Opaque Interactions in OT-CC: The Case of Sm'algya̲x Interrupted Vowels

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Sm'algya̲x, a Tsimshianic language spoken in northern British Columbia and New Metlakatla, Alaska, evidences a phenomenon termed "vowel interruption" by Dunn (1979). Dunn (1979:11) describes this process as one where the glottalization from a consonant following a long vowel "bleeds" into the preceding segment. Optionally, the consonant that carried the glottalization prior to the vowel interruption is deleted.

Turning to classic Optimality Theory (OT) (Prince & Smolensky, 1993/2002) in an attempt to explain an apparent counterbleeding interaction proves disappointing. As is frequently noted, OT has difficulty explaining processes that result in opaque outputs (McCarthy: 2007). Ranking constraints for the interaction of Sm'algya̲x vowel interruption and consonant deletion results in a ranking paradox; no ordering of constraints can explain both processes.

In the current paper, the data provided in Dunn (1978/1995, 1979:11) are examined. Data from Anderson (2013) are also discussed, providing more recent data than those in Dunn (1978/1995, 1979). An overview of the rule-based explanation is then provided, followed by an OT explanation illustrating the ranking paradox.

Following this, a brief introduction to McCarthy's (2007) framework of Optimality Theory with Candidate Chains (OT-CC) is provided. After exploring the interaction of vowel interruption and consonant deletion from the OT-CC framework, the discussion turns to some preliminary comments about motivations for the process of vowel interruption. The paper ends by proposing suggestions for future research, including further exploration into Sm'algya̲x syllable structure and analysis of additional data.

Keywords: Sm'algya̲x, Coast Tsimshian, opacity, counterbleeding, OT-CC, interrupted vowels

1 Language Background

Sm'algya̲x (var. Coast Tsimshian, Tsimshian, Tsimshianic, Tsimshian Proper, Ts'msyen, Ts'msyen Sm'algya̲x) is spoken in communities along the north coast of British Columbia, Canada, by approximately 180 individuals. It is also spoken in New Metlakatla in southeastern Alaska. The majority of Sm'algya̲x first-language speakers are over the age of 50; a small population of second-language speakers is also present (Lewis,

Simons, & Fennig, 2015). Part of the Tsimshianic language family, which includes Southern Tsimshian, Nisg̲a'a (Nass), and Gitksan, Sm'algy̲a̲x is an ergative-absolutive language with basic VAO/VS word order and polysynthetic morphology (Mulder & Sellers, 2010).

1.1 Sm'algy̲a̲x Phonology

1.1.1 Phonemes

According to Mulder (1994: 20), Sm'algy̲a̲x has thirty-eight consonant phonemes. Her table of the consonant phonemes is presented in Figure 1 below. It is pertinent to note especially that the language has a series of phonemic ejective stops, as well as the voiceless alveolar ejective affricate /ts'/. Also present are a series of palatalized, labialized, and uvular stops.

	bilabial	alveolar	palatalised	velar (plain)	labialised	uvular	pharyngeal	glottal
Stop:								
ejective	pʼ	tʼ	kʲʼ	kʼ	kʷʼ	qʼ		ʔ
voiceless	p	t	kʲ	k	kʷ	q		
voiced	b	d	gʲ	g	gʷ	ɢ		
Nasal:								
(plain)	m	n						
implosive	ˈm	ˈn						
Fricative:		s				χ	h	
Affricate:								
ejective		tsʼ						
voiceless		ts						
voiced		ʒ						
Approximate								
(plain)			j		w			
implosive			ˈj		ˈw			
unrounded:								
(plain)				ɯ̨				
implosive				ˈɯ̨				
Lateral:								
(plain)		l						
fricative		ɬ						
implosive		ˈl						

Figure 1: Sm'algy̲a̲x consonant phonemes

Sm'algy̲a̲x has contrastive long and short vowels; these are presented in Table 1. Additionally, glottalized and falling vowels occur, as do diphthongs, according to Dunn (1979). It should be noted that Dunn (1979) does not distinguish between interrupted vowels like those in the present discussion, resulting from metathesis, and what he terms glottalized vowels. It is, however, assumed that what he terms glottalized vowels are simply a series of VʔV.

Table 1: Sm'algya̲x vowel phonemes (Adapted from Dunn, 1978/1995 and Sasama 1997[1])

	Front	*Central*	*Back*
High	/i/ /iː/		/ɯ/ /ɯː/ /u/ /uː/
Mid	/e/ /eː/	/ə/	/o/ /oː/ /ɔ/ /ɔː/
Low	/a/ /aː/		

Minimal and near-minimal pairs, shown below in Example (1) illustrate contrastive vowel length. In each example pair, the first word represents the short vowel phoneme while the second provides the long vowel phoneme. Note that here, as seen in the transcribed form in 1(c), and throughout the paper, there is a departure from Dunn's (1979) transcription of glottalized consonants. While Dunn represents these as a series of a glottal stop preceding a consonant, ʔC, the choice is made in this discussion to transcribe these as a consonant with a glottalization feature: Cˀ. This helps to distinguish glottalized consonants from consonant clusters. In the examples in (1), the traditional practice of noting long vowels as Vː is followed.

(1)		*Token*	*Transcription*	*Gloss*
	a.	xsán	xsán	'gamble'
		xsáːn	xsáːn	'mosquito larvae'
	b.	gox	gɔx	'peck'
		gooxs	gɔːxs	'willow tree'
	c.	bip	bipʰ	'uncle-in-law' (address)
		bii'k	biːkˀ	'lie, tell a lie'
	d.	yel	jɛl	'drill'
		yeen	jɛːn	'fog'
	e.	amuks	ʔamúks	'listen, obey'
		amuus	ʔamúːs	'corner of a house' (inside)

[1] The identification of phonemes in Sm'algya̲x is far from straightforward. For example, Dunn (1970) presents only three short vowel phonemes: /i/, /e/, and /a/. In Dunn (1979 and 1978/1995), however, six vowels (all except /ə/) are listed, but not identified as phonemes. It seems that only the short vowel versions are represented as phonemes, with long vowels listed as variants. More recently, Stebbins and Hellwig (2010:44) provide a vowel inventory that includes vowels represented by IPA æ, æː and ɨ, ɨː and does not include ɯ, ɯː. The inventory does not clarify if the sounds presented are intended to represent phonemes; however, given that the inventory follows a discussion of the challenges associated with representing the sixty-five Sm'alg̲ya̲x phonemes in writing, it is likely that this is the case.

2 Vowel Interruption

2.1 As Evidenced in Sm'algya̲x

According to Dunn (1979: 11) long vowels undergo a process whereby they become "interrupted" with a glottal stop; this does not occur with short vowels.[2] These interrupted vowels occur when a long vowel is followed by a glottalized consonant. The glottalization bleeds into the long vowel which precedes the glottalized segment, thereby interrupting the vowel. In addition, after the vowel interruption occurs, the consonant is sometimes deleted. A later discussion by Dunn and Hays (1983: 47) briefly mentions the process, noting that vowels followed by a glottalized segment assimilate a laryngeal constriction and are realized as creaky. These vowels are then rearticulated, reflecting the perception of them as interrupted.

From the information provided by Dunn, this seems to be evidence of a phonological process at work, which suggests that these vowels differ from other glottalized vowels found in the language; these will be discussed further in §2.2.2

Phonetically, the interrupted vowels can be represented as [VʔV]. Phonemically, Sasama (1997: 48) analyzes them as /V:ʔC/. The data in Example (2) provide examples of vowel interruption. Note, however, that the choice is made in this discussion to depart from the standard notation of long vowels as V:. Instead, long vowels are noted as VV, thus, when two identical vowels are next to one another they should be interpreted as a long vowel. This choice is made in order to more clearly show the metathesis. Data points a-c are from Dunn's (1979) discussion of vowel interruption; points d-e are from Dunn's (1978/1995) dictionary. Finally, forms f-g are from Sasama's (1997) discussion of vowel interruption. To focus on the discussion at hand, tokens are provided only in phonetic forms.

[2] Sasama (1997) proposes that short vowels historically evidenced the interruption process. She notes that positing this helps to explain words such as gwe'a [gʷéːʔa] 'poor', which seems to show vowel interruption without a glottalized consonant following the long vowel.

(2)	*Uninterrupted form*	*Interrupted form*	*Gloss*
a.	biikˀ	bíʔɪkʰ	‘lie, tell a lie’
b.	nɛɛqˀ	nɛʔɪx	‘anal fin, dorsal fin’
c.	naaqˀ	naʔax	‘woman’s dress; skirt’
d.	ʔɔ́ɔtsˀn	ʔɔ́ʔɔtsn	‘spirit, nothingness’
e.	húupˀʰl	húʔupʰl	‘dark, evening, nighttime’
f.	łáatˀ	łáʔat	‘ball’
g.	t’úutsˀk	t’úʔutsk	‘black’

For all word pairs both forms are allowable, according to Dunn (1979:11) and Sasama (1997), respectively. Whether or not the interruption occurs is based on the preferred form used within a particular community or on speech quality; Sasama (1997) notes that the interrupted forms are more often observed in careful speech. However, more recent data suggests that this is not currently the case. For example, Anderson (2013) identifies only the members of two uninterrupted/interrupted word pairs as free variants. Likewise, some present-day Sm’algya̲x speakers seem to find only the interrupted forms acceptable (M. Ignace, personal communication). These issues will be discussed in §5.

The vowel interruption process appears to be one of metathesis; the vowel followed by [ʔ] is reordered so that the glottal stop precedes the vowel. As the vowel in the uninterrupted forms is long, this is somewhat obscured since the metathesis prompts the loss of the [+long] feature on the vowel, and can additionally trigger a shift in place for one of the resultant short vowels. It could also be the case that terming the process metathesis is an oversimplification.

2.1.1 Co-occurring processes

In some cases, lenition of the consonant that previously carried the glottalization occurs following the metathesis process discussed above. This is illustrated by the forms in Example (3).

(3)	*Initial Form*	*Lenited Form*	*Gloss*
a.	naaqˀ	naʔax	‘woman’s dress, skirt’
b.	soʌqˀ	sɔ́ʔax	‘robin’
c.	lɨksɔ́ʔaqʰ	lɨksɔʌx	‘door, doorway’

The pattern of consonant lenition seen in Example (3) can also extend further, with some consonants lenited to the point of deletion. This is illustrated in the examples in (4).

(4)		*Initial Form*	*Consonant Deletion*	*Gloss*
	a.	hanaaqˀ	hanáʔa	‘woman’[3]
	b.	haaqˀ	haʔa	‘goose’
	c.	nágˀɑ	náʔɑ	‘woman’s dress, skirt’

While the process of consonant lenition or deletion is optional, for the present discussion only those forms evidencing both vowel interruption and consonant deletion or lenition will be considered. This draws attention to the need for revisions to classic OT in order to account for opaque interactions.

2.2 Compared to Similar Phenomena in Other Languages

Prior to turning to a phonological explanation of vowel interruption, it is helpful to discuss some similar phenomena in other languages. This both demonstrates the plausibility of the vowel interruption process in Sm’algya̲x and shows its uniqueness from superficially comparable processes.

2.2.1 Echo vowels

Several languages evidence the presence of echo vowels. These are vowels that are rearticulated, often following a glottal stop, and have a perceptually weaker quality than the initial vowel (Gerfen & Baker, 2005). Such vowels are seen in Nisg̲a’a, a language closely related to Sm’algya̲x. Tarpent (1987: 117) notes that echo vowels occur following the release of /ʔ/ in preresonantal and preconsonantal positions. This is shown in the examples in (5)

(5)	*Underlying form*	*Surface form*	*Token*	*Gloss*
	móˀn	mɔ́ˀɔn	mo’on	‘salt’
	káˀskʷ	gʷáˀaskʷ	ga’askw	‘to look (around)’

2.2.2 Creaky vowels

Creaky vowels, variably termed laryngealized vowels or glottalized vowels, are attested in a variety of languages. For example, several Otomanguean languages have creaky vowels; these are often contrastive with breathy vowels. In Coatzospan Mixtec, a language spoken in southern Mexico, the production of laryngealized vowels is quite variable.

[3] Dunn (1979, 11) includes both of these forms. However, in Dunn’s (1978/1995) dictionary, he provides the forms [haná?a] and [haná?nqʰ] (entry 754). In a later entry, 756, he provides the form [haná?nqʰ] as the plural of [haná?a]

Gerfen and Baker (2005) note that the vowels have been described as "echo vowels" because the vowel appears to be briefly rearticulated; this results in the laryngealization not being present throughout the entire production of the vowel. Jalapa Mazatec, also Otomanguean, has a three-way voicing contrast amongst vowels: modal, breathy, and creaky (Gordon & Ladefoged, 2001). While perceptually the creaky vowels seem similar to those in Sm'algya̱x, they are clearly phonologically different in that the phonation is contrastive; this does not seem to be the case with the interrupted vowels.

A case more similar to the interrupted vowels in Sm'algya̱x is demonstrated in the laryngealized vowels of the Mixe-Zoque[4] language Sierra Popoluca. In this language, vowels are laryngealized (i.e. interrupted) when a glottal stop occurs with a long vowel in a syllable coda. As in Sm'algya̱x, this vowel laryngealization is not a contrastive feature (de Jong Boudreault, 2009: 107). De Jong Boudreault (2009) goes on to note that these vowels are perceived as VʔV, with the first vowel being a full vowel. What she marks with ʔ is a period of creaky voice; the second vowel is perceptually weaker in quality; as in those cases mentioned earlier in this section, she terms this weaker vowel an echo vowel.

Likewise, in another Mixe-Zoque language, Ayutla Mixe, rearticulated vowels interrupted with ʔ surface. Romero-Méndez (2008) comments that the environments in which glottal stop surfaces with vowels vary; glottal stop sometimes occurs with short vowels and in other environments occurs with a rearticulated vowel. He, along with Wichmann (1995: 72) speculates that this variation is due to a previously extant root of the form CVːʔCC. However, differing from the glottalized vowels in Sm'algya̱x, those in Ayutla Mixe are identified by Romero-Méndez (2008: 43) as an instantiation of a particular type of vowel nucleus. Additionally, both short and long vowels can carry the feature [+laryngeal]; as was stated previously, in Sm'algya̱x glottalization on vowels occurs only with

[4] The Tsimshianic languages have been proposed by some (e.g. Sapir 1921; Hymes, 1964) to be part of the same large family of languages as the Mixe-Zoque languages, as well as languages such as Yokuts, Klamath, Coos, and Sahaptian (Hymes 1964: 218). The existence of this proposed Penutian language family, and especially the membership of the Tsimshianic languages in such a family, has been questioned by many due to weak evidence and large geographical distance separating the languages. More recently, Tarpent (1997) has reconsidered the evidence for Coast Tsimshian's membership in the Penutian family, concluding that there is strong support for the hypothesis. While there are many valid arguments for both Tsimshian's exclusion from and inclusion in the Penutian grouping, this is beyond the scope of the current discussion.

long vowels.[5]

2.2.3 Interrupted vowels in Nisg̲a'a

Returning once again to the related Tsimshianic language, Nisg̲a'a, vowels interrupted with ʔ are also seen. While on the surface these look very much like the Sm'algyax interrupted vowels that are the topic of the present discussion, it is not necessarily the case that they result from glottal metathesis. Nevertheless, it is still prudent to make mention of such forms. It could potentially be the case that these forms are, indeed, evidence of the same process as in Sm'algyax, but show a form that, over time, has lost the glottalized consonant that triggered the process. Examples are provided in (6).

(6)	*Underlying form*	*Surface Form*	*Gloss*
a.	ʔiɬéʔ	ʔɪɬéʔɛ̝	'blood, to bleed'
b.	túwʔ	dú:ʔu̝	'over there'
c.	sóʔ	sɔ́ʔɔ̝	'(to take) food home from a feast'

Sasama (1997: 55) also draws attention to these similar vowels, providing additional examples from Tarpent (1987). These are provided in Example (7).

(7)	*Underlying form*	*Surface Form*	*Gloss*
a.	nté:ʔ	ndɛ:ʔɛ̝	'pass the…'
b.	titóʔ	didɔ́ʔɔ̝	'cheeks'
c.	kómʔsimʔ	gɔ́ʔˢmsimʔ	'go ahead! (pl.)'

Sm'algyax also contains forms with vowels interrupted by a ʔ that do not clearly result from glottal metathesis. For comparison, both with the Nisg̲a'a examples in (6) and (7) and the interrupted vowels resulting from metathesis that are the topic of the present discussion, some examples are provided in (8).

[5] However, Sasama (1997: 51-52) speculates that Sm'algyax historically distinguished between long and short glottalized vowels. She cites the examples of /kʷéːʔa/ [gʷéːʔɐ], 'poor' and /ʔáːʔa/ [ʔáːʔɐ], 'yes', saying that, while the vowel occurring after the glottal stop in both cases, [ɐ], is weak, and the vowel resembles an interrupted vowel, the only phonemic representation available is that provided, which has a different vowel phoneme [a] following the glottal stop.

(8)	*Surface form*	*Gloss*
a.	haʔáks	‘dipper’
b.	gʲɛ́ʔɛts	‘down South’
c.	yáʔansk^{h}	‘distribution, the act of passing around something’

2.2.4 Metathesis of glottalization

Moving briefly to a more general discussion of metathesis, glottal metathesis is evidenced in several languages. For example, this is seen in two Yuman languages, Kiliwa and the La Huerta dialect of Diegueño (Langdon 1976). In Kiliwa, glottal stops in pre-stressed initial positions metathesize with preceding, non-word initial nasals (Langdon 1976: 874). Glottal stops in La Huerta Diegueño also show metathesis, although the process is quite restricted, occurring only in verb forms where the glottal stop is in initial position and part of a pronominal prefix. In such cases, this initial glottal stop moves rightward to directly precede the verb root (Langdon 1976: 874). This is seen in the forms in Example (9):

(9)	*Language*	*Initial form*	*Glottal metathesis*	*Gloss*
	Kiliwa	pmʔi	pəʔmi	‘you said it’
	Diegueño	ʔnʸmkanap	nʸmkaʔnap	‘you told me’

The Algonquian language Blackfoot also shows glottal metathesis. Consider the example provided by Peterson (2004) in (10) that evidences glottal metathesis. Relevant segments are underlined. The first line presents the surface form after metathesis has occurred, while the second line shows the addition of the inchoative affix that appears to trigger the metathesis in this case.

(10) *nitáóʔmaiʔtakiwa*
nit-áʔ-omaiʔtakiwa
1-INCHOAT-believe
‘now I believe’
VʔVC ⟶ VVʔC

Peterson (2004: 107) proposes that, in Blackfoot, glottalization is a phonetic feature, rather than a phoneme, calling it the realization of the glottalization on a phonemically long vowel.

3 Previous Explanations

The discussion now returns to the topic of Sm’algya̲x interrupted vowels, considering explanations for the phenomenon from three theoretical

frameworks.[6] First, a rule-based account is discussed, followed by a traditional Optimality Theory (OT) account. As expected, OT cannot account for the counterbleeding opacity that results when the processes of vowel interruption and consonant deletion interact. This inability to account for the opaque interaction leads to the examination of the interacting processes from the framework of an extension of OT, namely, Optimality Theory with Candidate Chains (OT-CC).

3.1 Rule-Based Account

Those forms showing vowel interruption can be explained as a process of metathesis. A long vowel is interrupted with a glottal stop when it precedes a glottalized consonant. Thus, a word like húup^{ʔh}l would be realized as hú$ʔ$up^{h}l.
This is summarized in the metathesis rule in Figure 2.

$$VV ʔ C \longrightarrow V ʔ V C$$

Figure 2: Metathesis rule for vowel interruption

As discussed in §2.1.1, deletion of the formerly glottalized consonant can also occur following vowel interruption. For example, hanaaq^{ʔ} would be realized as haná$ʔ$a after both metathesis and glottalized consonant deletion occur. This is illustrated in the rule in Figure 3.

$$[\text{-sonorant}] \longrightarrow \emptyset / \_\_ \#$$

Figure 3: Rule for consonant deletion

3.1.1 Rule order in process interaction

In traditional rule-based theory, the processes of glottal metathesis and consonant deletion interact opaquely in a counterbleeding relationship. The consonant deletion rule obscures the context that triggered metathesis, making it appear that the metathesis rule has over applied. This can be seen by comparing the results of ordering the rule for consonant deletion with that for metathesis, shown in the sample derivations in Figure 4.

[6] It should also be noted that, in addition to the explanation provided in his 1979 grammar, Dunn has made additional attempts to address the issue of vowel interruption. For example, Dunn and Hays (1983) examine the process using Foley's (1977) phonetic bonding continua, which relies on a combination of the strength of features with the strength of the syllable position. More recently, Dunn (2015) explores a similar idea which he terms "syllable devolution". In this process, certain sounds, including [ʔ], in syllable codas lose features which are transferred to syllable peaks and onsets in a step-by-step process. He uses this gradual feature transference to account for the wealth of variation shown in certain lexical items.

	/haaqʔ/				/naaxʔ/		
Glottal Metathesis	haʔaq	Consonant deletion	haa	Glottal metathesis	naʔax	Consonant deletion	naa
Consonant deletion	haʔa	Glottal metathesis	---	Consonant deletion	naʔa	Glottal metathesis	---
✓	[haʔa]		[haa]	✓	[naʔa]		[naa]

Figure 4: Results of rule ordering

While rule ordering quite easily accounts for the interaction of metathesis and consonant deletion, it has many widely recognized weaknesses. For example, rules are language-specific, rather than universal, although the processes explained by a particular rule occur in multiple languages (e.g. syllable-final obstruent devoicing in German, per Wiese, 1996; as well as in Dutch, per Kager 1999: 14-17). Additionally, the presence of conspiracies, where several rules "conspire" to accomplish the same result, is also cited as a weakness of rule-based phonology (see, e.g. Kisseberth, 1970).

3.2 Optimality Theory Account

3.2.1 Overview of Optimality Theory

The problems previously mentioned, as well as others not treated here, served as a partial impetus to the development of Optimality Theory (OT). Prince and Smolensky, in their seminal work on the theory (1993/2002), note that every language has access to the same constraints; that is, the set of constraints is universal. Language differences, for instance, whether a particular language prefers epenthesis over deletion to eliminate disallowed consonant clusters, result from constraint ranking differences. Two types of constraints are posited: markedness constraints and faithfulness constraints. Faithfulness constraints evaluate potential outputs by comparing them to the initial inputs, while markedness constraints evaluate output forms.[7]

Notably, the universality of the constraint set guards against one of the weaknesses of rule-based theory: the promotion of descriptive completeness (McCarthy 2007). However, as will be shown in the analysis in §3.2.5, OT cannot account for many opaque interactions; counterbleeding interactions prove especially problematic. OT markedness constraints only evaluate outputs, and the opaque forms resulting from counterbleeding interactions are ones where, often, a more marked

[7] Alderete (2001) also proposes anti-faithfulness constraints. These constraints, as their name suggests, require that a related faithfulness constraint be violated.

structure is preferred as the winning candidate. Since the environment motivating the choice of an opaque, and more marked, output can no longer be seen in the surface structure, OT markedness constraints cannot account for why such a form is preferred over a transparent one (McCarthy 2007: 24-25). In this case, they cannot account for why something like 'haʔa' is preferred over 'haa'.

3.2.2 OT constraints for metathesis

As vowel interruption resulting from metathesis is the primary process considered in this discussion, constraints directly relevant to vowel interruption will be discussed first. Since metathesis is a re-ordering of segments, clearly a faithfulness constraint which assigns violations for such re-orderings in output forms is necessary. Often, the constraint employed is that of LINEARITY, whereby a violation is assigned for each pair of segments in the output whose order is reversed from their ordering in the input. However, here the choice is made to instead use Anttila, Fong, Beňuš, and Nycz' (2008) INTEGRITY-IO (INT-IO) constraint, as the glottalized consonants are best described as a single segment, Cʔ, rather than as a cluster of ʔC. The definition of INTEGRITY-IO is as follows:

> **INTEGRITY-IO (INT-IO):** Assign one violation for any series of segments in the input that is split in the output

In order to eliminate the fully faithful candidate containing the marked sequence V:Cʔ, a markedness constraint addressing this process is required. This is an ad-hoc constraint defined as follows:

> ***V:Cʔ** Assign one violation for each segment consisting of a long vowel followed by a glottalized consonant

While these constraints are those that are most directly related to the process of metathesis, additional constraints are also necessary to ensure that the correct candidate is selected as winner. These are discussed in §3.2.3. Following the introduction of these constraints, tableaux for both metathesis and consonant deletion are presented.

3.2.3 OT constraints for consonant deletion

Since the process is one of deletion, the faithfulness constraint MAX is necessary. The standard definition is used; this is as follows:

> **MAX**: Assign one violation for every segment in the input that is deleted in the output

As described above in §3.2.2, the fully faithful form of V:Cˀ appears to be dispreferred in Sm'algya̲x. Further, glottalized consonants alone seem to be dispreferred. In addition to the examples in the present discussion, other evidence from the language suggests that this is the case. For example, Dunn (1979: 12) notes that glottalized segments have a tendency to lose their glottalization feature and become voiced. This is seen in the forms in (11).[8]

(11)	*Initial Form*	*Form showing loss of glottalization*	*Gloss*
a.	qˀɑsqˀáʒn	gɑsgáʒn	'ants'
b.	kʷˀɪlí	gʷɨlí	'three' (of round and abstract objects)
c.	qˀɑsqʰós	gɑsgós	'crane, stork'

Thus, this suggests that an additional markedness constraint that addresses glottalized consonants is necessary. This constraint is defined as follows:

> ***Cˀ** Assign one violation for each segment in an output which consists of a glottalized consonant

In addition to the markedness constraint that disprefers glottalized consonants, the constraint NOCODA is also necessary. As it is often a coda consonant that deletes in these forms, this suggests that the language prefers to not have codas, or at least prefers not to have codas consisting of glottalized consonants. The standard definition of NOCODA is used; this is as follows:

> **NOCODA**: Assign one violation for every coda consonant in an output form

With faithfulness and markedness constraints that account for both processes, the discussion now turns to ranking these within classic OT.

[8] It is prudent to note, however, that while Dunn (1979: 12) provides these forms as pairs in a data list, they are not always listed as variants in Dunn's (1978/1995) dictionary. In other cases, it seems that the difference may be a dialectal one rather than a language-wide process. For example, in the case of the forms in example 11b, what is termed the initial form is labeled as being from the Prince Rupert dialect while the form with the loss of glottalization is provided in a separate entry and identified as being from the Hartley Bay dialect.

3.2.4 Constraint ranking for metathesis

Tableau 1 shows the ranking order for metathesis. The token selected, /biikʔ/, was chosen as, according to the information provided by Dunn (1978/1995), the language does not have a form that also evidences glottalized consonant deletion.

Tableau 1: Constraint ranking for metathesis

/biikʔ/	***V:Cʔ**	***Cʔ**	**MAX**	**INT-IO**	**NOCODA**
a. biikʔ	*!	*			*
b. bii			*!		
c. bikʔ		*!			*
→ d. biʔik				*	*
e. biʔi			*!	*	
f. bikʔi		*!		*	
g. biiʔ			*!		*

***V:Cʔ, *Cʔ, MAX >> INT-IO >> NOCODA**

The high-ranked markedness constraint *V:Cʔ assigns a fatal violation to the fully faithful form and passes the selection to *Cʔ. In this pass, both candidates (c) and (f) are eliminated, as both of these candidates contain a glottalized consonant. This constraint also assigns an additional violation to the fully faithful form, candidate (a). The choice then moves to the relatively high-ranked faithfulness constraint, MAX. In this pass, candidate (b), which deletes the coda, is eliminated. Likewise, candidates (e) and (g) are assigned fatal violations by MAX as they both delete the formerly glottalized consonant. While the three high-ranked constraints do most of the work in eliminating incorrect winners, crucially it is the ranking of INT-IO above NOCODA that ultimately selects the correct winning candidate, (d) over the other candidates.

In cases showing both vowel interruption and consonant deletion, the constraints would be in a different ranking order. Notably, NOCODA >> MAX in order to select the less faithful, yet preferred, candidate showing coda consonant deletion. This then results in an order like *V:Cʔ, *Cʔ, NOCODA >> MAX>> INT-IO. Having a different ranking order than that shown for metathesis is not problematic in this case. As mentioned previously, most of the forms in the language are in variation, according to Dunn (1979). Thus, these different ranking orders simply reflect the variation in the language; that, for example, a form like 'hanaʔaq', 'woman' and one like 'hanaʔa' are both allowed. Further, since there are no forms currently under consideration evidencing just Cʔ deletion without metathesis, providing a tableau attempting to show just this deletion is not informative. Thus, the discussion now turns a tableau illustrating the difficulty in accounting for the process interaction in OT.

3.2.5 Constraint ranking for interaction of processes

As evidenced in the previous discussion, while simply ranking INTEGRITY-IO >> NOCODA selects the correct candidate in the case of metathesis, attempting to account for the interaction of processes in classic OT proves problematic. This is seen in Tableau 2.

Tableau 2: Ranking paradox resulting from interaction of processes

	/haaqʔ/	***V:Cʔ**	***Cʔ**	**NOCODA**	**MAX**	**INT-IO**
	a. haaqʔ	*!	*	*		
←	b. haa				*	
	c. haqʔ		*!	*		
	d. haʔaq			*!		*
→	e. haʔa				*	*!
	f. haqʔa		*!			*
	g. haaʔ			*!	*	
	h. haaq			*!		

It is first important to note that, as was previously the case, the ranking order of the three markedness constraints is flexible. The constraints driving the selection of the winning candidate are the two faithfulness constraints, MAX and INTEGRITY-IO. Turning now to the assignment of violations, the fully faithful form, candidate (a), is eliminated by the high-ranked markedness constraint *V:Cʔ. Candidates (c) and (f), which both have glottalized consonants, are then eliminated by the high-ranked ***Cʔ**. The choice of candidates then passes to NOCODA; this assigns fatal violations to candidates (d), (g), and (h). The choice of winner moves then to MAX. As both remaining candidates (b) and (e) violate MAX, it is left to the lowest-ranked constraint, INTEGRITY-IO, to select the winner. However, this results in the incorrect choice of candidate (b) over the expected winner, candidate (e). A close examination of the constraint ranking further shows that there is no ranking order possible that will result in the selection of the correct winner.

How, then, can the interaction of metathesis and Cʔ deletion be accounted for? One option is to look to one of several extensions proposed to classic OT theory; it is to this that the discussion now turns.

4 Overview of OT-CC

While classic OT can elegantly deal with a variety of phonological phenomena, many opaque interactions, as demonstrated in §3.2.5, prove

problematic. Indeed, the inability of OT to account for opacity is one of its major weaknesses (McCarthy 2007). Rather than dispense with an otherwise strong theory, attempts were made to extend OT to better deal with opaque interactions (see, for example, Łubowicz, 2003 for a discussion of local constraint conjunction, Bermúdez-Otero, 1999 for stratal OT, McCarthy, 2003a for comparative markedness, or McCarthy 1999, 2003b for sympathy theory). [9]

A relatively more recent extension is McCarthy's (2007) Optimality Theory with Candidate Chains (OT-CC). This theory, at the most basic level, is a synthesis of the constraint rankings of OT with an expanded form of the derivations of rule-based theory (McCarthy 2007). The next several sections first briefly introduction the main principles of OT-CC and then move to an analysis of Sm'algya̲x interrupted vowels from within this framework.

4.1 Description of the Theory

4.1.1 Candidate Chains

In addition to the constraints familiar from OT, OT-CC also introduces what McCarthy (2007) terms *candidate chains*. These are chains of possible output forms, beginning with the fully faithful candidate and including a variable number of intermediate forms. Forms in a chain must meet the requirements of faithfulness, gradualness, and local optimality in order to be a part of an allowable candidate chain. These requirements, adapted from those in McCarthy (2007: 61-62), are explicated below:

> (i) **Faithful first member:** The first member of the chain is a fully faithful candidate. In other words, it violates no faithfulness constraints
> (ii) **Gradualness:** Faithfulness constraint violation occurs gradually. That is, each candidate in a chain shows an accumulation of the faithfulness violations of previous candidates while adding violation of only one additional faithfulness constraint. McCarthy (2007: 61) terms these gradual violations *localized unfaithful mappings*, or LUMs
> (iii) **Local optimality:** Each successive form in a chain shows harmonic improvement from the previous form. Additionally, the form is more harmonic than all other possible candidates that could result from a violation of the same faithfulness constraint. That is, the candidate evidences the "best" violation.

Due to the requirement of local optimality, OT-CC changes some

[9] The present discussion will not examine these; however, in addition to those references already provided the interested reader might also wish to consult McCarthy (2007: 27-55) for an overview of several of these extensions.

aspects of OT. Notably, consultation between GEN and EVAL is required in order for the grammar to determine which candidate is most harmonically improving and the best faithfulness violation. Additionally, due to the restriction of harmonic improvement, there are a limited number of candidates in the OT-CC set, compared to the infinite number in the OT candidate set (McCarthy 2007: 65).

4.1.2 LUMs and PREC Constraints

In order for the candidate chains to go beyond the derivations garnered from rule-ordering, while, at the same time maintaining consistency with the constraint-ranking architecture of OT, several additional requirements are necessary. First is the idea of LUMs. As mentioned before, this term refers to the *local unfaithful mappings* represented by each form in a candidate chain. The set of LUMs in a given chain is referred to as the LUM Sequence, or LUMSeq. Within a candidate chain, each form represents the addition of one LUM.

Precedence, or PREC, constraints result from the presence of convergent chains. As the name suggests, convergent chains occur when there are two or more chains that have the same output and the same LUMs. The chains differ only in the order of LUMs (McCarthy, 2007: 96). Rather than evaluate the same candidates in two different orders, these are treated as one candidate set. McCarthy's (2007: 98) formalization of PREC constraints specifies the order in which LUMs must be violated. Further, PREC constraints can only apply after all candidate chains, and any possible converging chains, are determined. These constraints can assign violations in two circumstances: If there are two constraints of the order (A, B), one violation can be incurred if a candidate has a structure that violates constraint B before constraint A. Additionally, PREC (A, B) can also assign a violation to a candidate that has a structure that violates constraint B without a preceding violation of constraint A.[10]

4.1.3 Review of key OT-CC definitions

Prior to moving to the proposed analysis of Sm'algya̱x interrupted vowels from within the OT-CC framework, key terms are presented in list form, and defined following McCarthy (2007) in Figure 5.

[10] In addition to LUMs and PREC constraints, McCarthy (2007: 95-99) also proposes the ideas of the $\mathcal{L}$-set and rLUMSeq. Due to the scope of the present discussion, these are not discussed; the phenomenon can be explained without these more technical aspects of the theory.

Candidate chain	A series of possible forms, beginning with the fully faithful form; each subsequent form reflects only one additional faithfulness constraint violation while also reflecting the accumulation of the violations of all previous forms
LUM	Acronym for 'local unfaithful mapping'; refers to the gradual faithfulness violations accrued by forms in a candidate chain
LUMSeq	The series of all LUMs violated by the forms in a given candidate chain
Convergent chains	Two or more candidate chains having the same output and same LUMs; differ only in the order of LUMs
PREC Constraints	Precedence constraints; they evaluate the relationship between the LUMs in an rLUMSeq

Figure 5: Definition of key terms in OT-CC

4.2 OT-CC Account of Sm'algya̲x Interrupted Vowels

The discussion now turns to a re-analysis of Sm'algya̲x interrupted vowels and consonant deletion from the framework of OT-CC. The formation of candidate chains will first be examined, followed by a presentation of tableaux.

4.2.1 Formation of candidate chains

To demonstrate how a candidate chain is formed, the paper revisits the example word /haaqʔ/ from §3.2.5. In Figure 6, the candidate chains are shown on the left and the LUMs are on the right. The first form in the chain, shown in (a), is the fully faithful candidate; as such it will be identical to the phonemic representation just presented. As a reminder, the relevant faithfulness constraints are MAX and INTEGRITY-IO (INT-IO), defined in §3.2.3 and 3.2.2, respectively.

a.	<haaqʔ>	ø
b.	<haaqʔ, haa>	MAX
c.	<haaqʔ haʔaq>	INT-IO
d.	<haaqʔ,haʔaq, haʔa>	INT-IO, MAX ✓

Figure 6: Formation of candidate chains for /haaqʔ/

Candidate chain (a) consists of only the fully faithful form. Chain (b) begins with the fully faithful form; the next form, haa, incurs one violation of MAX. Likewise, chain (c) begins with the faithful form; the output form haʔaq shows a violation of INT-IO due to the presence of metathesis. Finally, chain (d), which contains the winning output form haʔa, begins with the fully faithful form and then moves to the form haʔaq, which violates INT-IO, and then to the desired output, haʔa, which violates MAX.

Notably, there are far fewer candidates provided in the candidate chains than were considered in the OT account for haaqˀ provided in Tableau 2. This is due to the fact that the main problem that OT-CC is seeking to account for is why the candidate showing metathesis and consonant deletion, haˀa, is selected over haa; the candidate that the OT account incorrectly chooses as winner.

4.2.2 Application of OT-CC to the data

Now that the process of forming candidate chains has been examined, the discussion moves to the ranking of constraints in OT-CC. Note that, like in an OT tableau, candidates are presented along the leftmost column. Also like an OT tableau, constraints are ordered and ranked along the topmost row. However, note that the OT-CC tableau lists the faithfulness constraints that each candidate violates. Also note that an additional constraint has been added, namely a precedence constraint. As a reminder, precedence constraints specify the order in which faithfulness constraints must be violated. The precedence constraint employed here is defined as follows:

> **PREC (INT-IO, MAX)** : Assign one violation mark for any violation of INT-IO that is not preceded by a violation of MAX; additionally, assign one violation mark for any violation of MAX that follows a violation of INT-IO.

Tableau 3 shows the ranking of constraints for the output forms from the candidate chains provided in Figure 6. As was found in the classic OT analysis, the markedness constraint *V:Cˀ eliminates the fully faithful form, candidate (a). This candidate incurs a further violation from the *Cˀ constraint. The final markedness constraint, NOCODA, adds yet another violation to the fully faithful candidate (a), and assigns a fatal violation to candidate (c), which shows only metathesis. The selection of winner then moves to the first faithfulness constraint, MAX. This constraint assigns one violation to each of the remaining candidates: candidate (b) has deleted the final segment, qˀ, as has candidate (d). Thus, with these two forms tied, the choice passes to the precedence constraint. This constraint assigns a fatal violation to candidate (b), haa, resulting in a correct selection of candidate (d), which evidences both metathesis and consonant deletion.

Tableau 3: OT-CC constraint ranking for /haaqʔ/

/haaqʔ/	*V:Cʔ	*Cʔ	NOCODA	MAX	PREC(INT-IO, MAX)	INT-IO
a. haaqʔ Ø	*!	*	*			
b. haa **MAX**				*	*!	
c. haʔaq **INT-IO**			*!			*
→ d. haʔa **INT-IO, MAX**				*		*

4.3 Discussion of Results

The account provided above does seem to provide a fairly satisfying account of the counterbleeding opacity evidenced in the interaction of Sm'algya̲x vowel interruption and consonant deletion. However, many questions still remain; some of these will be addressed here.

First, the careful reader will have noted the omission of the candidate 'biik' in the tableau for metathesis (Tableau 1) and, likewise, the omission of the candidate 'haqa' in the tableau describing the interaction of processes (Tableau 2). Including a featural markedness constraint such as MAX-GLOTTAL eliminates such candidates, allowing for OT to provide an adequate account of the interaction of metathesis and consonant deletion. Likewise, the preference for candidates such as 'hanaʔa' over ones such as 'hanaaq' suggests that a constraint like MAX-GLOTTAL might be viable. However, based on the research conducted for this discussion, it is not clear that such a constraint accurately describes the preferences of Sm'algya̲x as a whole. For example, as described above in §3.2.3, Dunn (1979: 12) notes a tendency for glottalized segments to lose their glottalization feature and become voiced. With the limited examples provided, it is not clear whether this is a common process or not. If it is, then the analysis of the interaction of metathesis and consonant deletion could indeed be worth further consideration.

5 Interrupted Vowels in Modern Sm'algya̲x

As noted earlier, while Dunn (1979) maintains that all three forms, that without an interrupted vowel, that with an interrupted vowel, and that with an interrupted vowel and deleted consonant, are allowable in Sm'algya̲x, more recent data suggests that this is no longer the case. Most notably, the intuition of some present-day speakers is that the non-interrupted forms are not allowable (M. Ignace, personal communication). This is also seen in data from the Sm'algya̲x online talking dictionary (Anderson, 2013).

For example, consider again the token used in Tableau 1 to illustrate the constraint ranking for metathesis. While Dunn (1978/1995) provides both biiʔk and biʔikʰ as valid forms, Anderson (2013) only includes the form biʔikʰ:

(12)	*Dunn (1978/1995)*	*Anderson (2013)*
	biiʔk	-----
	biʔikʰ	biʔikʰ

In other cases, forms that Dunn (1979) used as support for the phenomenon of consonant deletion following vowel interruption are classified by Anderson (2013) as dialectal variants. For instance, Dunn (1979) provides hanaaqˀ and hanaʔa as forms for 'woman'. However, Anderson (2013) gives hanaʔax as the main entry, classifying hanaʔa as a dialectal variant.

(13)	*Dunn (1978/1995)*	*Anderson (2013)*
	hanaaqˀ	hanaʔax
	hanaʔa	hanaʔa

6 Further Research

With the questions remaining from the analysis as to whether or not a constraint such as MAX-GLOTTAL can be employed, and the changes evidenced in the data in Anderson (2013), it is clear that much work remains to be done to gain a clearer understanding of Sm'algya̲x vowel interruption. Completing a field study comparing the acceptability of interrupted and uninterrupted forms of the various data points presented in Dunn (1978/1995, 1979) would be beneficial both in terms of adding to the general body of work on Sm'algya̲x and also in terms of documenting the process of language change. Some of the difficulties encountered in the OT-CC analysis might be alleviated through this; perhaps the present-day forms would result in a proposal of either new constraints or new constraint rankings.

Additionally, examining the data within other theoretical frameworks might also prove useful in explaining the phenomenon. Perhaps, for example, the vowel interruption is a type of segment shift, analyzed by Gietz, Jurgec, & Percival (2015) with Harmonic Serialism (see McCarthy, 2010 for an overview). They note that such languages as Gitksan show segment shift, and, notably, Ayutla Mixe, mentioned previously in §2.2.2, shows laryngeal segment shift. If it is the case that the Sm'algya̲x glottal metathesis process is one of segment shift, Harmonic Serialism might be able to successfully account for the phenomenon.

Additionally, doing a thorough comparative analysis among vowels that appear to be interrupted in Sm'algya̱x, Nisga'a and Gitksan would be beneficial. This would not only likely provide insight into the process of vowel interruption, but might also lead to a better understanding of the motivation of vowel interruption.

Finally, and perhaps most importantly, gaining a more thorough understanding of Sm'algya̱x glottal metathesis and consonant deletion requires native speaker intuition. For example, a discussion of why an uninterrupted form like biik^{ʔ} is not allowed, and why the interrupted biʔik^{h} is, would likely lead to both a better understanding of the phenomenon itself as well as a clearer understanding of the motivation for glottal metathesis and subsequent vowel interruption.

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