Analyzing unbounded spreading with constraints: marks, targets, and derivations

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1 Introduction

Unbounded spreading is a well-attested type of assimilation that applies to as many segments as possible within some morphological or prosodic domain. For example, Johore Malay (Onn 1980, Walker 1998 [2000]) has a process that spreads the [+nasal] feature of a nasal consonant to every member of a following sequences of vowels and glides within the same Prosodic Word (PrWd). Spreading is blocked by all other segments: they do not undergo it themselves, and they prevent it from applying to segments that follow them. The form [pəŋãw̃ãsan] 'supervision' illustrates the process: the vocoids [ãw̃ã] following the nasal consonant [ŋ] take on the consonant's [+nasal] specification; the fricative [s] blocks further spreading. Other surface forms that show the effects of unbounded nasal spreading are given in (1).

(1) Examples of unbounded nasal spreading in Malay (Onn 1980, Walker 2000)

mĩnõm	'to drink'	mãkan	'to eat'	mə̃nãw̃ãn	'to capture'
bãŋõn	'to rise'	mãj̃ãŋ	'stalk (palm)'	mə̃ratappi	'to cause to cry'
mãʔãp	'pardon'	pəŋãw̃ãsan	'supervision'	pəŋə̃ŋãh̃ãn	'central focus'

In rule-based phonology, unbounded spreading processes are analyzed with iterative application of local spreading rules (Anderson 1974, 1980, 1982, Archangeli & Pulleyblank 1994, among others). For example, the nasal harmony process in Malay can be accounted for with the feature-changing rule in (2a) or the autosegmental rule in (2b).[1]

(2) Local spreading rules

a. [–consonantal]→[+nasal] / [+nasal]__

b.
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   X    V
   |  ,'
   |,'
[+nasal]
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These rules are *local* in the sense that they spread a feature from one segment to an immediately adjacent segment. The unboundedness of the process—the fact that it can in principle apply to any number of segments—follows from iterative application. The rule-based analysis of unbounded spreading is therefore conceptually similar to standard analyses of syntactic movement (e.g., Chomsky 1973, Chung 1982). Both decompose an apparently long-distance phenomenon into a sequence of more local operations.

Analyses of unbounded spreading that have been proposed within Optimality Theory ('OT'; Prince & Smolensky 1993/2002) work quite differently. To see this, contrast the rules in (2) with the constraint in (3), which is part of Walker's (1998 [2000]) analysis of the Malay nasal harmony process.[2]

[1]Except for the direction of spreading, these rules are identical to the two discussed by Anderson (1982:15–16).

[2]To streamline the discussion in the text, I have paraphrased Walker's constraint. The formal definition is as

(3) Non-local spreading constraint (paraphrased from Walker 2000:44)

SPREAD-R([+nasal],PrWd). For every [+nasal] autosegment n, assign one violation for every segment in the same prosodic word that is to the right of n's domain (where the *domain* of an autosegment is the sequence of segments that are associated to it).[3]

This constraint is *non-local*, because it compares the feature specifications of segments that are not adjacent. Indeed, the constraint scans an unbounded distance from the right edge of a [+nasal] domain, assigning one violation for every segment that lies between that edge and the right edge of the PrWd.

In this paper, I argue against constraints such as (3) on the grounds that they overgenerate: under certain rankings, they give rise to non-local interactions of a kind that are not attested. I argue further that this overgeneration problem cannot be given a satisfactory solution within the original formulation of OT. I therefore develop an alternative version of OT, one that adapts and extends the theory of Wilson (2001). The central proposal is that the constraints that drive spreading are targeted (and similar in many respects to rules such as those in (2)), and that unbounded spreading arises from iterative application of the constraints in a derivational model of phonology.

1.1 The problem

To illustrate the type of problem that arise for non-local spreading constraints, consider a language, like Malay, that spreads [+nasal] unboundedly from left to right. Vowels and glides undergo spreading; all other segments block it. Suppose also that, in general, this language eliminates word-final consonant clusters with vowel epenthesis. The (hypothetical) mappings /nawakat/→[nãw̃ãkat] and /dawakast/→[dawakasət] illustrate spreading and epenthesis, respectively. In order for these mappings to be possible at all, within OT, it must be the case that they lead to better-satisfaction of certain markedness constraints. We assume for the sake of argument that non-local SPREAD-R([+nasal],PrWd) is the constraint that drives spreading, and that some other markedness constraint (call it *CC#) forces epenthesis.

The crucial observation is that, for certain inputs, these two constraints *conflict*. The following tableau shows this by comparing two candidate outputs for the input /nawakast/, which combines the initial nasal consonant of /nawakat/ with the final cluster of /dawakast/.

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follows:

Let n be a variable ranging over occurrences of the feature specification [+nasal], and S consist of the sequence of segments $s_1 \ldots s_k$ in the prosodic word P. Let Assoc(n_i,s_i) mean that n is associated to s_i, where $s_i \in S$.

Then SPREAD-R([+nasal],Pwd) holds iff

i. $(\forall s_i \in S)[[\exists n\ (\mathrm{Assoc}(n,s_i))] \Rightarrow [(\forall s_j \in S\ [j>i \Rightarrow \mathrm{Assoc}(n,s_j)]]]$

ii. For each feature occurrence n associated to some segment in P, a violation is incurred for every $s_j \in S$ for which (i) is false.

[3]The definition of domain used here was proposed by Paul Smolensky in class lectures (2000). The alternative definition given by Safir (1982) could be used to define a non-autosegmental version of the constraint, which would be analogous to rule (2a).

(4) Non-local blocking of vowel epenthesis

	/nawakast/	SPREAD-R([+nasal],PrWd)	*CC#
a.	[nā̃w̃ākasət]	*****!	
b.	[nā̃w̃ākast]	****	*

The second candidate incurs one additional violation of SPREAD-R([+nasal],PrWd), because it contains one more segment (the epenthetic vowel) that lies to the right of the [+nasal] domain. If SPREAD-R([+nasal],PrWd) dominates *CC#, then this one additional violation is sufficient to prevent epenthesis from breaking up the final cluster. Generalizing beyond this particular input, the predicted pattern is as follows:

> Vowel epenthesis applies to a form with a final cluster *except when* there is a preceding [+nasal] feature anywhere in the word that is blocked from spreading to the right edge.

This is obviously problematic, because naturally-occurring epenthesis processes are never sensitive to this type of global, feature-based condition. Any real language that maps /dawakast/ to an output with an epenthetic vowel will also do the same for /nawakast/; the [nasal] feature of the segment at the left edge will not have any influence on epenthesis at the right edge. But non-local spreading constraints predict that such distal effects are possible.

This specific problem is only one of many, because non-locally evaluating constraints like SPREAD-R([+nasal],PrWd) conflict with many other standard constraints. For example, a symmetrical pattern can be derived by ranking SPREAD-L([+nasal],PrWd), the constraint that drives leftward spreading of [+nasal] within a PrWd, above ONSET. Suppose that ONSET generally compels consonant epenthesis before word-initial vowels, as in (hypothetical) /awatad/→[ʔawatad]. Higher-ranked SPREAD-L([+nasal],PrWd) can prevent epenthesis from applying when there is a [+nasal] feature anywhere in the word that cannot spread to the left edge, as in the mapping /awatan/→[awatā̃n] shown in tableau (5).

(5) Non-local blocking of consonant epenthesis

	/awatan/	SPREAD-L([+nasal],PrWd)	ONSET
a.	[ʔawatā̃n]	****!	
b.	[awatā̃n]	***	*

Other predicted patterns, all equally unattested, can be derived by replacing *CC# or ONSET with other well-known markedness constraints that drive epenthesis (e.g., *#CC, *CCC, NOCODA, *COMPLEX, and sonority sequencing constraints).

The undesired effects of non-local spreading constraints are not limited to the domain of epenthesis. In the following subsections, I outline the problems that arise with respect to reduplication, allomorph selection, affix positioning, and stress placement. This list is not intended to be exhaustive; rather, it serves merely to indicate the wide range of predicted but non-occurring patterns.

1.1.1 Reduplication

When ranked above the base-reduplicant correspondence constraint BR-MAX (McCarthy & Prince 1995, 1999), a constraint such as SPREAD-L([+nasal],PrWd) can have the effect of reducing a prefixal reduplicant to some minimal size whenever a [+nasal] feature is unable to spread to the left edge of a PrWd. For example, suppose a language in which the reduplicant is generally disyllabic, as in [wita-witapodu] (from the base of derivation [witapodu]). Minimization of the reduplicant is predicted for bases such as [witapõnu], which would reduplicate as [wi-witapõnu], with a monosyllabic reduplicant, or even as [witapõnu], with no reduplication at all. (The choice between these two outcomes would presumably depend on the ranking of a Realize-Morpheme constraint not shown here.)

(6) Non-local enforcement of a reduplicant size restriction

	/RED+witaponu/	SPREAD-L([+nasal],PrWd)	BR-MAX
a.	[wita-witaponu]	***!*-*****	****
b.	[wi-witapõnu]	** -*****	******
c.	[∅-witapõnu]	-*****	********

The resulting system has paradigms such as [witapodu]/[wita-witapodu] but [witapõnu]/[wi-witapõnu] (or [witapõnu]/[witapõnu]). No attested pattern exhibits this type of dependency between the size of the reduplicant and a feature that lies an unbounded distance from the site of reduplication.

1.1.2 Allomorph selection

According to the theory of phonologically-determined allomorphy proposed by Burzio (1994a), Kager (1996), Mester (1994), and others (see McCarthy 2002a:183–4, 152–6), the hierarchy of phonological constraints selects from two or more lexically-listed forms. Non-local spreading constraints such as SPREAD-R([+nasal],PrWd) can interfere with this selection, forcing it to depend on features that are arbitrarily distant from the location of the affix. For example, suppose that a certain suffixal morpheme μ has the listed forms {/tak/, /k/}, with /tak/ the default form. Sufficiently high-ranked SPREAD-R([+nasal],PrWd) can cause the shorter allomorph to be used whenever doing so minimizes the number of segments that lie to the right of a [+nasal] feature's domain.

(7) Non-local allomorph selection

	/natawas+μ/	SPREAD-R([+nasal],PrWd)	μ =/tuk/
a.	[nãtawas-tak]	****-**!*	
b.	[nãtawas-k]	****-*	*

As before, it is the overall system, not the particular form [nãtawas-k], that is unnatural. The ranking in (7) predicts that stems that differ with respect to [nasal] at any point, such as [datawas] and [nãtawas], take different suffix allomorphs. Such systems are not found.

Note that constraints like μ=/tuk/, which specifies the default allomorph, have been proposed by a number of researchers (e.g., Kager 1996). If constraints of this type are somehow eliminated, then other constraints (e.g., *CC# or FTBIN) could be used to favor the longer allomorph for stems such as [nãtawas]. Note also that, in the theories of allomorphy cited above, both of the candidates in this tableau satisfy input-output (IO) faithfulness with respect to μ. Therefore, the rankings of the IO-faithfulness constraints are irrelevant to the point made here.

1.1.3 *Affix positioning*

Noyer (1993) and others describe cases in which the position of an affix—before or after the stem—is determined by phonotactics. Non-local spreading constraints can also cause affixes to be 'mobile', but the resulting patterns are not like the ones found in real languages. The tableau in (8) shows a hypothetical case in which an affix /ta/, typically a prefix, is moved to suffix position under the influence of SPREAD-L([+nasal,PrWd). The constraint ALIGN-L(/ta/) is shorthand for the Generalized Alignment constraint that seeks to align the left edge of the affix with the left edge of the PrWd (see McCarthy & Prince 1993 and subsequent work). We can assume that some faithfulness constraint, such as I-CONTIGUITY (McCarthy & Prince 1995, 1999), prevents /ta/ from being realized as an infix.

(8) Suffixation to avoid spreading violations

	/ta+panaka/	SPREAD-L([+nasal],PrWd)	ALIGN-L(/ta/)
a.	[ta-pãnaka]	*!*-*	
b.	[pãnaka-ta]	*	******

Contrast this with the minimally-different form [ta-padaka], in which ALIGN-L(/ta/) is free to draw the affix to the beginning of the word. The predicted pattern is thus one of default prefixation, with suffixation occurring only when there is a [+nasal] segment anywhere in the stem.

1.1.4 *Stress placement*

Non-local spreading constraints can also give rise to displacement of stress and other properties that stand in the way of spreading. For example, Beckman (1998 [1999]) proposes the positional faithfulness constraint IDENT([nasal])/σ́, which is violated when an output segment in a stressed syllable has a [nasal] specification different from that of its input correspondent. The combination of IDENT([nasal])/σ́ and SPREAD-R([+nasal],PrWd) can, for example, shift regular penultimate stress to the final syllable iff this allows a [+nasal] feature to spread further without affecting any stressed segments. In tableau (9), I use the ranking NONFINALITY≫ALIGN-R(σ́) to stand for the part of the hierarchy that accounts for the default, penultimate location of stress.

(9) Stress shift to avoid spreading violations

	/nawata/	IDENT([nasal])/σ́	SPREAD-R([+nasal],PrWd)	NONFINALITY	ALIGN-R(σ́)
a.	[nãw̃ãta]	*!*	**		*
b.	[nãwáta]		*!***		*
c.	/nãw̃ãtá/		**	*	

The same ranking assigns penultimate stress to words that contain no [+nasal] segments (e.g., [dawáta]), as well as to words in which spreading further than the penult is blocked independently of stress (e.g., [nãtáwa], where the blocking segment is [t]). The resulting stress pattern depends on feature specifications in a way that is not attested.

1.1.5 *Generality of the problem*

It should be pointed out that these problems are not in any way specific to Walker's (1998 [2000]) theory of spreading. The same non-local interactions are predicted by constraints that align features (Akinlabi 1994, Archangeli & Pulleyblank 2002, Kirchner 1993, McCarthy 1997, Ringen & Heinamaki 1999; see also Pulleyblank 1996, Zoll 1996, 1997), constraints that align feature domains (Cole & Kisseberth 1994), constraints that extend features (Kaun 1995, 1996), and other spreading constraints of the type employed by Walker (Padgett 1995b, McCarthy to appear-a).

The property that all of these constraints have in common is schematized in (10). Given a representation in which one or more segments are associated to a feature [αF], one violation is assessed for every segment that is not associated to [αF], regardless of its distance from the other segments. This is non-local evaluation.

(10) Non-local evaluation

$$\begin{array}{lccccc} \text{violations:} & & & \ldots * \ldots & \\ \text{representation:} & [\ldots s_i & \ldots & s_j \ldots] \\ & | & & | \\ & [\alpha F] & & [-\alpha F] \end{array}$$

The alternative to non-local evaluation is to state the spreading constraints so that they compare the feature specifications of adjacent segments only (see also Bakovic 2000, 2002, Bakovic & Wilson 2000, Lombardi 1999, among others). I now take up this alternative, showing that it requires deep revisions to the original formulation of OT.

1.2 The proposal

The proposal made in this paper consists of two main claims. First, unbounded spreading is driven by targeted constraints that require adjacent segments, and only adjacent segments, to assimilate. For example, the local version of SPREAD-R([+nasal],PrWd) is violated by sequences of the form [+nasal][–nasal]. Given an instance of this type of sequence, the constraint is better-satisfied by changing the [–nasal] segment to [+nasal]. Second, the phonological grammar is derivational. The derivational framework allows the spreading constraints to apply iteratively, in a way somewhat similar to the rules in (2). And iteration is the only way to derive unbounded spreading from local changes.

Much of the theory needed to formalize these claims has already been developed in the literature. The hypothesis that phonological rules and constraints are subject to locality conditions is of course standard (see, for example, Odden 1994). The revised spreading constraints, which obey a strict locality condition, are formalized as targeted constraints in the sense of Wilson (2001) (see also Bakovic & Wilson (2000) and Hansson (2001)). And the overall organization of the grammar will be similar in some respects to the derivational versions of OT discussed by Black (1993), McCarthy (2000), Prince & Smolensky (1993/2002:79) (see also McCarthy 2002a:158–163; 166–170; 184).[4]

The novel aspects of the proposal involve how the *change* from one representation to another is integrated into the theory. Changes are of course essential to derivations. So once OT is applied derivationally, the following question arises immediately: What is the source of the changes?

[4]The proposal made here is that the grammar is derivational within a level. Kiparsky (to appear-a), McCarthy & Prince (2002a:172–174, 185), Rubach (2000), and others have argued that the grammar must also contain an ordered set of levels.

McCarthy (2000) provides arguments against the hypothesis that changes are created by a version of GEN that can perform only one of a limited set of operations at each step in the derivation. I propose instead that the changes are for the most part introduced by markedness constraints. The guiding intuition is as follows. Relative to the previous step of a derivation, a change is a loss of faithfulness. Because only markedness constraints can force the output to be unfaithful to the input (Moreton 1996/1999), it seems sensible to place most of the responsibility for making the changes—creating the unfaithful candidates—on those constraints.

I propose further that changes must be taken into account when candidates are evaluated. To see why this is necessary, consider again the Malay surface form [pəŋãw̃ãsan] from (1) and assume that the corresponding underlying form is /pəŋawasan/.[5] The goal is to have the grammar map /pəŋawasan/ to [pəŋãw̃ãsan] in a series of steps, each of which better-satisfies the local version of SPREAD-R([+nasal],PrWd). But this is impossible, given the original method of candidate evaluation in OT, as the following tableau shows.

(11) Insufficiency of OT evaluation

	Candidates	SPREAD-R([+nasal],PrWd)	SPREAD([+nasal],PrWd)	SPREAD([nasal],PrWd)
a.	[pəŋawasan]	*	* * *	* * *
b.	[pəŋãwasan]	*	* * *	* * *
c.	[pəŋãw̃asan]	*	* * *	* * *
d.	[pəŋãw̃ãsan]	*	* * *	* * *

Each successive candidate in this tableau is derived by spreading the [+nasal] feature forward by one segment. However, local SPREAD-R([+nasal],PrWd) registers no improvement for any of these steps: it is violated equally by all of the candidates, because each one contains a [+nasal][–nasal] sequence. The alternative versions of the local spreading constraint, SPREAD([+nasal],PrWd) and SPREAD([nasal], PrWd), also fail to prefer spreading. (Both of these alternative versions are violated once for every [+nasal][–nasal] or [–nasal][+nasal] sequence; they are included in this tableau for completeness only and are not discussed further.)

The constraints in (11) do not prefer incremental spreading because they evaluate candidates as in (12), which is McCarthy's (2003, to appear-a) more restrictive formulation of Prince & Smolensky's (1993/2002) original proposal.

(12) Constraint evaluation in OT (from McCarthy 2003)

$*\lambda$. Assign one mark for every instance of λ,

where λ is what McCarthy (2003, to appear-a) refers to as the *locus of violation* of the constraint.[6] Taking the locus of SPREAD-R([+nasal],PrWd) to be a [–nasal] segment that immediately follows a [+nasal] segment in the same PrWd, the marks in (11) follow straightforwardly from (12).

The solution to this problem requires us to think of the constraint that drives incremental spreading as not only defining the type of structure that violates it (λ), but also in some way specifying

[5]In fact /pəŋ/ is a prefix, but the morphology is not relevant here.

[6]The notion of locus of violation is similar to that of the *focus* of a rule (as opposed to the *determinant*). See Anderson (1974, 1982), who cites Howard (1973) for the focus/determinant distinction.

the change that removes a violation (δ). Here I simply state the change as part of the constraint, leaving the matter of deriving it from more general principles for later in the paper (see section 3.1.1). The 'T' prefixed to the constraint indicates that it is targeted; a general introduction to targeted constraints is given later in the paper (see section 3.1).

(13) T:SPREAD-R([+nasal],PrWd)

λ A [−nasal] segment that immediately follows a [+nasal] segment in the same PrWd.

δ [−nasal]→[+nasal]

This constraint is very similar (although not identical) to the rules in (2).[7] Consequently, as anticipated above, it can be used to generate candidates as well as evaluate them. For example, given the surface representation [pəŋawasan], the constraint identifies one locus of violation and specifies the change that the locus should undergo. The result is the competing representation [pəŋãwasan].

If T:SPREAD-R([+nasal],PrWd) evaluated candidates by simply assigning one mark for every locus, as in (12), then it would not prefer [pəŋãwasan] over [pəŋawasan], just as we saw in tableau (11). But intuitively the constraint *should* prefer the new candidate over the old one, because the change from [pəŋawasan] to [pəŋãwasan] has eliminated a locus of violation in exactly the way that the constraint demands. This intuition can be formalized as follows.

Let x and y be any two representations such that y is derived from x by the change Δ, which is assumed here to be a set of segment substitutions. The change is intended to include vacuous substitutions involving identical segments, so that the change from [pəŋawasan] to [pəŋãwasan] is the relation {(p,p), (ə,ə), (ŋ,ŋ), (a,ã), (w,w), ...}. The following definition of *repair* uses this notion of change and the ad-hoc notation C(x) to stand for the set containing all and only the loci of violation for constraint C in representation x. (McCarthy, to appear-a adopts a similar notation.)

(14) Def. Repair. A locus of violation $\lambda \in C(x)$ is repaired by the change Δ iff $\Delta(\lambda) \notin C(y)$.

That is, the change Δ repairs a locus of violation λ for constraint C iff Δ maps λ to a segment that is not a locus of violation for the constraint. In the change from [pəŋawasan] to [pəŋãwasan], the first [a] in the original candidate is repaired in this sense, because Δ([a])=[ã] is not a locus of violation.

The new definition of evaluation rewards repairs that occur in the way specified by a constraint; it does so by removing marks from the outcome of the change. ('TCOT' stands for 'OT with targeted constraints', the name I use to refer the framework developed in this paper.)

(15) Constraint evaluation in TCOT (to be revised)

Let C be any constraint that specifies both a locus of violation λ and a change δ, x and y be any two representations, and Δ be the change from x to y.

a. For every $\lambda \in C(x)$, assign one mark to x; for every $\lambda \in C(y)$, assign one mark to y.
b. For every $\lambda \in C(x)$ that is repaired in the way specified by δ, remove one mark from y.

[7] See section 2 for a general comparison of rule- and constraint- based analyses of spreading.

The first, mark-assigning part of this definition is just the original OT definition applied to both x and y. The effects of the second, mark-removing part are illustrated in the following tableau, where as before we take the original candidate to be [pəŋawasan] and the derived candidate to be [pəŋãwasan]. The notation '( )' is used to indicate removal of a mark.

(16) Illustration of mark removal

	Candidates	T:SPREAD-R([+nasal],PrWd)	Total marks
a.	[pəŋawasan]	$*$	$*$
b.	[pəŋãwasan]	$(*)$	$* + (\,) = \emptyset$

Note: '$(*)$' stands for a mark that is assigned by (15a) and removed by (15b).

Each of the candidates is assigned one mark by the first part of (15a), because each contains one locus of violation. For the original candidate, [pəŋawasan], no further adjustments to the marks are made, so it has one mark in total. But one mark is removed from the new candidate, [pəŋãwasan], because the non-vacuous part of the change, which maps [a] to [ã], repairs one violation in the way specified by the constraint. Therefore, the total mark count of this candidate is *zero* (i.e., its mark list is empty). It follows that, once the results of both mark assignment and mark removal are taken into account, the constraint prefers the new representation over the original one (by the fundamental harmony relation of OT, $\emptyset \succ *$; see Prince & Smolensky 1993:xx). This is exactly what was desired, and what the original definition of evaluation in OT could not provide.[8]

Up to this point, we have seen how T:SPREAD-R([+nasal],PrWd) can be used to generate one representation from another, and how the new representation is preferred by the constraint under the revised definition of evaluation. Unbounded spreading is accounted for by allowing this generation/evaluation step to apply any number of times. To carry the current example one step further, consider that in the new candidate [pəŋãwasan] there is a different locus ([w]) for which the constraint specifies the same change. The result is [pəŋãw̃asan], and the constraint prefers this representation over [pəŋãwasan] by an argument formally identical to the one given in (16). In principle, any number of segments can be nasalized by this type of iterative application.

There is one remaining problem, which arises from changes that undo spreading rather than advancing it. For example, consider the change from [pəŋãwasan] to [pəŋawasan], the inverse of the change analyzed in tableau (16). Intuitively, T:SPREAD-R([+nasal], PrWd) should disprefer the new candidate [pəŋawasan] relative to the old candidate [pəŋãwasan], just as it disprefers [pəŋawasan] relative to [pəŋãwasan] when the change runs in the opposite direction. But this does not follow from the revised definition of constraint evaluation in (15). Both candidates incur a single violation; the constraint does not prefer one over the other.

The key to the solution of this problem is found by looking more closely at the change Δ^{-1} that takes [pəŋãwasan] to [pəŋawasan]. Included in Δ^{-1} are the substitutions ([ã],[a]) and ([w],[w]).

[8] As should be clear from the discussion in the text, only the total marks are relevant for the comparison of candidates. However, in the interest of clarity I will continue to write '(*)' for a mark that is assigned by the first part of (15) but removed by the second part. The alternative would be to simply leave such a mark out of the tableau altogether, but this could lead to confusion regarding the locus of violation of a constraint. See section 3.5 for a more formal presentation of mark assignment and removal.

Note also that the notion of mark *removal* introduced in this paper is unrelated to the notion of mark *cancellation* in Prince & Smolensky (1993/2002).

Notice that Δ^{-1} repairs the locus of violation [w] in the original candidate ([pəŋãwasan]), because Δ^{-1}([w])=[w] is not a locus of violation in the new candidate ([pəŋawasan]). Crucially, however, the repair is *not* the one specified by the spreading constraint. The δ component of the constraint states that the way to remove the violation is by nasalizing the locus itself: [w]→[w̃]. But in fact the violation has been removed by a change in the context: [ã]→[a].

The solution, then, is to assume that the new definition of constraint evaluation has a certain symmetry. Just as a mark is removed from the new candidate (y) for every repair that is performed in the way specified by the constraint, a mark must be removed from the *old* candidate (x) for every repair that is done in a way *not* specified by the constraint. The final definition of TCOT constraint evaluation in (17) incorporates this symmetry.

(17) Constraint evaluation in TCOT (final version)
Let C be any constraint that specifies both a locus λ and a change δ, x and y be any two representations, and Δ be the change from x to y.

- a. For every $\lambda \in C(x)$, assign one mark to x; for every $\lambda \in C(y)$, assign one mark to y.
- b. For every $\lambda \in C(x)$ that is repaired in the way specified by δ, remove one mark from y.
- b.′ For every $\lambda \in C(x)$ that is repaired in a way not specified by δ, remove one mark from x.

The tableau for the inverse change (Δ^{-1}), given in (18), is now identical to the tableau for the original change (Δ) (see (16)). The constraint prefers [pəŋãwasan], with further spreading, regardless of which candidate is derived from the other.

(18) Illustration of symmetrical mark removal

	Candidates	T:SPREAD-R([+nasal],PrWd)	Total marks
a.	[pəŋawasan]	*	*
b.	[pəŋãwasan]	(*)	$* + (\,) = \emptyset$

In summary, I have argued that unbounded spreading requires a revision in a fundamental part of OT: the way in which constraints evaluate candidates. In the body of the paper, I develop the theory of targeted constraints, and of derivational TCOT, that is required to formally apply the new notion of mark removal, and I work out the empirical consequences of the theory for spreading and other phenomena. I also argue that the new definition of constraint evaluation in (17) is not an arbitrary addition to the theory of targeted constraints. Instead, it is one way of implementing the central axiom of the theory—namely, that a targeted constraint prefers only the change specified by its δ component—in terms of marks (see section 3.1.2).

1.3 Outline

The rest of the paper has three main parts. I begin the first part with a brief overview of the typology of unbounded spreading, focusing on the issue of which aspects of the phenomenon are known to follow from broader generalizations and which appear to be relatively unpredictable (section 2). The central point of this discussion is that OT constraint interaction, unlike rule application, allows conditions on the class of segments that undergo spreading to be reduced to independently motivated factors. This provides the main explanatory motivation for the analysis of unbounded spreading proposed in this paper, which is developed further in section 3. I review targeted constraints (section 3.1) and develop the new framework in which these constraints are used to generate candidates at each step of a derivation (3.2). I then develop the analysis itself, moving beyond the single-constraint case treated above to the general case of multiple interacting constraints (3.3). I conclude with some notes on how the analysis can be implemented in a computational, finite-state model of phonology (3.5).

The second part of the paper presents some further consequences and developments of the proposal. In addition to solving the overgeneration problem with which the paper began, the proposal provides descriptions for several phenomena that have been difficult to analyze in constraint-based phonology. These include 'mypoic' spreading (i.e., spreading that proceeds as far as possible despite the fact that it is blocked from reaching the edge of a domain), other directional processes for which non-local constraints have been proposed (e.g., right-to-left dissimilation), non-iterative spreading, and transparent segments. Myopia and directionality follow immediately from the proposal. Non-iterative spreading, recently analyzed in OT by McCarthy (to appear-a), is accounted for under the further assumption that certain constraints are themselves non-iterative (i.e., do not feed themselves). Segmental transparency, in which a feature appears to spread through one or more segments without affecting them, is accounted for by constraints are non-persistent (i.e., do not apply throughout the derivation). The resulting parameterized theory of constraints builds on earlier work by Anderson (1974), Archangeli & Pulleyblank (1994), and Myers (1991a). It applies beyond the empirical domain of assimilation, accounting for counterfeeding opacity in general (see Wilson, in prep.).

In the third part of the paper, I argue against alternative analyses of unbounded spreading that have been proposed within OT, including non-targeted constraints that contain conditions on the segments that undergo spreading, as well as approaches based on feature minimization, durational enhancement, and directional evaluation. The paper concludes with a summary and some remarks on the role of parallelism in phonology.

2 Conditions on spreading

For the purposes of this paper, I define unbounded spreading as assimilation that, given a trigger segment, can in principle apply to any number of other segments. The trigger bears a particular feature value either underlyingly or by another process. The segments that undergo spreading take on the same value.

Among the processes that satisfy this definition, I focus only on those that apply, in at least some cases, to adjacent segments. This is intended to exclude consonant harmony processes in which the trigger and the undergoer are always non-adjacent. A number of researchers have argued that consonant harmony is the result, not of local feature-changing operations or autosegmental spreading, but of distinct theoretical mechanisms such as consonant-to-consonant correspondence (Hansson 2001, Rose & Walker 2001, Walker 2000; cf. Gafos 1996, 1998 and Poser 1982).[9]

The restriction to processes that sometimes apply to adjacent segments is not intended to exclude vowel harmony or other processes that sometimes appear to apply across one or more transparent

[9]To limit the scope of the paper, I also ignore metaphony processes of the type analyzed by Hualde (1989), Walker (xxxx), and others. These processes seem to require additional assumptions about the form of spreading constraints (in particular, specifications of the prosody of the segments that undergo spreading) that go beyond the theory developed here.

segments. Following many others, I assume that vowel harmony is generally strictly local, because consonants intervening between harmonizing vowels participate fully in the process (Gafos 1996, Gafos & Lombardi 1999, Ní Chioasáin & Padgett 2001). And, as shown in section 4.4, the existence of surface transparent segments is fully compatible with the local spreading constraints proposed here.

Unbounded spreading has been the subject of extensive empirical and theoretical research within generative phonology. In-depth studies of unbounded spreading in particular languages, or related languages, include Clements & Sezer (1982), Davis (1995), Hoberman (1988), Ringen (1975 [1988]), and Vago (1976). Important typological studies have been conducted on vowel harmony (Vago 1980), tone spreading (xxxx), rounding harmony (Kaun 1995, 1996), nasal harmony (Cohn 1990, 1993b, Homer 1998, Piggott 1992, Walker 1998 [2000]), laryngeal harmony (Lombardi 1999), emphasis (or [RTR]) harmony (Bessell 1998), and others. And unbounded spreading has been central to many theoretical developments, including theories of iterative and directional rule application (Anderson 1974, Archangeli & Pulleyblank 1994:312–321; Howard 1973, Johnson 1972); the introduction of autosegmental phonology (Goldsmith 1976, Clements 1980) and the ensuing debate on which phenomena should be analyzed with separate autosegmental or metrical tiers (Anderson 1982, Poser 1982); the use of underspecification in accounting for transparency (Steriade 1978); arguments for privative features (Steriade 1995); and representational conditions on autosegmental linking (Bird 1995, Gafos 1996, Ní Chioasáin & Padgett 2001, Walker 1998 [2000]). Unbounded spreading has remained central within OT, where it has figured prominently in research on conditions that apply to specific spreading processes (Davis 1995, McCarthy 1997, Prince 1997, Smolensky 1995); the role of local conjunction (Bakovic 2000, Smolensky 1995); extensions of correspondence theory (Krämer 2000); variable ranking (Ringen & Heinamaki 1999); and directional evaluation (Eisner 2000; cf. section 5.4).

Against this broad background of data and theory, questions of explanation stand out sharply. What aspects of a given unbounded spreading process can be predicted? What principles predict them?

In answering these questions, it will be useful to compare the spreading rule in (2b), repeated in (19), and the slightly simplified version of Walker's (1998 [2002]) non-local spreading constraint in (3), repeated in (20).

(19) Nasal spreading rule

```
     X   V
     | ,'
  [+nasal]
```

(20) Nasal spreading constraint

SPREAD-R([+nasal],PrWd). For every [+nasal] autosegment n, assign one violation for every segment in the same prosodic word that is to the right of n's domain.

Both (19) and (20) agree that the direction of spreading, and the particular feature value that spreads, are unpredictable. These two aspects of the process are simply stated as part of the rule and the constraint, not derived in either case from general principle. With respect to directionality, this type of stipulation seems at present unavoidable. There may be cross-linguistic tendencies concerning the direction of spreading (Cohn1993b, Homer 1998, McCarthy 1997:240, note 7, Watson

1999), but no formalization of these tendencies or analysis of apparent counterexamples has been developed.

With respect to the spreading feature value, many researchers have claimed that only the positive values of certain features are observed to spread unboundedly. These features include [nasal] (Steriade 1995, xxxx), [round] (Steriade 1995, xxxx), and others. But no theory has succeeded in accounting for such generalizations. The hypothesis that the relevant features are privative, although often thought to provide an account, does not by itself impose any limitations on the processes that can be described. For example, unbounded spreading of [–nasal] can be simulated, even under the assumption that [nasal] is privative, with an autosegmental rule that delinks [+nasal] features in the environment of [0nasal] segments (i.e., segments that are not themselves linked to [+nasal] features). The ability to refer to the class of segments that do *not* bear a privative feature is necessary to describe certain phonological generalizations, as explicitly noted in Steriade (1995:148), so this hypothetical rule cannot be eliminated on general principle.

OT analyses have similarly failed to capture generalizations about which feature values spread. For example, Kiparsky (1993, 1994) proposes that the constraints that demand faithfulness to underlying marked values universally dominant the analogous constraints that demand faithfulness to unmarked values (e.g., assuming [+nasal] is generally more marked than [–nasal], IDENT([+nasal]) $\gg_{UG}$IDENT([–nasal])). But even with such a universal ranking enforced, there are still hierarchies that map disagreeing sequences of the form [+F][–F] (order irrelevant) to [–F][–F]. In the case of [nasal], this can be accomplished with hierarchies such as:

*NASALFRICATIVE, SPREAD-R([+nasal],PrWd) $\gg$ IDENT([+nasal]) $\gg$ IDENT([–nasal]).

This hierarchy generates mappings, such as (hypothetical) /nãw̃ã+sa/→[dawasa] (cf. /nãw̃ã/→[nãw̃ã]), that are indistinguishable from those of a grammar with an unbounded [–nasal] spreading rule. In short, universal rankings of the form IDENT([+F])$\gg_{UG}$IDENT([–F]) fail to account for generalizations about feature spreading, for the simple reason that higher-ranked feature co-occurence constraints can force IDENT([+F]) to be violated. The same argument applies to an alternative formalization in which marked values are subject to a superset of the faithfulness constraints that apply to unmarked values (de Lacy 2002, McCarthy & Prince 1999:44ff. (page citation to ROA version); cf. Prince xxxx). (I return to this issue in 3.1.1, making a novel proposal that does restrict the set of features that can spread.)

So far, I have only considered the ways in which rule (19) and constraint (20) are similar. But there is an important difference between them as well. Notice that, in addition to the stipulations that the rule and the constraint have in common, the rule also specifies the class of segments that undergo spreading (i.e., the class [–consonantal]). In contrast, the constraint assigns one violation for any segment, regardless of its features, to the right of a [+nasal] domain. The constraint is in this respect simpler, more general than the rule.

The source of the simplification is constraint interaction. As shown by the extensive typological studies of Cohn (1993b), Piggott (1998), and Walker's (1998 [2000]), all attested conditions on the segments that undergo [+nasal] spreading can be derived by ranking the spreading constraint with respect to the members of the universal subhierarchy in (21).[10]

(21) Nasal subhierarchy (from Walker 2000:39)
*NASOBSTRUENTSTOP≫*NASFRICATIVE≫*NASLIQUID≫*NASGLIDE≫
*NASVOWEL≫*NASSONORANTSTOP

Languages (like Malay) in which only vowels and glides undergo nasal spreading are analyzed by ranking SPREAD-R([+nasal],Pwd) between *NASLIQUID and *NASGLIDE. More important than this language-particular ranking, however, are the cross-linguistic predictions that follow from (21). One prediction is specific to spreading: If segments in the class referred to by constraint *NAS$_i$ can undergo spreading, then segments in the class referred to by *NAS$_j$ can also undergo spreading, where *NAS$_i$ and *NAS$_j$ are any two members of the nasal subhierarchy such that *NAS$_i$≫*NAS$_j$. Other predictions hold of different empirical domains. For example, if segments in the class referred to by *NAS$_i$ contrast for nasality, then segments in the class referred to by *NAS$_j$ must show that same contrast (where again *NAS$_i$≫*NAS$_j$). Similarly, if docking of a floating [+nasal] feature can create a segment referred to by *NAS$_i$, then it can also create a segment referred to by *NAS$_j$. The first two of these predictions are verified by Cohn (1993b), Piggott (1998), Walker (1998 [2000]). The last prediction has, as far as I know, not been systematically tested, but no counterexamples are known to me.

The general insight exemplified by Walker's (1998 [2000]) work is that conditions on undergoers can be accounted for with constraints that are independently motivated by facts from several other domains (e.g., surface inventories, and the operation of other processes such as feature docking). This idea has its roots in earlier work (Archangeli & Pulleyblank 1994, Padgett 1991, 1994, 1995, Pulleyblank 1989, Kiparsky 1985). But it has reached its full potential only within OT, where all effects must be derived from the interaction of a single set of constraints. Other examples from the literature include Bakovic (2000:ch.4), Kaun (1995, 1996) (on rounding harmony), McCarthy (1997) (on "emphasis" harmony); see also McCarthy (2002a:103–106; 180 for general discussion.

Many of these papers include examples in which the constraints that block a particular spreading process are nevertheless violated by other surface forms in the same language. For example, the constraint against associating [RTR] ([–ATR]) to high front segments ([iyʃj]) blocks rightward (perseveratory) spreading of [RTR] in Southern Palestinian Arabic, but is violated by leftward (anticipatory) spreading (McCarthy 1997). Such examples support OT, in which constraints are violable, over alternatives theories that make use of inviolable constraints only (e.g., McCarthy 1986, Halle & Idsardi 1995). McCarthy (1997) and Prince (1997) show further that OT—unlike closely related theories such as those of Archangeli & Pulleyblank (1994) and Davis (1997)—predicts that if two processes in the same language spread the same feature, then one of the processes must be 'stronger' than the other (i.e., the conditions that block one must be a subset of those that block the other). Although this prediction is not obviously correct (see Prince 1997, Smolensky 1995), in the absence of overwhelming evidence against it we should continue to adopt the more restrictive theory.

[10]See Walker 2000:37 and references cited there for feature-based formulations of the constraints in this subhierarchy.

To summarize the discussion up to this point, I noted that both rule- and constraint- based analyses stipulate certain aspects of unbounded spreading (i.e., direction and feature value). A certain degree of stipulation seems unavoidable, given current limitations on our knowledge of the generalizations that govern unbounded spreading and the failure of previous analyses to formally capture certain generalizations that are known. Rule-based analyses also stipulate conditions on undergoers. In contrast, OT analyses derive these conditions from independently-motivated, violable constraints. OT also uniquely predicts strong/weak relations among processes that spread the same feature.

This brings us back to the issue that was raised at the beginning of the paper: What is the proper formulation of the spreading constraints? As just reviewed, OT provides a restrictive theory of blocking conditions. However, spreading constraints such as (20) lead to a serious *loss* of restrictiveness on another front: they predict many unattested non-local interactions (see section 1.1). And local spreading constraints such as those considered in tableau (11) of section 1.2 are, given the original definition of OT constraint evaluation, simply unworkable.

The main goal of this paper is to develop a new framework, already outlined in section 1.2, that capitalizes on the explanatory potential of OT while avoiding the problems of previous OT analyses. The key first step towards this goal is to formalize the notion of a *targeted* markedness constraint.[11]

3 Targeted spreading constraints

In the analyses of unbounded spreading proposed in this paper, the constraints that drive spreading have the general form in (22). Recall that λ is the locus of violation and δ specifies the preferred change, or 'repair'. I have written the constraint as feature-changing, but it can easily be reformulated in autosegmental terms; see section 3.3.2. In the left-hand side of δ, '[0F]/[$-\alpha$F]' stands for the set that includes segments underspecified for [F] and segments specificied [$-\alpha$F].

(22) T:SPREAD-{L,R}([αF],D)
- λ A non-[αF] segment immediately to the {left, right} of an [αF] segment in the same domain D.
- δ [0F]/[$-\alpha$F]$\rightarrow$[αF]

This constraint belongs to the class of targeted markedness constraints. I introduce this class, and review the new definition of constraint evaluation that makes use of their unique properties, in section 3.1. Because targeted constraints specify both a problem (λ) and a repair (δ), they define two functions: they map candidates to lists of violations, just like other constraints; and they map candidates to candidate sets, by applying the change at the loci of violation. The formalization of the second function, which leads to a concomitant reduction of the GEN function of OT, is given in section 3.2. This leads directly to the analysis of unbounded spreading, including a range

[11]There are other aspects of unbounded spreading that have not yet been discussed. One is morphological sensitivity. I have little to say about this here, because it does not seem possible to predict whether a given spreading process will apply from stems to affixes (as in familiar vowel harmony systems such as the one in Turkish) or from affixes to stems (see Noske 2000, van der Hulst 1985 for systems of this type; cf. Bakovic (2000, 20002), where it is shown that stems retain a degree of control over spreading even in such systems). Other aspects of spreading include conditions on triggers and conditions that apply to triggers and undergoers jointly (as in *parasitic* harmony). I discuss these conditions in sections 3.3.2 and 3.3.3, respectively.

of attested blocking effects (section 3.3). The section ends with notes on the implementation of targeted constraints, as both generators and evaluators, within finite-state phonology (section 3.5).

3.1 Targeted constraints

The basic idea behind targeted constraints can be understood by thinking of markedness as a type of 'pressure' for change (as in Liberman & Prince 1977:318ff.). The pressure exerted by a non-targeted constraint is undirected, in the sense that *any* change that eliminates a violation is preferred by the constraint. In contrast, the pressure exerted by a targeted constraint is tightly focused. Among all of the alternative ways of eliminating a violation, the constraint prefers only one or more specific changes (which are specified by δ).

To formalize a version of OT with targeted constraints (TCOT), it is necessary to address two issues: how the changes preferred by a targeted constraint are determined (determination of targets); and how targeted constraints assign marks to candidates (candidate evaluation). In the following two subsections, I discuss each of these in turn. With respect to candidate evaluation, the present proposal departs from Wilson (2001) in a way that answers many of the objections to targeted constraints raised by McCarthy (2002b) and Pater (2003).

3.1.1 Determination of targets

In the original presentations of targeted constraints (Bakovic & Wilson 2000, Wilson 2001), it was claimed that targets are determined by a *minimal change* principle. Given a representation that contains a violation of a targeted constraint, the constraints prefers all and only the representations that result from the smallest (most minimal) changes that are sufficient to eliminate the violation.[12]

For many targeted constraints, a guide to the minimal change is provided by previous work on phonological *licensing* (Goldsmith 1990, 1993, Ito 1986, Ito & Mester 1993, Ito et al. 1995, Lombardi 1991 [1994], 1999, 2001, Steriade 1995, and others). Continuing with the pressure metaphor mentioned above, we can think of unlicensed elements as 'weak points' in a representation. The pressure applied by a targeted constraint can be eliminated only by changing these elements and leaving the rest of the structure intact.

An instructive example comes from the domain of laryngeal licensing. Lombardi (1991 [1994], 1999) claims that a laryngeal node of an obstruent is licensed iff it is released into a tautosyllabic sonorant. Lombardi (2001) shows further that the only cross-linguistically attested repair for word-final (hence unlicensed) voiced obstruents is devoicing. This can be accounted for with a targeted constraint that is violated by word-final voiced obstruents, given the hypothesis that the minimal change that is sufficient to eliminate a violation is the one identified by Lombardi: delinking of the unlicensed laryngeal node itself.[13]

[12]This is a generalization of the 'weak element principle' of Wilson (2001). Similar notions of minimal change appear in work by Halle & Vergnaud (1981) and Sommerstein (1973); cf. Myers (1991a).

[13]See Bakovic & Wilson (in prep.) for arguments that favor the targeted-constraint approach to laryngeal phonology over the positional-faithfulness analyses of Lombardi (1999), Steriade (1999b, 2001).

A further development of targeted constraints that incorporates maximum thresholds for change could simplify the constraint mentioned in the text. The constraint would be violated by all voiced obstruents. But its threshold would prevent it from changing any obstruents except those that are unlicensed. For space reasons, I leave the details of this

The relationship between minimality of change and (absence of) licensing becomes particularly close within the perceptual licensing framework of Steriade (1999b, 2001) (see also Fleischhacker xxxx, Zhang xxxx, among others). Steriade argues that an element is licensed to the degree that it is perceptually prominent or salient. In the case of laryngeal features, Steriade shows that the licensing position identified by Lombardi (1991 [1994], 1999) provides several robust cues for laryngeal distinctions (e.g., VOT and burst characteristics). Other positions provide fewer and/or less robust cues. The targeted constraint against word-final voiced obstruents (or, as mentioned in the previous footnote, against voiced obstruents in general) specifies loss of the laryngeal node as the preferred repair because that is the change that removes the element that is lacking robust cues.

Returning now to unbounded spreading, we find that previous research provides substantially less guidance for the determination of targets. Consideration of a form in which [+nasal] has spread some distance, such as [pəŋã w̃asan] (note the orality of the second [a]), brings us to the heart of the matter. What notion of minimal change ensures that the repair preferred by the targeted spreading constraint is further nasalization (as in [pəŋãw̃ãsan]) rather than denasalization ([pəŋãwasan])?

I propose a two-part answer. First, I adopt the simplifying assumption that the minimal change principle considers only changes within the 'window' that contains the locus of violation and the contextual segment (in [pəŋãw̃asan], the window is [w̃a]). Second, I assume that changing from a positive specification of [nasal] to a negative specification is more 'costly' than the opposite change.

(23) Relative costs of changes in [nasal]
The change from [+nasal] to [–nasal] is more costly (less minimal) than the change from [–nasal] to [+nasal].

Given these assumptions, the minimal change available to eliminate the spreading violation in [pəŋãw̃asan] is [a]→[ã]. This is the desired result.[14]

Assumption (23) is related to, and in some respects improves upon, previous work on [nasal] and other features. For example, Steriade (1995) proposes a perceptual basis for the (claimed) privativity of [nasal], [round], etc.: a feature is privative iff only one of its logically-possible values gives rise to a percept significantly different from that of the default state of the vocal tract. With respect to [nasal] in particular, the default state of the corresponding articulator (the velum) is raised. Therefore, only [+nasal], corresponding to velum lowering, yields a percept that is distinct in the relevant way. Rephrasing (23) in terms closer to those of Steriade (1995), the idea is that changing from a non-default state of the vocal tract to the default state is more costly, as far as the minimal change principle is concerned, than changing from the default state to a non-default state. (Presumably an articulatory cost metric would have the opposite properties.)

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development for future work.

[14]Strictly speaking, it must also be assumed that other logically-possible changes, such as deletion of the offending vowel ([a]→∅) are more costly than nasalization. It seems likely that this will follow from any sufficiently developed theory of the perceptual costs of various changes.

Assumption (23) is related to a law of assimilation proposed by Schachter (1969), which states that marked feature values dominate over unmarked feature values in assimilation. If [+nasal] is marked relative to [–nasal], then Schachter's law and (23) have the same consequences for this feature.

As noted in section 2 above, the result of Steriade's assumptions—that the opposition is [nasal] vs. $\emptyset$, not [+nasal] vs. [–nasal]—do not account for the generalization that only nasality (not orality) can spread. The fixed faithfulness rankings proposed by (Kiparsky 1993, 1994) and the subset relations among faithfulness constraints proposed by (de Lacy 2002, McCarthy & Prince 1999) also fail to do this. In contrast, (23) does account for the generalization, because it governs the preferences of *all* targeted constraints. Whenever either [+nasal]→[–nasal] or [–nasal]→[+nasal] could in principle remove a violation of a targeted constraint, the constraint can prefer only the latter.[15]

Indeed, by adopting (23)—in a generalized form—we can eliminate privativity and fixed faithfulness rankings (or subset relations). This simplifies the theory considerably. Every feature is binary, as the phonetic arguments of Cohn (1990), Keating (1998), and others independently require. There is a single IDENT(F) constraint for every feature [F]. If only one of the values of a feature has perceptual effects significantly distinct from those of the speech-specific default state, then (23) applies and the feature behaves as if it were privative as far as spreading is concerned. On the other hand, if both values lead to perceptible deviations from the default state, then (23) does not apply (i.e., [+F]→[–F] and [–F]→[+F] are equally costly). I assume that, when this is the case, the value that spreads must be determined by constraint-specific stipulation. For example, both [+ATR] (corresponding to tongue root advancement) and [–ATR] (corresponding to tongue root retraction) produce perceptible deviations from the default state (Steriade 1995). Therefore, T:SPREAD-$\{$L,R$\}$([+ATR],D) and T:SPREAD-$\{$L,R$\}$([–ATR],D) are distinct constraints that prefer different repairs. In this way, the present proposal explains the fact that [–ATR] spreads in some languages, whereas other negative values, such as [–nasal] and [–round], never do.

In summary, I have made some assumptions about the relative costs of different feature changes in order to derive the targets of spreading constraints from the principle of minimal change. I have also argued that these assumptions, unlike privativity or universal faithfulness rankings / subset relations, explain typological generalizations about the set of features that spread unboundedly.

3.1.2 Candidate evaluation

In this subsection, I review and provide additional motivation for the definition of constraint evaluation given in (17), which is repeated in (24). (Recall the definition of repair given in (14).)

(24) Constraint evaluation in TCOT
Let C be any constraint that specifies both a locus of violation λ and a change δ, x and y be any two representations, and Δ be the change from x to y.

a. For every $\lambda \in \mathrm{C}(x)$, assign one mark to x; for every $\lambda \in \mathrm{C}(y)$, assign one mark to y.
b. For every $\lambda \in \mathrm{C}(x)$ that is repaired in the way specified by δ, remove one mark from y.

[15]There are two apparent counterexamples that have been noted in the literature. First, in some languages nasal consonants become pre-/post- oralized in the context of preceding/following vowels (Anderson 1976, Steriade 1993). I take this to be a matter of timing of velum lowering relative to the consonant's place gesture, and therefore not to be a true counterexample to (23). Second, some languages have mappings of the form /mt/→[pt], in which a [+nasal] consonant changes to [–nasal] before a following [–voice] consonant (Hayes 1986a). As originally proposed by Hayes (1986a), such mappings can be decomposed into two steps: one that spreads [–voice] to the nasal (/mt/→[m̥t]), and one that denasalizes the resulting voiceless nasal (/m̥t/→[pt]). Neither of these mappings requires a targeted constraint with preferences that are contrary to (23).

b.′ For every $\lambda \in C(x)$ that is repaired in a way not specified by δ, remove one mark from x.

Recall that (24a) is McCarthy's (2003, to appear-a) formulation of Prince & Smolensky's (1993/2002) theory of evaluation; it applies to all constraints (targeted and non-targeted). (24b) and (24b′) apply only to targeted constraints—that, is only to constraints that specify a particular change (δ) for removing violations, where δ is restricted by the minimal change principle.

The new parts of the proposal were designed to address the problem of accounting for unbounded spreading, as well as to solve a major problem for the theory of Wilson (2001) that was pointed out by McCarthy (2002b) and Pater (2003). I briefly comment on the latter before returning to the main argument.[16]

The problem for the targeted-constraint framework proposed in Wilson (2001) is that, under certain rankings, a targeted constraint can give rise to repairs other than the one that it specifies. Consider, for example, the targeted constraint against word-final obstruents that was discussed in section 3.1.1 (referred to here as T:*[–son,+voi]#) . This constraint specifies devoicing as the preferred change. Therefore, given a surface form such as [fob] (based on Wolof /fob/ 'to carry, take; to pick up (a child)'; see Munro & Gaye 1997), the constraint prefers the alternative [fop] (which is the actual surface form in Wolof when the root is unsuffixed; see Ka 1988 on final devoicing in Wolof).

(25) Optimality of devoicing

/fob/	T:*[–son,+voi]#	IDENT([voice])	MAX-C
a. [fob]	*!		
b. ☞[fop]		*	

But if the constraint evaluated candidates as in (24a) only—that is, by simply assigning one mark for every locus of violation—then it would also prefer (for example) deletion of the obstruent.

(26) Problem: Optimality of deletion

/fob/	T:*[–son,+voi]#	IDENT([voice])	MAX-C
a. [fob]	*!		
b. ☞[fo]			*

If IDENT([voice]) outranks MAX-C, as in this tableau, then T:*[–son,+voi]# and IDENT([voice]) force deletion of word-final voiced obstruents to be optimal. This is at odds with Lombardi's (2001) generalization that devoicing is the only cross-linguistically attested 'solution' for final voiced obstruents. The problem for the theory in Wilson (2001) is essentially the same; it arises from the transitive closure of the harmony relation ($\succ$): [fop]$\succ$[fob] (by T:*[–son,+voi]#) and [fo]$\succ$[fop] (by IDENT([voice])) imply [fo]$\succ$[fob] (by transitivity). (This example is formally identical to others given in McCarthy 2002b, Pater 2003.)

The current proposal solves this and similar problems with mark removal. The change from [fob] to [fo] is not the one specified by T:*[–son,+voi]#. Therefore, when this change is considered, the

[16] In work in preparation, I show that other problems raised by McCarthy (2002b) are also substantially resolved by the proposal made here, although perhaps not with the full generality claimed in Wilson (2001).

mark assigned to [fob] is removed according to (24b′). (Recall that '(∗)' stands for a mark that is assigned and then removed.)

(27) Non-optimality of deletion

/fob/	T:*[−son,+voi]#	IDENT([voice])	MAX-C
a. ☞[fob]	(∗)		
b. [fo]			∗!

The faithful candidate [fob] is unmarked relative to the unfaithful candidate [fo], therefore the MAX-C violation of the latter causes it to lose the pairwise comparison. Therefore, as desired, the targeted constraint can force devoicing but not deletion.

Returning now to unbounded assimilation, a related problem is noted by McCarthy (1997, 2003), McCarthy & Prince (1999), and Walker (1998 [2000]). When spreading of a feature [αF] is blocked (for whatever reason), the question arises of why [αF] does not simply delink from the original trigger. No known language uses delinking as a last-resort alternative to spreading. But all previous OT theories of spreading—including all those cited in section 1, as well as the original version of targeted-constraint theory proposed in Wilson (2001)—predict that such languages should exist. The relevant type of comparison appears in (28), where nasal spreading is used to illustrate the problem. (As before, the problem for Wilson (2001) arises from transitive closure: [dawasa]≻[nãw̃ãs̃ã] (from *NASALFRIC) and [nãw̃ãs̃ã]≻[nawasa] (from T:SPREAD-R([+nasal])) imply [dawasa]≻[nãw̃ãs̃ã], by transitivity.)

(28) Problem: Optimality of denasalization

/nawa+sa/	*NASALFRIC	T:SPREAD-R([+nasal])	IDENT([nasal])
a. [nãw̃ãsa]		∗!	
b. ☞[dawasa]			∗

Given the schema for targeted spreading constraints in (22), mark removal solves this problem in exactly the same way as the previous one. The correct form of the pairwise comparison, in the new theory, is as follows:

(29) Non-optimality of denasalization

/nawa+sa/	*NASALFRIC	T:SPREAD-R([+nasal])	IDENT([nasal])
a. ☞[nãw̃ãsa]		(∗)	
b. [dawasa]			∗!

Delinking does not result in a representation that the spreading constraint prefers, because delinking is not the repair that the constraint specifies (recall the discussion in section 3.1.1 on the determination of targets).

So far, I have discussed the consequences of (24b′) only. The main motivation for (24b), as discussed in section 1.2, is that it allows constraints such as T:SPREAD-R([+nasal]) to prefer incremental spreading. Instead of recapitulating the entire discussion here, I simply repeat the relevant tableau (from (16)).

(30) Optimality of incremental spreading

	Candidates	T:SPREAD-R([+nasal],PrWd)
a.	[pəŋawasan]	$*!$
b.	☞[pəŋãwasan]	$(*)$

The mark assigned in [pəŋãwasan] is removed, given the change [pəŋawasan]→[pəŋãwasan], because there is one locus of violation in the original candidate that is eliminated in the way designated by the constraint.

In summary, there is substantial empirical evidence for the claim that relative harmonies are calculated with the principles of mark removal in (24b) and (24b′), in addition to the standard principle of mark assignment in (24a). To conclude this subsection, I show that mark removal can be justified on theoretical grounds as well.

The central idea of the theory of targeted constraints is that, relative to a given marked structure, only specific alternatives are preferred. This idea can be formulated as an axiom:

(31) Axiom of targeted constraints
Let C be any constraint that specifies both a locus of violation λ and a change δ, x be any candidate that contains a single instance of λ, and y be the representation derived from x by the change Δ.
C prefers y over x iff Δ is the identity relation except that λ is mapped to $\delta(\lambda)$.

In order to simplify the following discussion, I have stated the axiom so that it applies only to candidates containing a single locus of violation. The general formulation, which applies to candidates containing any number of loci, is straightforward (and already anticipated in (24)).

I assume, in addition to (31), that all preferences (relative harmonies) must be expressed with marks. Then (24b) and (24b′) can be thought of as book-keeping devices that ensure that the axiom holds for any x and y that satisfy the stated conditions. There are three cases to consider:

- The change Δ does not repair the instance of λ in x.
  It follows from the formal definition of repair (14) that y must incur at least as many marks as x. Therefore, the constraint does not prefer y over x, as required.

- The change Δ repairs the instance of λ in x, but not in the way specified by δ.
  As we saw in tableaux (26) and (28), this case presents the real danger to axiom (31). The danger is averted by (24b′), which removes the mark from x. This makes x absolutely unmarked with respect to the constraint. Therefore, the constraint again does not prefer y over x. (The alternative solution for this case would be to *add* a mark to y. This is in fact the method used in the computational formalism outlined in section 3.5)

- The change Δ repairs the instance of λ in x in the way specified by δ.
  This case divides into two sub-cases. (i) If mapping λ to $\delta(\lambda)$ does not introduce a new locus of violation, then x has one mark and y has none: the constraint prefers the latter, as required. (ii) If mapping λ to $\delta(\lambda)$ does introduce a new locus of violation, then the mark assigned to y

for that locus is removed by (24b) (which applied vacuously in subcase (i)). Therefore, x has one mark and y has none: the constraint again prefers the latter.[17]

In conclusion, the axiomatic approach to targeted-constraint theory reveals (24b) and (24b′) to be mark-based manifestations of the core notion of what a targeted constraint is, not assumptions made just to fit particular facts.

However, there is one piece of the theory still missing. Notice that the components of (24) that remove marks rely upon the existence of a particular change (Δ) in a particular direction (i.e., from x to y, not vice versa). But nothing in the discussion up to this point identifies the source of the change. As anticipated in section 1.2, I propose that targeted constraints serve this function. The result is a derivational theory in which the role of GEN—arguably the least well-understood component of OT—is substantially reduced.

3.2 Reducing GEN

The intuition behind this part of the proposal draws upon the formal work of Moreton (1996/1999) (see also McCarthy 2002a:101–103; 180). Moreton has proved that, in the original formulation of OT, only sufficiently high-ranked markedness constraints can force the output to be unfaithful to the input. The idea developed here is that targeted markedness constraints do not just prefer unfaithful outputs (for certain inputs): they also create them.

In the strongest version of this idea, all unfaithful candidates would be generated by targeted constraints. I propose instead that only melodic unfaithfulness arises from the constraints. Variations in prosodic parsing are generated by a remaining part of GEN that I refer to as GEN_{Pros}. The assumption that GEN_{Pros} exists is supported by arguments that entire prosodic parses are computed and evaluated in parallel (Burzio 1994a, Cohn & McCarthy 1994/1998, Prince & Smolensky 1993, among others), and is clearly related to previous assumptions of persistent syllabification (Hayes 1989, Ito 1986, McCarthy 1979) and persistent footing (Hayes 1995:114–115, Halle & Vergnaud 1987).[18]

Formally, the proposal is this. A targeted constraint C is a pairing of a locus of violation (λ) with a change (δ). For each C, there is a constraint-specific function GEN_C (i.e., $\text{GEN}_{(\lambda,\delta)}$) that maps candidates to candidate sets. GEN_C returns the set containing all and only the candidates that can be derived from the original candidate by applying the change δ to zero or more instances of the locus λ. GEN_{Pros} then applies to this set, adding all universally-possible prosodic parses of the candidates created by the constraint. If x is the original candidate, then the resulting candidate set is $\text{GEN}_{Pros}(\text{GEN}_C(x))$ (i.e., $[\text{GEN}_{Pros} \circ \text{GEN}_C](x)$, where '$\circ$' is the function composition operator).

For example, suppose that x is [(ná.ki.)nu] (where parentheses mark foot boundaries and periods mark syllable boundaries) and C is T:SPREAD-R([+nasal]). The constraint generates the set:

[17] The only remaining problem would be cases in which applying δ to a single locus of violation would introduce more than one new violation. I am not aware of such cases, and therefore set the issue aside here.

[18] The existence of GEN_{Pros} in turn suggests that the constraints responsible for prosodic parsing are also non-targeted, and that differences in prosodic structure are ignored when applying mark removal. For completeness, I adopt both of these assumptions, but do not discuss prosodic parsing further in this paper.

$\text{GEN}_C(x) = \{[(\text{ná.ki.})\text{nu}], [(\text{nấ.ki.})\text{nu}], [(\text{ná.ki.})\text{nũ}], [(\text{nấ.ki})\text{nũ}]\}$.

Then GEN_{Pros} applies to give $[\text{GEN}_{Pros} \circ \text{GEN}_C](x)$, which contains the members of $\text{GEN}_C(x)$ and all of the candidates that pair the same melodies with other prosodies allowed by UG (including [(na.kí.)nu], [na.(ki.nú)], [(nấk.)(ín.ũ)], and many others).

Candidate sets generated in this way have a lattice structure, as illustrated in (32). Each candidate in $\text{GEN}_C(x)$ corresponds to a unique *subset* of the set of violation loci in x (here, {[a], [u]}). The corresponding subset contains all and only the loci that are changed by δ in the derivation of the candidate. The resulting candidate lattice is shown in the left-hand side of (32). GEN_{Pros} adds another dimension to the lattice, expanding each node into a set of candidates that differ only in prosodic parsing. This is shown in the right-hand side of (32).

(32) Lattice structure of the candidate set

Candidates returned by GEN_C	Composition of GEN_{Pros} and GEN_C
[(nấ.ki)nũ]	GEN_{Pros}([(nấ.ki)nũ])
/ \	/ \
[(nấ.ki.)nu] [(ná.ki.)nũ]	GEN_{Pros}([(nấ.ki.)nu]) GEN_{Pros}([(ná.ki.)nũ])
\ /	\ /
[(ná.ki.)nu]	GEN_{Pros}([(ná.ki.)nu])

Once GEN_C and GEN_{Pros} have applied, the resulting candidate set is evaluated by the entire hierarchy. Therefore, the output of one generation/evaluation (gen/eval) step is H-max($[\text{GEN}_{Pros} \circ \text{GEN}_C](x)$). Optimality is defined exactly as in OT, by pairwise comparison of marks in a way that respects the strict-domination relations among the constraints (Prince & Smolensky 1993, McCarthy 2002b:6–8; see section 3.5 for further formalization in the present theory).

All that remains is to embed individual gen/eval steps within a larger derivational framework. I assume that the derivation begins with a surface form that is identical in all respects to the input.[19] And I assume that the constraint-specific GEN_C functions are applied in the order specified by the hierarchy (from top to bottom). In order to account for iterative phenomena such as unbounded spreading, each GEN_C must be allowed to apply any number of times (until the output stops changing). Putting all of this together yields the derivational TCOT formalism in (33).

(33) Derivational TCOT

Let $\text{H} = [\text{C}_1 \gg \text{C}_2 \cdots \gg \text{C}_n]$ be any constraint hierarchy and in be any input.

a. The initial output, out_0, is the surface form that is identical to in.

b. For every constraint C_k ($1 \leq k \leq n$), an output is derived by repeatedly generating with $[\text{GEN}_{Pros} \circ \text{GEN}_{C_k}]$ and selecting the most harmonic member of the candidate set with the entire hierarchy H.

  i. The initial output for C_k, $out_{k,0}$, is equal to out_{k-1}.

[19]The existence of a candidate identical to the input is essential to the formal results of Moreton (1996/1999) mentioned earlier. An alternative to the assumption in the text is that there is an initial optimization that selects the most harmonic member of $\text{GEN}_{Pros}(in)$, where in is the input. This is similar to the optimization in McCarthy's (xxxx) definition of the fully-faithful candidate (FFC).

ii. For $m{>}0$, $out_{k,m}$ = H-max([$\text{GEN}_{Pros} \circ \text{GEN}_{C_k}$]($out_{k,m-1}$)). If $out_{k,m} = out_{k,m-1}$, then the final output for C_k, out_k, is equal to $out_{k,m}$ and generation with C_k ends.

c. The final output of the last constraint, out_n, is the output that the grammar generates for input in.

This is the framework I assume in the rest of the paper. It is both similar to, and in certain crucial respects different from, previous derivational formalisms. Like the derivational versions of OT considered in Prince & Smolensky (1993) and McCarthy (2000, 2002a:158–163; 166–170; 184), the entire hierarchy evaluates the candidates produced by each generation step. But the original conception of candidate generation in OT—that it is performed by an auxiliary function, perhaps with a fixed repertoire of operations—survives here only in the restricted form of GEN_{Pros}. For the most part, generation is tightly integrated with evaluation (targeted constraints do both) and the changes considered at each step are determined by λ and δ (as restricted by the minimal change principle).

The present formalism is also similar to the derivational framework of *SPE* (Chomsky & Halle 1968) and subsequent work, because both impose a language-particular (extrinsic) ordering on the changes that are made. Several researchers have criticized extrinsic ordering of the *SPE* type on the grounds that it is unnecessary (Iverson 1995) and/or insufficient (Anderson 1974, Kisseberth 1973, Koutsoudas et al. 1974, Myers 1991a). However, the following consideration mitigates such objections in the present context. Every OT grammar is a largely extrinsic hierarchy of the constraints (universal rankings notwithstanding). The present proposal does not add a *new* extrinsic ordering. Instead, it uses the hierarchy to determine the sequence in which the GEN_C functions apply. A single ordering is thus held responsible for all the predictions of the grammar: those that follow from constraint conflict, and those that follow from derivational sequence.

* * *

In the preceding subsections, I have introduced targeted constraints, discussed the new definition of candidate evaluation, and presented a derivational framework in which targeted constraints take over much of the work previously attributed to GEN. The theory has already yielded new solutions to problems involving typological limitations on the possible 'repairs' for a given marked structure (see tableaux (27) and (29)). It also has all of the components necessary to provide an empirically-adequate, restrictive theory of unbounded spreading, thus fulfilling the main goal of the paper.

3.3 Unbounded spreading

In this section, I present the general analysis of unbounded spreading within the framework developed above. I focus first on the interaction of targeted spreading constraints with feature co-occurrence constraints such as those in Walker's (1998 [2000]) nasal subhierarchy, which are also targeted in the current approach. I then turn to cases of *parasitic* harmony, in which spreading applies only to segments that share certain features with the trigger. Following Kaun (1995, 1996), I analyze parasitic harmony with constraints that require a spreading feature to be uniformly implemented by every segment in its domain. I also show that these constraints are motivated by patterns other than spreading, such as backness dissimilation in Ainu (Archangeli & Pulleyblank 1994, Ito 1984, Mester 1988). Together with feature co-occurrence constraints and conditions on triggers, they yield a factorial typology of unbounded spreading that closely fits the observed typology.

3.3.1 *Blocking by feature co-occurrence constraints*

To illustrate how targeted spreading constraints interact with feature co-occurrence constraints, I return to the Malay nasal harmony process in (1). Recall that [+nasal] spreads left-to-right within the PrWd, affecting any number of vowels and glides. Other segments block spreading.

Walker (1998 [2000]) accounts for this process with the hierarchy in (34).

(34) Hierarchy for Malay nasal harmony (from Walker 1998 [2000])
*NASOBSTRUENTSTOP≫*NASFRICATIVE≫*NASLIQUID≫SPREAD-R([+nasal],PrWd)
≫*NASGLIDE≫*NASVOWEL≫IDENT([nasal])≫*NASSONORANTSTOP

This hierarchy, like others studied by Walker, is created by ranking SPREAD-R([+nasal],PrWd) and IDENT([nasal]) relative to each other and the members of the nasal subhierarchy (21). The fact that glides and vowels undergo spreading is accounted for by ranking SPREAD-R([+nasal],PrWd) above *NASGLIDE and *NASVOWEL; the fact that other segment types do not undergo the process is accounted for by placing all of the other members of the subhierarchy above the spreading constraint. IDENT([nasal]) is ranked below SPREAD-R([+nasal],PrWd), as it must be if spreading is to occur at all. IDENT([nasal]) is also ranked below every member of the subhierarchy except *NASSONORANTSTOP, in order to account for the fact that nasal vowels and glides appear on the surface only as the result of spreading (i.e., to account for the fact that there is not a nasal/oral contrast for these segments).

The hierarchy in the present analysis is identical to (34), except that the spreading constraint and the members of the nasal subhierarchy are targeted. The schema for targeted spreading constraints, given in (22) and repeated in (35), has already been discussed at length. I propose (36) as the schema for the targeted nasal markedness constraints.

(35) T:SPREAD-{L,R}([αF],D)
λ A non-[αF] segment immediately to the {left, right} of an [αF] segment in the same domain D.
δ [0F]/[$-\alpha$F]$\rightarrow$[αF]

(36) T:*NAS-*k*
λ A [+nasal] segment in natural class *k*.
δ [+nasal]$\rightarrow$[–nasal]

In instantiating this schema, I adopt the natural classes argued for by Walker (obstruent stops, fricatives, etc.).[20] Rather than working through the assumptions necessary to derive the preferred repair (δ) from the minimum change principle, I simply state that it is denasalization. Thus the schema is closely related to rules of [+nasal] delinking, the linking rules of Chomsky & Halle (1968), and other 'default' rules (see Kiparsky 1985, Myers 1991a); something equivalent to them would seem to be indispensable under any approach.

As in previous discussions, the form [pəŋãw̃ãsan] provides a good test-case for the analysis, because it contains an instance of nasal spreading that does not reach the edge of the prosodic domain.

[20] Again, see Walker (2000:37) and references cited there for possible feature-based definitions of the classes.

In (37), I show how this surface form is derived given the assumption that the underlying form is /pəŋawasan/ (again, the morphology is irrelevant). I show further below that the same surface form is derived under different assumptions about the underlying form that are consistent with richness of the base (Prince & Smolensky 1993, McCarthy 2002a:70–1). Throughout, I ignore prosodic structure (and therefore GEN$_{Pros}$) except for the assumption that the entire form is contained within a single PrWd. (Because the argument of a GEN$_C$ function is always identical to the input of the current step, I use '(·)' instead of spelling that argument out. One way to read a derivation such as this one is first to look down the column labeled 'Output', getting a basic understanding of how the surface form is derived, and then concentrating on the optimizations for individual steps.)

(37) Derivation for /pəŋawasan/→[pəŋãw̃ãsan]

Step	Input	Candidate set	Output	Comments
0	/pəŋawasan/		[pəŋawasan]	
1	[pəŋawasan]	GEN$_{\text{T:*NasObstrStop}}$(·) = {[pəŋawasan]}	[pəŋawasan]	no change
2	[pəŋawasan]	GEN$_{\text{T:*NasFricative}}$(·) = {[pəŋawasan]}	[pəŋawasan]	no change
3	[pəŋawasan]	GEN$_{\text{T:*NasLiquid}}$(·) = {[pəŋawasan]}	[pəŋawasan]	no change
4,1	[pəŋawasan]	GEN$_{\text{T:Spread-R([+nasal],PrWd)}}$(·) = {[pəŋawasan], [pəŋãwasan]}	[pəŋãwasan]	incremental spreading
4,2	[pəŋãwasan]	GEN$_{\text{T:Spread-R([+nasal],PrWd)}}$(·) = {[pəŋãwasan], [pəŋãw̃asan]}	[pəŋãw̃asan]	incremental spreading
4,3	[pəŋãw̃asan]	GEN$_{\text{T:Spread-R([+nasal],PrWd)}}$(·) = {[pəŋãw̃asan], [pəŋãw̃ãsan]}	[pəŋãw̃ãsan]	incremental spreading
4,4	[pəŋãw̃ãsan]	GEN$_{\text{T:Spread-R([+nasal],PrWd)}}$(·) = {[pəŋãw̃ãsan], [pəŋãw̃ãs̃an]}	[pəŋãw̃ãsan]	no change
5	[pəŋãw̃ãsan]	GEN$_{\text{T:*NasGlide}}$(·) = {[pəŋãw̃ãsan], [pəŋãwãsan]}	[pəŋãw̃ãsan]	no change
6	[pəŋãw̃ãsan]	GEN$_{\text{T:*NasVowel}}$(·) = {[pəŋãw̃ãsan], [pəŋaw̃ãsan], [pəŋãw̃asan], [pəŋaw̃asan]}	[pəŋãw̃ãsan]	no change
7	[pəŋãw̃ãsan]	GEN$_{\text{Ident([nasal])}}$(·) = {[pəŋãw̃ãsan]}	[pəŋãw̃ãsan]	no change
8	[pəŋãw̃ãsan]	GEN$_{\text{T:*NasSonStop}}$(·) = {[pəŋãw̃ãsan], [pəʟãw̃ãsan]}	[pəŋãw̃ãsan]	no change

Note: Steps are indexed by k (position in the hierarchy) and m (iteration of a given constraint), as in definition (33); m is omitted if there is only one iteration for a constraint.

Step 0 of the derivation is trivial, and simply makes explicit that the initial output is the surface form identical to the input. Steps 1–3 are also trivial for this input, because none of the segments violate the first three constraints in the hierarchy. Therefore, in each case the candidate set created by the corresponding GEN$_C$ function contains only one member—the output of the previous step—and that candidate is of course optimal.[21]

Once the derivation reaches the targeted spreading constraint, the candidate sets and input/output mappings are no longer degenerate. In Step 4,1 (i.e., the first iteration of T:SPREAD-R([+nasal], PrWd), which is the fourth constraint in the hierarchy), the generation function maps [pəŋawasan] to the set {[pəŋawasan], [pəŋãwasan]}. The new candidate, in which [+nasal] has spread forward by one segment, is determined to be optimal by the calculation shown in (38). (In this and subsequent tableau, for space reasons I show only the relevant portion of the hierarchy and in some cases simplify the names of the constraints.)

(38) First iteration of spreading

	[pəŋawasan]	T:SPREAD-R([+nasal])	T:*NASGLIDE	T:*NASV	IDENT([nasal])
a.	[pəŋawasan]	*!			
b.	☞ [pəŋãwasan]	(*)		*	*

The T:SPREAD-R([+nasal],PrWd) mark incurred by [pəŋãwasan] is removed by part (24b) of the new definition of candidate evaluation, as discussed extensively in sections 1.2 and 3.1.2. The other marks are assigned exactly as in the original formulation of OT.

Because the input and the output of the first iteration of T:SPREAD-R([+nasal],PrWd) are not identical, the GEN function of this constraint continues to apply. Two further iterations (Steps 4,2–3) spread the [+nasal] segment forward by two more segments. The relevant tableaux, omitted here, are like (38) in that only constraints ranked lower than T:SPREAD-R([+nasal],PrWd) are violated by spreading.

On the final iteration of T:SPREAD-R([+nasal],PrWd) (Step 4,4), the generation function applies to [pəŋãw̃ãsan] and produces the candidate set {[pəŋãw̃ãsan], [pəŋãw̃ãs̃an]}. The new candidate violates a constraint ranked higher than T:SPREAD-R([+nasal],PrWd), therefore spreading is blocked at this point.

(39) Spreading blocked by higher-ranked feature co-occurrence constraint

	[pəŋãw̃ãsan]	T:*NASFRIC	T:*NASLIQ	T:SPREAD-R([+nasal])
a.	☞ [pəŋãw̃ãsan]			*
b.	[pəŋãw̃ãs̃an]	*!		(*)

This type of interaction—in which a higher-ranked constraint prevents spreading from applying in a particular context—was shown in section 2 to be the source of the general explanatory advantage that OT analyses have over rule-based analysis. This advantage is maintained in the present approach, even though certain core principles of OT have been revised. Note further that T:*NASFRIC does work in the analysis over and above blocking spreading. For example, it accounts for the absence of a nasal/oral fricative contrast in virtue of outranking IDENT([nasal]). Given this constraint set, the ranking T:*NASFRIC≫IDENT([nasal]) follows by transitivity of domination from T:SPREAD-R([+nasal])≫IDENT([nasal]) (necessary for spreading) and *NASFRIC≫T:SPREAD-R([+nasal]) (necessary for blocking). Therefore, the system predicts the absence of a contrast given the independently-established patterns of spreading and blocking.

[21] In a full analysis GEN_{Pros} would also apply at each step, and the optimizations would not be trivial as far as prosodic structure is concerned.

The result of the competition in (39) is that the output of Step 4,4 is identical to the input of that step. Therefore, iteration of T:SPREAD-R([+nasal]) ends—spreading has gone as far as it can—and the derivation moves on to the next constraint in the hierarchy.

What follows are four steps (Steps 5–8) in which non-trivial candidate sets are generated but the output does not change. Consider Step 5, for example, in which $\text{GEN}_{\text{T:*NASGLIDE}}$ is the generation function. Applied to [pəŋãw̃ãsan], the function returns the set {[pəŋãw̃ãsan], [pəŋãwãsan]}. As shown in tableau (40), the new candidate loses the competition.[22]

(40) Re-enforcement of spreading by multiple violation

	[pəŋãw̃ãsan]	T:SPREAD-R([+nasal])	T:*NASGLIDE	T:*NASVOWEL	IDENT([nasal])
a.	☞ [pəŋãw̃ãsan]	*	*	**	
b.	[pəŋãwãsan]	*!*	( )	**	*

The new candidate loses because it contains two instances of the locus of violation of T:SPREAD-R([+nasal]) (i.e., two [–nasal] segments right-adjacent to [+nasal] segments), while the old candidate has only one.

Similar optimizations account for Steps 6 and 8. The comparison between [pəŋãw̃ãsan] and [pəŋãw̃asan] in Step 6 contains an instance of mark removal by (24b), therefore I give the tableau here for the purpose of illustrating this part of the theory. (To establish that [pəŋãw̃ãsan] is optimal at this step, it is sufficient to show that it wins a pairwise comparison against each of the new candidates. In order to give a single tableau for the entire optimization, it is necessary to use a version of (24b) that assigns marks rather than removing them; see section 3.5.)

(41) Re-enforcement of spreading by mark removal

	[pəŋãw̃ãsan]	T:SPREAD-R([+nasal])	T:*NASGLIDE	T:*NASVOWEL	IDENT([nasal])
a.	☞ [pəŋãw̃ãsan]	(*)	*	* *	
b.	[pəŋãw̃asan]	*!	*	(*)	*

The mark that T:SPREAD-R([+nasal]) assigns to [pəŋãw̃ãsan] is removed, because the change from [w̃] to [w] repairs the locus of violation [s] in a way other than that specified by the constraint. See sections 1.2 (tableau (18)) and 3.1.2 (tableau (30)) for similar cases of mark removal.

To conclude the discussion of this derivation, I should make explicit two assumptions about faithfulness. First, notice that the generation function for Step 7 is $\text{GEN}_{\text{IDENT([nasal])}}$. However, up to this point generation functions have been defined for targeted constraints only. I assume that the function for all other constraints (i.e., faithfulness constraints such as IDENT([nasal]) and non-targeted markedness constraints) maps any given candidate x to the singleton set $\{x\}$. Therefore, although non-targeted constraints are fully compatible with the proposal, and are crucially involved in evaluation, they never play a meaningful role in generation. For this reason, I omit steps such as this one from all subsequent derivations.

[22]This is the first tableau in which mark removal applies to a candidate that does not violate the relevant constraint (here, T:*NASGLIDE). For completeness, I represent the fact that mark removal is applicable with '( )', but note that this is *harmonically identical to no mark at all*. That is, mark removal applied to an empty mark list returns an identical, empty mark list; it does not create some kind of 'anti-mark'.

Second, the question arises of whether faithfulness constraints require the current output to be faithful to the initial input (here /pəŋawasan/), or to the output of the previous step. I assume the latter, following previous work is derivational OT. This assumption is not necessary here, but it becomes crucial in the analysis of transparent segments (see section 4.4).

I have now demonstrated how the present analysis accounts for a specific case of spreading from a specific input. Extending the analysis to other instances of the process, such as the other examples in (1), is straightforward. Therefore, I conclude this subsection with a discussion of the role of the input in the analysis.

With the exception of nasal stops, all segments in Malay surface as [−nasal] unless they have undergone nasal harmony. The OT principle of richness of the base requires the grammar to account for such predictable features. The way to demonstrate that the grammar does so is to consider inputs containing configurations that are not legal on the surface, and show that these are mapped to legal surface forms. For example, recall that in the previous derivation spreading was blocked from applying to the [s] in [pəŋãw̃ãsan]. Would the output be different if the input were /pəŋãw̃ãs̃ãn/, in which the fricative and every other segment after [ŋ] is [+nasal]?

In fact, the grammar maps this input to the same output as before. To see why, consider that (after T:*NASOBSTRSTOP has applied vacuously) the generation function for T:*NASFRIC produces the candidate set {[pəŋãw̃ãs̃ãn], [pəŋãw̃ãsãn]}. The second candidate is optimal according to a calculation similar to the one in tableau (39). That is, the same rankings that prevent [+nasal] from spreading to a fricative also remove [+nasal] when it is present underlying. The derivation then continues down the hierarchy, with no further change in the output, until it reaches T:*NASVOWEL. The generation function for this constraint produces the candidate set {[pəŋãw̃ãsãn], [pəŋaw̃ãsãn], [pəŋãw̃asãn], [pəŋãw̃ãsan], [pəŋaw̃asãn], [pəŋaw̃ãsan], [pəŋãw̃asan], [pəŋaw̃asan]} (i.e., one candidate for every subset of the set of violation loci, which is the set containing the three instances of [ã] in the word). The winner of this competition is [pəŋãw̃ãsan], as indicated by the following pairwise comparison with [pəŋãw̃ãsãn]. (As noted above, when the candidate set contains more than two members it is necessary to use mark addition instead of subtraction to present the entire optimization in a single tableau.)

(42) Elimination of spurious nasality

[pəŋãw̃ãsãn]	T:SPREAD-R([+nasal])	T:*NASGLIDE	T:*NASVOWEL	IDENT([nasal])
[pəŋãw̃ãsãn]	*	*	* * *!	
☞ [pəŋãw̃ãsan]	*	*	*(*)	*

The same ranking that accounts for the absence of an oral/nasal vowel contrast in general (i.e., T:*NASVOWEL≫IDENT([nasal])) ensures that input [+nasal] specifications are removed from surface vowels that are not in the spreading context on the surface.

The derivation from /pəŋãw̃ãs̃ãn/ to [pəŋãw̃ãsan] does not *prove* that the input [nasal] specifications of segments other than nasal stops never have an effect on the output. But it does indicate that the form of the proof would be the same as in the original version of OT. More generally, the revised definition of candidate evaluation and the derivational nature of the grammar do not change the OT treatment of non-contrastive properties (see Kirchner 1997, McCarthy 2002a:71–76).

* * *

In this section, I have analyzed the interaction of targeted spreading constraints with feature co-occurrence constraints. Despite the difference in framework, the interaction is very similar to that in OT. Constraints ranked higher than the spreading constraints (such as T:*NASFRIC) account for blocking. Those same constraints also play a role in accounting for the surface inventory (and other surface properties) of a language, as do lower-ranked constraints (such as T:*NASVOWEL). Further examples of the interaction between spreading and feature co-occurrence constraints appear in sections 4.1 (tableau (61)) and 4.4 (derivation (76)); see also section 3.3.3 on the factorial typology.

3.3.2 Blocking by uniformity constraints

Cole & Trigo (1988) give the name *parasitic harmony* to spreading processes that apply only if the trigger and the undergoer already share a particular feature. Cole & Trigo discuss cases of parasitic harmony in Yowlumne Yokuts (Newman 1941), Menomini (Bloomfield 1962, 1975), and Maasai (Tucker & Mpaayei 1955). Other cases are found in Javanese (Benua 1998, Dudas 1976), Ngbaka (Churma 1984, Mester 1988), Shona (Beckman 1995, 1997, 1998 [1999]), Vata (Kiparsky 1985:108).

According to Cole & Trigo's (1988) proposal, parasitic harmony arises from a spreading rule that contains multiple linking as part of its structural description. For example, the rule they propose for Yowlumne [round] harmony—which applies only to vowels of the same height (ignoring the well-known opacity caused by lowering)—requires the trigger and the undergoer to be linked to the same [αhigh] autosegment.

(43) Parasitic harmony rule for Yowlumne (from Cole & Trigo 1988:23)

$$\begin{array}{l} [+\text{round}] \\ \;\; | \diagdown \\ \;\; x \ldots x \\ \;\;\; \diagdown \diagup \\ \;\; [\alpha\text{high}] \end{array}$$

This rule suffers from the same sort of formal arbitrariness that was pointed out in the discussion of blocking conditions (see section 2). Why does the rule require the trigger and undergoer to link to the same [αhigh] autosegment, instead of requiring that they link to *different* autosegments? Both requirements can be stated in the formal vocabulary of autosegmental phonology. But only the former corresponds to an attested spreading process: no known language exhibits an anti-parasitic harmony, in which triggers and undergoers must crucially disagree on some feature.

A more restrictive theory of parasitic harmony is proposed in Kaun's (1995, 1996) OT analysis of rounding harmony. Instead of building multiple-linking conditions into the constraints that drive spreading, Kaun derives parasitic harmony from independent constraints that require features to be implemented uniformly in all associated segments. In essence, the idea behind these constraints is that a single autosegment in the phonology should correspond to a single gesture (or 'posture', Kaun 1995) in the phonetics. The constraint responsible for the height agreement condition on Yowlumne rounding harmony is defined as follows:[23]

(44) UNI([+round]) (from Kaun 1995:87)
A [+round] autosegment must have 'a uniform execution mechanism throughout its span of association.'

As Kaun discusses, this constraint is violated when a single [+round] autosegment is associated to vowels of different heights, because high and non-high vowels have different rounding gestures (Linker 1982). Ranking UNI([+round]) above a general [round] spreading constraint (i.e., one that does not require the trigger and the target to be featurally similar) has the effect of preventing vowels of different heights from harmonizing (see Kaun 1995, 1996 for relevant tableaux).

In the rest of this subsection, I incorporate a slightly modified version of Kaun's uniformity constraints into the current proposal and briefly discuss the representational implications of this analysis of parasitic harmony. I then show that uniformity constraints play a role in accounting for dissimilation patterns such as the one in Ainu analyzed by Ito (1984) and Mester (1988). This application of the constraints was not explored in Kaun's work or subsequent literature, and provides another instance in which the constraints used to block spreading are independently motivated by other facts.

Up to this point in the paper, the analysis has not required any specific assumptions about the representation of spreading. I have remained neutral on the issue of whether spreading affects segment-internal feature matrices or adds associations to autosegments. Because Kaun's uniformity constraints refer explicitly to linked structures, incorporating them into the theory requires us to assume the latter, autosegmental representation. (See Hayes 1986a and others for arguments that support the autosegmental analysis of spreading, and Bakovic 2000 and others for opposing arguments.)

Mainly for reasons of precision, I propose a version of the uniformity constraints that is even more strongly autosegmental than (44). The key idea, which builds on Kaun's original insight, is that the span of one autosegment [αF] is required to be contained within the span of another autosegment [βG]. If all the segments associated to [αF] are also associated to [βG], then [αF] is guaranteed to be uniformly implemented throughout its span (as far as the effects of [G] are concerned). Under such circumstances, we can think of [αF] and [βG] as if they were fused together along the span of [αF], behaving as a single feature that corresponds to a synergistic set of phonetic gestures. In previous theories, such synergies have been encoded in rigid feature-geometric domination relations (see, for example, Mester 1988, Padgett 1991, 1994, 1995). Here they are more fluid, arising not from the representations but from constraints that fit the schema in (45).[24]

[23] I have changed some details of the formulation of the constraint without affecting its content.

[24] See Padgett (2003) for additional arguments that relations among features should be imposed by violable constraints rather than fixed geometries.

(45) T:UNI([F]$\subseteq$[G]). Let [αF] and [βG] be any two autosegments such that there is some segment associated to both [αF] and [βG].

- λ A segment s that is associated to [αF] but not to [βG].
- δ Delink [αF] from s.

For the purposes of the following discussion, only the locus of violation (λ) component of this constraint is necessary. I have specified a change (δ) as well, but must leave the task of justifying this component for future work. Notice also that (45) provides a formalism for uniformity constraints, but does not determine which instantiations of [αF] and [βG] correspond to actual constraints. This I take to be the role of substantive factors such as those identified by Kaun (1995, 1995) and work cited there.

The ranking T:UNI([rnd]$\subseteq$[hi])$\gg$T:SPREAD-R([+round],PrWd) accounts for rounding harmony processes, such as the one in Yowlumne, that are parasitic on height specifications. (This analysis is identical in important respects to the one given in Kaun (1995, 1996).) The autosegmental version of the targeted spreading constraint is given in (46). And two schematic tableaux are given in (47), where '$[\ldots]_{[\alpha F]}$' is used to indicate the span of an autosegment [αF]. (This notation is taken from Kaun 1995 and Smolensky 1995, who independently propose it as an alternative to autosegmental diagrams. I do not adopt the feature-domains theory of Cole & Kisseberth 1995, which uses a similar notation.)

(46) T:SPREAD-R([+round]) (autosegmental version)
Let s_i and s_j be any two adjacent segments such that s_i precedes s_j and s_i is associated to a [+round] autosegment r.

- λ Segment s_j if it is not associated to r.
- δ Add an association from s_j to r

(47) Rounding harmony parasitic on height

/$[[V]_{[+rd]}]_{[\alpha hi]}$ $[[V]_{[-rd]}]_{[\alpha hi]}$/	T:UNI([rnd]$\subseteq$[hi])	T:SPREAD-R([+round])	IDENT([round])
a. $[[V]_{[+rd]}$ $[V]_{[-rd]}]_{[\alpha hi]}$		*!	
b. ☞$[[V\ \ V]_{[+rd]}]_{[\alpha hi]}$		( )	*

/$[[V]_{[+rd]}]_{[\alpha hi]}$ $[[V]_{[-rd]}]_{[-\alpha hi]}$/	T:UNI([rnd]$\subseteq$[hi])	T:SPREAD-R([+round])	IDENT([round])
a. ☞$[[V]_{[+rd]}]_{[\alpha hi]}$ $[[V]_{[+rd]}]_{[-\alpha hi]}$		*	
b. $[[V]_{[\alpha hi]}$ $[V]_{[-\alpha hi]}]_{[+rd]}$	*!	( )	*

In the first tableau, [+round] is able to spread rightward without violating T:UNI([rnd]$\subseteq$[hi]) because the two vowels are linked to the same [αhigh] autosegment. A somewhat subtle aspect of the analysis is that adjacent instances of [αhigh] must be reduced to a single autosegment before rounding harmony applies. This, I assume, can be accomplished with a *STRUC constraint (Prince & Smolensky 1993) against [αhigh] features (see also the discussion of Beckman 1997 in section 5.2), or with a fusional OCP (Obligatory Contour Principle) constraint. Note that this constraint need not outrank IDENT([high]) in order to replace a sequence [αhigh] [αhigh] with a single [αhigh]. In other words, it is not predicted that the height specifications of any vowels are changed, only that the number of [high] autosegments and the pattern of associations can be changed by the input/output mapping.

The second tableau illustrates how the uniformity constraint blocks spreading between vowels that disagree in height. By hypothesis, there is no spreading process that changes the [$-\alpha$high] vowel to [αhigh]. Therefore, linking the [+round] autosegment to both vowels violates T:UNI([rnd]$\subseteq$[hi]). (There are technically two violations of the constraint in the last candidate, one for each [high] autosegment.)

The type of analysis in (47) extends straightforwardly to other cases of parasitic harmony. Importantly, no ranking of these constraints gives rise to an anti-parasitic process in which spreading applies only to segments that disagree on a particular feature. The present theory, like Kaun's, is therefore more restrictive than the one based on rules such as the one in (43).

As I now show, uniformity constraints have another use as well. Because these constraints are violated by certain patterns of multiple linking, they can have the effect of forcing dissimilation in addition to blocking assimilation. The relevant dissimilation patterns are those in which two segments that disagree on one feature [G] must also disagree on another feature [F]; segments that agree on [G] are not subject to dissimilation. Patterns of this type are found in Ainu (Chiri 1952; Archangeli & Pulleyblank 1994:98–101, Ito 1984, Mester 1988), Tzeltal (Slocum 1948; Ito 1984:511), and Yucatec Maya (Krämer 2000). For purposes of illustration, I analyze the Ainu pattern, drawing heavily on the original contributions of Ito (1984) and Mester (1988).

The Ainu pattern has been discussed many times in the literature, so I simply summarize the facts (based on Ito 1984:505–506). The transitivizing verbal suffix, like the possessive suffix, has two surface realizations. When attached to certain roots, the suffix is identical to the preceding vowel, as in [pis-i] 'to ask', [ker-e] 'to touch', [tus-u] 'to shake', [pop-o] 'to boil', and [tas-a] 'to cross'. For other roots, the suffix is a high vowel that disagrees in backness with preceding non-low vowels, as in [pir-u] 'to wipe', [ket-u] 'to rub', [mus-i] 'to choke', and [hop-i] 'to leave behind', and that is either front or back after low vowels, as in [kar-i] 'to rotate' and [rap-u] 'to flutter'. It is apparently not possible to predict which realization of the suffix is used for a given root; the backness of a high suffix vowel that is attached to a low-vowel root also appears to be unpredictable.

Ito (1984) proposes that the suffix is underlyingly just V (a [+syllabic] segment with no place features) and that the realization of the suffix is determined by the root melody. The suffix is realized as a high vowel and dissimilates in backness when it attaches to roots that end in a floating [+high] feature; it is realized as a copy vowel after other roots. I propose instead that the suffix itself has two allomorphs: V (as in Ito's analysis) and $V_{[+high]}$ (a [+syllabic, +high] segment unspecified for place features). Each allomorph selects an arbitrary class of roots.[25]

The main idea of the analysis is that the [back] feature of the root can associate to the bare V allomorph, but not the $V_{[+high]}$ allomorph, because only the former is subject to a process of [high]

[25]It is possible to modify the analysis presented here to conform to Ito's assumptions about underlying representations, but allowing floating features in roots raises richness of the base issues that I am not prepared to address here. Instead of restricting the floating melodic units to [+high], as Ito (1984) does, we would have to consider the full range of possible floating features, including floating class nodes and floating sequences. (Similar issues arise for Zoll's (1996, 1997) approach to ghost segments, where the possibility of sequences of floating features is not addressed.) Ito (19884) does not provide any independent evidence for the floating [+high] features, therefore the two analyses are empirically indistinguishable as far as I can tell.

spreading that applies before [back] spreading. Dissimilation of the $V_{[+high]}$ allomorph is therefore forced by an OCP constraint that applies to the [back] tier. The crucial rankings are given below.

(48) Rankings for Ainu dissimilation

a. [high] spreading respects underlying specifications, and applies before [back] spreading
   IDENT([high])$\gg$T:SPREAD-R([αhigh])$\gg$T:SPREAD-R([αback])
b. [back] spreading is parasitic on [high] spreading
   T:UNI([back]$\subseteq$[high])$\gg$T:SPREAD-R([αback])
c. [back] dissimilates by the OCP
   T:OCP([αback])$\gg$T:V[–back]$\gg$T:V[+back]

I define the new constraints (T:OCP([αback]), T:V[–back], T:V[+back]) and motivate the rankings as the analysis progresses. Cases involving the less-specified allomorph V require essentially just the ranking T:SPREAD-R([high])$\gg$T:SPREAD-R([back]), as illustrated in the following derivation. Height spreads first, establishing the multiple linking that is necessary to spread backness without violating the uniformity constraint.

(49) Spreading of [high] and [back] to the V allomorph

Step	Input	Candidate set	Output
0	/p o p + V/ [ ]$_{-hi}$ [ ]$_{+bk}$		[p o p - V] [ ]$_{-hi}$ [ ]$_{+bk}$
1	[p o p - V] [ ]$_{-hi}$ [ ]$_{+bk}$	GEN$_{\text{T:SPREAD-R}([\alpha\text{high}])}(\cdot)$ = {[p o p - V], [p o p - V]} [ ]$_{-hi}$ [ ]$_{-hi}$ [ ]$_{+bk}$ [ ]$_{+bk}$	[p o p - V] [ ]$_{-hi}$ [ ]$_{+bk}$
2	[p o p - V] [ ]$_{-hi}$ [ ]$_{+bk}$	GEN$_{\text{T:UNI}([\text{back}]\subseteq[\text{high}])}(\cdot)$ (applies vacuously)	[p o p - V] [ ]$_{-hi}$ [ ]$_{+bk}$
3	[p o p - V] [ ]$_{-hi}$ [ ]$_{+bk}$	GEN$_{\text{T:SPREAD-R}([\alpha\text{back}])}(\cdot)$ = {[p o p - V], [p o p - V]} [ ]$_{-hi}$ [ ]$_{-hi}$ [ ]$_{+bk}$ [ ]$_{+bk}$	[p o p - V] [ ]$_{-hi}$ [ ]$_{+bk}$

The key step in this derivation is shown in tableau (50). T:SPREAD-R([back]) generates a candidate in which [back] has spread from the root vowel to the suffix vowel. This candidate does not violate T:UNI([back]$\subseteq$[high]), given the linking established in the previous step, and is therefore optimal.

(50) Spreading of [back] licensed by multiple linking of [high]

	T:UNI([back]⊆[high])	T:SPREAD-R([αback])
a. [p o p - V] [ ]$_{-hi}$ [ ]$_{+bk}$		*!
b. ☞ [p o p - V] [ ]$_{-hi}$ [ ]$_{+bk}$		( )

A few more remarks on (49) before we turn to the other suffix allomorph. First, I assume that IDENT([F]) constraints are not violated when a segment that is underlyingly unspecified for [F] corresponds to a surface segment that is specified for that feature. Thus [–high] is allowed to spread to the V allomorph, even though IDENT([high]) dominates T:SPREAD-R([high]). Second, the derivation does not end with the application of $\text{GEN}_{\text{T:SPREAD-R([}\alpha\text{back])}}$, of course, but all of the other generation/evaluation steps are vacuous. The OCP constraints (formalized below) are not violated by the output of (50). And constraints that enforce default specifications for [back] and [high] are prevented from changing the output by the higher-ranked spreading and faithfulness constraints. Finally, I assume that the other features of the root vowel (such as [round]) are spread to the suffix, or filled in according to the inventory of Ainu, by constraints not shown here.

Now consider a case, minimally different from the previous one, in which the $V_{[+high]}$ allomorph attaches to a mid-vowel root, as in [ket-u] 'to rub' and [hop-i] 'to leave behind'. Spreading of [high] is prevented from applying to $V_{[+high]}$ by dominant IDENT([high]). This in turn prevents spreading of [back], because T:UNI([back]⊆[high]) blocks [back] autosegments from associating to vowels that are linked to different [high] features. The [back] specification of the vowel is therefore determined by the interaction of the OCP([αback]) constraint in (51) with the two default-specification constraints in (52) and (53). (For concreteness, I have assumed that T:V[–back] dominates T:V[+back], but the opposite ranking would produce the same results in this analysis.)

(51) T:OCP([αback])

λ An [αback] autosegment that is adjacent to another [αback] autosegment.

δ [αback]→∅

(52) T:V[–back]

λ A [+syllabic] segment that is not specified [–back].

δ [0back]/[+back]→[–back]

(53) T:V[+back]

λ A [+syllabic] segment that is not specified [+back].

δ [0back]/[–back]→[+back]

The notion of adjacency referred to in the OCP constraint is a strict one: two autosegments are adjacent iff they are linked to adjacent segments. I assume that the preferred repair is deletion of one of two adjacent, identical autosegments.[26]

[26] This assumption is not obviously compatible with the minimal change principle discussed in 3.1.1. Why isn't fusion of two adjacent, identical obstruents always selected as the repair (see also the next footnote)? I leave this problem open here, noting that previous theories have likewise simply assumed that the OCP can cause deletion (see Odden 1987, Yip 1988).

The constraints in (52) and (53) belong to the same family as the constraints in the nasal subhierarchy (see (21) in section 2). I have represented their preferred repairs somewhat loosely in the δ specifications above. Consider, for example, a vowel that violates T:V[–back] because it is unspecified ([0back]). From the perspective of the minimal change principle, there are two equivalently minimal ways of repairing this violation: either a new [–back] autosegment is inserted and linked to the vowel, or a [–back] autosegment is spread from an adjacent segment. Similar options exist for a vowel that is specified [+back]: the [+back] autosegment delinks from the vowel—and presumably deletes if it is not associated to any other segment—and either a new [–back] autosegment or one that is associated to an adjacent segment fills in the gap. These changes are equally minimal, in the relevant sense, under the assumption that there is a negligible perceptual difference (if any) between a [–back][–back] sequence and a single multiply-linked instance of [–back]. More generally, the assumption is that, on all tiers, linked structures and sequences of identical elements are perceptually non-distinct.

The derivation for [ket-u] 'to rub' exhibits all of the relevant interactions, including the conflict between T:OCP([αback]) and T:V[–back].

(54) Backness dissimilation of the $V_{[+high]}$ allomorph

Step	Input	Candidate set	Output
0	/k e t + V/ $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}$		[k e t - V] $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}$
1	[k e t - V] $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}$	$\text{GEN}_{\text{T:SPREAD-R}([\alpha\text{high}])}(\cdot) =$ {[k e t - V], [k e t - V]} $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\qquad]_{-hi}$ $[\ ]_{-bk}$ $[\ ]_{-bk}$	[k e t - V] $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}$
2	[k e t - V] $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}$	$\text{GEN}_{\text{T:UNI}([\text{back}]\subseteq[\text{high}])}(\cdot)$ (applies vacuously)	[k e t - V] $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}$
3	[k e t + V] $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}$	$\text{GEN}_{\text{T:SPREAD-R}([\alpha\text{back}])}(\cdot) =$ {[k e t - V], [k e t - V]} $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}$ $[\qquad]_{-bk}$	[k e t - V] $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}$
4	[k e t - V] $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}$	$\text{GEN}_{\text{T:OCP}([\alpha\text{back}])}(\cdot)$ (applies vacuously)	[k e t - V] $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}$
5	[k e t - V] $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}$	$\text{GEN}_{\text{T:V}[-\text{back}]}(\cdot) =$ {[k e t - V], [k e t - V], [k e t - V]} $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}$ $[\qquad]_{-bk}$ $[\ ]_{-bk}\ [\ ]_{-bk}$	[k e t - V] $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}$
6	[k e t - V] $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}$	$\text{GEN}_{\text{T:V}[+\text{back}]}(\cdot) =$ {[k e t - V], [k e t - V]} $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}$ $[\ ]_{-bk}\ [\ ]_{+bk}$	[k e t - V] $[\ ]_{-hi}\ [\ ]_{+hi}$ $[\ ]_{-bk}\ [\ ]_{+bk}$

The critical point in this derivation comes when T:V[–back] attempts to specify the suffix vowel as [–back]. As shown in tableau (55), this is prevented by dominant T:UNI([back]⊆[high]), which blocks multiple linking, and T:OCP([back]), which blocks insertion of a new [–back] autosegment. Consequently, the lowest-ranked constraint is able to force the suffix vowel to surface as [+back].[27]

[27]Note that T:V[–back] is violated equally by [0back] and [+back] vowels, therefore it does not over-ride T:V[+back] in this case. This is fully consistent with the principles of mark removal that were introduced earlier in the paper.

(55) Blocking of default [–back] by uniformity and the OCP

	T:UNI([back]⊆[high])	T:OCP([αback])	T:V[–back]
a. ☞ [k e t - V] [ ]$_{-hi}$ [ ]$_{+hi}$ [ ]$_{-bk}$			*
b. [k e t - V] [ ]$_{-hi}$ [ ]$_{+hi}$ [ ]$_{-bk}$	*!		( )
c. [k e t - V] [ ]$_{-hi}$ [ ]$_{+hi}$ [ ]$_{-bk}$ [ ]$_{-bk}$		*!	( )

A similar derivation accounts for forms such as [hop-i] 'to leave behind', except that the backness of the suffix vowel is determined by T:V[–back].

The derivations for forms with high-vowel roots such as [pir-u] 'to wipe', [ket-u] 'to rub' are also similar, with one subtlety. According to the formal definition in (35), a targeted spreading constraint is violated only by adjacent segments that *disagree* with respect to the spreading feature. Adjacent segments that have the same specification do not fall under the purview of the constraint, and so it proposes no repair for them. Therefore, when the [+high] allomorph of the suffix is added to a vowel with a [+high] root, SPREAD-R([αhigh]) applies vacuously. It follows that, just as in the preceding derivation, the parasitic condition on [back] spreading is not met; the end result is dissimilation. Somewhat less formally, the idea is that [back] spreads only when a bond between the root and suffix vowel has already been established by [high] spreading. Simple height agreement is not sufficient to form that bond.[28]

I leave open the problem of accounting for the behavior of $V_{[+high]}$ after low-vowel roots. Following a suggestion of Ito (1984:509), Archangeli & Pulleyblank (1994:99–101) propose that there are in fact two low vowels in the underlying inventory, only one of which is [+back]. This approach is available in principle to any theory that adopts richness of the base, but I do not pursue it here.

To conclude the presentation of the analysis, I would like to emphasize the role of the constraint T:UNI([back]⊆[high]) in the analysis, and remark on the relationship to previous work. The importance of the uniformity constraint is most apparent for forms in which $V_{[+high]}$ attaches to mid-vowel roots, such as [ket-u] 'to rub' and [hop-i] 'to leave behind'. Forms containing the other allomorph, such as [ker-e] 'to touch' and [pop-o] 'to boil', show that a single set of features can be associated to more than one vowel. The question is then why [back] should be unable to spread just when the suffix has an independent [high] feature. Uniformity provides the answer. (Forms in

[28]Another detail of the analysis turns on T:V[–back]. The question is why this constraint cannot have the effect of spreading *both* the [high] and the [back] feature of a [+high,–back] root vowel to the $V_{[+high]}$ allomorph, a move that would prevent dissimilation. A number of answers are possible, but I have not been able to decide among them. It could be that the theory of targeted constraints imposes a formal condition on such constraints, preventing them from affecting features that are really not in their purview. Alternatively, some constraint could prevent the independent [+high] feature of the suffix from being lost, or prevent the [+high] feature of the root vowel from associating to a different morpheme (a type of morphological uniformity effect). Notice that a constraint against spreading would have to be dominated by T:SPREAD([αhigh]) but ranked above T:V[–back].

which $V_{[+high]}$ attaches to high-vowel roots make the same point, albeit in a way that depends more on fine details of the constraints and representations.) Note further that T:UNI([back]⊆[high]) dominates and blocks *two* lower-ranked constraints in (T:SPREAD-R([αhigh]) and T:V[–back]), a situation that is fully expected within OT.

Turning now to previous analyses, several earlier proposals have been incorporated, in generalized and simplified forms, into the current analysis. Perhaps the most important connection is to the work of Mester (1988), who was the first to see that parasitic harmony and dissimilation of the type found in Ainu are fundamentally related. Two of Mester's main ideas are incorporated here. The first is that dissimilation can be reduced to an effect of the OCP on the [back] tier. The second is that the reduction is possible only once a dependency between [high] and [back] has been established. For Mester, the relationship is one of language-particular tier ordering: [high] depends on [back]. In this analysis, the relationship is reversed and enforced by constraint: [back] linking depends on [high] linking. This dependency exists in all languages (i.e., the uniformity constraint is universal). Its effects in Ainu are due to language-particular ranking, the sole source of cross-linguistic variation in OT. It should also be noted that Mester's (1988) analysis accounts for the inventory of possible surface forms, but not for particular input/output mappings. The present analysis derives the inventory from the mappings.

In the original generative treatment of Ainu, Ito (1984) discusses the importance of these facts for autosegmental phonology, for the formulation of rules (as feature filling or feature changing), and for typology. Ito's central idea—that multiple linking can exempt structures from otherwise applicable rule and constraints—is also explored by Prince (1984) and is formalized in the Linking Condition of Hayes 1986 (see also Schein & Steriade 1986). It is adopted here in the form of autosegmental representations and the OCP constraint, which is not violated by multiple linking. The distinction between feature-filling and feature-changing application (see Kiparsky 1985:98) is derived from the interaction of faithfulness and spreading constraints: only unspecified vowels are eligible for spreading when faithfulness is dominant, as was seen in the comparison between (49) and (54). With respect to typology, Ito suggests that all languages with vowel dissimilation also allow sequences of identical vowels (represented as linked structures). This generalization seems to be predicted by any theory, including the present one, that adopts richness of the base and derives dissimilation from the OCP. Linked structures that are present in the input surface unaltered. New linked structures are created when universal spreading constraints apply to unspecified vowels (and to specified vowels as well, if faithfulness is lower-ranked).

Finally, the default-specification constraints introduced above can be viewed as simplified versions of the Ainu Melodic Dissimilation rule of Archangeli & Pulleyblank (1994:99). This rule, which applies to the transitivizing suffix only, inserts [+back] except when doing so would create a violation of the OCP. It is replaced here by phonological constraints, T:V[–back] and T:V[+back]. The fact that these constraints do not affect all morphemes follows from the assumptions about underlying representations and the interaction with three higher-ranked constraints (T:UNI([back]⊆[high]), T:OCP([back]), and IDENT([back])).

* * *

I have argued that the uniformity constraints of Kaun (1995, 1996), in slightly modified form, are crucial for the analysis of both parasitic harmony and dissimilation. This contributes to two main projects of the paper. First, it extends the argument, central to all OT analyses, that conditions on spreading are most insightfully analyzed with constraint interaction rather than rule-internal specifications. Second, the analysis of Ainu demonstrates that the derivational TCOT framework can account for intricate patterns of constraint interaction—patterns that are often assumed to lie within the reach of non-derivational theories only.

3.3.3 Factorial typology

In this subsection, I briefly consider the factorial typology that emerges from rereankings of targeted spreading, feature co-occurrence, and uniformity constraints. To focus the discussion, I use the parametric theory of rules proposed in Archangeli & Pulleyblank (1994:chs.4 and 5) as a guide to the main dimensions along which spreading processes differ. The relevant parameters are listed below in the order that they will be discussed.[29]

(56) Parameters of rule application (from Archangeli & Pulleyblank 1994)

a. Undergoer conditions
b. Trigger conditions

Subsections 3.3.1 and 3.3.2 presented the analyses of what are, in Archangeli & Pulleyblank's terms, two types of conditions on undergoers. Feature co-occurrence constraints block spreading from creating marked segments, under rankings that can be schematized by **M≫S**. Uniformity constraints block spreading from applying to segments that do not share certain features with the trigger; the schema for this interaction is **U≫S**. Obviously, the opposite rankings (S≫M and S≫U) give rise to spreading patterns that are free of these conditions. A more interesting pattern arises when **S** is subordinated to both **M** and **U**. This corresponds to the fourth cell of the factorial typology in (57).

(57) Factorial typology (**S, M, U**)

	Undergoers			
Ranking	unmarked	marked	similar	dissimilar
S≫M; S≫U	Y	Y	Y	Y
M≫S; S≫U	Y	N	Y	Y
S≫M; U≫S	Y	Y	Y	N
M≫S; U≫S	Y	N	Y	N

In this table, 'unmarked' and 'marked' refer to the status of the outcome of spreading, with respect to **M**, and 'similar' and 'dissimilar' refer to the linking condition imposed by **U**. The ranking schema **M,U≫S** predicts spreading processes that apply iff the outcome is unmarked *and* the undergoer is similar to the trigger. This prediction is borne out by the [round] harmony process of Hixkaryana, Kachin, and Tsou, all discussed by Kaun (1995, 1996; see references cited there for the original sources).

Many other logically-possible patterns cannot be derived from any ranking of the constraints. It is predicted that no process applies iff the outcome is marked (regardless of trigger-undergoer

[29]For obvious reasons, I have used the term 'undergoer' rather than 'target' throughout the paper, and therefore make the corresponding change in parameter (56a). See section 4 for additional parameters from Archangeli & Pulleyblank (1994).

similarity). It is also predicted that no process applies iff the undergoer is dissimilar from the trigger (independently of markedness). These and other predictions are borne out by the empirical typology as well, as work by Bakovic (2000), Kaun (1995, 1996) and others has shown (see section 2).

The factorial typology in (57) does not account for all attested spreading patterns, however, primarily because it makes no provision for independent conditions on triggers.[30] Unlike conditions on undergoers, trigger conditions are not straightforwardly derivable from independent markedness constraints. Some spreading processes apply only from *unmarked* triggers. For example, one regressive [+ATR] harmony process in Lango (Archangeli & Pulleyblank 1994, Smolensky 1995) applies only when the trigger is [+high]: that is, only when the trigger satisfies *[+ATR,–high] (see Archangeli & Pulleyblank 1994 on the grounding of this constraint). Other spreading processes are limited to *marked* triggers. Kaun (1995, 1996) identifies a number of such cases, grouping them under the heading "bad vowels spread."

For the first type of trigger condition, Smolensky (1995) proposes a local-conjunction analysis that is conceptually similar to the grounding analysis of Archangeli & Pulleyblank (1994). For the second type, Kaun (1995, 1996) proposes an account that involves essentially specifying certain features of the trigger within the spreading constraint itself. Clearly, Kaun's proposal could be mechanically extended to account for unmarked trigger conditions. I have not found a way of generalizing Smolensky's proposal to marked triggers. In what follows, I tentatively propose a new analysis that draws upon the same insights (originally due to Kaun) that were used to motivate the uniformity constraints.

The basic idea is that what is traditionally considered to be a single feature value, such as [+ATR], should instead be understood as a *family* of values. Members of the same family have different phonetic realizations because of their synergistic and antagonistic relations with other features associated to the same segment. The realization of [+ATR] together with [+high] is different from its realization together with [–high], just as the realization of [+round] depends on the specifications for [high] and [back] (Kaun 1995), and the realization of consonant place features depends on the specification for [continuant] (Kaun 1995, Padgett 1991, 1994, 1995). Phonological spreading constraints can refer either to entire families, as has been done so far, or to specific members. For example, using the ad-hoc notation $[+\text{ATR}]_{[+\text{high}]}$ and $[+\text{ATR}]_{[-\text{high}]}$ to stand for the versions of [+ATR] in [+high] and [–high] segments, respectively, T:SPREAD-{L,R}($[+\text{ATR}]_{[+\text{high}]}$) and T:SPREAD-{L,R}($[+\text{ATR}]_{[-\text{high}]}$) are distinct constraints. The former accounts for spreading from unmarked triggers, the latter for spreading from marked ones.[31]

This proposal is more restrictive than one that allows spreading constraints to arbitrarily specify features of the trigger, because only certain other specifications have a significant effect on the realization of any given feature. For example, although [high] has clear articulatory and acoustic effects on [ATR], [nasal] presumably does not. Therefore, a process that spreads [ATR] from [+nasal] segments only would not be possible in this system (because, e.g., $[+\text{ATR}]_{[+\text{nasal}]}$ is not

[30] 'Independent' because the ranking M,U≫S has the effect of limiting *both* undergoers and triggers to segments that are unmarked with respect to M.

[31] Note that these constraints refer to the [high] specification of the trigger only. The specifications of the undergoers are governed by independent feature co-occurrence and uniformity constraints, as already discussed.

distinct from simply [+ATR]). More generally, the proposal draws upon and extends a large body of previous work on featural enhancement and antagonism (see, for example, Archangeli & Pulleyblank 1994, Padgett 1993). The proposal also has the prospect of explaining why trigger conditions exist: a given phonological entity such as [+ATR] has many phonetic implementations; individual languages can select one of these as the argument of a spreading process.

3.4 Summary

In this section, I have developed the targeted analysis of unbounded spreading that was outlined in section 1.2. Two central themes have run throughout the discussion. The first is that of targeted constraints as evaluators and generators. All of the other theoretical innovations of the paper, including the notion of mark removal and the derivational TCOT formalism, rely upon and support the core property of targeted constraints: namely, that they specify particular resolutions to the 'pressures' of marked structures. The second theme is the role of constraint interaction in explaining attested restrictions on spreading. This does not highlight a new aspect of the theory, but rather shows that original results obtained within OT are preserved in TCOT, even though the two frameworks differ on many fundamental points.

3.5 Notes on computation

The computational properties of OT are analyzed extensively in Albro (1997, xxxx), Eisner (1997, 2000, 2003), Ellison (1994), Frank & Satta (xxxx), Gerdemann & van Noord (2000), Hammond (1997), Heiberg (1999), Karttunen (1998), Riggle (xxxx), Tesar (xxxx), and others. One point of emerging consensus is that, with the notable exception of reduplication, many necessary phonological constraints can be formalized as finite-state machines and that optimization can therefore be performed by a modified version of Dijkstra's (xxxx) best-paths algorithm (see especially Albro 1997 and Eisner 1997; for general introductions to finite-state automata and transducers, see Perrin 1990 and Roche & Schabes 2001).

TCOT seems to be fully compatible with this view. However, the formulations of candidate generation and optimization originally developed for OT need to be modified somewhat in the new framework. I give two short notes on these modifications here, focusing first on generation and then on optimization.

A targeted constraint is obviously more complex than an ordinary OT constraint, because it contains both a locus of violation and a designated change. However, targeted constraints can be formalized with a slight extension of the definition of a finite-state machine. The idea is to distinguish between two sets of transitions: those that specify the *environment* (including the locus), and those that specify the *repair*. For example, the targeted constraint for rightward spreading of [+nasal] would have the environment transitions $\langle 0 \rightarrow 1$, [+nasal], $0\rangle$ and $\langle 1 \rightarrow 2$, [–nasal], $1\rangle$. The repair transition would be $\langle 1 \rightarrow 2$, [+nasal]$\rangle$, meaning that any sequence that matches the environment should be transformed by changing the second segment to [+nasal]. (The numbers at the beginning and end of each transition are states of the machine; the numbers at the end of the environment transitions indicate weights: '1' here has the same meaning as '$*$' in the rest of the paper.)

Given a candidate also represented as a FSM, such as $\langle 0 \rightarrow 1$, n$\rangle$, $\langle 1 \rightarrow 2$, a$\rangle$, the instances of the structural description of the constraint in the candidate can be identified by a type of FSM-intersection (thanks to Jason Riggle for originally suggesting this to me). The repair can then be performed with an operation that is similar (if not identical) to those in the *graph grammar* formalism (Nagl 1979). For example, intersecting the targeted constraint for nasal spreading and the candidate just described essentially aligns the transitions in the environment of the constraint with those in the candidate (i.e., ⟨0→1, [+nasal], 0⟩ is aligned with ⟨0→1, n⟩, and ⟨1→2, [–nasal], 1⟩ with ⟨1→2, a⟩). The repair transition then ⟨1→2, [+nasal]⟩ 'applies' to the transition in the candidate that is aligned with the second environment transition, changing the [nasal] feature of the label on that transition and leaving everything else constant. The result is a new candidate, ⟨0→1, n⟩ ⟨1→2, ã⟩, that competes with the first one.

Many candidates can be, as it were, superimposed in the same FSM, thereby allowing computation of the optimal candidate to proceed more efficiently. However, the superposition obviously cannot obscure the structural distinctions that are needed for constraint evaluation. Eisner (1997) has worked out this part of the theory in detail for a restricted class of constraints. This class seems to be too restrictive, and the precise set of distinctions that must be preserved is a matter of current work in computational phonology, just as it always has been in theoretical phonology.

Turning now to optimization, I do not currently have a fully formalized finite-state proposal. However, there is a version of the mark assignment and mark removal principles that is easy to work with formally, and that allows multiple candidates to be compared simultaneously. The idea here is to keep the marks of the original candidate—the input to the current step of the derivation—constant, and adjust the marks of all the other candidates that are generated from it. This implies that mark addition rather than mark removal is used to implement part (24b′) of the definition of TCOT constraint evaluation; this change of perspective does not affect the outcome of any of the optimizations in the paper.

I give one example here, which is based on Step 6 of the derivation in (37) (section 3.3.1). Tableau (58) shows how the candidates fare with respect to one another when marks are assigned as in the original formulation of OT. The candidate that is identical to the input of this step of the derivation is marked with (i). This is the desired winner. But the actual winner, candidate (a), is one in which nasal harmony has been undone in order to eliminate a violation of T:*NASV.

(58) Candidate comparison before mark adjustments

	[pəŋãw̃ãsan]	T:SPREAD-R([+nasal],PrWd)	T:*NASV	IDENT([nasal])
i.	[pəŋãw̃ãsan]	*	**!	
a. ☞	[pəŋãw̃asan]	*	*	*
b.	[pəŋaw̃ãsan]	**!	*	*
c.	[pəŋawasan]	**!		**

These marks are adjusted by the new definition of candidate evaluation as shown in tableau (59). As just mentioned, the marks of candidate (i) are held constant. Therefore, in order to record the fact that the change from [pəŋãw̃ãsan] to [pəŋãw̃asan] is not the one preferred by T:SPREAD-R([+nasal],PrWd), a mark is *added* to [pəŋãw̃asan] (rather than being removed from [pəŋãw̃ãsan]). I use the ad-hoc notation '⊛' to indicate the added mark. (Note that ⊛ and * are equivalent as far as the computation of relative harmony is concerned.)

(59) Candidate comparison after mark adjustments

[pəŋãw̃ãsan]		T:SPREAD-R([+nasal],PrWd)	T:*NASV	IDENT([nasal])
i. ☞	[pəŋãw̃ãsan]	*	**	
a.	[pəŋãw̃asan]	*⊛!	(*)	*
b.	[pəŋaw̃ãsan]	**!	(*)	*
c.	[pəŋawasan]	**!⊛	()()	**

Adding one T:SPREAD-R([+nasal],PrWd) to candidate (a) is sufficient to ensure that candidate (i) is optimal, as desired. The other mark adjustments in (59) are included for completeness: candidate (c) incurs an additional violation of T:SPREAD-R([+nasal],PrWd) because the change from [pəŋãw̃ãsan] to [pəŋawasan] is not the one preferred by the targeted constraint; and mark removal applies to (a)–(c) with respect to T:*NASV, which prefers denasalization of nasal vowels.

In principle, any number of candidates can be compared by first assigning marks as in (58) and then adjusting the marks of the unfaithful candidates as in (59). Comparisons involving more than two candidates therefore do not pose a formal problem for the theory, although integrating the procedure of mark adjustment into the finite-state setting must, as noted, be left for future work.

4 Further applications

The grammatical formalism developed in this paper has a number of applications in addition to those developed in previous sections. In this section, I discuss several applications that are closely related to the analysis of unbounded spreading, sketching how the framework accounts for mypoia, other directional processes (such as dissimilation), non-iterative spreading, transparent segments, and a problematic post-lexical tone pattern identified by Hyman (1993). Some of the analyses follow from the framework as it stands; others motivate a new parameterization of constraints that, together with the derivational order of candidate generation, yields a general targeted-constraint approach to counterfeeding opacity. (The general targeted-constraint approach to opacity, including application to cases of opacity that do not involve spreading and analysis of counterbleeding, is developed more fully in Wilson (in prep.).)

To set the stage for the analyses, it is useful to recall once more Archangeli & Pulleyblank's (1994) parametric theory of rules.

(60) Parameters of rule application (from Archangeli & Pulleyblank 1994)
   a. Undergoer conditions
   b. Trigger conditions
   c. Direction (left-to-right vs. right-to-left)
   d. Iteration (iterative vs. noniterative)

I have already discussed how the present theory accounts for conditions on undergoers (60a) and triggers (60b). Myopic spreading and other directional processes are accounted for with constraint-internal specifications of direction, just as in (60c). The analysis of non-iterative spreading requires another constraint-internal parameter that, essentially like (60d), prevents a constraint from feeding itself (for the purposes of candidate generation). Another parameter, not present in Archangeli & Pulleyblank's system but related to proposals by Chafe (1968), Myers (1991), is needed to account for transparent segments and other opacity effects.

4.1 Myopia

Anderson (1980) was the first to point out the problem that the configuration in (61) poses for analyses that do not explicitly specify the direction of spreading. Segments s_1 and s_3 have different specifications for the spreading feature [F]. By hypothesis, neither s_1 nor s_3 can change to agree with the other, but s_2 could in principle agree with either (as I have indicated by not assigning it a value for [F]).

(61) Medial segment problem

$$\begin{array}{ccc} s_1 & s_2 & s_3 \\ | & & | \\ [\alpha F] & & [-\alpha F] \end{array}$$

Which specification should the medial segment take on? A non-directional account of spreading predicts that the outcome is either indeterminate (either specification for s_2 is possible) or determined by other aspects of the system (such as default rules or feature co-occurrence constraints). However, in the instances of (61) identified by Anderson (1980) and others, the outcome is in fact determined by spreading.

Within OT, Bakovic (2000:87–89; 92ff., 2002) discusses the medial segment problem in detail, showing conclusively that it supports a cyclic analysis of vowel harmony over an analysis based only on positional faithfulness to roots (see also Kirchner 1993). In this subsection, I analyze an example of the problem that cannot be straightforwardly handled with cyclicity. I then discuss the relationship between the cyclic theory and the directional theory; I argue that the two are compatible, and that each is necessary to account for different aspects of unbounded spreading.[32]

As Bakovic (2000, 2002) shows, cyclic application of spreading solves the medial segment problem when the structure of the form is $[[[s_1]s_2]s_3]$, where brackets indicate cyclic domains. The specification of s_2 is determined on the second cycle (second bracketed domain); s_2 agrees with s_1. That specification is then transferred to the entire form (containing disharmonic s_3). In Bakovic's analysis, the transfer is performed by a family of Stem-Affixed Form (SA) faithfulness constraints that require segments in the affixed form $[[[s_1]s_2]s_3]$ to be identical to their correspondents in $[[s_1]s_2]$.[33]

Cyclic application is not sufficient, as Bakovic (2000) also notes, when s_2 and s_3 are in the same cycle: $[[s_1]s_2\ s_3]$. Given this structure, the specification of s_2 must be determined by a single optimization in which both s_1 and s_3 are present.

The particular example discussed by Bakovic (2000) is the Turkish progressive suffix, which surface as [Ijor] after consonant-final stems (Underhill 1976). The first vowel ([I]) harmonizes in [back] and [round] with the preceding vowel, as shown in the examples in (62). The second vowel

[32]Thanks to Eric Bakovic for pointing out that the medial segment problem could be solved in the present framework, and for discussion of the material in this subsection.

[33]SA-faithfulness constraints are similar to output-to-output (OO) faithfulness constraints (Benua 1998, Burzio 1994a, 1996, Kenstowicz 1996, 1997, and others). SA- and OO- faithfulness differ with respect to whether the 'base' of an affixed form needs to be an independent word; see Bakovic (2000:ch.2) and discussion at the end of this subsection.

of the suffix ([o]) is invariant, as non-high back vowels generally are in Turkish (see Underhill 1976, among others). These two vowels are clearly introduced in the same cycle. Therefore, cyclic application—as enforced by SA-Faithfulness or any other mechanism—cannot explain why [I] harmonizes with the stem vowel rather than with the following [o].

(62) Medial segment problem in the Turkish progressive suffix (examples from Bakovic 2000:87)

gel–ijor	'come (neg.-prog.-1sg.)'	(*gel–ujor)
dur–ujor	'stand (neg.-prog.-1sg.)'	
gyl–yjor	'laugh (neg.-prog.-1sg.)'	(*gyl–ujor)
atʃ–ɯjor	'open (neg.-prog.-1sg.)'	(*atʃ–ujor)

If Turkish harmony is analyzed with constraints that spread [back] and [round] from left-to-right, following the traditional idea that the process is inherently directional, then these facts follow immediately. Two of the relevant optimizations are shown in (63). In the first, the [–back] specification of the stem vowel in [gel–ijor] spreads to the following vowel. For the sake of argument, I assume that the underlying specification of the affected vowel is /u/; see Underhill (1976) and Bakovic (2000) for discussion of alternatives. In the second optimization, further spreading of [–back] is blocked by a constraint against non-high front unrounded vowels.[34]

(63) Myopia in the Turkish progressive suffix

a. First iteration of spreading

[gel–ujor]	T:*[–hi,–bk,+rd]	T:SPREAD-R([αback])	T:*[–bk,+rd]	IDENT([back])
[gel–ujor]		*!		
☞[gel–ijor]		(*)	*	*

b. Second iteration of spreading

[gel–ijor]	T:*[–hi,–bk,+rd]	T:SPREAD-R([αback])	T:*[–bk,+rd]	IDENT([back])
☞[gel–ijor]		*	*	
[gel–ijɤr]	*!	(*)		*

Assimilation of the first suffix vowel to the stem is optimal, even though the second suffix vowel remains opaque. By comparing these tableaux with those in (38) and (39) of section 3.3.1, we see that the analysis of this case of vowel harmony is formally identical to the analysis of nasal spreading in Malay. In both cases, spreading proceeds as far as possible in the designated direction despite the fact that it is ultimately blocked. That is, spreading is *myopic*. The present theory predicts myopia because—according to the principles of mark assignment and removal in (24)—local assimilation always results in a representation that better-satisfies the spreading constraint.

Directional spreading constraints supplement the theory of vowel harmony in Bakovic (2000), as just illustrated, but they do not eliminate the need for SA-faithfulness. Drawing on a wide range of previous work, Bakovic (2000:71–72) argues that SA-faithfulness is necessary to account for various paradigmatic effects (cf. McCarthy (to appear-b), who argues that the inflectional evidence cited by Bakovic should be analyzed with a different type of faithfulness). And, within the domain of spreading, SA-faithfulness is crucial to the analysis of dominant-recessive harmony systems (see especially Bakovic 2000:ch.4). Such a system would be analyzed in the present framework

[34] I use segmental rather than autosegmental notation here to simplify the tableaux.

with targeted spreading constraints that drive the dominant value in both directions, along with other constraints that restrict and shape the effects of dominant-value spreading. In the pattern that Bakovic refers to as "residual stem control", those constraints include SA-faithfulness.

4.2 Other directional processes

Directionality presents a general problem for the original formulation of OT, one that is not limited to unbounded spreading. Another example comes from the consonant harmonies analyzed by Gafos (1996), Hansson (2001), Rose & Walker (2001), and Walker (2000). Hansson (2001) in particular argues that non-targeted constraints are not sufficient to account for right-to-left consonant harmonies such as [+voice] harmony in Ngizim (pp. 319–334) and sibilant harmony in Chumashan languages (pp. 336–351). Hansson shows that it is not possible to analyze all consonant-harmony processes in terms of local spreading or reduplication (cf. Gafos 1996), that the correspondence-based theory of Walker (2000) fails to provide a general account of directionality (pp. 339–340; the same point applies to Rose & Walker 2001), and that an IO-faithfulness account of directionality is problematic to say the least (pp.275–276, n.6).

Hansson's own proposal has two main components. First, harmonizing consonants stand in a type of correspondence relation, as also proposed by Rose & Walker (2001) and Walker (2000). Second, the constraints that demand identity of corresponding consonants are targeted constraints that refer explicitly to direction. An example of one Hansson's targeted constraints, which uses the markedness statement in (64), is given in (65). (Here *CC-correspondence* refers to the aforementioned correspondence relation, which is assumed to be right-to-left asymmetric: $C_1 \leftarrow C_2$, not $C_1 \leftrightarrow C_2$.)

(64) CC/ANT (contextual markedness statement) (from Hansson 2001:342)

a. Given a CC-correspondence pair of consonants, $C_1 \leftarrow C_2$, where C_2 = [αant(erior)], then:

b. C_1 = [$-\alpha$ant] is marked.

(65) T:IDENT([ant])-CC (from Hansson 2001:342)[35]

Candidate x' is preferred over x ($x' \succ x$) iff x' is exactly like x except that at least one target consonant C_i is not marked according to CC/ANT.

Although Hansson's proposal was formulated within an earlier version of targeted-constraint theory, it transfers easily into the framework developed here. As suggested in Hansson (2001:444–445), it seems most parsimonious to eliminate the correspondence component of the proposal and simply require consonants to harmonize. The asymmetry of the correspondence relation assumed by Hansson (2001), Rose & Walker (2001), and Walker (2000) is not sufficient to account for directionality. And once the constraints that require harmony are targeted, correspondence becomes unnecessary. Therefore, a constraint such as (65) would be reformulated as follows:

(66) T:HARMONIZE-L([ant])

λ A [$-\alpha$ant] consonant that is followed by an [αant] consonant.

δ [$-\alpha$ant]$\rightarrow$[αant]

This should not be taken as a novel proposal; rather, it is a version of the theory in Hansson 2001 that is simplified in a way already anticipated in that work. The important point is that, as Hansson

[35] I have changed some typographical details of Hansson's constraint without affecting its content.

argues in depth, targeted constraints provide the only coherent analysis of directionality within the empirical domain of consonant harmony.[36]

The same appears to be true in the domain of dissimilation. To illustrate the problems that arise when targeted constraints are not used, I draw upon Kenstowicz & Banksira's (1999) analysis of [continuant] dissimilation in Chaha. Based on the paradigms of approximately 1,000 verbal roots (see Banksira 1993, 1997), Kenstowicz & Banksira establish that [x] and [k] are in complementary distribution: [k] occurs when there is a following fricative ([fszʕ]); [x] occurs in every other context.[37]

Certain aspects of the distribution of [x] and [k] can be analyzed with the general OT schema for complementary distribution (Kirchner 1997, McCarthy 2002a). The required ranking is DISSIM([cont])≫*k≫*x,IDENT([cont]), where DISSIM([cont]) is violated when there are two or more [–sonorant,–continuant] segments in the same word and *k and *x are abbreviations for the markedness constraints violated by voiceless dorsal stops and voiceless dorsal fricatives, respectively. However, as Kenstowicz & Banksira (1999) point out, this ranking is not sufficient to account for the *direction* of dissimilation. There are really two directionality-related generalizations to explain. First, the input distinction between /x...[–son,+cont]/ and /k...[–son,+cont]/ is neutralized to [k...[–son,+cont]]. Second, the input distinction between /[–son,+cont]...x/ and /[–son,+cont]...k/ is neutralized to [[–son,+cont]...x]; that is, a preceding fricative does not cause /x/ to dissimilate. The second generalization is established by forms such as [sənəx] ('be weakened (perfect)'), [yə-fxər] ('multiply (jussive)'), and others cited by Kenstowicz & Banksira (1999:574–576).

Kenstowicz & Banksira (1999:576–577) identify various independent factors (such as a dispreference for labial stops, and the stridency of /s,z/) that could prevent dissimilation from applying to fricatives other than /x/. However, in their analysis, these factors are not sufficient to account for the second generalization just noted. Therefore, they specifically craft their dissimilation constraint so that it is violated by [x...[–son,+cont]] but not by [[–son,+cont]...x].

(67) Dissimilation constraint (from Kenstowicz & Banksira 1999:576)
    *[x]...[–sonorant,+continuant]

This analysis can be simplified, and the factors identified by Kenstowicz & Banksira can be brought to the fore, if dissimilation is instead driven by a targeted constraint that is inherently directional (68).

(68) T:DISSIM-L([cont])
    λ A [–son,+cont] segment that is followed by a [–son,+cont] segment.
    δ [+cont]→[–cont]

[36]See also Hansson (2001), Rose & Walker (2001), and Walker (2000) for other factors that influence consonant harmony, such as intervening distance and independent similarity. These factors could be incorporated into the locus of violation (λ) of constraints such as (66) or, in the best case, derived from independent constraints.

[37]There are limited exceptions, as is generally the case with root phonotactics (see Pierrehumbert 1993, Frisch, Broe & Pierrehumbert 1995 for a general approach to this problem). Kenstowicz & Banksira (1999:574) note that [k] also arises by devoicing of /g/ and degemination and hardening of /xː/; I ignore these sources of [k] here.

Under the targeted-constraint analysis, dissimilation applies to (for example) /x...s/ structures, because the constraint specifies a change that is not blocked by any higher-ranked constraint (tableau (69a)). The process does not apply to /s...x/, because the constraint does not prefer a change in the rightmost fricative and the leftmost fricative is prevented from changing by IDENT([strident]) (tableau (69b)). (I assume that non-application to /f...x/ and /ʕ...x/ is accounted for by other dominant constraints.)

(69) Targeted analysis of dissimilation

a. Dissimilation applies

[x...s]	IDENT([strid])	T:DISSIM-L([cont])	T:*k	IDENT([cont])
[x...s]		*!	( )	
☞[k...s]		( )	*	*

b. Dissimilation is blocked

[s...x]	IDENT([strid])	T:DISSIM-L([cont])	T:*k	IDENT([cont])
☞[s...x]		*		
[t...x]	*!	( )		*

The advantage of this type of analysis, as has been stressed many times in the paper, is that it reduces the limitations of the process (except for directionality) to independently-motivated constraints. This avoids the formal arbitrariness of constraints such as (67) (e.g., why does the constraint specifically mention [x]? why not *[s]...[–son,+cont]? or *[x]...[s]?). Dissimilation is driven by universal targeted constraints that apply to broad natural classes; the segment-specific intricacies of particular processes follow from interaction.

Kenstowicz & Banksira (1999:577) briefly mention an alternative approach to directionality that would appear to make targeted constraints unnecessary. They point out that, if constraints such as ALIGN-L/R([αF]) are permitted (where the domain of alignment is understood to be the PrWd), then the direction of Chaha [continuant] dissimilation can be accounted for with the ranking ALIGN-L([–cont])$\gg$ ALIGN-L([+cont]). However, this alternative faces many problems. If ALIGN-L/R([αF]) constraints are available, then it is easy to construct hierarchies that generate unattested surface distributions. For example, the ranking ALIGN-R([–cont])$\gg$IDENT([cont])$\gg$ALIGN-L([–cont]) limits [–continuant] segments to the right edge of the word, a distribution that runs counter to well-known cross-linguistic generalizations. Feature-specific alignment constraints also give rise to the same unattested patterns as non-local spreading constraints like SPREAD-R([+nasal],PrWd) (see section 1.1). Indeed, the only legitimate use for constraints such as ALIGN-L([–cont]) seems to be to determine the direction of assimilation and dissimilation processes. Targeted constraints do this internally, thus avoiding the unattended and pathological consequences.

The connection between dissimilation and targeted-constraint theory was first made by McCarthy (2002:288). McCarthy considers a hypothetical typological generalization—that liquid dissimilation in /lVlV/ always affects the first /l/—and shows that a constraint similar to (68) can account for it. I have focused on a different point here. The fundamental claim of OT is that constraint interaction provides an insightful, reductive analysis of complex grammatical patterns. In order to maintain this claim, with respect to dissimilation and other processes that apply directionally, targeted constraints are necessary. Of course, it may also be the case that targeted constraints provide the only viable analyses of typological generalizations such as the one imagined by McCarthy (who does not suggest an alternative account and argues against one based on positional faithfulness).

4.3 Non-iterative spreading

Two major claims have been made in this paper: that there is a class of targeted phonological constraints; and that these constraints generate candidates in a derivational order determined by the hierarchy. The applications of the framework to myopia and directionality devolve from the first claim. The applications discussed in this and subsequent subsections pertain mainly to the derivational character of the system.

The first application, to cases in which spreading does not iterate, builds on recent work by McCarthy (to appear-b:37–40 [pages from ROA version]). McCarthy's arguments against other OT approaches to non-iterative spreading (such as those in Alderete 1988, Bickmore 1996, and Myers 1997) are not recapitulated here. Instead, I focus on how non-iterativity is analyzed in the present framework. I then briefly compare this with McCarthy's proposal, which is based on *comparative* markedness constraints.

In the definition of derivational TCOT (33), repeated below in (70), a constraint C_k is allowed to repeatedly generate candidates until the input and output of a gen/eval step are identical.

(70) Derivational TCOT

Let H = $[C_1 \gg C_2 \cdots \gg C_n]$ be any constraint hierarchy and in be any input.

a. The initial output, out_0, is the surface form that is identical to in.

b. For every constraint C_k ($1 \leq k \leq n$), an output is derived by repeatedly generating with [$\text{GEN}_{C_k} \circ \text{GEN}_{Pros}$] and selecting the most harmonic member of the candidate set with the entire hierarchy H.

   i. The initial output for C_k, $out_{k,0}$, is equal to out_{k-1}.

   ii. For $m>0$, $out_{k,m}$ = H-max([$\text{GEN}_{C_k} \circ \text{GEN}_{Pros}$]($out_{k,m-1}$)). If $out_{k,m} = out_{k,m-1}$, then the final output for C_k, out_k, is equal to $out_{k,m}$ and generation with C_k ends.

c. The final output of the last constraint, out_n, is the output that the grammar generates for input in.

Repeated application of a spreading constraint is inconsistent with patterns, such as the one in Ekegusii discussed by Bickmore (1996) and McCarthy (to appear-b), in which a feature or tone spreads non-iteratively. A relevant contrast from Ekegusii is [ó-go-kór-á] 'to do' (from /ó-go-kór-a/) vs. [ó-go-kór-ér-a] 'to do for' (from /ó-go-kór-er-a/). High tones (H) are marked by acute accents; low tones (L) are unmarked. The important fact is that the high tone from the root /kór/ spreads exactly one tone-bearing unit to the right: thus it reaches the final vowel in the first form, but not in the second one, where the applicative suffix intervenes. Application of a targeted spreading constraint T:SPREAD-R(H) as specified in (70b) incorrectly predicts *[ó-go-kór-ér-á].

The solution I propose is that targeted constraints come in pairs, one iterative and one non-iterative. An iterative constraint is able to generate candidates repeatedly, and exists throughout the derivation. A non-iterative constraint generates candidates only once, at step (k,1) (where, as in (70),

k is the index of the constraint), and is *removed from the hierarchy* after that gen/eval step. I use the notation T‡ to indicate that a constraint is non-iterative. Iterative constraints have no special marking.[38]

The targeted constraint that drives rightward H spreading, T:SPREAD-R(H), is defined in (71). The non-iterative version of the constraint is T‡:SPREAD-R(H).[39]

(71) T:SPREAD-R(H)
  λ A non-high-toned TBU that immediately follows a high-toned TBU.
  δ Spread H

Non-iterative spreading as in Ekegusii follows from a ranking in which T‡:SPREAD-R(H) dominates T:SPREAD-R(H), with a faithfulness constraint that is violated by tone spreading in the middle. I assume for the purposes of demonstration that tones associate to syllable nodes, and that IDENT(T) is violated once for every pair of corresponding segments s_i and s_j (one in the input and one in the output) such that s_i is in a syllable linked to a tone of type T (here T∈{L,H}) and s_j is not in a syllable linked to a tone of type T.

Given the input /ó-go-kór-er-a/, T‡:SPREAD-R(H) generates the candidate set {[ó-go-kór-er-a], [ó-go-kór-ér-a]}).[40] The second candidate is optimal because T‡:SPREAD-R(H) dominates IDENT(T).

(72) Non-iterative H spreading in Ekegusii

[ó-go-kór-er-a]	T‡:SPREAD-R(H)	IDENT(T)	T:SPREAD-R(H)
[ó-go-kór-er-a]	*!		*
☞[ó-go-kór-ér-a]	(*)	*	(*)

After this step, T‡:SPREAD-R(H) is removed from the hierarchy. The derivation proceeds, passing over IDENT(T) (which, being a faithfulness constraint, is not involved in generation) to T:SPREAD-R(H). The iterative spreading constraint does generate a candidate with further spreading, but that candidate does not become optimal.

(73) Failure of further spreading

[ó-go-kór-er-a]	IDENT(T)	T:SPREAD-R(H)
☞[ó-go-kór-ér-a]		*
[ó-go-kór-ér-á]	*!	(*)

This analysis can be generalized to other cases of non-iterative spreading by replacing T‡:SPREAD-R(H) with other non-iterative spreading constraints. The general schema for non-iterativity is T‡:SPREAD-L/R([αF])$\gg$IDENT(F)$\gg$T:SPREAD-L/R([αF]).

McCarthy (to appear-b) develops an alternative analysis of Ekegusii spreading that capitalizes on the fact that (to continue with the same example) the disagreeing sequence in [ó-go-kór-er-a] is

[38]Instead of being removed from the hierarchy, as proposed in the text, a non-iterative constraint could also be placed in a stratum with its iterative counterpart or demoted to the bottom of the hierarchy; all of these alternatives are equivalent. The notation T‡ will become clearer when non-persistent constraints, designated by T†, are introduced in subsection 4.4: non-iterative constraints are in a certain sense 'doubly' non-persistent.

[39]The locus of violation for these constraints is very similar to the locus of AGREE-R(H) in McCarthy 2003:39.

[40]The first H in the word does not spread for reasons discussed in Bickmore (1997); I ignore this detail here.

in some sense present in the input /ó-go-kór-er-a/, whereas the disagreeing sequence in [ó-go-kór-ér-a] is not. McCarthy proposes that the former sequence violates an *old* markedness constraint $_{\text{O}}$AGREE-R(H), while the latter violates a *new* markedness constraint $_{\text{N}}$AGREE-R(H). Only $_{\text{O}}$AGREE-R(H) dominates tone faithfulness, therefore the 'old' disagreeing sequence is repaired by spreading but the 'new' one is not. Other markedness constraints also have old and new versions, just as all targeted constraints are assumed here to have iterative and non-iterative manifestations.

Non-iterative constraints and old markedness constraints are clearly related. However, they differ crucially with respect to the importance of the initial input of an optimization. An old markedness constraint is violated by a given locus iff that locus stands in transitive (t-) correspondence with a locus in the fully-faithful candidate (FFC; McCarthy to appear-b:6–11). This predicts that, for example, a tone that is floating in the input could never spread non-iteratively. In the FFC, the tone would be floating, not docked. Therefore, the FFC would not contain a locus of AGREE-R(H) violation (with respect to that tone) and $_{\text{O}}$AGREE-R(H) would be satisfied by every candidate.

The general prediction is that a non-iterative process can apply only if its structural description is present in the input (technically, the FFC). Other examples are easy to construct. To give one more, McCarthy analyzes non-iterative vowel deletion, as in Lardil /pulumunitami/→ [pulumunita] 'young female dugong' (McCarthy to appear-b:34–35 and references cited there), with $_{\text{O}}$FINAL-C. The specific prediction in this case is that non-iterative vowel deletion could never be fed by final consonant deletion, hiatus resolution, or any other process.

In contrast, the application of a non-iterative constraint does not depend on the original input, but rather on the input from the preceding step of the derivation. Therefore, nothing in the system developed here precludes a tone that is underlyingly floating from spreading non-iteratively, or a vowel that is exposed to the left edge by some other process from undergoing non-iterative deletion. The constraint responsible for docking the tone would simply have to be ranked higher than $T^{\ddagger}$:SPREAD-R(H) (so that docking precedes spreading in the derivation); similarly, final consonant deletion could feed non-iterative vowel deletion, given certain rankings. At this time, I am not aware of evidence that supports the greater descriptive power of non-iterative constraints. However, it seems plausible that such evidence will be found, either directly or from arguments based on richness of the base (which demands a heterogeneous pool of input structures).[41]

The idea that there are non-iterative constraints alongside iterative ones of course echos earlier proposals about rules (Anderson 1982, Archangeli & Pulleyblank 1994, and others). The assumption that grammars operate derivationally is necessary in the current framework, just as it was in the

[41] Note also that comparative markedness does not provide a viable solution to the myopia problem discussed in subsections 3.3.1 and 4.1. Suppose that the grammar operates derivationally, and that the old version of a particular spreading constraint dominates the new version: $_{\text{O}}$AGREE([αF])$\gg_{\text{N}}$AGREE([αF]). This ranking yields myopic, iterative spreading. The problem is that $_{\text{O}}$AGREE([αF])$\gg_{\text{N}}$AGREE([αF]) is the ranking that McCarthy (to appear-b) uses to account for *non-iterative* spreading (in non-derivational OT). Therefore, comparative markedness cannot account for both myopia (which requires derivations) and non-iterativity (which requires parallelism). If non-iterative constraints are introduced to solve this problem, then the original motivation for comparative markedness is lost.

McCarthy gives a similar argument against some versions of derivational OT, based on the existence of synchronic chain-shifts. Within the present framework, non-iterative constraints provide an analysis of chain-shifts as well as of non-iterative spreading (both of which belong to the larger class of counterfeeding interactions).

earlier theories. And that assumption is in turn supported by the success of analyses such as those given here and in the following subsections.

4.4 *Transparent segments*

An ordinary targeted constraint (T) gives rise to potentially many gen/eval steps, and remains in the hierarchy throughout a derivation. A non-iterative constraint ($T^{\ddagger}$) generates candidates only once, and is removed from the hierarchy after that step. I claim that there is a third type of targeted constraint, intermediate between these two, which I refer to as *non-persistent* and designate by $T^{\dagger}$. A non-persistent constraint generates candidates repeatedly, and can therefore account for unbounded processes. It is removed from the hierarchy when the output of one of its gen/eval steps is identical to the input for that step (i.e., at the end of (70b) in the definition of derivational TCOT).

Non-persistent constraints are crucial, in the present framework, for the analysis of transparent segments. The particular example of transparency that I analyze is found in Wolof (Bakovic & Wilson 2000, Ka 1988, Archangeli & Pulleyblank 1994, Pulleyblank 1996). The analysis essentially follows Bakovic & Wilson (2000), with specific modifications noted below.

As is well-known (see the references just cited), high vowels are transparent to left-to-right [–ATR] spreading in Wolof. On the surface, a high vowel does not become [–ATR] when it is preceded by a [–ATR] vowel. But a high vowel does not block [–ATR] spreading either, as shown by examples such as [tɛɛr-uw-ɔɔn] 'welcomed' and [tɛk-ki-lɛɛn] 'untie!' (from Archangeli & Pulleyblank 1994:231). In these examples, the suffixes [-ɔɔn] and [-lɛɛn] agree with the [–ATR] specification of the preceding root vowel, which in some sense passes over the intermediate high vowels. (Compare the examples [reer-oon] 'was lost' and [toxi-leen] 'go and smoke!', from Archangeli & Pulleyblank 1994:227, 231, which show the same suffixes surfacing as [+ATR] when the first root vowel is [+ATR]).[42]

The main idea of Bakovic & Wilson's (2000) analysis is that forms such as [tɛɛr-uw-ɔɔn] and [tɛk-ki-lɛɛn] are optimal because they are minimally different from other forms in which [–ATR] has spread through the entire word. By itself, the spreading constraint would yield [tɛɛr-ʊw-ɔɔn] and [tɛk-kɪ-lɛɛn]. The actual surface forms win because they come as close as possible to these outputs, while still satisfying an undominated targeted constraint against [+high,–ATR] vowels.

The targeted constraint from Bakovic & Wilson (2000) is given in (74). (The constraint has been modified to fit the format adopted throughout the paper. See Archangeli & Pulleyblank (1994) among others on the markedness of [+high, –ATR] segments and Bakovic & Wilson (2000:46–47) for discussion of the substantive basis for the change that is preferred by this constraint.)

(74) T:*[+high,–ATR] (from Bakovic & Wilson 2000:46)
 λ A segment that is both [+high] and [–ATR].
 δ [–ATR]→[+ATR]

In the analysis developed here, the constraint that drives [ATR] spreading is also targeted. However, a few simple calculations show that the constraint cannot be a non-iterative constraint (i.e.,

[42] Tones have been omitted from the Wolof forms cited here.

T†:SPREAD-R([αATR])) or an ordinary (iterative and persistent) one (i.e., T:SPREAD-R([αATR])). Non-iterative T‡:SPREAD-R([αATR]) is insufficient because [ATR] spreading in Wolof can in principle affect any number of vowels (see, for example, genn-əndoo 'to go out together' and door-ənte 'to hit each other' from Archangeli & Pulleyblank 1994:228; note that [ə] is the general [+ATR] counterpart of [a]). T:SPREAD-R([αATR]) is insufficient because it would either force all vowels to surface as [–ATR] after [–ATR] roots (75a) or predict that spreading is blocked by high vowels (75b).[43]

(75) Insufficiency of T:SPREAD-R([αATR])

a. T:SPREAD-R([αATR])≫T:*[+high,–ATR]

[tɛk-ki-leen]	T:SPREAD-R([αATR])	T:*[+high,–ATR]	IDENT([ATR])
[tɛk-ki-leen]	*!		
☞[tɛk-kɪ-leen]	(*)	*	*

[tɛk-kɪ-leen]	T:SPREAD-R([αATR])	T:*[+high,–ATR]	IDENT([ATR])
[tɛk-kɪ-leen]	*!		
☞[tɛk-kɪ-lɛɛn]	(*)	*	*

b. T:*[+high,–ATR]≫T:SPREAD-R([αATR])

[tɛk-ki-leen]	T:*[+high,–ATR]	T:SPREAD-R([αATR])	IDENT([ATR])
☞[tɛk-ki-leen]		*	
[tɛk-kɪ-leen]	*!	(*)	*

As these tableaux indicate, the spreading constraint must in some sense both dominate and be dominated by the constraint against [+high,–ATR] segments. Bakovic & Wilson (2000) achieve this effect with a fairly complex definition of harmonic ordering that relies on a principle called *priority of the more harmonic* (see also Wilson 2001). I now show that the same effect can be achieved, within the framework of this paper, with a non-persistent spreading constraint.

The crucial rankings are T†:SPREAD-R([ATR])≫T:*[+high,–ATR]≫T:SPREAD-R([ATR])≫ IDENT([ATR]). The non-persistent constraint applies first in the derivation, with the effect that the [ATR] value of the root is spread throughout the word. Then the non-persistent constraint is removed from the hierarchy, and T:*[+high,–ATR] generates candidates in which all and only the [+high,–ATR] vowels are changed to [+ATR]. All other vowels retain the specifications imposed by spreading. The result is high-vowel transparency, as illustrated in derivation (76) below.

This derivation makes use of all of the theoretical resources that have been developed in the paper. The initial step of spreading is myopic, and therefore depends on mark removal. T†:SPREAD-R([ATR]) applies iteratively, feeding itself, but is crucially non-persistent. The step in which the [+high,–ATR] vowel becomes [+ATR]—while everything else in the form remains constant—depends on the targeted character of T:*[+high,–ATR] and the core hypothesis that targeted constraints are largely responsible for candidate generation. And the over-arching derivational framework makes it possible for T†:SPREAD-R([ATR]) to be crucially active early on, and entirely absent at subsequent steps.

[43]I ignore the possibility of eliminating the T:*[+high,–ATR] violation by changing the vowels to [–high]. If this change is preferred by T:*[+high,–ATR], it can be prevented by ranking IDENT([high]) above that constraint.

(76) Derivation for /tɛk-ki-leen/→[tɛk-ki-lɛɛn]

Step	Input	Candidate set	Output	Comments
0	/tɛk-ki-leen/		[tɛk-ki-leen]	
1,1	[tɛk-ki-leen]	$\text{GEN}_{\text{T}^\dagger:\text{SPREAD-R([ATR])}}(\cdot)$ = {[tɛk-ki-leen], [tɛk-kɪ-leen]}	[tɛk-kɪ-leen]	incremental spreading
1,2	[tɛk-kɪ-leen]	$\text{GEN}_{\text{T}^\dagger:\text{SPREAD-R([ATR])}}(\cdot)$ = {[tɛk-kɪ-leen], [tɛk-kɪ-lɛɛn]}	[tɛk-kɪ-lɛɛn]	incremental spreading
1,3	[tɛk-kɪ-lɛɛn]	$\text{GEN}_{\text{T}^\dagger:\text{SPREAD-R([ATR])}}(\cdot)$ = {[tɛk-kɪ-lɛɛn]}	[tɛk-kɪ-lɛɛn]	vacuous application
	$\text{T}^\dagger$:SPREAD-R([ATR]) is removed from the hierarchy			
2	[tɛk-kɪ-lɛɛn]	$\text{GEN}_{\text{T:*[+high,–ATR]}}(\cdot)$ = {[tɛk-kɪ-leen], [tɛk-ki-lɛɛn]}	[tɛk-ki-lɛɛn]	[+high,–ATR] vowels eliminated
4	[tɛk-ki-leen]	$\text{GEN}_{\text{T:SPREAD-R([ATR])}}(\cdot)$ = {[tɛk-ki-leen], [tɛk-kɪ-lɛɛn]}	[tɛk-ki-lɛɛn]	spreading blocked

Note: Steps are indexed by k (position in the hierarchy) and m (iteration of a given constraint); m is omitted if there is only one iteration for a constraint.

One representational issue should be addressed explicitly. Assuming (as in section 3.3.2) that spreading is represented autosegmentally, it might appear that the change from [tɛk-kɪ-lɛɛn] to [tɛk-ki-lɛɛn] necessarily results in a 'gapped' configuration, with a [–ATR] autosegment associated to root [ɛ] and suffix [ɛɛ], but not medial [i]. Because many researchers have argued that such representations are universally ill-formed (xxxx), this would appear to be a problem for the present analysis. Fortunately, there is an alternative representation that does not contain a gap. In the notation introduced in section 3.3.2, the change is from [[tɛk-kɪ-lɛɛn]$_{\text{[-ATR]}}$] to [[tɛk]$_{\text{[-ATR]}}$-[ki]$_{\text{[+ATR]}}$-[lɛɛn]$_{\text{[-ATR]}}$] (with two [–ATR] autosegments) not to [[tɛk-[kɪ]$_{\text{[+ATR]}}$-lɛɛn]$_{\text{[-ATR]}}$] (which contains a gap). The two potential outcomes of the change are perceptually equivalent under the assumption that the acoustic effects of a linked structure are negligibly different from those of two independent and identical features (as assumed in section 3.3.2). Therefore, they are equally close to [tɛk-kɪ-lɛɛn] as far as the minimal-change principle is concerned (see section 3.1). Both would in principle be preferred by T:*[+high,–ATR], but only the representation without a gap is allowed by UG.

The analysis of transparency developed above embodies the main idea of Bakovic & Wilson (2000): that transparency is the result of minimal, targeted divergence from full spreading. But it is otherwise more closely related to previous analyses of Myers (1991a), Walker (1998 [2000]), and others, all of which depend on an intermediate representation in which spreading is complete. I conclude this subsection by showing how the new analysis accounts for *opaque* segments, which are found in many languages, including Wolof, and which are problematic for Bakovic & Wilson's approach.

In Wolof, short low vowels ([a]) generally undergo [+ATR] spreading, raising to [ə] (an exceptional, non-alternating vowel occurs in the agentive suffix [-kat]). But long low vowels ([aa]) are opaque: they do not undergo [+ATR] spreading from the left, and they cause following mid vowels to surface as [–ATR], as in [door-aat-ɛ] 'to hit usually' (*[door-aat-e]) and [gen-aalɛ] 'to go out also' (*[gen-aale]). (In this description, I have drawn once more upon Archangeli & Pulleyblank 1994:xx–xx.)

The straightforward approach to the opacity of [aa] is to rank a constraint against [əə] (call this constraint C) above the spreading constraint. The same schema, with a different C, extends to the analysis of [-kat]. However, this is incompatible with Bakovic & Wilson's analysis, which uses this schema to account for *transparent* vowels. Bakovic & Wilson propose a solution to a special case of this problem, but the general difficulty is left unresolved.[44]

The present analysis does not face this problem, because it provides two positions in the hierarchy for constraints like C. The constraints responsible for 'repairing' transparent vowels are ranked between the non-persistent spreading constraint T†:SPREAD-R([ATR]) and T:SPREAD-R([ATR]), as we saw in (76). The constraints responsible for enforcing opacity outrank both T†:SPREAD-R([ATR]) and T:SPREAD-R([ATR]). This ranking prevents an opaque vowel from undergoing harmony at any step of the derivation. Consequently, a vowel later in the word harmonizes with the opaque one, never having been reached by the root vowel's [ATR] specification.

4.5 Post-lexical tone spreading in Dagbani

In this final application of the derivational TCOT framework, I propose a solution to a problem raised in Hyman's (1993) detailed analysis of post-lexical tone in Dagbani (see also Wilson 1970). I analyze only a small part of the system here; see Hyman (1993) and Wilson (1970) for additional data and analysis.

The problem that Hyman (1993:240ff.) identifies is one of persistence and non-persistence. A spreading process is persistent (in the original sense of Chafe 1968 and Myers 1991a): it applies at two non-contiguous steps of the derivation. A ban on contour tones is non-persistent: it eliminates contour tones created by the first application of spreading, but not by the second application. As Hyman (1993:245ff.) argues in detail, both applications occur in the same, post-lexical part of the phonology. The pattern is therefore problematic both for theories in which rules apply in a fixed order (i.e., cannot be persistent) and for theories in which the rule/constraint that simplifies contour tones must apply persistently within a level (Myers 1991b).

The two derivations in (77) below, repeated from Hyman (1993), illustrate the problem. (I have suppressed a late process that delinks a low (L) tone from a syllable that is also associated to a high (H) tone and that is followed by a L or pause; see Hyman 1993:243. This does not interact in any significant way with the spreading and contour simplification processes studies here; it applies non-vacuously at the end of derivation (77b).)

In the first application of H-tone spreading, a H spreads one TBU to the right, and the resulting HL (falling) contour is simplified by delinking the L. In the second application of H-tone spreading, the H spreads rightward to the following TBU, but the resulting contour is not simplified (by the processes under discussion here). Further spreading of H is therefore blocked by the ban on

[44]More specifically, the problem still remains in languages, like Wolof, that have both transparent and opaque segments. This well-attested pattern is also problematic for the feature-domain theory of Cole & Kisseberth (1994). It would also be problematic for an analysis within Sympathy Theory (McCarthy 1999, 2003a) that used a spreading constraint as the selector. (See Ito & Mester (1997) on the possibility of sympathetic selection by markedness constraints (but cf. Ito & Mester 2001, 2003).) In Walker's (1998 [2000]) Sympathy analysis of transparency, the problem is circumvented by a major modification of the way in which the sympathy candidate is selected; further consequences of this modification have not, as far as I know, been explored.

(77) Persistent spreading and non-persistent simplification (derivations from Hyman 1993:243)

lexical representation	a. pag-a akarma H L H	b. san-a akarma H L L H
First application of H-tone spreading	pag-a akarma H L H	san-a akarma H L L H
Second application of H-tone spreading	pag-a akarma H L H	san-a akarma H L L H
phonetic representation	[páɣ ákârmá] 'woman's drummer'	[sán ákàrmá] 'stranger's drummer'

crossing association lines (Bird 1996, Hammond 1988, Sagey 1988), given the assumption that H and L tones are on the same tier.

The main idea of the present analysis is that contour-tone simplification in Dagbani is accounted for with a non-persistent targeted constraint. The corresponding persistent constraint is too low-ranked to affect the output. More specifically, I assume that only the non-persistent version of (78) is active in this language.[45]

(78) T:NoContour-R
- λ A TBU α that is associated to two or more distinct tones.
- δ Remove the association from α to the rightmost tone

Non-persistent T†:NoContour-R interacts with the persistent and non-persistent versions of a spreading constraint that is similar, but not identical, to the one used in section 4.3. In the earlier discussion, I tacitly assumed that the spreading violation in a structure such as (79a) could only be repaired by both adding an association to the H and removing the association to the L, as in (79b). Call this *assimilatory* spreading. For the purposes of analyzing Dagbani, it is necessary to also recognize another type of spreading that involves addition of an association but not delinking, as in (79c). Call this *associational* spreading. (The distinction between assimilatory and associational spreading is similar to the distinction between feature-changing and feature-filling rules in previous frameworks.)

(79) Assimilatory vs. associational spreading

a. α α H L	b. α α H L	c. α α H L

In assimilatory spreading, all of the tonal associations of a TBU are determined by the preceding TBU; this is very similar to the traditional notion of assimilation. In associational spreading,

[45]This constraint is essentially identical to Myers' (1991a) persistent rule of contour simplification. I assume, as does Myers, that there could be another constraint, T:NoContour-L, which delinks the first tone of a contour. The notation '-L/-R' in these constraints is adopted from McCarthy (to appear-b).

the tonal associations of a TBU are only partly determined by the preceding context; this type of spreading draws heavily on the core autosegmental notions of tiers and associations. Instead of choosing between these two conceptions of spreading, I propose that both are universally available. Assimilatory spreading is demanded by constraints such as (80). Associational spreading follows from constraints such as (81).

Let α_i and α_j be any two adjacent TBUs such that α_i precedes α_j, T be the rightmost tone (if any) that is associated to α_i, and T-Assoc(α_j) be the set of tones associated to α_j.

(80) T:SPREAD-R(H) (assimilatory)

- λ An α_j such that T-Assoc(α_j) is not equal to {T} (i.e., T-Assoc(α_j)$\neq${T})
- δ Add an association from α_j to T; remove other associations from α_j

(81) T:SPREAD-R(H) (associational)

- λ An α_j such that T-Assoc(α_j) does not contain T (i.e., T-Assoc(α_j)$\not\supseteq${T})
- δ Add an association from α_j to T

These two constraints demand spreading of the *rightmost* tone of α_i to the following TBU α_j. This makes sense under the view that phonological spreading emerges from and enhances phonetic coarticulation: the rightmost tone of one TBU exerts the greatest coarticulatory influence on the following TBU. (Obviously, the leftward counterparts of the constraints would refer to the leftmost tone of α_j.) Notice also that the change preferred by associational T:SPREAD-R(H) is not stipulated, but follows from the locus of violation (λ) and the minimal-change principle. Addition of an association is the minimal change that eliminates a violation; to remove associations as well would be superfluous.

The hierarchy that accounts for Dagbani is T†:SPREAD-R(H)$\gg$T†:NOCONTOUR-R$\gg$T:SPREAD-R(H)$\gg$IDENT(T), where the two spreading constraints are associational. The non-persistent version of T:NOCONTOUR-R, as well as the persistent and non-persistent versions of the assimilatory spreading constraints, are ranked below IDENT(T). (The non-iterative versions of all of the targeted constraints are also at the bottom of the hierarchy.)

The resulting derivations are very similar to those in (77) above, therefore I simply present some of the relevant tableaux. Suppose that the input to the post-lexical phonology is [pág-á àkàrmá]. The generation function of T†:SPREAD-R(H) returns the candidate set {[pág-á àkàrmá], [pág-á âkàrmá]} and the new candidate, which contains a contour tone, wins the competition. (For ease of exposition, I use diacritic notation here and below as a shorthand for the real autosegmental structures.)

(82) Incremental spreading

[pág-á àkàrmá]	T†:SPREAD-R(H)	T†:NOCONTOUR-R	T:SPREAD-R(H)	IDENT(T)
[pág-á àkàrmá]	*!		*	
☞[pág-á âkàrmá]	( )	*	( )	*

T†:SPREAD-R(H) is able to force the creation of a contour because it dominates T†:NOCONTOUR-R. But now T†:SPREAD-R(H) is removed from the hierarchy, because it no longer applies non-vacuously (recall that this constraint only refers to the rightmost tone of the first TBU in a sequence). This allows T†:NoContour-R to simplify the contour in the next step. Its generating function returns {[pág-á âkàrmá], [pág-á ákàrmá]}, and the singly-linked structure wins.

(83) Contour tone simplification

[pág-á âkàrmá]	T†:NoContour-R	T:Spread-R(H)	Ident(T)
[pág-á âkàrmá]	*!		
☞[pág-á ákàrmá]	( )	*	*

After this step, T†:NoContour-R applies vacuously—no contours remain to be simplified—and is therefore removed from the hierarchy. Now T:Spread-R(H) applies, pushing the H tone one TBU further to the right and creating another contour.

(84) Incremental spreading

[pág-á ákàrmá]	T:Spread-R(H)	Ident(T)
[pág-á ákàrmá]	*!	
☞[pág-á ákârmá]	( )	*

At this point the derivation ends. Associational T:Spread-R(H) is not violated by the current, correct surface form, therefore its associated Gen function is the identity map. And Ident(T) blocks changes preferred by lower-ranked constraints..

To summarize this analysis, the complex interaction between spreading and contour simplification in Dagbani is derived here from the assumption that targeted constraints come in persistent and non-persistent pairs—the same assumption that is needed to account for transparent segments (see subsection 4.4). The analysis is very similar to the one suggested by Hyman (1993), as well as to Myers' (1991a) analysis of a related pattern in Shona. But the derivational framework developed here addresses many of the problems that have surrounded the notion of persistence in previous work. For example, Myers (1991a) claims that a there is a universal persistent rule of contour simplification. But Dagbani shows that this claim is incorrect, and all of the tone patterns discussed here and in Myers (1991a) can be accounted for by interleaving persistent and non-persistent constraints in the hierarchy. Similarily, many researchers have claimed that prohibitions on marked structures cannot be 'turned off' (i.e., must be persistent or entirely non-existent) within a level (Myers 1991b and others). Dagbani again shows that this condition is too strong (as originally pointed out by Hyman (1993)). The solution is to recognize a class of non-persistent constraints that are indeed deactivated (removed from the hierarchy) at determined points in the derivation.

4.6 Summary

In the preceding subsections, I have focused on a number of descriptive difficulties faced by the original formulation of OT (and other theories such as the persistent-rules framework of Chafe 1968 and Myers 1991a). In some cases, the difficulties are overcome by the central hypothesis that the relevant markedness constraints are targeted. Other cases rely more heavily on the hypothesis that phonological grammars are derivational, and require an enriched theory of constraints in which non-iterative and non-persistent varieties exist alongside iterative, persistent ones.

Any proposal that enhances the descriptive power of a theory necessarily reduces that theory's restrictiveness. Although I cannot address all of the restrictiveness issues that are raised by the proposals made above, I should make a few points. First, the formalization of non-iterative and non-persistent constraints imposes inherent limitations on the patterns that can be described. For example, it would be impossible to analyze a hypothetical language that is like Dagbani except that the sequence spread–simplify occurs exactly n times (for some arbitrary $n>1$). The first iteration of this sequence is performed by T†:SPREAD-R(H) and T†:NOCONTOUR-R. After these constraints are removed from the hierarchy, none of the remaining constraints can ensure that only $n-1$ further iterations are performed. Similarly, the present framework cannot fall into an endless cycle in which a feature is spread, then delinked from its new associate, then spread again, etc. Such cycles pose a real danger for theories with persistent rules. But here the cycle must end: at the point when all of the non-persistent and non-iterative constraints have been removed from the hierarchy. Note also that the existence of non-iterative and non-persistent constraints does not jeopardize the restrict subset prediction of OT analyses of spreading, according to which two processes that spread the same feature must stand in a strong/weak relation with one another (see section 2). Blocking effects can arise only from persistent markedness constraints; therefore, the original OT predictions stand.

Second, the specifications for iterativity and persistence do not fully cross-classify. Once a non-iterative constraint is removed from the hierarchy, there is no way in which it could apply persistently: non-iterative implies non-persistent. Therefore, there are only three types of targeted constraints: persistent and iterative (T), non-persistent and iterative (T†), and non-persistent and non-iterative (T‡). This connection between persistence and iterativity is a novel one, and could conceivably impose non-obvious limitations on the analysis of spreading and other process types.

Third, and perhaps most importantly, non-iterative and non-persistent constraints have many applications outside the domain of spreading. McCarthy (to appear-b) motivates old markedness constraints with a number of attested patterns that are otherwise problematic for OT. Non-iterative constraints can account for all of the same facts. (See section 4.3 for an overview of McCarthy's proposal, and a comparison of the predictions of old markedness and non-iterative constraints.) And non-iterative and non-persistent constraints together provide a general approach to counter-feeding opacity (Kiparsky 1973, Kirchner 1996, McCarthy 1999, 2003a; see Wilson (in prep.)).

5 Comparison with alternatives

The primary motivation for the targeted analysis of unbounded spreading is the insufficiency of previous analyses within OT. As discussed in the introduction (see section 1.1), alignment-based spreading constraints such as the one in (3) predict many unattested non-local interactions (e.g., blocking of word-final epenthesis by the presence of a feature at the beginning of the word). Other non-local formulations of the spreading constraints give rise to exactly the same problems. Local, non-targeted spreading constraints avoid these problematic predictions by comparing the feature specifications of adjacent segments only. However, as shown in section 1.2 (see tableau (11)), these constraints are unable to account for incremental spreading that does not reach the edge of a domain. That is, in the terms of section 4.1, the constraints fail to capture the myopic nature of spreading.

There are two general alternative solutions to this problem, in addition to the one that I have proposed. The first is to abandon a constraint-based model of phonology, and return to an analysis that uses iterative spreading rules such as those in (2). I have argued against this alternative, most extensively in section 2, on the grounds that it is not as restrictive as an approach within OT. The central issue is the status of conditions on undergoers. Many OT analyses have successfully explained these conditions with constraints that are motivated by other facts, whereas rule-based analyses must simply stipulate them. Moreover, as I noted at the beginning of the paper, the targeted constraints for unbounded spreading are in fact closely related to iterative rules. The major difference between them follows from the central thesis of OT: the spreading constraints interact with other constraints through strict domination relations, and thereby retain the restrictiveness of previous OT proposals.

The second alternative is to attempt to formulate different, non-targeted spreading constraints. If this alternative were successful, and if the resulting theory were as restrictive and empirically successful as the one based on targeted constraints, then the modifications to OT proposed in this paper would be unnecessary. In the following subsections, I briefly consider a number of other spreading constraints that have been considered in the OT literature. The conclusion is that none of them provides a viable alternative.[46]

5.1 Embedded undergoer conditions

One way of reformulating non-targeted, local spreading constraints is to embed conditions on undergoers within them. For example, to account for nasal harmony in Malay (see sections 1 and 3.3), we could use a constraint that is violated by [+nasal][–nasal] sequences iff the [–nasal] segment is also [–consonantal]. This constraint is in fact proposed by McCarthy & Prince (1995, 1999); they refer to it as $*NV_{oral}$.[47]

As illustrated in the tableau below, $*NV_{oral}$ correctly prefers spreading from a nasal consonant to every following vowel and glide. Once spreading reaches a segment that is [–cons] (or the end of the PrWd), the constraint is satisfied. (Compare the constraints in (11), which are violated equally by all of the candidates in this tableau.)

(85) Unbounded spreading with an embedded condition on undergoers

Candidates	$*NV_{oral}$	IDENT([nasal])
[pəŋawasan]	*!	
[pəŋãwasan]	*!	*
[pəŋãw̃asan]	*!	**
[pəŋãw̃ãsan]		***

[46]A third alternative is to use fixed rankings to solve the overgeneration problems causes by non-local spreading constraints. (See also McCarthy & Prince (1995:32, note 21), where fixed rankings are explicitly appealed to as a necessary part of the theory of spreading.) For reasons of space, I am unable to discuss this alternative in detail here. Note, however, that the fixed ranking proposed by Pater (2003)—that segmental faithfulness constraints universally dominate featural markedness constraints—is not sufficient to solve all of the problems raised in section 1.1. Note also that the present framework provides descriptive abilities (e.g., analyses of directional phenomena and of counterbleeding) that are not generally available in OT, and that would not seem to follow from any fixed-ranking approach.

[47]The theory of undergoer conditions was not the focus of McCarthy & Prince's (1995) discussion, therefore $*NV_{oral}$ should probably be considered a provisional part of their analysis. Another example of this type of constraint comes from Lombardi (1999:272): the constraint AGREE requires two segments to agree in voicing iff they are both obstruents ([–sonorant]).

NB: In this tableau, and all of the others in this section (section 5), marks are assigned according to the original definition of OT; no mark removal applies.

Although descriptively successful in certain cases, constraints such as $*NV_{oral}$ have exactly the same arbitrary character as spreading rules like those in (2). Observationally, conditions on undergoers align with other markedness effects (e.g., limitations on inventories and on the outcomes of other processes). This cannot be explained by packaging the conditions into specific spreading constraints. To give just one more example, consider cases in which only high vowels undergo round harmony (Kaun 1995, 1996). Such cases could be accounted for with the undergoer-specific constraint *[+round][+high,–round], which essentially amounts to "[+round] must spread rightward except when doing so would create a [–high,+round] vowel." But, as Kaun and others have shown, the dispreference for [–high,+round] vowels is not specific to spreading; therefore, it should not be embedded within the spreading constraint.

It might be objected that constraints such as $*NV_{oral}$ and *[+round][+high,–round] are not necessarily arbitrary. There could, after all, be a theory of constraints that permits NV_{oral} but not $*NC_{oral}$, and *[+round][+high,–round] but not *[+round][–high,–round]. However, that theory would in many instances duplicate what is already accomplished in OT by constraint interaction. Because interaction is the more general and restrictive way of imposing conditions on processes, constraint-internal "except when" clauses should be avoided whenever possible. (See Prince 1997 for foundational discussion of such 'endogenous' constraints on OT.)

Spreading constraints with embedded undergoer conditions also make bizarre typological predictions: namely, that in some languages segments will actively avoid being eligible for spreading. For example, *[+round][+high,–round] could cause a [+high,–round] vowel to become [–high] iff it is immediately preceded by a [+round] vowel (i.e., the predicted process is 'post-round lowering of high unrounded vowels'). Nothing like this is attested.

5.2 Feature minimization

In one of the first analyses of unbounded spreading within OT, Beckman (1997) argues against introducing an explicit spreading constraint (see especially Beckman 1997:27–32). According to Beckman, spreading derives instead from a proper understanding of feature markedness. A single autosegment [αF] incurs *one* violation of the feature-markedness constraint *[αF] regardless of how many segments are associated to it. Therefore, the feature-markedness violations of the output can be minimized by minimizing the number of features. Spreading does this.[48]

The feature minimization theory of spreading is an attractive one. It is conceptually related to the notion of feature licensing, as developed by Goldsmith (1990, 1993), Ito & Mester (1993), Ito & Mester (1995), and Steriade (1995) (see also Beckman 1997:39, note 25).[49] And it correctly predicts that segments that fail to undergo a spreading process should surface with the least-marked feature value possible (Beckman 1997:33; this generalization is stated, in essence, by Steriade xxxx).

[48]The way in which *[αF] constraints evaluate candidates follows from the more general principle of *Feature-Driven Markedness*, Beckman (1997:19).

[49]In the terms of Steriade (1995), Beckman's proposal is most closely related to earlier theories of *indirect* licensing.

However, feature minimization does not provide an adequate analysis of unbounded spreading, failing for basically the same reasons as local, non-targeted spreading constraints. With respect to feature-markedness constraints, nothing is gained by partial spreading of the type found in examples such as Malay [pəŋā̃w̃āsan]. As shown in the following tableau, each step of [+nasal] spreading results in the same number of *[+nasal] and *[–nasal] violations.

(86) Insufficiency of feature minimization

Candidates	*[+nasal]	*[–nasal]
$[[\text{pə}]_{[\text{-nas}]}[\text{ŋ}]_{[\text{+nas}]}[\text{awasa}]_{[\text{-nas}]}[\text{n}]_{[\text{+nas}]}]$	**	**
$[[\text{pə}]_{[\text{-nas}]}[\text{ŋa}]_{[\text{+nas}]}[\text{wasa}]_{[\text{-nas}]}[\text{n}]_{[\text{+nas}]}]$	**	**
$[[\text{pə}]_{[\text{-nas}]}[\text{ŋaw}]_{[\text{+nas}]}[\text{asa}]_{[\text{-nas}]}[\text{n}]_{[\text{+nas}]}]$	**	**
$[[\text{pə}]_{[\text{-nas}]}[\text{ŋawa}]_{[\text{+nas}]}[\text{sa}]_{[\text{-nas}]}[\text{n}]_{[\text{+nas}]}]$	**	**

Similarly, feature minimization does not determine the direction of spreading in cases of myopia (cf. (61) and (62) in section 4.1). Beckman's proposal could of course be augmented with other constraints that resolve the ties in (86) and solve the myopia problem. But unless these additional constraints are targeted, they will run into the difficulties discussed at the beginning of the paper.[50]

5.3 Durational enhancement

Flemming (1995) proposes that spreading serves the functional goal of enhancing the perceptibility of the feature that is extended. This idea is formalized with universal subhierarchies of DURATION constraints, as in (87).[51]

(87) Duration subhierarchy (from Flemming 1995:52–57, ch.4)

$$\text{DURATION}([\alpha\text{F}]) = d \gg \text{DURATION}([\alpha\text{F}]) = d{+}1 \gg \text{DURATION}([\alpha\text{F}]) = d + 2 \gg \cdots$$

Notice that longer durations for [αF] are demanded by lower-ranked constraints. This provides an interesting account of the observation, discussed many times in this paper, that a feature spreads as far as possible even if cannot reach the edge of a domain. For example, a duration subhierarchy can, under certain rankings, account for the [+nasal] spreading found in [pəŋā̃w̃āsan]. (In the following tableau, I have assumed that distances are measured in segments, but other units would yield the same result; Flemming argues explicitly for subsegmental units.)

(88) Unbounded spreading as durational enhancement

Candidates	DUR([+nas]) =1	DUR([+nas]) =2	DUR([+nas]) =3	DUR([+nas]) =4	⋯	IDENT([nas])
[pəŋawasan]		*!	*	*		
[pəŋāwasan]			*!	*		*
[pəŋāw̃asan]				*!		**
☞[pəŋāw̃āsan]						***

[50]An additional argument against the feature-minimization approach to spreading comes from Padgett's (1995b) analysis of nasal place assimilation. As Padgett shows, a constraint that demands spreading is required to account for languages, like Kpelle, in which both places features of a complex stop spread to a preceding nasal (e.g., /N+gb/→[ŋm+gb]; note that [ŋ+gb] (or [m+gb]) would satisfy feature markedness equally well.

[51]I have changed the format of Flemming's constraints slightly, in a way that does not affect their content.

Although successful in this particular case, subhierarchies of duration constraints incorrectly predict that spreading can be sensitive to the *number* of segments that undergo the process. For example, if IDENT([nasal]) were ranked between DUR([+nas])=3 and DUR([+nas])=4, then [+nasal] spreading would halt as soon as three segments were associated to the feature. This type of numerical calculation is obviously not involved in any attested spreading process.[52]

At first sight, it would seem possible to avoid this problem by collapsing duration subhierarchies into single constraints. On closer inspection, however, this is formally unworkable. How many violations should the first candidate in tableau (88) receive from the collapsed constraint DURATION([+nasal])? Without imposing an arbitrary numerical limit on the distance of spreading (i.e., essentially terminating the '· · · ' in (87) at some particular value), we cannot answer this question. And whatever limit we impose will not do justice to the unbounded nature of the phenomenon (in the same way that imposing an arbitrary limit on the number of phrasal embeddings would distort the nature of syntactic competence).

5.4 Directional evaluation

The final alternative to be considered is the *directional evaluation* proposal of Eisner (2000). Like the proposal made in this paper, directional evaluation represents a significant departure from the original formulation of OT. And, also like the current proposal, the broader consequences of Eisner's innovation are not entirely clear. The remarks here are therefore preliminary, to be refined by future work in both frameworks.

The essence of Eisner's proposal is that the marks assigned by an individual constraint are harmonically ordered according to the location of the violating structures in the output. A constraint that evaluates candidates left-to-right prefers 'later' violations over 'earlier' ones. A constraint that evaluates right-to-left imposes the opposite ordering on its marks.[53]

Directional provides a solution the myopia problem that we encountered in sections 3.3.1 and 4.1. For example, myopic rightward spreading as in [pəŋãw̃ãsan] can be accounted for with the locally-evaluating constraint $*[+\text{nasal}][-\text{nasal}]_{LR}$, which evaluates candidates left-to-right. As the following tableau shows, this constraint prefers extension of the [+nasal] feature to the vowels and glides after [ŋ] despite the fact that [s] blocks further spreading. (I have used position within the column under the constraint to evoke the harmonic ordering imposed on the marks.)

(89) Directional evaluation accounts for myopic spreading

	Candidates	$*[+\text{nasal}][-\text{nasal}]_{LR}$
a.	[pəŋawasan]	*!
b.	[pəŋãwasan]	*!
c.	[pəŋãw̃asan]	*!
d. ☞	[pəŋãw̃ãsan]	*

[52] A formally-identical problem arises for the MINLINK family of syntax constraints proposed in Legendre et al. (1998).

[53] Technically, the locations of the violations are determined by reference to the fixed input representation; see Eisner (2000) for details.

However, the constraint *[+nasal][–nasal]$_{RL}$, which is exactly like the one above except that it evaluates from right-to-left, predicts an unattested pattern in which spreading is *non-myopic*. Hypothetical forms such as /pəŋawa/ undergo spreading (/pəŋawa/→/pəŋãw̃ã/), because it is possible for the feature to spread all the way to the right edge of the word. But forms such as /pəŋawasan/ do not undergo the process, because the end of the domain cannot be reached and every increment of spreading gives rise to a less-harmonic violation of the constraint.

(90) Directional evaluation predicts non-myopic spreading

	Candidates	*[+nasal][–nasal]$_{RL}$
a. ☞	[pəŋawasan]	*
b.	[pəŋãwasan]	*!
c.	[pəŋãw̃asan]	*!
d.	[pəŋãw̃ãsan]	*!

What optimizations like this one reveal is that the directional-evaluation analysis fails to capture the local nature of spreading. Directional evaluation predicts that, in some languages, the decision to spread at one point in the domain depends on whether spreading can apply at another, unboundedly distant point. This type of dependency is not found in natural spreading processes, and is not predicted by the targeted-constraint analysis. Therefore, in the absence of any principle within Eisner's theory that would allow *[+nasal][–nasal]$_{LR}$ but exclude *[+nasal][–nasal]$_{RL}$, the targeted analysis is more consistent with the empirical typology.

6 Conclusion

In their formulation of OT, Prince & Smolensky (1993/2002) adopt the hypothesis that a constraint C assigns one violation mark for every instance of its structural description (see also McCarthy 2003, to appear-a). Under this hypothesis, marks simply re-represent candidates in a way that makes all and only the distinctions that are relevant to the constraints (see Bakovic & Wilson 2000 for discussion of the notion of re-representation). This conception of mark assignment is so entrenched that there would appear to be no alternative. It is adopted, more or less explicitly, in every previous grammatical theory that employs constraints or filters (e.g., Goldsmith 1990, 1993, Halle & Idsardi 1995, Paradis 1988, Singh 1987). Nevertheless, I have argued that it is incorrect.

The conception I have proposed differs fundamentally with respect to the objects of evaluation. Instead of assigning marks to candidates considered individually, targeted constraints take into account the change from one representation to another ($x \rightarrow y$). The presence of a locus of violation in both x and y does not imply that the two candidates are equally harmonic. The presence of a locus of violation in x, and the absence of one in y, does not imply that y is preferred. Rather, the marks of y are computed relative to the loci of violation in x and the change (Δ) that relates the two representations. A mark is removed from y for every locus in x that is eliminated in the way specified by the δ component of a targeted constraint. A mark is removed from x (alternatively, assigned to y) for every locus in x that is removed in a way that does not accord with δ. [54]

[54] Sommerstein (1974) is the only other non-standard proposal about constraint evaluation that I have found. Sommerstein's (1974:76) definition of *alleviation* of a violation is similar to the definition of mark assignment given in this paper, because it is explicitly comparative (i.e., alleviation is determined by comparing two forms, not by considering forms individually). However, in Sommerstein's theory *any* change could potentially alleviate a violation; this is a

The main motivation for this proposal comes from unbounded spreading. Because spreading potentially feeds itself, applying it to one segment does not necessarily reduce the number of sequences that meet the structural description of a local spreading constraint (*[αF][$-\alpha$F]). Because it is unbounded, no arbitrary numerical limit can be incorporated into such a constraint. It follows from this, and the arguments against non-local spreading constraints, that evaluation does not consist entirely of mark assignment. Mark removal, as formalized in (70), is needed as well.

The new theory of constraint evaluation has both prerequisites and consequences. The prerequisites are a derivational framework—the only kind that accommodates small, incremental changes of the type needed here—and a source for the changes themselves. I have shown that the theory of targeted constraints can be extended to satisfy these requirements. The order of derivation follows the order of the hierarchy. Targeted constraints, which by their very definition prefer specific repairs, provide the source for changes, taking over much of the work of GEN.

The major consequence is an empirically-successful and restrictive analysis of unbounded spreading, one that combines insights of previous rule- and constraint- based approaches. Spreading is strictly local and iterative. Conditions on spreading follow whenever possible from strict domination relations between the spreading constraints and other constraints that are independently motivated. Further consequences hold for the analysis of dissimilation, for the treatment of directionality in phonology, and for the description of various counterfeeding interactions.

A number of residual issues remain for future research. One is the precise form of the minimal change principle, discussed most extensively in section 2, that limits the preferences of targeted constraints. I have made one specific assumption about minimality in this paper: namely, that for certain features the change from a positive specification to a negative specification is more costly than the opposite change (23). This is related to, and more restrictive than, previous theories of privativity and fixed faithfulness rankings. However, it is not at present motivated by the same type of perception data that determines targets in other cases (see Bakovic & Wilson 2000, Wilson 2001, which draws heavily on the work of Steriade 1999ab, 2000 and others).

Perhaps the most topical issue is whether the derivational formalism proposed here can provide adequate analyses of the patterns that have, within the original version of OT, been taken to be the hallmarks of parallel constraint interaction. The present system retains a degree of parallelism in its treatment of prosody (recall that all prosodic parses are generated and evaluated in parallel at each step of a derivation). It is also possible to incorporate parallel selection of lexically-listed allomorphs, and parallel computation of reduplicants, into the framework. Arguments against derivationalism in other domains are scarcer, and in some cases do not apply to the present proposal.[55] Future work should be directed at uncovering segmental and featural phenomena that seem to require parallel optimization, and assessing their implications for the theory. If none are forthcoming, the question still remains (just as it did in earlier work on persistent syllabification and footing) of why prosodic and melodic phonology should differ in this way.

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major point of difference with the current proposal.

[55]For example, as noted in section 4.3, the argument for parallelism based on synchronic chain-shifts does not apply to the current theory, which includes non-iterative constraints.

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