Vowel reduction as information loss[*]

John Harris
University College London

Abstract

Vowel reduction degrades phonetic information in the speech signal and should be understood as having an analogous impact on phonological representations.

Reduction follows two apparently contradictory routes in vowel space, yielding either centralised values (the ‘centripetal’ pattern) or the corner values *a, i, u* (the ‘centrifugal’ pattern). What unifies these vowels is the relative simplicity of their acoustic spectra compared to those of mid peripheral vowels. Spectral complexity can be taken as one measure of the amount of phonetic information present in a speech signal at a given time. On this basis, centripetal and centrifugal reduction can both be construed as resulting in a loss of phonetic information.

In selectively targeting non-prominent positions, reduction has the effect of enhancing syntagmatic contrasts among vowels. Representing vowels in terms of three basic components manifested as *a, i* and *u* allows informational asymmetries of this sort are to be directly recorded in phonological grammars.

1 Introduction

There are at least two respects in which the set of phonological effects traditionally referred to as VOWEL REDUCTION can be said to constitute a unitary phenomenon. First, they target positions that are prosodically or morphologically weak, most especially unstressed syllables or affixes. Second, they neutralise contrasts, producing contracted versions of vowel systems that appear in strong positions.

The unity appears to dissolve, however, as soon as we consider the specific effects that reduction has on vowel quality. At least when described in traditional articulatory terms, these follow two seemingly contradictory routes in vowel space. One is ‘centripetal’, in which reduced reflexes are drawn into a centralised region. The other is ‘centrifugal’, in which vowels are dispersed to the far corners of the space. Recently this divergence has been attributed to constraints that bring conflicting pressures to bear on vowels in sites targeted by reduction: some constraints call for prominence to be reduced, others for contrasts to be enhanced (Crosswhite 2001, to appear).

I wish to suggest here that the qualitative effects of vowel reduction re-emerge as a unitary phenomenon once we take account of its impact on the phonetic-informational content of speech signals. The spectral profiles of centralised vowels and the ‘corner’ or ‘point’ vowels can be viewed as less complex than those of mid peripheral vowels. Centripetal and centrifugal reduction thus have the shared effect of diminishing the amount of phonetic information in the speech signal.

There is no reason to suppose that this asymmetry should be reflected in phonological grammars in anything other than a direct manner. Traditional articulatory feature theory is ill-equipped to do this. By contrast, representing vowel quality in terms of three components manifested as the corner values *a, i* and *u* (the ‘AIU’ model) allows these asymmetries to be captured quite straightforwardly. Specifically, the loss of phonetic information accompanying vowel reduction is matched by a loss of phonological information in the form of the suppression of AIU components.

The paper runs as follows. It starts with a review of centripetal and centrifugal patterns of vowel reduction (§2) and discusses how these are treated in Crosswhite’s functionalist, constraint-based account (§3). §4 describes how both types of reduction can be viewed as suppressing phonetic information in the speech signal. §5 shows how this effect is parallelled by the suppression of AIU components in phonological grammars. The analysis of vowel reduction as information loss prompts a reassessment of certain widely held assumptions about its teleology, in particular the notion that it is the phonologised reflex of target undershoot in speech production. This issue is taken up in the concluding section (§6).

2 Centrifugal and centripetal reduction

In centrifugal reduction, vowels disperse towards the corner values *i, u, a*. Where an entire vowel system is affected in this way, the contracted subsystem excludes mid vowels, either through raising or lowering. The raising and lowering patterns are exemplified by the discrepancy between strong (stressed) and weak (unstressed) vowels in Luiseño in (1) and Belorussian in (2) (data from Crosswhite, to appear).

(1) (a) Luiseño

<table>
<tr><td>Strong</td><td><i>i</i></td><td><i>e</i></td><td><i>a</i></td><td><i>o</i></td><td><i>u</i></td></tr>
<tr><td>Weak</td><td colspan="2"><i>i</i></td><td><i>a</i></td><td colspan="2"><i>u</i></td></tr>
</table>

(b)

cóka	‘to limp’	*cukáʃkas*	‘limping’
hédin	‘will open’	*hidíki*	‘to uncover’
capómkat	‘liar’	*cápumkatum*	‘liars’
máha	‘to stop’	*mahámhaʃ*	‘slow’
kúmit	‘smoke’	*kumíkmiʃ*	‘smoke coloured’
ṣúkat	‘deer’	*páṣukat*	‘elk’
takítkiʃ	‘straight’	*tákiʃ*	‘pottery stone’

(2) (a) Belorussian

<table>
<tr><td>Strong</td><td><i>i</i></td><td><i>e</i></td><td><i>a</i></td><td><i>o</i></td><td><i>u</i></td></tr>
<tr><td>Weak</td><td><i>i</i></td><td colspan="3"><i>a</i></td><td><i>u</i></td></tr>
</table>

(b)	*nóɣi*	‘legs’	*naɣá*	‘leg’
	kól	‘pole (nom.)’	*kalá*	‘pole (gen.)’
	vʲósnɨ	‘spring (gen.)’	*vʲasná*	‘spring (nom.)
	mʲót	‘honey (nom.)’	*mʲadóvɨ*	‘honey (adj.)’
	ʃépt	‘whisper’	*ʃaptátsʲ*	‘to whisper’
	réki	‘rivers’	*raká*	‘river’
	spʲétsʲ	‘to ripen’	*paspʲávatsʲ*	‘to mature’
	klʲéj	‘glue’	*klʲajónka*	‘oil-cloth’

In centripetal reduction, peripheral vowels are centralised towards some schwa-like quality. While it is unusual for an entire vowel system to be centripetally contracted, it is common to find this pattern co-occurring with centrifugal reduction. An example is Bulgarian, where a five-vowel stressed inventory contracts to three through the raising of mid vowels and the centralisation of *a* (see Anderson 1996; Crosswhite, to appear):

(3) (a) Bulgarian

<table>
<tr><td>Strong</td><td><i>i</i></td><td><i>e</i></td><td><i>a</i></td><td><i>o</i></td><td><i>u</i></td></tr>
<tr><td>Weak</td><td colspan="2"><i>i</i></td><td><i>ə</i></td><td colspan="2"><i>u</i></td></tr>
</table>

(b)	*róguf*	‘of horn’	*rugát*	‘horned’
	ónzi	‘that (masc.)’	*unázi*	‘that (fem.)’
	sélu	‘village’	*silá*	‘villages’
	rábutə	‘work’	*rəbótnik*	‘worker’
	grát	‘city’	*grədéts*	‘town’

The co-occurrence of centripetal and centrifugal reduction can manifest itself asymmetrically in the front and back regions of a vowel system. The seven-term stressed system of Catalan, for example, exhibits front centralisation and back raising in unstressed positions (data from Palmada Félez 1991):

(4) (a) Catalan

<table>
<tr><td>Strong</td><td><i>i</i></td><td><i>e</i></td><td><i>ɛ</i></td><td><i>a</i></td><td><i>ɔ</i></td><td><i>o</i></td><td><i>u</i></td></tr>
<tr><td>Weak</td><td><i>i</i></td><td colspan="3"><i>ə</i></td><td colspan="3"><i>u</i></td></tr>
</table>

(b)	*prím*	‘slim’	*əprimár*	‘to slim’
	sérp	‘snake’	*sərpəntí*	‘winding’
	pɛ́l	‘hair’	*pəlút*	‘hairy’
	gát	‘cat’	*gətɛ́t*	‘kitten’
	ʎúm	‘light’	*ʎuminós*	‘luminous’
	gós	‘dog’	*gusɛ́t*	‘puppy’
	pɔ́rt	‘port’	*purtuári*	‘of the port’

A similar asymmetry is evident in Neapolitan Italian, where front centralisation extends to *i* (Bafile 1997):

(5) (a) Neapolitan Italian

Strong	*i*	*e*	*ɛ*	*a*	*ɔ*	*o*	*u*
Weak	*ə*			*a*	*u*		

(b)

díʃə	'he says'	*dəʃítə*	'say (imp. pl)'
péʃkə	'I fish'	*pəʃkatórə*	'fisherman'
séččа	'cuttle fish'	*səccətɛ́lla*	'small cuttlefish'
vékə	'he sees'	*vərítə*	'see (imp. pl.)'
tɛ́nə	'he keeps'	*tənítə*	'keep (imp. pl.)'
kórrə	'he runs'	*kurrítə*	'run (imp. pl.)'
pɔ́rta	'he brings'	*purtátə*	'bring (imp. pl.)'
pɔ́kə	'a little'	*pukuríllə*	'a very little'

One question raised by this brief survey is whether the apparently divergent routes followed by reducing vowels reflect fundamentally distinct types of process. We will now consider one recent analysis that assumes this to be the case.

3 Vowel reduction in functional OT

Vowel reduction resembles consonantal lenition in certain obvious respects, including a propensity to occur in prosodically weak positions and to neutralise contrasts. In 'phonetically-driven' Optimality Theory, it has recently been claimed that different types of lenition – spirantisation, vocalisation, debuccalisation, etc. – are all part of a single scenario in which constraints favouring the preservation of contrasts are outranked by constraints penalising the expenditure of articulatory effort (Kirchner 1998, in press). The effort-based constraints are claimed to be functionally live, in the sense that they embody the same kind of mechanical factors that drive target undershoot in speech production (cf. Flemming 1995, 2001).

In spite of the strong similarities with lenition, this kind of account cannot be directly extended to vowel reduction, because of the conflicting articulatory trajectories followed by its centripetal and centrifugal variants. Centripetal centralisation can plausibly be linked to target undershoot, for example by invoking the reduced distance the tongue body has to travel from a hypothetical neutral position. But no such account is available for centrifugal reduction, where the corresponding distances for the corner vowels are arguably greater than for mid peripheral vowels.

Crosswhite's response is to posit two formally distinct types of vowel reduction (2001, to appear), thereby denying a straightforward comparison with lenition. The difference, she claims, reflects distinct phonetic teleologies, only one of which is related to target undershoot. The two types are distinguished by the relative ranking of two constraint families that bring conflicting pressures to bear on vowels in weak positions: one calls for contrasts to be enhanced, the other for prominence to be reduced.

Contrast-enhancing constraints favour the maximal dispersion of vowels in weak positions. The motivation for such constraints derives from the fact that the detectability of certain feature values can vary from one position to another, reflecting differences in the availability of acoustic cues (cf. Steriade's (1997) notion of 'licensing by cue'). The speaker is supposedly reluctant to expend ineffectual effort in deploying feature values in positions where their acoustic cues are diminished or absent altogether. Applied to reduction, the idea is that the point vowels possess a perceptual robustness that allows them to be more readily perceived in weak positions than other vowels.

Prominence-reducing constraints disfavour the appearance of salient vowel qualities in weak positions, where salience correlates with some measure of sonority, intensity or duration. When responding to constraints of this sort, weak positions will prefer higher (hence less sonorous) vowels over lower.

Individual reduction-inducing constraints stipulate whether or not a particular feature specification is licensed in a particular position, thereby expressing the potential effects of reduction on each vowel within a system. For example, *[–high, –low]/σ̆ bars mid vowels from unstressed syllables. Scalar raising results when the set of prominence-reducing constraints is ranked *en bloc* above the set of contrast-enhancing constraints. This is the pattern evidenced by Bulgarian in (3), where low raises to mid-central while mid raises to high. Interleaving constraints from the two different families produces asymmetric systems, such as the front centralisation and back raising of mid vowels encountered in Neapolitan Italian (see (5)).

The notion of contrast enhancement connects in a rather direct way with independently established principles of auditory-acoustic phonetics – for example with those embodied in Lindblom's dispersion model of vowel-system design (Lindblom 1986, Diehl *et al.* 2003). The same cannot be said of the notion of prominence. As Crosswhite herself acknowledges, prominence – like its component, sonority – has never been shown to have any clearly definable phonetic correlate.

Moreover, in the case of scalar raising, there is a clear asymmetry that prominence reduction is unable to account for. Bulgarian seems to be typical of scalar systems in that the compression of the vowel space produced by raising shifts mid vowels up the periphery but shifts low *a* up a centralised route. Mid raising is consistent with both contrast enhancement and prominence reduction. On the other hand, only the latter factor can be involved in the raising of low to central (since the output is not one of the point values). But under prominence reduction it should be equally possible for *a* to follow a peripheral path, producing *a* > *e* or *a* > *o*. After all, at least according to standard definitions, mid peripheral vowels are no more or less sonorous than mid central.[1] But reduction of *a* by peripheral raising is at best highly marked.

In Optimality Theory, this kind of markedness asymmetry is typically expressed by imposing a universally fixed ranking on the relevant constraints and shifting the burden of explanation onto the functional factors that drive them. However, in this instance, neither of the two main functional factors supposedly driving reduction is able to explain the asymmetry in question.

In short, the combined notions of contrast enhancement and prominence fail to explain why mid peripheral vowels are consistently rejected as outputs of reduction. The fundamental question posed by reduction thus remains unanswered: what unifies the class of corner and central vowels that makes them suitable occupants of weak positions? In the next sections, I will outline an alternative approach to this question that focuses on a property of vowel quality which, unlike sonority, has clear phonetic correlates, namely the nature of phonetic information contained in vocalic speech signals.

4 Vowel reduction as information loss in the speech signal

To get a handle on the notion of vocalic information, let us briefly remind ourselves of a number of fundamental characteristics of speech. We start with the standard view of speech as a carrier signal modulated by acoustic events that convey linguistic information (cf. Ohala 1992, Traunmüller 1994).

In the unmarked case, the carrier is a periodic waveform lacking spectral peaks – the acoustic effect produced by a neutrally open vocal tract shape. Any quality associated with this aspect of the speech signal is primarily non-linguistic, divulging details about the talker's organism (sex, age, size, etc.), mental state (emotions, attitude, etc.) and physical location.

Linguistically significant information – that part of the speech signal traditionally referred to as phonetic quality – resides in modulations that deviate from the carrier baseline along a number of parameters involving spectral shape, amplitude, periodicity and fundamental frequency. In the case of vowel quality, the modulations take the form of spectral peaks created by convergences between pairs of formants.

Of the different vocalic qualities conveying phonetic (i.e. linguistically significant) information, those associated with the corner vowels *a*, *i* and *u* are special in a number of respects, three of which Crosswhite (to appear) draws attention to. First, they are quantal in the sense of Stevens (1989): that is, their spectral shapes remain relatively stable across a range of articulations. Second, they are focalised: they are characterised by convergences between pairs of formants (or between F0 and F1) that are perceived as single spectral prominences (Lieberman 1976, Stevens 1989, Schwartz *et al.* 1997). Third, the qualities are dispersed in the sense of Lindblom (1986): they are maximally distinct in auditory-acoustic vowel space, a characteristic that is reflected in their most favoured status in vowel-system universals.

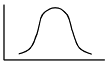
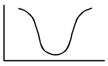
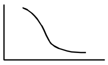
The focalised nature of the corner vowels sets them apart from unfocalised schwa. The spectrum of schwa displays evenly spaced formants, the structure associated with an unmodulated carrier signal. In *a*, F1 and F2 converge to create an energy peak in the middle of the vowel spectrum (roughly 0Hz to 2.5kHz for an average adult male). In *i*, there is one peak at the top of the vowel spectrum, representing the convergence of F2 and F3, with another peak at the bottom created by the convergence of F0 and F1. In *u*, F1 and F2 converge to form a peak at the bottom of the vowel spectrum.

The magnitude of a modulation carrying vocalic information can be measured in terms of the extent to which its spectral characteristics deviate from the neutral baseline defined by the carrier signal. Let us treat this measure as providing an indication of the modulation's capacity to bear phonetic information: the larger the modulation, the more phonetic information it bears. By comparing focalised and non-focalised vowel spectra, we then get a sense of how centripetal reduction can be viewed as a loss of phonetic information. Centralising any of the corner qualities to schwa involves the suppression of energy peaks, thereby merging the vowel spectrum with the background defined by the carrier signal.

What is perhaps not so clear is how, from this perspective, centrifugal reduction could also be said to involve a loss of phonetic information. However, a correlation of this sort can be established by taking account of the relative complexity of the spectral patterns associated with different vowel qualities. The corner vowels can be construed as simplex in the sense that each projects a unitary spectral pattern onto the acoustic signal (Harris & Lindsey 1995, 2000). On the other hand, mid peripheral vowels are spectrally more complex in that they can viewed as amalgamations of these simple patterns.

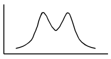
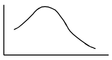
To see this, consider first the spectral profiles of the corner vowels as they are depicted in Figure 1. Each vowel in the figure is associated with a schematic filter response curve, displaying amplitude (y-axis) and the frequency range (x-axis) relevant for vowel quality. In the case of *a* (Figure 1a), a unitary spectral pattern can be discerned in the form of a MASS – a concentration of energy (the convergence of F1 and F2) in the centre of the vowel spectrum, with troughs at top and bottom. For *i* (Figure 1b), the corresponding pattern can be described as a DIP: energy is distributed both towards the top of the vowel spectrum (the convergence of F2 and F3) and the bottom (F0 and F1), with a trough in between. For *u* (Figure 1c), the pattern forms a RUMP: there is a marked skewing of energy (the convergence of F1 and F2) to the lower half of the vowel spectrum.

Figure 1. Spectral shapes and schematic filter response curves: *a, i, u*.

		Spectral shape	Schematic filter response
(a)	*a*	‘Mass’: mass of energy located in the centre of the vowel spectrum, with troughs at top and bottom.	
(b)	*i*	‘Dip’: energy distributed to the top and bottom of the vowel spectrum, with a trough in between.	
(c)	*u*	‘Rump’: marked skewing of energy to the lower half of the vowel spectrum.	

Compare these simplex spectral patterns with the profiles of mid vowels, which – as depicted in Figure 2 – can be construed as complex. *e* shares with *i* a clear energy gap between F1 and F2. However, F1 and F2 are closer together in *e* than in *i*; that is, as with *a*, energy is concentrated in a central region, with troughs at top and bottom of the vowel spectrum. As portrayed in Figure 2a, this configuration can be viewed as a combination of *a*’s mass pattern and *i*’s dip. *o* shares with *u* a marked skewing of energy towards the lower end of the vowel spectrum. However, in *o* the peak energy is located far enough away from the bottom of the vowel spectrum for a trough to be identifiable below it. As portrayed in Figure 2b, this configuration can be viewed as a combination of *a*’s mass pattern and *u*’s rump.

Figure 2. Complex spectral shapes and filter response curves: *e* and *o*.

		Spectral shape	Schematic filter response
(a)	*e*	Dip and mass	
(b)	*o*	Rump and mass	

The simplex spectral shapes mass, dip and rump can be considered the basic components of phonetic information contained in vocalic speech signals. It is now possible to see how centrifugal vowel reduction can be interpreted as a loss of phonetic information. Reducing a peripheral mid vowel by raising or lowering removes one of its spectral components. Raising (*e* > *i*, *o* > *u*) suppresses the mass property that mid vowels share with *a*, while lowering suppresses either the dip (*e* > *a*) or the rump (*o* > *a*) properties shared with high vowels.

To summarise: what unifies the class of vowels that are the preferred outputs of reduction is their low degree of spectral complexity. Each of the point vowels projects a simplex spectral shape, while schwa projects none at all. Both centrifugal and centripetal reduction thus diminish the amount of phonetic information borne by vocalic speech signals. Peripheral raising and lowering remove part of the spectral information contained in mid vowels, while centralisation to schwa guts a vowel of all informational content.

5 Vowel reduction as information loss in phonology

In this section, I present a case for assuming that informational differences between reduced and unreduced vowels should be transparently recorded in phonological grammars.

Phonological grammars encode the knowledge that enables the reception and transmission of linguistic information by sound. Phonological features are the units of the grammar that code the specifically segmental or melodic aspect of this information. A reasonable first assumption is that the mapping between features and signal information is relatively direct.

The flow of phonetic information across speech signals is uneven: linguistically significant modulations are of a greater magnitude at certain points in time than at others. As described in the previous section, this is the situation we encounter in the temporal alternation between unreduced and reduced vowels in strong and weak positions. The same general point can be made with respect to consonants, especially where alternating weak positions are selectively targeted by lenition (see Harris & Urua 2001). If the assumption about the directness of the feature-to-signal relation is correct, we expect this unevenness to be reflected in phonological representations. That is, segments in strong positions should bear richer feature specifications than segments in weak positions.

A correlation of this sort is not readily expressible by means of standard SPE-type features. In its undiluted form, standard feature theory requires any segment to bear as much feature specification as the next. As a result, vowel reduction is represented as the replacement of one set of feature values by another. As illustrated in (6), a reduced vowel thus contains as much phonological information as an unreduced counterpart.

(6) (a) *e* (b) *ə*

$$\begin{bmatrix} \text{-high} \\ \text{-low} \\ \text{-back} \\ \text{-round} \\ : \end{bmatrix} \qquad \begin{bmatrix} \text{-high} \\ \text{-low} \\ \text{+back} \\ \text{-round} \\ : \end{bmatrix}$$

Informational imbalances can be introduced into standard-feature representations by allowing subsets of values to be underspecified – a scenario that arises if vowel reduction is expressed as the deletion of feature values (cf. Zoll 1996). The appeal of this approach is greatly diminished, however, if we wish to model reduction by means of output constraints. For a representation to qualify as authentic output, it must be phonetically interpretable, and with standard features that means it must be fully specified. A case might be made for relaxing this requirement in the case of schwa, if this vowel can be regarded as lacking an articulatory target (cf. Keating 1988). But the analysis cannot be extended to centrifugal reduction, since the point vowels cannot be treated as targetless. Any high-ranked constraint that effects reduction by banning a particular feature value will routinely be matched by a constraint that requires the complement value to be specified so as to ensure the reduced vowel is phonetically interpretable. In other words, with standard features, any specificational unevenness potentially associated with reduction is automatically smoothed out in output.

The main factor preventing SPE-type feature theory from giving direct expression to informational asymmetries is its fundamentally articulatory orientation. This lends an indirectness to the relation between speech signals and features that removes the possibility of any kind of isomorphism between them. The listener supposedly extracts linguistic information from speech signals not by parsing proximal acoustic modulations but by retrieving the distal articulatory movements that produce them – as assumed by the motor-theory and direct-realist models of speech perception (Liberman & Mattingly 1985, Fowler 1986). Even if we grant the possibility that articulations are in and of themselves information-bearing, there is no obvious sense in which different movements could be said to carry differing degrees of information. How, for example, could the tongue-body gesture for a mid peripheral vowel bear any more or less information than that for a high vowel?

If phonological features are to express informational asymmetries in any direct way, they have to be defined in auditory-acoustic terms. In the case of vowels, this cannot be immediately taken to imply definitions based on continuous or categorical values for individual formants (*pace* Flemming 2001). This format is no better than articulatory features at capturing asymmetries. Representing vowel contrasts in terms of values for the first two or three formants yields a uniform degree of specificational complexity across all qualities, reduced and unreduced. Schwa, for example, is no less specifiable for formant values than any other vowel. In any event, the auditory processing of vocalic speech signals by humans is known not to involve tracking the centre frequencies of individual formants. What is required instead is a feature system that codes the gross spectral characteristics of vowel quality, in the spirit of Jakobson, Fant & Halle (1952).

A system of vowel features exclusively dedicated to the representation of linguistically significant information will code the spectral prominences that modulate the carrier wave in vocalic speech signals. There will be no place in such a system for specifications that code properties of the carrier itself, such as periodicity (cf. the standard specification of vowels as [+voice] and [+continuant]) or the dispersed formant structure of schwa. If it is correct to identify the prominences with the three basic spectral shapes mass, dip and rump, then it makes sense to see these as the acoustic signatures of information-based vowel features. In a tripartite model of vowel phonology, it is immediately clear what these features are: the AIU components map readily to the spectral shapes in question (cf. Harris & Lindsey 2002).

Recall the bare essentials of the AIU model – those design properties that are shared by all of its main theoretical variants.[2] Each of the point vowels manifests one of the AIU components: *a* = [A]; *i* = [I]; *u* = [U]. Mid vowels are compounds: *e* = [A, I]; *o* = [A, U]. Schwa lacks any specification. (7) spells out how these representations map to the spectral shapes mass, dip and rump.

(7)

	VOWEL	COMPONENT	SPECTRAL CORRELATE
(a)	*a*	[A]	mass
	i	[I]	dip
	u	[U]	rump
(b)	*e*	[A, I]	mass & dip
	o	[A, U]	mass & rump
(c)	*ə*	[ ]	

The model has built-in specificational asymmetries that map in a direct way onto informational asymmetries in the speech signal. Each of the representationally simplex point vowels, shown in (7)a, maps to a single spectral shape. Each of the representationally complex mid vowels, shown in (7)b, maps to a spectrum composed of two shapes. Representationally null schwa, shown in (7)c, maps to the spectral baseline associated with the carrier signal.

Within the AIU framework, vowel reduction is straightforwardly represented as the suppression of phonological information. Consider the example of Bulgarian, illustrated in (3) above and tabulated in (8) below (cf. Anderson 1996).

(8)

Strong	*i* [I]	*e* [I, A]	*a* [A]	*o* [U, A]	*u* [U]
Weak	[I] *i*		[ ] *ə*	[U] *u*	

The component [A] is supported in strong positions but excluded from weak positions. Suppression of [A] produces reduction by raising, both centrifugal (*e/o* > *i/u*) and centripetal (*a* > *ə*). The overall effect on a canonical five-vowel system is to restrict representationally complex vowels (*e* and *o*) to strong positions. The analysis thus illustrates how the AIU model gives representational expression to the asymmetries between a maximal vowel inventory and a contracted counterpart: the larger the system, the more representationally complex the vowels it is able to contain.

Whenever claims have been made about the phonetic naturalness of the AIU model, these have, more often than not, been offered as *post hoc* explanations of observed phonological patterning in vowel-system typology and natural-class behaviour (see for example Anderson & Ewen 1987). In pursuing the information-based approach outlined here, we arrive at the AIU model via a rather different, more immediately phonetic route. The transparency of the phonology-speech mapping defined by the model resides in the close fit it provides between phonological information and signal information: the component complexity of vowel representations goes hand in hand with spectral complexity. The model thus allows us to view vowel reduction as degrading information not only in the speech signal but also in phonology.

6 Teleology of vowel reduction: attention versus effort

A familiar functionalist take on vowel reduction is that it is the phonologised reflex of target undershoot in speech production. It has been demonstrated that decreasing duration, one of the correlates of weak stress, compresses the acoustic space occupied by vowels (Lindblom 1963). This effect is often attributed to the inherent inertia of the speech mechanism: the articulators fail to reach hypothetical vowel targets that are more readily achieved with longer durations (cf. Flemming 1995, Kirchner 1998).

In the functionalist version of Optimality Theory reviewed in §3, vocal-organ inertia is seen as the main factor driving vowel reduction. This is part of a wider picture in which the needs of talkers and listeners are in competition with one another. The pressure for the speaker to minimise the expenditure of articulatory effort asserts itself in weak positions but is curtailed in strong positions, where it is offset by a listener-oriented pressure for distinctions to be preserved.

It would be wrong to take this explanation for granted, since it is by no means the only plausible functional interpretation of reduction. One alternative account, with at least as strong a claim to plausibility, focuses on speech as a collaborative enterprise between talker and listener. Briefly, it runs like this. Talkers direct listeners' attention to prominent positions by selectively increasing and the amount of attention they devote to production. That is, in prominent positions, ‘hyperarticulation’ (Lindblom 1990) works in tandem with ‘hyperperception’ (see Cole *et al.* 1978). Meanwhile talkers ‘hypoarticulate’ (Lindblom 1990) in non-prominent positions, selectively decreasing attention to production. The overall communicative effect is to modulate attention across speech signals (cf. de Jong 2002): the occurrence of hypoarticulated weak positions enhances the prominence of intervening strong positions. Positionally sensitive vowel reduction, like consonantal lenition, can be understood as accentuating the syntagmatic contrast between information-heavy prominent syllables and information-light weak syllables. On this view, reduction is part of planned speech behaviour rather than an accidental by-product of vocal-organ inertia.

It is hardly surprising that this scenario is not the first to spring to mind when reduction is described in terms of orthodox articulatory features, given that these provide no direct way of characterising informational asymmetries between strong and weak positions. One of the advantages of the AIU model, on the other hand, is that it allows the syntagmatic contrast between information-heavy and information-light vowels to be directly reflected in phonological grammars.

References

Anderson, J. M. (1996). The representation of vowel reduction: non-specification and reduction in Old English and Bulgarian. *Studia Linguistica* 50. 91-105.

Anderson, J. M. & C. J. Ewen (1987). *Principles of Dependency Phonology*. Cambridge: Cambridge University Press.

Anderson, J. M. & C. Jones (1974). Three theses concerning phonological representations. *Journal of Linguistics* 10. 1-26.

Anderson, J. M. & J. Durand (eds.) (1987). *Explorations in Dependency Phonology*. Foris: Dordrecht.

Bafile, L. (1997). L’innalzamento vocalico in napoletano: un caso di interazione fra fonologia e morfologia. In L. Agostiniani (ed.), *Atti del III Convegno Internazionale della Società Internazionale di Linguistica e Filologia Italiana*, 1-22. Napoli: Edizioni Scientifiche Italiane.

Carr, P. & C. J. Ewen (eds.) (to appear). *Festschrift for John Anderson*. Amstrerdam: Benjamins.

Cole, R. A., J. Jakimik & W. E. Cooper (1978). Perceptibility of phonetic features in fluent speech. *Journal of the Acoustical Society of America* 64. 44-56.

Crosswhite, K. (2001). *Vowel reduction in Optimality Theory*. New York: Routledge

Crosswhite, K. (to appear). Vowel reduction. In B. Hayes, R. Kirchner & D. Steriade (eds.), *Phonetically-based phonology*. Cambridge: Cambridge University Press.

Diehl, R. L., B. Lindblom & C. P. Creeger (2003). Increasing realism of auditory representations yields further insights into vowel phonetics. *Proceedings of the 15th International Congress of Phonetic Sciences*, Vol. 2, 1381-1384. Adelaide: Causal Publications.

Durand, J. (ed.) (1986). *Dependency and non-linear phonology*. London: Croom Helm.

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

Flemming, E. (2001). Scalar and categorical phenomena in a unified model of phonetics and phonology. *Phonology* 18. 7-44.

Fowler, C. A. (1986). An event approach to the study of speech perception from a direct-realist perspective. *Journal of Phonetics* 14. 3-28.

Goldsmith, J. A. (1985). Vowel harmony in Khalkha Mongolian, Yaka, Finnish and Hungarian. *Phonology Yearbook* 2. 251-274.

Harris, J. & G. Lindsey (1995). The elements of phonological representation. In J. Durand & F. Katamba (eds.), *Frontiers of phonology: atoms, structures, derivations*. Harlow, Essex: Longman. 34-79.

Harris, J. & G, Lindsey (2000). Vowel patterns in mind and sound. In N. Burton-Roberts, P. Carr & G. Docherty (eds.), *Phonological knowledge: conceptual and empirical issues*, 185-205. Oxford: OUP.

Harris, J. & E-A. Urua (2001). Lenition degrades information: consonant allophony in Ibibio. *Speech, Hearing and Language: Work in Progress* 13 (University College London). 72-105.

Hulst, H. van der (1989). Atoms of segmental structure: components, gestures and dependency. *Phonology* 6. 253-84.

Hulst, H. van der & N. Smith (1985). Vowel features and umlaut in Djingili, Nyangumarda and Warlpiri. *Phonology Yearbook* 2. 275-302.

Jakobson, R., G. Fant & M. Halle (1952). *Preliminaries to speech analysis*. Cambridge, MA: MIT Press.

Jong, K. de (2002). Attention modulation and the formal properties of stress systems. *CLS* 36. 71-91.

Kaye, J., J. Lowenstamm & J-R. Vergnaud (1985). The internal structure of phonological elements: a theory of charm and government. *Phonology Yearbook* 2. 305-328.

Keating. P. A. (1988). Underspecification in phonetics. *Phonology* 5. 275-292.

Kirchner, R. M. (1998). An effort-based approach to consonant lenition. PhD dissertation, UCLA.

Kirchner, R. M. (in press). Phonological contrast and articulatory effort. To appear in L. Lombardi (ed.), *Segmental processes in Optimality Theory*, Cambridge University Press.

Liberman, A. M. & I. G. Mattingly (1985). The motor theory of speech perception revised. *Cognition* 21. 1-36.

Lieberman, P. (1976). Phonetic features and physiology: a reappraisal. *Journal of Phonetics* 4. 91-112.

Lindblom, B. (1963). Spectrographic study of vowel reduction. *JASA* 35. 1773-1781.

Lindblom, B. (1986). Phonetic universals in vowel systems. In J. J. Ohala & J. J. Jaeger (eds.), *Experimental phonology*, 13-44. Orlando: Academic Press.

Lindblom, B. (1990). Explaining phonetic variation: a sketch of the H&H Theory. In H. J. Hardcastle & A. Marchal (eds.), *Speech production and speech modeling*, 403-439. Dordrecht: Kluwer.

Ohala, J. J. (1992). Alternatives to the sonority hierarchy for explaining segmental sequential constraints. *CLS: Papers from the Parasession on the Syllable*. 319-338.

Ohala, J. J. (1995). Phonetic explanations for sound patterns: implications for grammars of competence. *Proceedings of the 13th International Congress of Phonetic Sciences, Stockholm, August 1995*, vol. 2. 52-59.

Palmada Félez, B. (1991). La fonologia del català i els principis actius. Doctoral dissertation, Universitat Autònoma de Barcelona.

Rennison, J.(1984). On tridirectional feature systems for vowels. Wiener linguistische Gazette. 33-34, 69-93. Reprinted in Durand 1986, 281-303.

Schane, S. S. (1984). The fundamentals of Particle Phonology. *Phonology Yearbook* 1. 129-156.

Schwartz, J. L., L. J. Boë, N. Vallée & C. Abry (1997). The dispersion-focalization theory of

vowel systems. *Journal of Phonetics* 25. 255-286.
Steriade, D. (1997). Phonetics in phonology: the case of laryngeal neutralization. Ms, UCLA.
Stevens, K. N. (1989). On the quantal nature of speech. *Journal of Phonetics* 17. 3-46.
Traunmüller, H. (1994). Conventional, biological and environmental factors in speech communication: a modulation theory. *Phonetica* 51. 170-183.
Zoll, C. (1996). Parsing below the segment in a constraint-based framework. PhD dissertation, UC Berkeley.

Notes

* This is a draft of a chapter en route to publication in Carr & Ewen (to appear). Earlier versions were presented at *Des représentations aux contraintes* (Université de Toulouse-Le Mirail, July 2003) and the Cambridge Linguistics Circle (March 2004).

1 One response might be to try to refine the definition of sonority in some way that would allow peripheral and central mid qualities to be distinguished. It is difficult to see how this could be achieved without referring circularly to the very reduction effects sonority is supposed to explain – for example, by specifying schwa as less sonorous than *e* on the grounds that it occurs in positions characterised by lower intensity and/or shorter duration.

2 The seminal work on AIU is Anderson & Jones' (1974) presentation of Dependency Phonology (see also Anderson & Ewen 1987 and the contributions to Durand 1986 and Anderson & Durand 1987). For related versions of AIU theory, see for example Rennison (1984), Schane (1984), Goldsmith (1985), van der Hulst & Smith (1985), Kaye, Lowenstamm & Vergnaud (1985) and van der Hulst (1989).