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*The relationship between coronal place and vowel backness**

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This paper presents evidence that tongue-body position is always specified in the phonological representation of coronals, even where it is non-contrastive. Tongue-body position is needed to account for the typology of interactions between coronal consonants and adjacent vowels. For example, coronals only condition vowel fronting if they are produced with a front tongue body (usually anterior coronals), and only coronals produced with a back tongue body (usually retroflexes) condition vowel retraction. However, coronals do not have a fixed tongue-body position. Tongue-body position is affected by the position of the tongue tip/blade, because these articulators are physically connected, so each type of coronal has a preferred tongue-body position that facilitates the production of the coronal constriction. These preferences can be overridden, however, e.g. due to assimilation to a vowel. Optimality-theoretic feature co-occurrence constraints provide a good account of this type of dependency between articulators.

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).[1] 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]

(1)	i	y		u
	e	ø		o
			a,aː	

* Many thanks to audiences at WECOL 2001, Stanford and MIT for comments on talks based on this research, and to the associate editor and three anonymous reviewers for helpful comments and criticisms.

[1] Transcriptions follow IPA conventions as far as possible, except that [a] is used to denote a low central vowel throughout the paper.

(2) a. kyt̪ 'decide' kut̪ 'bracket'
hø 'boots' ho 'river'
b. t̪yt̪ 'to take off' *t̪ut̪ t̪ʊk 'bald head'[2]
t̪øn̪ 'a shield' *t̪on̪ t̪ok '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 analysed 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 Koḍagu (also known as Koḍava) contrasts front and back unrounded vowels, as shown in (3) and (4) (Emeneau 1970, Ebert 1996).

(3)

i	ɯ	u	iː	ɯː	uː
e	ɤ	o	eː	ɤː	oː
	a			aː	

(4) kiːt̪ɯ 'torn piece' kɯːd̪a 'below'
et̪t̪ɯ 'arrive!' ɤt̪t̪ɯ 'ox' (Ebert 1996: 7)

But front vowels do not appear before retroflexes, so although back vowel–retroflex sequences are well attested (5),[3] the comparable front vowel–retroflex sequences shown in the third column of (5) are ill-formed. This pattern results from the retraction of vowels before retroflexes (see §7.1 for details).

(5)

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

2 The high back vowel is lax in [tʰʊk], because high vowels are always lax before velars in Cantonese.

3 Data are from Emeneau (1970) unless otherwise noted. Data from Burrow & Emeneau (1984) are marked 'DED' (*Dravidian etymological dictionary*).

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 articulations; they are simply preferred for reasons of ease of articulation. These preferences may be outranked by other constraints, for example to realise contrastive velarisation on a coronal. A velarised 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 velarised 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 Koḍagu, 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 stipulations concerning 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 constraint in an optimality-theoretic analysis (Prince & 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 co-occurrence constraint, although of course they may share tongue-body features as a result of this constraint.

The paper is organised 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 §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 1998: 355), otherwise considerable stretching of the tongue is required. This fronted tongue-body position causes the relatively high second formant (F2) frequencies typically observed adjacent to anterior coronals, even when adjacent to back vowels (Manuel & Stevens 1995). Öhman (1966: 167) directly observed forward movement of the tongue body in coronals produced between back vowels in an X-ray study of Swedish.

There are some differences between dentals and alveolars, as discussed in §9, but all anterior coronals favour 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 & Nihilani 1999; Arrernte: Anderson 1997).

It is common to make a distinction between two types of non-anterior laminal coronals: palato-alveolars and alveolo-palatals. The latter are essentially palatalised palato-alveolars (Hume 1992, Ladefoged & Maddieson 1996: 154f), and so are necessarily produced with a front tongue body. True palatals ([c ɟ ç j], etc.), on the other hand, are not coronals in the sense intended here, since they are articulated with the front of the tongue body, not the tongue blade, but they are by definition front.

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 postalveolars, in which the tip of the tongue forms a constriction just behind the alveolar ridge (Ladefoged & 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 *et al.* 1974). Tongue-body retraction during retroflexes has been observed experimentally in Tamil by Wiltshire & Goldstein (1997), and is reported by Emeneau (1970: 194) to be a general property of retroflexes in Dravidian languages.[4]

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 & Maddieson 1994, Butcher 1995, Spajić *et al.* 1996). 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.[5]

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

[4] A reviewer suggests that all retroflexes are necessarily produced with a back tongue body – i.e. this is an inviolable constraint rather than the violable preference argued for here. It is difficult to support such a strong claim, because there are few phonetic studies that examine retroflexes in front vowel contexts (where a non-back tongue-body position is most likely), and even fewer that provide direct evidence for the position of the tongue body. In any case there is good evidence that retroflexes can be produced with a front or central tongue-body position, most directly from X-ray data on palatalised retroflex sibilants in Russian (Keating 1991, 1993). In addition, the combination of palatographic and acoustic evidence in Dave's (1977) study of Gujarati strongly suggest that the retroflexes are produced with a front or central tongue-body position following front vowels in this language, and acoustic data on palatalised retroflex trills in Toda (Spajić *et al.* 1996) indicates that these are both retroflex (F3 is low at their onset) and non-back, if not actually palatalised until late in the consonant (F2 is relatively high at the onset of the consonant and rises throughout) (*pace* Hamann 2003: 47f).

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

unimportant, so velars also assimilate to the tongue-body positions of adjacent vowels (Öhman 1966, Houde 1967).

Note that the terminology used here to classify coronals is standard but not universally used, so there are cases in which classifications differ from common practice in describing a particular language. For example, the Russian non-anterior sibilant is often referred to as a palato-alveolar, but it is in fact apical (Keating 1991: 35, 1993: 7), and therefore retroflex in the terms used here.

3 An analysis of interactions between coronal place and vowel backness

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

(6) a. ANTERIOR→FRONT (ANT→FRONT)
[+anterior] → [front]
b. PALATO-ALVEOLAR→FRONT (PA→FRONT)
[−anterior, laminal] → [front]
c. RETROFLEX→BACK (RETRO→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].[6] 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 analysed here (§6), so it is necessary to distinguish three tongue-body positions on the front–back dimension. These distinctions are also motivated by the existence of languages with minimal contrasts between front, central and back vowels (Ladefoged & Maddieson 1996: 290ff), e.g. Norwegian, which contrasts /y ʉ u/ (Kristoffersen 2000), and Nimboran, which is reported to contrast /i ɨ ɯ/ (Anceaux 1965). 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.[7]

[6] The terms 'front', 'central' and 'back' are used to describe tongue-body position following standard practice in descriptive articulatory phonetics (see, for example, the *IPA Handbook* (1999: 10–11).

[7] Cf. Gnanadesikan (1997) for a proposal to employ similar scalar features in phonology.

The features [apical] and [laminal] are used rather than [±distributed] (Chomsky & 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.[8] 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 ANT→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, PA→FRONT is violated by [−anterior, laminal] coronals with [central] or [back] tongue-body positions, and RETRO→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 in §6 that front retroflexes are more marked than central retroflexes. This difference is formalised in terms of an additional constraint *FRONTRETROFLEX, which is violated by [−anterior, apical, front] segments, and is ranked above RETRO→BACK.

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

In most of the analyses below, assimilation between adjacent consonants and vowels is driven by AGREE[backness], which penalises 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 [$^{\text{i}}$] and back tongue body by superscript [$^{\text{ɯ}}$] – these notations are shorthand for the relevant feature matrices, e.g. [t$^{\text{ɯ}}$] is [coronal, +anterior, apical, back, −sonorant], etc.).

8 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 even if they are apical, due to compression of the tongue tip against the roof of the mouth. Conversely, laminal palato-alveolars can have short constrictions for speakers with pronounced alveolar ridges.

(7)

tu	ANT→FR	AGREE[bk]	IDENT[bk]$_V$
a. $t^{ɯ}u$	*!		
b. $t^{i}u$		*!	
☞ c. $t^{i}y$			*

ANT→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 realisation of the back vowel [u]. The constraint which requires faithful realisation 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.

Fronting by palato-alveolars is derived by a similar ranking, with PA→FRONT in place of ANT→FRONT. It is hypothesised that PA→FRONT universally ranks above ANT→FRONT, so whenever anterior coronals condition vowel fronting, palato-alveolars do so as well (§5).[9]

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 RETRO→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.[10]

(8)

iʈ	RETRO→BK	AGREE[bk]	IDENT[bk]$_V$
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 minimisation that can be outranked by other constraints. For example, realising velarisation or uvularisation

9 The use of fixed rankings to derive implicational universals is discussed in Prince & Smolensky (1993: 185ff) and McCarthy (2002: 117ff).

10 The articulatory requirements of retroflexes and their significance for the phonology of these sounds is discussed briefly in Flemming (1995, 2002: 90f) and at length in Hamann (2003). The latter dissertation was not available to me when I originally wrote this paper, and so is not discussed in detail, but a key difference from the present proposal is that Hamann (2003) employs inviolable articulatory constraints, whereas it is a central thesis of this paper that the constraints relating coronal place to tongue-body backness are violable.

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 palatalised and velarised dentals (Bender 1968), e.g. [t̪ʲɔ] 'ignite' *vs.* [t̪ˠɔ] 'sugar cane'. The emphatic coronals of Arabic also involve a back tongue-body position. This is often referred to as pharyngealisation, but this is somewhat misleading, since the constriction is much higher than in a primary pharyngeal consonant (McCarthy 1994, Ladefoged & Maddieson 1996: 366), so McCarthy (1994) proposes the term 'uvularisation'. Like velarisation, this secondary articulation results in a low F2 (Al-Ani 1970, Card 1983), but the two articulations seem to differ in that the tongue body is high and back in velarisation, but is lower in uvularisation.

These violations of ANT→FRONT are motivated by faithfulness to secondary articulations, as in the ranking in (9). The realisation of velarisation or uvularisation contrasts is taken to involve faithfulness to the input [back] specification of a consonant, enforced by the constraint IDENT [backness]$_C$ (the subscript indicates that this IDENT constraint applies to consonants).

(9) IDENT[backness]$_C$ ≫ ANT→FRONT

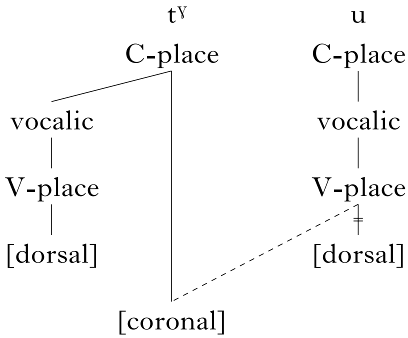
The effect of a coronal on adjacent vowels depends on its actual tongue-body position. So only anterior coronals that are actually produced with a front tongue body can condition fronting of vowels. If the preference for this tongue-body position is violated, then no fronting effect is predicted. On the contrary, since velarised and uvularised 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 (10b), but front elsewhere (Card 1983).

(10) a.	bæːs	'he kissed'	b.	bɑːsˤ	'bus'
	fæːdi	(boy's name)		fɑːdˤi	'empty'
	kæmæːn	'also'			

Vowels are also retracted adjacent to velarised consonants in Marshallese (Bender 1968), although this effect has been analysed by Choi (1992) as phonetic interpolation through unspecified vowels, rather than phonological assimilation to [back].

Models in which vowel fronting is conditioned by the coronal specification of a consonant (e.g. Clements 1991, Hume 1992, Clements & Hume 1995) predict that velarised coronals should be able to condition vowel fronting. For example, in the model proposed by Clements & Hume (1995), a velarised coronal has a [coronal] consonant place, while velarisation is specified by the feature [dorsal] under the V-place node in (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 velarised or pharyngealised 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 analysed as a consequence of RETRO→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 realisation 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 RETRO→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 the 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 summarised in (12).

(12) *The predicted typology of interactions between coronal place and vowel backness*

a. ANT→FRONT
   - vowel fronting — tu → ty
   - coronal retraction — ut̺ → uʈ

b. RETRO→BACK
   - vowel retraction — iʈ → ɯʈ
   - coronal advancement — iʈ → it̺
   - laminalisation — ʂi → ʃi

c. PA→FRONT

vowel fronting	ʃu → ʃy
apicalisation	ʃu → ʂ̺u
coronal advancement[11]	t̠u → t̪u

(12) 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 generalisations about the directionality of the observed consonant–vowel interactions.

4 Directionality effects

Interactions between vowels and coronals vary in their directionality, for example in Koḍagu, 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 generalisation is that retroflexes primarily interact with preceding vowels, as in Koḍagu (an exception is discussed in §7.2). This generalisation can be understood as a consequence of the fact that 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 formalise the 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 bipositional 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]. Where a feature associates to only closure or release, this is indicated by prefixing 'clo:', for closure, or 'rel:', for release.

[11] Palato-alveolar stops are transcribed with a subscript line, e.g. [t̠], following Ladefoged & Maddieson (1996: 15).

(13) Retroflex→BackClosure (Retro→BackClo)
[−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.

(14) Agree[backness]
A consonant closure or release must have the same value of backness as the vowel adjacent to that phase of the consonant.

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 minimisation since it disprefers tongue-body movement, but it more specifically favours an arrangement in which transitions between vowels occur during consonants rather than during the vowels themselves. This arrangement serves to minimise vocalic transitions which might adversely affect the perception of vowel quality.

There are cases in which non-retroflex coronals condition fronting of following vowels but not preceding vowels. 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.

(15) a. Anterior→FrontRelease (Ant→FrontRel)
[+anterior] → rel:[front]
b. Palato-alveolar→FrontRelease (PA→FrontRel)
[−anterior, laminal] → rel:[front]

There is no evidence that these types of coronals are routinely given dynamic realisations, 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 place contrasts other than those between retroflexes and apical alveolars (Redford & Diehl 1999, Steriade 2001, Wright 2001).

The release-specific constraints in (15) are in addition to the general constraints Ant→Front and PA→Front, since these coronals sometimes interact with both preceding and following vowels. On the other hand, it is not clear whether a general constraint Retro→Back is motivated in addition to Retro→BackClo, since retroflexes only seem to condition retraction of preceding vowels. The only case in which retroflexes interact with following vowels involves loss of retroflexion before front vowels (Acoma; §7.2), and is analysed without resort to Retro→Back. This asymmetry between closure and release makes sense if retroflexes are consistently given dynamic realisations of the kind described above.[12]

[12] Bhat (1973: 47) speculates that retroflex fricatives and affricates are produced with retroflexion sustained through the consonant. There is not much data on the

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 summarised in (12) above is fully attested, analysing 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.

The schematic ranking for fronting conditioned by anterior coronals is given in (16). The markedness constraints ANT→FRONT and AGREE [backness] motivate unfaithful realisations 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 ANT→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] (IDENT [ant]), which requires input [anterior] specifications to be preserved in the output, must be ranked below IDENT[backness]$_V$.

(16) *Vowel fronting conditioned by anterior coronals*
ANT→FRONT, AGREE[backness], IDENT[ant] $\gg$ IDENT[backness]$_V$

Fronting of vowels by palato-alveolars is derived by a similar ranking, in which PA→FRONT replaces ANT→FRONT, as in (17).

(17) *Vowel fronting conditioned by palato-alveolars*
PA→FRONT, AGREE[backness] $\gg$ IDENT[backness]$_V$

Note that employing two independent constraints, PA→FRONT and ANT→FRONT, predicts that fronting by palato-alveolars and anterior coronals should be independent. However PA→FRONT may rank above ANT→FRONT universally since palato-alveolars are typically characterised 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. Koḍagu exemplifies this pattern (§7.1).

Vowel fronting is illustrated below from Cantonese and Lahu.

realisation of retroflex fricatives, but spectrograms of Toda retroflex fricatives in Shalev *et al.* (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 analysed without recourse to RETRO→BACK, it does suggest that manner-related differences in the behaviour of retroflexes would be worth investigating.

5.1 Cantonese

As outlined in §1, back vowels are fronted between dentals in Cantonese, resulting in neutralisation of the contrast between front and back rounded vowels (18b). Dentals are the only coronal consonants in Cantonese, but neutralisation also occurs between the palatal glide and a dental (18c).

(18)	a.	kyt̪	‘decide’		kut̪	‘bracket’
		hø	‘boots’		ho	‘river’
	b.	t̪yt̪	‘to take off’	*t̪ut̪	t̪ʊk	‘bald head’
		t̪øn̪	‘a shield’	*t̪on̪	t̪ok	‘to carry (on shoulders)’
	c.	jyt̪	‘moon’	*jut̪		
		jøt̪	‘weak’	*jot̪		

The evidence for vowel fronting comes from distributional patterns alone, so in principle, the restriction against sequences like *[t̪ut̪] could instead be derived from a process affecting coronals in the context of back vowels. However this would imply an unprecedented process, according to which one dental becomes non-coronal where a back vowel is preceded and followed by dentals. The fronting analysis, on the other hand, appeals to an established phonetic and phonological effect, and posits an assimilation process in which both conditioning consonants are adjacent to the affected vowel.

The schematic constraint ranking for vowel fronting between anterior coronals was given in (16), 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 (16) 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, following the basic principle of local conjunction that two violations of a constraint in a local domain are worse than a single violation (Smolensky 1995).

The ranking for vowel fronting in Cantonese is then as shown in (19). Superscripts preceding consonants indicate closure specifications for backness, while superscripts following consonants mark release specifications.

(19)

t̪ut̪	ANT→FR	AGREE[bk]$_2$	IDENT[ant]	IDENT[bk]$_V$
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. t^{ɯ}u^{ɯ}t			*!*	

Faithful realisation of a back vowel between coronals is not possible, because the undominated constraint ANT→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 the tongue-body position of at least one adjacent consonant, ruling out candidate (b). So either the vowel must be fronted (d) or a coronal must be made non-anterior (e). Since IDENT[backness]$_V$ is lower-ranked, vowel fronting is the optimal outcome (d). The palatal glide [j] is inherently front, and so also conditions fronting.

To derive the fact that back vowels may occur with a single coronal, AGREE[backness] must be ranked below IDENT[backness]$_V$, as in (20). A back vowel adjacent to a single front consonant does not violate AGREE [backness]$_2$, so the faithful realisation (b) is possible.

(20)

kut̪	ANT→FR	AGREE[bk]$_2$	IDENT[ant]	IDENT[bk]$_V$	AGREE[bk]
a. kᵚuᵚt̪	*!				
☞ b. kᵚuⁱt̪					*
c. kⁱyⁱt̪				*!	

5.2 Lahu

Lahu, a Lolo-Burmese language spoken in Thailand, China, Burma and Laos (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 (21a), but these central vowels cannot follow coronal consonants (alveolars and palato-alveolars), as shown in (21b) (data from Matisoff 1988).[13]

(21) a. hi 'eight' hɨ 'to agree' hu 'to fry'
e 'mother' ə 'to pour out' o 'sleep'

b.

ni	'to look at, try doing'	*nɨ	*nə
ʧʰi	'this'	*ʧʰɨ	*ʧʰə
ti	'only'	*tɨ	*tə
ʃi	'yellow, golden'	*ʃɨ	*ʃə
tse	'arrow'	*tsɨ	*tsə
de	'something useless'	*dɨ	*də
le	'to play'	*lɨ	*lə
ji	'to go'	*jɨ	*jə

The same restriction applies following palatal glides. The absence of central vowels in these environments can be analysed in terms of a process

[13] Matisoff states that the alveolar sibilants can be followed by the high central vowel /ɨ/, but in fact the sounds that he phonemicises in this way are realised as syllabic fricatives (1988: 7). That is, Matisoff's /tsɨ/ is phonetically [tsz̩], in which the syllabic is fully assimilated to the preceding coronal.

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 in other environments; Matisoff 1973: 5). Although I have not been able to identify any alternations illustrating vowel fronting, it seems unlikely that the historical fronting effect of coronals has been reanalysed, because the alternative analysis of the distributional restriction would involve a process in which coronal consonants change to some non-coronal place before central vowels, which is an unattested and unexpected process.

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) Ant→FrontRel, Agree[backness], Ident[ant] ≫ Ident[backness]$_V$

To account for the directionality of assimilation, Ant→FrontRel must be high-ranked – this constraint requires only the release of a coronal to be front, so only following vowels are fronted, as shown in (23). (Central tongue-body position is indicated by superscript [^{ɨ}].)

(23)

tɨ	Ant→FrRel	Agree[bk]	Ident[bk]$_V$
a. t^{ɨ}ɨ	*!		
b. t^{i}ɨ		*!	
☞ c. t^{i}i			*

A preceding central vowel is not fronted (e.g. [k^{h}ɨnuʔ] ‘shoes’), because the closure of the coronal can assimilate to 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→FrRel	Agree[bk]	Ident[bk]$_V$	Ant→Fr
☞ a. ɨ^{ɨ}t^{i}i				*
b. i^{i}t^{i}i			*!	
c. ɨ^{i}t^{i}i		*!		

Additional constraints are required to account for the fact that back vowels are not fronted after these coronals. A similar pattern is observed in Koḍagu (§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, i.e. candidate (25a) is preferred to candidate (b). IDENT[round] must also be highly ranked in order to prevent fronting and unrounding of back rounded vowels (c). Central vowels are free to undergo fronting, because the result is a well-formed front unrounded vowel.[14]

(25)

tu	ANT→FRREL	IDENT[rd]	*[fr,+rd]	AGREE[bk]	IDENT[bk]$_V$
☞ a. t^iu				*	
b. t^iy			*!		*
c. t^ii		*!			*

The fact that palato-alveolars condition fronting as well indicates that PA→FRONTREL also outranks AGREE[backness]. As noted above, PA→FRONTREL may always be ranked above ANT→FRONTREL, 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).[15]

(26) PA→FRREL

ANT→FRREL IDENT[rd] *[fr,+rd] IDENT[ant]

AGREE[bk]

IDENT[bk]$_V$

ANT→FR

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: 11) describes it as similar to the vowel in the English word *father*, which is a back vowel in most accents. If it is in fact central, fronting of this low vowel might be blocked by a constraint against low front vowels, since these vowels do not occur in Lahu and are marked cross-linguistically.

[14] A reviewer suggests that the fact that only central vowels undergo fronting could be analysed by positing that central vowels lack a backness specification, as proposed by Clements (1991). Then fronting central vowels would be a lesser violation of faithfulness than changing [back] to [front]. However, this analysis is difficult to reconcile with the observation that central vowels condition variation in coronal place – i.e. consonants assimilate to the backness of central vowels (§6), so AGREE[backness] would have to require agreement in non-specification of a back feature, which runs counter to the usual notion of underspecification, and would make unspecified backness essentially a third value of backness, as proposed here.

[15] Complex rankings, including this one, were checked with the aid of OTSoft (Hayes *et al.* 2003).

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 /t̺ n̺/ 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: 155) reports that this pattern of variation is common in Eastern Australian languages that lack contrasts between apical alveolar and retroflex consonants.

A similar pattern is observed in Walmatjari (Hudson & Richards 1969: 175–176), which does contrast apical alveolar and retroflex consonants but neutralises these contrasts word-initially. The contextual variation in anteriority arises in this position of neutralisation: the neutralised apicals are alveolar following [i] (27a), but retroflex following [a u] (27b).[16]

(27) a.	jiŋgi **l**anda	'poke!'	b.	jaɹu **ɭ**anda	'wound it!'
	pari **n**ʊŋʊdʲaɽi	'boy, bleeding'		maŋa **ʈ**arpaɽa	'hold the girl!'

In both patterns of variation, anterior apicals are found after front vowels, while retroflexes occur after back vowels. These interactions between anteriority and vowel backness are expected, given the constraints Ant→Front and Retro→BackClo. So a straightforward analysis of this pattern is that these apicals assimilate the tongue-body position of preceding vowels, and their anteriority is then governed primarily by these effort-minimisation constraints, since faithfulness to anteriority is low-ranked in the relevant contexts (28). This ranking derives retroflexes following back vowels (28a) and alveolars following front vowels (28b). A retroflex input is assumed in (28b) 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)

a. ut̺	Agree[bk]	Retro→BkClo	Ant→Fr	Ident[ant]
i. uⁱt̺	*!			
ii. uᵚt̺			*!	
☞ iii. uᵚʈ				*

b. iʈ	Agree[bk]	Retro→BkClo	Ant→Fr	Ident[ant]
☞ i. iⁱt̺				*
ii. iⁱʈ		*!		
iii. iᵚʈ	*!			

16 Although Hudson & Richards (1969) does not give morpheme-by-morpheme glosses, it is clear from Richards & Hudson (1996) that [landa] in (27a) and [ɭanda]

However, there are several complications that motivate refinements of this analysis. First, there are two differences between Wargamay and Walmatjari that must be accounted for: (i) in Wargamay, apicals are only optionally retroflexed after back vowels, whereas no optionality is described in Walmatjari, and (ii) the languages differ in the effect of central vowels. In Wargamay, apical coronals are retroflexed only after [u], and are alveolar after low central [a], but in Walmatjari apical coronals are retroflexed after both central [a] and back [u]. There is also a broader typological issue that must be addressed: vowel-conditioned variation between alveolar and retroflex is common in Australian languages, but appears to be much more restricted across languages in general. This is unexpected given the analysis sketched in (28), which implies that allophonic retroflexion arises because retroflexes are less effortful than anterior coronals in certain vowel contexts.

It will be argued that all of these aspects of the data can be accounted for if retroflexes are more effortful than anterior coronals in most contexts, so retroflexion in these Australian languages is motivated not by effort constraints, but by the need to enhance the distinctiveness of the apical *vs.* laminal contrasts. However, effort constraints do serve to limit the environments in which this enhancement can apply. We will see that this analysis has the consequence that allophonic retroflexion is less likely in languages without apical–laminal contrasts (i.e. most languages), because the motivation for retroflexion from enhancement is absent in these languages. We will also see that a simple difference in the relative ranking of enhancement and effort constraints on retroflexes determines whether or not central vowels condition retroflexion in a given language. Finally, the free variation observed in Wargamay will be analysed in terms of crucial unranking of these same effort and enhancement constraints: effort constraints favour the alveolar realisation, while enhancement favours a retroflex realisation, so variation results where these constraints are unranked.

We will first address the problem of accounting for the restricted nature of allophonic retroflexion, proposing additional effort and enhancement constraints on retroflexes. These constraints will then be applied to the analysis of Walmatjari and Wargamay in turn.

The broader typological observation that must be kept in mind while analysing these Australian languages is that there seems to be a general dispreference for retroflexes in most contexts. For example, languages with a single series of coronal stops have dental or alveolar stops, not retroflexes. This dispreference for retroflexes is difficult to explain if we pursue the analysis sketched in (28), where retroflexion arises because it is the least effort articulation for an apical alveolar in the relevant vowel contexts. This is particularly clear given the case of Walmatjari, where apical coronals are retroflexed after both back and central vowels. If this pattern arises because retroflexes are less effort than alveolars following

in (27b) are realisations of the same word, the imperative of the root /lan/ 'spear, pierce'.

central and back vowels, then we should expect to find languages with a single series of coronals that are realised as alveolars only after front vowels, and as retroflexes in all other contexts, i.e. a language with predominantly retroflex coronals. This pattern does not seem to be attested, suggesting that retroflexes are universally more marked than anterior coronals even where these must be produced with a central tongue body. Formally, this generalisation implies that RETRO→BACK is universally ranked above ANT→FRONT, so a retroflex with a central tongue body [ᶤʈ] is necessarily worse than an alveolar with a central tongue body [ᶤt̺] – the former violates RETRO→BACK and the latter violates ANT→FRONT, but according to the universal ranking, violation of RETRO→BACK is always worse. Consequently allophonic retroflexion cannot be motivated by assimilation to the tongue-body position of a central vowel. In addition to this fixed ranking, we adopt a general constraint against retroflexion, *RETROFLEX, to account for the observed markedness of retroflexes.[17]

The conclusion that RETRO→BACK universally ranks above ANT→FRONT has implications for the analysis of Walmatjari because apicals are retroflexed after the central vowel [a] in this language. Given the reasoning just outlined, this pattern cannot be explained in terms of effort-minimisation constraints, so some other factor must motivate retroflexion.

The hypothesis advanced here is that retroflexes are preferred over apical alveolars in languages like Walmatjari because retroflexes are perceptually more distinct from laminal coronals than are 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 were misidentified as laminals about 1% of the time. In addition, a study by Anderson & Maddieson (1994) of the acoustic correlates of similar coronal place contrasts in Tiwi found that retroflexes were acoustically better distinguished from other coronals than were 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. This constraint is only applicable where [apical] is contrastive, but this aspect of the constraint is left unformalised here (see Flemming 2001 for discussion of constraints of this type).

(29) APICAL→RETROFLEX (APICAL→RETRO)
Contrastively [apical] coronals must be [−anterior].

[17] A reviewer points out that Maddieson (1984) lists the Dravidian language Kota as having a retroflex sibilant as its only sibilant, suggesting that the dispreference for retroflexes might not apply equally to stops and fricatives. However, Maddieson's source on Kota, Emeneau (1944), indicates that this language has [s] in free variation with [ʧ], and that retroflex [ʂ] appears only adjacent to other retroflexes. Retroflex [ʂ] also does not figure in the list of Kota consonants in Burrow & Emeneau (1984), and is claimed to be an allophone of /s/ in Krishnamurti (2003: 53), so Kota is certainly not a straightforward counterexample to the markedness of retroflexes.

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.

The preference for retroflex apicals is opposed by the fixed hierarchy of effort constraints against retroflexion in (30). The top-ranked effort constraint *FrontRetroflexClosure (*FrontRetroClo) bans only [clo:front, −anterior, apical] segments – i.e. front retroflexes – whereas Retro→BackClo bans both front and central retroflexes, as described in (6) above, and *Retroflex bans all retroflexes. The resolution of the conflict between enhancement and effort minimisation depends on the ranking of the enhancement constraint Apical→Retro with respect to these effort constraints.

(30) *FrontRetroClo ≫ Retro→BackClo ≫ *Retroflex

We will first apply these constraints in the analysis of word-initial apicals in Walmatjari. In this position, enhancement prevails in all except the most difficult environment for producing a retroflex, i.e. adjacent to a front vowel. This pattern follows from the ranking in (31), in which only *FrontRetroClo outranks Apical→Retro, so retroflexion is favoured 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]. Ident[ant] must be ranked below *FrontRetroClo and Apical→Retro, so the anteriority of coronals is determined by the vowel context rather than faithfulness to any input value of [anterior].

(31) Agree[backness], *FrontRetroClo ≫ Apical→Retro ≫
Retro→BackClo ≫ *Retroflex

The derivation of retroflexes after [a u] and alveolars after [i] is illustrated in (32). These tableaux only include candidates that satisfy Agree[backness] since this constraint is undominated, and consequently omitted from the tableaux. As usual, unfaithful derivations are illustrated to demonstrate the irrelevance of underlying [anterior] specifications in this analysis.

(32)

		*FrRetroClo	Apical→Retro	Retro→BkClo	Ident[ant]
a.	iʈ				
	i. iⁱʈ	*!		*	
	☞ ii. iⁱt̺		*		*
b.	at̺				
	☞ i. aᶤʈ			*	*
	ii. aᶤt̺		*!		
c.	ut̺				
	☞ i. uᵚʈ				*
	ii. uᵚt̺		*!		

As shown in (32a), Walmatjari advances word-initial 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/ → [it̠]). To block these possibilities IDENT[backness]$_V$ and faithfulness to input [apical]/[laminal] specifications (IDENT[laminal]) must outrank APICAL→RETRO. Note that these alternative repairs are observed in other languages (§7).

Finally, Walmatjari does contrast retroflexes and apical alveolars in word-internal postvocalic positions. This pattern can be analysed in terms of a high-ranked positional faithfulness constraint, specific to the post-vocalic environment (33), although this aspect of the analysis is not of primary interest here (see Steriade 1995, 2001 for analysis of the distribution of retroflexion contrasts).

(33) 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.

So the complete ranking is as in (34).

(34) IDENT[ant]/V__

AGREE[bk] *FRRETROCLO IDENT[bk]$_V$ IDENT[lam]

APICAL→RETRO

RETRO→BKCLO IDENT[ant]

Note that retraction of coronals is not motivated by ANT→FRONT, according to this analysis; rather, it is motivated by APICAL→RETRO, so while the predicted correlation between back vowels and retroflexes is attested, it does not result directly from the coronal–backness effort constraints. Rather the correlation between back vowels and retroflexes arises from an enhancement-based preference for retroflexion which is permitted to apply where retroflexion is not too effortful – i.e. after non-front vowels. On the other hand, retroflexion is blocked after front vowels by *FRONTRETROCLO (32a), which corresponds to the expected pattern, where coronal advancement is conditional by front vowels.

Wargamay can also be analysed 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→RETRO below RETRO→BACKCLO, as in (35), 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].

(35) Agree[backness], *FrontRetroClo ≫ Retro→BackClo ≫ Apical→Retro, *Retroflex

The operation of this ranking is illustrated in (36). Again, only candidates that satisfy undominated Agree[backness] are included. After front vowels (36a) and central vowels (36b), retroflexion is unacceptable since it would violate Retro→BackClo. After back vowels (36c), retroflexion is acceptable since the retroflex can be realised with a back tongue body. Variation between retroflex and apical alveolar realisations in this context is derived by allowing variation in the ranking of Apical→Retro and *Retroflex (Reynolds 1994, Anttila 1997), so both rankings are acceptable. If Apical→Retro is ranked higher, retroflexion is optimal, while the reverse ranking derives the apical alveolar output (36c). Finally, the constraint Ant→Front must not be ranked above *Retroflex, otherwise we derive only retroflexes after back vowels, rather than variation, since candidate (36c.i) violates this constraint (variation in ranking is indicated by jagged lines between the constraints).

(36)

		*Retro→BkClo	Apical→Retro	*Retro	Ant→Fr
a.	iʈ				
	☞ i. i$^{\text{i}}$t̺		*		
	ii. i$^{\text{i}}$ʈ	*!		*	
b.	aʈ				
	☞ i. a^{ɨ}t̺		*		*
	ii. a^{ɨ}ʈ	*!		*	
c.	ut				
	☞ i. u^{ɯ}t̺		*		*
	☞ ii. u^{ɯ}ʈ			*	

The complete constraint ranking for Wargamay is shown in (37). In addition to the rankings already motivated, Ident[ant] 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. Ident[laminal] (Ident[lam]) and Ident [backness]$_V$ are undominated, so advancement of retroflexes is preferred over a change in apicality or vowel fronting.

(37) Ident[lam] Ident[bk]$_V$ Agree[bk] Retro→BkClo

Apical→Retro *Retro

Ident[ant] Ant→Fr

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 palatalisation 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 also 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 analysed 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 RETRO→BACK. In the Australian languages discussed above, 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[ant], IDENT[lam] and IDENT[backness]$_V$.

Vowel retraction is exemplified from Koḍagu, which is analysed in more detail below, and laminalisation is attested in Acoma (§7.2).

7.1 Retraction of vowels: Koḍagu

Koḍagu exemplifies retraction of vowels before retroflexes. As outlined in §1, Koḍagu contrasts front and back unrounded vowels, and back rounded vowels, but front vowels cannot appear before retroflexes (unless the vowel is preceded by a palato-alveolar – see below), as shown in (5) above. This distribution is the result of retraction of front vowels by retroflexes. This is the historical origin of the back unrounded vowels, and although evidence for alternations is limited, it is clear that the distributional restriction has not been reanalysed as advancement of retroflexes after front vowels, which could derive a similar distribution. First, the only alternation described in the literature involves optional vowel retraction: /niː-ɖa/ 'you (SG GEN)' → [nɯːɖa]/[niːɖa], cf. [niːnɯ] 'you (SG NOM)' (Ebert 1996: 7, 32). Ebert suggests that the unretracted form of the dative pronoun is a paradigm-uniformity effect (cf. Steriade 2000), since the rest of the paradigm contains front [iː], and front vowels never precede retroflexes within stems. Second, as discussed below, vowel retraction is blocked by a preceding palato-alveolar, hence [ʧeɖi] 'a spark', not *[ʧɤɖi]. This restriction receives a natural analysis in terms of the fronting effect of the palato-alveolars on the following vowel blocking the retracting effect of the retroflex, but the alternative analysis according to which front vowels condition advancement of retroflexes would leave the blocking effect of a preceding palato-alveolar as a complete mystery.

The core of the analysis is illustrated in (38). The constraint RETRO→BACKCLO requires retroflexes to be realised 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.

(38)

iʈ	AGREE[bk]	RETRO→BKCLO	IDENT[bk]$_V$
a. iⁱʈ		*!	
b. iᵚʈ	*!		
☞ c. ɯᵚʈ			*

The faithfulness constraints IDENT[ant] and IDENT[lam] must also be ranked above IDENT[backness]$_V$, otherwise the retroflex could be made anterior (39b) or palato-alveolar (39c), instead of vowel being retracted.

(39)

iʈ	AGREE[bk]	RETRO→BKCLO	IDENT[ant]	IDENT[lam]	IDENT[bk]$_V$
☞ a. ɯᵚʈ					*
b. iⁱt̪			*!		
c. iⁱʧ				*!	

There is an additional complication: back unrounded vowels never appear after palato-alveolars [ʧ ʤ], and retroflexes fail to condition vowel retraction in this context (40a) (Emeneau 1970: 184). Note that dentals do not block retraction (40b).[18]

(40) a. ʧeɖi 'a spark' (DED) b. t̪ɯːʈ- 'to rub, stroke'
ʧiɳɳi 'small' (DED) t̪ɤɭi 'laughter'

[18] There is evidence that the fronting effect of palato-alveolars is morphologically bounded, because Ebert shows back unrounded suffix vowels following root-final palato-alveolars, e.g. [aːnʤ-ɤɳɖ-inʤ-ɤ] 'I was choosing' (1996: 19). This morphological conditioning could be analysed in a variety of ways, including output–output faithfulness constraints (e.g. Steriade 2000) or level ordering (e.g. Kiparsky, to appear), but is peripheral to the main point here. The morphological bounding makes it difficult to determine whether the palatal glide [j] blocks fronting, because there do not seem to be any examples of the relevant sequence (palatal glide–unrounded vowel–retroflex) internal to a stem. One systematic factor behind this gap is the fact that [j] cannot occur word-initially (Ebert 1996: 6).

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 formalised by the constraint PA→FrontRel. In conjunction with Agree[backness], this constraint derives vowel fronting after palato-alveolars. Where a palato-alveolar precedes and a retroflex follows, as in (41), the palato-alveolar prevails, because PA→FrontRel is ranked above Retro→BackClo.

(41)

ʧeɖ	PA→FrRel	Agree[bk]	Retro→BkClo	Ident[bk]$_V$
☞ a. ʧⁱeⁱɖ			*	
b. ʧⁱeᵚɖ		*!		
c. ʧⁱɤᵚɖ		*!		*
d. ʧᵚɤᵚɖ	*!			*

Dentals do not have this effect (40b), so Koḍagu 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 Ant→Front (§5).

Palato-alveolars do not condition fronting of back rounded vowels (e.g. [ʧokkɯ] 'intoxication', DED). 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 Koḍagu.

(42)

ʧo	PA→FrRel	Id[rd]	*[fr,+rd]	Agree[bk]	Retro→BkClo	Id[bk]$_V$
☞ a. ʧⁱo				*		
b. ʧⁱø			*!			*
c. ʧᵚo	*!					
d. ʧⁱe		*!				

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 Laminalisation of retroflexes: Acoma

Acoma (Miller 1965) exemplifies laminalisation of retroflexes before front vowels. In this language retroflexes and palato-alveolars contrast before non-front vowels (43a), but retroflexes are neutralised to palato-alveolars before front vowels, giving rise to the alternations shown in (43b) (alternating segments are shown in bold).

(43) a. ʔaʃaˀni ‘a step’ ʔaʂaˀni ‘wheat’
ʧuːda ‘plums’ ʈʂuːkaʧa ‘did you see it?’

b. /s’i-dʲaːtiʂ-atʲə/ s’idʲaːtiʂatʲə ‘we (DUAL) are holding him’
/s’i-dʲaːtiʂ-i/ s’idʲaːtiʃi ‘we (PL) are holding him’
/ʂ-aːku/ ʂaːku ‘you bit him’
/ʂ-izʐaːʧuˀwa/ ʃizʐaːʧuˀwa ‘you woke up

This pattern can be analysed in terms of the constraint RETRO→BACKCLO. The retroflex must assimilate to the following front vowel, but this conflicts with the preferred back tongue-body position for a retroflex (RETRO →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 (44) below.

The analysis employs a somewhat ad hoc constraint PALATALISATION, ‘closure and release of a consonant must be front before a front vowel’ (cf. Padgett 2003), rather than an AGREE constraint, because assimilation appears to be asymmetrical here: consonants are palatalised before front vowels, but there is no evidence of assimilation to back vowels. It is not unusual to find palatalisation conditioned by front vowels, without any comparable velarisation effects being conditioned by back vowels (as in the Russian pattern analysed by Padgett 2003, 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 (44).

(44)

ʂi	RETRO→BKCLO	PAL	IDENT[lam]
a. ⁱʂⁱi	*!		
b. ᵚʂⁱi		*!	
☞ c. ⁱʃⁱi			*

The faithfulness constraints IDENT[backness]$_V$, and IDENT[ant] must also be ranked above IDENT[lam] to block other possible resolutions of the conflict between PALATALISATION and RETRO→BACKCLO, i.e. vowel retraction (45b) or coronal advancement (45c).

(45)

ʂi	RETRO→BKCLO	PAL	IDENT[bk]$_V$	IDENT[ant]	IDENT[lam]
☞ a. ⁱʃⁱi					*
b. ᵚʂᵚɯ			*!		
c. ⁱsⁱi				*!	

Other examples of laminalisation are observed in Polish and in the historical development of Gujarati. Polish has a retroflex fricative, but its palatalised counterpart is a non-anterior laminal (Keating 1991). A palatalised retroflex would violate RETRO→BACK, so laminalisation serves to satisfy this constraint. In the development of Gujarati from Indo-Aryan, retroflex [ʂ] became laminal non-anterior [ʃ] before front vowels and glides (Hall 1996).[19]

8 Effects of back vowels on palato-alveolars

A final set of repairs are predicted to be motivated by 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 Koḍagu (§7.1), while unfaithfulness to [anterior] yields coronal advancement (/ʃu/ → [s̪u]) and unfaithfulness to [laminal] yields apicalisation (/ʃu/ → [ʂu]). The latter processes are exemplified in Wargamay and Molinos Mixtec, respectively.

8.1 Apicalisation of palato-alveolars: Molinos Mixtec

In Molinos Mixtec (Hunter & 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 (46), 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-minimisation constraints PA→FRONTREL and *RETROFLEX.

(46) ʃĩː ‘side’ ʂãː ‘very’
ʒeʔe ‘outside’ ʐoʔo ‘rope’

The analysis is illustrated by the tableaux in (47).

(47)

		PA→FRREL	AGREE[bk]	*RETRO	IDENT[lam]
a.	ʂi				
	i. ʂ^{j}i			*!	
	☞ ii. ʃ^{j}i				*
b.	ʃu				
	☞ i. ʂ^{ɯ}u			*	*
	ii. ʃ^{j}u		*!		
	iii. ʃ^{ɯ}u	*!			

The ranking *RETROFLEX ≫ IDENT[lam] 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 (47a). However, AGREE[backness] requires the release of a consonant to assimilate to

[19] Thanks to an anonymous reviewer for bringing this case to my attention.

the backness of a following vowel. Where that vowel is back, this means that a palato-alveolar fricative violates PA→FRONTREL (47b.iii), so apicalisation to a retroflex is preferred (47b.i). Note that the same outputs result if /ʃi/ is taken as the input in (47a), and /ʂ̺u/ as the input in (47b), since IDENT[lam] is not decisive in either tableau.

In addition, IDENT[backness]$_V$ and IDENT[ant] must rank above IDENT [lam], so that apicalisation is preferred over vowel fronting or coronal advancement, as shown in (48).

(48)

ʃu	PA→FRREL	IDENT[bk]$_V$	IDENT[ant]	*RETRO	IDENT[lam]
☞ a. ʂ̺ᶬu				*	*
b. ʃⁱy		*!			
c. s̻ᶬu			*!		

8.2 Advancement of palato-alveolars: Wargamay laminals

As mentioned in §6, the Australian language Wargamay contrasts apical coronals /t̺ n̺/ and laminal coronals /t̻ n̻/. Both apicals and laminals vary in their realisation, depending on vowel context. The realisation of apicals was analysed in §6, while the realisation 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 realising the laminals as [−anterior]. Some constraint favouring palato-alveolar laminals is certainly required to account for Australian languages in which palato-alveolars appear in all environments, so that there are no dentals, e.g. Dyirbal (Dixon 2002: 559) and Wergaia (Hercus 1986: 73, 106). On the other hand, there are no languages in which the only coronals are palato-alveolar, so this constraint can only be operative in languages with apical–laminal contrasts, as is predicted if the preference for palato-alveolars is based on enhancement of apical–laminal contrasts.

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 are 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 dental stops – both were identified with almost 100% accuracy.

This analysis of Wargamay is implemented in terms of the constraint LAMINAL→PA (LAM→PA): 'contrastively [laminal] stops must be [−anterior]'. This constraint creates a preference for palato-alveolar rather than dental laminals (49a), 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 (49b). PA→FRONTREL and LAM→PA are unranked, so the outcome of the conflict is variable: both dentals and palato-alveolars are possible (49b.i, ii). Before front vowels, palato-alveolars do not violate PA→FRONTREL, so there is no variation (49a).

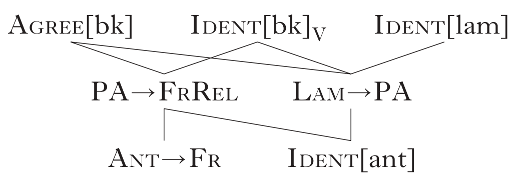
(49)

		AGREE[bk]	PA→FRREL	LAM→PA	ANT→FR	IDENT[ant]
a.	t̪i					
	i. t̪^{i}i			*!		
	☞ ii. t̠^{i}i					*
b.	t̠u					
	☞ i. t̪^{ɯ}u			*	*	*
	☞ ii. t̠^{ɯ}u		*			
	iii. t̠^{i}u	*!				

As noted above, dentals are also preferably produced with a front tongue body, as expressed by the constraint ANT→FRONT, so PA→FRONTREL must rank above ANT→FRONTREL to account for the preference for dentals before non-front vowels. We have hypothesised 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).

In addition, IDENT[backness]$_V$ and IDENT[lam] must be undominated to block alternative repairs of sequences of a laminal followed by a back vowel: vowel fronting and apicalisation. So the full ranking for Wargamay laminals is as shown in (50).

(50)



Examination of the ranking for Wargamay apicals in (37) shows that the common constraints are AGREE[backness], ANT→FRONT and the faithfulness constraints, and that the rankings of these constraints in the two analyses are consistent: AGREE[backness] ≫ ANT→FRONT, IDENT[ant]; and IDENT[backness]$_V$, IDENT[lam] ≫ IDENT[ant]. That is, there is a basic contrast between apicals and laminals, given undominated IDENT[lam], 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.

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 analysed as showing that laminals are dental by default, but are palatalised to palato-alveolars before front vowels, since palato-alveolar realisations 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 ANT→FRONT.

9 Palatalisation

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 the secondary articulation of palatalisation and coronal place.

The tongue-body fronting that is characteristic of anterior coronals is distinct from palatalisation.[20] Palatalisation 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 F2 at the release of a palatalised 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 palatalised 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 centralised quality.[21]

Anterior coronals are most easily produced with this less extreme tongue-body position, so palatalisation can result in modifications of coronal place, particularly retraction to a laminal postalveolar articulation. For example, Keating (1991) notes that in Polish, palatalisation of dentals yields alveolo-palatals, which are essentially palatalised palato-alveolars (Hume 1992, Ladefoged & Maddieson 1996: 154f), while in Japanese, dentals are palatalised to palato-alveolars before the high front vowel [i]

20 It is not clear whether [back] tongue-body position needs to be distinguished from velarisation, because much less is known about the phonetics and phonology of contrastive velarisation.

21 This feature specification is based on phonetic similarity rather than phonological patterning – that is, plain front coronals are specified as [front, −tense], on the grounds that they seem to involve a similar tongue-body position to lax front vowels. I do not currently have any evidence that front coronals group with lax vowels in phonological patterns.

(Vance 1987). Following Keating (1993), we can analyse the tendency for palatalisation of coronals to yield palato-alveolars 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 postalveolar constriction with the tongue blade by raising it a little, so palato-alveolars are very compatible with palatalisation. 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 palatalisation within the class of anterior coronals, with dentals being less compatible than alveolars: in Russian the plain coronal stops are dental, while their palatalised 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, e.g. Malayalam (Stevens *et al.* 1986, Dart & Nihilani 1999) and Tohono O'odham (Dart 1991). Stevens *et al.* 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.[22] So we posit constraints against palatalised dentals and alveolars, ranked as in (51).

(51) *PALATALISEDDENTAL ≫ *PALATALISEDALVEOLAR

In addition to accounting for the interactions between palatalisation 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, there were actually two allophones of the 'retroflex' fricative. Both were apical, contrasting with laminal dental [s̪] and laminal postalveolar [ɕ], but they differed in anteriority: a

[22] 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 realised as palato-alveolars before [i] and as dentals before [a u]. However, this pattern is essentially the same as observed in Wargamay (§8.2), and can be analysed in the same way without positing any direct 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.

[+anterior] allophone [s̺] appeared following high front [i], while a [−anterior] allophone [ʂ] appeared following [u]. In other words different ruki environments gave rise to different allophones of the 'retroflex' fricative: the high front vowel conditioned a change from laminal dental [s̻] to apical alveolar [s̺], while [r u k] conditioned a change to [−anterior, apical] [ʂ]. Given this picture, the change conditioned by high front [i] is not anomalous; it is in accord with the observation that alveolars are more compatible with palatalisation than dentals. That is, the change can be analysed as involving [s̻] assimilating the [+tense, front] tongue-body position of a preceding [i]. The shift in place from laminal dental to apical alveolar then occurs to avoid a violation of *PALATALISEDDENTAL.

The remaining environments, [r u k], can be accounted for as follows. Retroflexion following [u] can be analysed as the result of assimilation of the back tongue-body position of this sound in combination with the constraint ANT→FRONT, as in Wargamay (§6). The effect of [k] can be analysed 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].[23] A similar inventory of dorsal consonants is observed in Yanyuwa, for example (Ladefoged & Maddieson 1996: 34f). The [r] is usually assumed to be retroflex (Whitney 1889: 18f), in which case retroflexion following this sound is direct assimilation to its coronal place of articulation. These various assimilations must be motivated by a general AGREE constraint, which requires [s̻] to share at least [tense], backness and coronal place specifications with a preceding segment.[24]

This analysis must remain speculative since it is not possible to examine the realisation of retroflexes in a dead language, but there are considerations that support its plausibility. First, 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). Second, the proposal that the 'retroflex' sibilant was apical but not retroflex in all contexts helps to eliminate an apparent problem concerning the participation of [r] in ruki: as noted above, [r] is usually assumed to be retroflex since it participates in ruki and conditions retroflexion of /n/ (Whitney 1889: 64f), but many of the early Sanskrit grammarians describe this sound as alveolar (Allen 1961: 53ff). Given the present analysis, this inconsistency can be resolved if we posit

[23] The Sanskrit palatals are sometimes assumed to be palato-alveolar affricates, but descriptions by early grammarians indicate that they were palatal stops (Whitney 1889: 42, Allen 1961: 52).

[24] 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.

that [r] was in fact an apical alveolar, so assimilation of [s̺] to [r] resulted in apical alveolar [s̺] rather than a true retroflex.

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-minimisation constraints that specify the least effort tongue-body position for each type of coronal (52a), together with two enhancement constraints that bear on the realisation of apical–laminal contrasts (52b). The co-occurrence 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.

(52) a. Ant→Front
PA→Front
Retro→BackClo
*FrontRetroClo
b. Apical→Retro
Lam→PA

Coronals can affect vowel place because these constraints specify preferred tongue-body positions for coronals which can spread to adjacent vowels. Vowels 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 (52a), 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 & 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 palatalisation or velarisation (e.g. Sagey 1986). The analyses presented here motivate a return to more phonetically detailed representations. In addition we have seen evidence that it is necessary to distinguish front, central and back tongue-body positions (see especially §6), and the analysis of directionality entails even more phonetic detail in phonological representations, distinguishing closure and release features for consonants.

Second, the way in which interactions between coronals and vowels are analysed is fundamentally different from the feature-based approach exemplified by Clements (1991) and Hume (1992), who analyse 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 ANT→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 (/iʈ/ → [it̺]; §6). To analyse this process as direct assimilation, we would have to posit that front vowels are specified as [+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, §9). A similar problem arises with back vowels, because they condition [+anterior] in laminals (/t̠u/ → [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 velarised and uvularised dentals. We saw in §3 that velarised dentals are problematic for a theory that treats vowel fronting as spreading of [coronal], because even a velarised coronal is [coronal], and consequently is predicted to be able to condition fronting. In the analysis proposed here, a velarised dental has a back tongue body, in violation of ANT→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 (ANT→FRONT). However, a back dental is less marked than a back palato-alveolar (PA→FRONT ≫ ANT→FRONT), and preserves the [laminal] specification of a palato-alveolar, so it can be the most faithful realisation of a palato-alveolar before a back vowel, as seen in Wargamay (§8.2).

Finally, the coronal–backness constraints in (52a) differ significantly from redundancy rules, because redundancy rules operate in one direction only, whereas the coronal–backness constraints predict that vowels should influence coronal place as well as *vice versa*. That is, a redundancy rule of the form [+anterior] → [front] would fill in a default [front] specification on anterior coronals, which could play a role in an analysis of fronting conditioned by anterior coronals. But we have also seen that if an anterior coronal assimilates to the tongue-body position of a back vowel, the coronal can be retracted to retroflex (§6). The redundancy rule entertained above offers no account of this phenomenon, because it does not fill in a value of [anterior] based on backness. As we have seen, the interactions between coronal place and vowel backness run in both directions: coronals can affect vowel backness, and vowel backness can affect coronal place. The bidirectional relationship is captured by the constraints in (52a), because they are co-occurrence constraints, while redundancy rules would lead us to expect interactions to operate in one direction only.

In short, the analyses demonstrate that violable OT co-occurrence constraints relating distinct features provide a good model of the articulatory dependency that results from the physical connection between the tongue tip/blade and the tongue body.

REFERENCES

Al-Ani, Salman H. (1970). *Arabic phonology*. The Hague: Mouton.

Allen, W. Sidney (1961). *Phonetics in Ancient India*. London: Oxford University Press.

Anceaux, J. C. (1965). *The Nimboran language: phonology and morphology*. The Hague: Martinus Nijhoff.

Anderson, Victoria (1997). The perception of coronals in Western Arrernte. *Proceedings of the 5th European Conference on Speech Communication and Technology* (*Eurospeech 1997*). Rhodes, Greece. Vol. 1. 389–392.

Anderson, Victoria & Ian Maddieson (1994). Acoustic characteristics of Tiwi coronal stops. *UCLA Working Papers in Phonetics* **87**. 131–162.

Anttila, Arto (1997). Deriving variation from grammar. In Frans Hinskens, Roeland van Hout & W. Leo Wetzels (eds.) *Variation, change and phonological theory*. Amsterdam: Benjamins. 35–68.

Bender, Byron W. (1968). Marshallese phonology. *Oceanic Linguistics* **7**. 16–35.

Bhat, D. N. S. (1973). Retroflexion: an areal feature. *Working Papers on Language Universals* **13**. 27–67.

Bhat, D. N. S. (1974). Retroflexion and retraction. *JPh* **2**. 233–237.

Bradley, David (1979). *Lahu dialects*. Canberra: Australia National University Press.

Burrow, T. & M. B. Emeneau (1984). *A Dravidian etymological dictionary*. 2nd edn. Oxford: Clarendon.

Butcher, Andrew (1995). The phonetics of neutralisation: the case of Australian coronals. In Jack Windsor Lewis (ed.) *Studies in general and English phonetics: essays in honour of Professor J. D. O'Connor*. New York: Routledge. 10–38.

Card, Elizabeth A. (1983). *A phonetic and phonological study of Arabic emphasis*. PhD dissertation, Cornell University.

Cheng, Lisa L. S. (1991). Feature geometry of vowels and co-occurrence restrictions in Cantonese. *WCCFL* **9**. 107–124.

Choi, John D. (1992). *Phonetic underspecification and target interpolation: an acoustic study of Marshallese vowel allophony*. PhD dissertation, UCLA. Distributed as *UCLA Working Papers in Phonetics* **82**.

Chomsky, Noam & Morris Halle (1968). *The sound pattern of English*. New York: Harper & Row.

Clements, G. N. (1991). Place of articulation in consonants and vowels: a unified theory. *Working Papers of the Cornell Phonetics Laboratory* **5**. 77–123.

Clements, G. N. & Elizabeth V. Hume (1995). The internal organization of speech sounds. In John Goldsmith (ed.) *The handbook of phonological theory*. Cambridge, Mass. & Oxford: Blackwell. 245–306.

Dart, Sarah N. (1991). *Articulatory and acoustic properties of apical and laminal articulation*. PhD dissertation, UCLA. Distributed as *UCLA Working Papers in Phonetics* **79**.

Dart, Sarah N. & Paroo Nihilani (1999). The articulation of Malayalam coronal stops and nasals. *Journal of the International Phonetic Association* **29**. 129–142.

Dave, Radhekant (1977). Retroflex and dental consonants in Gujarati: a palatographic and acoustic study. *Annual Report of the Institute of Phonetics, University of Copenhagen* **11**. 27–156.

Dixon, R. M. W. (1980). *The languages of Australia*. Cambridge: Cambridge University Press.

Dixon, R. M. W. (1981). Wargamay. In R. M. W. Dixon & Barry J. Blake (eds.) *Handbook of Australian languages*. Vol. 2. Amsterdam: Benjamins. 1–144.

Dixon, R. M. W. (2002). *Australian languages: their nature and development*. Cambridge: Cambridge University Press.

Ebert, Karen (1996). *Koḍava*. Munich: Lincom Europa.

Emeneau, M. B. (1944). *Kota texts*. Part 1. Berkeley & Los Angeles: University of California Press.

Emeneau, M. B. (1970). Koḍagu vowels. *Journal of the American Oriental Society* **90**. 145–158.

Flemming, Edward (1995). *Auditory representations in phonology*. PhD dissertation, UCLA.

Flemming, Edward (2001). Contrast and perceptual distinctiveness. To appear in Bruce Hayes, Robert Kirchner & Donca Steriade (eds.) *The phonetic bases of markedness*. Cambridge: Cambridge University Press.

Flemming, Edward (2002). *Auditory representations in phonology*. New York: Routledge. Revised version of Flemming (1995).

Fowler, Carol A. (1994). Invariants, specifiers, cues: an investigation of locus equations as information for place of articulation. *Perception and Psychophysics* **55**. 597–610.

Gnanadesikan, Amalia E. (1994). The geometry of coronal articulations. *NELS* **24**. 125–139.

Gnanadesikan, Amalia E. (1997). *Phonology with ternary scales*. PhD dissertation, University of Massachusetts, Amherst.

Gudschinsky, Sarah C. (1959). *Proto-Popotecan: a comparative study of Popolocan and Mixtecan*. Baltimore: Waverly Press.

Hall, T. Alan (1996). Inalterability and sibilant neutralization in Gujarati. *Lingua* **99**. 11–20.

Hamann, Silke (2003). *The phonetics and phonology of retroflexes*. PhD dissertation, University of Utrecht. Published by LOT, Utrecht.

Hayes, Bruce (1998). Some research strategies for feature theory. Paper presented at the 4th Annual Mini-Symposium on Phonetics and Phonology, University of California, Berkeley.

Hayes, Bruce, Bruce Tesar & Kie Zuraw (2003). *OTSoft 2.1*. Software package, http://www.linguistics.ucla.edu/people/hayes/otsoft/.

Hercus, L. A. (1986). *Victorian languages: a late survey*. Canberra: Australian National University.

Houde, Robert A. (1967). *A study of tongue body motion during selected speech sounds*. PhD dissertation, University of Michigan.

Hudson, Joyce & Eirlys Richards (1969). The phonology of Walmatjari. *Oceanic Linguistics* **8**. 171–189.

Hume, Elizabeth (1992). *Front vowels, coronal consonants and their interaction in non-linear phonology*. PhD dissertation, Cornell University.

Hume, Elizabeth & Keith Johnson (eds.) (2001). *The role of speech perception in phonology*. San Diego: Academic Press.

Hunter, Georgia G. & Eunice V. Pike (1969). The phonology and tone sandhi of Molinos Mixtec. *Linguistics* **47**. 24–40.

IPA Handbook (1999). *Handbook of the International Phonetic Association: a guide to the use of the International Phonetic Alphabet*. Cambridge: Cambridge University Press.

Kao, Diana L. (1971). *Structure of the syllable in Cantonese*. The Hague: Mouton.

Keating, Patricia A. (1991). Coronal places of articulation. In Carole Paradis & Jean-François Prunet (eds.) *The special status of coronals: internal and external evidence*. San Diego: Academic Press. 29–48.

Keating, Patricia A. (1993). Phonetic representation of palatalization versus fronting. *UCLA Working Papers in Linguistics* **85**. 6–21.

Kiparsky, Paul (to appear). *Paradigm effects and opacity*. Stanford: CSLI.

Krishnamurti, Bhadriraju (2003). *The Dravidian languages*. Cambridge: Cambridge University Press.

Kristoffersen, Gjert (2000). *The phonology of Norwegian*. Oxford: Oxford University Press.

Ladefoged, Peter & Ian Maddieson (1996). *The sounds of the world's languages*. Cambridge, Mass. & Oxford: Blackwell.

Lindblom, B., S. Pauli & J. Sundberg (1974). Modeling coarticulation in apical stops. In Gunnar Fant (ed.) *Proceedings of the Speech Communication Seminar*. Vol. 2: *Speech production and synthesis by rules*. Stockholm: Almqvist & Wiksell. 87–94.

Lombardi, Linda (1999). Positional faithfulness and voicing assimilation in Optimality Theory. *NLLT* **17**. 267–302.

McCarthy, John (1994). The phonetics and phonology of Semitic pharyngeals. In Patricia A. Keating (ed.) *Phonological structure and phonetic form: papers in laboratory phonology III*. Cambridge: Cambridge University Press. 191–233.

McCarthy, John (2002). *A thematic guide to Optimality Theory*. Cambridge: Cambridge University Press.

Maddieson, Ian (1984). *Patterns of sounds*. Cambridge: Cambridge University Press.

Manuel, S. Y. & K. N. Stevens (1995). Formant transitions: teasing apart consonant and vowel contributions. In Kjell Elenius & Peter Branderud (eds.) *Proceedings of the 13th International Congress of Phonetic Sciences*. Vol. 4. Stockholm: KTH & Stockholm University. 436–439.

Marsh, James (1969). Mantjiltjara phonology. *Oceanic Linguistics* **8**. 131–152.

Matisoff, James A. (1973). *The grammar of Lahu*. Berkeley: University of California Press.

Matisoff, James A. (1988). *The dictionary of Lahu*. Berkeley: University of California Press.

Miller, Wick R. (1985). *Acoma grammar and texts*. Berkeley & Los Angeles: University of California Press.

Öhman, S. E. G. (1966). Coarticulation in VCV utterances: spectrographic measurements. *JASA* **39**. 151–168.

Padgett, Jaye (2003). Contrast and post-velar fronting in Russian. *NLLT* **21**. 39–87.

Prince, Alan & Paul Smolensky (1993). *Optimality Theory: constraint interaction in generative grammar*. Ms, Rutgers University & University of Colorado, Boulder. To appear, Cambridge, Mass.: MIT Press.

Redford, Melissa A. & Randy L. Diehl (1999). The relative perceptual distinctiveness of initial and final consonants in CVC syllables. *JASA* **106**. 1555–1565.

Reynolds, William T. (1994). *Variation and phonological theory*. PhD dissertation, University of Pennsylvania.

Richards, Eirlys & Joyce Hudson (1996). *Walmajarri–English dictionary*. Darwin: Summer Institute of Linguistics.

Sagey, Elizabeth (1986). *The representation of features and relations in nonlinear phonology*. PhD dissertation, MIT.

Shalev, Michael, Peter Ladefoged & Peri Bhaskararao (1993). Phonetics of Toda. *UCLA Working Papers in Phonetics* **84**. 89–126.

Smolensky, Paul (1995). On the internal structure of the constraint component *Con* of UG. Handout of talk presented at UCLA.

Spajić, Siniša, Peter Ladefoged & Peri Bhaskararao (1996). The trills of Toda. *Journal of the International Phonetic Association* **26**. 1–21.

Steriade, Donca (1993). Closure, release, and nasal contours. In Marie Huffman & Rena Krakow (eds.) *Nasals, nasalization, and the velum*. Orlando: Academic Press. 401–470.

Steriade, Donca (1994). Complex onsets as single segments: the Mazateco pattern. In Jennifer Cole & Charles Kisseberth (eds.) *Perspectives in phonology*. Stanford: CSLI. 203–291.

Steriade, Donca (1995). Neutralization and the expression of contrast. Ms, UCLA.

Steriade, Donca (2000). Paradigm uniformity and the phonetics–phonology boundary. In Michael B. Broe & Janet B. Pierrehumbert (eds.) *Papers in laboratory phonology V: acquisition and the lexicon*. Cambridge: Cambridge University Press. 313–334.

Steriade, Donca (2001). Directional asymmetries in place assimilation: a perceptual account. In Hume & Johnson (2001). 219–250.

Stevens, Kenneth N. (1998). *Acoustic phonetics*. Cambridge, Mass.: MIT Press.

Stevens, Kenneth N., Samuel Jay Keyser & Haruko Kawasaki (1986). Toward a phonetic and phonological theory of redundant features. In Joseph S. Perkell & Dennis H. Klatt (eds.) *Invariance and variability in speech processes*. Hillsdale, NJ: Erlbaum. 426–449.

Vance, Timothy J. (1987). *An introduction to Japanese phonology*. Albany: State University of New York Press.

Whitney, William Dwight (1889). *A Sanskrit grammar*. 2nd edn. Boston: Ginn.

Wiltshire, Caroline & Louis Goldstein (1997). Tongue tip orientation and coronal consonants. *Proceedings of the Eastern States Conference on Linguistics* **14**. 216–225.

Wright, Richard (2001). Perceptual cues in contrast maintenance. In Hume & Johnson (2001). 251–277.