assignment must be ordered between segmental processes). The tableaux in (28) illustrate this with the derivation of ['t͡sə-θət]. The stress pattern of this word is unexpected given words like [ɬəq^{w}-'θat] 'get all wet' (23a.i), where the full vowel attracts primary stress. A lexically indexed constraint (Pater 2007, 2009) is employed to differentiate these words, which penalizes words that bear the index II and assign primary stress to an affix: *StressedAffix$_{\text{II}}$. If this exceptionality is associated to the root, then the index must propagate up to the word level (Jurgec & Bjorkman

2018). However, this appears to be construction-specific, as other roots do not uniformly block affix stress; compare [ˈjəθ-əs-t] 'tell him', which attracts stress away from the recipient suffix /-as/, another locus of [low] shift, with [jəθəs-ˈt-alə] 'tell-TR-you(PL)' (Suttles 2004: 240, 477). Formalization aside, *STRESSEDAFFIX$_{\text{II}}$ blocks stress from being assigned to the suffix (28c). Because the low vowel cannot be stressed, the [low] feature is delinked, lowering its sonority, and satisfying $*{-}\Delta_{\omega} \geq \{\text{i,u}\}$ (28d); deletion is ruled out by MAXLINKED(low). Stressing the root vowel improves on $*{-}\Delta_{\omega} \geq$ ə, which penalizes all vowels that are not the DTE of the word, but because this constraint is low ranked, it is not yet active (28b). The [low] feature is deleted in the second step, satisfying *FLOAT and [low]→ˈσ (28h). Because neither vowel is stressed, linking the [low] feature fatally violates $*{-}\Delta_{\omega} \geq \{\text{i,u}\}$ by needlessly increasing their sonority (28f, g). Finally, the leftmost schwa is stressed, improving on $*{-}\Delta_{\omega} \geq$ ə (28j), and the derivation converges in the fourth step.

(28)

low
|
t͡sə-θat → 't͡sə-θət

low | t͡sə-θat II	$*-\Delta_\omega \geq \{i,u\}$	*StressedAffix$_{II}$	*Float	Max(link)	Align-L('σ)	[low]→'σ	$*-\Delta_\omega \geq ə$	Max(low)	Dep(link)
low | a. t͡sə-θat	W 1		L	L		1	2		
low | b. 't͡sə-θat	W 1		L	L		1	L 1		
low | c. t͡sə-'θat		W 1	L	L	W 1	L	L 1		
low → d. t͡sə-θət			1	1		1	2		
low e. t͡sə-θət			W 1			W 1	2	L	
low / f. t͡sa-θət	W 1					W 1	2	L	W 1
low | g. t͡sə-θat	W 1					W 1	2	L	W 1
→ h. t͡sə-θət							2	1	
i. t͡sə-θət							W 2		
→ j. 't͡sə-θət							1		
→ k. 't͡sə-θət							1		

If the [low] feature was not deleted before stress was assigned, nothing would block the grammar from linking it to the root vowel, yielding the wrong output *['t͡sa-θət]. This motivates bifurcating Max(low) into two constraints: the general Max(low) and the specific MaxLinked(low). The latter is ranked high enough to allow [low] features to float rather than being deleted directly off of vowels, and the former is crucially ranked low enough to allow floating features to delete when they cannot be linked. This is impossible with a single Max(low) constraint, as the support in (29) summarizes.

(29) *A ranking paradox with a unified MAX(low) constraint*

	*FLOAT	[low]→ˈσ	MAX(low)
low a. ˈkʷes-θət (100i) ∼ ˈkʷes-θət (100j)	L	L	W
low b. t͡sə-θət (28h) ∼ t͡sə-θət (28e)	W	W	L

To summarize the analysis above, low vowels must be stressed to surface faithfully. Otherwise, the [low] feature is delinked. If it can link to a stressed mid vowel, it does, and otherwise, it is deleted. Shift in Halkomelem is thus derived as delinking+linking. Other suffixes, including /-aqʷ/ ‘head’ and the attributive /-aʔɬ/ exceptionally block [low] from delinking, and license it by linking it to a stressed vowel; the examples in (30) illustrate. In these examples, the position of the stress marker follows Bianco (1996) in assuming that onset clusters are maximally composed of two plosives. As expected, these suffixes surface faithfully when they attract primary stress (30a). When they do not, instead of reducing to schwa, the suffixes surface with low vowels (30b–e). When the stressed vowel is [e] or [ə], the [low] feature is linked to it, lowering it to [a] (30d, e). As with [low] shift, there are exceptions, such as [ˈχəɬ-aqʷ] ‘have a headache’ (Suttles 2004: 312).

(30) *Exceptional suffixes that retain [low]* (Suttles 2004: 21, 187, 268–269, 289, 293–294)

low
(a) (i) nəˈw-aqʷ-cəs-tən ‘thimble’

low
(ii) sɬənəˈj-aʔɬ ʃˈxʷqʷəltən ‘woman’s word, women’s language’

low low
(b) (i) ˈstᶿʼamˀ-aqʷ ‘skull’

low low
(ii) sˈnat͡sʼ-aʔɬ ˈqʷʼeχt ‘someone else’s “claim” (e.g., wapato pond)’

low
(c) (i) ˈɬit͡sʼ-aqʷ ‘cut one’s hair’

low
(ii) s-ˈjix-aʔɬ ‘southern or Puget Sound canoe type’

low low
(d) (i) t͡ɬʼeqt-aqʷ → ˈt͡ɬʼaqt-aqʷ ‘high (of a mountain)’

low low
(ii) sjəwenˀ-aʔɬ ʃxʷqʷeləwən → sjəˈwanˀ-aʔɬ ʃˈxʷqʷeləwən

‘old people’s ways of thinking’

low low
(e) (i) s-χəlt͡sʼ-aqʷ → ˈs-χalt͡sʼ-aqʷ ‘silly, crazy’

While the exceptional behavior of the attributive could be explained by the phonotactic restriction against [əʔ] (see Gietz et al. 2023: 43 for discussion), this is unlikely for the suffix /-aqʷ/, which Suttles (2004) usually transcribes without a glottal stop (see, e.g., page 312). Instead, the exceptional behavior of these suffixes is modeled by a lexically indexed constraint against delinking [low], MAX(link)$_{\text{I}}$. The tableaux in (31) illustrate /-aqʷ/ surfacing faithfully in [ˈstᶿʼamˀ-aqʷ] ‘skull’ (30b.i). In the first step, the root vowel is stressed, improving on $*{-}\Delta_{\omega} \geq \{\text{i,u}\}$ (31b), and the derivation converges in the second step (31c). Delinking (31d) or deleting the [low] feature from the suffix would satisfy $*{-}\Delta_{\omega} \geq \{\text{i,u}\}$, but is ruled out by MAX(link)$_{\text{I}}$.

(31)

low low low low
st$^{\theta}$’am$^{\text{ʔ}}$-aq^{w} → 'st$^{\theta}$’am$^{\text{ʔ}}$-aq^{w}

low low st$^{\theta}$’am$^{\text{ʔ}}$-aq^{w} I	Max(link)$_{I}$	$*\text{–}\Delta_{\omega} \geq \{i,u\}$	*Float	Max(link)	[low]→'σ	$*\text{–}\Delta_{\omega} \geq ə$
low low a. st$^{\theta}$’am$^{\text{ʔ}}$-aq^{w}		W 2			W 2	W 2
low low → b. 'st$^{\theta}$’am$^{\text{ʔ}}$-aq^{w}		1			1	1
low low → c. 'st$^{\theta}$’am$^{\text{ʔ}}$-aq^{w}		1			1	1
low low d. 'st’$^{\theta}$am$^{\text{ʔ}}$-əq^{w}	W 1	L	W 1	W 1	1	1

Along similar lines, Max(link)$_{I}$ prevents [low] from shifting onto a stressed mid vowel. The tableaux in (32) illustrate with the derivation of ['t͡ɬaqt-aq^{w}] ‘high (of a mountain)’ (30d.i). After the root vowel is stressed in the first step (32b), the [low] feature is linked to it (32d). This licenses the [low] feature, satisfying [low]→'σ. Delinking (32e) or deleting the [low] feature is blocked by Max(link)$_{I}$ in this step, and in the next step (32g), where the derivation converges (32f).

(32)

low   low
| /|
t͡ɬ’eqt-aqʷ → ˈt͡ɬ’aqt-aqʷ

low | t͡ɬ’eqt-aqʷ I	Max(link)$_I$	$*{-}\Delta_\omega \geq \{i,u\}$	*Float	Max(link)	[low]→ˈσ	$*{-}\Delta_\omega \geq ə$	Dep(link)
low | a. t͡ɬ’eqt-aqʷ		W 2			1	W 2	
low | → b. ˈt͡ɬ’eqt-aqʷ		1			1	1	
low | c. ˈt͡ɬ’eqt-aqʷ		1			W 1	1	L
low /| → d. ˈt͡ɬ’aqt-aqʷ		1				1	1
low e. ˈt͡ɬ’eqt-əqʷ	W 1	L	W 1	W 1	W 1	1	L
low /| → f. ˈt͡ɬ’aqt-aqʷ		1				1	
low / g. ˈt͡ɬ’aqt-əqʷ	W 1	L		W 1		L	

The analysis models [low] shift as delinking+linking and extends to exceptional forms that license [low] through linking alone. Unlike Kibondei high tones and Logoori moras, I agree with Gietz et al. (2023) that unlicensed [low] features must be deleted. Otherwise, they are expected incorrectly to link to stressed schwas. However, this does not necessitate a single-step shift operation. As the present analysis demonstrates, it suffices to bifurcate Max(F) into a general constraint and a specific constraint that penalizes deleting linked features, MaxLinked(F). Furthermore, the analysis Gietz et al. (2023) present cannot account for [low] shift across intervening vowels.

As discussed above, [low] shifts onto stressed mid vowels even when a vowel intervenes. Intervening vowels are not limited to schwa, as the examples in (33) illustrate. Gietz et al.’s analysis has [low] shift onto an adjacent stressed mid vowel and deleting otherwise (except when blocked, as with the exceptional suffixes in 30). The ranking arguments of their analysis are summarized in the support in (34); candidates are taken from tableaux 26 and 39 on pages 41 and 48, respectively.

(33) *[low] shift across a lexical vowel* (Hukari & Peter 1995: 91, 100)

low low
(a) teʔmil-θat → ˈtaʔməl-θət ‘cool off’

low low
(b) t’epiʔ-θat → ˈt’apiʔ-θət ‘rot (go rotten, of a log)’

(34) *Skeletal basis of the analysis in* Gietz et al. (2023)

	*Unstressed/a	*Float	Max[+low]	Ident
low a. ˈnat͡s’-θət ~ ˈnet͡s’-θət			W	L
low low low b. ˈpaj-θət ~ ˈpaj-θət		W	L	
low low low c. ˈpaj-θət ~ ˈpaj-θat	W		L	L

The problems examples like those in (33) present for their analysis are that linking or shifting the suffix [low] onto the intervening vowel is not harmonically improving, and delinking but not deleting [low] contradicts their ranking. The former problem is illustrated in the tableau in (35). Linking (35b) or shifting the [low] feature (35c) onto the intervening vowel does not improve on any phonotactic constraint, and is harmonically bounded by the fully faithful candidate (35a). The latter problem is illustrated in the support in (36). If the delinking candidate is chosen as optimal, Max[+low] must dominate *Float, contradicting the ranking established in (34). In order to preserve the [low] feature and link it across the intervening vowel in a future step, the grammar cannot delete [low] features, yielding floating features that Gietz et al. specifically argue their analysis avoids (pp. 46–48). This can be remedied by bifurcating Max, as above, but doing so eliminates any explanatory power gained by positing a single-step shift operation. Thus, as with Kibondei, not only is it not necessary to posit a single-step shift operation to model [low] shift in Halkomelem, but the analysis Gietz et al. (2023)

present in support of doing so is empirically inadequate. Once again, it is not my claim that every analysis of Halkomelem with a single-step shift operation fails, but Gietz et al.'s does.

(35) *The fully faithful candidate harmonically bounds linking or shifting [low] onto the intervening vowel*

low ˈteʔməl-θat	*Unstressed/a	*Float	Max[+low]	Ident
a. low ˈteʔməl-θat	1			
☹ b. low ˈteʔmal-θat	2			1
☹ c. low ˈteʔmal-θət	1			2
d. low ˈteʔməl-θət		1		1
e. ˈteʔməl-θət			1	1

(36) *Delinking but not deleting the [low] feature yields a ranking paradox*

	*Unstressed/a	*Float	Max[+low]	Ident
a. low ˈteʔməl-θət ~ ˈteʔməl-θət		L	W	
b. low ~ low low ˈpaj-θət ~ ˈpaj-θət		W	L	

4. Typology

The previous two sections demonstrate that, at least for Kibondei and Halkomelem, positing a single-step shift operation is superfluous. Further, the analyses Gietz et al. (2023) offer for these languages are not empirically adequate. This section turns to a typological perspective on shift. It demonstrates that, instead of increasing empirical coverage, a single-step shift operation actually makes it impossible to model attested patterns.

Following the typological modeling in Gietz et al. (2023: 48–53), typologies of Kibondei-like systems were calculated with and without a single-step shift operation (the Python scripts used in the calculation are available online at https://github.com/aphonologist/hs-shift). As in the analyses above, Gen was able to delete features, remove autosegmental links to features, and add autosegmental links to features. One typology additionally allowed Gen to model shift in a single step. Con comprised the faithfulness constraints Max(link), Dep(link), Max(F), and Max-Linked(F), and the phonotactic constraints *Float, *Link(F), *F], and Align-R (definitions of these constraints are given in Appendix E). Both typologies were run on six inputs, which each contained five segments (or F-bearing units more generally). One input contained a floating feature, and the other five contained one feature linked to one segment.

In total, the two typologies produced 38 languages; 27 were shared between them. The typology calculated without a single-step shift operation included an additional five languages, and the typology calculated with it included an additional four languages. Surprisingly, the typology with more operations available to Gen was smaller (31 languages) than the more restricted typology (32 languages). The table in (37) summarizes the typologies in terms of input–output mappings (see Appendix E for the constraint rankings). Language numbers in bold were only produced in the typology without a single-step shift operation, and those that are underlined were only produced in the typology with one. Double arrows ⇒ indicate spreading, and single arrows → indicate shifting; delinked features float in the output.

(37) *The typology as input-output mappings*

	Pre-penult	Penult	Final	Floating
(1)	⇒final	⇒final	faithful	→final
(2)	⇒final	⇒final	faithful	delete
(3)	⇒final	⇒final	faithful	faithful
(4)	→final	⇒final	faithful	→final
(5)	→final	→final	faithful	→final
(6)	→final	→final	faithful	delete
(7)	⇒penult	faithful	→penult	→penult
(8)	⇒penult	faithful	→penult	delete
(9)	⇒penult	faithful	delink	faithful

(10)	⇒penult	faithful	delete	→penult
(11)	⇒penult	faithful	delete	delete
(12)	⇒penult	faithful	faithful	→penult
(13)	⇒penult	faithful	faithful	delete
(14)	⇒penult	faithful	faithful	faithful
(15)	→penult	faithful	→penult	→penult
(16)	→penult	faithful	→penult	delete
(**17**)	→penult	faithful	delete	→penult
(**18**)	→penult	faithful	delete	delete
(**19**)	→penult	faithful	faithful	→penult
(**20**)	→penult	faithful	faithful	delete
(21)	delink	⇒final	faithful	faithful
(22)	delink	delink	delink	faithful
(23)	delink	delink	faithful	faithful
(24)	delete	⇒final	faithful	→final
(25)	delete	⇒final	faithful	delete
(26)	delete	→final	faithful	→final
(27)	delete	→final	faithful	delete
(28)	delete	delete	faithful	delete
(29)	delete	delete	delete	delete
(30)	faithful	faithful	→penult	→penult
(31)	faithful	faithful	→penult	delete
(32)	faithful	faithful	delink	faithful
(**33**)	faithful	faithful	delete	→penult
(34)	faithful	faithful	delete	delete
(35)	faithful	faithful	faithful	→final
(36)	faithful	faithful	faithful	→penult
(37)	faithful	faithful	faithful	delete
(38)	faithful	faithful	faithful	faithful

For a more compact representation, the table in (38) summarizes the typology in terms of the possible outputs of a given grammar. In other words, it represents the sets of phonotactically well-formed strings. In this table, Ø represents a segment (or F-bearing unit) not linked to a feature, and F represents a segment linked to a feature. The numerical notation is taken from Chomsky & Halle (1968); F^n_m denotes the set of strings composed of the symbol F of at least length m and at most length n. From this perspective, it is clear that positing a single-step shift operation is unnecessary. The four languages uniquely produced in that typology (8, 16, 24, 31) are produced without a single-step shift operation. Further, no grammar with a single-step shift operation can model languages that only allow a feature on the penultimate or final segment (38.vii); this pattern is uniquely produced without such an operation (**19**, **20**). Because it is attested, grammars with a single-step shift operation undergenerate.

(38) *The typology as sets of output forms*

(i)	Long span at end	$\varnothing_0 F_0$	1, 2, 3
(ii)	Short span at end	$\varnothing_0 F_0^2$	4, 21, 24, 25
(iii)	Long span at penult	$\varnothing_0 F_0 \varnothing$	7, 8, 9, 10, 11
(iv)	Long span at penult or singleton at end	$\varnothing_0 F_0 \varnothing \cup \varnothing_0 F$	12, 13, 14
(v)	Singleton anywhere	$\varnothing_0 F_0^1 \varnothing_0$	35, 36, 37, 38
(vi)	Singleton non-finally	$\varnothing_0 F_0^1 \varnothing$	30, 31, 32, **33**, 34
(vii)	Singleton at penult or end	$\varnothing_0 F_0^1 \varnothing_0^1$	**19**, **20**
(viii)	Singleton at end	$\varnothing_0 F_0^1$	5, 6, 23, 26, 27, 28
(ix)	Singleton at penult	$\varnothing_0 F_0^1 \varnothing$	15, 16, **17**, **18**
(x)	No features	$\varnothing_0$	22, 29

One language that attests this pattern (38.vii) is Wolaitta (Omotic; Amha 1996). With the exception of words with historically frozen suffixes, bare nouns and adjectives in the language all have a single high tone associated either to the final syllable (39(i)) or the penult (39(ii)).

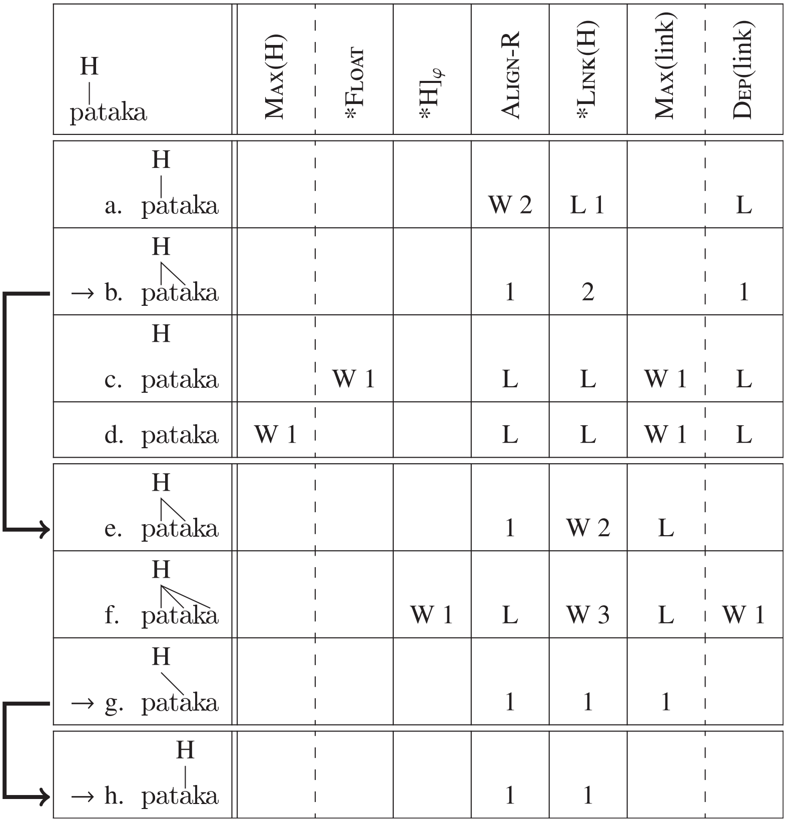
(39) *Final (i) and penultimate (ii) tone in Wolaitta* (Amha 1996: 115–116)

(a)	(i) zar$\overset{\text{H}}{\text{e}}$	‘lizard’	(ii) z$\overset{\text{H}}{\text{a}}$re	‘relative’
(b)	(i) ʃoor$\overset{\text{H}}{\text{o}}$	‘neighbour’	(ii) si$\overset{\text{H}}{\text{i}}$re	‘nose’
(c)	(i) miʃir$\overset{\text{H}}{\text{a}}$	‘bride’	(ii) nam$\overset{\text{H}}{\text{i}}$sa	‘hunger’
(d)	(i) karaab$\overset{\text{H}}{\text{e}}$	‘drum’	(ii) mala$\overset{\text{H}}{\text{a}}$ta	‘sign’

Assuming richness of the base (Prince & Smolensky 1993/2004), the grammar of Wolaitta must map any underlying form with one high tone onto an output, where the high tone is associated to one of the two final syllables. The grammar illustrated below (40)–(41), minimally different from that for Kibondei, does exactly that. A hypothetical input with an initial high tone (40a) surfaces with penultimate tone (40h), having linked it to the penult (40e) and then removed the underlying association (40g). Words with underlyingly final high tones, such as [miʃirá] ‘bride’ (39c.i), surface faithfully (41a). Delinking the high tone satisfies $*\text{H}]_{\varphi}$, but violates the higher ranked *Float (41b), and deleting it violates the high ranked

Max(H) (41c). Thus, underlyingly final tones surface in situ and all others shift to the penult.

(40) *Shift to penult in Wolaitta as linking+delinking (hypothetical)*



H pataka	Max(H)	*Float	*H]$_\varphi$	Align-R	*Link(H)	Max(link)	Dep(link)
H a. pataka				W 2	L 1		L
H → b. pataka				1	2		1
H c. pataka		W 1		L	L	W 1	L
d. pataka	W 1			L	L	W 1	L
H e. pataka				1	W 2	L	
H f. pataka			W 1	L	W 3	L	W 1
H → g. pataka				1	1	1	
H → h. pataka				1	1		

(41) *Final high tones surface faithfully*

<table>
<tr><th>H
|
miʃira</th><th>Max(H)</th><th>*Float</th><th>*H]$_\varphi$</th><th>*Link(H)</th><th>Max(link)</th></tr>
<tr><td>H
|
→ a. miʃira</td><td></td><td></td><td>1</td><td>1</td><td></td></tr>
<tr><td>H
b. miʃira</td><td></td><td>W 1</td><td>L</td><td>L</td><td>W 1</td></tr>
<tr><td>c. miʃira</td><td>W 1</td><td></td><td>L</td><td>L</td><td>W 1</td></tr>
</table>

All six languages that shift pre-penultimate features to the penult (15, 16, **17**, **18**, **19**, **20**) share the ranking *F] ≫ Align-R ≫ Dep(link), Max(link). If Gen is able to shift a feature in one step, it is impossible to keep final features in place under this ranking, as the tableau in (42) illustrates. By shifting the high tone onto the penult, the unintended winner satisfies *H]$_\varphi$ without violating a higher ranked constraint (42b).

(42) *Final high tones cannot surface faithfully with a single-step shift operation*

<table>
<tr><th>H
|
miʃira</th><th>*H]$_\varphi$</th><th>Align-R</th><th>Dep(link)</th><th>Max(link)</th></tr>
<tr><td>H
|
☹ a. miʃira</td><td>W 1</td><td>L</td><td>L</td><td>L</td></tr>
<tr><td>H
|
→ b. miʃira</td><td></td><td>1</td><td>1</td><td>1</td></tr>
</table>

This problem is avoided by eschewing a single-step shift operation. As in Kibondei, regressive shift requires an intermediate step with a floating feature. Whether this is optimal is determined by the constraint ranking. Thus, requiring an intermediate step crucially shapes the typology, echoing arguments against parallel theories of Gen (McCarthy 2006, 2008b).

As a point of comparison, in their reported typologies, Gietz et al. (2023) do not allow features to float. As they point out (p. 49), their results do not reflect a complete typology, but a subset where *FLOAT is never dominated. Nevertheless, they spuriously conclude (pp. 51–53) that regressive shift to the penult is impossible without a single-step shift operation. Because regressive shift requires an intermediate optimum that violates *FLOAT, it is excluded from their typology not because GEN is too restrictive, but because they do not provide a full typology.

The results of this section support the conclusions drawn in the previous two sections. Not only is a single-step shift operation superfluous, grammars that assume it undergenerate with respect to the attested typology.

5. CONCLUSION

Like the content of CON, exactly what operations are available to GEN is an empirical question. Every Harmonic Serialism grammar in part poses hypotheses about the sets of constraints and operations. When the attested typology is only consistent with a superset or subset of the assumed operations, it is necessary to change our hypothesis of what comprises GEN.

With respect to shift, an input–output mapping where a feature associated with some segment loses its underlying association and surfaces associated to another segment, McCarthy (2006, 2008b) argues that it is empirically adequate to restrict GEN to create or remove one autosegmental link per step. Gietz et al. (2023), however, argue that that approach is infeasible and propose that GEN must also include a single-step shift operation. This paper refutes their arguments and supports the more restrictive hypothesis of GEN. The analyses of shift in Kibondei and Halkomelem above do not rely on a single-step shift operation and adequately model the data. Gietz et al.'s analyses, on the other hand, do not stand up to scrutiny and do not make a convincing argument in favor of a single-step shift operation. Furthermore, typological modeling reveals that a single-step shift operation reduces the empirical adequacy of Harmonic Serialism, rather than increasing it. I conclude that the more restricted operation set is empirically superior to the superset proposed by Gietz et al. (2023).

A. KIBONDEI APPENDIX

This appendix presents the full analysis of Kibondei; that is more tableaux are included here than in the text of the paper and tableaux include more candidates. Harmonically bounded candidates in tableaux are grayed out.

The GEN function is based on Lamont (2022a, b): it can delete any tone (linked or floating),[5] remove the leftmost/rightmost link of a tone, add a local link, and link a floating tone to any syllable. These operations are restricted by the No Crossing Constraint (Goldsmith 1976). As a simplification, I do not include candidates where a high tone is linked to a syllable that is already linked to a high tone. Lamont

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[5] Because deletion is never optimal in the analysis, Kibondei is not informative on the exact nature of autosegmental deletion.

(2022a, b) allows this operation and automatically fuses the two high tones. This can be avoided by including a faithfulness constraint against fusion.

The constraints used in the analysis are defined below (43–52). Their ranking is represented in the Hasse diagram immediately following (53).

(43) MAX(H): Assign one violation for every high tone deleted by GEN.

(44) MAX(link): Assign one violation for every autosegmental link deleted by GEN.

(45) DEP(link): Assign one violation for every autosegmental link inserted by GEN.

(46) ALIGN-R: For every high tone, assign one violation for every syllable that intervenes between the rightmost syllable associated to the high tone and the right end of the phonological phrase.

(47) *CONTOUR: Assign one violation for every syllable associated to more than one tone.

(48) CRISPEDGE-L: Assign one violation for every high tone associated to a syllable that precedes the leftmost segment of its corresponding morpheme.

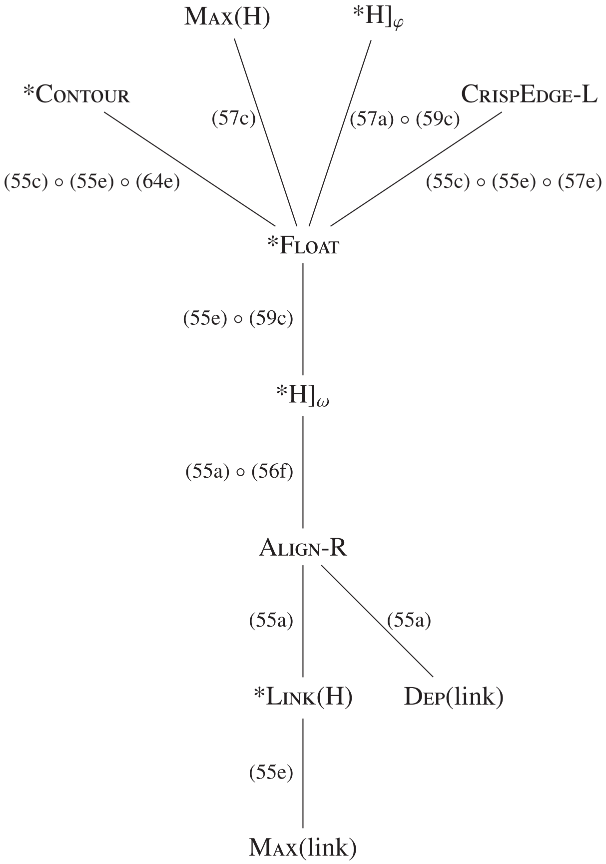
(49) *FLOAT: Assign one violation for every tone not linked to a syllable.

(50) *LINK(H): Assign one violation for every autosegmental link to a high tone.

(51) $*H]_{\varphi}$: Assign one violation for every high tone linked to a phrase-final syllable.

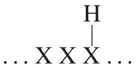
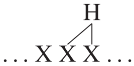
(52) $*H]_{\omega}$: Assign one violation for every high tone linked to a word-final syllable.

(53) *Hasse diagram for Kibondei*



As a further simplification, because regressive linking does not improve on any of the constraints (54), I exclude those candidates.

(54) *Regressive linking is not harmonically improving*

	Max(H)	*H]$_{\varphi}$	CrispEdge-L	*Contour	*Float	*H]$_{\omega}$	Align-R	Dep(link)	*Link(H)	Max(link)
→ a. 										
b. 			(W)	(W)		(W)		W	W	

The analysis ignores phrase-penultimate vowel lengthening and treats syllables as the tone-bearing units.

Tableaux included in this appendix:

Section A.1.1	No tableaux
Section A.1.2	/á-senga/ → [a-séːnga] ‘CL.1 is cutting’ (55) /á-senga ɲama/ → [a-sénga ɲaːma] ‘CL.1 is cutting meat’ (56)
Section A.1.3	No tableaux
Section A.2.1	/ku-dá/ → [kuː-da^{H}] ‘to eat’ (57)
Section A.2.2	/tí-dá/ → [tíː-da^{H}] ‘we ate’ (58)
Section A.2.3	/ni-a-dá n-k^{h}ooʃo/ → [n-a-da n-k^{h}oóːʃo] ‘I am eating cashew nuts’ (59–60) /ni-a-dá bamía/ → [n-a-da bám!ːa] ‘I am eating okra’ (61–62) /ku-dá n-k^{h}ánde/ → [ku-dá n-k^{h}!áːnde] ‘to eat food’ (63)
Section A.3.1	/ku-kòmá/ → [ku-kòːma^{H}] ‘to kill’ (64)
Section A.3.2	/á-kòmá/ → [á-kòːma^{H}] ‘CL.1 is killing’ (65)
Section A.3.3	/ka-kòmá twaɲika/ → [ka-kòma twaɲíːka] ‘CL.1 killed a snake’ (66–67) /ku-fisá héa/ → [ku-fisá h!éːa] ‘to hide money’ (68) /ni-a-tùngá ʃaíi/ → [n-a-tùnga ʃá!íːi] ‘I am composing a poem’ (69–70)
Section A.4.1	/ku-òmbéza/ → [ku-òmbéːza] ‘to ask for’ (71) /ku-hàgiá/ → [ku-hàgíːa] ‘to sweep’ (72)
Section A.4.2	/á-hàgiá/ → [á-hàgíːa] ‘CL.1 is sweeping’ (73–75)
Section A.4.3	/ni-a-òmbéza n-guo/ → [n-a-òmbéza n-guːo] ‘I am asking for clothes’ (76) /ka-hàgiá sakafu/ → [ka-hàgia sakáːfu] ‘CL.1 swept the floor’ (77–78)

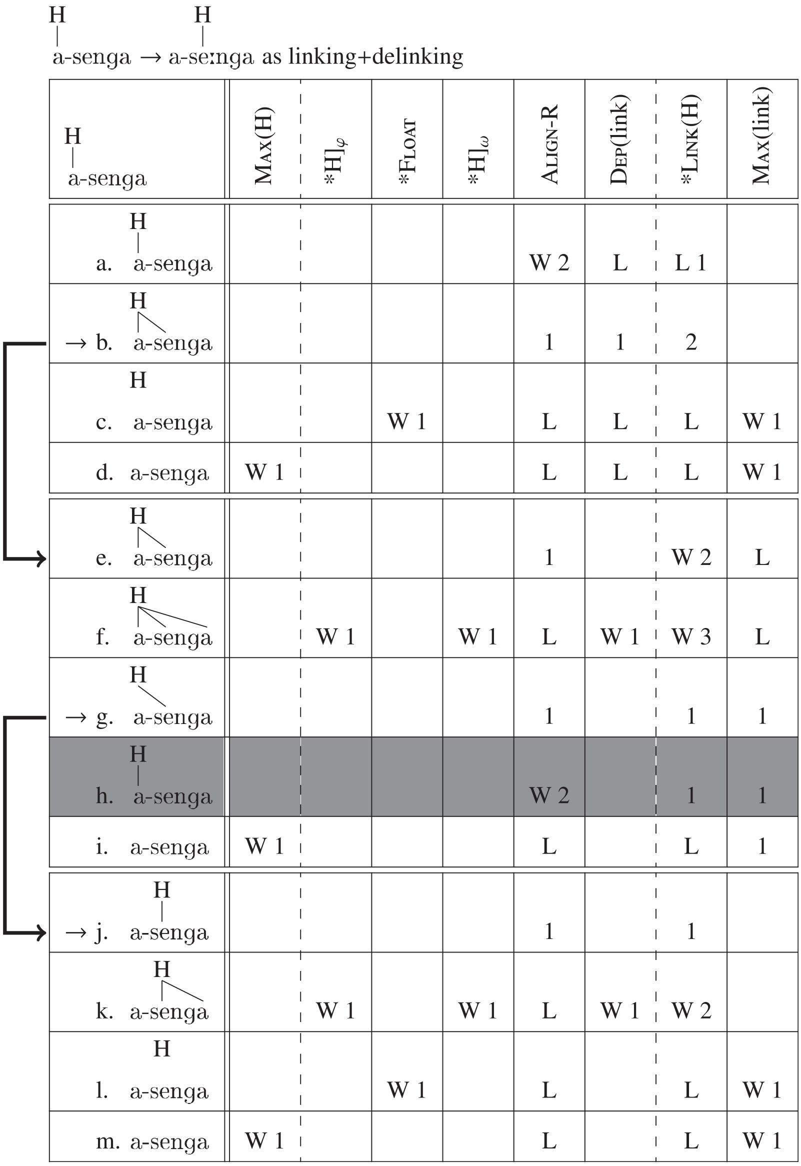
A.1. TONELESS VERBS

A.1.1. *Toneless prefix*

Because there is no motivation to insert a high tone, no tableaux are needed.

A.1.2. *High toned prefix*

(55)

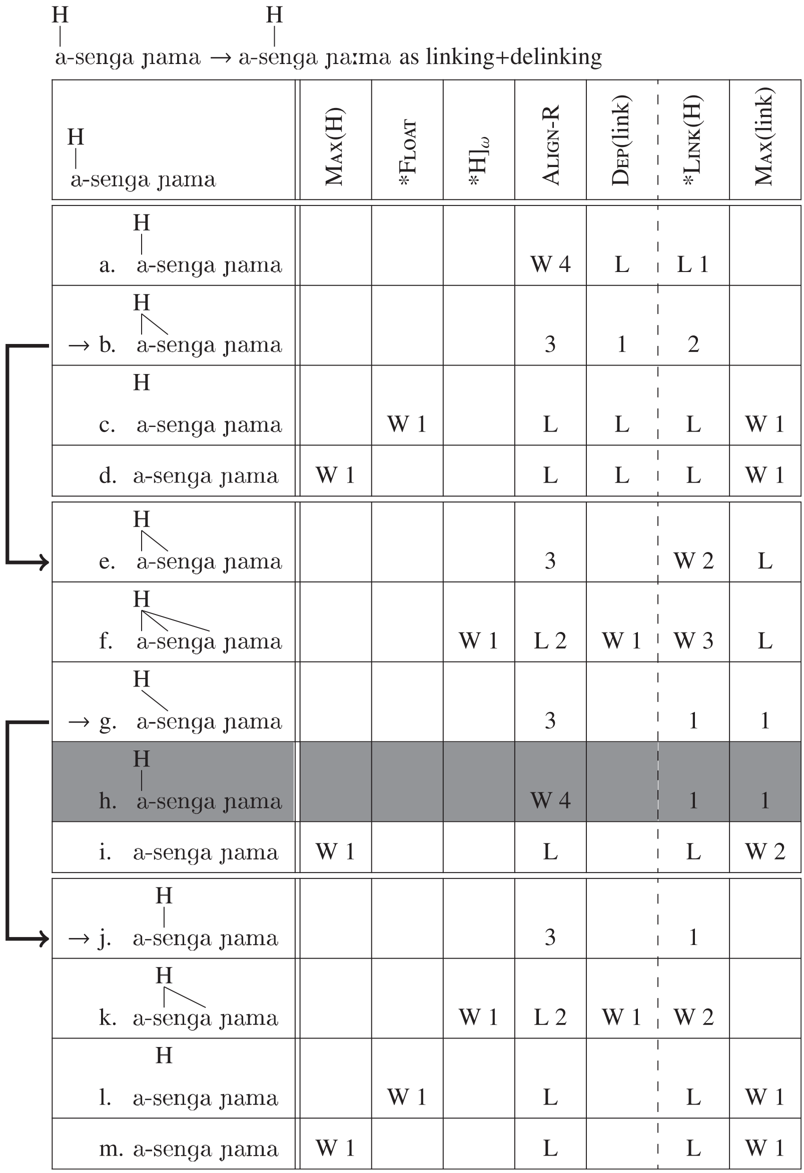


H H

a-senga → a-seːnga as linking+delinking

H a-senga	Max(H)	*H]$_\varphi$	*Float	*H]$_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
a. a-senga					W 2	L	L 1	
→ b. a-senga					1	1	2	
c. a-senga			W 1		L	L	L	W 1
d. a-senga	W 1				L	L	L	W 1
e. a-senga					1		W 2	L
f. a-senga		W 1		W 1	L	W 1	W 3	L
→ g. a-senga					1		1	1
h. a-senga					W 2		1	1
i. a-senga	W 1				L		L	1
→ j. a-senga					1		1	
k. a-senga		W 1		W 1	L	W 1	W 2	
l. a-senga			W 1		L		L	W 1
m. a-senga	W 1				L		L	W 1

(56)



H H

a-senga ɲama → a-senga ɲaːma as linking+delinking

H a-senga ɲama	MAX(H)	*FLOAT	*H]$_\omega$	ALIGN-R	DEP(link)	*LINK(H)	MAX(link)
H a. a-senga ɲama				W 4	L	L 1	
H → b. a-senga ɲama				3	1	2	
H c. a-senga ɲama		W 1		L	L	L	W 1
d. a-senga ɲama	W 1			L	L	L	W 1
H e. a-senga ɲama				3		W 2	L
H f. a-senga ɲama			W 1	L 2	W 1	W 3	L
H → g. a-senga ɲama				3		1	1
H h. a-senga ɲama				W 4		1	1
i. a-senga ɲama	W 1			L		L	W 2
H → j. a-senga ɲama				3		1	
H k. a-senga ɲama			W 1	L 2	W 1	W 2	
H l. a-senga ɲama		W 1		L		L	W 1
m. a-senga ɲama	W 1			L		L	W 1

A.1.3 *Phrase-medial*

Because there is no motivation to insert a high tone, no tableaux are needed.

A.2. MONOSYLLABIC VERBS

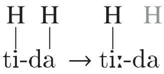
A.2.1. *Toneless prefix*

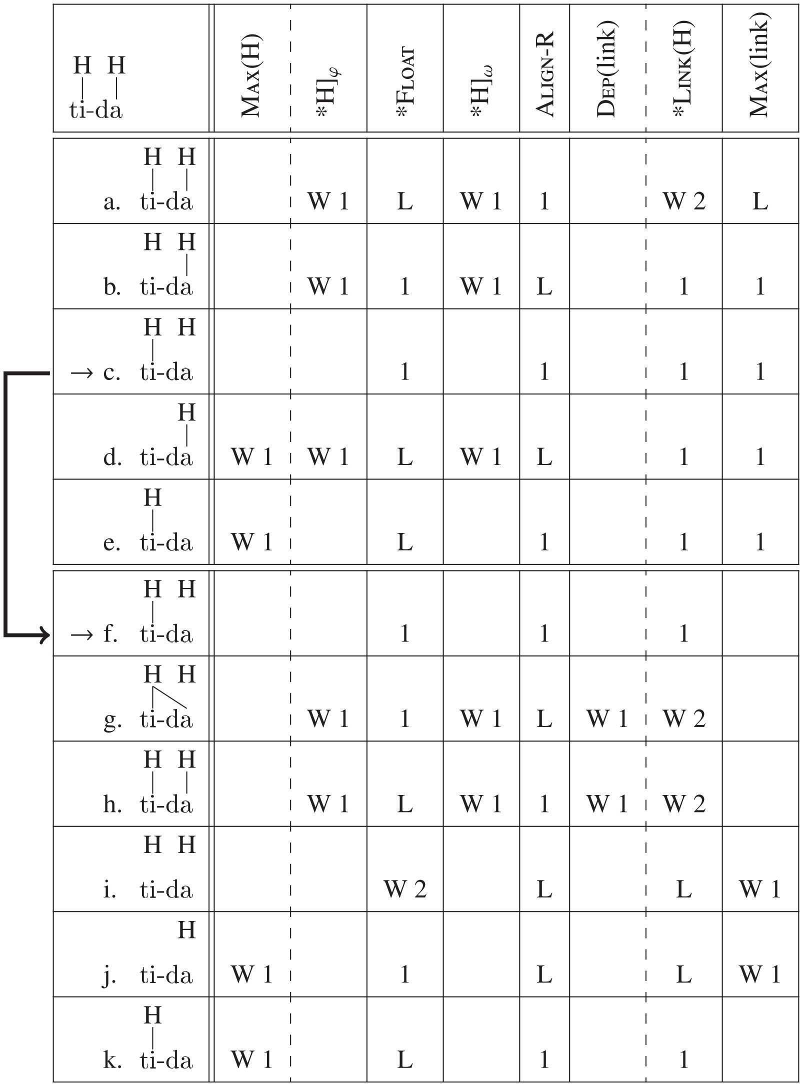
(57)
H   H
\|
ku-da → kuː-da

H | ku-da	Max(H)	$*H]_{\varphi}$	CrispEdge-L	*Float	$*H]_{\omega}$	Align-R	Dep(link)	*Link(H)	Max(link)
H | a. ku-da		W 1		L	W 1			W 1	L
H → b. ku-da				1					1
c. ku-da	W 1			L					1
H → d. ku-da				1					
H / e. ku-da			W 1	L		W 1	W 1	W 1	
H | f. ku-da		W 1		L	W 1		W 1	W 1	
g. ku-da	W 1			L					

A.2.2. *High toned prefix*

(58)





H H ti-da	Max(H)	*H]$_\varphi$	*Float	*H]$_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
a. H H ti-da		W 1	L	W 1	1		W 2	L
b. H H ti-da		W 1	1	W 1	L		1	1
→ c. H H ti-da			1		1		1	1
d. H ti-da	W 1	W 1	L	W 1	L		1	1
e. H ti-da	W 1		L		1		1	1
→ f. H H ti-da			1		1		1	
g. H H ti-da		W 1	1	W 1	L	W 1	W 2	
h. H H ti-da		W 1	L	W 1	1	W 1	W 2	
i. H H ti-da			W 2		L		L	W 1
j. H ti-da	W 1		1		L		L	W 1
k. H ti-da	W 1		L		1		1	

A.2.3. *Phrase-medial*

(59)

H H
ni-a-da n-k^{h}ooʃo → n-a-da n-k^{h}ooːʃo as linking+delinking, Steps 1-3

H ni-a-da n-k^{h}ooʃo	Max(H)	*Float	*H]$_{\omega}$	Align-R	Dep(link)	*Link(H)	Max(link)
H a. ni-a-da n-k^{h}ooʃo			1	W 3	L	L 1	
H → b. ni-a-da n-k^{h}ooʃo			1	2	1	2	
H c. ni-a-da n-k^{h}ooʃo		W 1	L	L	L	L	W 1
d. ni-a-da n-k^{h}ooʃo	W 1		L	L	L	L	W 1
H e. ni-a-da n-k^{h}ooʃo			W 1	2		W 2	L
H f. ni-a-da n-k^{h}ooʃo			W 1	L 1	W 1	W 3	L
H → g. ni-a-da n-k^{h}ooʃo				2		1	1
H h. ni-a-da n-k^{h}ooʃo			W 1	W 3		1	1
i. ni-a-da n-k^{h}ooʃo	W 1			L		L	1
H j. ni-a-da n-k^{h}ooʃo				W 2	L	L 1	
H → k. ni-a-da n-k^{h}ooʃo				1	1	2	
H l. ni-a-da n-k^{h}ooʃo		W 1		L	L	L	W 1
m. ni-a-da n-k^{h}ooʃo	W 1			L	L	L	W 1

(60)

H　　　　　　　　　　　H
|　　　　　　　　　　　|

ni-a-da n-kʰooʃo → n-a-da n-kʰooːʃo as linking+delinking, Step 4 and convergence

H |\\ ni-a-da n-kʰooʃo	Max(H)	$*\mathrm{H}]_{\varphi}$	*Float	$*\mathrm{H}]_{\omega}$	Align-R	Dep(link)	*Link(H)	Max(link)
n. H |\\ ni-a-da n-kʰooʃo					1		W 2	L
o. H |\\\\ ni-a-da n-kʰooʃo		W 1		W 1	L	W 1	W 3	L
→ p. H \\ ni-a-da n-kʰooʃo					1		1	1
q. H | ni-a-da n-kʰooʃo					W 2		1	1
r. ni-a-da n-kʰooʃo	W 1				L		L	W 2
→ s. H | ni-a-da n-kʰooʃo					1		1	
t. H |\\ ni-a-da n-kʰooʃo		W 1		W 1	L	W 1	W 2	
u. H ni-a-da n-kʰooʃo			W 1		L		L	W 1
v. ni-a-da n-kʰooʃo	W 1				L		L	W 1

(61)

H H → H↓H
ni-a-da bamia → n-a-da bamiːa as linking+delinking, steps 1-2

H H ni-a-da bamia	Max(H)	*H]φ	*Float	*H]ω	Align-R	Dep(link)	*Link(H)	Max(link)
H H a. ni-a-da bamia				1	W 4	L	L 2	
H H → b. ni-a-da bamia				1	3	1	3	
H H c. ni-a-da bamia		W 1		1	3	1	3	
H H d. ni-a-da bamia			W 1	L	L 1	L	L 1	W 1
H H e. ni-a-da bamia			W 1	1	3	L	L 1	W 1
H f. ni-a-da bamia	W 1			L	L 1	L	L 1	W 1
H g. ni-a-da bamia	W 1			1	3	L	L 1	W 1
H H h. ni-a-da bamia				W 1	3		W 3	L
H H i. ni-a-da bamia		W 1		W 1	L 2	W 1	W 4	L
H H → j. ni-a-da bamia					3		2	1
H H k. ni-a-da bamia				W 1	W 4		2	1
H H l. ni-a-da bamia			W 1	W 1	L 2		2	1
H m. ni-a-da bamia	W 1				L 1		L 1	W 2
H n. ni-a-da bamia	W 1			W 1	L 2		2	1

(62) ni-a-$\overset{\substack{\text{H}\\|}}{\text{da}}$ bam$\overset{\substack{\text{H}\\|}}{\text{i}}$a → n-a-da $\overset{\substack{\text{H}\\|}}{\text{ba}}m\overset{\substack{\downarrow\text{H}\\|}}{\text{iː}}$a as linking+delinking, convergence

ni-a-da $\overset{\substack{\text{H}\\|}}{\text{ba}}m\overset{\substack{\text{H}\\|}}{\text{i}}$a	Max(H)	*H]$_\varphi$	*Float	*H]$_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
→ o. ni-a-da $\overset{\substack{\text{H}\\|}}{\text{ba}}m\overset{\substack{\text{H}\\|}}{\text{i}}$a					3		2	
p. ni-a-da $\overset{\substack{\text{H}\\|}}{\text{ba}}m\overset{\substack{\text{H}\\|\ \backslash}}{\text{ia}}$		W 1		W 1	L 2	W 1	W 3	
q ni-a-da $\overset{\text{H}}{\text{ba}}m\overset{\substack{\text{H}\\|}}{\text{i}}$a			W 1		L 1		L 1	W 1
r. ni-a-da $\overset{\substack{\text{H}\\|}}{\text{ba}}m\overset{\text{H}}{\text{i}}$a			W 1		L 2		L 1	W 1
s. ni-a-da bam$\overset{\substack{\text{H}\\|}}{\text{i}}$a	W 1				L 1		L 1	W 1
t. ni-a-da $\overset{\substack{\text{H}\\|}}{\text{ba}}$mia	W 1				L 2		L 1	W 1

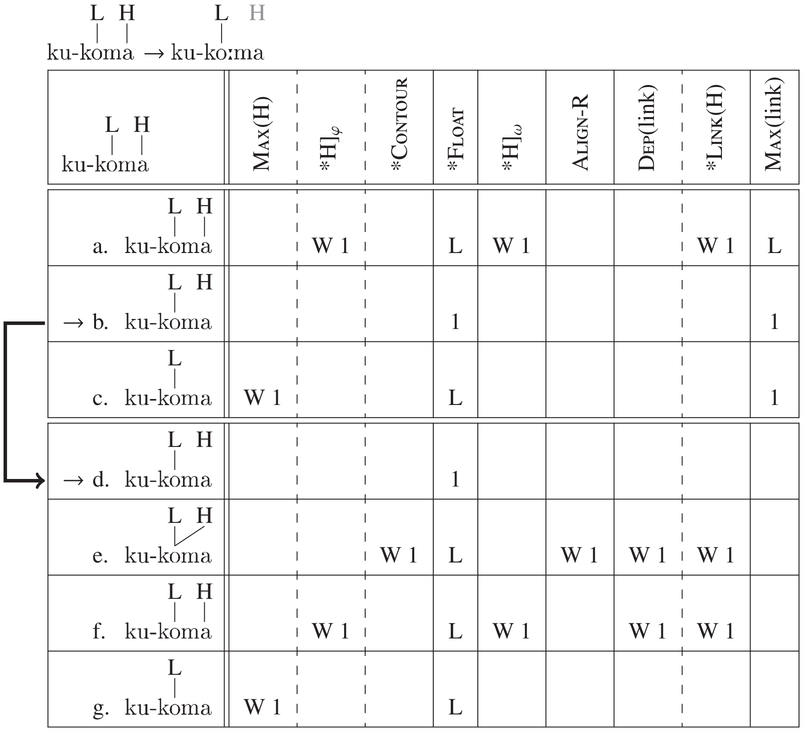
(63) $\text{ku-d}\overset{\text{H}}{\overset{|}{\text{a}}}\ \text{n-k}^{\text{h}}\overset{\text{H}}{\overset{|}{\text{a}}}\text{nde} \rightarrow \text{ku-d}\overset{\text{H}}{\overset{|}{\text{a}}}\ \text{n-k}^{\text{h}}\overset{{}^{\downarrow}\text{H}}{\overset{|}{\text{a}}}\text{ːnde}$

$\text{ku-d}\overset{\text{H}}{\overset{|}{\text{a}}}\ \text{n-k}^{\text{h}}\overset{\text{H}}{\overset{|}{\text{a}}}\text{nde}$	Max(H)	$*\text{H}]_{\varphi}$	*Float	$*\text{H}]_{\omega}$	Align-R	Dep(link)	*Link(H)	Max(link)
→ a. $\text{ku-d}\overset{\text{H}}{\overset{|}{\text{a}}}\ \text{n-k}^{\text{h}}\overset{\text{H}}{\overset{|}{\text{a}}}\text{nde}$				1	3		2	
b. $\text{ku-d}\overset{\text{H}}{\overset{|}{\text{a}}}\ \text{n-k}^{\text{h}}\overset{\text{H}}{\overset{|}{\text{a}}}\text{nd}\overset{\diagdown}{\text{e}}$		W 1		W 2	L 2	W 1	W 3	
c. $\text{ku-d}\overset{\text{H}}{\text{a}}\ \text{n-k}^{\text{h}}\overset{\text{H}}{\overset{|}{\text{a}}}\text{nde}$			W 1	L	L 1		L 1	W 1
d. $\text{ku-d}\overset{\text{H}}{\overset{|}{\text{a}}}\ \text{n-k}^{\text{h}}\overset{\text{H}}{\text{a}}\text{nde}$			W 1	1	L 2		L 1	W 1
e. $\text{ku-da}\ \text{n-k}^{\text{h}}\overset{\text{H}}{\overset{|}{\text{a}}}\text{nde}$	W 1			L	L 1		L 1	W 1
f. $\text{ku-d}\overset{\text{H}}{\overset{|}{\text{a}}}\ \text{n-k}^{\text{h}}\text{ande}$	W 1			1	L 2		L 1	W 1

A.3. DISYLLABIC VERBS

A.3.1. *Toneless prefix*

(64)

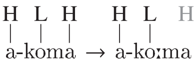


L H ku-koma → L H ku-koːma

L H ku-koma	Max(H)	$*H]_\varphi$	*Contour	*Float	$*H]_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
L H a. ku-koma		W 1		L	W 1			W 1	L
L H → b. ku-koma				1					1
L c. ku-koma	W 1			L					1
L H → d. ku-koma				1					
L H e. ku-koma			W 1	L		W 1	W 1	W 1	
L H f. ku-koma		W 1		L	W 1		W 1	W 1	
L g. ku-koma	W 1			L					

A.3.2. *High toned prefix*

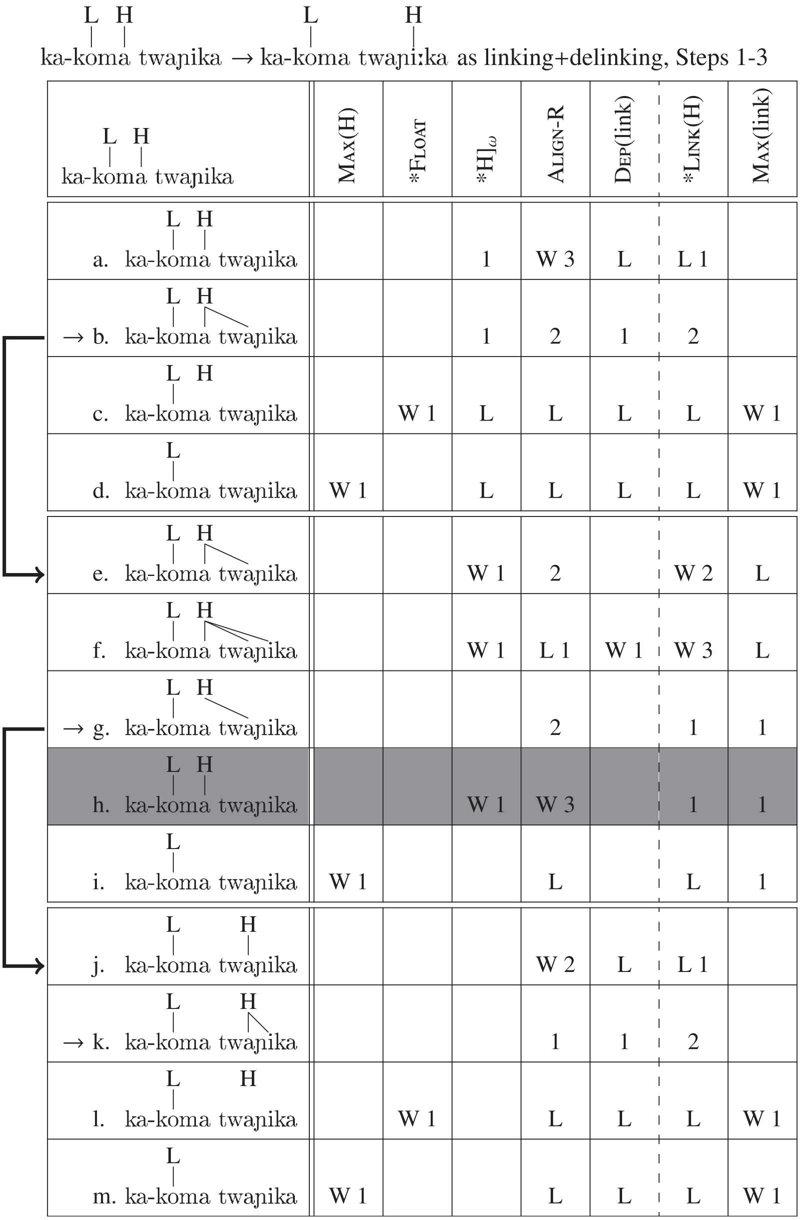
(65)



	Max(H)	$*\mathrm{H}]_{\varphi}$	*Contour	*Float	$*\mathrm{H}]_{\omega}$	Align-R	Dep(link)	*Link(H)	Max(link)
a. 		W 1		L	W 1	2		W 2	L
b. 		W 1	W 1	L	W 1	L 1	W 1	W 3	L
c. 		W 1		1	W 1	L		1	1
→ d. 				1		2		1	1
e. 	W 1	W 1		L	W 1	L		1	1
f. 	W 1			L		2		1	1
→ g. 				1		2		1	
h. 			W 1	1		L 1	W 1	W 2	
i. 			W 1	L		W 3	W 1	W 2	
j. 		W 1		L	W 1	2	W 1	W 2	
k. 				W 2		L		L	W 1
l. 	W 1			1		L		L	W 1
m. 	W 1			L		2		1	

A.3.3. *Phrase-medial*

(66)

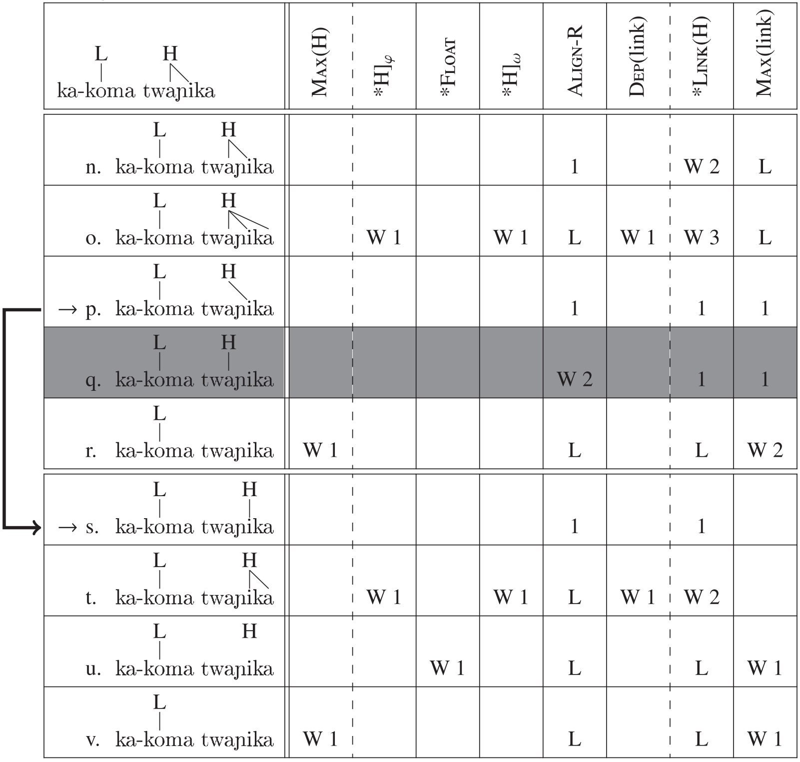


L H ka-koma twaɲika → L H ka-koma twaɲiːka as linking+delinking, Steps 1-3

L H ka-koma twaɲika	Max(H)	*Float	*H]$_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
L H a. ka-koma twaɲika			1	W 3	L	L 1	
L H → b. ka-koma twaɲika			1	2	1	2	
L H c. ka-koma twaɲika		W 1	L	L	L	L	W 1
L d. ka-koma twaɲika	W 1		L	L	L	L	W 1
L H e. ka-koma twaɲika			W 1	2		W 2	L
L H f. ka-koma twaɲika			W 1	L 1	W 1	W 3	L
L H → g. ka-koma twaɲika				2		1	1
L H h. ka-koma twaɲika			W 1	W 3		1	1
L i. ka-koma twaɲika	W 1			L		L	1
L H j. ka-koma twaɲika				W 2	L	L 1	
L H → k. ka-koma twaɲika				1	1	2	
L H l. ka-koma twaɲika		W 1		L	L	L	W 1
L m. ka-koma twaɲika	W 1			L	L	L	W 1

(67)

L H L H
ka-koma twaɲika → ka-koma twaɲiːka as linking+delinking, step 4 and convergence



L H ka-koma twaɲika	Max(H)	$*\mathrm{H}]_{\varphi}$	*Float	$*\mathrm{H}]_{\omega}$	Align-R	Dep(link)	*Link(H)	Max(link)
L H n. ka-koma twaɲika					1		W 2	L
L H o. ka-koma twaɲika		W 1		W 1	L	W 1	W 3	L
L H → p. ka-koma twaɲika					1		1	1
L H q. ka-koma twaɲika					W 2		1	1
L r. ka-koma twaɲika	W 1				L		L	W 2
L H → s. ka-koma twaɲika					1		1	
L H t. ka-koma twaɲika		W 1		W 1	L	W 1	W 2	
L H u. ka-koma twaɲika			W 1		L		L	W 1
L v. ka-koma twaɲika	W 1				L		L	W 1

(68)

LH H → LH ↓H
ku-fisa hea → ku-fisa heːa

LH H ku-fisa hea	Max(H)	*H]$_\varphi$	*Float	*H]$_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
→ a. LH H ku-fisa hea				1	3		2	
b. LH H ku-fisa hea		W 1		W 2	L 2	W 1	W 3	
c. LH H ku-fisa hea			W 1	L	L 1		L 1	W 1
d. LH H ku-fisa hea			W 1	1	L 2		L 1	W 1
e. L H ku-fisa hea	W 1			L	L 1		L 1	W 1
f. LH ku-fisa hea	W 1			1	L 2		L 1	W 1

(69)
L H H → L H↓H
| | | → | \ /
ni-a-tunga ʃaii → n-a-tunga ʃaiːi as linking+delinking, Step 1

L H H | | | ni-a-tunga ʃaii	Max(H)	$*H]_\varphi$	*Float	$*H]_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
L H H | | | a. ni-a-tunga ʃaii				1	W 4	L	L 2	
L H H | \\ | → b. ni-a-tunga ʃaii				1	3	1	3	
L H H | | |\\ c. ni-a-tunga ʃaii		W 1		W 2	3	1	3	
L H H | | d. ni-a-tunga ʃaii			W 1	L	L 1	L	L 1	W 1
L H H | | e. ni-a-tunga ʃaii			W 1	1	3	L	L 1	W 1
L H | | f. ni-a-tunga ʃaii	W 1			L	L 1	L	L 1	W 1
L H | | g. ni-a-tunga ʃaii	W 1			1	3	L	L 1	W 1

(70) L H H → L H↓H

ni-a-tunga ʃaii → n-a-tunga ʃaiːi as linking+delinking, Step 2 and convergence

L HH ni-a-tunga ʃaii	Max(H)	*H]$_\varphi$	*Float	*H]$_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
L H H h. ni-a-tunga ʃaii				W 1	3		W 3	L
L H H i. ni-a-tunga ʃaii		W 1		W 2	L 2	W 1	W 4	L
L H H → j. ni-a-tunga ʃaii					3		2	1
L H H k. ni-a-tunga ʃaii				W 1	W 4		2	1
L H H l. ni-a-tunga ʃaii			W 1	W 1	L 2		2	1
L H m. ni-a-tunga ʃaii	W 1				L 1		L 1	W 2
L H n. ni-a-tunga ʃaii	W 1			W 1	L 2		2	1
L HH → o. ni-a-tunga ʃaii					3		2	
L HH p. ni-a-tunga ʃaii		W 1		W 1	L 2	W 1	W 3	
L HH q. ni-a-tunga ʃaii			W 1		L 1		L 1	W 1
L HH r. ni-a-tunga ʃaii			W 1		L 2		L 1	W 1
L H s. ni-a-tunga ʃaii	W 1				L 1		L 1	W 1
L H t. ni-a-tunga ʃaii	W 1				L 2		L 1	W 1

A.4. TRISYLLABIC VERBS

A.4.1. *Infinitive*

(71) $\text{ku-}\overset{\substack{\text{L}\\|}}{\text{o}}\text{mb}\overset{\substack{\text{H}\\|}}{\text{e}}\text{za} \rightarrow \text{ku-}\overset{\substack{\text{L}\\|}}{\text{o}}\text{mb}\overset{\substack{\text{H}\\|}}{\text{e}}\text{ːza}$

$\text{ku-}\overset{\substack{\text{L}\\|}}{\text{o}}\text{mb}\overset{\substack{\text{H}\\|}}{\text{e}}\text{za}$	MAX(H)	*H]$_\varphi$	*FLOAT	*H]$_\omega$	ALIGN-R	DEP(link)	*LINK(H)	MAX(link)
→ a. $\text{ku-}\overset{\substack{\text{L}\\|}}{\text{o}}\text{mb}\overset{\substack{\text{H}\\|}}{\text{e}}\text{za}$					1		1	
b. $\text{ku-}\overset{\substack{\text{L}\\|}}{\text{o}}\text{mb}\overset{\substack{\text{H}\\|\diagdown}}{\text{e}}\text{za}$		W 1		W 1	L	W 1	W 2	
c. $\text{ku-}\overset{\substack{\text{L}\\|}}{\text{o}}\text{mb}\overset{\substack{\text{H}\\ }}{\text{e}}\text{za}$			W 1		L		L	W 1
d. $\text{ku-}\overset{\substack{\text{L}\\|}}{\text{o}}\text{mbeza}$	W 1				L		L	W 1

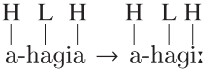
(72)

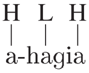
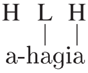
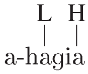
L H → L H

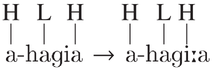
ku-hagia → ku-hagiːa as delinking+linking

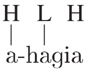
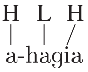
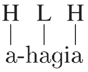
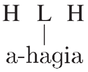
L H ku-hagia	Max(H)	*H]$_\varphi$	*Contour	*Float	*H]$_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
L H a. ku-hagia		W 1		L	W 1			W 1	L
L H → b. ku-hagia				1					1
L c. ku-hagia	W 1			L					1
L H d. ku-hagia				W 1		L	L	L	
L H e. ku-hagia			W 1			W 2	1	1	
L H → f. ku-hagia						1	1	1	
L H g. ku-hagia		W 1			W 1	L	1	1	
L h. ku-hagia	W 1					L	L	L	
L H → i. ku-hagia						1		1	
L H j. ku-hagia		W 1			W 1	L	W 1	W 2	
L H k. ku-hagia				W 1		L		L	W 1
L l. ku-hagia	W 1					L		L	W 1

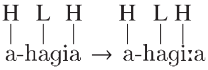
A.4.2. *High toned prefix*

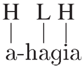
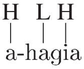
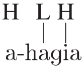
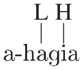
(73)  as delinking+linking, Step 1

	Max(H)	$*\text{H}]_\varphi$	*Contour	*Float	$*\text{H}]_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
a. 		W 1		L	W 1	3		W 2	L
b. 		W 1	W 1	L	W 1	L 2	W 1	W 3	L
c. 		W 1		1	W 1	L		1	1
→ d. 				1		3		1	1
e. 	W 1	W 1		L	W 1	L		1	1
f. 	W 1			L		3		1	1

(74)  as delinking+linking, Step 2

	Max(H)	*H]$_\varphi$	*Contour	*Float	*H]$_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
g. 				W 1		L 3	L	L 1	
h. 			W 1	W 1		L 2	1	2	
i. 			W 1			W 5	1	2	
→ j. 						4	1	2	
k. 		W 1			W 1	L 3	1	2	
l. 				W 2		L	L	L	W 1
m. 	W 1			W 1		L	L	L	W 1
n. 	W 1					L 3	L	L 1	

(75)  as delinking+linking, convergence

	Max(H)	*H]$_\varphi$	*Contour	*Float	*H]$_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
→ o. 						4		2	
p. 			W 1			L 3	W 1	W 3	
q. 		W 1			W 1	L 3	W 1	W 3	
r. 				W 1		L 1		L 1	W 1
s. 				W 1		L 3		L 1	W 1
t. 	W 1					L 1		L 1	W 1
u. 	W 1					L 3		L 1	W 1

A.4.3. *Phrase-medial*

(76) ni-a-$\overset{L}{\overset{|}{\text{o}}}mb\overset{H}{\overset{|}{\text{e}}}$za n-guo → n-a-$\overset{L}{\overset{|}{\text{o}}}mb\overset{H}{\overset{|}{\text{e}}}$za n-guːo

ni-a-$\overset{L}{\overset{|}{\text{o}}}mb\overset{H}{\overset{|}{\text{e}}}$za n-guo	Max(H)	*Float	*H]$_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
→ a. ni-a-$\overset{L}{\overset{|}{\text{o}}}mb\overset{H}{\overset{|}{\text{e}}}$za n-guo				3		1	
b. ni-a-$\overset{L}{\overset{|}{\text{o}}}mb\overset{H}{\overset{|\diagdown}{\text{ez}}}$a n-guo			W 1	L 2	W 1	W 2	
c. ni-a-$\overset{L}{\overset{|}{\text{o}}}mb\overset{H}{\text{e}}$za n-guo		W 1		L		L	W 1
d. ni-a-$\overset{L}{\overset{|}{\text{o}}}$mbeza n-guo	W 1			L		L	W 1

(77)

L H → L H
ka-hagia sakafu → ka-hagia sakaːfu as linking+delinking, Steps 1-3

L H ka-hagia sakafu	MAX(H)	*FLOAT	*H]ω	ALIGN-R	DEP(link)	*LINK(H)	MAX(link)
L H a. ka-hagia sakafu			1	W 3	L	L 1	
L H → b. ka-hagia sakafu			1	2	1	2	
L H c. ka-hagia sakafu		W 1	L	L	L	L	W 1
L d. ka-hagia sakafu	W 1		L	L	L	L	W 1
L H e. ka-hagia sakafu			W 1	2		W 2	L
L H f. ka-hagia sakafu			W 1	L 1	W 1	W 3	L
L H → g. ka-hagia sakafu				2		1	1
L H h. ka-hagia sakafu			W 1	W 3		1	1
L i. ka-hagia sakafu	W 1			L		L	W 2
L H j. ka-hagia sakafu				W 2	L	L 1	
L H → k. ka-hagia sakafu				1	1	2	
L H l. ka-hagia sakafu		W 1		L	L	L	W 1
L m. ka-hagia sakafu	W 1			L	L	L	W 1

(78) L H → L H
ka-hagia sakafu → ka-hagia sakaːfu as linking+delinking, Step 4 and convergence

L H ka-hagia sakafu	Max(H)	*H]$_\varphi$	*Float	*H]$_\omega$	Align-R	Dep(link)	*Link(H)	Max(link)
L H n. ka-hagia sakafu					1		W 2	L
L H o. ka-hagia sakafu		W 1		W 1	L	W 1	W 3	L
L H → p. ka-hagia sakafu					1		1	1
L H q. ka-hagia sakafu					W 2		1	1
L r. ka-hagia sakafu	W 1				L		L	W 2
L H → s. ka-hagia sakafu					1		1	
L H t. ka-hagia sakafu		W 1		W 1	L	W 1	W 2	
L H u. ka-hagia sakafu			W 1		L		L	W 1
L v. ka-hagia sakafu	W 1				L		L	W 1

B. Gietz et al.'s constraint definitions

This appendix provides Gietz et al.'s (2023: 30-32) definitions of the constraints that appear in the support in (15).

(79) *NonFinality / NonFin*
Assign a violation mark for every High tone that is associated with the final syllable. (Gietz et al. 2023: 30)

(80) *Align(H, R; PWd, R; σ) / Align-R*
Assign a violation mark for every triplet < syllable, High tone, Prosodic Word >, if the syllable follows the High tone within the same Prosodic Word and the High tone is not associated with the preceding Prosodic Word. (Gietz et al. 2023: 30)

(81) *Max(H)*
Assign a violation mark for every input High tone that does not have an output correspondent. (≡ No High tone deletion.) (Gietz et al. 2023: 30)

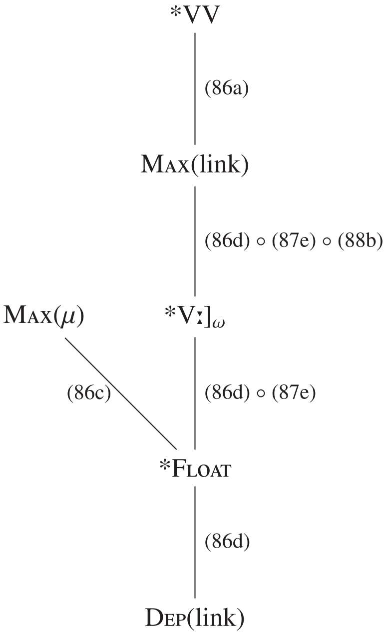
(82) *OCP*
Assign a violation mark for every pair of High tones linked to adjacent TBUs within a Prosodic Word. (Gietz et al. 2023: 31)

(83) *NoLongT*
Let a tone be associated with multiple TBUs. Assign a violation mark for each such TBU beyond the first. (Gietz et al. 2023: 31)

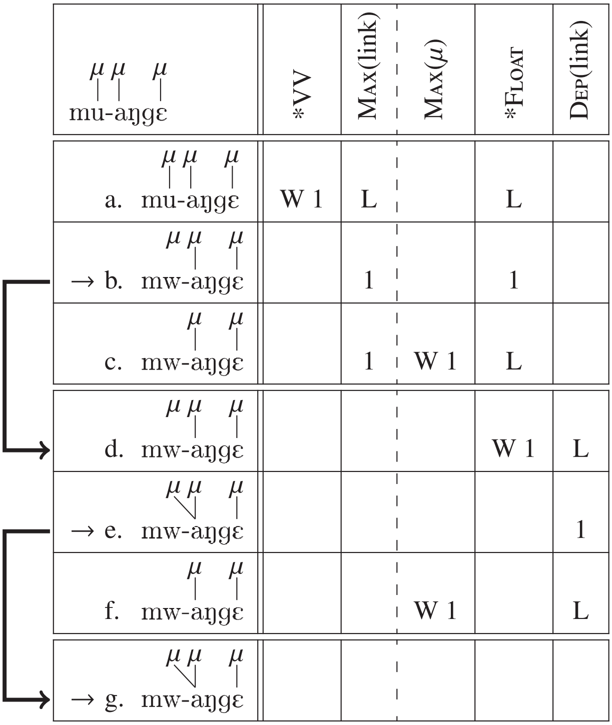
(84) *Base-Identity*
Let μ_b be a TBU of the base (an isolated Prosodic Word) and μ_d be the corresponding TBU of the derived form (a phrase).
Assign a violation mark if μ_b is associated with a High tone and μ_d is not. (Gietz et al. 2023: 32)

C. Logoori appendix

(85) *Hasse diagram for Logoori*



(86) mu-aŋgɛ → mw-aŋgɛ as delinking+linking



mu-aŋgɛ	*VV	Max(link)	Max(μ)	*Float	Dep(link)
a. mu-aŋgɛ	W 1	L		L	
→ b. mw-aŋgɛ		1		1	
c. mw-aŋgɛ		1	W 1	L	
d. mw-aŋgɛ				W 1	L
→ e. mw-aŋgɛ					1
f. mw-aŋgɛ			W 1		L
→ g. mw-aŋgɛ					

(87) $\overset{\mu\,\mu}{\text{mu-a}} \rightarrow \overset{\mu\,\mu}{\text{mw-a}}$

μ μ mu-a	*VV	Max(link)	*Vː]$_\omega$	Max(μ)	*Float	Dep(link)
μ μ a. mu-a	W 1	L			L	
μ μ → b. mw-a		1			1	
μ c. mw-a		1		W 1	L	
μ μ → d. mw-a					1	
μ μ e. mw-a			W 1		L	W 1
μ f. mw-a				W 1	L	

(88) $\overset{\mu\ \ \mu\,\mu\mu}{\text{mbegá}} \rightarrow \overset{\mu\ \ \mu\,\mu\mu}{\text{mbegá}}$

μ μ μμ mbegá	Max(link)	*Vː]$_\omega$	Max(μ)	*Float
μ μ μμ → a. mbegá		1		
μ μ μμ b. mbegá	W 1	L		W 1
μ μμ c. mbegá	W 1	L	W 1	

D. HALKOMELEM APPENDIX

This appendix presents the full analysis of Halkomelem; that is more tableaux are included here than in the text of the paper and tableaux include more candidates. Harmonically bounded candidates in tableaux are grayed out.

The GEN function is identical to that used for Kibondei with the addition of an operation that designates one syllable as the head of the word. The constraints used in the analysis not already defined are defined below (89–93). Their ranking is represented in the Hasse diagram immediately following (94).

Some of the candidates raise representational questions, such as (104d), where [low] is linked to a high vowel. Because this is never optimal, it is irrelevant for the analysis exactly how to interpret this. Likewise, when [low] is delinked from an underlying mid vowel as in (100m–n), it could plausibly result in either a mid vowel or schwa. Again, because these candidates are not optimal, the resolution of this question is irrelevant to the analysis.

(89) $*{-}\Delta_{\omega} \geq$ {i,u}: Assign one violation for every vowel more sonorous than a high vowel (i.e., [a]) that is not the Designated Terminal Element of a word.

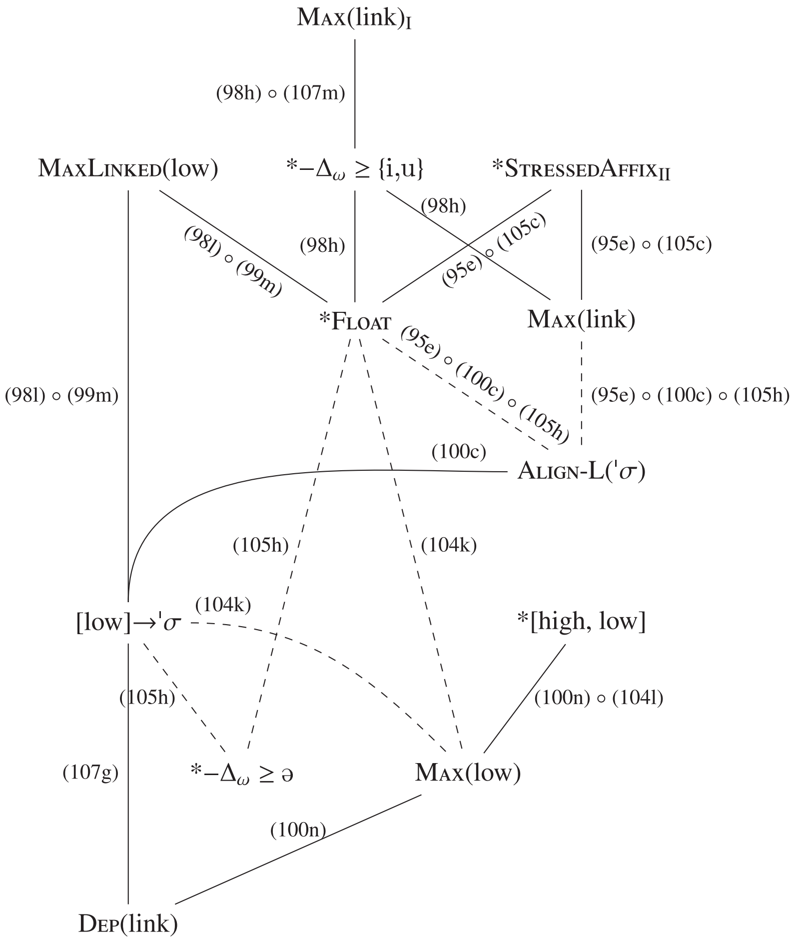
(90) $*{-}\Delta_{\omega} \geq$ ə: Assign one violation for every vowel more sonorous than schwa (i.e., [i, u, e, a]) that is not the Designated Terminal Element of a word.

(91) ALIGN-L('σ): For every stressed syllable, assign one violation for every syllable that intervenes between it and the left edge of the word.

(92) *[high, low]: Assign one violation for every segment specified as both high and low.

(93) [low]→'σ: Assign one violation for every [low] feature not linked to a stressed syllable.

(94) *Hasse diagram for Halkomelem*



(95) low
ɬəqʷ-θat → low
ɬəqʷ-ˈθat

low ɬəqʷ-θat	MAXLINKED(low)	$*{-}\Delta_\omega \geq \{i,u\}$	*FLOAT	MAX(link)	ALIGN-L(ˈσ)	[low]→ˈσ	$*{-}\Delta_\omega \geq ə$	MAX(low)	DEP(link)
a. low ɬəqʷ-θat		W 1			L	W 1	W 2		
b. low ˈɬəqʷ-θat		W 1			L	W 1	1		
→ c. low ɬəqʷ-ˈθat					1		1		
d. low ɬaqʷ-θat		W 2			L	W 1	W 2		W 1
e. low ɬəqʷ-θət			W 1	W 1	L	W 1	W 2		
f. ɬəqʷ-θət	W 1			W 1	L		W 2	W 1	
→ g. low ɬəqʷ-ˈθat					1		1		
h. low ɬaqʷ-ˈθat		W 1			1		1		W 1
i. low ɬəqʷ-ˈθət			W 1	W 1	1	W 1	1		
j. ɬəqʷ-ˈθət	W 1			W 1	1		1	W 1	

(96) low low
θələq-talˀ-əstəxʷ → θələq-ˈtalˀ-əstəxʷ, Step 1

low θələq-talˀ-əstəxʷ	MaxLinked(low)	$*{-}\Delta_\omega \geq \{\mathrm{i,u}\}$	*Float	Max(link)	Align-L(ˈσ)	[low]→ˈσ	$*{-}\Delta_\omega \geq$ ə	Max(low)	Dep(link)
low a. θələq-talˀ-əstəxʷ		W 1			L	W 1	W 5		
low b. ˈθələq-talˀ-əstəxʷ		W 1			L	W 1	4		
low c. θəˈləq-talˀ-əstəxʷ		W 1			L 1	W 1	4		
low → d. θələq-ˈtalˀ-əstəxʷ					2		4		
low e. θələq-taˈlˀ-əstəxʷ		W 1			W 3	W 1	4		
low f. θələq-talˀ-əsˈtəxʷ		W 1			W 4	W 1	4		
low g. θəlaq-talˀ-əstəxʷ		W 2			L	W 1	W 5		W 1
low h. θələq-talˀ-astəxʷ		W 2			L	W 1	W 5		W 1
low i. θələq-təlˀ-əstəxʷ			W 1	W 1	L	W 1	W 5		
j. θələq-təlˀ-əstəxʷ	W 1			W 1	L		W 5	W 1	

(97)
low   low
θələq-talˀ-əstəxʷ → θələq-ˈtalˀ-əstəxʷ, convergence

low θələq-ˈtalˀ-əstəxʷ	MaxLinked(low)	$*{-}\Delta_\omega \geq \{i,u\}$	*Float	Max(link)	Align-L(ˈσ)	[low]→ˈσ	$*{-}\Delta_\omega \geq$ ə	Max(low)	Dep(link)
low → k. θələq-ˈtalˀ-əstəxʷ					2		4		
low l. θələq-ˈtalˀ-əstəxʷ		W 1			2		4		W 1
low m θələq-ˈtalˀ-əstəxʷ		W 1			2		4		W 1
low n. θələq-ˈtəlˀ-əstəxʷ			W 1	W 1	2	W 1	4		
o. θələq-ˈtəlˀ-əstəxʷ	W 1			W 1	2		4	W 1	

(98) low low low
nas-θat → 'nas-θət, Steps 1-2

low low nas-θat	MaxLinked(low)	$*\text{-}\Delta_\omega \geq \{i,u\}$	*Float	Max(link)	Align-L('σ)	[low]→'σ	$*\text{-}\Delta_\omega \geq ə$	Max(low)
a. low low nas-θat		W 2				W 2	W 2	
→ b. low low 'nas-θat		1				1	1	
c. low low nas-'θat		1			W 1	1	1	
d. low low nəs-θat		1	W 1	W 1		W 2	W 2	
e. low low nas-θət		1	W 1	W 1		W 2	W 2	
f. low nəs-θat	W 1	1		W 1		1	W 2	W 1
g. low nas-θət	W 1	1		W 1		1	W 2	W 1
h. low low 'nas-θat		W 1	L	L		1	1	
i. low low 'nəs-θat		W 1	1	1		W 2	1	
→ j. low low 'nas-θət			1	1		1	1	
k. low 'nəs-θat	W 1	W 1	L	1		1	1	W 1
l. low 'nas-θət	W 1		L	1		L	1	W 1

(99) low low low
nas-θat → ˈnas-θət, Step 3 and convergence

low low ˈnas-θət	MaxLinked(low)	$*{-}\Delta_{\omega} \geq \{i,u\}$	*Float	Max(link)	[low]→ˈσ	$*{-}\Delta_{\omega} \geq$ ə	Max(low)	Dep(link)
m. low low ˈnas-θət			W 1		W 1	1	L	
n. low low ˈnas-θat		W 1	W 1		W 1	1	L	W 1
o. low low ˈnas-θat		W 1			W 1	1	L	W 1
p. low low ˈnəs-θət			W 2	W 1	W 2	1	L	
q. low ˈnəs-θət	W 1		W 1	W 1	W 1	1	1	
→ r. low ˈnas-θət						1	1	
→ s. low ˈnas-θət						1		
t. low ˈnas-θat		W 1				1		W 1
u. low ˈnəs-θət			W 1	W 1	W 1	1		
v. ˈnəs-θət	W 1			W 1		1	W 1	

(100) kʷes-θ$\overset{\text{low}}{\text{a}}$t → ˈkʷ$\overset{\text{low}}{\text{a}}$s-θət, Steps 1-3

low kʷes-θat	MaxLinked(low)	*−$\Delta_\omega \geq$ {i,u}	*Float	Max(link)	Align-L(ˈσ)	[low]→ˈσ	*−$\Delta_\omega \geq$ ə	Max(low)	Dep(link)
low a. kʷes-θat		W 2				1	W 2		
low → b. ˈkʷes-θat		1				1	1		
low c. kʷes-ˈθat		1			W 1	L	1		
low d. kʷas-θat		W 2				1	W 2		W 1
low e. kʷes-θət		1	W 1	W 1		1	W 2		
f. kʷes-θət	W 1	1		W 1		L	W 2	W 1	
low g. ˈkʷes-θat		W 1	L	L		1	1		
low h. ˈkʷas-θat		W 1	L	L		L	1		W 1
low → i. ˈkʷes-θət			1	1		1	1		
j. ˈkʷes-θət	W 1		L	1		L	1	W 1	
low k. ˈkʷes-θət			W 1			W 1	1		L
low → l. ˈkʷas-θət							1		1
low m ˈkʷes-θat		W 1				W 1	1		1
n. ˈkʷes-θət							1	W 1	L

(101)

low low

kʷes-θat → ˈkʷas-θət, convergence

low ˈkʷas-θət	MaxLinked(low)	$*-\Delta_\omega \geq$ {i,u}	*Float	Max(link)	[low]→ˈσ	$*-\Delta_\omega \geq$ ə	Max(low)	Dep(link)
low → o. ˈkʷas-θət						1		
low p. ˈkʷas-θat		W 1				1		W 1
low q. ˈkʷes-θət			W 1	W 1	W 1	1		
r. ˈkʷes-θət	W 1			W 1		1	W 1	

(102) low low
peθə-θat → ˈpaθə-θət, Steps 1-2

low peθə-θat	MaxLinked(low)	$*{-}\Delta_\omega \geq$ {i,u}	*Float	Max(link)	Align-L(ˈσ)	[low]→ˈσ	$*{-}\Delta_\omega \geq$ ə	Max(low)	Dep(link)
low a. peθə-θat		W 2				1	W 3		
low → b. ˈpeθə-θat		1				1	2		
low c. peˈθə-θat		W 2			W 1	1	2		
low d. peθə-ˈθat		1			W 2	L	2		
low e. peθa-θat		W 3				1	W 3		W 1
low f. peθə-θət		1	W 1	W 1		1	W 3		
g. peθə-θət	W 1	1		W 1		L	W 3	W 1	
low h. ˈpeθə-θat		W 1	L	L		1	2		
low i. ˈpeθa-θat		W 2	L	L		1	2		W 1
low → j. ˈpeθə-θət			1	1		1	2		
k. ˈpeθə-θət	W 1		L	1		L	2	W 1	

(103)

low low

peθə-θat → ˈpaθə-θət, Step 3 and convergence

low ˈpeθə-θət	MaxLinked(low)	$*{-}\Delta_\omega \geq$ {i,u}	*Float	Max(link)	[low]→ˈσ	$*{-}\Delta_\omega \geq$ ə	Max(low)	Dep(link)
low l. ˈpeθə-θət			W 1		W 1	2		L
low → m. ˈpaθə-θət						2		1
low n. ˈpeθa-θət		W 1			W 1	2		1
low o. ˈpeθə-θat		W 1			W 1	2		1
p. ˈpeθə-θət						2	W 1	L
low → q. ˈpaθə-θət						2		
low r. ˈpaθa-θət		W 1				2		W 1
low s. ˈpeθə-θət			W 1	W 1	W 1	2		
t. ˈpeθə-θət	W 1			W 1		2	W 1	

(104)

low
hiːl-θat → ˈhiːl-θət

low hiːl-θat	MaxLinked(low)	$*{-}\Delta_\omega \geq \{i,u\}$	*Float	Max(link)	Align-L(ˈσ)	[low]→ˈσ	*[high, low]	$*{-}\Delta_\omega \geq ə$	Max(low)	Dep(link)
low a. hiːl-θat		W 2				1		W 2		
low → b. ˈhiːl-θat		1				1		1		
low c. hiːl-ˈθat		1			W 1	L		1		
low d. hiːl-θat		W 2				1	W 1	W 2		W 1
low e. hiːl-θət		1	W 1	W 1		1		W 2		
f. hiːl-θət	W 1	1		W 1		L		W 2	W 1	
low g. ˈhiːl-θat		W 1	L	L		1		1		
low h. ˈhiːl-θat		W 1	L	L		L	W 1	1		W 1
low → i. ˈhiːl-θət			1	1		1		1		
j. ˈhiːl-θət	W 1		L	1		L		1	W 1	
low k. ˈhiːl-θət			W 1			W 1		1	L	
low l. ˈhiːl-θət							W 1	1	L	W 1
low m. ˈhiːl-θat		W 1				W 1		1	L	W 1
→ n. ˈhiːl-θət								1	1	
→ o. ˈhiːl-θət								1		

(105)

low
t͡sə-θat → ˈt͡sə-θət

low t͡sə-θat II	MaxLinked(low)	$*{-}\Delta_\omega \geq \{i,u\}$	$*$StressedAffix$_{II}$	*Float	Max(link)	Align-L(ˈσ)	[low]→ˈσ	$*{-}\Delta_\omega \geq ə$	Max(low)	Dep(link)
low a. t͡sə-θat		W 1		L	L		1	2		
low b. ˈt͡sə-θat		W 1		L	L		1	L 1		
low c. t͡sə-ˈθat			W 1	L	L	W 1	L	L 1		
low d. t͡sa-θat		W 2		L	L		1	2		W 1
low → e. t͡sə-θət				1	1		1	2		
f. t͡sə-θət	W 1			L	1		L	2	W 1	
low g. t͡sə-θət				W 1			W 1	2	L	
low h. ˈt͡sə-θət				W 1			W 1	L 1	L	
low i. t͡sə-ˈθət			W 1	W 1		W 1	W 1	L 1	L	
low j. t͡sa-θət		W 1					W 1	2	L	W 1
low k. t͡sə-θat		W 1					W 1	2	L	W 1
→ l. t͡sə-θət								2	1	
m t͡sə-θət								W 2		
→ n. ˈt͡sə-θət								1		
o. t͡sə-ˈθət			W 1			W 1		1		
→ p. ˈt͡sə-θət								1		

(106)

low low → low low

stᶿʼamˀ-aqʷ → ˈstᶿʼamˀ-aqʷ

low low stᶿʼamˀ-aqʷ I	MaxLinked(low)	Max(link)$_I$	$*{-}\Delta_\omega \geq \{i,u\}$	*Float	Max(link)	Align-L(ˈσ)	[low]→ˈσ	$*{-}\Delta_\omega \geq ə$	Max(low)
low low a. stᶿʼamˀ-aqʷ			W 2				W 2	W 2	
low low → b. ˈstᶿʼamˀ-aqʷ			1				1	1	
low low c. stʼᶿaˈmˀ-aqʷ			1			W 1	1	1	
low low d. stʼᶿəmˀ-aqʷ			1	W 1	W 1		W 2	W 2	
low low e. stʼᶿamˀ-əqʷ		W 1	1	W 1	W 1		W 2	W 2	
low f. stʼᶿəmˀ-aqʷ	W 1		1		W 1		1	W 2	W 1
low g. stʼᶿamˀ-əqʷ	W 1	W 1	1		W 1		1	W 2	W 1
low low → h. ˈstᶿʼamˀ-aqʷ			1				1	1	
low low i. ˈstʼᶿəmˀ-aqʷ			1	W 1	W 1		W 2	1	
low low j. ˈstʼᶿamˀ-əqʷ		W 1	L	W 1	W 1		1	1	
low k. ˈstʼᶿəmˀ-aqʷ	W 1		1		W 1		1	1	W 1
low l. ˈstʼᶿamˀ-əqʷ	W 1	W 1	L		W 1		L	1	W 1

(107)

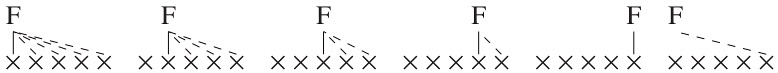
low low
t͡ɬ’eqt-aqʷ → ˈt͡ɬ’aqt-aqʷ

low t͡ɬ’eqt-aqʷ I	MaxLinked(low)	Max(link)$_I$	$*{-}\Delta_\omega \geq \{i,u\}$	*Float	Max(link)	Align-L(ˈσ)	[low]→ˈσ	$*{-}\Delta_\omega \geq ə$	Max(low)	Dep(link)
low a. t͡ɬ’eqt-aqʷ			W 2				1	W 2		
low → b. ˈt͡ɬ’eqt-aqʷ			1				1	1		
low c. t͡ɬ’eqˈt-aqʷ			1			W 1	L	1		
low d. t͡ɬ’aqt-aqʷ			W 2				1	W 2		W 1
low e. t͡ɬ’eqt-əqʷ		W 1	1	W 1	W 1		1	W 2		
f. t͡ɬ’eqt-əqʷ	W 1	W 1	1		W 1		L	W 2	W 1	
low g. ˈt͡ɬ’eqt-aqʷ			1				W 1	1		L
low → h. ˈt͡ɬ’aqt-aqʷ			1					1		1
low i. ˈt͡ɬ’eqt-əqʷ		W 1	L	W 1	W 1		W 1	1		L
j. ˈt͡ɬ’eqt-əqʷ	W 1	W 1	L		W 1			1	W 1	L
low → k. ˈt͡ɬ’aqt-aqʷ			1					1		
low l. ˈt͡ɬ’eqt-aqʷ			1		W 1		W 1	1		
low m. ˈt͡ɬ’aqt-əqʷ		W 1	L		W 1			L		
n. ˈt͡ɬ’eqt-əqʷ	W 1	W 1	L		W 2			1	W 1	

E. TYPOLOGY

This appendix presents the constraint rankings as skeletal bases (Brasoveanu & Prince 2011) for the 38 languages produced in the typology. Bases in the left column are from the typology without a single-step shift operation, and those in the right column are from the typology with one.

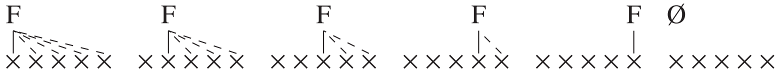
(1)



Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	L	L	e	e	L	e	e
L	e	e	W	W	e	e	e
L	e	e	e	W	e	W	W
e	L	L	W	e	L	e	e
e	L	L	e	e	L	W	e
e	e	L	e	W	e	e	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	L	L	e	e	L	e	e
L	e	e	W	W	e	e	e
L	e	e	e	W	e	W	W
e	L	L	W	e	L	e	e
e	L	L	e	e	L	W	e
e	e	L	e	W	e	e	e

(2)



Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	L	L	e	e	L	e	e
L	e	e	W	W	e	e	e
L	e	e	e	W	e	e	W
e	W	W	e	e	W	L	e
e	e	L	e	W	e	e	e
e	e	e	W	e	e	L	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	L	L	e	e	L	e	e
L	e	e	W	W	e	e	e
L	e	e	e	W	e	e	W
e	W	W	e	e	W	L	e
e	e	L	e	W	e	e	e
e	e	e	W	e	e	L	e

(3)

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	L	L	e	e	L	e	e
L	e	e	e	W	e	e	e
e	W	W	L	e	W	e	e
e	e	e	L	e	e	W	e

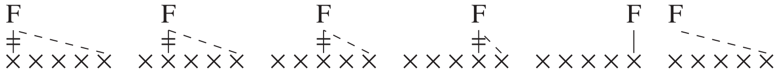
Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	L	L	e	e	L	e	e
L	e	e	e	W	e	e	e
e	W	W	L	e	W	e	e
e	e	e	L	e	e	W	e

(4)

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	L	L	e	e	e
e	L	L	W	e	L	e	e
e	L	L	e	e	L	W	e
e	e	L	e	W	e	e	e
e	e	e	L	e	e	W	W

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	L	L	e	e	e
e	L	L	W	e	L	e	e
e	L	L	e	e	L	W	e
e	e	L	e	W	e	e	e
e	e	e	L	e	e	W	W

(5)



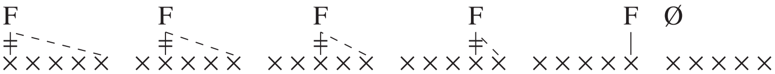
Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	L	e	e	e	e
e	L	L	W	e	L	e	e
e	L	L	e	e	L	W	e
e	e	W	e	L	e	e	e
e	e	e	L	e	e	W	W

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	L	e	e	e	e
e	L	L	W	e	L	e	e
e	L	L	e	e	L	W	e
e	e	W	e	L	e	e	e
e	e	e	L	e	e	W	W

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	L	L	e	e	L	e	e
L	e	e	W	e	e	e	e
L	e	e	e	e	e	W	W
e	L	L	e	e	L	W	e
e	e	W	e	L	e	e	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	L	e	e	L	L	e	e
L	e	L	W	e	e	e	e
L	e	e	e	e	e	W	W
e	L	L	e	e	L	W	e
e	e	W	e	L	e	e	e

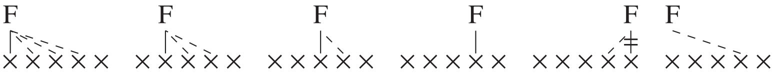
(6)



Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	L	L	e	e	L	e	e
L	e	e	W	e	e	e	e
L	e	e	e	e	e	e	W
e	W	W	e	e	W	L	e
e	e	W	e	L	e	e	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	L	e	e	L	L	e	e
L	e	L	W	e	e	e	e
L	e	L	e	e	e	e	W
e	W	W	e	e	W	L	e
e	e	W	e	L	e	e	e

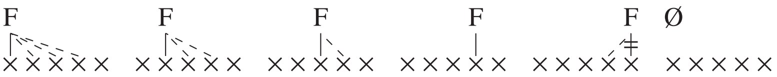
(7)



Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	e	W	e	e	e	e
L	e	e	e	e	e	W	e
W	e	L	e	e	L	e	e
e	e	e	L	e	e	W	W
e	W	e	L	L	e	e	e
e	e	L	e	W	e	e	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	W	e	e	L	e	e	e
L	e	e	W	e	e	e	e
L	e	e	e	e	e	W	e
W	e	L	e	e	L	e	e
e	e	L	e	W	e	e	e

(8)



n/a

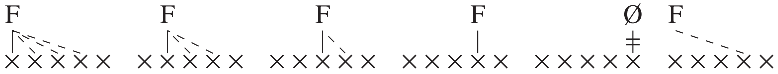
Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	W	e	e	L	e	e	e
L	e	e	W	e	e	e	e
L	e	e	e	e	e	e	W
W	e	L	e	e	L	L	e
e	e	L	e	W	e	e	e

(9)

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	e	e	W	e	e	e
W	e	L	L	e	L	e	e
e	W	e	e	L	e	e	e
e	e	e	L	e	e	W	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	e	e	W	e	e	e
W	e	L	L	e	L	e	e
e	W	e	e	L	e	e	e
e	e	e	L	e	e	W	e

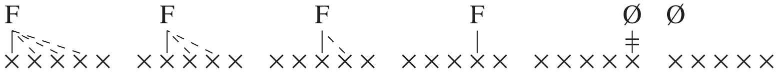
(10)



ALIGN-R	*F]	*LINK(F)	*FLOAT	MAX(link)	DEP(link)	MAX(F)	MAXLINKED(F)
L	e	e	e	e	e	W	e
W	e	L	e	e	L	e	e
e	W	e	e	L	e	L	L
e	e	e	W	e	e	L	L
e	e	L	e	W	e	e	e

n/a

(11)



Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	e	W	W	e	e	e
W	e	L	e	e	L	L	e
e	W	e	L	L	e	e	e
e	e	L	e	W	e	e	e
e	e	e	L	e	e	e	W
e	e	e	W	e	e	L	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	e	e	W	e	e	e
W	e	L	L	e	L	e	e
e	W	e	e	L	e	e	e
e	e	e	L	e	e	e	W
e	e	e	W	e	e	L	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	e	e	W	e	e	W
W	e	L	e	e	L	L	e
e	W	e	e	L	e	e	L
e	e	L	e	W	e	e	e
e	e	e	W	e	e	L	L

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	e	e	W	e	e	e
W	e	L	e	e	L	L	L
e	W	e	e	L	e	e	e
e	e	e	W	e	e	L	L

(12)

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	W	e	e	e	e	e	e
L	e	e	W	e	e	e	e
L	e	e	e	e	e	W	e
W	e	L	e	e	L	e	e
e	L	e	W	W	e	e	e
e	L	e	e	W	e	W	W
e	e	L	e	W	e	e	e

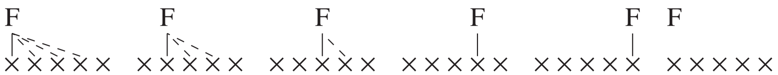
Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	W	e	e	e	e	e	e
L	e	e	W	e	e	e	e
L	e	e	e	e	e	W	e
W	e	L	e	e	L	e	e
e	L	e	e	W	e	e	e

(13)

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	W	e	e	e	e	e	e
W	e	L	e	e	L	L	e
e	L	e	W	W	e	e	e
e	L	e	e	W	e	e	W
e	e	L	e	W	e	e	e
e	e	e	W	e	e	L	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	W	e	e	e	e	e	e
W	e	L	e	e	L	L	e
e	L	e	e	W	e	e	e
e	e	e	W	e	e	L	e

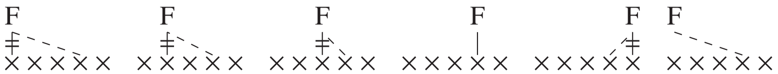
(14)



Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	W	e	e	e	e	e	e
W	e	L	L	e	L	e	e
e	L	e	e	W	e	e	e
e	e	e	L	e	e	W	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	W	e	e	e	e	e	e
W	e	L	L	e	L	e	e
e	L	e	e	W	e	e	e
e	e	e	L	e	e	W	e

(15)



Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	e	W	e	e	e	e
L	e	e	e	e	e	W	e
W	e	L	e	e	L	e	e
e	e	e	L	e	e	W	W
e	W	e	L	e	e	e	e
e	e	W	e	L	e	e	e

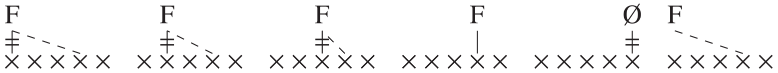
Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	W	e	e	e	e	e	e
L	e	L	W	e	e	e	e
L	e	L	e	e	e	W	e
W	e	e	e	L	L	e	e
e	e	W	e	L	e	e	e

(16)

n/a

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	W	e	e	e	e	e	e
L	e	L	W	e	e	e	e
L	e	L	e	e	e	e	W
W	e	W	e	e	e	L	e
W	e	e	e	L	L	e	e
e	e	W	e	L	e	e	e

(17)



Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	e	e	e	e	W	e
W	e	L	e	e	L	e	e
e	W	e	e	e	e	L	L
e	e	e	W	e	e	L	L
e	e	W	e	L	e	e	e

n/a

(18)

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	e	W	e	e	e	e
W	e	L	e	e	L	L	e
e	W	e	L	e	e	e	e
e	e	W	e	L	e	e	e
e	e	e	L	e	e	e	W

n/a

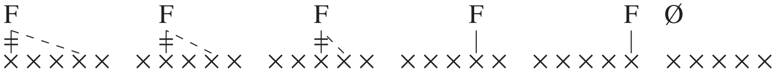
Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	e	e	e	e	e	W
W	e	L	e	e	L	L	e
e	W	e	e	e	e	e	L
e	e	W	e	L	e	e	e
e	e	e	W	e	e	e	L

(19)

n/a

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	W	e	e	e	e	e	e
L	e	e	e	e	e	W	e
W	e	L	e	e	L	e	e
e	L	e	W	e	e	e	e
e	L	e	e	e	e	W	W
e	e	W	e	L	e	e	e

(20)



n/a

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	W	e	e	e	e	e	e
W	e	L	e	e	L	L	e
e	L	e	W	e	e	e	e
e	L	e	e	e	e	e	W
e	e	W	e	L	e	e	e

(21)

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	e	L	e	e	e
e	L	L	e	W	L	e	e
e	W	W	L	e	W	e	e
e	e	e	L	e	e	W	e

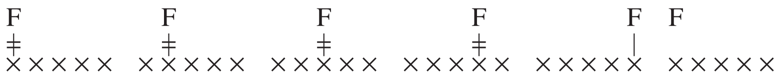
Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	e	L	e	e	e
e	L	L	e	W	L	e	e
e	W	W	L	e	W	e	e
e	e	e	L	e	e	W	e

(22)

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	W	L	L	e	e	e
e	W	W	L	L	e	e	e
e	e	e	L	e	e	W	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	W	L	L	e	e	e
e	W	W	L	L	e	e	e
e	e	e	L	e	e	W	e

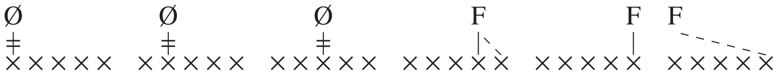
(23)



Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	L	L	e	e	e
e	L	L	W	W	e	e	e
e	e	e	L	L	W	e	e
e	e	e	L	e	e	W	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	L	L	e	e	e
e	L	L	W	W	e	e	e
e	e	e	L	L	W	e	e
e	e	e	L	e	e	W	e

(24)



n/a

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	e	L	e	L	L
e	L	L	e	e	L	W	e
e	e	L	e	W	e	e	e
e	e	e	W	e	e	L	L

(25)

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	L	L	e	e	e
e	L	e	W	W	L	e	e
e	W	W	e	e	W	L	e
e	e	L	e	W	e	e	e
e	e	e	L	e	e	e	W
e	e	e	W	e	e	L	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	e	L	e	e	L
e	L	e	e	W	L	e	W
e	W	W	e	e	W	L	e
e	e	L	e	W	e	e	e
e	e	e	W	e	e	L	L

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	L	L	e	e	e
e	L	e	W	W	L	e	e
e	W	W	e	e	W	L	e
e	e	L	e	W	e	e	e
e	e	e	L	e	e	e	W
e	e	e	W	e	e	L	e

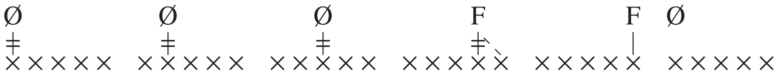
Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	e	L	e	e	L
e	L	e	e	W	L	e	W
e	W	W	e	e	W	L	e
e	e	L	e	W	e	e	e
e	e	e	W	e	e	L	L

(26)

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	e	e	e	L	L
e	L	L	e	e	L	W	e
e	e	W	e	L	e	e	e
e	e	e	W	e	e	L	L

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	e	e	e	L	L
e	L	L	e	e	L	W	e
e	e	W	e	L	e	e	e
e	e	e	W	e	e	L	L

(27)



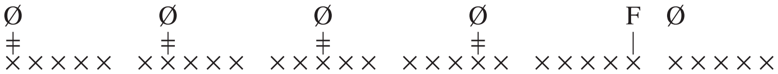
Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	L	e	e	e	e
e	L	L	W	e	L	e	e
e	W	W	e	e	W	L	e
e	e	W	e	L	e	e	e
e	e	e	L	e	e	e	W

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	L	e	e	e	e
e	L	L	W	e	L	e	e
e	W	W	e	e	W	L	e
e	e	W	e	L	e	e	e
e	e	e	L	e	e	e	W

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	e	e	e	e	L
e	L	L	e	e	L	e	W
e	W	W	e	e	W	L	e
e	e	W	e	L	e	e	e
e	e	e	W	e	e	e	L

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	e	e	e	e	L
e	L	L	e	e	L	e	W
e	W	W	e	e	W	L	e
e	e	W	e	L	e	e	e
e	e	e	W	e	e	e	L

(28)



Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	L	L	e	e	e
e	L	L	W	W	e	e	e
e	e	e	L	L	W	e	e
e	e	e	L	e	e	e	W
e	e	e	W	e	e	L	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	L	L	e	e	e
e	L	L	W	W	e	e	e
e	e	e	L	L	W	e	e
e	e	e	L	e	e	e	W
e	e	e	W	e	e	L	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	e	L	e	L	L
e	L	L	e	W	e	W	W
e	e	e	W	e	e	L	L
e	e	e	e	L	W	L	L

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	e	e	L	e	L	L
e	L	L	e	W	e	W	W
e	e	e	W	e	e	L	L
e	e	e	e	L	W	L	L

(29)

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	W	L	L	e	e	e
e	W	W	L	L	e	e	e
e	e	e	L	e	e	e	W
e	e	e	W	e	e	L	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	W	L	L	e	e	e
e	W	W	L	L	e	e	e
e	e	e	L	e	e	e	W
e	e	e	W	e	e	L	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	W	e	L	e	L	L
e	W	W	e	L	e	L	L
e	e	e	W	e	e	L	L

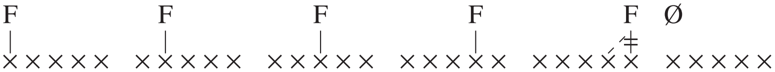
Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
W	e	W	e	L	e	L	L
e	W	W	e	L	e	L	L
e	e	e	W	e	e	L	L

(30)

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	W	e	e	W	e	e
e	W	e	L	L	e	e	e
e	e	L	W	e	L	e	e
e	e	L	e	e	L	W	e
e	e	e	L	e	e	W	W

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	W	e	e	W	e	e
L	e	e	e	W	W	e	e
e	W	e	e	L	L	e	e
e	e	L	W	e	L	e	e
e	e	L	e	e	L	W	e

(31)



n/a

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	W	e	e	W	L	e
L	e	e	e	W	W	e	e
e	W	e	e	L	L	e	e
e	e	L	W	e	L	e	e
e	e	L	e	e	L	e	W

(32)

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	L	W	W	e	e	e
L	e	W	L	e	W	e	e
e	W	e	L	L	e	e	e
e	e	e	L	e	e	W	e

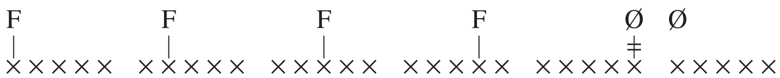
Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	L	W	W	e	e	e
L	e	W	L	e	W	e	e
e	W	e	L	L	e	e	e
e	e	e	L	e	e	W	e

(33)

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	W	e	e	W	e	e
e	W	e	e	L	e	L	L
e	e	L	e	e	L	W	e
e	e	e	W	e	e	L	L

n/a

(34)



Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	L	W	W	e	e	e
L	e	W	e	e	W	L	e
e	W	e	L	L	e	e	e
e	e	e	L	e	e	e	W
e	e	e	W	e	e	L	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	L	W	W	e	e	e
L	e	W	L	e	W	e	e
e	W	e	L	L	e	e	e
e	e	e	L	e	e	e	W
e	e	e	W	e	e	L	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	L	e	W	e	W	W
L	e	W	e	e	W	L	e
e	W	e	e	L	e	L	L
e	e	e	W	e	e	L	L

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	L	e	W	e	W	W
L	e	W	e	e	W	L	L
e	W	e	e	L	e	L	L
e	e	e	W	e	e	L	L

(35)

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	W	e	e	W	e	e
W	L	e	e	e	e	e	e
e	e	L	W	e	L	e	e
e	e	L	e	e	L	W	e

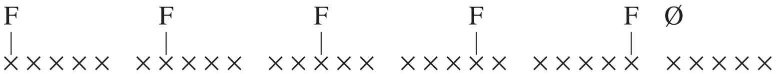
Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	e	W	e	e	W	e	e
L	e	e	e	W	W	e	e
W	L	e	e	e	e	e	e
e	e	L	W	e	L	e	e
e	e	L	e	e	L	W	e

(36)

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	W	e	e	e	e	e	e
L	e	W	e	e	W	e	e
e	L	e	W	W	e	e	e
e	L	e	e	W	e	W	W
e	e	L	W	e	L	e	e
e	e	L	e	e	L	W	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	W	e	e	e	e	e	e
L	e	W	e	e	W	e	e
e	L	e	e	W	W	e	e
e	e	L	W	e	L	e	e
e	e	L	e	e	L	W	e

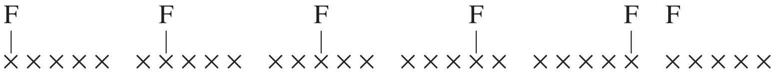
(37)



Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	L	L	W	W	e	e	e
L	L	L	e	W	e	W	W
L	e	W	e	e	W	L	e
e	e	e	W	e	e	L	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	L	L	W	W	e	e	e
L	L	L	e	W	e	W	W
L	L	e	e	W	W	e	e
L	e	W	e	e	W	L	e
e	e	e	W	e	e	L	e

(38)



Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	L	L	W	W	e	e	e
L	e	W	L	e	W	e	e
e	e	e	L	e	e	W	e

Align-R	*F]	*Link(F)	*Float	Max(link)	Dep(link)	Max(F)	MaxLinked(F)
L	L	L	W	W	e	e	e
L	e	W	L	e	W	e	e
e	e	e	L	e	e	W	e

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit http://doi.org/10.1017/S0022226723000294.

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