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The relationship between coronal place and vowel backness

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Abstract:

It has been proposed that coronal consonants and front vowels are both specified [coronal] (e.g. Hume 1992). This leads to the prediction that all coronals can condition fronting of adjacent vowels. While fronting of vowels by coronals is attested (e.g. in Cantonese), not all kinds of coronals can condition fronting - retroflexes condition retraction of vowels. We propose an account of the effects of coronals on vowels according to which they involve simple assimilation to the tongue body position of the coronal – i.e. coronals that condition fronting are produced with a fronted tongue body, while coronals which condition backing of vowels are produced with a more retracted tongue body. Tongue body position is affected by the position of the tongue tip and blade because these articulators are physically connected, so for each type of coronal there are preferred tongue body positions that minimize the effort of producing the coronal constriction. This analysis also accounts for the fact that vowel backness can affect coronal place.

1. Introduction

It is well established that coronals can condition fronting of vowels (Clements 1991, Hume 1992). For example, Cantonese has a maximal system of vowel contrasts shown in (1), contrasting front and back rounded vowels (2a), but back rounded vowels cannot appear between coronal consonants (2b) (Kao 1971). As Cheng (1991) argues, this distributional restriction can be understood as resulting from fronting of vowels between coronals. Other examples of vowel fronting conditioned by coronals are discussed in Clements (1991), Hume (1992) and Flemming (2002).

(1)

i	y	u
e	ø	o
	a,aː	

(2)

a.	kʰy̪t̪	‘decide’	kʰu̪t̪	‘bracket’
	hø	‘boots’	ho	‘river’
b.	t̪ʰyt	‘to take off’	*t̪ʰu̪t̪	t̪ʰʊk ‘bald head’
	t̪ʰø̪n̪	‘a shield’	*t̪ʰo̪n̪	t̪ʰok ‘to carry (on shoulders)’

Data like these have been used to support the proposal that both front vowels and coronal consonants are specified as [coronal] (Clements 1991, Hume 1992). Fronting of vowels by coronals can then be analyzed as spreading [coronal] from consonant to vowel. However, not all types of coronals can condition vowel fronting. In particular, retroflexes condition vowel retraction (Bhat 1973, Gnanadesikan 1994). For example, the Dravidian language Kodagu contrasts front and back unrounded vowels (3, 4) (Emeneau 1970, Ebert 1996). But front vowels do not appear before retroflexes (5)[1]. This pattern results from the retraction of vowels before retroflexes.

(3)

i	ɯ	u
e	ɤ	o
	a	

(4)

kiːt̪ɯ	‘torn piece’	kɯːd̪a	‘below’	
et̪̪ɯ	‘arrive!’	ɤt̪̪ɯ	‘ox’	(Ebert 1996:7)

(5)

ɯɖi	‘the whole’	**uɖ**ɯ-	‘to put on (sari)’ (DED 587)	***iɖ**
k**ɯːɭ**ɯ	‘lower, below’	k**uːɭ**ɯ	‘cooked rice’ (DED 1911)	***iːɭ**
ɤɳe	‘double’ (DED 457)	**oɳ**ak-	‘to dry’ (DED 601)	***eɳ**
k**ɤːɖ**ɯ	‘ruin’	k**oːɖ**ɤ	‘monkey’ (DED 2196)	***eːɖ**

One of the basic questions addressed in this paper is which coronals condition fronting of vowels, and which condition retraction. The answer proposed here is that the effect of coronals on adjacent vowels depends on the position of the tongue body during the coronal. Coronals that condition fronting are produced with a fronted tongue body, while coronals that condition retraction are produced with a back tongue body. That is, these phenomena involve simple assimilation in tongue body position.

The position of the tongue body during a coronal is influenced by the nature of the coronal constriction because the tongue tip is attached to the tongue body, so placement of the tip and blade of the tongue to form a constriction is facilitated if the tongue body moves cooperatively. We will see that dentals, alveolars, and palato-alveolars are preferentially produced with a fronted tongue body, whereas retroflexes are most easily produced with a retracted tongue body position. However, these tongue body positions are not inherent to the coronal

[1] Data are from Emeneau (1970) unless otherwise noted. Data from Burrow and Emeneau (1984) are marked ‘DED’ (Dravidian Etymological Dictionary), together with the number of their entry in the dictionary.

articulations, they are simply preferred for reasons of ease of articulation. These preferences may be out-ranked by other constraints, for example to realize contrastive velarization on a coronal. A velarized coronal is then correctly predicted to condition vowel retraction only, regardless of the nature of the coronal constriction. Analyses that attribute the fronting effect of coronals to their [coronal] specification incorrectly predict that velarized coronals should be able to condition vowel fronting.

While constraints on preferred combinations of coronal articulations and tongue body positions find their initial motivation in the analysis of the effects of coronals on vowels, they also predict that vowels should affect the place of adjacent coronals. For example, retroflexes are preferentially produced with a back tongue body. Vowel retraction, as in Kodagu, results where vowels assimilate to this preferred tongue body position. But if a retroflex is forced to assimilate to the tongue body position of a front vowel instead, then loss of retroflexion can result, since retroflexion is difficult to produce with a front tongue body. We will explore the range of predicted interactions and show that they are all attested.

Besides providing a more complete account of the relationship between coronal place and vowel backness, the analysis developed here has a number of interesting implications. First, tongue body position must be represented on coronals, even where it is highly redundant, so the analyses here provide evidence for relatively detailed, redundant phonological representations. Second, the relationships between coronal and dorsal articulations are established by constraints rather than representations. Most previous analyses of vowel fronting by coronals have sought to identify some feature that is shared by coronals and front vowels, proposing that front vowels are specified as [coronal]. By contrast, the present analysis argues that certain coronals are predisposed to have a fronted tongue body, where the predisposition is implemented as a violable Optimality Theoretic constraint (Prince and Smolensky 1993). The availability of this type of analysis shows that it is not appropriate to conclude that sound types must share a feature just because they interact in assimilation processes. The interaction may instead be mediated by a constraint that relates the two sound types (Hayes 1998). That is, coronals and front vowels need not inherently share any feature, because the relationship between anterior coronals and frontness is established by a feature cooccurrence constraint.

The paper is organized as follows: §2 presents evidence for the ease of articulation constraints assumed in the analyses. §3 presents an Optimality Theoretic analysis of the basic patterns of interaction between coronals and vowel backness, and outlines the full typology of interactions that is predicted by the proposed constraints. Some refinements to the basic analysis are introduced in §4

to account for directionality effects. In §§5-9 the typology of coronal-backness interactions is exemplified with analyses from a variety of languages. Conclusions are presented in section §10.

2. The articulatory basis of interactions between coronal place and vowel backness

As noted above, the placement of the tongue tip and blade to form a coronal constriction is facilitated if the tongue body moves cooperatively since the tongue tip and blade ride on the tongue body. The preferred tongue body position depends on the nature of the coronal constriction. The basic divisions are between anterior coronals (dentals and alveolars), non-anterior laminal coronals (palato-alveolars), and non-anterior apical coronals (retroflexes).

Anterior coronals (dentals and alveolars) require the tongue tip and/or blade to be at or near the front teeth. This is most easily achieved if the tongue body is in a relatively forward position (Öhman 1966:167, Stevens 1999:355), otherwise considerable stretching of the tongue is required. This fronted tongue body position is observed in Öhman's (1966) X-ray study of Swedish (p.167), and is reflected in the relatively high second formant (F2) frequencies typically observed adjacent to anterior coronals, even when adjacent to back vowels (Manuel and Stevens 1995).

There are some differences between dentals and alveolars, as discussed in §9, but all anterior coronals favor a fronted tongue body position and consequently pattern alike in most interactions with vowel backness.

Non-anterior laminal coronals (palato-alveolars) involve a constriction formed by the tongue blade, behind the alveolar ridge. The tongue blade is just in front of the tongue body, so it is difficult to place the blade in the palato-alveolar region without the tongue body being close to the hard palate, i.e. fronted. This fronted tongue body position results in high F2 adjacent to palato-alveolars. Studies of a variety of languages have found that palato-alveolars have higher F2 transitions than other coronals, suggesting a stricter fronting requirement at this place of articulation (English: Fowler 1994, Malayalam: Dart 1991, Dart and Nihilani 1999, Arrernte: Anderson 1997).

Non-anterior apical coronals (retroflexes) cover a range of articulations from full retroflexion, in which the underside of the tongue tip contacts the hard palate, to apical post-alveolars, in which the tip of the tongue forms a constriction just behind the alveolar ridge (Ladefoged and Maddieson 1996:25ff.). Extreme

curvature of the front of the tongue is necessary to produce full retroflexion with a front tongue body. Even more modest retroflexion is problematic with a front tongue body, because forming a palatal constriction for a front vowel involves raising the front of the tongue body, which tends to roll the tongue tip forward and down. It is easiest to curl the tongue tip back towards the palate if the tongue body is back, allowing the front of the tongue to be lowered, leaving room for the tip to curl back behind the alveolar ridge (Bhat 1974, Lindblom and Sundberg 1974). Tongue body retraction during retroflexes has been observed experimentally in Tamil by Wiltshire and Goldstein (1997), and is reported by Emeneau (1970:194) to be a general property of retroflexes in Dravidian languages.

This picture is complicated somewhat by the fact that many retroflexes are phonetically dynamic. That is, the tongue tip is most fully retracted at the formation of the constriction, but the tongue tip moves forward during the consonant constriction, and is released at or just behind the alveolar ridge (Dave 1977, Anderson and Maddieson 1994, Spajić et al 1994, Butcher 1995). This dynamic pattern means that it is the closure phase of a retroflex that requires a back tongue body position, since this is the portion of the consonant that is most retroflexed. We will see below that this is significant in explaining the directionality of effects involving retroflexes, e.g. retroflexes retract preceding vowels, not following vowels[2].

Labials and plain velars are not subject to any comparable restrictions on the backness of the tongue body, so they do not exert any general fronting or backing effect on vowels. Production of a labial constriction is unaffected by tongue body backness, so labials can assimilate to the tongue body positions of adjacent vowels. Although velars are articulated with the tongue body, the precise positioning of the closure seems to be relatively unimportant, so velars also assimilate to the tongue body positions of adjacent vowels (Öhman 1966, Houde 1967).

3. An analysis of interactions between coronal place and vowel backness

The preferences outlined above can be formalized in terms of three basic constraints relating each type of coronal articulation to a preferred tongue body position (6).

[2] Steriade (1995, 2001) demonstrates that the dynamic realization of retroflexes also has consequences for the distribution of contrasts between retroflexes and apical alveolars.

(6) ANTERIOR→FRONT: [+anterior] → [front]
PALATO-ALVEOLAR→FRONT: [-anterior, laminal] → [front]
RETROFLEX→BACK : [-anterior, apical] → [back]

To interpret these constraints properly, it is necessary to clarify the nature of the features [front], [apical] and [laminal]. Vowel backness is treated here as a scale with three ordered values, [front], [central] and [back]. It is standard to make only a binary distinction between front and back vowels using the feature [back], but this leaves no general way to distinguish central vowels. We will see that central vowels pattern distinctly from both back and front vowels in some of the phenomena analyzed here (§6), so it is necessary to distinguish three tongue body positions on the front-back dimension. It would be possible to employ two binary features for this purpose, e.g. [+/-back] and [+/-front], but for present purposes it is more straightforward to treat backness as a scale so the three values can be referred to together in constraints like IDENT(backness) and AGREE(backness), introduced below[3].

The features [apical] and [laminal] are used rather than [+/-distributed] (Chomsky and Halle 1968:312f.) because the part of the tongue used to form a coronal constriction is relevant to the preferred tongue body position, whereas the length of the constriction is not[4]. The specifications [apical] and [laminal] are mutually exclusive – i.e. a given coronal is either [apical] or [laminal]. Two features are used rather than, for example, [+/-laminal] to make the representations easier to read.

With these representational assumptions in place, it can be seen that ANTERIOR→FRONT requires [+anterior] coronals to have a front tongue body, so it is violated by anterior coronals with [central] or [back] tongue body positions. Similarly, PALATO-ALVEOLAR→FRONT is violated by [-anterior, laminal] coronals with [central] or [back] tongue body positions, and RETROFLEX→BACK is violated by [-anterior, apical] coronals with [front] or [central] tongue body positions.

It would be plausible to further differentiate between the dispreferred tongue body positions. For example, anterior coronals may well be more difficult to produce with a back tongue body than with a central tongue body, but this further distinction is not necessary for the analyses developed here. However, we will see evidence that front retroflexes are more marked than central retroflexes in §6. This difference is formalized in terms of an additional constraint

[3] Cf. Gnanadesikan (1997) for a proposal to employ similar scalar features in phonology.
[4] It is often assumed that apicals are [-distributed] and laminals are [+distributed], but Keating (1993) shows that this is not the case. For example, retroflexes can have long constrictions although apical, due to compression of the tongue tip against the roof of the mouth. Conversely laminal palato-alveolars can have short constrictions in speakers with pronounced alveolar ridges.

*FRONTRETROFLEX which is violated by [-anterior, apical, front] segments, and is ranked above RETROFLEX□ BACK.

Note that the anterior coronals produced with a fronted tongue body are distinct from palatalized coronals. Indeed, there is evidence that palatalization is dispreferred with most types of anterior coronals. This evidence, and the representation of the distinction between fronted and palatalized coronals is discussed in §9.

In most of the analyses below, assimilation between adjacent consonants and vowels is driven by AGREE(backness) which penalizes adjacent consonant and vowel segments that differ in position on the backness dimension (cf. Lombardi 1999) (a more precise formulation is given in §4).

These constraints are sufficient to derive fronting by anterior coronals and palato-alveolars, and retraction by retroflexes. The analysis of fronting by anterior coronals is illustrated in (7) (front tongue body is indicated by superscript [^{i}] and back tongue body by superscript [^{ɯ}]). ANTERIOR□ FRONT is undominated, so anterior coronals must be produced with a front tongue body, i.e. candidate (a) is eliminated. But AGREE(backness) is also undominated, so consonant and vowel must be produced with the same tongue body position. This is inconsistent with faithful realization of the back vowel [u]. The constraint which requires faithful realization of the backness specification of the vowel, IDENT(backness)$_V$, is ranked lowest, so the optimal candidate is (7c), where the vowel assimilates to the preferred tongue body position of the anterior coronal.

(7)

	/tu/	ANTERIOR□ FRONT	AGREE (backness)	IDENT (backness)$_V$
a.	t^{ɯ}u	*!		
b.	t^{i}u		*!	
c. ☞	t^{i}y			*

Fronting by palato-alveolars is derived by a similar ranking, with PALATO-ALVEOLAR□ FRONT(PA□ FRONT) in place of ANTERIOR□ FRONT. It is hypothesized that PA□ FRONT universally ranks above ANTERIOR□ FRONT, so whenever anterior coronals condition vowel fronting, palato-alveolars do so as well (§5).

Retraction of vowels before retroflexes involves the constraint ranking in (8). The preference for retroflexes to be produced with a back tongue body is enforced by RETROFLEX□ BACK. This constraint and the assimilation constraint, AGREE(backness), are ranked above IDENT(backness)$_V$, so vowels are retracted, assimilating to the preferred tongue body position of the retroflex.

(8)

	/iʈ/	RETROFLEX ⇒ BACK	AGREE (backness)	IDENT (backness)$_V$
a.	$i^{i}ʈ$	*!		
b.	$i^{ɯ}ʈ$		*!	
c.	☞ $ɯ^{ɯ}ʈ$			*

However, the proposed constraints have implications that go beyond these two basic phenomena. First, these analyses do not make particular tongue body positions inherent to each type of coronal. The constraints on the relationship between types of coronals and tongue body position simply specify the least-effort coronal-backness configurations. That is, they implement a preference for effort minimization that can be out-ranked by other constraints. For example, realizing velarization or uvularization contrasts on anterior coronals involves violating the preference for producing this type of coronal with a front tongue body. Marshallese, an Austronesian language, exhibits contrasts between palatalized and velarized dentals (Bender 1968), e.g. [t̪^{j}ɔ] 'ignite' vs. [t̪^{ˠ}ɔ] 'sugar cane'. Similarly the emphatic coronals of Arabic involve a back tongue body position. This is often referred to as pharyngealization, but this is somewhat misleading, since the constriction is much higher than in a primary pharyngeal consonant (McCarthy 1994, Ladefoged and Maddieson 1996:366). Consequently McCarthy (1994) proposes the term 'uvularization'. Like velarization, this secondary articulation results in a low second formant (Al-Ani 1970, Card 1983), but the two articulations seem to differ in that the tongue body is high and back in velarization, but is lower in uvularization.

These violations of ANTERIOR⇒ FRONT are motivated by faithfulness to secondary articulations, as in the ranking in (9). The realization of velarization or pharyngealization contrasts is taken to involve faithfulness to the input [back] specification of a consonant, enforced by the constraint IDENT(backness)$_C$.

(9) IDENT(backness)$_C$ >> ANTERIOR⇒ FRONT

The effect of a coronal on adjacent vowels depends on its actual tongue body position. So only anterior coronals that are actually produced with a front tongue body can condition fronting of vowels. If the preference for this tongue body position is violated then no fronting effect is predicted. On the contrary, since velarized and uvular zed coronals have a back tongue body position, they are expected to condition vowel retraction. This is the case in Arabic, where vowels are retracted in the environment of emphatics. The effect is particularly striking on low vowels, which are back in emphatic environments but front elsewhere (Card 1983) (10). Vowels are also retracted adjacent to velarized consonants in

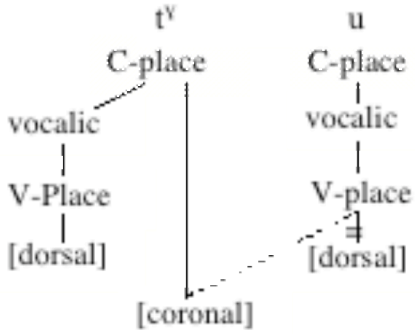
Marshallese (Bender 1968), although this effect has been analyzed by Choi (1992) as phonetic interpolation through unspecified vowels rather than phonological assimilation to [back].

(10)

bæːs	'he kissed'		bɑːsˤ	'bus'
fæːdi	(boy's name)		fɑːdˤi	'empty'

Models in which vowel fronting is conditioned by the coronal specification of a consonant (e.g. Clements 1991, Hume 1992, Clements and Hume 1995) predict that velarized coronals should be able to condition vowel fronting. For example, in the model proposed by Clements and Hume (1995) a velarized coronal has a [coronal] consonant place, while velarization is specified by the feature [dorsal] under the V-Place node (11). The primary [coronal] place specification should be able to spread to an adjacent vowel, conditioning fronting. This is problematic since there are no cases in which velarized or pharyngealized consonants condition fronting.

(11)



The other prediction that follows from the analysis outlined so far is that interactions between vowels and coronal consonants should go in both directions. We have seen that the place of a coronal consonant can affect vowel backness, but vowel backness is also predicted to affect the place of articulation of coronals. For example, vowel retraction conditioned by retroflexes has been analyzed as a consequence of RETROFLEX□ BACK, which creates a dispreference for front retroflexes, and AGREE(backness), which disprefers movement of the tongue body between adjacent coronals and vowels. These two constraints create a conflict in sequences of a front vowel and a retroflex, such as [iʈ]. A faithful realization of this input necessarily violates one of the constraints, as shown in (8) above. In that tableau it was shown that the conflict could be resolved by retracting the vowel, violating faithfulness to [back], but it could also be satisfied by advancing the

coronal to alveolar, violating faithfulness to [anterior]. This avoids a violation of RETROFLEX□ BACK because this constraint is not applicable to an alveolar, and alveolars are preferentially produced with a front tongue body. This pattern of vowel-dependent variation in coronal place is attested in a number of Australian languages, as we will see below (§6).

In general, AGREE(backness) can create conflicts between vowel backness and the backness preference of an adjacent coronal. Such a conflict can be resolved by changing vowel backness to make it compatible with coronal, or by modifying the coronal to make it more compatible with the vowel. A coronal may be modified by a change in [anterior], or in [apical]/[laminal]. So the constraints introduced above predict the typology of interactions between coronal place and vowel backness summarized in table 1. The table shows the three coronal-backness constraints, and the different types of 'repairs' that can serve to satisfy each constraint while also satisfying AGREE(backness). Much of the rest of the paper is devoted to showing that these predicted interactions are in fact attested, but before presenting these data we will introduce a refinement of the coronal-backness constraints, designed to account for some generalizations about the directionality of the observed consonant-vowel interactions.

ANTERIOR□ FRONT	
vowel fronting	tu → ty
coronal retraction	u̪t̪ → ut̪
RETROFLEX□ BACK	
vowel retraction	it̪ → ɯt̪
coronal advancement	it̪ → i̪t̪
laminalization	s̪i → ʃi
PA□ FRONT	
vowel fronting	ʃu → ʃy
apicalization	ʃu → s̪u
coronal advancement[5]	t̻u → t̪u

Table 1. The predicted typology of interactions between coronal place and vowel backness.

[5] Palato-alveolar stops are transcribed with a subscript line, [t̻], following Ladefoged and Maddieson (1996:15).

4. Directionality effects

Interactions between vowels and coronals vary in their directionality, for example in Kodagu vowels are retracted before retroflexes, whereas in Lahu (§5.2) vowels are fronted after anterior and palato-alveolar coronals. The constraints proposed above do not provide any way to derive directional assimilation so some modifications are required to account for these restrictions. Furthermore, directionality does not seem to vary arbitrarily, but is systematically related to the nature of the interaction involved. The main generalization is that retroflexes primarily interact with preceding vowels, as in Kodagu. This generalization can be understood as a consequence of the fact many retroflexes are only fully retroflexed at the onset of constriction because the constriction is released via an anterior movement of the tongue tip (§2). Since only the onset of a retroflex is fully retroflexed, only the onset requires a back tongue body position. So assimilation of a preceding vowel to the onset of a retroflex can result in vowel backing, but assimilation of a following vowel to the release of a retroflex does not (cf. Bhat 1973:46f. for a similar explanation).

To formalize this analysis, it is necessary to distinguish closure and release phases of consonants, allowing for the possibility of distinct backness specifications in each position. This is related to Steriade's (1993, 1994) proposal to represent stops in terms of closure and release positions, but this bi-positional representation is extended here to consonants of all manners, whereas in Steriade's proposal it is restricted to stops and nasals.

We then need to posit a constraint RETROFLEX□ BACKCLOSURE which specifies that only the closure of a retroflex needs to be [back] (12). Where a feature associates to only closure or release, this is indicated by prefixing *clo:*, for 'closure', or *rel:*, for 'release'.

(12) RETROFLEX□ BACKCLOSURE: [-anterior, apical] □ clo:[back]

The assimilation constraint, AGREE(backness), is then formulated to require agreement between the closure phase of a consonant and a preceding vowel, and between the release phase of a consonant and a following vowel (13). This formulation implies that a retroflex with a [back] closure can only condition retraction of a preceding vowel. AGREE(backness) is probably motivated in part by effort minimization since it disprefers tongue body movement, but it more specifically favors an arrangement in which transitions between vowels occur during consonants rather than during the vowels themselves. This arrangement serves to minimize vocalic transitions which might adversely affect the perception of vowel quality.

(13) AGREE(backness): A consonant closure or release must have the same value of backness as an adjacent vowel.

Non-retroflex coronals sometimes condition fronting of following vowels only. This pattern is accounted for in terms of position-specific variants of the other coronal-backness constraints, requiring a front tongue body position at the release of anterior coronals and palato-alveolars (14). There is no evidence that these types of coronals are routinely given dynamic realizations, but it is clear that tongue body movements can occur during most consonant types (Öhman 1966). The fact that these constraints single out the release phase reflects the perceptual importance of consonant release for most place contrasts other than those between retroflexes and apical alveolars (Steriade 2001, Wright 2001, Redford and Diehl 1999).

(14) ANTERIOR FRONTRELEASE: [+anterior] rel:[front]
PALATO-ALVEOLAR FRONTRELEASE: [-anterior, laminal] rel:[front]

The release-specific constraints in (14) are in addition to the general constraints ANTERIOR FRONT and PALATO-ALVEOLAR FRONT, since these coronals sometimes interact with preceding vowels as well as following vowels. On the other hand, it is not clear whether a general constraint RETROFLEX BACK is motivated in addition to RETROFLEX BACKCLOSURE. This asymmetry makes sense if retroflexes are consistently given dynamic realizations of the kind described above[6].

5. Vowel fronting conditioned by anterior and palato-alveolar coronals

We now turn to the task of showing that the predicted typology of coronal-backness interactions summarized in table 1 (above) is fully attested, analyzing representative phenomena in terms of the constraints proposed in §3 and §4. We begin in this section with vowel fronting conditioned by anterior and palato-alveolar coronals.

[6] Bhat (1973) speculates that retroflex fricatives and affricates are produced with retroflexion sustained through the consonant (p.47). There is not much data on the realization of retroflex fricatives, but spectrograms of Toda retroflex fricatives in Shalev, Ladefoged and Bhaskararao (1993) show relatively steady spectral shape through the fricative, so Bhat may be correct. This would imply that fricative and affricate retroflexes should be more affected by following vowels than other retroflexes. Interestingly there is one case in which retroflexion is affected by a following vowel, Acoma (§7.2), and the consonants involved are all fricatives and affricates. Although this case can be analyzed wthout recourse to RETROFLEX BACK, it does suggest that manner-related differences in the behavior of retroflexes would be worth investigating.

The schematic ranking for fronting conditioned by anterior coronals is given in (15). The markedness constraints ANTERIOR FRONT and AGREE(backness) motivate unfaithful realizations of sequences involving anterior coronals and back vowels. AGREE(backness) requires the coronal to assimilate to the adjacent back vowel, but this would result in a dispreferred tongue position for an anterior coronal, violating ANTERIOR FRONT. One way to satisfy these constraints is to front the vowel, but another resolution is to retract the coronal to retroflex, since retroflexes are compatible with a back tongue body. So to derive vowel fronting, IDENT(anterior), which requires input [anterior] specifications to be preserved in the output, must be ranked below IDENT(backness)$_V$ (15).

(15) Vowel fronting conditioned by anterior coronals:
ANTERIOR FRONT, AGREE(backness), IDENT(ant) >> IDENT(backness)$_V$

Fronting of vowels by palato-alveolars is derived by a similar ranking in which PALATO-ALVEOLAR FRONT (PA FRONT) replaces ANTERIOR FRONT (16).

(16) Vowel fronting conditioned by palato-alveolars:
* PA FRONT, AGREE(backness) >> IDENT(backness)$_V$

Note that employing two independent constraints, PA FRONT and ANTERIOR FRONT, predicts that fronting by palato-alveolars and anterior coronals should be independent. However PA FRONT may rank above ANTERIOR FRONT universally since palato-alveolars are typically characterized by a fronter tongue body than anterior coronals (§2). This ranking implies that palato-alveolars should condition fronting of vowels wherever anterior coronals do so. This is true of Lahu (§5.2 below) and Moroccan Arabic (Hume 1992:7), the only relevant cases of which I am aware. This ranking further predicts that palato-alveolars can have fronting effects where anterior coronals do not. Kodagu exemplifies this pattern (§7.1).

Vowel fronting is illustrated here from the languages Cantonese and Lahu.

5.1 Cantonese

As outlined in section 1, back vowels are fronted between dentals in Cantonese, resulting in neutralization of the contrast between front and back rounded vowels (17b). Dentals are the only coronal consonants in Cantonese, but neutralization also occurs between the palatal glide and a dental (17c).

(17) a. $k^h y̪t̪$ ‘decide’ $k^h u̪t̪$ ‘bracket’
hø ‘boots’ ho ‘river’

b. $t̪^h yt$ ‘to take off’ $*t̪^h u̪t̪$ $t̪^h ʊk$ ‘bald head’
$t̪^h øn̪$ ‘a shield’ $*t̪^h on̪$ $t̪^h ok$ ‘to carry (on shoulders)’

c. $jy̪t̪$ ‘moon’ $*ju̪t̪$
$jø̪t̪$ ‘weak’ $*jo̪t̪$

The schematic constraint ranking for vowel fronting between anterior coronals has already been given in (15), but some additional details must be supplied to derive the particular facts of Cantonese. In Cantonese vowels are only fronted when preceded and followed by coronals, whereas the ranking in (15) derives fronting by a single coronal. The Cantonese pattern can be derived by local conjunction of AGREE(backness) with itself, in the domain of the syllable (Smolensky 1995). That is, we posit a constraint AGREE(backness)^2, which is violated only if backness changes in both the CV and VC portions of a syllable, so the constraint is violated by sequences such as [$t^i u^i t$], but not by [$k^ɯ u^i t$]. This conjoined constraint is always ranked above the basic AGREE(backness) constraint.

The ranking for vowel fronting in Cantonese is then as shown in (18). Superscripts preceding consonants indicate closure specifications for backness, while superscripts following consonants mark release specifications. Faithful realization of a back vowel between coronals is not possible because the undominated constraint ANTERIOR FRONT requires the dentals to be produced with a front tongue body, ruling out candidates (a) and (c), and AGREE(backness)^2 requires the vowel to agree with tongue body position of at least one adjacent consonant, ruling out candidate (b). So either the vowel must be fronted or a coronal (d) must be made non-anterior (e). Since IDENT(backness)$_V$ is lower ranked, vowel fronting is the optimal outcome (candidate d).

(18)

	/t̪ut̪/	ANT FRONT	AGREE (backness)^2	IDENT (anterior)	IDENT (backness)$_V$
a.	$t̪^ɯ u^ɯ t̪$	*!*			
b.	$t̪^i u^i t̪$		*!		
c.	$t̪^ɯ u^i t̪$	*!			
d. ☞	$t̪^i y^i t̪$				*
e.	$t̪^ɯ u^ɯ t̪$			*!*	

To derive the fact that back vowels may occur with a single coronal, AGREE(backness) must be ranked below IDENT(backness)$_V$ (19). A back vowel adjacent to a single front consonant does not violate AGREE(backness)^2, so the faithful realization (candidate b) is possible.

(19)

/kuṯ/	ANT FRONT	AGREE (backness)^2	IDENT (anterior)	IDENT (backness)$_V$	AGREE (backness)
a. $k^{ɯ}u^{ɯ}t̪$	*!				
b. ☞ $k^{ɯ}u^{i}t̪$					*
c. $k^{i}y^{i}t̪$				*!	

5.2 Lahu

Lahu (Matisoff 1973, 1988, Bradley 1979) provides evidence for the fronting effects of anterior and palato-alveolar coronals. Lahu distinguishes front, central and back high and mid vowels (20) (data from Matisoff 1988), but these central vowels cannot follow coronal consonants (alveolars and palato-alveolars) (21)[7]. The same restriction applies following palatal glides. The absence of central vowels in these environments can be analyzed in terms of a process of vowel-fronting conditioned by these consonants (historically, the coronals and palatals blocked the retraction of earlier front vowels that resulted in the front-central contrast (Matisoff 1973:5)).

(20)

hí	'eight'	hɨ	'agree'		hu	'fry'
e	'mother'	ə	'to pour out'		ó	'sleep'

(21)

ni	'look at, try doing'	*nɨ	*nə
tʃ^{h}i	'this'	*tʃ^{h}ɨ	*tʃ^{h}ə
tí	'only'	*tɨ	*tə
ʃí	'yellow, golden'	*ʃɨ	*ʃə
tse	'arrow'	*tsɨ	*tsə
dê	'something useless'	*dɨ	*də
lē	'to play'	*lɨ	*lə
jì	'go'	*jɨ	*jə

[7] Matisoff states that the alveolar sibilants can be followed by the high central vowel /ɨ/, but in fact the sounds that he phonemicizes in this way are realized as syllabic fricatives (p.7). That is Matisoff's /tsɨ/ is phonetically [tsz̩], in which the syllabic is fully assimilated to the preceding coronal.

The basic constraint ranking is thus similar to Cantonese, except that the relevant assimilation constraint is AGREE(backness), since fronting is conditioned by a single preceding coronal (22). To account for the directionality of assimilation, ANTERIOR FRONTRELEASE (ANT FRONTREL) must be high-ranked – this constraint requires only the release of a coronal to be front, so only following vowels are fronted (23). (Central tongue body position is indicated by superscript [ɨ]).

(22) ANT FRONTREL, AGREE(backness), IDENT(anterior) >> IDENT(backness)$_V$

(23)

/tɨ/	ANT FRONTREL	AGREE (backness)	IDENT (backness)$_V$
a. tɨɨ	*!		
b. tɨɨ		*!	
c. ☞ tɨi			*

A preceding central vowel is not fronted because the closure of the coronal can assimilate the tongue body position of the vowel, satisfying AGREE(backness) without violating ANT FRONTREL (24a). ANT FRONT, which requires both closure and release to be front, must be ranked below IDENT(backness)$_V$ otherwise it would force fronting of both preceding and following vowels.

(24)

/ɨti/	ANT FRONTREL	AGREE (backness)	IDENT (backness)$_V$	ANT FRONT
a. ☞ ɨtɨi				*
b. ɨtɨi			*!	
c. ɨtɨi		*!		

Additional constraints are required to account for the fact that back vowels are not fronted in these contexts. A similar pattern is observed in Kodagu (§7.1), where palato-alveolars have a fronting effect on back unrounded vowels, but not on back rounded vowels. Neither language allows front rounded vowels in any context, so whatever constraints govern the basic inventory of vowel contrasts can account for the non-application of fronting in these cases, if they rank above AGREE(backness). We will assume for present purposes that the relevant constraint simply forbids front rounded vowels: *[front, +round]. Ranked above Agree(backness), this constraint prevents the creation of front rounded vowels through assimilation (25), i.e. candidate (a) is preferred to candidate (b).

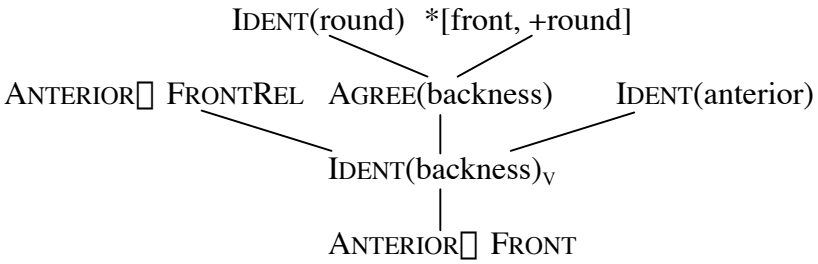
IDENT(round) must also be highly ranked in order to prevent fronting and unrounding of back rounded vowels (candidate d). Central vowels are free to undergo fronting, because the result is a well-formed front unrounded vowel.

(25)

	/tu/	ANT FRONTREL	IDENT (round)	*[front, +round]	AGREE (backness)	IDENT $(\text{backness})_V$
a.	☞ $t^{i}u$				*	
b.	$t^{i}y$			*!		*
c.	$t^{i}i$		*!			*

The fact that palato-alveolars condition fronting as well indicates that PA FRONT also outranks AGREE(backness). As noted above, PA FRONT may always be ranked above ANTERIOR FRONT, in which case this ranking automatically follows from the ranking in (22), above. So the full ranking for Lahu fronting is as shown in (26). Rankings between constraints are indicated by lines running from the dominant constraint down to the dominated constraint.

(26)



Lahu is reported to have a low central vowel, but no fronting is described in this case. It is not clear that this vowel is actually central, since Matisoff (1973) describes it as similar to the vowel in the English word *father* (p.11), which is a back vowel in most accents. In any case, any fronting of the low vowel would be allophonic, since there is no contrast with a low front vowel, and so might not be noted.

6. Retraction and advancement of apical coronals: Wargamay and Walmatjari

In Cantonese and Lahu, consonant place affects vowel backness, but vowel backness can also affect the place of articulation of coronal consonants. For example, in Wargamay (Dixon 1981) there is a contrast between apical coronals /t̪, n̪/ and laminal coronals /t̻, n̻/, but both types of consonants can vary in

anteriority. The apicals are usually alveolar, but are optionally retroflex following the back vowel [u] (there are only three vowels, [i, a, u]). Dixon (1980) reports that this pattern of variation is common in Eastern Australian languages that lack contrasts between apical alveolar and retroflex consonants (p.155).

A similar pattern is also observed in Walmatjari (Hudson and Richards 1969) which does contrast apical alveolar and retroflex consonants, but neutralizes these contrasts word-initially. The contextual variation in anteriority arises in this position of neutralization: the neutralized apicals are alveolar following [i], but retroflex following [a, u]:

(27)	jiŋgi **l**anda	'poke'	pɑri **n**ʊŋʊdʲɛɽi	'boy, bleeding'
	jaɹu **ɭ**anda	'wound it'	maŋa **ʈ**arpaɽa	'hold the girl!'

In both languages anterior apicals are found after front vowels, while retroflexes are occur after back vowels. These interactions between anteriority and vowel backness are expected given the constraints ANTERIOR□ FRONT (ANT□ FRONT) and RETROFLEX□ BACKCLOSURE (RETRO□ BACKCLO). So a straightforward analysis of this pattern is that apicals assimilate the tongue body position of preceding vowel, and their anteriority is then governed primarily by these effort minimization constraints, since faithfulness to anteriority is low-ranked (28-29). This ranking derives retroflexes following back vowels (28), and alveolars following front vowels (29). A retroflex input is assumed here to show that the alveolar is preferred even if it is unfaithful – clearly this would also be the optimal output if the input were specified as alveolar.

(28)

/uʈ/	AGREE (backness)	RETRO□ BACKCLO	ANT□ FRONT	IDENT (ant)
a. u^{i}ʈ̟	*!			
b. u^{ɯ}ʈ̟			*!	
c. ☞ u^{ɯ}ʈ				*

(29)

/iʈ/	AGREE (backness)	RETRO□ BACKCLO	ANT□ FRONT	IDENT (ant)
a. ☞ i^{i}ʈ̟				*
b. i^{i}ʈ		*!		
c. i^{ɯ}ʈ	*!			

However, this basic analysis needs some refinement in order to account for cross-linguistic variation in the effect of central vowels on apicals. In Wargamay,

apical coronals are alveolar after the low central vowel [a]. But in Walmatjari apical coronals are retroflexed after both central [a] and back [u].

One possible line of analysis is to attribute this difference to differences in the relative ranking of RETRO□ BACKCLO and ANTERIOR□ FRONT. A central tongue body position is not preferred with either anterior or retroflex coronals since RETRO□ BACKCLO is violated by a retroflex with a central tongue body, and ANTERIOR□ FRONT is violated by an anterior coronal with a central tongue body, so an apical that assimilates to a central vowel necessarily violates one of these constraints. The preferred violation depends on their relative ranking, so if ANTERIOR□ FRONT is ranked higher, then retroflexes are preferred after central vowels, as in Walmatjari, and if RETROFLEX□ BACK is ranked higher, then apical alveolars are preferred, as in Wargamay.

Although appealingly simple, this analysis of Walmatjari has some problematic typological implications. Languages with only a single series of coronals have dental or alveolar stops, not retroflexes. But if ANTERIOR□ FRONT can rank above RETROFLEX□ BACK, then we can derive a language with a single series of coronal consonants that are realized as alveolars only after front vowels, and as retroflexes in all other contexts, i.e. a language with predominantly retroflex coronals.

The problem with the ranking ANTERIOR□ FRONT >> RETROFLEX□ BACK is that it makes most anterior coronals (i.e. those with back or central tongue body position) more marked than most retroflexes, whereas general typological considerations suggest that retroflexes are more marked than anterior coronals in most contexts. In other words, typological evidence suggests that retroflexes are generally dispreferred relative to anterior coronals (alveolars and dentals), probably because full retroflexion is a relatively effortful articulation. To account for these typological generalizations, we need to that RETROFLEX□ BACK is universally ranked above ANTERIOR□ FRONT. We also adopt a general constraint against retroflexion, *RETROFLEX to account for the general markedness of retroflexes.

Given this basic dispreference for retroflexes, we must identify some other factor that leads to a preference for retroflexes in languages like Walmatjari. The claim advanced here is that retroflexes are preferred over apical because retroflexes are perceptually more distinct from laminal coronals than apical alveolars. Evidence comes from Anderson's (1997) study of perceptual confusions between coronals in the Australian language Arrernte. She found that apical alveolar stops and nasals were misidentified as laminals about 10% of the time, whereas retroflexes where misidentified as laminals about 1% of the time. In addition, a study by Anderson and Maddieson (1994) of the acoustic correlates of similar coronal place contrasts in Tiwi found that retroflexes were acoustically

better distinguished from other coronals than apical alveolars. So retroflexion of apicals enhances the distinction between apical and laminal coronals.

This analysis is implemented in terms of a constraint APICAL RETROFLEX (30). This constraint is only applicable where [apical] is contrastive but this aspect of the constraint is left unformalized here (see Flemming 2001 for discussion of constraints of this type). Given this restriction, we avoid the prediction that there should be languages with only retroflex coronals since the preference for retroflexes only arises where there is a contrast between apical and laminal coronals, as in Walmatjari and Wargamay.

(30) APICAL RETROFLEX: contrastively [apical] coronals must be [-anterior].

The preference for retroflex apicals is opposed by the fixed hierarchy of effort constraints against retroflexion (31). So there is a conflict between enhancement and effort minimization. The resolution of this conflict depends on the ranking of the enhancement constraint APICAL RETROFLEX with respect to the effort constraints.

(31) *FRONTRETROFLEXCLOSURE >> RETROFLEX BACKCLOSURE >> *RETROFLEX

In Walmatjari, enhancement prevails in all except the most difficult environment for producing a retroflex, adjacent to a front vowel. This pattern follows from the ranking in (32), in which only *FRONT RETROFLEXCLOSURE (*FRONTRETROCLO) out-ranks APICAL RETROFLEX, so retroflexion is favored unless it would have to be produced with a front tongue body. The closure of a consonant is required to share the tongue body position of a preceding vowel by undominated AGREE(backness).

(32) AGREE(backness), *FRONT RETROCLO >> APICAL RETRO >> RETRO BACKCLO >> *RETROFLEX

IDENT(anterior) must be ranked below *FRONT RETROFLEX and APICAL RETROFLEX so the anteriority of coronals is determined by the vowel context rather than faithfulness to any input value of [anterior]. The derivation of retroflexes after [a, u] and alveolars after [i] is illustrated in the (33-35). These tableaux only include candidates that satisfy AGREE(backness) since this constraint is undominated. This constraint is consequently omitted from the tableaux. As usual, unfaithful derivations are illustrated to demonstrate the irrelevance of underlying [anterior] specifications in this context.

(33)

/iʈ/	*FRONT RETROCLO	APICAL → RETRO	RETRO→ BACKCLO	IDENT (ant)
a. i^{i}ʈ	*!		*	
b. ☞ i^{i}t̪		*		*

(34)

/at̪/	*FRONT RETROCLO	APICAL → RETRO	RETRO→ BACKCLO	IDENT (ant)
a. ☞ a^{i}ʈ			*	*
b. a^{i}t̪		*!		

(35)

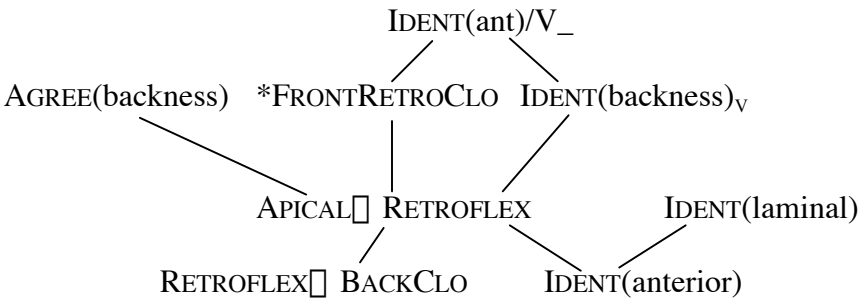
/ut̪/	*FRONT RETROCLO	APICAL → RETRO	RETRO→ BACKCLO	IDENT (ant)
a. ☞ u^{ɯ}ʈ				*
b. u^{ɯ}t̪		*!		

Walmatjari advances retroflexes to apical alveolars after front vowels. There are two other possible repairs of sequences like [iʈ]: the vowel could be retracted (iʈ→ ɯʈ), or the retroflex could be made laminal, while remaining [-anterior] (iʈ→ it̪). To block these possibilities IDENT(backness)$_V$ must outrank APICAL→ RETROFLEX, and faithfulness to input [apical]/[laminal] specifications (IDENT(laminal)) must rank above IDENT(anterior). These alternative repairs are observed in other languages (§7).

Finally, Walmatjari does contrast retroflexes and apical alveolars in post-vocalic position. This pattern can be analyzed in terms of a high-ranked positional faithfulness constraint, specific to the post-vocalic environment (36), although this aspect of the analysis is not of primary interest here (see Steriade 1995, 2001 for analysis of the distribution of retroflexion contrasts). So the complete ranking is as in (37).

(36) IDENT(ant)/V_ : The [anterior] specification of an output segment following a vowel in the same word must be the same as its corresponding input segment.

(37)



Note that retraction of coronals is not motivated by ANTERIOR FRONT according to this analysis, it is motivated by APICAL RETROFLEX, so while the predicted correlation between back vowels and retroflexes is attested, it is not clear that it results from the coronal-backness effort constraints. On the other hand, retroflexion is blocked after front vowels by *FRONT RETROCLO (33), which is the expected pattern of coronal advancement conditioned by front vowels.

Wargamay can also be analyzed in very similar terms. This language makes much more restricted use of retroflexes: they only occur after back vowels. This distribution is derived by ranking APICAL RETROFLEX below RETROFLEX BACK (38), so apicals are enhanced by retroflexion only where it is easiest to do so, i.e. where the tongue body is back. Again, the closure of a consonant is forced to share the tongue body position of a preceding vowel by undominated AGREE(backness).

(38) AGREE(backness), *FRONT RETROFLEXCLO
>> RETROFLEX BACKCLO >> APICAL RETROFLEX, *RETROFLEX

The operation of this ranking is illustrated in (39-41). Again, only candidates that satisfy undominated AGREE(backness) are included. After front vowels (39) and central vowels (40), retroflexion is unacceptable since it would violate RETROFLEX BACKCLO. After back vowels, retroflexion is acceptable since the retroflex can be realized with a back tongue body (41). Variation between retroflex and apical alveolar realizations in this context is derived by allowing variation in the ranking of APICAL RETROFLEX and *RETROFLEX (Anttila 1997, Reynolds 1994), so both rankings are acceptable. If APICAL RETROFLEX is ranked higher, retroflexion is optimal, while the reverse ranking derives the apical alveolar output (41). The constraint ANTERIOR FRONT must not be ranked above *RETROFLEX otherwise we derive only retroflexes after back vowels, rather than variation, since candidate (41a) violates this constraint.

(39)

/iʈ/	RETRO BACKCLO	APICAL RETRO	*RETRO	ANT FRONT
a. ☞ i^{i}t̪		*		
b. i^{i}ʈ	*!		*	

(40)

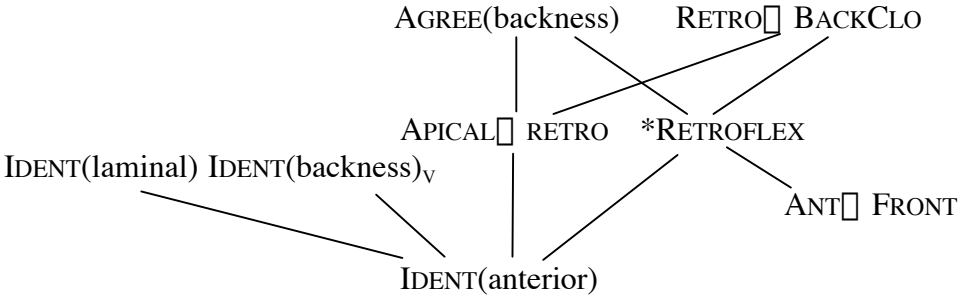
/aʈ/	RETRO BACKCLO	APICAL RETRO	*RETRO	ANT FRONT
a. ☞ a^{i}t̪		*		*
b. a^{i}ʈ	*!		*	

(41)

/ut/	RETRO BACKCLO	APICAL RETRO	*RETRO	ANT FRONT
a. ☞ u^{ɯ}t̪		*		*
b. ☞ u^{ɯ}ʈ			*	

The complete constraint ranking is shown in (42). In addition to the rankings already motivated, IDENT(anterior) is ranked below APICAL RETRO and *RETROFLEX so faithfulness never determines anteriority, deriving the fact that there is no contrast between apical alveolars and retroflexes in Wargamay. And IDENT(laminal) and IDENT(backness)$_V$ are ranked above IDENT(anterior), so advancement of retroflexes is preferred over a change in apicality or vowel fronting.

(42)



Again, retroflexion is motivated by APICAL RETRO rather than ANT FRONT, although in this case the same results can be derived if ANT FRONT replaces APICAL RETRO, as can be seen from the tableaux in (39)-(41). So there is some ambiguity as to the basis for this correlation between back vowels and retroflexes, although it is clear that it exists.

The effects of vowel backness on coronal anteriority observed in Wargamay and Walmatjari are not accounted for by the analysis of coronals in Hume (1992).

Hume argues that front vowels are [-anterior] to account for the relationship between palatalization and palato-alveolar place in coronals (§9), so they would not be expected to condition a shift from a [-anterior] retroflex to a [+anterior] alveolar. We will see in §8.2 that front vowels are associated with [-anterior] laminals, so front vowels cannot be straightforwardly associated with either [+anterior] or [-anterior].

Note that Walmatjari and Wargamay show that central vowels pattern as intermediate between front and back vowels, as we would expect given their phonetic character. That is, they pattern with back vowels in conditioning retroflexes in Walmatjari, but they pattern with front vowels in conditioning alveolars in Wargamay. If central vowels were treated as [+back, -round], as is often assumed, then we would expect them to pattern consistently with the back vowels.

7. Front vowels and retroflex consonants

The pattern of coronal advancement analyzed in the previous section is just one resolution of a conflict that arises in sequences of a front vowel and a retroflex consonant, such as [iʈ]. AGREE(backness) forces assimilation, but if the retroflex assimilates the front tongue body position of the vowel, it violates RETROFLEX□ BACK. In the Australian languages this conflict is resolved by changing the retroflex into an alveolar, which is compatible with a front tongue body. An alternative is a change from apical to laminal, yielding a palato-alveolar which is also compatible with a front tongue body, or the vowel could be retracted, assimilating to the preferred tongue body position of the retroflex. The preferred resolution depends on the relative ranking of the faithfulness constraints IDENT(anterior), IDENT(laminal), and IDENT(backness)$_V$.

Vowel retraction is exemplified from Kodagu, which is analyzed in more detail below and laminalization is attested in Acoma (§7.2).

7.1 Retraction of vowels: Kodagu

Kodagu exemplifies retraction of vowels before retroflexes. As outlined in section 1, Kodagu contrasts front and back unrounded vowels, and back rounded vowels, but front vowels cannot generally appear before retroflexes (Emeneau 1970, Ebert 1996) (43). This distribution can be analyzed as the result of retraction of front vowels by retroflexes, certainly this is the historical origin of the back unrounded vowels.

(43)	**ɯɖi**	‘the whole’	**uɖɯ-**	‘to put on (sari)’	***iɖ**
	kɯːɭɯ	‘lower, below’	**kuːɭɯ**	‘cooked rice’	***iːɭ**
	ɤɳe	‘double’	**oɳak-**	‘to dry’	***eɳ**
	kɤːɖɯ	‘ruin, rottenness’	**koːɖɤ**	‘monkey’	***eːɖ**

The core of the analysis is illustrated in (44). The constraint RETROFLEX BACKCLO requires retroflexes to be realized with a back tongue body at closure, and AGREE(backness) is ranked above IDENT(backness)$_V$, so a preceding vowel must assimilate to this tongue body position.

(44)

/iʈ/	RETRO BACKCLO	AGREE (backness)	IDENT (backness)$_V$
a. iʲʈ	*!		
b. iʷʈ		*!	
c. ☞ ɯʷʈ			*

The faithfulness constraints IDENT(ant) and IDENT(laminal) must also be ranked above IDENT(backness)$_V$, otherwise the retroflex could be made anterior (45b) or palato-alveolar (45c) instead of retracting the vowel.

(45)

/iʈ/	RETRO BACKCLO	AGREE (backness)	IDENT (ant)	IDENT (laminal)	IDENT (backness)$_V$
a. ☞ ɯʷʈ					*
b. iʲʈ̪			*!		
c. iʲtʃ				*!	*

There is an additional complication: back unrounded vowels never appear after palato-alveolars [tʃ, dʒ], and retroflexes fail to condition vowel retraction in this context (Emeneau 1970:184) (46a). Note that dentals do not block retraction (46b).

(46)	a.	tʃeɖi	‘a spark’ (DED 1528)	tʃiɳɳi	‘small’ (DED 2594)
	b.	t̪ɯːʈ-	‘to rub, stroke’	tɤɭi	‘laughter’

This receives a straightforward analysis as vowel fronting conditioned by palato-alveolars. That is, palato-alveolars are preferentially produced with a front tongue body at release, as formalized by the constraint PA FRONT REL. In conjunction with AGREE(backness), this constraint derives vowel fronting after palato-alveolars. Where a palato-alveolar precedes and a retroflex follows, as in

(47), the palato-alveolar prevails because PA FRONT REL is ranked above RETROFLEX BACK.

(47)	/tʃeɖ/	PA FRONTREL	RETRO BACKCLO	AGREE (backness)	IDENT $(backness)_V$
a.	☞ $tʃ^{i}e^{i}ɖ$		*		
b.	$tʃ^{i}e^{ɯ}ɖ$			*!	
c.	$tʃ^{i}ɤ^{ɯ}ɖ$			*!	*
d.	$tʃ^{ɯ}ɤ^{ɯ}ɖ$	*!			*

Dentals do not have this effect (46b) so Kodagu provides evidence that the constraint motivating fronting by palato-alveolars must be distinct from the constraint motivating fronting by anterior coronals, as proposed here. This pattern is also consistent with the hypothesis that PA FRONT is always ranked above ANTERIOR FRONT (§5).

Palato-alveolars do not condition fronting of back rounded vowels (e.g. [tʃokkɯ] 'intoxication', DED 2853). As in the analysis of Lahu fronting, this is attributed to a high-ranked constraint against front rounded vowels, *[front, +round], which blocks the appearance of front rounded vowels in any context in Kodagu (48).

(48)	/tʃo/	PA FRONTREL	IDENT (round)	*[front, +round]	RETRO BACKCLO	AGREE (backness)	IDENT $(backness)_V$
a.	☞ $tʃ^{i}o$					*	
b.	$tʃ^{i}ø$			*!			*
c.	$tʃ^{ɯ}o$	*!					
d.	$tʃ^{i}e$		*!				

As observed in the introduction, retraction of vowels by retroflexes is a significant phenomenon because it shows that not all coronals can condition vowel fronting, contrary to the prediction made by analyses in which [coronal] directly conditions vowel fronting.

7.2 Laminalization of retroflexes: Acoma

Acoma (Miller 1965) exemplifies laminalization of retroflexes before front vowels. In this language retroflexes and palato-alveolars contrast before non-front

vowels (49a), but retroflexes are neutralized to palato-alveolars before front vowels (49b).

(49) a.	ʃína	'louse'	*ʂi	
	kaʃéená	'albino'	*ʂe	
	k'úutʃi^{ʔ}ni	'yellow'	*t̪ʂi	
b.	ʔaʃá^{ʔ}ni	'a step'	ʔaʂá^{ʔ}ni	'wheat'
	haatʃ'ani	'tooth'	hát̪ʂani	'horn'
	tʃu̯udá	'plums'	t̪ʂûukatʃa	'did you see it?'

This pattern can be analyzed in terms of the constraint RETROFLEX□ BACKCLO. The retroflex must assimilate to the following front vowel, but this conflicts with the preferred back tongue body position for a retroflex (RETROFLEX□ BACKCLO). The conflict is resolved by changing the retroflex to a palato-alveolar. This involves a change from apical to laminal only, since retroflexes and palato-alveolars are both [-anterior]. The key constraint rankings are shown in (51).

The analysis employs a somewhat ad hoc constraint PALATALIZATION (PAL), 'closure and release of a consonant must be front before a front vowel', rather than an AGREE constraint because assimilation appears to be asymmetrical here: consonants are palatalized before front vowels, but there is no evidence of assimilation to back vowels. It is not unusual to find palatalization conditioned by front vowels, without any comparable velarization effects being conditioned by back vowels (as in Russian, for example), but this pattern is simply stipulated here, since it is tangential to the issue of interactions between coronal place and vowel backness. The operation of this ranking is illustrated in (51).

(50)

	/t̪ʂi/	RETRO□ BACKCLO	PAL	IDENT (laminal)
a.	^{i}t̪ʂ^{i}i	*!		
b.	^{ɯ}t̪ʂ^{i}i		*!	
d. ☞	^{i}ʃ^{i}i			*

The faithfulness constraints IDENT(backness)$_V$ and IDENT(anterior) must also be ranked above IDENT(laminal) to block other possible resolutions of the conflict between PALATALIZATION and RETROFLEX□ BACKCLO, i.e. vowel retraction (51b) or coronal advancement (51c).

(51)	/ʂi/	RETRO□ BACKCLO	PAL	IDENT (backness)$_V$	IDENT (anterior)	IDENT (laminal)
a.	☞ $^{i}ʃ^{i}i$					*
b.	$^{ɯ}ʂ^{ɯ}ɯ$			*!		
c.	$^{i}s^{i}i$				*!	

Another example of laminalization is observed in Polish. Polish has a retroflex fricative, but its palatalized counterpart is a non-anterior laminal (Keating 1991). A palatalized retroflex would violate RETROFLEX□ BACK, so laminalization serves to satisfy this constraint.

8. Effects of back vowels on palato-alveolars

A final set of repairs are predicted to be motivated by the PA□ FRONT in sequences of a palato-alveolar and a back vowel, such as [ʃu]. The assimilation constraint, AGREE(backness), and PA□ FRONT cannot both be satisfied in a sequence like [ʃu] without violating faithfulness to backness, [anterior], or [laminal]. Violating faithfulness to backness results in vowel fronting, as observed in Lahu (§5.2) and Kodagu (§7.1), while unfaithfulness to [anterior] yields coronal advancement (ʃu□ ʂ̟u) and unfaithfulness to [laminal] yields apicalization (ʃu□ ʂu). The latter processes are exemplified in Wargamay and Molinos Mixtec respectively.

8.1 Apicalization of palato-alveolars: Molinos Mixtec

In Molinos Mixtec (Hunter and Pike 1969) palato-alveolar [ʃ, ʒ] are in allophonic variation with retroflex [ʂ, ʐ], with the palato-alveolars appearing before front vowels, and the retroflexes before back vowels, a pattern which is also observed in Mazatec (Gudschinsky 1959). That is, Molinos Mixtec only contrasts anterior [s] and non-anterior [ʃ/ʂ], so the laminality of non-anterior coronals is non-contrastive, and can be dictated by the effort minimization constraints PA□ FRONTREL, and *RETROFLEX.

The analysis is illustrated by the tableaux in (52)-(53). The ranking *RETRO >> IDENT(laminal) derives the fact that there is no contrast between apical retroflexes and laminal palato-alveolars, and, in the absence of other factors, palato-alveolars are preferred (52). However, AGREE(backness) requires the release of a consonant to assimilate to the backness of a following vowel. Where that vowel is back, this means that a palato-alveolar fricative violates PA□ FRONTREL (53c), so apicalization to a retroflex is preferred (53a). Note that

the same outputs result if /ʃi/ is taken as the input in (52), and /ʂu/ as the input in (53), since IDENT[laminal] is not decisive in either tableau.

(52)

/ʂi/	PA FRONTREL	AGREE (backness)	*RETRO	IDENT (laminal)
a. ʂ^{i}i			*!	
b. ☞ ʃ^{i}i				*

(53)

/ʃu/	PA FRONTREL	AGREE (backness)	*RETRO	IDENT (laminal)
a. ☞ ʂ^{ɯ}u			*	*
b. ʃ^{i}u		*!		
c. ʃ^{ɯ}u	*!			

In addition, IDENT(backness)$_V$ and IDENT(anterior) must rank above IDENT(laminal) so apicalization is preferred over vowel fronting or coronal advancement, as shown in (54).

(54)

/ʃu/	PA FRONTREL	IDENT (backness)$_V$	IDENT (ant)	*RETRO	IDENT (laminal)
a. ☞ ʂ^{ɯ}u				*	*
b. ʃ^{i}y		*!			
c. ʂ^{ɯ}u			*!		

8.2 Advancement of palato-alveolars: Wargamay laminals

As mentioned in §6, the Australian language Wargamay contrasts apical coronals /t̪, n̪/ and laminal coronals /t̻, n̻/. Both apicals and laminals vary in their realization depending on vowel context. The realization of apicals was analyzed in §6, while the realization of the laminals exemplifies advancement of palato-alveolars in the environment of back vowels. According to Dixon (1981), the laminals are usually laminal and non-anterior (palato-alveolars, in the terminology used here). Optional laminal dental allophones can be found before [a, u], but not before front [i].

The analysis proposed here is structurally similar to the analysis of allophonic variation between apical alveolars and retroflexes in Wargamay and Walmatjari. That is, palato-alveolar stops are generally more marked than dental stops, as shown by the cross-linguistic preference for dentals, but palato-alveolar

stops are more distinct from apicals than laminal dentals, so an apical-laminal contrast is enhanced by realizing the laminals as [-anterior]. However, this enhancement is blocked where production of a palato-alveolar would be too effortful, i.e. where it would violate PA FRONT. There are also Australian languages in which the preference for palato-alveolar laminals dominates, so palato-alveolars appear in all environments, e.g. Dyirbal (Dixon 2002:559) and Wergaia (Hercus 1986:73, 106).

Anderson's (1997) study of the perception of Arrernte coronals provides some evidence for the hypothesis that palato-alveolars are more distinct from apicals than dentals: palato-alveolar nasals are misperceived as apicals about 5% of the time, while dental nasals are misperceived as apical 22% of the time. However, ceiling effects make it impossible to distinguish performance on palato-alveolar and dentals stops – both were identified with almost 100% accuracy.

This analysis is implemented in terms of the constraint LAMINAL PA: 'contrastively [laminal] stops must be [-anterior]'. This constraint creates a preference for palato-alveolar rather than dental laminals (55), but PA FRONTREL requires palato-alveolars to have a front tongue body at release, so undominated AGREE(backness) creates a conflict between these two requirements where the following vowel is not front (56). PA FRONTREL and LAMINAL PA are unranked, so the outcome of the conflict is variable: both dentals and palato-alveolars are possible (56a,b). Before front vowels, palato-alveolars do not violate PA FRONTREL, so there is no variation (55).

As noted above, dentals are also preferably produced with a front tongue body, as expressed by the constraint ANTERIOR FRONT, so PA FRONTREL must rank above ANTERIOR FRONTREL to account for the preference for dentals before non-front vowels. We have hypothesized that this ranking may well be universal – it is more difficult to produce a back palato-alveolar than to produce a back anterior coronal (§5).

(55)

/t̪i/	AGREE (backness)	PA FRONTREL	LAMINAL PA	ANT FRONT	IDENT (ant)
a. t̪ʲi			*!		
b. ☞ t̻ʲi					*

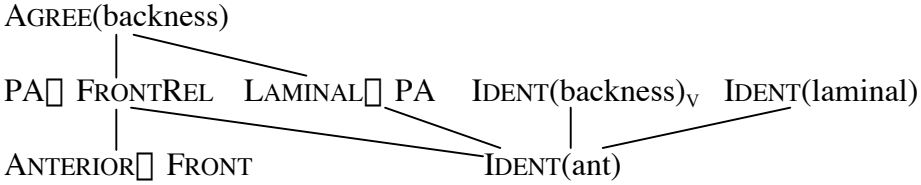
(56)

/t̻u/	AGREE (backness)	PA FRONTREL	LAMINAL PA	ANT FRONT	IDENT (ant)
a. ☞ t̪ʷu			*	*	*
b. ☞ t̻ʷu		*			
c. t̻ʲu	*!				

In addition, IDENT(backness)$_V$ and IDENT(laminal) must rank above IDENT(anterior) to block alternative repairs of sequences of a laminal followed by a back vowel: vowel fronting and apicalization. So the full ranking for Wargamay laminals is as shown in (57).

Examination of the ranking for Wargamay apicals (42) shows that the common constraints are AGREE(backness), ANTERIOR FRONT, and the faithfulness constraints, and that the rankings of these constraints in the two analyses are consistent: AGREE(backness)>>ANTERIOR FRONT, IDENT(ant); and IDENT(backness)$_V$, IDENT(laminal)>>IDENT(ant). That is, there is a basic contrast between apicals and laminals, given undominated IDENT(laminal), but both apicals and laminals vary in anteriority depending on vowel context. These variations are motivated by AGREE(backness), which requires the coronals to assimilate to the tongue body positions of adjacent vowels.

(57)



Dixon (1980) reports that many Australian languages that lack a contrast between dentals and palato-alveolars show allophonic variation comparable to Wargamay – palato-alveolars appear before front vowels, and dentals appear elsewhere. Wargamay is particularly interesting however, because it exhibits variation between dentals and palato-alveolars before non-front vowels. This shows that the pattern of variation cannot be analyzed as showing that laminals are dental by default, but are palatalized to palato-alveolars before front vowels, since palato-alveolar realizations are attested before non-front vowels also. Instead we have argued for a general preference for palato-alveolars as most distinct from apicals which conflicts with effort constraints before non-front vowels. So Wargamay exemplifies advancement of palato-alveolars before non-front vowels, a pattern which is predicted by ranking PA FRONT above ANTERIOR FRONT.

9. Palatalization

The preceding sections have exemplified all of the predicted patterns of interaction between coronal consonants and vowel backness. In this section we briefly review interactions between palatalization and coronal place.

The tongue body fronting that is characteristic of anterior coronals is distinct from palatalization. Palatalization involves a narrow constriction between the front of the tongue body and the hard palate, as in the vowel [i], resulting in a very high second formant at the release of a palatalized consonant. The tongue body position is less extreme in plain anterior coronals, forming a less narrow constriction, probably slightly further back, resulting in lower values of F2, more comparable to a lax front vowel such as [ɪ]. Accordingly, we will represent palatalized consonants as [front, +tense], whereas plain fronted coronals are [front, -tense]. The feature [-tense] is taken to denote a less narrow constriction, and a slightly centralized quality.

Anterior coronals are most easily produced with this less extreme tongue body position, so palatalization can result in modifications of coronal place, particularly retraction to a laminal post-alveolar articulation. For example, Keating (1991) notes that in Polish, palatalization of dentals yields alveopalatals, which are essentially palatalized palato-alveolars (Ladefoged and Maddieson 1996:154f.), while in Japanese, dentals are palatalized to palato-alveolars before the high front vowel [i] (Vance 1987). Following Keating (1993), the tendency for palatalization of coronals to yield palato-alveolars can be analyzed in terms of the articulatory interaction between the tongue body constriction and the position of the tongue tip/blade.

To form a narrow constriction against the hard palate, the front of the tongue body must be curved into the vault of the palate, and this curvature naturally turns the tongue tip downwards. From this position it is easy to form a post-alveolar constriction with the tongue blade by raising it a little, so palato-alveolars are very compatible with palatalization. Forming an anterior coronal constriction is more difficult because the tongue tip/blade must be extended and curved upwards to contact the alveolar ridge without also forming a palato-alveolar contact.

Russian provides evidence for a difference in compatibility with palatalization within the class of anterior coronals, with dentals being less compatible than alveolars: in Russian the plain coronal stops are dental, while their palatalized counterparts are laminal alveolars (Keating 1991, 1993). In fact dentals tend to be produced with a less fronted tongue body than alveolars, as indicated by lower F2 adjacent to dentals, as is observed in languages that contrast dentals and alveolars such as Malayalam (Stevens et al 1986, Dart and Nihilani 1999) and Tohono O'odham (Dart 1991). Stevens et al (1986) suggest that dentals are most easily produced with a less fronted tongue body because a dental constriction is more easily formed if the front of the tongue is flattened, whereas

full fronting involves curving the front of the tongue downwards[8]. So we posit constraints against palatalized dentals and alveolars, ranked as in (58).

(58) *PALATALIZEDDENTAL >> *PALATALIZEDALVEOLAR

In addition to accounting for the interactions between palatalization and coronal place noted above, these constraints might also help to explain the RUKI rule of Sanskrit, which appears to present an anomalous association between retroflexion and the high front vowel [i]. By the RUKI rule, dental [s̪] becomes retroflex [ʂ] following the sounds [r, u, k, i] (Whitney 1889:61). Thus it appears that retroflexion is conditioned by a high front vowel, contrary to the pattern exemplified above. The analysis proposed here is based on the speculation that the retroflex fricative in Sanskrit was subject to contextual variation comparable to what we have observed in languages like Wargamay and Walmatjari. That is, the fricatives labeled 'retroflex' have in common that they are apical, as opposed to the laminal dental [s̪] and laminal palato-alveolar [ʃ], but they vary between more or less anterior realizations. Specifically, the realization following high front [i] is sufficiently advanced to be characterized as [apical, +anterior], while it is [-anterior] following [u]. In this case the high front vowel conditioned a change from laminal dental to apical alveolar rather than from [+anterior] to [-anterior]. Rather than being anomalous, this change is in accord with the observation that alveolars are more compatible with palatalization than dentals. That is, the change can be analyzed as involving [s̪] assimilating the [+tense, front] tongue body position of a preceding [i]. The shift in place to apical alveolar then occurs to avoid a violation of *PALATALIZEDDENTAL.

The remaining environments, [r, u, k] can be accounted for as follows: The [r] is assumed to be retroflex (Whitney 1889:18f.), so retroflexion following this sound is direct assimilation of its coronal place of articulation. Retroflexion following [u] can be analyzed as the result of assimilation of the back tongue body position of this sound in combination with the constraint ANTERIOR□ FRONT, as in Wargamay and Walmatjari (§6). The effect of [k] can be analyzed in the same way if we adopt Whitney's (1889:15) speculation that this sound was a back velar, which is plausible given that it contrasted with palatal [c]. These various assimilations must be motivated by a general AGREE

[8] Stevens et al (1986) actually argue for an association between dentals and back vowels based on allophonic variation in root-final laminals in Lardil: they are realized as palato-alveolars before [i] and as dentals before [a, u]. However, this pattern is essentially the same as observed in Wargamay (§6), and can be analyzed in the same way without positing any affinity between dentals and back vowels. The position taken here is that Stevens et al are correct in arguing that a fully fronted tongue body is dispreferred in dentals, but they are incorrect in suggesting that a back tongue body is preferred.

constraint, which requires [ʂ] to share at least [tense], backness and coronal place specifications with a preceding segment[9].

This analysis must remain speculative since it is not possible to examine the realization of retroflexes in a dead language, but a number of factors support its plausibility. First, the RUKI rule was allophonic – there was no contrast between dental and retroflex fricatives (Whitney 1889:21f., 62), so there is no reason to expect consistently strong retroflexion. Second, we have already seen that vowel conditioned variation in anteriority of coronals is attested in Australian languages, and it is also known that vowel context can have an effect on degree of retroflexion even where a retroflexion contrast is maintained: Dave's (1977) palatographic study of retroflexes in Gujarati shows considerably less retraction of retroflexes after [i] than following non-front vowels, and similar effects are described in the Australian language Mantjiltjara (Marsh 1969).

10. Conclusions

We have seen that fronting of vowels after coronals is just one of a much broader range of interactions between coronal place and vowel backness. All of these patterns of interaction can be accounted for in terms of effort-minimization constraints that specify the least effort tongue body position for each type of coronal (59), together with two enhancement constraints that bear on the realization of apical-laminal contrasts (60). The cooccurrence of coronal articulations and tongue body positions is constrained because the tongue tip and blade are attached to the tongue body, so the formation of a coronal constriction can be facilitated if the tongue body moves cooperatively.

(59) ANTERIOR□ FRONT
PALATO-ALVEOLAR□ FRONT
RETROFLEX□ BACKCLOSURE
*FRONTRETROFLEXCLOSURE

(60) APICAL□ RETROFLEX
LAMINAL□ PA

Coronals can affect vowel place because these constraints specify preferred tongue body positions for coronals which can spread to adjacent vowels. Vowels

[9] The AGREE constraint could require agreement in all place features as long as violation is assessed gradiently so major place assimilation can be blocked by higher-ranked faithfulness constraints. Since [ʂ] does not contrast with apical [ʂ] or retroflex [ʂ], faithfulness to the features differentiating these sounds are relatively low-ranked, and so would be susceptible to assimilation.

affect coronal place when their backness specification spreads to an adjacent coronal. If the vowel backness specification conflicts with the preferences of the coronal place (59), then a shift in coronal place can occur to better satisfy these constraints.

This analysis not only provides better analytical coverage of the full range of coronal-backness interactions, it also has some more general theoretical implications. First, the analyses presented here depend on representing the tongue body position during coronal consonants. Although Chomsky and Halle (1968) assumed that all consonants have specifications for the features [high], [low], and [back], it has become more common to assume that non-dorsal consonants are not specified for tongue body features unless they involve a contrastive secondary articulation such as palatalization or velarization (e.g. Sagey 1986). The analyses presented here motivate a return to more phonetically detailed representations. The analysis of directionality entails even more phonetic detail, distinguishing closure and release features for consonants.

Second, the way in which interactions between coronals and vowels are analyzed is fundamentally different from the feature-based approach of Clements (1991) and Hume (1992), and might be applicable to other interactions between phonetically distinct features such as tone and voicing. Clements and Hume analyze fronting of vowels by coronals as direct assimilation. That is, front vowels are argued to be specified as [coronal], so vowel fronting results from the vowel assimilating to the [coronal] specification of the consonant. The analysis proposed here treats this interaction between coronal place and vowel backness as indirect, and mediated by constraints. The vowel assimilates to the front tongue body position of the coronal, but a plain coronal is only front as a result of a constraint like ANTERIOR□ FRONT. Similarly, where a front vowel conditions a shift from retroflex to alveolar, the [+anterior] specification is not acquired directly from the vowel. Instead the consonant assimilates the [front] feature of the vowel, and this results in a change to [+anterior] through the mediation of the constraint RETRO□ BACKCLO.

It is not possible to treat all of the attested coronal-backness interactions as direct assimilation because front and back vowels condition contradictory feature changes. For example, front vowels condition [+anterior] in apical coronals (it□ it̪, §6). To analyze this process as direct assimilation, we would have to posit that front vowels are specified [+anterior], in effect. But this would imply that front vowels could condition [+anterior] in laminals also, which is not the case - they are associated with [-anterior] palato-alveolars (§8.2). A similar problem arises with back vowels because they condition [+anterior] in laminals (t̪u□ t̪u, §8.2), but not in apicals, where they are associated with [-anterior] retroflexes (§6). However, if we assume that the basic assimilation process involves the backness dimension in every case then the various effects of vowel backness on

coronal place follow from the coronal-backness constraints and the interaction between them.

It is also important that the coronal-backness constraints are ranked, violable constraints rather than being redundancy rules specifying invariant tongue body features for each coronal place. Violability allows for exceptions to the preferences expressed by the constraints, like velarized and uvularized dentals. We saw in §3 that velarized dentals are problematic for a theory that treats vowel fronting as spreading of [coronal], because even a velarized coronal is [coronal], and consequently is predicted to be able to condition fronting. In the analysis proposed here, a velarized dental has a back tongue body, in violation ANTERIOR FRONT, and consequently assimilation yields vowel retraction.

Constraint ranking plays an important role in accounting for the fact that dentals can condition vowel fronting (§5) while a change from palato-alveolar to dental can be conditioned by a back vowel (§8.2). According to the analyses developed here, dentals can condition vowel fronting because they are preferably produced with a front tongue body (ANTERIOR FRONT). However, a back dental is less marked than a back palato-alveolar (PA FRONT >>ANTERIOR FRONT), and preserves the [laminal] specification of a palato-alveolar, so it can be the most faithful realization of a palato-alveolar before a back vowel, as seen in Wargamay (§8.2).

So the analyses demonstrate that OT constraints relating distinct features provide a more flexible approach to interactions between classes of sounds than representational stipulations that two features such as [front] and [coronal] are in fact the same, or that front vowels are always specified [-anterior]. A constraint-based approach might be applicable to other cases of interaction between phonetically distinct features such as tone and laryngeal features (Hombert 1978, Bradshaw 1999) or ATR and obstruent voicing (Trigo 1991 , Vaux 1996).

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