

Contrast, Comparison Sets, and the Perceptual Space*

Máire Ní Chiosáin Jaye Padgett
University College Dublin UC Santa Cruz

Abstract

In recent years a number of researchers have argued that, in order to adequately explain contrast and its effects, phonology must be systemic: evaluation of a form cannot occur in isolation from unrelated contrasting forms, but must take such forms – what we call a ‘comparison set’ – into account. This presents a formal and empirical challenge for systemic approaches. This paper explores the comparison set within the general approach of dispersion theory, focusing on two matters: the ‘problem of infinity’ and idealisation. A further challenge for the theory, though one shared by many non-systemic approaches too, involves substantiating claims about perceptual distance that underpin the approach. Our discussion of the latter issue focuses on secondary palatalisation contrasts in onset versus coda position, with perceptual data from Irish. Our overall goal in this paper is to clarify the nature of these challenges and to outline our own approach to them.

1. Introduction

In the past ten years a number of works have pursued a *systemic* approach to contrast in phonology. According to this approach, the goodness of a form must be judged with respect to other forms with which it contrasts (Flemming 1995/2002, Bradley 2001, Ní Chiosáin and Padgett 2001, Lubowicz 2003, Padgett 2003a-c, Sanders 2003, Flemming 2004, Bradley and Delforge 2006, Ito and Mester to appear, Padgett and Zygis to appear). Because it is inspired in part by the phonetic work of Lindblom (1986, 1990), Flemming (1995/2002) dubbed one version of this general approach *dispersion theory*.

In dispersion theory (DT), contrast exerts an influence on grammaticality in two ways. First, there are constraints that require a given form to be sufficiently perceptually distinct from other contrasting output forms. In the work of Flemming (1995/2002, 2004) these are referred to as Minimal Distance (MINDIST) constraints. MINDIST constraints are relativised to a particular dimension of contrast, such as vowel colour (roughly second formant value, implemented by backness and roundness gestures). We can conceive of such a dimension of contrast as a scale of perceptual distance, as shown in (1). A constraint $MINDIST_{Col}=n$ requires that potential minimal pairs¹ differing in colour (such as [bit] and [but]) differ by at least n on this scale. For dimensions of contrast like this allowing more than a binary distinction, a family of constraints is posited, as in (2). The ranking shown is taken to be universal, since contrasts like [i,y] are inherently more confusable than those like [i,u].²

(1) Vowel colour scale (high vowels)

i	y	ɨ	ɯ	u
1	2	3	4	5

(2) Minimal distance constraints for colour

$\text{MINDIST}_{\text{Col}=1} \gg \text{MINDIST}_{\text{Col}=2} \gg \text{MINDIST}_{\text{Col}=3} \gg \text{MINDIST}_{\text{Col}=4} \gg \text{MINDIST}_{\text{Col}=5}$

Second, there are constraints requiring that contrasts themselves be maintained. (It would be possible to vacuously satisfy MINDIST constraints by neutralising, for example, /bit/ and /but/ to [bit].) Padgett (2003a-c) argues that, in addition to standard faithfulness (as in McCarthy and Prince 1995), the theory should incorporate the constraint *MERGE:

(3) *MERGE: No word of the output has multiple correspondents in the input.

One argument for systemic constraints like these comes from a ‘postvelar fronting’ sound change that affected East Slavic roughly between the twelfth and fourteenth centuries (Padgett 2003a). The vowel /i/ fronted to [i] after velar consonants, as shown below. (Palatalisation before front vowels was a general requirement.) Two questions can be asked about postvelar fronting: (a) why did it occur, and (b) why did it occur only after velars?

(4) Russian postvelar fronting

kjiev	>	k ^j iev	'Kiev'
gib ^j el ^j	>	g ^j ib ^j el ^j	'ruin/death'
xitrij	>	x ^j itrij	'clever'

According to the analysis in Padgett (2003a), fronting occurred because [i] versus [u] is a perceptually better contrast than [ɨ] versus [ɯ]. This can be seen in the tableau below. The set of forms in the input and candidate outputs are viewed as idealised representations of a language. In East Slavic at the time postvelar fronting occurred, velars did not occur before [i], because an earlier sound change had mutated velars before [i] to palatoalveolars. Hence the gap in the set of forms where [k^ji] should be. The [p]-initial forms stand in for consonants of non-velar place of articulation, all of which could occur before [i]. The constraint $\text{MINDIST}_{\text{Col} \geq 4}$ penalises every pair of forms like [p^ji] versus [pi], potential minimal pairs differing only in vowel colour, if they do not differ at least as much as [i] versus [u] do. (See (1).) Due to postvelar fronting, candidate (5b) has one fewer violation of this constraint than (5a) does. ([k^ji] versus [ku] is a better contrast than [ki] versus [ku] is.) Obligatory palatalisation before front vowels is assumed in this tableau.

As for the second question, fronting is argued to have occurred only following velars because in any other context it would have been neutralising. Candidate (5c) shows this: /pi/ has fronted to [p^ji], violating *MERGE. (Its derivational history can be traced by the numerical

subscripts, which refer to entire forms like [pu].) Because there were no words having velars before [i], postvelar fronting did not violate *MERGE. Given a ranking *MERGE >> MINDIST_{Col} ≥ 4, (5)c) is avoided even though it is superior in maintaining perceptually distinct colour contrasts.

(5) Analysis of postvelar fronting

	p ⁱ ₁	p ₂ ⁱ	pu ₃	*MERGE	MINDIST _{Col} ≥ 4	IDENT _{Col}
	t ^ʃ ₄ ⁱ	k ₅ ⁱ	ku ₆			
a.	p ⁱ	p _i	pu		***!	
	t ^ʃ _i	k _i	ku			
b.	p ⁱ	p _i	pu		**	*
	k ⁱ ₅		ku			
	t ^ʃ _i					
c.	p ⁱ _{1,2}		pu	*!		**
	k ⁱ ₅		ku			
	t ^ʃ _i					

The analysis of postvelar fronting makes clear how it can be useful to appeal to systemic constraints, constraints regulating the perceptual distance of contrast and the occurrence of neutralisation. And the works cited at the outset demonstrate that there are many such facts requiring appeal to these systemic notions. Yet systemic approaches to phonology such as DT raise formal and empirical challenges. One obvious challenge involves substantiating claims about perceptual distance that undergird systemic accounts. There is still a great deal we do not know about the perceptual organisation of speech sounds. Another challenge involves how one determines what might be called the ‘comparison set’. If the goodness of a form depends on its relationship to other contrasting forms, then how are we to decide exactly *which* other forms matter? Our goal in this paper is to clarify the nature of these challenges and to discuss our approach to them.

2. Comparison sets

A general challenge for systemic approaches to phonology is the challenge of the comparison set: if the realisation of a form like Irish [p^ʃɔ:n] ‘pen’ depends in part on the existence of contrasting forms like [pɔ:n] ‘pawshop’ (see section 3), then how do we decide exactly *which* other forms matter in this way?³ If [pɔ:n] has such a bearing on [p^ʃɔ:n], do [d^vin^ʃi] ‘people’, or [tʰaŋɡol^viəxt] ‘linguistics’? Where does it end, and how can we know? Since the set of possible forms is infinite, this is no trivial problem. We divide this challenge into two parts, the ‘problem of infinity’, and a discussion of idealisation.

2.1 The problem of infinity

Ní Chiosáin and Padgett (2001) and Padgett (2003a-c) assume that inputs and candidate outputs in DT are entire *languages*, in this respect following Flemming (1999). If we view a language as a set of possible words (putting aside phrases), then we could restate this assumption in the following way: the input to an optimality theoretic tableau is the set of all possible words (effectively the entire ‘rich base’), while a candidate output is some subset (proper or not) of this set. However, analysts cannot grapple with entire languages at one time. For the purposes of analysis, Ní Chiosáin and Padgett (2001) and Padgett (2003a-c) employ a strategy of severe idealisation, discussed further below.

Though the use of idealisation seems reasonable, the assumption we are abstracting away from – that inputs and outputs are languages – raises questions. A worry for this assumption arises from the fact that the set of all possible words is infinite. It is infinite, even assuming that the number of features, and therefore of segment types, is finite, because words can be indefinitely long. If a candidate language can contain an infinite number of forms, then it can violate a given constraint an infinite number of times. This is of concern because it can undermine crucial constraint comparisons.⁴

Consider for example the analysis of postvelar fronting in (5). In that analysis *MERGE outranks $\text{MINDIST} \geq 4$, and this explains why fronting occurs only following velars. The tableau in (7) repeats (5), but now considers the implications of infinite sets of forms. (Forms with [tʃ] have been omitted to ease reading the tableau.) Next to forms like [pʲi] and [ku] there are possible forms such as [pʲila] and [kula], as well as [pʲilala] and [kulala], and so on. Once all of these forms are counted, it can be seen that (7)a) and (7)b) will each incur an infinite number of MinDist violations (one for [pʲi] versus [pi], another for [pʲila] versus [pila], etc.), and (7)c) an infinite number of *MERGE violations (one for [pʲi_{1,2}], another for [pʲila_{1,2}], etc.).

The algorithm given by Prince and Smolensky (1993/2004) for determining the relative harmony of two candidates for a constraint C has two parts:

- (6) Relative harmony of candidates A and B with respect to constraint C
 - (a) if candidate A has no violations of C and candidate B has some violations, eliminate B;
 - (b) otherwise, remove one violation mark from each candidate and try (a) again.

(6)b) applies recursively until either A or B is eliminated, or there are no more violations to compare. For two candidates that have infinite violations, the problem arises in the case of (6)b).

With *MERGE >> $\text{MINDIST} \geq 4$, we can still eliminate (7)c) by clause (6)a), because (7)a) and (7)b) have no violations of *MERGE. The problem is the comparison between (7)a) and (7)b), which in (5) are distinguished by the number of MINDIST violations. The intuition we want to capture is that faithful (7)a) is worse than (7)b) because it has more MINDIST violations, since postvelar fronting has not occurred. But if both candidates have an infinite number of MINDIST violations that must be assessed, we cannot make this distinction using (6)b). Without this distinction, candidate (7)a) will (incorrectly) win.

(7) Postvelar fronting with infinite constraint violations

	$p^j i_1$	pi_2	pu_3			
		ki_4	ku_5			
	$p^j i a_6$	$p i a_7$	$p u a_8$	*MERGE	$MINDIST_{Col} \geq 4$	$IDENT_{Col}$
		$k i a_9$	$k u a_{10}$			
	(etc...)					
a. ☞	$p^j i_1$	pi_2	pu_3			
		ki_4	ku_5			
	$p^j i a_6$	$p i a_7$	$p u a_8$		∞	
		$k i a_9$	$k u a_{10}$			
	(etc...)					
b. ☹	$p^j i_1$	pi_2	pu_3			
	$k^j i_4$		ku_5			
	$p^j i a_6$	$p i a_7$	$p u a_8$		∞	$\infty!$
	$k^j i a_9$		$k u a_{10}$			
	(etc...)					
c.	$p^j i_{1,2}$		pu_3			
	$k^j i_4$		ku_5			
	$p^j i a_{6,7}$		$p u a_8$	$\infty!$		∞
	$k^j i a_9$		$k u a_{10}$			
	(etc...)					

However, as Abby Kaplan (p.c.) points out to us, the issue exemplified by (7) is not one of formal intractability. The infinities in question are enumerable, and it is easy to show that the $MINDIST_{Col}$ violations of (7)b) are a subset of those of (7)a): (7)a) has *one* $MINDIST_{Col} \geq 4$ violation involving velars for every two involving labials, while (7)b) has *none*. For many if not all cases where infinite violations are being compared, a superset-subset relationship of this sort might be demonstrable. Seen in this way, this infinite comparison is not so far removed from (6) as it might appear: the point of (6) is to eliminate the candidate having the superset of violations! Though it would require an elaboration of (6) to accommodate comparing infinite violations as in (7), we see no obvious reason why this could not be done. However, in the spirit of exploration we discuss here means by which candidates might be restricted to finiteness.

Working within a framework called *contrast preservation theory* (which she abbreviates PC theory), Lubowicz (2003) proposes one way to guarantee a finite comparison set: the set is defined in relation to a given input I under consideration, and the length of forms included in the set is limited by the length of I .⁵ Specifically, the input comparison set consists of all forms that can be derived by the following operations (which may be combined): a) replacing any segments of I with any one segment each, b) deleting any segments of I , or c) inserting any one segment before or after any segments of I . Candidate outputs consist of forms that are a subset (proper or not) of these input forms, as in DT. The possibilities for the input are illustrated schematically in (8), for the Irish form /pɔ:n/ ‘pawnshop’. Replacing one original segment gives for example (8)a). In (8)b), a segment has been replaced, but also two have been added. Example (8)c) combines all three operations. In effect, this comparison set is defined as a kind of

‘neighbourhood’ around *W*, in the sense familiar from psycholinguistics, except that it is a maximally inclusive neighbourhood: all forms of length *n* share the same comparison set. And as is usual in systemic theories, this set includes all possible words, not just existing lexical items.

(8) Deriving a comparison set (Lubowicz 2003)

	p		ɔ:		n		
a.	p		ʌ:		n		pʌ:n
b.	p	l	ʌ:		n	ə	pʌ:nə
c.	m	ɑ			k		mɑk

Because only one segment can be inserted into any ‘slot’ to the left or right of an original segment, the number of forms in this comparison set is finite. In fact, it is all forms of length $2n+1$ or less, where *n* is the length of *I*. Though finite, this set can be very large. For a three-segment form *I* like /pɔ:n/ (where $2n+1 = 7$), assuming for discussion that the number of segment types available universally is 100 (though this is too low), the set includes $100^7 + 100^6 + \dots + 100^1$ forms. Lubowicz’s actual analyses therefore employ severe idealisation, as those of Ní Chiosáin and Padgett (2001) and Padgett (2003a-c) do.

As noted, one property of this approach to determining a comparison set is that it is done relative to a designated form *I*, ‘the form of interest’, e.g. /pɔ:n/. This property in turn entails variability in the content of that set. If form *I* consists of three segments like /pɔ:n/, the comparison set consists of all possible words of length 0-7 segments; for a 4-segment *I* like /dʲinʲi/ ‘people’ the set includes the same forms plus forms of length 8-9 segments; and so on. This variability in the formal characterization of the comparison set may not be desirable.⁶ For this reason and for the sake of simplicity we suggest a different means to achieve finiteness: impose an absolute upper limit on the length of forms that can be admitted into the set of candidate outputs. Assuming this limit is universal and inviolable, it should take the form of a restriction on OT’s Gen function. The set of inputs therefore remains infinite, but Gen filters out forms beyond a certain length, so that each output candidate is necessarily a set of forms that is finite in number. A limit on the length of forms can reasonably be motivated by the increasing processing difficulty of longer forms.

It is worth mentioning one other conceivable approach to the problem of infinity: take the object of evaluation in DT to be *inventories*: for example, the input is the set of all possible segment types, and output candidates are subsets of this set. (The work of Flemming 1995/2002, 2004 often presents in this way, though this seems to be an expository strategy rather than a theoretical claim.) Inventories are by nature finite, and inventories of *segments* are much smaller than sets of possible words, even for modest-length words. If comparison sets are inventories, however, they cannot in fact be inventories of segments. To see this, consider first postvelar fronting once again. The explanation for fronting after velars (and not after labials, for example) is the prior lack of forms like **kʲi*. This is not a gap in the inventory of *segments* but in the inventory of something larger, such as syllables. Similarly, Ní Chiosáin and Padgett (2001) and Padgett (2003b) argue for a systemic account of the realisation of palatalisation and velarisation

on consonants, in which the quality of the following vowel plays a key role. The analysis requires comparing sequences like [b^ji] and [b^yi]. Lubowicz (2003) also motivates analyses that make sense only when sequences of vowel and consonant are compared. If such analyses are to be possible, then the inventory in question can consist of units no smaller than the syllable (or perhaps the demisyllable, Fujimura 1979).

It is not clear, however, that even a syllable-like constituent is large enough to permit systemic explanations of phonological patterns. For example, Sanders (2003) argues that word-level nasal harmony in Tuyuca is motivated by constraints requiring two words to differ in nasality by as many segments as possible. Padgett (2003c) proposes a DT analysis of rhotic distribution in Catalan which requires comparison of phrase-level forms like *mà restà* ‘the hand remained’ and *mar està* ‘the sea is’. More generally, it is desirable to pursue a theory in which phonological effects of all sorts – including harmonies, stress and segment interactions, etc. – can be explored with the benefit of systemic principles where they seem beneficial. For these reasons, we advocate an approach to systemic phonology in which the objects of analysis are the same as for other theories of phonology: words and phrases. Avoiding the issues that arise when candidate sets are infinite – assuming they should be avoided – therefore requires imposing length limits on this set of forms, as discussed above.

2.2 Idealisation

In previous works we have discussed the role of idealisation in systemic phonology, and argued that systemic theories are no different from others in their need for idealisation (Ní Chiosáin and Padgett 2001, Padgett 2003a-c). Here we discuss some concrete strategies for idealising, and argue that idealisation involves making explicit one’s analytical premises.

The puzzle that leads to idealisation is not hard to see: given the vast number of possible forms – even if it is finite – how are we to determine the relevance of these forms to a particular form, or set of forms, under consideration? Taking up the example from the introduction, suppose we are interested in the palatalisation contrast seen in Irish [p^jɔ:n] ‘pen’ versus [pɔ:n] ‘pawnshop’. What forms need to be taken into consideration for such an analysis? This group of forms is what we mean by ‘comparison set’.

Idealisation involves reducing the set of relevant forms to a small number which *represent* or exemplify only those factors considered to be relevant for an analysis. For example, though words might be of great length, length per se (as opposed to prosodic factors like position with respect to stress, word-initial or -final position, etc.) seems to have only a modest bearing on phonology. That is, processes like flapping, vowel reduction, voicing assimilation, etc., do not greatly depend on word length. This means that we can often restrict an analysis to forms of only one or two syllables in length, and assume that the results generalise to larger words.

Within these parameters, further progress in idealising is made by paying attention to what phonological factors seem to be independent of each other. For example, there is little or no evidence that word-final obstruent voicing ever depends on the quality of a preceding vowel, or that stress assignment depends on consonantal place of articulation. The independence of such factors is judged normally from known phonological patterns themselves, though perceptual studies can in principle lend support. Note that the question of what matters is a *substantive* one

whose answer will depend on the phenomenon under consideration. Further, it is by nature *empirical* and therefore subject to revision as we make discoveries. For these reasons, we do not think there can be a formal procedure for determining an idealisation, any more than there can be a formal procedure to tell us what candidates and constraints to include in any standard OT tableau (see below). Rather, such decisions must be up to the experience and ingenuity of the analyst.

Consonantal palatalisation is perhaps a relatively challenging case, because the occurrence of palatalisation is known to depend on at least position (e.g., preconsonantal, word-final, etc.), place of articulation of the consonant in question, and quality of the neighbouring vowel (Takatori 1997, Ní Chiosáin and Padgett 2001, Padgett 2001, Kochetov 2002, Padgett 2003b). Further, palatalisation contrasts can in fact involve palatalised, plain, and velarised consonantal realisations, depending especially on vowel context. Even limiting ourselves to word-initial versus -final position, three places of articulation, and five vowel qualities, this might seem to suggest consideration of at least 135 forms: the 45 shown in (9), and analogous forms having coronals and velars.

(9) Idealised comparison set for palatalisation contrast (labials only)

pip	pip ^j	pip ^y	p ^j ip	p ^j ip ^j	p ^j ip ^y	p ^y ip	p ^y ip ^j	p ^y ip ^y
pep	pep ^j	pep ^y	p ^j ep	p ^j ep ^j	p ^j ep ^y	p ^y ep	p ^y ep ^j	p ^y ep ^y
pap	pap ^j	pap ^y	p ^j ap	p ^j ap ^j	p ^j ap ^y	p ^y ap	p ^y ap ^j	p ^y ap ^y
pop	pop ^j	pop ^y	p ^j op	p ^j op ^j	p ^j op ^y	p ^y op	p ^y op ^j	p ^y op ^y
pup	pup ^j	pup ^y	p ^j up	p ^j up ^j	p ^j up ^y	p ^y up	p ^y up ^j	p ^y up ^y

However, we need not consider all of these forms simultaneously, in one OT tableau, because some of the factors at work are plausibly independent of others. The realisation of palatalisation on labials, for example, possibly does not depend on the realisation of palatalisation on coronals or velars in the same language. Therefore we can construct separate tableaux for each place of articulation. Likewise, the realisation of palatalisation on initial consonants is plausibly independent of that on final consonants. Therefore, instead of one tableau with all of the forms in (9), we can construct two with only the 15 forms each in (10). We have already pared things down to a somewhat manageable size. An analysis will consist of one constraint ranking, and six tableaux ((10)a-b * three places of articulation), each having subsets of the forms in (10)a, or (10)b), etc.

(10) Revised comparison set for palatalisation contrast (labials only)

a.	pi	p ^j i	p ^y i	b.	ip	ip ^j	ip ^y
	pe	p ^j e	p ^y e		ep	ep ^j	ep ^y
	pa	p ^j a	p ^y a		ap	ap ^j	ap ^y
	po	p ^j o	p ^y o		op	op ^j	op ^y
	pu	p ^j u	p ^y u		up	up ^j	up ^y

We may well go still further, though. It is not obvious that the realisation of palatalisation before one vowel depends on its realisation before another vowel. If we assume it does not, then we can employ one tableau for the series [pi, p^ji, p^yi], another for [pe, p^je, p^ye], and so on (see for example Ní Chiosáin and Padgett 2001, Padgett 2003b).

Idealisation of this sort is desirable because it makes analyses manageable. It is *defensible* to the extent we are correct in assuming that ignored factors do not matter. As we have noted in other works, idealisation occurs in any linguistic analysis (as well as in other scientific fields), where it is desirable and defensible for the same reasons; it is not a new feature of systemic theories. What is new here is rather (1) the more *obvious* need to idealise when doing systemic phonology, since we must take contrasting forms into consideration, and (2) the need to be *explicit* about how we idealise in order to be clear on what the input is, and what candidate outputs are.

Lurking behind this discussion of idealisation is the worry, which some may feel when encountering systemic theories, that formal rigour or clarity of predictions has been compromised. For example, we might ask how safe the postvelar result is, given its dependence on idealisation. It is clear how the analysis works in (5) given the forms entertained in the idealisation, but one can imagine other forms *not* entertained that might undermine the explanation. For example, though fronting has improved the contrast between /ki/ and /ku/, it has presumably worsened that between /ki/ and /k^je/, since [k^ji] is closer to [k^je] than [ki] is. Perhaps including /k^je/ within the idealisation, along with pertinent perceptual distance constraints, would change the result.

Though this is a real concern, it is not at all particular to systemic theories. Consider the standard OT tableau in (11)i), for example, which presents an analysis of regressive voicing assimilation making use of constraints familiar from the literature on assimilation and positional faithfulness (e.g., Lombardi 1999, Padgett to appear). Candidate (11)ib) wins as desired. But this result can be undermined by candidates we have failed to consider, such as (11)iid), which would win given the current constraints.

(11) (i) Idealisation in standard OT

	/akba/	Spread(voi)	Ident _{Ons} (voi)	Ident(voi)
a.	akba	*!		
b.	agba			*
c.	akpa		*!	*

(ii) Result undermined given new candidates, e.g.,

d.	akəba			
----	-------	--	--	--

The possibility of such dark horse candidates is painfully familiar to anyone who has worked in OT. In the case of (11), obvious solutions to the analytical problem come to mind, e.g., introduce a high-ranking faithfulness constraint against vowel insertion. (Similarly, the worry about [k^ji] versus [k^je] could be addressed by assuming that MINDIST for vowel height is

low-ranked.) But this should not obscure the underlying point: for any analysis, it is always possible that a candidate not considered exists, one which might undermine the analysis presented and may even be very hard to handle were it discovered. There is nothing in the formalism of OT that helps us with this problem. To put it differently, even the most precisely formalised analysis in OT is only as good as the assumptions that go into it, in particular the constraints and candidates that constitute the premises of the analysis. And this is simply a version of a more general fact of life for theorists of any sort: no matter how precisely formalised and internally coherent an analysis is, it is subject to defeat once underlying assumptions are shifted.

Bringing the point back to the specifics of DT, the point is that an idealisation is not merely an analytical convenience. Rather, it represents an explicit claim about the premises of an analysis, that is, about what matters and what does not matter in analysing the phenomenon in question. DT does not differ in employing idealisation, only in the degree to which idealisation is made apparent.

3. Perceptual distance and phonology

In the past decade or so a good deal of work has emerged motivating the use of perceptual features and perceptual explanations in phonology (besides work in DT, see especially Steriade 1997, Boersma 1998, Steriade 2001a). In all of these works, the perceptual distance of contrasts is a foundational notion. The vowel colour scale seen in (1) is repeated here as an example. The idea of perceptual distance of course implies a perceptual space (what Steriade 2001a calls a ‘P-map’).

(12) Vowel colour scale (high vowels)

i	y	ɨ	ɯ	u
1	2	3	4	5

The use of perceptual distance plays a key role in the realms of both markedness and faithfulness. Its use in markedness is clear in DT (see the introduction, and below), and it is implicit in the theory of licensing by cue (Steriade 1997). As for faithfulness, Steriade (2001a-b) argues convincingly that perceptual distance of input-output mappings is important to resolving the ‘too many solutions’ problem in phonology (compare Wilson 2001, for whom the use of perceptual distance is also key). The theory of positional faithfulness (Casali 1996-7, Beckman 1997-1998) also draws implicitly on the notion of perceptual distance, since it is motivated in part by the claim that contrasts are better realised in certain strong positions. Since the perceptual space has become fundamental to so much explanation in phonology, it is likely that perceptual studies will occupy an increasingly important place in the theory. (Two recent works combining perceptual studies with phonological theory are Kochetov 2002, and Kawahara 2006.) Drawing on our own work (Ní Chiosáin and Padgett 2007), we illustrate here the use of perceptual data to inform phonological analysis. The empirical focus is on secondary palatalisation contrasts in onset versus coda position, with perceptual data from Irish.

Recent cross-linguistic surveys (Takatori 1997, Kochetov 2002) have established some typological implications concerning secondary palatalisation contrasts (e.g., [p^ha] versus [pa]).

For example, syllable-final contrasts imply syllable-initial contrasts, and contrasts in labials imply also contrasts in dentals. Kochetov (2002), on the basis of articulatory, acoustic and perceptual studies of palatalisation in Russian, argues that these asymmetries follow from perceptual biases.⁷ To put it simply, the more marked contrasts are those that are perceptually more difficult to discern. For example, Kochetov argues that a language like Bulgarian, having only onset palatalisation, lost the coda contrast historically due to its perceptual weakness.

It is well known that listeners can find it challenging to perceive phonemic contrasts that do not exist in their language. For this reason, it would not do to test the perceptual claim about onset versus coda palatalisation only on speakers of Bulgarian. The problem is one of circularity: we would like to argue that Bulgarian lacks the coda contrast because that contrast is perceptually difficult; but in Bulgarian the coda contrast may be perceptually difficult in any case *because* it does not exist. To avoid this circularity, we can test the perceptual claim against languages which have a palatalisation contrast in both onset and coda position. If we find an asymmetry in such cases, we can plausibly claim that there is a language-independent perceptual bias, and that this bias is itself the cause of markedness asymmetries. Russian is such a language, and so is Irish.

Traditionally, the consonant system of Irish is divided into two opposing sub-systems, the ‘slender’ (palatalised/plain) consonants and the ‘broad’ (velarised/labialised/plain) consonants. The phonemic oppositions, given below, are usually represented as palatalised/nonpalatalised; the phonetic realisations, however, vary according to place of articulation and environment.⁸

(13) Irish phoneme inventory

	Labial		Coronal		Dorsal		Glottal
Voiceless stop	p	p ^j	t	t ^j	k	k ^j	
Voiced stop	b	b ^j	d	d ^j	g	g ^j	
Voiceless fricative	f	f ^j	s	ʃ	x	x ^j	h
Voiced fricative	v	v ^j			ɣ	ɣ ^j	
Nasal	m	m ^j	n	n ^j	ŋ	ŋ ^j	
Liquid			l	l ^j			
			r	r ^j			

Examples of contrastive palatalisation in Irish are given in (14)a (onset), (14)b (coda), and (14)c), where (final) palatalisation encodes grammatical categories such as plural and genitive.

(14) Palatalisation contrasts in Irish⁹

a.	b̥ɔ:n	‘white’	bʲɔ:n	‘peak’
	pɔ:n	‘pawnshop’	pʲɔ:n	‘pen’
b.	br̥ɔ:d	‘drizzle’	br̥ɔ:dʲ	‘neck, throat’
	skɔl	‘supernatural being’ (m sg)	skɔlʲ	‘shadow’ (f sg)
c.	kat	‘cat’ sg	katʲ	‘cat’ pl
	b̥ɔ:d	‘boat’ nom sg/gen pl	b̥ɔ:dʲ	‘boat’ nom pl/gen sg

We carried out an AX discrimination (‘same-different’) task involving pairs of words like *pɔ:n-pʲɔ:n*, *rap-rapʲ*. The factors manipulated were syllable position (initial versus final), voicing, and place of articulation (labial versus coronal), though only syllable position is discussed here. The vowel in the stimuli was always [a] or [ɔ]. Stimuli were recorded by a native speaker of Irish, and were in most cases real words, though a few were nonce words. Subjects were 10 native Irish speakers of Connaught Irish (West Galway).¹⁰ The numbers in Figure 4.1 and 4.2 show the difference in correct responses between coda (84%) and onset (94%) positions ($F(1, 9) = 12.30$, $p = .007$). That is, subjects were better at distinguishing pairs like *pɔ:n-pʲɔ:n* than pairs like *rap-rapʲ*.

[FIGURE 1 NEAR HERE]

Figure 1 Mean correct ‘different’ responses: coda vs. onset (by subject)

[FIGURE 2 NEAR HERE]

Figure 2 Mean correct ‘different’ responses: coda vs. onset (all subjects)

Our results are similar to Kochetov’s in motivating a perceptual disparity between onset and coda palatalisation contrasts. Results like these can be used to motivate a dispersion-theoretic analysis of the onset-coda asymmetry. In particular, they indicate that there is an asymmetry in perceptual distance like that given schematically in (15).

(15) Perceptual distance asymmetry between onset and coda palatalisation contrast

pa.....pʲa	‘Onset palatalisation distance’
ap.....apʲ	‘Coda palatalisation distance’

The Minimal Distance constraints of DT refer to disparities in perceptual distance like this. Since the details of the perceptual space for palatalisation are not as well understood as those of the space for vowels – for example, how close in absolute terms are different units like [ap] and [apʲ], what is the shape and dimensionality of this space – we do not try to formalise them here. In particular, rather than use a numbered scale as in (12), we refer directly to ‘onset palatalisation distance’ and ‘coda palatalisation distance’ in the constraint formulations. What we *can* infer from our results is the relevance of this distinction. It can be encoded via the constraints, and

fixed universal ranking, shown in (16).¹¹ (However, since all the contrasts we consider here meet the constraint $MINDIST_{Coda-Pal}$, this constraint is not shown in the tableaux below.)

(16) Minimal distance constraints for palatalisation

- a. $MINDIST_{X-Pal}$: Potential minimal pairs differing in secondary palatalisation differ at least as much as C versus C^j in position X do.
- b. $MINDIST_{Coda-Pal} \gg MINDIST_{Onset-Pal}$

Neutralisation of a palatalisation contrast in the coda, as in Bulgarian (see Kochetov 2002), is captured by the ranking shown in (17). Candidate (17)a includes a pair of forms (ap₃-ap^j₄) that violates $MINDIST_{Onset-Pal}$. It violates this constraint because the contrast in coda palatalisation in [ap] versus [ap^j] is not as good as an onset palatalisation contrast. Candidates (17)b-d satisfy this constraint vacuously by coda neutralisation. Of the latter forms, (17)d neutralises more than is necessary. Candidates (17)b-c differ in whether neutralisation is to the marked or unmarked (as judged by *C^j, a constraint with articulatory motivation), with the unmarked outcome favoured.

(17) Neutralisation of the coda contrast (as in Bulgarian)

	pa ₁ ap ₃	p ^j a ₂ ap ^j ₄	$MINDIST_{Onset-Pal}$	*MERGE	*C ^j
a.	pa ₁ ap ₃	p ^j a ₂ ap ^j ₄	*!		**
b. +	pa ₁ ap _{3,4}	p ^j a ₂		*	*
c.	pa ₁	p ^j a ₂ ap ^j _{3,4}		*	**!
d.	pa _{1,2} ap _{3,4}			**!	

In the case of languages like Irish and Russian, where the palatalisation contrast in coda position is maintained, *MERGE outranks the perceptual $MINDIST$ constraint (as well as the articulatory *C^j), as shown below.

(18) No neutralisation (as in Irish)

	pa ₁ ap ₃	p ^j a ₂ ap ^j ₄	*MERGE	MINDIST _{Onset-Pal}	*C ^j
a. +	pa ₁ ap ₃	p ^j a ₂ ap ^j ₄		*	**
b.	pa ₁ ap _{3,4}	p ^j a ₂	*!		*
c.	pa ₁	p ^j a ₂ ap ^j _{3,4}	*!		**
d.	pa _{1,2} ap _{3,4}		*!*		

As the reader can verify, ranking *C^j at the top will predict a language with no palatalisation contrast, as in English.

Recalling section 2, the analysis above exemplifies the role of idealisation in systemic phonology. For the purposes of this analysis, it has been assumed that everything but onset versus coda position of a plain versus palatalisation contrast can be ignored. Hence the input is always the same, the four forms [pa, p^ja, ap, ap^j] representative of all that is assumed to matter. Outputs are always subsets of this input (proper or not). In many cases, ignoring other factors is justified by our (relative) confidence that they never have any bearing on the facts at hand. In this case, we have also abstracted away from some factors that likely *do* matter to a full analysis of the onset-coda asymmetry, such as quality of the neighbouring vowel, and place of articulation of the consonant. Therefore, though the analysis given is formally unproblematic, it is indeed an idealisation.

Returning to the main issue here, we conclude this section by discussing a major challenge for the programme of building phonological explanations on perceptual studies. This challenge follows from the language-particularity of perception already mentioned. It has long been known that speech perception is shaped by linguistic experience (see Strange 1995 for an overview of research). For example, German speakers have more difficulty distinguishing [ɛ] from [æ] than English speakers do (Barry 1989); English distinguishes these sounds as phonemes, while German does not. Further, ‘reorganisation’ of perception based on native contrasts begins within the first year of life (Kuhl 1991, Best 1994). Since the point of dispersion theory, licensing by cue theory, and related work is to harness the perceptual space to *explain* phonological patterns – including systems of contrast – these facts raise crucial questions: to what extent does a language-independent perceptual map exist, and how we can get information about it? Is there, after all, any language-independent answer to the question of how perceptually distinct [ap] is from [ap^j]?

Johnson (2004) and Huang (2004) discuss this issue, as well as the question whether choosing the right experimental method can help disentangle language-particular perception from a hypothesised universal perceptual map, assuming the latter exists. Building on earlier

observations that different experimental tasks can elicit so-called ‘phonetic’ versus ‘auditory’ perception, these works explore the effect of tasks carrying a low-memory load and emphasising fast responses. Such tasks might favour the ‘auditory’ perception mode and, to the extent that low-level auditory processing is not language-particular, therefore tell us something about the universal perceptual space. An example of such a task is an AX (same-different) discrimination task, in which the interstimulus interval is very short (allowing listeners to judge based on auditory memory traces rather than recall of categories), the same two stimulus types are compared within blocks, and fast responses are encouraged (reaction times are measured). The Irish perceptual data described above was gathered by such a task. In an experiment with a similar design comparing Polish and English speakers’ ability to discriminate among Polish sibilants, Zygis and Padgett (2006) find that, while Polish and English speakers differ notably in errors made, the patterns revealed by reaction times are more similar. Still, the prospects of a universal perceptual space remain unclear. On the other hand, the increasing reliance of phonological theories on perceptual distance claims gives us a compelling reason to pursue research into the perceptual space in spite of the challenges.

4. Conclusion

Since candidate outputs in dispersion theory are sets of forms, they can each contain infinite forms and therefore trigger infinite violations. The relative harmony of candidates having infinite violations can in principle be evaluated assuming that violations are countably infinite and that violations due to one candidate can be shown to be a subset of those due to another. However, this represents a qualitative elaboration over the current algorithm in optimality theory for determining candidate harmony. Should we wish to avoid moving in this direction, then we must impose limits on the length of possible words entertained by OT, in order to avoid infinite constraint violations. We have made no claims about what such a length limit should be, since the precise answer does not affect the basic point. In any case, explicit idealisations must play a key role in systemic theories. This is not a formal issue, in our view, but a specific version of a more general methodological issue confronting all theories.

Perceptual distance, and a hypothesised universal perceptual map, are notions that undergird a great deal of current phonological theory, particularly OT. They play a key role in dispersion theory, licensing by cue theory, positional faithfulness, and accounts of the ‘too many solutions problem’. Perceptual studies are therefore likely to become a more important source of evidence for phonological claims. Though this will be a challenging research programme, it is an exciting one for phonology.

References

- Barry, William J. (1989). Perception and production of English vowels by German learners: instrumental phonetic support in language teaching. *Phonetica* **49.1**. 19-54.
- Beckman, Jill (1997). Positional faithfulness, positional neutralization, and Shona vowel harmony. *Phonology* **14.1**. 1-46.
- Beckman, Jill (1998). *Positional faithfulness*. Ph.D. dissertation, University of Massachusetts, Amherst.

- Best, Catherine T. (1994). The emergence of native-language phonological influences in infants: a perceptual assimilation model. In Nusbaum, H.C. and J. Goodman (eds.) *The development of speech perception: the transition from speech sounds to spoken words*. Cambridge, MA: MIT Press. 167-224.
- Boersma, Paul (1998). *Functional phonology: formalizing the interactions between articulatory and perceptual drives*. The Hague: Holland Academic Graphics.
- Bradley, Travis G. (2001). *The phonetics and phonology of rhotic duration contrast and neutralization*. Doctoral dissertation, Pennsylvania State University.
- Bradley, Travis G. and Ann Marie Delforge (2006). Systemic contrast and the diachrony of Spanish sibilant voicing. In Arteaga, Deborah and Randall Gess (eds.) *Historical Romance Linguistics: Retrospectives and Perspectives*. Amsterdam: John Benjamins. 19-52.
- Casali, Roderic F. (1996). *Resolving hiatus*. Los Angeles: Ph.D. dissertation, UCLA.
- Casali, Roderic F. (1997). Vowel elision in hiatus contexts: which vowel goes? *Language* **73**. 493-533.
- Flemming, Edward (1995/2002). *Auditory representations in phonology*. Doctoral dissertation, UCLA [published in 2002 by Routledge, New York].
- Flemming, Edward (1999). How to formalize constraints on perceptual distinctiveness. Handout of paper presented at 'The role of speech perception phenomena in phonology', a satellite workshop to ICPHS, San Francisco.
- Flemming, Edward (2004). Contrast and perceptual distinctiveness. In Hayes, Bruce, Robert Kirchner and Donca Steriade (eds.) *Phonetically-based phonology*. Cambridge: Cambridge University Press.
- Fujimura, Osamu (1979). An analysis of English syllables as cores and affixes. *Zeitschrift für Phonetik, Sprachwissenschaft und Kommunikationsforschung* **32**. 471-476.
- Huang, Tsan (2004). *Language-specificity in auditory perception of Chinese tones*. Ph.D. dissertation, The Ohio State University.
- Ito, Junko and Armin Mester (to appear). Systemic markedness and faithfulness. *Proceedings of CSL* **39**.
- Johnson, Keith (2004). Cross-linguistic perceptual differences emerge from the lexicon. In Agwuele, Augustine, Willis Warren and Sang-Hoon Park (eds.) *Proceedings of the 2003 Texas Linguistics Society Conference*. Somerville, MA: Cascadilla Proceedings Project. 26-41.
- Kawahara, Shigeto (2006). A faithfulness ranking projected from a perceptibility scale: the case of [+voice] in Japanese. *Language* **82.3**, 536-74.
- Kochetov, Alexei (2002). *Production, perception, and emergent phonotactic patterns*. New York: Routledge.
- Kuhl, Patricia K. (1991). Human adults and human infants show a "perceptual magnet effect" for the prototypes of speech categories, monkeys do not. *Perception and psychophysics* **50.2**. 93-107.
- Lindblom, Björn (1986). Phonetic universals in vowel systems. In Ohala, John J. and Jeri J. Jaeger (eds.) *Experimental phonology*. Orlando: Academic Press. 13-44.
- Lindblom, Björn (1990). Explaining phonetic variation: a sketch of the H&H theory. In Hardcastle, William J. and Alain Marchal (eds.) *Speech production and speech modelling*. Dordrecht: Kluwer. 403-439.

- Lombardi, Linda (1999). Positional faithfulness and voicing assimilation in Optimality Theory. *Natural language and linguistic theory* **17.2**. 267-302.
- Lubowicz, Anna (2003). *Contrast preservation in phonological mappings*. Ph.D. dissertation, UMass, Amherst.
- McCarthy, John J. and Alan Prince (1995). Faithfulness and Reduplicative Identity. In Beckman, Jill, Laura Walsh Dickey and Suzanne Urbanczyk (eds.) *University of Massachusetts Occasional Papers in Linguistics 18*. Amherst, MA: GLSA Publications. 249-384.
- Ní Chasaide, A. (1999). Irish. *Handbook of the International Phonetics Association*. Cambridge: Cambridge University Press. 111-116.
- Ní Chiosáin, Máire and Jaye Padgett (2001). Markedness, segment realization, and locality in spreading. In Lombardi, Linda (ed.) *Segmental phonology in Optimality Theory: constraints and representations*. Cambridge: Cambridge University Press. 118-156.
- Ní Chiosáin, Máire and Jaye Padgett (2007). A perceptual study of Irish palatalization. Paper presented at the Annual Meeting of the LSA, Anaheim, CA, 2007.
- Padgett, Jaye (1997). Perceptual distance of contrast: vowel height and nasality. In Walker, Rachel, Motoko Katayama and Daniel Karvonen (eds.) *Phonology at Santa Cruz Vol. 5*. Santa Cruz, CA: Linguistics Research Center, UC Santa Cruz. 63-78.
- Padgett, Jaye (2001). Contrast dispersion and Russian palatalization. In Hume, Elizabeth and Keith Johnson (eds.) *The role of speech perception in phonology*. San Diego, CA: Academic Press. 187-218.
- Padgett, Jaye (2003a). Contrast and post-velar fronting in Russian. *Natural language and linguistic theory* **21.1**. 39-87.
- Padgett, Jaye (2003b). The emergence of contrastive palatalization in Russian. In Holt, D. Eric (ed.) *Optimality Theory and language change*. Dordrecht: Kluwer Academic Press. 307-335.
- Padgett, Jaye (2003c). Systemic contrast and Catalan rhotics. Ms., University of California, Santa Cruz.
- Padgett, Jaye (to appear). Russian voicing assimilation, final devoicing, and the problem of [v]. *Natural language and linguistic theory*.
- Padgett, Jaye and Marzena Zygis (to appear). The evolution of sibilants in Polish and Russian. *Journal of Slavic linguistics*.
- Prince, Alan and Paul Smolensky (1993/2004). *Optimality theory: constraint interaction in generative grammar*. Ms., Rutgers University, New Brunswick, NJ, and University of Colorado, Boulder 1993. Published by Blackwell, 2004.
- Quiggin, E. (1906). *A dialect of Donegal*. Cambridge: Cambridge University Press.
- Sanders, Nathan (2003). *Opacity and sound change in the Polish lexicon*. Doctoral dissertation, University of California, Santa Cruz.
- Steriade, Donca (1997). Phonetics in phonology: the case of laryngeal neutralization. Ms., UCLA.
- Steriade, Donca (2001a). Directional asymmetries in place assimilation: a perceptual account. In Hume, Elizabeth and Keith Johnson (eds.) *The role of speech perception in phonology*. New York: Academic Press. 219-250.
- Steriade, Donca (2001b). The phonology of perceptibility effects: the P-map and its consequences for constraint organization. Ms., MIT.

- Strange, Winifred (1995). Cross-language studies of speech perception: a historical review. In Strange, Winifred (ed.) *Speech perception and linguistic experience*. Baltimore: York Press. 3-45.
- Takatori, Yuki (1997). *A study of constraint interaction in Slavic phonology*. New Haven: Ph.D. dissertation, Yale University.
- Tessier, Anne-Michelle (2004). Input "clusters" and contrast preservation in OT. In Schmeiser, B., V. Chand, A. Kelleher and A. Rodriguez (eds.) *Proceedings of WCCFL 23*. Somerville, MA: Cascadilla Press. 101-114.
- Wilson, Colin (2001). Consonant cluster neutralisation and targeted constraints. *Phonology* **18.1**. 147-197.
- Zygis, Marzena and Jaye Padgett (2006). A perceptual study of Polish fricatives, and its relation to historical sound change. Poster presented at the 10th Laboratory Phonology Conference, Paris.

* This research was supported by faculty research funds granted by the University of California, Santa Cruz, and by the Forschungsinstitut für Geistes- und Sozialwissenschaften, Universität Siegen. We are grateful to Adam Albright, Abby Kaplan, Ania Lubowicz, Steve Parker, Ruth Kramer, and Kie Zuraw for comments that improved this paper.

¹ A 'potential minimal pair' is a pair of output forms all of whose corresponding segments but one are identical. See Padgett (2003a,b,c).

² Compare Flemming (1995 [2002, 2004] to Padgett (1997) and Ní Chiosáin and Padgett (2001) for somewhat different approaches to constraints in DT. The discussion in this paper combines aspects of both.

³ The Irish forms here and elsewhere in the paper are representative of western dialects of Irish.

⁴ Thanks to John McCarthy and Alan Prince for bringing this issue to our attention.

⁵ See Tessier (2004) for another proposal for deriving a finite comparison set for any input *I*, based on the constraint rankings of a language.

⁶ Abby Kaplan (p.c.) notes that it entails a surprising 'observer-dependence': if the 'form of interest' is (for example) [pɔːn], then hypothetical [pɔːnlala] will not be included in the comparison set; however, the comparison set for [pɔːnlala] will include [pɔːn]!

⁷ 'Syllable-initial and -final' are approximations to a truth that is more nuanced and dependent on precise phonetic context, a fact we abstract away from here.

⁸ Palatalisation usually involves a raised-fronted dorsum and, in some dialects, a palatal off-glide preceding back long-vowels. Velarised consonants involve a retracted dorsum, though in some cases the secondary articulation is more accurately characterised as uvularisation, (e.g., Ní Chasaide 1999 on Doirí Beaga Irish, a northern dialect). Broad labials preceding certain front vowels are frequently labialised (e.g., Quiggin 1906 on northern Irish dialects, Ní Chasaide 1999).

⁹ Abbreviations are as follows: m(asculine), f(eminine), s(in)g(ular), pl(ural), nom(inative), gen(itive).

¹⁰ For details about the experiment see Ní Chiosáin and Padgett (2007).

¹¹ Kochetov (2002) couches his account in terms of positional faithfulness theory. He also argues that the implied rankings are inferred by learners based on the perceptual disparity, rather than being universally given.



