Phonological change in Optimality Theory

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As has normally been the case for all major phonological frameworks, the relationship between Optimality Theory (OT) and historical phonology works both ways: OT provides new angles on long-standing diachronic questions, whilst historical data and models of change bear directly on the assessment of OT. For our purposes, it will be convenient to classify phonological changes under two headings, roughly corresponding to the neogrammarian categories of 'sound change' and 'analogy':

(i) in **phonologization**, extragrammatical phonetic effects give rise to new phonological patterns;

(ii) in **reanalysis**, a conservative grammar is replaced by an innovative grammar that generates some of the old phonological output in a new way.

In this light one can see that phonological change raises two main questions for OT:

(i) Is markedness a mere epiphenomenon of recurrent processes of phonologization, or does markedness on the contrary constrain both phonologization and reanalysis?

(ii) What optimality-theoretic resources best explain reanalysis: input optimization, innate biases in the ranking of output-output correspondence constraints, both, or neither?

It turns out that the answers to these questions may require OT to depart significantly from the form in which it was first proposed (Prince & Smolensky 1993): OT may need to acknowledge that markedness constraints are not innate but are rather constructed by the child during acquisition, and it may need to adopt a stratal-cyclic approach to morphology-phonology and syntax-phonology interactions.

THE RÔLE OF MARKEDNESS IN PHONOLOGICAL CHANGE

OT asserts that speakers of natural languages know implicitly that certain phonological structures are dispreferred or suboptimal. This knowledge is represented in their grammars by means of violable **markedness constraints** such as the following:

(1) *Two markedness constraints*

a. VOICEDOBSTRUENTPROHIBITION
Assign one violation mark for every segment bearing the features [-sonorant, +voice].

b. CODACOND-[±voice]
Assign one violation mark for every token of the feature [±voice] that is exhaustively dominated by rhymal segments.

Particular languages impose relationships of strict dominance upon a universal set of constraints **CON**. According to **factorial typology**, the class of possible natural languages is defined by all the ranking permutations of CON.

In OT, the hypothesis that CON includes constraints against voiced obstruents (1a) but not against voiceless obstruents, and against voice oppositions in the syllable coda (1b) but not in the onset, would explain the statements in (2). (2a) is formulated as an absolute negative universal, (2b) as an implicational universal. Both are representative of the class of typological generalizations known as **markedness laws** (Hayes & Steriade 2004: 3).

(2) *Two markedness laws*

a. No language requires obstruents to be voiced in the coda.

b. If a language licenses voice contrasts in the coda, then it also licenses voice contrasts in the onset.

Phonological change and the problem of grounding

A major question arises over the fact that most of the markedness constraints posited by optimality-theoretic phonologists have proved to be **grounded** in phonetics. Consider, for example, the phonetic motivation of (1b). A key phonetic cue to obstruent voice specifications is Voice Onset Time (VOT), i.e. the duration (positive or negative) of the interval between the offset of an obstruent and the first glottal pulse for a following sonorant. By definition, VOT is available only in presonorant contexts. In consequence, VOT cues are frequently absent from the coda, and so voice contrasts are less perceptible syllable-finally than syllable-initially. Thus, (1b) turns out to ban voice oppositions in an environment where they are difficult to realize phonetically. The problem for OT is to account for this relationship between markedness constraints *qua* internal grammatical entities and the external phonetic phenomena on which they are grounded.

There have been two main types of response to the problem of grounding: (i) diachronic reductionism and (ii) nonreductionism. **Diachronic reductionists** argue that markedness laws such as (2) are epiphenomena of phonetically driven changes, and that postulating markedness constraints like (1) in the theory of grammar is therefore unnecessary. The proponents of diachronic reductionism typically adopt Ohala's (1992) model of phonologization by misparsing, in which phonological structures that pose articulatory, acoustic, or auditory difficulties suffer from higher rates of misperception and are therefore more likely to be inadvertently altered or lost in historical change. In this view, no language licenses voice contrasts in the coda whilst neutralizing them in the onset simply because, if listeners have historically managed to parse the signal correctly in phonetically unfavourable environments (i.e. in the coda, where VOT cues are often absent), they will *a fortiori* have succeeded in phonetically favourable environments (i.e. in the onset).

Two sharply different groups of phonologists have espoused diachronic reductionism in respect of markedness. One group comprises formalist (Hyman 2001) and radically formalist (Hale & Reiss 2000) linguists who insist that phonology is autonomous and phonetically arbitrary, and must accordingly be strictly separated from phonetics. The other group consists of radically functionalist phonologists and phoneticians who deny the existence of autonomous principles of phonological organization, and for whom phonology emerges from phonetics in the process of language use (e.g. Bybee 2001, Blevins 2004). Despite their irreconcilable differences, both groups agree that the problem of grounding is fatal to OT.

Nonreductionists, in contrast, maintain that markedness constraints, even if grounded on phonetic phenomena, are nonetheless indispensable components of phonological grammar. A sizable subgroup of nonreductionists account for grounding by suggesting that markedness constraints are neither innate nor acquired by induction over the primary linguistic data, but are rather **constructed** by the child on the basis of her experience of phonetic difficulty in performance (Boersma 1998, Hayes 1999, Hayes & Steriade 2004, Bermúdez-Otero & Börjars 2006). In the historical arena, some adherents of OT have opposed diachronic reductionism by advancing the argument that markedness constraints impose key restrictions upon phonological changes, whether driven by phonologization or by reanalysis (Kiparsky 2004, Bermúdez-Otero & Börjars 2006).

Diachronic arguments against markedness constraints

The reductionist critique of OT relies heavily on **Ockham's razor**. Reductionists contend that phonetic factors suffice to account for the dispreferred status of phonological entities such as voiced obstruents or voice features licensed by coda consonants; they see no reason for positing a cognitive representation of these factors in the shape of optimality-theoretic markedness constraints, which are therefore deemed superfluous. As noted by Bermúdez-Otero & Börjars (2006: §6.1), implicit in this argument is a crucial claim: the fact that learners acquire phonological grammars containing apparently markedness-driven processes and complying with markedness laws is held not to raise **Plato's Problem** (Chomsky 1986). Thus, diachronic reductionists follow Ohala in emphasizing the rôle of the parser in phonologization and downplaying the contribution of higher principles of grammatical organization. For Ohala, the conditions for phonologization arise when the parser, as it filters out noise from the phonetic signal, errs either by excess (**hypercorrection**) or by defect (**hypocorrection**). Diachronic reductionists assume that, at this point, the innovative patterns present in the distorted data delivered by the parser are incorporated into the grammar of the learner (or, for functionalist reductionists, of the adult listener) by mechanisms of **induction** (or 'cognitive entrenchment', 'pattern association', 'Hebbian learning', etc.); see Hale (2000: 252), Bybee (2001).

Diachronic reductionists reinforce their application of Ockham's razor with the argument that OT's factorial typology technique is empirically inadequate, in that it is simultaneously too permissive (predicting unattested language types) and too restrictive (failing to allow for exceptions to markedness laws). The overpermissiveness problem concerns **gaps in factorial typology**. Consider, for example, *NC̥, the markedness constraint that penalizes sequences of a nasal followed by a voiceless obstruent. Permuting the ranking of *NC̥ relative to independently motivated faithfulness constraints predicts a wide range of repair strategies for NC̥ clusters, of which some are attested (e.g. postnasal voicing, nasal deletion, denasalization) and some are not (e.g. metathesis, vowel epenthesis). The gaps, it is argued, cannot be eliminated by revising the theory of phonological representations or the composition of CON; rather, the unattested repairs are held to be impossible because they cannot arise from a phonetically driven change or series of changes (Myers 2002).

Factorial typology is also charged with excessive restrictiveness because it fails to allow for so-called **crazy rules** (Bach & Harms 1972), which are claimed to violate markedness laws. The following examples have figured prominently in the debate:

(i) In some dialects of English, an intrusive [ɹ] or [l] is inserted in certain hiatus contexts. This is alleged to refute OT's prediction that epenthetic segments should be unmarked (e.g. Blevins 1997, Hale & Reiss 2000, McMahon 2000).

(ii) Lezgi exhibits monosyllabic nouns in which a long voiced plosive in the coda alternates with a short plain voiceless plosive in the onset (3). This alternation is claimed to violate the markedness law in (2a) (Yu 2004).

(3) *Lezgi's crazy alternation*

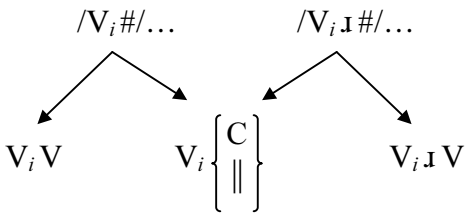
SING	PL/OBL	
pa**bː**	pa**p**a	'wife'
ga**dː**	ga**t**u	'summer'
me**gː**	me**k**er	'hair'

Such phenomena are significant for two reasons. First, OT's critics contend that the existence of crazy rules shows markedness laws to be mere **typological tendencies**, rather than **strict universals**. If so, explanations for markedness laws should be sought in diachronic emergence, rather than in universal phonological principles such as CON: notably, universals derived by factorial typology should be exceptionless. Secondly, crazy rules are created by processes of reanalysis such as rule telescoping and rule inversion. In English, for example, *r*- and *l*-intrusion are commonly assumed to have arisen through the inversion of older natural rules that deleted /ɹ/ and /l/ in nonprevocalic environments (see Figure 1). Diachronic reductionism predicts this state of affairs: it is argued that markedness laws are typological tendencies that emerge from recurrent processes of phonetically driven change; reanalysis is expected not to obey markedness laws because it is not driven by phonetics, but by cognitive principles governing the relationship between phonology, morphology, and the lexicon.

Linking *r*

Lexicon: $/V_i\#/ \neq /V_i\,ɹ\#/$ (contrast)

Distribution: $ɹ \rightarrow \varnothing \;/\; \_\_ \begin{Bmatrix} C \\ \| \end{Bmatrix}$



Intrusive *r*

Lexicon: $/V_i\#/ \approx /V_i\,ɹ\#/$ (no contrast)

Distribution: $ɹ \rightarrow \varnothing \;/\; \_\_ \begin{Bmatrix} C \\ \| \end{Bmatrix}$

$\varnothing \rightarrow ɹ \;/\; V_i \_\_ V$

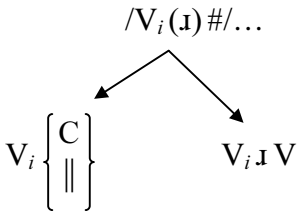


Figure 1. Linking *r* is replaced by intrusive *r* through rule inversion (based on Vennemann 1972: §2). Phonological environments are stated segmentally in order to avoid controversial analytical commitments on syllabic affiliation. The distributional statements are merely descriptive. In stratal versions of OT, intrusive *r* can be analysed as a two-step process, with FINALC driving insertion of [ɹ] in the environment V_i __ $_{\omega}$] at the (stem and) word levels, followed by deletion of nonprevocalic [ɹ] at the phrase level.

Diachronic arguments for markedness constraints

OT supporters challenge many of the basic assumptions of diachronic reductionism. Hayes & Steriade (2004: 26-7), for example, reject Ohala's model of phonologization by misparsing, asserting instead that phonological innovations typically originate in child errors retained into adulthood and propagated to the speech community. Child errors normally reflect **endogenous strategies** for adapting the adult phonological repertory to the child's restricted production capabilities. It is assumed that these strategies capitalize on knowledge acquired through the child's experience of phonetic difficulty and represented by means of markedness constraints (Boersma 1998, Hayes 1999, Bermúdez-Otero & Börjars 2006). Compared with Ohala's, this approach to phonologization assigns a very different —though equally crucial— rôle to factors related to perception: highly salient errors are less likely to be retained into adulthood or to be adopted by other speakers. In this light, consider Amahl's famous *puzzle-puddle* shift (Smith 1973):

(4)		Adult target	Amahl's adaptation
	puzzle	pʌ**z**əl	pʌ**d**əl
	puddle	pʌ**d**əl	pʌ**g**əl

This shift was endogenous; it did not originate in misparsing, for Smith shows that Amahl's phonological discrimination was adult-like. Anecdotally, a strategy like Amahl's may well have given rise to the English word *tickle*, which is related to Old Norse *kitla* and/or Latin *titillāre* but is not now felt to be a childish mispronunciation.

On a different front, Kiparsky (2004) proposes a set of criteria for distinguishing between mere typological tendencies and strictly universal markedness laws, which admit no exceptions. Kiparsky regards (2a) as a strict universal: he rejects Yu's claim that the Lezgi data in (3) provide a counterexample to (2a), arguing that the alternating plosives in (3) derive from underlying voiced geminates. Kiparsky nonetheless accepts that explanations based on diachronic emergence are appropriate for typological tendencies. If, accordingly, CON is held accountable only for nonemergent strict universals, then gaps in factorial typology need not be fatal to OT. Along these lines, the refutation of diachronic reductionism involves two tasks:

(i) to show that maintaining compliance with strictly universal markedness laws in the course of phonological change raises Plato's Problem and therefore requires the postulation of markedness constraints;

(ii) to show that there are no radically crazy phonological rules, understood as genuine phonological processes that violate the strict universals implicit in CON.

According to Kiparsky (2004) and Bermúdez-Otero & Börjars (2006), the fact that languages continue to comply with universal markedness laws despite constant change raises Plato's Problem. The claim rests on what Bermúdez-Otero and Börjars call **the Jakobson-Kiparsky argument** (Jakobson 1929), neatly summarized in Kiparsky's (2004) dictum: "Whatever arises through language change can be lost through language change". Note that, like the neogrammarians, Ohala's theory of hypocorrection predicts that phonologization is blind: it is driven by local phonetic properties and operates without regard for its global effects on the phonological system. However, a sequence of blind changes could easily lead to the violation of a universal markedness law. To explain why this does not happen, one must postulate grammatical principles (such as optimality-theoretic markedness constraints) that block phonologization or force a reanalysis in the relevant situations.

Consider, for example, a hypothetical language with the following properties:

(i) a two-way laryngeal contrast between plain and voiced obstruents,

(ii) no closed syllables,
(iii) syllabic trochees and a ban on degenerate feet.

Suppose now that, historically, this language becomes subject to two phonological changes, applying in the following order:

(i) first, a lenition process voicing plain obstruents in foot-internal position;
(ii) later, a process of apocope creating closed syllables in word-final position.

The outcome of this scenario is given in Table 1.

Table 1. A diachronic scenario potentially conflicting with markedness law (2a).

1. *Initial state*	a.ˈta.ta	a.ˈta.da	a.ˈda.ta	a.ˈda.da
2. *Lenition*	a.ˈta.**d**a	a.ˈta.da	a.ˈda.**d**a	a.ˈda.da
3. *Apocope*	a.ˈtad	a.ˈtad	a.ˈdad	a.ˈdad

Once lenition and apocope have taken place, children are exposed to adult data in which all coda obstruents are voiced. In this situation, diachronic reductionism predicts that learners will inductively acquire the following phonotactic generalization:

(5) If an obstruent is in the rhyme, it must be voiced.

The knowledge that (5) is incorrect and, in fact, universally impossible is clearly beyond the reach of inductive cognitive mechanisms.

In OT, in contrast, the emergence of (5) is blocked because (5) is not a member of CON, nor is there a ranking of CON capable of replicating its effects. Even if markedness constraints are constructed rather than innate, the child will not add (5) to her constraint set simply because plain obstruents are easier to produce than voiced ones. In our scenario, therefore, OT predicts that learners will interpret the absence of voiceless obstruents in the coda either as a lexical fact or as a result of morphological processes that are not phonotactically driven. Notably, (5) will fail to display the properties of productive phonological generalizations, such as application to neologisms and nativized loans. In support of this conclusion, I note that, as expected, Lezgi has not extended the crazy alternation in (3) to loans from Turkic, Arabic, or other Lezgian languages (Yu 2004: §5.7).

Bermúdez-Otero & Börjars (2006: §6.5) deploy similar arguments in their discussion of *l*-intrusion in American English dialects (Gick 1999: §3). Historically, intrusive *l* arose through the inversion mechanism sketched in Figure 1. This involved the reanalysis of linking *l* patterns such as those in (6), where prevocalic [l] alternates with nonprevocalic [∅] after /ɔː/ and /ə/.

(6)	a.	[dɹɔː]	[dɹɔː**l**ɪŋ]
		drawl	*drawling*
	b.	[kɹuːwə]	[kɹuːwə**l**ækt]
		cruel	*cruel act*

Nonetheless, Gick reports that most dialects exhibit *l*-intrusion only after /ɔː/:

(7) a. *l*-intrusion: after /ɔː/ *the law*[l] *is*…

b.	no *l*-intrusion:	after /ɑː/	*the bra*[∅] *is…*
		after /ə/	*the idea*[∅] *is…*

Since the alternations in (6a) and (6b) are entirely parallel, this restriction is unexpected: why should linking *l* have undergone inversion after /ɔː/, but not after /ɑː/ or /ə/? The key lies in the fact that, in these dialects, the V-place features of /l/ are identical with those of /ɔː/, but different from those of /ɑː/ and /ə/. Accordingly, [l] is inserted only when it can acquire its V-place through spreading from the preceding vowel (see Figure 2). Bermúdez-Otero and Börjars argue that this reanalysis transcends mere inductive generalization and therefore lies beyond the reach of the impoverished learner assumed by diachronic reductionists: using their knowledge of markedness, children rejected highly marked [l] as an epenthetic hiatus breaker, except where its V-place features were already available in the local context. This shows that the rule of *l*-intrusion is **not radically crazy** and, more generally, that phonological processes (as opposed to morphological or lexical patterns) created by reanalysis are constrained by markedness.

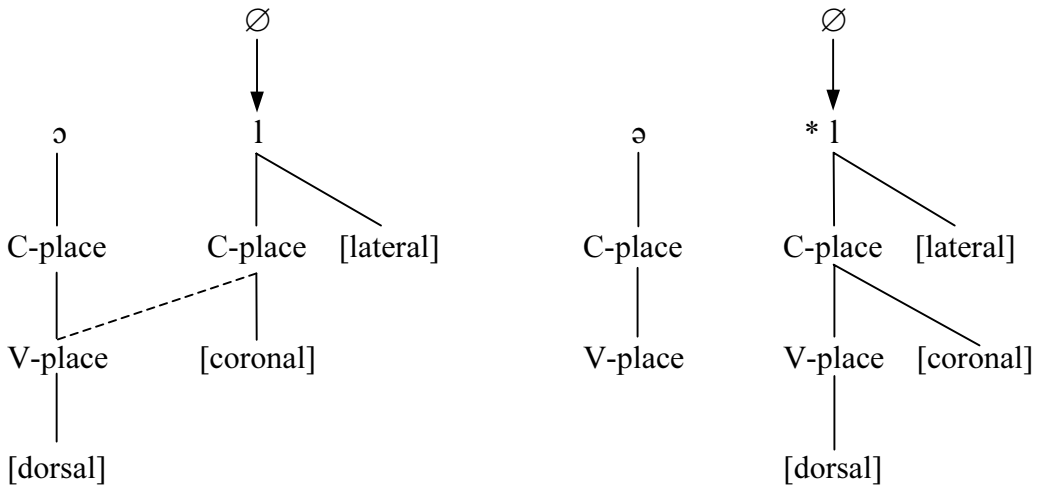


Figure 2. English /l/ is a complex segment with coronal C-place and dorsal V-place. In most American English dialects with *l*-intrusion, the insertion of [l] as a hiatus breaker is licensed by V-place sharing with /ɔː/, but blocked by V-place disagreement with /ə/. The feature geometry assumed here, with the C-place node dominating the V-place node, is standard, but is not crucial to the argument.

THE RÔLE OF INPUT OPTIMIZATION IN REANALYSIS

The diachronic scenario outlined in Table 1 and the evidence of *l*-intrusion analysed in Figure 2 indicate that markedness laws play a crucial rôle in controlling reanalysis: CON forces learners to analyse certain patterns in the primary linguistic data as being partly or wholly lexical or morphological, rather than phonological. We shall now consider how other components of OT contribute to our understanding of phonological reanalysis. This section will focus specifically on OT's principles for the selection of input representations. I shall refer to these principles using the term **input optimization**, rather than Prince & Smolensky's (1993: §9.3) 'lexicon optimization', for the latter begs the question whether or not phonology

is stratified; in a stratal model, inputs to noninitial levels need not be stored in the lexicon, although they can be (see Bermúdez-Otero forthcoming).

According to a long tradition of research in diachronic generative phonology, one of the main mechanisms of analogical change is **input restructuring**. The history of Yiddish provides a well-known example (see Bermúdez-Otero & Hogg 2003: §1.3 and references therein). In Middle High German, word-final obstruents were subject to devoicing; in Yiddish, however, the alternations created by devoicing were levelled, with underlying voiced obstruents freely surfacing in word-final position.

(8)		'day'	'days'
	Old High German	*ta**g***	*ta**g**-a*
	Middle High German	*ta**c***	*ta**g**-e*
	Yiddish	*to**g***	*te**g***

The conditions for reanalysis were created by a phonological process of apocope that targeted final /-ə/. Apocope caused final devoicing to underapply massively in surface representations (Table 2).

Table 2. Yiddish: surface underapplication of final devoicing.

	'day'		'gift'	
NOM/ACC.SG	*tac*	*tac*	*gebe*	***geb***
GEN.SG	*tages*	*tages*	*gebe*	***geb***
DAT.SG	*tage*	***tag***	*gebe*	***geb***
NOM/ACC.PL	*tage*	***tag***	*gebe*	***geb***
GEN.PL	*tage*	***tag***	*geben*	*geben*
DAT.PL	*tagen*	*tagen*	*geben*	*geben*
	before /-ə/ loss	*after /-ə/ loss*	*before /-ə/ loss*	*after /-ə/ loss*

In (9) we see that a synchronic grammar could recapitulate this historical development by means of two phonological processes applying in counterfeeding order.

(9)		SING	PL
	input	/tag/	/tag-ə/
	devoicing	tak	—
	apocope	—	tag
	output	[tak]	[tag]

Yiddish learners, however, failed to acquire such a grammar: they were unable to posit inflectional suffixes consisting of underlying /-ə/ because this vowel never surfaced.

Rule-based theories of phonology have never succeeded in delivering a satisfactory account of such instances of input restructuring. Two fundamental problems stand in their way. First, the learner's choice of input representations must be informed by the system of input-output mappings that she has acquired (and vice versa; see e.g. Tesar & Smolensky 2000: §5.2). However, rule-based theory has never produced an explicit formal account of the acquisition of rule systems. To do so is probably impossible, as the grammar space defined

by rule-based phonological models is too poorly structured to be searched effectively by an informed learner.

In rule-based frameworks, moreover, the formal demands of descriptive adequacy conflict with the empirical evidence of acquisition and change (Bermúdez-Otero & Hogg 2003: §2.2). Rule-based theories typically rely on lexical underspecification to solve the Duplication Problem, which arises over the fact that the well-formedness conditions that lexical representations obey statically coincide to a very large extent with the well-formedness conditions that phonological processes enforce dynamically in the derivation of grammatically complex expressions (Clayton 1976). Acquiring underspecified lexical representations requires a powerful learner actively pursuing a strategy of lexicon minimization. Psycholinguistic and diachronic evidence, however, suggests that learners in fact follow a conservative what-you-see-is-what-you-get strategy and require positive evidence to abandon the **identity map**, in which inputs are identical with the corresponding outputs.

OT, in contrast, holds promising prospects for research into input restructuring, as it incurs neither of these difficulties. First, the assumption of a finite CON has enabled learnability experts to devise fully formalized **constraint ranking algorithms**, which can be drawn upon in input selection (e.g. Tesar & Smolensky 2000). Secondly, OT is an **output-oriented** theory, in that no constraints directly evaluate input representations. Rather, the grammar must work in such a way that every possible input is associated with a well-formed output (**Richness of the Base**). This removes the requirement of lexicon minimization. In fact, the fundamental insight behind Prince & Smolensky's (1993: §9.3) original formulation of their 'lexicon optimization' principle is that, when combined with minimal constraint violation, output orientation defines the identity map as the default option in input selection. Consider, for example, a constraint hierarchy $\mathcal{H}$ such that there are two potential input representations i_1 and i_2 for a given output o. Since markedness constraints refer only to outputs, the mappings $i_1 \rightarrow o$ and $i_2 \rightarrow o$ will tie on markedness; they will differ solely in terms of faithfulness violations. To achieve the most harmonic mapping, then, the learner need only choose the input representation that is closest to the output.

In the early days of OT, historical phonologists were quick to realize the advantages of input optimization (see references in Holt 2003). Since then, however, progress has been halting and unsatisfactory: the theory of input selection remains underdeveloped and cannot in its current state serve the needs of historical phonologists interested in reanalysis. This theoretical stagnation has been caused partly by neglect: in strictly parallel versions of OT, once the phonologist has satisfied himself (i) that the constraint hierarchy generates well-formed outputs for every possible input and (ii) that there is a viable input for every output, he has little incentive to ask what input representation is actually selected by the learner and how, crucial though these questions are to the psycholinguist and to the historical linguist. In **Stratal OT**, however, the picture is rather different, and it is to be hoped that research in this framework will supply the want of an adequate theory of input selection (Bermúdez-Otero forthcoming). In what follows I outline a few promising avenues of research.

First, it appears that the learning algorithm must be set up in such a way that children search for a **single input representation** for all the output alternants of each minimal grammatical unit at the current level of analysis (though, of course, the search may fail, as in cases of suppletion). Input optimization mechanisms should be allowed to come into play only when, for a given minimal unit, there is found to be more than one possible input representation meeting this requirement. Otherwise, in cases of alternation input optimization would cause the learner to store every alternant in the lexicon as a means to avoid unfaithful mappings (see Prince & Smolensky 1993: §9.3).

Several scholars have suggested that children require **positive evidence from alternations** in order to depart from the identity map (e.g. Bermúdez-Otero 2003: §4.4; Bermúdez-Otero & Hogg 2003: §2.1; Hayes 2004). In this view, it is only when confronted with alternations such as (10a) that children acquiring German contemplate input-output mappings that violate the faithfulness constraint IDENT-[±voice] (10b):

(10) a. RAːt RAːd-əS
wheel *wheel*-GEN.SG

b. IDENT-[±voice]
If α is segment in the output and β is a correspondent of α in the input, then assign one violation mark if α and β do not have the same value for the feature [±voice].

This assumption yields the right results in the Yiddish case discussed above. After apocope, the phonological realization of inflectional feature complexes such as [DAT, SING] was nonalternatingly null: the learner therefore had no motivation for deviating from the identity map by positing suffixal /-ə/.

An interesting line of enquiry, however, concerns how learners may use evidence from alternations in order to detect unfaithful mappings in nonalternating items (Bermúdez-Otero 2003, forthcoming; McCarthy forthcoming). Exploiting the resources of Stratal OT, Bermúdez-Otero proposes a principle of **Archiphonemic Prudence** to deal with this problem. The basic idea is this: if the learner discovers an unfaithful mapping /α/→[β] in alternating items at level *l* (e.g. the phrase level), then she is required to consider /α/ as a possible input representation for nonalternating tokens of [β] as well; if, given current constraint rankings, /α/ proves a viable input representation for some nonalternating token of [β], say [β_i], then the form that contains [β_i] is set aside; later in the acquisition process, the learner uses the constraint hierarchy of the next higher level (e.g. the word level) to choose among the various possible input representations for [β_i].

The principle of Archiphonemic Prudence presupposes an account of how learners choose among competing input representations for an alternating item, yet this is an area where our understanding remains particularly deficient. Inkelas (1995) and Tesar & Smolensky (2000: §5.2) suggest that the faithfulness cost of each input representation is calculated by adding faithfulness violations across the entire paradigm; Tesar and Smolensky call this **paradigmatic lexicon optimization**. This is an appealingly simple proposal, but it appears to make the wrong predictions in respect of analogical change. Consider, for example, a hypothetical situation where there are two competing input representations i_1 and i_2 for a given noun stem *N* in a language with a rich case system. In addition, assume the following:

(i) i_1 allows the nominative form to be derived faithfully, but causes a violation of the faithfulness constraint FAITH_1 in the illative;
(ii) i_2 allows the illative to be derived faithfully, but causes a violation of the faithfulness constraint FAITH_2 in the nominative;
(iii) FAITH_1 dominates FAITH_2.

In this situation, paradigmatic lexicon optimization favours i_2, since this input representation allows the higher-ranked faithfulness constraint FAITH_1 to be satisfied. Suppose, however, that the child is in a state of **transient underdetermination**: i_1 and i_2 produce different outputs for case forms of *N* that she has not yet encountered in her trigger experience. In these circumstances, the child is vulnerable to input restructuring, potentially leading to analogical change. As we have seen, paradigmatic lexicon optimization favours i_2, thereby

creating pressure for analogical levelling from the illative to the other cases (see Figure 3). We know, however, that, for morphological reasons, levelling is in fact far more likely to proceed from the nominative.

input	**output**	FAITH$_1$	FAITH$_2$
i_1	o_a (NOM)		
	o_b (ILL)	*!	
i_2 ☜	o_a (NOM)		*
	o_b (ILL)		

Figure 3. Paradigmatic lexicon optimization (Inkelas 1995, Tesar & Smolensky 2000) predicts analogical levelling in the wrong direction. If the pattern of faithfulness violations across the paradigm is the paramount criterion for input selection, input i_2 will be selected, triggering levelling from the illative form. On morphological grounds, however, i_1 is far more likely to be selected, with levelling from the nominative.

To avoid this problem, Bermúdez-Otero (2003: §4.4; forthcoming) proposes a weaker version of input optimization, which merely requires input representations to be **Pareto-optimal**.

(11) *Input optimization: revised version*

a. Input representations must be Pareto-optimal.

b. An input representation is Pareto-optimal if, and only if, it has no competitor that (i) generates **all** output alternants no less efficiently and (ii) generates **some** output alternant more efficiently.

Here, input efficiency is measured in terms of the violation of ranked faithfulness constraints, as in previous formulations of input optimization. According to (11), however, two input representations are both Pareto-optimal if one input performs better than the other input in one paradigm cell, but worse than the other input in a different paradigm cell. In such situations, principle (11) predicts that the choice between the two inputs will depend on morphological or lexical criteria.

Finally, a word should be said about the rise of **synchronic paradigm effects**. Consider, for example, the English rule of homorganic cluster simplification which maps underlying /ŋg/ onto [ŋ] in the coda. As is well-known, this process applies normally within stem-level constructions, but overapplies before word-level suffixes and words beginning with a vowel:

(12)	*long*	[lɒ**ŋ**]	normal application
	longitude	[lɒ**ŋg**ɪtjuːd]	normal nonapplication
	longish	[lɒ**ŋ**ɪʃ]	overapplication (word-level domain)
	long effect	[lɒ**ŋ**ɪfɛkt]	overapplication (phrase-level domain)

Stratal OT generates this synchronic paradigm effect without recourse to output-output correspondence constraints. From a diachronic viewpoint, the effect can be seen to arise through successive rounds of input restructuring at different levels in the grammar (Figure 4). There is therefore no need to stipulate innate biases in the ranking of output-output correspondence constraints (cf. Hayes 2004). In particular, Stratal OT correctly predicts that, synchronically, misapplication in lexical domains implies misapplication in phrasal domains (cf. Hayes 2000: 102). Diachronically, the theory accounts for the typical life cycle of a phonological pattern, in which its domain gradually shrinks along the way to morphologization and lexicalization.

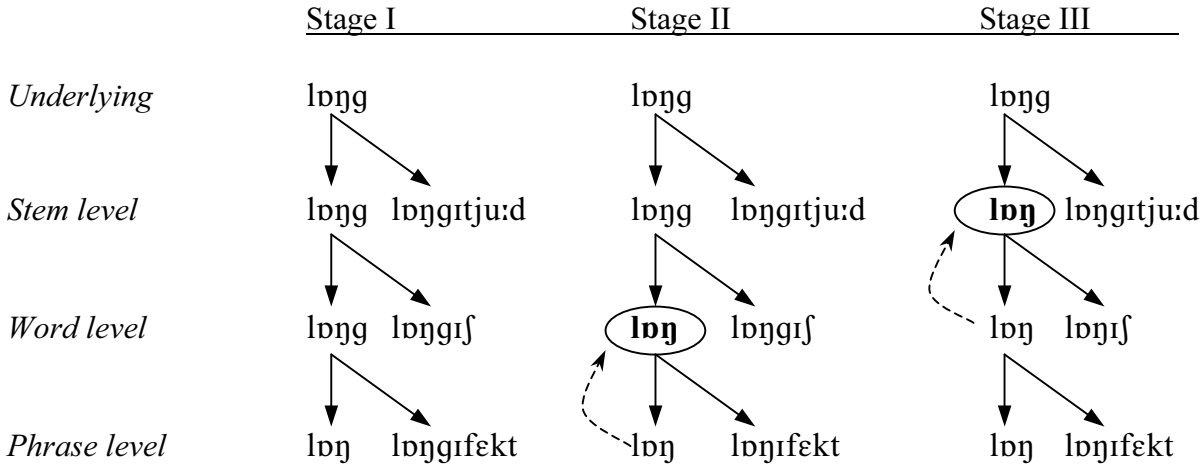


Figure 4. The life cycle of phonological patterns in Stratal OT: in the history of English, successive rounds of input restructuring at progressively higher levels in the grammar cause the domain of homorganic cluster simplification to shrink. Stage I corresponds to the formal speech of orthoepist James Elphinston (mid 18th century; see Rohlfing 1984); Stage II corresponds to Elphinston's colloquial speech; Stage III corresponds to contemporary Received Pronunciation.

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