Icy Targets*

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Abstract

A common assumption is that no segment can be both a target and a blocker of the same assimilation pattern. This paper reports on three cases to the contrary. These patterns involve two kinds of targets: regular targets allow further assimilation, whereas *icy* targets terminate it. To distinguish between the two types of targets, I present a representational solution complemented by OT constraints. The main idea is that autosegmental spreading involves maximally binary, headed, and recursive domains. The distribution of heads is such that any non-final target is a head of some feature domain, whereas the final target is not. Icy targets can be associated with a feature, but cannot be heads, which effectively terminates further spreading.

1 Introduction

Classic Optimality Theory (OT; Prince & Smolensky 1993/2004; McCarthy & Prince 1993a,b, 1995, 1999) shifted the focus of phonological investigation from representations to operations. This makes sense because OT constraints can refer to segmental properties without invoking features, nodes, or association lines. At the same time, OT constraints may make reference to representations, as is the practice of some researchers (e.g. Myers 1997; Morén 1999/2001, 2003; Hyde 2001, 2002; Uffmann 2005; Blaho 2008). With the advent of Harmonic Serialism (McCarthy 2009; Elfner 2009; Pruitt 2010) and Harmonic Grammar (Potts et al. 2010; Mullin 2011) representations are once again becoming crucial.

This paper presents evidence that representations are essential even in standard OT. I focus on a phenomenon that offers support for a particular structure of autosegmental spreading. I show that targets of assimilation fall into two groups, with the difference

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being representational. The empirical finding is that some targets also act as blockers. These segments are termed *icy targets*. The very existence of icy targets is surprising and is inconsistent with the standard assumptions about assimilation. In particular, what appears to be insufficient is the assumption that features can be either compatible (as in targets) or entirely incompatible (blockers). Icy targets instead reveal that two features may be *partially* compatible.

One way to capture this partial compatibility is to say that there are at least two different kinds of relationships between a feature and a segment. I make use of an early autosegmental model that distinguishes headed and non-headed segments. The main prediction is that while some segments cannot be heads of the spreading feature, they can be non-heads of the same spreading feature. These segments are icy targets. A simple extension of constraints on prosodic heads to constraints on feature heads is sufficient to model the behavior of icy targets.

The paper is organized as follows. Section 2 presents an example of icy targets, and shows why a standard account with elements of Autosegmental Phonology and OT excludes them. Section 3 reviews two early models of autosegmental representations. The prevailing model has no restriction on branching, whereas the alternative model limits all branching to maximally binary. Even though the latter model is considerably more complex, it correctly predicts a distinction between two different types of targets. This is because binary branching allows for a formalization of two types of relationships between a spreading feature and its target. Section 4 presents a full analysis of icy targets in Icelandic. The Icelandic case is particularly compelling since icy targets interact with a separate process that changes icy targets into regular targets of assimilation. Icelandic is an example of vowel harmony, which is complemented by two other kinds of assimilation in the following two sections. Section 5 extends icy targets to consonant harmony—Nati retroflexion in Sanskrit. Section 6 discusses nasal harmony in Ikwere. Combined, these three case studies show that icy targets are not restricted to any particular type of assimilation. Section 7 contrasts the present approach with four alternative OT accounts, which are all less adept at capturing this pattern. Some are similar to a classic autosegmental account which excludes icy targets entirely. Others allow for icy targets, but in a non-restrictive way that results in many unattested patterns. Section 8 concludes the paper.

The contribution of this paper is two-fold. First, I introduce icy targets as an attested pattern in different types of assimilation. Under this particular view, new light is shed on the data and some previously well-known but poorly understood alternations are unified. Second, I offer a representational account, which is a simple extension of an early autosegmental treatment. The proposed solution gives evidence that representations are key in phonological theory.

2 The challenge

Icy targets are found in u-umlaut in Icelandic (1), which involves fronting and rounding. A suffixal /ʏ/ targets the low unrounded vowel /a/ in the root. Shown in (1-a) are monosyllabic roots containing [a] in the nominative singular. This vowel alternates with [œ] when followed by the dative plural suffix *-ʏm*. U-umlaut interacts with vowel reduction, a process that raises all unstressed (i.e. non-initial) instances of [œ] to [ʏ]. The data in (1-b) indicate that an underlying /a/ is subject to fronting, rounding, and raising in the dative plural. Of particular interest are polysyllabic roots with multiple [a]'s, as in (1-c). Most roots exhibit u-umlaut and reduction. Fronting and rounding affect all [a]'s. Furthermore, all unstressed vowels also raise and surface as [ʏ], whereas the initial vowel surfaces unreduced. For example, 'suit of clothes' contains two [a]'s in the nominative singular. In the dative plural, suffixal /ʏ/ fronts and rounds a preceding /a/, but because of reduction, the segment is realized as [ʏ] rather than [œ]. The derived [ʏ] is a further trigger, turning the preceding /a/ into [œ]. These data indicate that u-umlaut applies to the whole word.

Finally, some roots are not subject to reduction (1-d). Given what we know so far, we would expect that fronting and rounding applied to all /a/'s. Surprisingly, this is not what happens. Instead, these roots show that [œ] terminates assimilation. For instance, the dative plural form of 'Japanese' is *j*[a]*p*[œ]*n*[ʏ]*m*, and not **j*[<u>œ</u>]*p*[œ]*n*[ʏ]*m* as we would have expected if [œ] were a regular target, allowing further fronting and rounding.

(1) Icelandic u-umlaut (Anderson 1972, 1974, Orešnik 1975, 1977)

a. U-umlaut in monosyllables

NOM.SG	DAT.PL	
b[<u>a</u>]rn	ˈb[<u>œ</u>]rn[ʏ]m	'child'
ˈd[<u>a</u>]lir	ˈd[<u>œ</u>]l[ʏ]m	'valley'

b. Vowel reduction

ˈh[ɛ]r[<u>a</u>]ð	ˈh[ɛ]r[<u>ʏ</u>]ˌð[ʏ]m	'district'
ˈ[ɔ]ð[<u>a</u>]l	ˈ[ɔ]ð[<u>ʏ</u>]ˌl[ʏ]m	'allodium'

c. Polysyllables with reduction

ˈf[<u>a</u>]tn[<u>a</u>]ð	ˈf[<u>œ</u>]tn[<u>ʏ</u>]ˌð[ʏ]m	'suit of clothes'
ˈb[<u>a</u>]k[<u>a</u>]ˌri	ˈb[<u>œ</u>]k[<u>ʏ</u>]ˌr[ʏ]m	'baker'

d. Polysyllables without reduction

ˈj[a]p[<u>a</u>]ˌni	ˈj[a]p[<u>œ</u>]ˌn[ʏ]m	'Japanese'
ˈ[a]lm[a]ˌn[<u>a</u>]k	ˈ[a]lm[a]ˌn[<u>œ</u>]k[ʏ]m	'calendar'

It is crucial to take into account both types of roots at the same time. The unreduced roots reveal that fronting and rounding target /a/, yielding [œ]. At the same time, the resulting [œ] blocks any further assimilation. That is, [œ] is an icy target—a target and a blocker. The reduced roots complement such a conclusion, since [ʏ] appears to be a regular target, allowing fronting and rounding of any subsequent targets.[1]

Icy targets present a theoretical challenge to all existing theories of assimilation. Here, I demonstrate this for a standard autosegmental account within OT for two reasons. First, this approach has been shown to capture most assimilation patterns. Second, reviewing the classic autosegmental approach is appropriate because the solution will also be autosegmental.

In Autosegmental Phonology assimilation is feature spreading, which involves adding association lines between the assimilatory feature and target root nodes (Goldsmith 1976, 1990; Clements 1976/1980, 1985a; Kiparsky 1981). This mapping involves an unfaithful mapping between the input and output. In OT, this disparity is attributed to a markedness constraint which outranks the inhibiting faithfulness constraint. There are different proposals regarding what this markedness constraint is, and this choice is essentially an entirely separate question that has very little to do with icy targets. One

[1] Note that the blocking property of [œ] is independent of any known blocking effects, including bona fide blockers or domain edges. For example, if a prosodic or morphological edge restricted assimilation to exactly one target, there would be no iterative assimilation in reduced roots.

established approach is to extend Generalized Alignment (McCarthy & Prince 1993a) to segmental features. The logic behind this approach is simple: a candidate that has the relevant feature aligned with a domain is less marked than a candidate with no alignment.

Icelandic involves spreading of two features. Here, I assume binary features, but the current approach is entirely consistent with privative features.[2] The standard approach would be to say that [−back] and [+round] spread. At this point, I want to briefly demonstrate the problem, and for that reason I will give a description based on a single feature, [+round]. In Icelandic, [+round] targets (low) vowels within a prosodic word, which is enforced by the alignment constraint in (2). Note that the constraint is formally gradient; I use it here solely for expositional reasons. In section 4.2.1, I propose a modified, categorical constraint.

(2) Align([+round], L; PWd, L; V) (Kirchner 1993; McCarthy 2003:78)
$\forall$[+round] if $\exists$PWd, assign one violation-mark $\forall$V that intervenes between the Leftmost segment associated with [+round] and the nearest Left Edge of some PWd.

Next is the antagonistic faithfulness constraint. In Autosegmental Phonology, assimilation is adding association lines rather than features. Faithfulness constraints to associations are widely used in OT literature that makes use of autosegmental representations.[3] In this particular case, the faithfulness constraint prohibits linking of [+round] with a root node. The constraint DepLink[+round] in (3) is violated once by every association line to [+round], which is present in the output, but not in the input.

(3) DepLink[+round] (after Itô et al. 1995; Myers 1997; Lombardi 1998; Morén 1999/2001; Archangeli & Pulleyblank 2002; Blaho 2008)
Let $\times_i \Re \times_o$.
Assign a violation mark, iff $\times_o$ is associated with [+round] and $\times_i$ is not.

The two constraints proposed so far either (i) prefer spreading within a domain or (ii) inhibit spreading entirely. Since we are looking at icy targets which also act as blockers, the final constraint should address segmental blocking. Blocking is standardly attributed to feature co-occurrence constraints (Archangeli & Pulleyblank 1994; Walker 1998/2000; Kaun 1995, 2004, and many others). In Icelandic, low vowels terminate rounding, which suggests that [−low] is not compatible with [+round]. The combination of these two features is marked.

(4) *[+round +low] (henceforth, *œ) (Kaun 1995, 2004)
Assign a violation for every $\times$ that is associated with [+round] and [+low].

I now turn to the ranking. Tableau (5) shows an Icelandic input that prefers an icy target candidate (a). Given the three constraints, however, the actually attested candidate (a) is harmonically bounded by the other two candidates (Samek-Ludovici & Prince 1999, 2002).

[2] For a full implementation of such an approach to assimilation, see [suppressed].

[3] See Morén (1999/2001) for a full discussion of faithfulness constraints for associations, and Blaho (2008) for an extension to segmental features.

(5) japœnʏm ‘Japanese.DAT.PL’

[+rd] / j a p a n - ʏ m / [+lo] [+lo]	AL([+rd],L;ω,L;V)	DEPLINK[+rd]	*œ
[+rd] j a p œ n ʏ m a. ☹ [+lo] [+lo]	1	1	1
[+rd] j a p a n ʏ m b. [+lo] [+lo]	2 W	L	L
[+rd] j œ p œ n ʏ m c. [+lo] [+lo]	L	2 W	2 W

Although icy targets are attested, they are not predicted by the standard autosegmental approach using alignment constraints and feature co-occurrence constraints. In response, I propose a representational solution complemented by OT constraints. In a nutshell, the idea is that some structures are found on regular targets but not on icy targets, and that these structures are referred to by some constraints.

3 Binary Domains Theory

Icy targets present an important piece of evidence that the classic concept of association is deficient. One solution to this challenge would be to posit different types of associations, but this may be difficult to formalize. What I propose instead is to modify the representation of feature spreading altogether. This modification is based on some early autosegmental proposals.

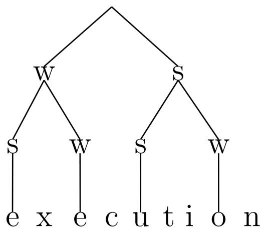
This section is organized as follows. Section 3.1 highlights the differences between association in Autosegmental Phonology and Metrical Theory. Only the latter concept is consistent with icy targets. Section 3.2 formalizes this approach and introduces a novel theory of feature spreading—Binary Domains Theory. The theory incorporates headedness and binarity into the feature spreading mechanism. These well-established concepts are discussed in section 3.3. Section 3.4 complements the representational elements with OT constraints.

3.1 Association in Metrical Theory

In phonology, association has been used in at least two different ways. One use is that of Autosegmental Phonology where it is used primarily for tone and segmental features. The other use is that of Metrical Theory where it is used for prosodic phenomena (Liberman & Prince 1977; Hayes 1984). So far I have used the association consistent with Autosegmental Phonology. I will now focus on the second option, Metrical Theory.

In Metrical Theory, association groups prosodic constituents such as moras and syllables into higher units such as feet. In other words, prosodic units exhibit hierarchical structure. Such a representation is in (6), which shows prosodification of a single English word. Syllables are linked into higher constituents, which consist of a strong (s) and a weak (w) part. These are in turn joined into a higher constituent, again consisting of a strong and a weak part. In this example, prosody can be thought of as rhythmic organization, consisting of alternating peaks and troughs. The second and the fourth vowels (*execution*) are less prominent that the first (*execution*), which is in turn less prominent than the third vowel (*execution*).

(6) Representation in Metrical Theory (Liberman & Prince 1977:268, slightly modified)

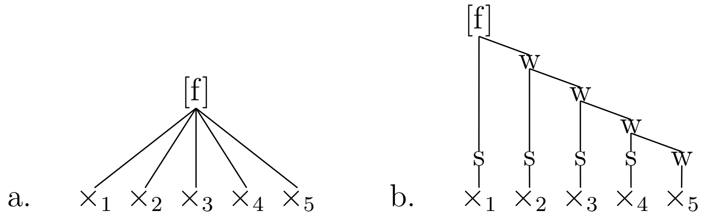


Two observations about (6) are in order. First, all branching is maximally binary. Second, branching is hierarchical, consisting of peaks/heads and troughs/dependents. Such representations capture the generalization about rhythmic patterns across human languages (Liberman & Prince 1977; Hayes 1980, 1984; Prince 1983; Selkirk 1984). Prosody typically forms binary units in which the two constituents have a different status. Features, on the other hand, rarely exhibit such patterns. More specifically, no known case of feature spreading involves a rhythmic skipping of every other target.

Nevertheless, the representations of Metrical Theory have been used to account for feature spreading in some literature (Vergnaud 1979; Zubizarreta 1979; Steriade 1981; Zubizarreta 1982; Halle & Vergnaud 1980, 1981; Kaye 1982; Poser 1982; Leben 1982). As pointed out by Leben (1982), the autosegmental and metrical model were considered equally capable of capturing segmental processes in the early days of Autosegmental Phonology. Being that there were no reported segmental or tonal patterns which could distinguish between the two models, the metrical representations were ultimately rejected because they are more complex than the alternative. In particular, the metrical representations require additional structures (such as heads) and make restrictions on branching, which are not required in the non-metrical representations. It turns out that icy targets present a crucial case in which the two models make different predictions. As we have seen in section 2, classic autosegmental representations in OT cannot account for icy targets. I will now show that the metrical representations can account for icy targets.

In (7), I show two representations involving a feature [f] that spreads from the initial root node $\times_1$ and targets all other root nodes. The representation in (7-a) makes no distinction among root nodes. All are in an equivalent relationship with respect to the feature [f]. Any of the root nodes could be a trigger or a target. In other words, [f] is equally aligned with all root nodes; the fact that it is graphically aligned with the third root node does not bear any significance. The representation in (7-b) also depicts a single feature linked to five root nodes, yet it is markedly different. The feature [f] spreads in a binary fashion. The highest node (marked as [f]) is linked to the leftmost root node $\times_1$ and to another node, which is in turn linked to $\times_2$ and another node. The domains are recursive. Note that all but the rightmost root node are heads (indicated by 's'). Of the two representations, (7-b) is considerably more complex, but it also contains more information. In particular, the trigger is $\times_1$ rather than any other root node.

(7) Autosegmental (a) and metrical (b) representations



The representations of stress in (6) and spreading in (7-b) exhibit many similarities when compared. Both contain association lines connecting different elements. Not more than two elements are connected to a higher node, creating (maximally) binary domains. Each of these domains are headed.

Concurrently, there are also significant differences between the two representations. The higher nodes in (6) connect lower non-recursive nodes. This is also true for the final w-node in (7-b). However, most nodes are linked to other nodes that already contain a *w* themselves. Put differently, while nodes in (6) represent higher constituents (i.e. feet), representations in (7-b) represent the same type of constituents, and constituents themselves can be recursive. Another difference concerns the lower nodes. In the representation of stress in (6), they form a sequence of alternating heads and dependents. This contrasts with (7-b), where only the final root node is connected to a dependent, while all other nodes are heads.

These representational differences can be attributed to the fact that prosody and feature spreading also differ from one another. Prosody prefers maximum contrast between adjacent elements, leading to sequences of peaks and troughs, while feature spreading is a neutralization process, reducing contrast between segments. In feature spreading, some phonological properties of targets are neutralized when affected by a spreading feature. In this context, headedness allows us to express degrees of neutralization. As we will see, headed targets show a greater degree of neutralization than non-headed targets. Hence, proposing multiple adjacent heads in feature spreading make sense.

Final targets have a special status compared to all other targets. Most targets are both heads and dependents of a feature. Their being headed has to do with the fact that they are better at neutralizing contrast than final targets, which are not headed. This distinction is directly relevant to icy targets. In Icelandic (section 2), for example, some vowels prefer to be final targets, which can be associated with a feature, but cannot be heads of a feature. That is why they can be targets yet also concurrently terminate spreading.

A distinction between heads and dependents would not make sense in classic Autosegmental Phonology, but it does make sense within Metrical Theory. In what follows, I will propose a theory of spreading, which formalizes the intuitions of Metrical Theory and extend it to feature spreading.

3.2 Formalism

Binary Domains Theory (BDT) is a theory of spreading that extends the concept of association within Metrical Theory to segmental features. In particular, I propose a feature spreading mechanism that restricts spreading to headed binary domains, where spreading to multiple targets creates recursive domains.

In rule-based Autosegmental Phonology, feature spreading is a simple two step operation: (i) associate a feature with a target and (ii) repeat the first step until no further targets are available. Here, I propose that association lines themselves are not enough. In addition, they are complemented by restrictions on Gen. The first and foremost is the restriction on branching; all branching is maximally binary:

(8) Strict Binarity
All branching is maximally binary.

The consequence of Strict Binarity (8) is the creation of a recursive node if more than one target is available. Another restriction of BDT is that two root nodes linked to the same feature do not have the same status. One way to formalize this is to use headedness. That is, spreading to one target will result in exactly one head, the triggering root node, and one non-head. Spreading to multiple targets will create multiple feature nodes, which have their own head, as defined in (9). Crucially for the patterns discussed in this paper, a head is defined as a root node. Similar restrictions on feature heads are found in the literature (e.g. Cassimjee & Kisseberth 1989; Kisseberth 1994; Cole & Kisseberth 1995a,b; Cassimjee & Kisseberth 1998; McCarthy 2004; Smolensky 2006).

(9) Feature head
For every branching node of [f], there is exactly one $\times$ that is a Head of [f].

What follows from the restrictions in (8) and (9) is that every pair of adjacent root nodes associated with feature [f] will have a separate feature node and a separate head. Because there is one head for every pair of root nodes, a string of n segments associated with the same feature will have $n-1$ heads.

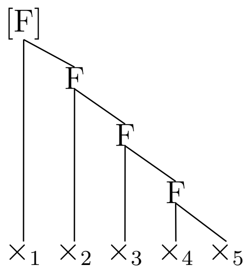
The remaining issue is the distribution of heads. Here, I will assume that triggers are always heads. A trigger in this context is a segment that (i) is associated with a feature in the input and output, and (ii) triggers spreading. A trigger of an [f]-spreading pattern is always a head of [f], as in (10).[4]

(10) Triggers are heads
Let $i_j \Re o_k$ for $j, k \in [1, n]$.
Then i_j, o_k and o_l, $k \neq l$ are associated with the autosegment [f] iff o_k is a Head of [f].

The three restrictions (8)–(10) make the head assignment in feature spreading predictable. In a string of segments associated with [f], all but the final target will be heads of [f], without exception.

In order to make the distinction between a head and a dependent clear, I propose a slight modification to how feature spreading is represented graphically. In (11), we see rightwards spreading of [f] from the leftmost root node $\times_1$ that targets all root nodes. The representation in (11) is a notational variant of the second representation in (7). Capital letters designate a feature node of [f], whose head is the directly dependent root node below it. The square brackets designate the trigger. In (11), there is only one instance of feature [f], which is associated with five segments. Of these root nodes, four are heads and one is not a head. An association line linking a root node to a head is sufficient to express spreading of a feature to a segment.

[4]In some languages, triggers may be deleted by a separate process. These cases are not subject to (10), and require additional mechanisms of head assignment. One option is to assign a head to the segment that is closest to an edge of a prosodic domain. However, this issue is beyond the scope of this paper.

(11) 

To summarize, BDT places several restrictions on feature spreading. First, branching is maximally *binary*. Second, spreading to multiple targets creates *recursive* domains. Third, the recursive domains are *headed*, and the distribution of heads is predictable.

3.3 Headedness, binarity, and recursion

BDT introduces binarity, headedness, and recursion to one theory of autosegmental spreading. These three concepts are well supported in other areas of linguistic theory.

Headedness is a relation found throughout prosodic theory. Any prosodic constituent has a head (Liberman & Prince 1977; Nespor & Vogel 1986; Hayes 1995; de Lacy 2006). For example, each foot must have a head (syllable or mora). Similarly, a prosodic word must be headed by a foot or a syllable. In prosodic theory, heads may have independent cues of prominence, such as phonetic correlates of stress (intensity, duration, formant frequencies) or segmental distributions (e.g. more contrast is possible on heads than on dependents, see Beckman 1998; Benua 1997; Crosswhite 2001; Smith 2005; de Lacy 2006).

Headedness has also been proposed for feature spreading, which is a notion that BDT shares with other recent approaches to feature domains (Cassimjee & Kisseberth 1989; Kisseberth 1994; Cole & Kisseberth 1995a,b; Cassimjee & Kisseberth 1998; McCarthy 2004; Smolensky 2006; Potts et al. 2010). Most of these accounts see the triggering segment as a head, while all the targets are only dependents. BDT differs in three ways from other feature domain theories. First, BDT allows maximally binary domains with one one head and one one dependent, rather then an unbounded domain with any number of dependents. Second, domains are recursive, creating heads on all but the final target. Third, heads in BDT represent only structural prominence, and not a separate instance of some autosegment. The distinction between a head and an autosegment builds on Hyde's (2002, 2007) proposal which divorces prosodic prominence and footing.

Finally, headedness has also been used elsewhere in phonology (for a review, see Dresher & van der Hulst 1998). In Dependency Phonology, for example, features within segments may be headed (Anderson & Ewen 1987; van der Hulst 1989).[5] In short, headedness is well established in phonology.

The idea that feature spreading involves a binary constituent is also consistent with many other aspects of phonological theory. For example, feet are standardly assumed to consist of not more than two syllables, and syllables most commonly consist of not more than two moras (e.g. Hayes 1995). Prosodic words and phonological phrases have also

[5]Note that BDT does not state anything about the feature content of individual segments, but merely posits headedness in feature spreading.

been analyzed as binary.[6] As regards morphological domains, Lahrouchi (2010) analyzes Tashlhiyt roots as consisting of binary branching constituents.

Binarity is also found in feature spreading processes involving tone. Many Bantu languages show spreading within a binary domain (see Kisseberth & Odden 2003 for an overview): Chichewa (Myers 1999), Cilungu (Bickmore 2007), Ekegusii (Bickmore 1997), Enakhauwa (Cassimjee & Kisseberth 1998), Kikuyu (Clements & Ford 1979; Clements 1984), Kinyarwanda (Myers 2003), Rimi (Myers 1997), Setswana (Mmusi 1992), Shona (Odden 1981; Myers 1987), and many others. Similar patterns are also found in various Japanese dialects (Nitta 2001) and in Serbo-Croatian (Inkelas & Zec 1988; Zec 1999; Becker 2007).

The third element of the theory is recursion. Unlike the binarity and headedness, recursion does not appear to be as prevalent in prosodic theory. However, most early work on prosody posits recursive footing for what has later been established as unparsed material (Liberman & Prince 1977; Kiparsky 1979; McCarthy 1979, 1982; Hayes 1980; Selkirk 1980b; Halle & Vergnaud 1987). Similar proposals have been put forward more recently by Grijzenhout (1990) and Rice (2011). Prosodic units larger than the syllable are often considered to be recursive.[7] Van der Hulst (2010) provides an overview of recursion in phonological theory. Recursion is also proposed for segment-internal structure (Sagey 1990; Odden 1994; Clements 1991; Clements & Hume 1995; Morén 2003, 2006). The main proposal is that the vowel place node is recursive on the consonant place node.

Although BDT assumes recursive domains, the data presented in this paper do not offer a distinction between recursive and overlapping domains; both models are equally adept at explaining icy targets. Overlapping structures are only slightly less common than recursive. A standard example of this type are overlapping syllables which create ambisyllabic segments (Kahn 1976). A more recent proposal extends the same idea to overlapping footing (Hyde 2001, 2002, 2007). The choice for recursive rather than overlapping domains in this paper is largely due to the early autosegmental models.

3.4 Constraints on heads

BDT is a representational theory that makes a distinction between two types of segments. When linked to the same autosegment, some root nodes are headed, while others are not. However, such a distinction is inert on its own, and needs a separate mechanism to affect phonological computation. In OT, such mechanisms are constraints. In this section, I present constraints that penalize segments containing a head of a feature.

Segmental blocking is standardly attributed to feature co-occurrence constraints (4). This approach is based on the reasoning that the spreading feature is incompatible with another feature. A blocker lacks the spreading feature and satisfies a feature co-occurrence constraint. A target, on the other hand, violates a feature co-occurrence constraint. Icy targets cannot be attributed to the effect of feature co-occurrence constraints, as demonstrated in (5).

BDT involves several distinct components. One component is association between a feature to a root node. Another component is headedness; heads fall on some segments

[6] For binary prosodic words, see Itô & Mester 1992; Prince & Smolensky 1993/2004; Ussishkin 2000; Karvonen 2005; Kabak & Revithiadou 2009. For binary phonological phrases, see Ghini 1993; Inkelas & Zec 1995; Selkirk 2000; Truckenbrodt & Sandalo 2002; Schreuder & Gilberts 2004; Schreuder 2006; Truckenbrodt 2007; Elfner to appear.

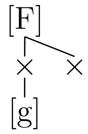
[7] For examples of recursive prosodic domains see Nespor & Vogel 1986; Itô & Mester 1992, 2008b, 2009; Peperkamp 1997; Fox 2000; Truckenbrodt 2007; Kabak & Revithiadou 2009; Elfner 2010, to appear.

but not on others. Icy targets can be associated with a feature, but cannot be heads of a particular feature when they also have some other feature. This calls for a more specific markedness constraint: a positional markedness constraint (Zoll 1998b; Piggott 2000; Crosswhite 2001; Smith 2005; de Lacy 2001, 2002, 2006). The rationale behind positional markedness constraints is that prominent positions (onsets, first syllables, stressed positions) make additional restrictions on what segments (or features) they permit. Positional markedness constraints may for instance refer to heads of prosodic constituents. Some languages do not allow syllable heads (nuclei) to be consonants; a positional markedness constraint prohibits a combination of a syllable head and a consonant (Itô 1986/1988; Zec 1988/1994, 1995; Prince & Smolensky 1993/2004; Broselow et al. 1997; Morén 2000, 1999/2001; Gouskova 2004). Other languages make restrictions on what is a possible foot head or a possible word head, enforced by constraints on foot heads and word heads, respectively (Kenstowicz 1997; de Lacy 2001, 2002, 2004, 2006, 2007b; Gouskova 2010). Similar constraints can be extended to feature heads in (12). The constraint is violated whenever a head of a feature [f] is also associated with a feature [g]. In the notation presented in (11), heads are marked by capitals, and this is reflected in the constraint name, which also contains a capital to designate heads—*[F g]. The structure in (12-b) includes a segment that violates the constraint.

(12) *[F g]

a. Assign a violation mark for every root node ×, iff × is a Head of a feature [f] and × is associated with [g].

b. *



Constraints on heads *[F g] differ from feature co-occurrence constraints *[f g]. While the former penalize only root nodes that are both heads of [f] and are associated with a [g], the latter penalize all segments that are associated with [f] and [g]. The dependents of [f] never violate *[F g], while they do violate *[f g] if they also contain [g]. In other words, the two constraints are in a stringency relation. This fact will play a crucial role in the analysis of icy targets, which satisfy *[F g], but not *[f g].

This concludes the discussion of the feature spreading mechanism, its formal properties, and the constraints that may inhibit spreading.

4 Icelandic

Icelandic u-umlaut is a prototypical case of icy targets. Recall section 2, where I attempted to account for the Icelandic data using classic autosegmental representations and OT constraints that refer to them. This attempt ultimately failed, because no established constraint can block spreading from an icy target. In response to this challenge, I introduced a representational modification of feature spreading (section 3). The basic idea of the new proposal is that branching is maximally binary and creates recursive nodes and domains. Each binary node is associated to a head and a dependent root node. This allows for a distinction between two types of targets: regular targets can be either heads or dependents of a feature, whereas icy targets can be dependents, but not heads.

The Icelandic icy target is [œ], which is associated with [−back] and [+round], but cannot be a head of these features. In other words, heads of the two features cannot be [+low] vowels. Such a conclusion is further supported by a separate reduction pattern, which raises unstressed [œ] to [ʏ]. These derived vowels are no longer [+low], which means that the restrictions on heads no longer apply. Consequently, spreading does not terminate.

In this section, I analyze the icy target pattern found in Icelandic. In section 4.1, I review the Icelandic data. In section 4.2, I give an analysis which is based on representational modifications of BDT (section 3.2), constraints on heads (section 3.4), and standard OT constraints.

4.1 Data

Icelandic u-umlaut is well described and has a long tradition of analyses within Generative Phonology (Anderson 1972, 1974, 1976a,b; Anderson & Iverson 1976; Howard 1972; Orešnik 1975, 1977; Richter 1982; Kiparsky 1984, 1985; Grijzenhout 1990; Árnason 1992; Karvonen & Sherman 1997; Gibson & Ringen 2000).

Icelandic has eight contrastive vowel qualities. The vowel inventory in (13) is complemented by features used in the analysis below. While other features are also needed to describe the vowel inventory fully, these are not directly relevant to u-umlaut. The particular features I use are rather standard, and are in line with the previous analyses of the pattern. The icy target segment [œ] is boxed.

(13) Icelandic vowel inventory (Thráinsson 1994)

	[−back]		[+back]	
[−low]	i			u
	ɪ	ʏ		
[+low]	ɛ	$\boxed{\text{œ}}$	a	ɔ
	[−rd]	[+rd]	[−rd]	[+rd]

Note that Icelandic distinguishes two front round vowels {ʏ, œ}, which differ in terms of the feature [low]. U-umlaut is triggered by a /ʏ/ which targets /a/ and turns it into [œ]. In terms of features, u-umlaut can be analyzed as spreading of [−back] and [+round] from a front high lax vowel /ʏ/ targeting only [+low] vowels.

The data in (14) show alternations in monosyllables when followed by a suffix. U-umlaut is triggered by several suffixes, which all contain an underlying /ʏ/. The data in this section come from Anderson (1972, 1974), Orešnik (1975, 1977) and Árnason (1992).[8] Only vowels are transcribed.

(14) U-umlaut in monosyllables

st[a]ð	'place.ACC.SG'	ˈst[œ]ð[ʏ]m	'place.DAT.PL'
b[a]nki	'bank.NOM.SG'	ˈb[œ]nk[ʏ]m	'bank.DAT.PL'
ˈg[a]ta	'street.NOM.SG'	ˈg[œ]t[ʏ]	'street.NOM/ACC.PL'
ˈf[a]ra	'go, travel'	ˈf[œ]r[ʏ]ll	'rambling'
ˈs[a]ga	'history'	ˈs[œ]g[ʏ](ˌleg[ʏ]r)	'historical'

[8] I also consulted Gunnar Hrafn Hrafnbjargarson—who was a linguist and a native speaker of Icelandic—for additional data.

Vowel reduction is a separate rule which raises all unstressed/non-initial [œ] to [ʏ]. The forms in (15) show that the output [a] in the nominative singular is not subject to vowel reduction, while [œ] is. Icelandic vowel reduction needs a separate account, which is outside the current discussion (see Crosswhite 2001; Smith 2005; de Lacy 2006, for independent proposals). The reduced roots will be analyzed later in (21) and (44).

(15) Vowel reduction

a. œ → ʏ / σ_1 ___ σ_0 C_1 ʏ

b.

NOM.SG	DAT.PL	
ˈh[ɛ]r[a̲]ð	ˈh[ɛ]r[ʏ̲]ˌð[ʏ]m	‘district’
ˈm[ɛ]ð[a̲]l	ˈm[ɛ]ð[ʏ̲]ˌl[ʏ]m	‘drug’
ˈ[ɔ]ð[a̲]l	ˈ[ɔ]ð[ʏ̲]ˌl[ʏ]m	‘allodium’

Vowel reduction interacts with u-umlaut. When [œ] surfaces as a result of u-umlaut, [œ] is raised to [ʏ], which creates a further trigger. In turn, u-umlaut applies again, resulting in an apparently iterative rule. Initial [œ] never reduces. More examples are provided in (16).

(16) Polysyllables with reduction

NOM.SG	DAT/ACC.PL	
ˈf[a̲]tn[a̲]ð	ˈf[œ̲]tn[ʏ̲]ˌð[ʏ]m	‘suit of clothes’
ˈb[a̲]k[a̲]ˌri	ˈb[œ̲]k[ʏ̲]ˌr[ʏ]m	‘baker’
ˈb[a̲]n[a̲]ˌni	ˈb[œ̲]n[ʏ̲]ˌn[ʏ]m	‘banana’
ˈ[a̲]lt[a̲]ˌri	ˈ[œ̲]lt[ʏ̲]ˌr[ʏ]	‘altar’
ˈk[a̲]st[a̲]ˌli	ˈk[œ̲]st[ʏ̲]ˌl[ʏ]m	‘citadel’

One class of words does not exhibit vowel reduction, as shown in (17). In these roots, u-umlaut is limited to the last vowel of the root. The restriction on the root-final vowel does not depend on secondary stress. For example, both ˈ[a]*tl*[œ̲]ˌ*s*[ʏ]*m* ‘atlas-DAT.PL’ and ˈ[a]*lm*[a]ˌ*n*[œ̲]*k*[ʏ]*m* ‘calendar-DAT.PL’ show no reduction, despite the fact that the root-final vowel has secondary stress in ‘calendar’, but not in ‘atlas’. Grijzenhout (1990) builds on this fact and proposes recursive feet to account for the pattern. While her approach works for Icelandic, it does not for other cases of icy targets, to be discussed in the subsequent sections.[9]

(17) Polysyllables without reduction

NOM.SG	DAT.PL	
ˈ[a]tl[a̲]s	ˈ[a]tl[œ̲]ˌs[ʏ]m	‘atlas’
ˈkv[a]ðr[a̲]t	ˈkv[a]ðr[œ̲]ˌt[ʏ]m	‘square’
ˈsk[a]nd[a̲]ˌli	ˈsk[a]nd[œ̲]ˌl[ʏ]m	‘scandal’
ˈk[a]r[a̲]t	ˈk[a]r[œ̲]ˌt[ʏ]m	‘carat’
ˈ[a]lm[a]ˌn[a̲]k	ˈ[a]lm[a]ˌn[œ̲]k[ʏ]m	‘calendar’

[9]The data are complicated by the fact that epenthetic [ʏ] does not trigger u-umlaut (see Finley 2008 for a review of similar cases). Furthermore, u-umlaut may also be triggered by floating affixes. Sometimes, there are several pronunciations available for each form. For example, ‘cask.DAT.PL’ can be pronounced with reduction kj[œ]r[ʏ]ld[ʏ]m, without reduction but with icy targets kj[a]r[œ]ld[ʏ]m, and without reduction throughout the root kj[œ]r[œ]ld[ʏ]m. Here, I account for the first and the second variety.

4.2 Analysis

In this section, I give an analysis of icy targets in Icelandic. I first introduce the constraints, followed by an evaluation of a form without reduction. Then I move on to reduced forms. Finally, I discuss the remaining issues.

Recall that u-umlaut can be analyzed in terms of spreading of [−back] and [+round]. Furthermore, recall that a high front round vowel /ʏ/ acts as a trigger, targeting only a back low unrounded vowel /a/, turning it into [œ]. The non-participation of other segments is somewhat puzzling, but it suggests that the features [−back] and [+round] cannot spread separately. Only a segment that is both [−back] and [+round] can be a trigger, and only a segment that is neither [−back] nor [+round] is targeted. For example, Icelandic also has [u] in its inventory (13), yet [u] never triggers rounding nor undergoes fronting. A phenomenon of joint spreading of two features, which fail to spread separately is a case of the sour grapes problem (Padgett 1995).

There are several ways of analyzing this sour grapes pattern. The first option is representational, in which a feature node dominating [−back] and [+round] spreads rather than two separate features. For example, vowel place is such a feature node in most autosegmental accounts (Clements 1985b, 1991; Clements & Hume 1995; Sagey 1990; Odden 1991, 1994; Morén 2003, 2006). Segments that already have this feature node associated with only one of the two features are not targeted and do not trigger any spreading.

Another option is constraint-based. Conjoined faithfulness and markedness constraints (e.g. Baković 2000; Łubowicz 2002b) can model the patterns in which two features must spread, but one cannot. I demonstrate this point for [ɔ]. The ranking MaxLink[+rd] ≫ DepLink[−bk]&$_{seg}$Align-L[+rd] penalizes candidates that only spread [−back] but not [+round]. Since [ɔ] already contains [+round] (which is retained due to the high ranked MaxLink[+round]) spreading of [−back] alone incurs a violation of the conjoined constraint. In contrast, the mapping /a/ → [œ] does not violate the constraint, since both features spread, and the alignment constraint in DepLink[−back]&$_{seg}$Align-L[+round] is not violated. The sour grapes problem is a challenge for classic OT and the Icelandic pattern is no exception. This question is essentially beyond the scope of this paper.

4.2.1 Alignment

Feature spreading is enforced by markedness constraints. As we have seen in section 2, one approach includes feature alignment to a domain edge (Kirchner 1993; Smolensky 1993; Cole & Kisseberth 1995b; Itô & Mester 1995a; Akinlabi 1996; Pulleyblank 1996; Golston 1996; McCarthy 1997; Ringen & Vago 1998; Archangeli & Pulleyblank 2002, among many others). In (2), I made use of the alignment constraint Align([+round], L; PWd, L; V).

Classic alignment constraints face several challenges. To start with, alignment produces pathologies. For example, the constraint Align([+round], L; PWd, L; V) can be satisfied only by spreading of [+round] to the *nearest* left edge of a prosodic word, which can be either the prosodic word containing the trigger or the first following one. This pathology is known as the Midpoint Pathology (Hyde 2008).

Another challenge to alignment is formal. Alignment constraints required for feature spreading are gradient. For example, the locus of violation for the constraint Align([+round], L; PWd, L; V) are all vowels between the leftmost vowel and the left edge of a word. The size of the locus—or the number of violating vowels—matters. It is crucial for the analysis that one vowel incurs less violation marks than two, two vowels incur less violation marks than three vowels, etc. McCarthy (2003) shows that the effects of gradient alignment can be achieved with categorical constraints, hence Con should contain only categorical constraints. While this formal problem is independent of the main argument of this paper, which is the existence of icy targets, it is nevertheless necessary to use some kind of markedness constraints that drive assimilation. Since I will use alignment constraints, I would like to show that they can be modified to retain the gradient effect (i.e. each vowel incurs a violation mark) even if they are formally categorical (i.e. there is at most one violation mark per locus of violation).

Hyde (2008) proposes markedness constraints that retain many characteristics of classical alignment constraints. In particular, the constraints prefer outputs in which two categories (features, domains) are aligned with one another. However, while classical alignment constraints assign violation marks to categories and their edges, Hyde's constraints assign violation marks to sets of violating pairs or triplets of categories. This means that for a given input, the violation marks will be dependent on both the aligned categories and the offending categories. More specifically, while the categorical alignment constraint Align([+round], R, Prosodic Word, R) can be violated maximally once per instance of [+round], Hyde's constraints effectively incur violation marks for each unrounded segment after [+round], as long as such a segment is within a Prosodic Word.

The alignment constraint required in Icelandic is based on one type of Hyde's constraints, which he calls *right edge distance sensitive*. These constraints penalize triplets of (prosodic) domains that satisfy particular structural requirements. In (18) we see an implementation of Hyde's template that captures u-umlaut. The feature alignment constraint assigns a violation mark for every triplet ⟨PWd, [+round], vowel⟩ if and only if (i) the PWd is associated with [+round] and a vowel, and (ii) [+round] precedes the vowel.

(18) Align-L[+round]
*⟨PWd, [+rd], v⟩ / PWd
v [+rd]

The definition of Align-L[+round] (18) includes the notion of precedence. In Autosegmental Phonology, precedence is established between like categories (Goldsmith 1976). For any two root nodes, there is a unique precedence relation: one always precedes the other. Similarly, for any two instances of the same feature, one always precedes the other. The definition in (18) requires a precedence relation between a vowel and [+round]. As long as the relevant vowel precedes all segments associated with [+round], the constraint is clearly violated. When the vowel is associated with the relevant instance of [+round], however, there is no precedence relation among them, and the constraint is satisfied. For this reason, spreading to vowels will satisfy the constraint Align-L[+round]. The precise formalization of alignment constraints is rather complex—see Hyde (2008) and [suppressed] for details. The presentation here is limited to the constraints required for assimilation.

The modified alignment constraints are superior to classic alignment. First, the constraint in (18) is formally categorical, since each triplet constitutes a locus of violation, which incurs exactly one violation mark. Furthermore, this constraint is never satisfied by spreading outside of the word.[10] Now that I cleared up the relevant formal issues behind alignment constraints, I proceed to an analysis of Icelandic u-umlaut.

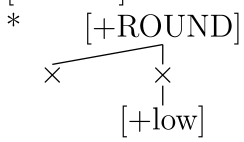
4.2.2 Roots without reduction

In Icelandic, the alignment constraint Align-L[+round] in (18) outranks the faithfulness constraint DepLink[+round] (3). If it were the opposite, no spreading would occur. However, as seen in (5), these two constraints cannot account for icy targets. There must be another, dominant constraint that inhibits spreading from some targets.

In section 3.2, I proposed that spreading is restricted to maximally binary branching. When spreading to multiple targets is preferred, recursive domains are added. Each domain contains a head and a non-head node. Icy targets can be associated with a feature, but cannot be a head, which is why they terminate spreading. Recall the constraint template against heads of features in (12). The constraint *[F g] is violated by a root node that is associated with [g], while also being a head of [f]. The headed feature is the one that spreads—[+round] Icelandic. The second feature is the one that distinguishes icy from regular targets. In Icelandic, only the low vowel [œ] inhibits spreading, but not by a high vowel [ʏ] (cf. section 4.1). This means that the constraint on heads is violated by [œ], but not by [ʏ]. The second feature is [+low]. The constraint *[+ROUND +low] in (19) penalizes heads of [+round] that are also associated with [+low]. Heads are marked by capitals.

(19) *[+ROUND +low]

a. Assign a violation mark for every root node ×, iff × is a Head of the feature [+round] and × is associated with [+low].

b. 

Icy targets are found in the forms without reduction like *j*[a]*p*[œ]*n*[ʏ]*m* 'Japanese.DAT.PL'. The ranking of the three constraints is shown in (20). Candidate (a) shows spreading to one target and contains one feature head. Recall that a branching feature node is marked by a capital, and the root node containing a head is aligned with the corresponding feature node. In addition, triggers (or segments with no spreading) contain square brackets to indicate a single instance of a feature. Candidate (b) has no spreading and hence does not contain any feature heads. Candidate (c) shows total spreading and candidate (d) shows additional raising of the second vowel to [ʏ].

[10]Several other problems with classic alignment constraints persist even in this new version of alignment constraints (see Baković 2000, Wilson 2003, Krämer 2003, McCarthy 2004, 2009, Blaho 2008, Finley 2008, inter alia). These issues are beyond the scope of this paper. See [suppressed] for an indepth treatment of alignment.

(20) japœnʏm ‘Japanese.DAT.PL’

[+rd] / j a p a n - ʏ m / [+lo] [+lo]	MaxLink[+lo]	*[+RD+lo]	Align-L[+rd]	DepLink[+rd]
[+RD] j a p œ n ʏ m a. ☞ [+lo] [+lo]			1	1
[+rd] j a p a n ʏ m b. [+lo] [+lo]			2 W	L
[+RD] +RD j œ p œ n ʏ m c. [+lo] [+lo]		1 W	L	2 W
[+RD] +RD j œ p ʏ n ʏ m d. [+lo]	1 W		L	2 W

Recall tableau (5) and the fact that the alignment and faithfulness constraints cannot produce an icy target candidate. By introducing heads in the representation of spreading and constraints that refer to them, the predictions are different. The evaluation of the new alignment constraint is identical to the classic Align([+round], L; PWd, L; V). For example, candidate (20-a) has three vowels. The feature [+round] is associated with the second and the third vowel, which themselves do not violate the alignment constraint. The leftmost vowel, on the other hand, does. This is because the leftmost vowel precedes the root nodes associated with [+round] and it is not associated with that instance of [+round]. In short, the alignment constraint prefers spreading to all vowels preceding the trigger, which is the case for candidate (c). However, this candidate fatally violates the constraint on heads *[+ROUND +low]. Of the remaining candidates, (a) fares best on alignment. Candidate (d) shows raising enforced by *[+ROUND +low], however, this candidate also fatally violates Max[+low]. We can conclude that BDT can account for icy targets in Icelandic words without reduction.

4.2.3 Roots with reduction

Forms with reduction follow a different pattern. In reduced roots, rounding is complemented by an additional rule that raises unstressed [œ] to [ʏ]. Unexpectedly, a derived [ʏ] triggers rounding of preceding low vowels. While this fact is indeed unexpected if viewed from a classic representational view, it is predicted under BDT. In particular, the constraint on heads *[+ROUND +low] restricts spreading from [œ], but not from [ʏ]. Since *[+ROUND +low] is never violated by [ʏ], rounding can spread to preceding low vowels, as enforced by the alignment constraint Align-L[+round] which outranks the faithfulness constraint DepLink[+round].

The forms with reduction are similar to those without reduction in that the constraint on heads outranks the alignment constraint. At the same time, there are also some differences in the ranking. The difference between unreduced and reduced words is lexical. There are several ways of capturing this situation in OT. One option includes the use of (partially) different grammars. The model based on cophonologies gives a different ranking of the same constraints across variants (Inkelas et al. 1996, 1997; Inkelas & Zoll 2005, 2007; Anttila 2002).[11] In the forms without reduction as in (20), MAXLINK[+low] outranks the alignment constraint ALIGN-L[+round]. As a consequence, rounding never triggers raising. On the other hand, in the forms with reduction like *d*[œ]*s*[ʏ]*ð*[ʏ]*st*[ʏ]*m* 'most exhausted.DAT.PL' in (21) the constraint MAXLINK[+low] is ranked below ALIGN-L[+round]. Hence, vowels are raised and rounding applies iteratively. Here I do not attempt to analyze the reduction pattern, which needs a separate account, I merely discuss the constraints already introduced for forms without reduction.

In tableau (21), candidate (a) wins because it exhibits reduction in all unstressed vowels and u-umlaut throughout the root, satisfying the high ranked *[+ROUND +low] and ALIGN-L[+round]. Other candidates violate one of these two constraints. Candidate (b) has no spreading, fatally violating ALIGN-L[+round]. Candidate (c) has an icy target, and the preceding unrounded vowels violate the alignment constraint. This candidate would be the winner in the ranking required for unreduced words, shown in tableau (20). The difference between the roots with reduction and those without reduction is in the ranking of MAXLINK[+low]. Candidate (d) with total spreading but no reduction incurs two violation marks on *[+ROUND +low] since two low vowels contain a head of [+round].

(21) dœsʏðʏstʏm 'most exhausted.DAT.PL'

[+rd] / d a s a ð a s t ʏ m / [+lo] [+lo] [+lo]	*[+RD+lo]	AL-L[+rd]	MAXLINK[+lo]	DEPLINK[+rd]
a. ☞ [+RD] +RD +RD d œ s ʏ ð ʏ s t ʏ m [+lo]			2	3
b. [+rd] d a s a ð a s t ʏ m [+lo] [+lo] [+lo]		3 W	L	L
c. [+RD] d a s a ð œ s t ʏ m [+lo] [+lo] [+lo]		2 W	L	1 L
d. [+RD] +RD +RD d œ s œ ð œ s t ʏ m [+lo] [+lo] [+lo]	2 W		L	3

[11]The attested variation is also consistent with an alternative approach based on lexical indexation (Itô & Mester 1995a,b, 1999, 2001, 2003, 2008a; Fukazawa et al. 1998; Pater 2000, 2007, 2009). According to this approach, constraints come in two classes—general and morphologically relativized (i.e., indexed).

4.2.4 Roots with /œ/

We have now seen that BDT unifies both types of words in Icelandic by positing a single constraint on heads. Before I conclude the analysis of Icelandic, I would like to address one further prediction of BDT. As we have seen, the defining characteristic of icy targets is that they terminate spreading. In the present context, this fact is attributed to restrictions on feature heads that are formalized both in terms of representations and constraints. However, these restrictions do not distinguish between underlying and derived segments. Consequently, the prediction is that when an icy target segment appears in the input, no spreading occurs.

Underlying /œ/ is limited to a small set of roots. One such example is *m*[œ]*r* 'suet'. However, to determine whether /œ/ triggers rounding or not, we need to look for roots with a preceding /a/. To the best of my knowledge, only one root has such characteristics: [a]*m*[œ]*b*[a] 'amoeba'. We can see that rounding does not spread to the preceding /a/, which is in line with the predictions. More specifically, BDT correctly predicts that an input /œ/ does not trigger u-umlaut, since the constraint against feature heads *[+ROUND +low] in (19) applies to all output low vowels (underlying or derived). The remaining point is to demonstrate this effect.

Tableau (22) shows the evaluation for the Icelandic input /amœba/ 'amoeba'. Candidates without spreading differ with respect to headedness. Recall that heads are defined only for binary branching feature nodes, as in (9). That is, when there is a feature node linked to two root nodes, exactly one of these two root nodes is a head. This definition says nothing about features linked to a single root node. Hence, both structures are possible: one that contains a head and one that does not. Candidate (22-b) contains a head, which is indicated by a capitalized [+ROUND]. This candidate fatally violates *[+ROUND +low]. The winning candidate (a), on the other hand, does not contain a head. Candidate (b) also harmonically bounds (a). Candidate (c) shows deletion of the [+round] feature, which fatally violates of MaxLink[+round]. Candidate (d) with spreading also violates *[+ROUND +low].

The final candidate (e) has an epenthetic [+round]. Epenthesis differs from spreading in that no feature heads are involved. Since *[+ROUND +low] is not violated in this case, it might be possible that this constraint prefers feature copying rather than spreading. However, as evident from the tableau, the constraint *[+ROUND +low] is not able to generate feature epenthesis rather than spreading. This is because the epenthetic candidate (e) additionally violates the alignment constraint. It actually turns out that candidate (e) is harmonically bounded by (b), since it violates DepLink[+round] and Dep[+round] (not shown) in addition to the alignment constraint.

(22) amœba ‘amoeba’

[+rd] / a m œ b a / [+lo] [+lo] [+lo]	MaxLink[+rd]	*[+RD+lo]	Al-L[+rd]	DepLink[+rd]
a. ☞ [+rd] a m œ b a [+lo] [+lo] [+lo]			1	
b. [+RD] a m œ b a [+lo] [+lo] [+lo]		1 W	1	
c. a m a b a [+lo] [+lo] [+lo]	1 W		L	
d. [+RD] œ m œ b a [+lo] [+lo] [+lo]		1 W	L	1 W
e. [+rd] [+rd] œ m œ b a [+lo] [+lo] [+lo]			1	1 W

Tableau (22) demonstrates that unary domains consisting solely of heads are harmonically bounded and can never surface. This is because candidates with a single head without a dependent violate *[F g], while the candidates lacking a head do not, without violating any other constraints. In other words, heads are a marked configuration, which can surface only if spreading is preferred.

There is one final consideration. Given Richness of the Base, heads can appear in the input. If so, they must map to some well-formed output. In Icelandic, underlying heads on /œ/ have no effect on the output, since constraints on heads are markedness constraints. Markedness constraints evaluate only outputs, it does not matter whether heads are present in the input or not.[12]

This concludes the analysis of u-umlaut in Icelandic. BDT has been shown to account for the absence of any spreading from [œ] in a simple, yet quite restrictive fashion.

5 Sanskrit

So far in this paper, I introduced the concept of icy targets in Icelandic and gave a representational account of it. In particular, I claimed that feature spreading is maximally binary, hierarchical, and recursive. We have seen that Icelandic u-umlaut involves vowel place features. In this section, I extend the account to a case of assimilation that involves a consonant feature. Thus, icy targets are not specific to vowel harmony, but may also be found in other types of assimilation. This section focuses on icy targets found in Nati in Sanskrit, which is a case of consonant harmony. I first describe the data (section 5.1), followed by an analysis based on constraints on feature heads (section 5.2).

[12] I remain agnostic whether faithfulness constraints can refer to feature heads. If so, such constraints are ranked below *[+RD +lo] in Icelandic.

5.1 Data

Much like Icelandic u-umlaut, Nati in Sanskrit has drawn a great deal of attention in the history of Generative Phonology (Johnson 1972; Selkirk 1980a; Kiparsky 1985; Schein & Steriade 1986; Cho 1991; Hall 1997; Ní Chiosáin & Padgett 1997; Gafos 1996/1999; Hansson 2001; Rose & Walker 2004; Kaplan 2008). Nati is an alternation in which retroflexion spreads within coronals. In particular, a feature responsible for retroflexion spreads from the continuants {r, ʂ} to the first following /n/. The resulting retroflex [ɳ] is an icy target, blocking further spreading.

The coronal inventory of Sanskrit including the relevant features is presented in (23). There are three sets of coronal segments: dental, retroflex, and palatal consonants. Within each set, there are four oral stops, one nasal, and two continuants. Only continuants can serve as triggers in Nati, and the only target is /n/ which is turned into [ɳ].

(23) Sanskrit coronal inventory (Whitney 1889; Gafos 1996/1999)

	[− c o n t i n u a n t]					[+c]		
[+anterior]	t	t^{h}	d	d^{h}	n	s	l	[−distributed]
[−anterior]	ʈ	ʈ^{h}	ɖ	ɖ^{h}	$\boxed{\text{ɳ}}$	ʂ	r	
	c	c^{h}	ɟ	ɟ^{h}	ɲ	ʃ	j	[+distributed]
	[− n a s a l]				[+n]	[−n]		

I follow most previous accounts in assuming that retroflex coronals are [−anterior] and [−distributed]. (e.g. Johnson 1972; Schein & Steriade 1986; Sagey 1990; Hall 1997; Ní Chiosáin & Padgett 2001). These two features spread together in Nati, but cannot spread separately. This is parallel to the situation found in Icelandic, which has joint rounding and fronting.

The data in (24) demonstrate that /n/ alternates with [ɳ] only if preceded by a trigger continuant {r, ʂ}. The alternation applies across vowels and non-coronal consonants (e.g. [kʂub^{h}-aːɳ̲a] 'quake-MID.PART') within the same phonological phrase (Selkirk 1980a). Coronals fall into three groups with respect to their role in Nati. Retroflex coronal continuants {r, ʂ} trigger spreading. The dental nasal stop /n/ is the target. All other coronals block the process. For instance, 'wipe-MID.PART' surfaces faithfully [marj-aːn̲a], rather than with retroflexion *[marj-aːɳ̲a], because [j] interferes with spreading. Palatal coronals cannot become retroflex (Hamann 2003; Hall & Hamann 2010).

(24) Nati Retroflexion (Whitney 1889; Allen 1951; Schein & Steriade 1986)

With Nati		No Nati	
iʂ-ɳ̲aː	'seek-PRES'	mr̩d-naː	'be gracious-PRES'
pr̩-ɳ̲aː	'fill-PRES'		
puːr-ɳ̲a	'fill-PAS.PART'	b^{h}ug-na	'bend-PAS.PART'
vr̩k-ɳ̲a	'cut up-PAS.PART'		
pur-aːɳ̲a	'fill-MID.PART'	kʂved-aːna	'hum-MID.PART'
kʂub^{h}-aːɳ̲a	'quake.MID.PART'	marj-aːna	'wipe-MID.PART'
cakʂ-aːɳ̲a	'see-MID.PART'		
kr̩p-a-maːɳ̲a	'lament-MID.PART'	kr̩t-a-maːna	'cut-MID.PART'

The icy target pattern becomes apparent when more than one /n/ follows a retroflex coronal continuant, as in (25). For example, in [varɳ̲-an̲aː-n̲am] 'description-MID.PART-

GEN.PL' only the first coronal nasal is retroflex, while the rest remain unaffected. This reveals that [ɳ] is an icy target: retroflexion spreads to [ɳ], which also blocks further spreading. In other words, while {r, ʂ, ɳ} can be associated with the feature [−anterior], only {r, ʂ} can be the triggers.

(25) Icy targets (Whitney 1889; Hansson 2001)

With Nati		No Nati	
pra-ɳi-naːja	'lead forth'	n̲iː	'lead'
		kr̩ɳ-vaːn̲a	'make-MIDDLE.PART'
tvar-aɳaː	'hasting-MID.PART'	varɳ-an̲aː-nam	'description-MID.PART-GEN.PL'

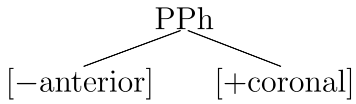
Nati strongly resembles Icelandic u-umlaut in one respect: both show icy targets. This similarity is mirrored in the analysis. I will make use of the mechanism of BDT developed for Icelandic u-umlaut and extend it to Sanskrit retroflex harmony.

5.2 Analysis

Here, I analyze Nati as the spreading of two features, [−distributed] and [−anterior]. While these two features are rather standard, the fact that they spread is not so straightforward. By and large, vowels make better targets than consonants, which means that features generally skip consonants, not vowels (Howard 1972; Jensen 1974; Odden 1994; Steriade 1995). For example, there is no language in which [+round] would target a consonant across an intervening vowel. A very similar pattern, however, is attested in Nati and in consonant harmony (Hansson 2001; Rose & Walker 2004). A standard analysis of consonant harmony is Agreement by Correspondence. In this approach, assimilation is attributed to the surface correspondence between consonants, not spreading. The crucial question is whether Nati constitutes a genuine case of consonant harmony, and if so, can it be analyzed as agreement rather than spreading. Hansson (2001) and Rose & Walker (2004) observe that Nati is anomalous with respect to other consonant harmonies in two respects. First, Nati shows restrictions on triggers not found in other consonant harmonies. Second, the Nati triggers {ʂ, r} and targets [ɳ] do not form a natural class to the exclusion of all other segments. This clashes with the vast majority of consonant harmony cases, in which triggers affect similar segments. Consequently, Hansson (2001) concludes that Nati does not affect agreement, but is a case of spreading. Here, I adopt such a conclusion. At the same time, I remain agnostic whether consonant harmony *in general* can be attributed to spreading or not.

If Nati is a case of spreading, it must be driven by one or more alignment constraints. As we have seen in section 4.2.1, alignment constraints have three variables: a domain, a spreading feature, and some targeted structure (e.g. a vowel). Here, I will account for spreading of [−anterior], and leave out [−distributed] entirely (as I have done with [−back] in Icelandic). The feature [−anterior] targets all coronals. One way to capture this is to say that all segments that are associated with [+coronal] are targets and referred to by the alignment constraint. This is grounded in the fact that retroflexion shows different locality facts than vowel harmony. In particular, we know of languages in which retroflexion is triggered by one coronal and targets another across all vowels—such as Sanskrit and Kinyarwanda (Walker et al. 2008). Furthermore, there are also languages in which retroflexion targets vowels across non-coronals—as in some dialects of Kalasha (Heegård & Mørch 2004). However, we know of no languages with retroflexion that targets vowels and consonants across a (non-retroflex) coronal. This suggests that the features responsible for retroflexion—which includes [−anterior]—prefer coronal consonants to other segments. In the present context, such preference can be captured with alignment constraints. Hence, the alignment constraint active in Nati contains [−anterior] as the spreading feature and [+coronal] as the third category, as in (26). The domain is a phonological phrase (Selkirk 1980a). The constraint is similar to Align-L[+round] in its structure, but involves different features and precedence relations.

(26) Align-R[−anterior]
*⟨PPh, [−anterior], [+coronal]⟩ /

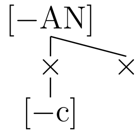


Spreading of [−anterior] is preferred when Align-R[−anterior] (26) outranks the faithfulness constraint DepLink[−anterior]. This, however, is not the complete story. Recall that retroflexion shows a restrictive pattern with only continuants as triggers. Furthermore, derived retroflex nasals are icy targets, terminating further retroflexion. The restrictions on icy targets are formalized in terms of markedness constraints on feature heads. In Nati, nasals pattern with oral stops. This strongly suggests that the relevant constraint penalizes feature heads of [−anterior] on plosives. This constraint, *[−ANTERIOR −continuant] (27), outranks the alignment constraint. Keep in mind that constraints on heads do not have a directional value. Hence, they are equally violated by a left-headed structure as in (27-b), or a mirror-image right-headed structure.

(27) *[−ANTERIOR −continuant]

a. Assign a violation mark for every root node ×, iff × is a Head of the feature [−anterior] and × is associated with [−continuant].

b. *



The effects of the constraint on heads *[−ANTERIOR −continuant] can be seen in tableau (28), where three candidates are shown. Candidate (a) has an icy target, candidate (b) has no spreading, while candidate (c) has total spreading. Candidate (c) contains two heads of [−anterior] on [ɳ], and thus crucially violates *[−ANTERIOR −continuant]. Of the remaining candidates, the winning candidate (a) violates the alignment constraint one time fewer than candidate (b). Note that the alignment constraint is effectively violated once by each anterior coronal.

(28) var̥ɳanaːnaːm ‘description.GEN.PL’

[−an] / v a r̥ n - a n aː - n aː m / [+c] [+c] [+c] [+c]	*[−AN−c]	ALIGN-R[-an]	DEPLINK[−an]
a. ☞ [−AN] va r̥ ɳ a n aː n aːm [+c] [+c] [+c] [+c]		2	1
b. [−an] va r̥ n a n aː n aːm [+c] [+c] [+c] [+c]		3 W	L
c. [−AN] −AN −AN va r̥ ɳ a ɳ aː ɳ aːm [+c] [+c] [+c] [+c]	2 W	L	3 W

The analysis of Nati just discussed complements Icelandic. Both languages involve a similar pattern that offers support for a theory of autosegmental spreading with headed, binary, and recursive domains.

6 Ikwere

Up to this point, I have discussed two cases of icy targets. Both patterns are specific to one class of triggers and targets, to the exclusion of all other segments. In particular, Icelandic u-umlaut involves vowels, whereas Nati in Sanskrit involves only coronal consonants; all other segments are transparent. The next step would be to look at patterns which have no transparent segments. Nasal harmony often affects an uninterrupted string of targets, and will be the focus of the discussion in this section. In particular, I describe the icy target pattern in Ikwere nasal harmony.

Ikwere displays icy targets just like Icelandic and Sanskrit. At the same time, Ikwere differs from the other two patterns in several respects. First, no segments are transparent. This fact is attributed to alignment constraints. Second, nasal harmony is bidirectional, which is predicted by two alignment constraints that differ solely in the precedence relations. Third, icy targets are limited to leftward spreading, and do not appear in rightward spreading. As we have seen so far, icy targets are enforced by a separate directionless constraint on feature heads. Such a constraint can be ranked above one, but below the other alignment constraint. In Ikwere, the constraint on heads is ranked above than the constraint preferring leftward spreading, but below the one preferring rightward spreading.

6.1 Data

Ikwere nasal harmony is triggered by underlying nasal vowels and targets both preceding and following segments within “phonological roots” (Clements & Osu 2005). Consonants fall into two main groups, shown in (29). Obstruents (first and second row) block spreading, while non-obstruents (third row) nasalize (fourth row). Icy targets in Ikwere are nasal sonorant stops {m, 'm, n}. They alternate with their non-nasal counterparts {ḅ, 'ḅ, l}.[13] The segments involved in the icy target pattern are boxed in the inventory below.

(29) Ikwere consonant inventory (Clements & Osu 2005)

[−sonorant]		p		f	t	s	c	k	k^w			} BLOCKERS
	[−nasal]	b		v	d	z	ɟ	g	g^w			
[+sonorant]		ḅ	'ḅ		l	r	j	ɰ	w	h	h^w	} TARGETS
	[+nasal]	m	'm		n	r̃	j̃	ɰ̃	w̃	h̃	$\tilde{h}^w$	

The data in (30) reveal the role of these two groups of segments in nasal harmony. Obstruents always block nasalization (30-a). We know this because plain obstruents can appear next to nasal vowels. Sonorants, on the other hand, are targets (30-b). A sequence of sonorants will always agree in nasality. For example, the form [ɔbã̱ṟ̃ã] 'blood' is attested because the sequence [ãr̃ã] agrees in nasality, while the forms *[ɔbaṟã̱]/*[ɔbã̱ṟa] 'blood' are unattested. This is because sonorants cannot act as blockers in nasal harmony. These co-occurrence generalizations are supported by alternations in which nasality spreads to suffixes (30-c).

(30) Ikwere nasal harmony (Clements & Osu 2005)

a. Obstruents block harmony
   bis̱ĩ 'poison'
   baḏũ 'human being'
   mãḵɔ 'also'

b. Sonorants undergo harmony
   ɔbãṟ̃ã 'blood'
   mɔ̃ỹ̱ɔ̃ 'urine'
   ɛkãṟ̃ã 'strong odor'

c. Morphologically complex forms
   o kẽ-g̱^{w}u 's/he is holding'
   (ɔ) bya-ṟʊ [...] 's/he came yesterday' (ɔ) w̃ɔ̃-ṟ̃ʊ̃ [...] 's/he drank some wine'
   (o) ri-ḻem 's/he has eaten' (ɔ) bã-ỹã-ṉẽm 'she has come in'

A closer look at the data in (30) raises some concerns. In particular, the forms with nasalized sonorants always involve multiple nasal vowels, which means that it is impossible to tell which vowel is the trigger. I will now demonstrate that this issue is not crucial for the analysis. In (31), I consider a hypothetical string /karawaka/ with four vowels, which could all be underlyingly nasal. The input with the final nasal vowel /karawakã̱/ (31-a) must surface faithfully, because the preceding stop blocks nasal harmony. The remaining three inputs map to the same output.

[13] Two of these segments {ḅ, 'ḅ} are non-explosive stops. Non-explosive stops are cross-linguistically rare. Clements & Osu (2002, 2003) show that the articulation of non-explosive stops exhibits no build-up of oral air pressure during occlusion and no audible explosion at release. This leads them to conclude that non-explosive stops are not proper plosives. While this poses a significant challenge for most feature theories, it is ultimately beyond the scope of this paper, which is to account for icy targets.

(31) Possible mappings in Ikwere

a. /karawakã̲/ → [karawakã]
b. /karawã̲ka/ ↘
c. /karã̲waka/ → [kãr̃ãw̃ãka]
d. /kã̲rawaka/ ↗

The actual data and the hypothetical forms indicate that a sonorant will always surface nasal as long as it is next to another nasal sonorant. What the data do not reveal is which of multiple nasal vowels is the trigger. Regardless of which of the first three vowels is underlyingly nasal, we get the same output (31-b)–(d). With this caveat in mind, we can proceed to nasal sonorant stops, the distribution of which is different.

Nasal sonorant stops {m, 'm, n} differ from other sonorants. The coronal sonorant stop [n] alternates with the coronal lateral [l], while bilabial sonorant stops {m, 'm} alternate with bilabial non-explosive stops {ḅ, 'ḅ} (cf. [ḅ̲ekej] 'white man', [ɔkʷʊ̃] 'palm nut' vs. [akʷʊ̃-m̲ẽkej] 'coconut'). The behavior of nasal sonorant stops {m, 'm, n} is somewhat puzzling at first. The data in (32) come in two sets. First, we see that {m, 'm, n} can occur between two nasal vowels. These unequivocally show that nasal sonorant stops are targets at least in some positions. Furthermore, the alternations suggest that nasals are targets in rightward spreading. What about leftward spreading? This is where the second set of data is relevant. In (32-b) we see nasal sonorant stops in the position between an oral and a nasal vowel. Given the data in (32-a) we would expect that such forms are not possible, since nasals are only possible when flanked by nasal vowels (or word boundaries). The only way to make sense of these data is to say that {m, 'm, n} are icy targets in leftward spreading. This means that they undergo nasalization, but also block it, hence the preceding vowels are oral. If we then return to the data in (32-a), it becomes clear that the trigger is the leftmost vowel. In short, the nasal sonorant stops are regular targets in rightward spreading, but icy targets in leftward spreading.

(32) Nasal sonorant stops

a.	w̃ẽn̲ẽ	'sibship'			
	ɔmĩr̃ĩm̲ã	'meat, flesh'			
	mmĩn̲ĩm̲ĩ	'species of tree'			
	(o) ri-l̲em	's/he has eaten'		(ɔ) w̃ɔ̃-n̲ɛ̃m	's/he has drunk'
b.	kɪn̲ã	'now'			
	ɪbɪn̲ẽ	'type of fruit'			
	akam̲ʊ̃	'pap'			
	ogʷum̲ãgala	'chameleon'			

To make the distributional facts clear, let us look at what happens to hypothetical mappings as we have done for other sonorants. In (33), I consider a hypothetical string /lelele/, in which exactly one vowel is nasal, yielding three possible inputs. The interest of the current discussion is the status of the segmental pair {l, n}. Recall that other sonorant consonants are always flanked by nasal vowels as in (31-b–d). This differs from the behavior of {l, n}. If [n] were a target in both directions, all inputs should map to [nẽnẽnẽ], which is not the case. Instead we get three different outputs, which suggest that [n] terminates rightward spreading and is an icy target.[14]

[14]An alternative solution why nasal harmony terminates at a nasal sonorant stop would be to say that spreading applies within a syllable. However, we have already seen in (31) that nasal harmony applies beyond the syllable boundary of the triggering vowel when the target is a sonorant. Hence, it seems

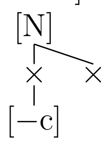
(33) Possible mappings in Ikwere
  a. /lelelẽ̲/ → [lelenẽ̲]
  b. /lelẽ̲le/ → [lenẽ̲nẽ]
  c. /lẽ̲lele/ → [nẽ̲nẽnẽ]

To sum up, the data strongly suggests that {m, 'm, n} are icy targets in leftward nasal harmony, but regular targets rightward nasal harmony.

6.2 Analysis

I analyze Ikwere nasal harmony in three steps. First, I account for icy targets by introducing the relevant constraint on heads. Second, I discuss the alignment constraints. Finally, I present the ranking of these constraints.

Recall section 3.4 and the fact that icy targets surface due to the constraints on feature heads *[F g]. As we have just seen, icy targets in Ikwere are nasal sonorant stops {m, 'm, n}. A rather standard assumption is that the features which distinguish nasal sonorant stops from other nasal sonorants are [+nasal] and [−continuant]. The constraint *[+NASAL −continuant] in (34) penalizes plosives which are heads of the [+nasal] feature. Nasal sonorant stops {m, 'm, n} violate this constraint if they spread [+nasal]. Other sonorants are all continuants, and satisfy this constraint. Oral stops satisfy this constraint vacuously, since they cannot be associated with the feature [+nasal] and block spreading, which is attributed to a separate constraint. Note that the representation in (34-b) represents only one configuration in which the constraint is violated, while its mirror variant is omitted.

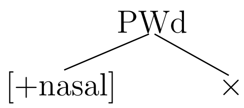
(34) *[+NASAL −continuant]
  a. Assign a violation mark for every root node ×, iff × is a Head of the feature [+nasal] and × is associated with [−continuant].
  b. *


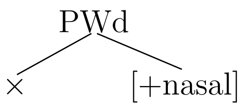
Ikwere nasal harmony applies in both directions. Bidirectional spreading is well attested. Here, I claim that bidirectional assimilation consist of two separate unidirectional patterns. The evidence behind such a claim comes from languages with directional asymmetries. In some languages, the two unidirectional patterns differ in terms of targets, blockers, or transparent segments. For example, emphasis spread in Southern Palestinian Arabic is unbounded within a prosodic word leftwards, but in the opposite direction, emphasis is blocked by {i, j, ʃ, ʒ} (Davis 1995). Applecross Gaelic (Ternes 1973; Walker 1998/2000) and Epena Pedee (Harms 1985, 1994) show unbounded nasal spreading rightwards, but only within the same syllable leftwards. Somali has vowel harmony in which [+atr] spreads leftwards within an intonational phrase, but spreads to the following clitic rightwards (Andrzejewski 1955; Saeed 1993, 1999; Krämer 2003). These languages show bidirectional spreading with different behavior in one direction compared to the other and demonstrate that bidirectional spreading needs to be treated as consisting of two unidirectional patterns. The current approach captures the distinction

unlikely that nasal harmony is limited to the same syllable only when the target is a nasal sonorant stop, but not otherwise. Even if we were to entertain such an option, it is not clear how to model it.

between the two directions by specifying precedence between two categories in alignment constraints.

Ikwere bidirectional nasal harmony can be accounted for by using two separate alignment constraints that differ solely in their precedence relations. The first one targets any preceding segments, while the second one targets any following segments. Both constraints have [+nasal]. The domain of the two constraints is a phonological word, which includes the phonological root and all suffixes (for details see Clements & Osu 2005). All segments are targeted (blocking by obstruents is attributed to a separate feature co-occurrence constraint, which is not central to the analysis here). The two alignment constraints are in (35).

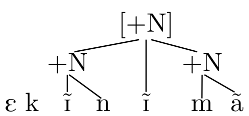
(35) a. ALIGN-R[+nasal]
*⟨PWd, [+nasal], ×⟩ / 

b. ALIGN-L[+nasal]
*⟨PWd, [+nasal], ×⟩ / 

Both alignment constraints outrank the faithfulness constraint DEPLINK[+nasal]. The remaining issue is the ranking of the two alignment constraints with respect to each other. This is where the constraint *[+NASAL −continuant] (34) becomes relevant. This constraint prefers icy targets to regular targets. However, icy targets surface only in leftward spreading, while the same segment is a regular target in rightward spreading. This suggests that the two alignment constraints need to be ranked differently with respect to the constraint on heads. Icy targets surface in leftward spreading, which indicates that the constraint penalizing spreading from icy targets *[+NASAL −continuant] outranks the spreading constraint ALIGN-L[+nasal]. On the other hand, rightward spreading shows no icy targets, which suggests that ALIGN-R[+nasal] outranks *[+NASAL −continuant].

The ranking is shown in tableau (36). The input /ɛkɪlĩḅa/ 'plantain' contains a nasal vowel, which acts as a trigger of nasal harmony. The winning candidate (a) satisfies ALIGN-R[+nasal], but incurs a violation of *[+NASAL −continuant]. Candidate (b) shows no spreading and fatally violates ALIGN-R[+nasal]. Candidate (c) shows spreading to two adjacent icy targets, which also fatally violates ALIGN-R[+nasal]. Candidate (d) shows nasalization which is blocked by an obstruent. This candidate incurs two violations of *[+NASAL −continuant], once for each nasal sonorant stop. The second violation is fatal.[15]

[15] Candidate (36-e) is theoretically possible, but is not generated because of other restrictions on autosegmental representations. See [suppressed] for further discussion.

(36-e) 

(36) ɛkɪnĩmã ‘plantain’

[+n] / ɛ k ɪ l ĩ ḅ a /	Align-R[+n]	*[+N−continuant]	Align-L[+n]	DepLink[+n]
a. ☞ [+N] +N ɛ k ɪ n ĩ m ã		1	3	3
b. [+n] ɛ k ɪ l ĩ ḅ a	2 W	L	4 W	L
c. [+N] ɛ k ɪ n ĩ m a	1 W	L	3	2 L
d. [+N] +N +N ɛ k ĩ n ĩ m ã		2 W	2 L	4 W

Note that most candidates in (36) contain a feature node that seemingly has ternary branching. At first, this appears to be contrary to Strict Binarity (8), which says that all branching is maximally binary. However, recall the claim that bidirectional spreading is a combination of two separate spreading processes: one applying leftwards and the other rightwards. This means that each of the two processes requires their own binary branching node to initiate spreading in the first place. In other words, the highest node in the representations of candidates (a), (c) and (d) actually represents two nodes rather than one, although it is graphically represented only once.

We have now seen that Ikwere shows icy targets but with a particular twist. Nasals are icy targets in leftward spreading, but (regular) targets in rightward spreading. These differences in directionality are predicted by an approach based on alignment constraints. Two alignment constraints that differ solely in directionality are ranked differently. One alignment constraint outranks the constraint on feature heads which enforces icy targets, while the other alignment constraint is outranked by the constraint on feature heads.

Ikwere nasal harmony complements the two other cases of icy targets found in Icelandic u-umlaut and Sanskrit Nati retroflexion. The three cases of icy targets can be modeled using constraints on feature heads. These constraints may interact with other constraints, which has a different effect in each of the languages. In Ikwere, the constraint on feature heads is ranked differently with respect to two alignment constraints. Icy targets are thus limited to leftward spreading, while they are regular targets in rightward spreading. In Icelandic, on the other hand, MaxLink[+low] outranks the constraints on feature heads in unreduced roots, but not in reduced ones. Icy targets are preferred to raising in unreduced roots, while the situation is reversed in reduced roots. One contribution of this paper is to show that Icelandic, Sanskrit and Ikwere are typologically similar. BDT successfully traverses any differences and reveals the icy targets as a consistent pattern with a unified analysis.

7 Alternatives

BDT significantly modifies the representation of feature spreading with evidence coming from icy targets. Recall section 2 in which I showed that a classical autosegmental approach does not have an analysis of icy targets. While showing that an autosegmental approach based on well-established OT constraints (such as alignment and faithfulness) cannot capture icy targets is a sufficient condition for crucially modifying the concept of association, it is also necessary to show why other approaches to assimilation within OT cannot model icy targets.

In this section, I flesh out why four other approaches also fail to predict icy targets. Section 7.1 discusses feature domain theories which are too restrictive. Section 7.2 focuses on non-iterativity. Even though non-iterative spreading resembles icy targets, a closer examination reveals that the two phenomena are not identical. Section 7.3 deals with positional licensing. While licensing can easily account for the main pattern, it fails to account for all the data. Section 7.4 introduces sequential markedness constraints. These constraints can model icy targets, but they also predict many unattested patterns. BDT, on the other hand, predicts icy targets without excessive overgeneration.

7.1 Feature domains

Feature domain theories differ from Autosegmental Phonology in that they do not assume association lines. Instead, assimilation is characterized in terms of domains. When a feature is contained within a single segment, the domain of that feature is limited to that segment. When a feature is realized over multiple segments as a result of assimilation, the domain of that feature is extended from a single trigger to encapsulate all targets. At first such a representation appears to be a notational variant of association lines. In particular, a target associated with a feature is equivalent to a target within a domain of a feature. However, there are several differences between the two approaches. One of them is that feature domains are headed. Headedness is what feature domain theories share with BDT. The difference lies in the distribution of heads. As we have seen, heads in BDT are found in all but the final target. In feature domain theories, each domain has exactly one head. Most typically, a trigger is a head. Yet other segments can also serve as heads. For example, a constraint may require a head to be at the edge of a domain. Thus, the target furthest from the trigger could also be a head. This target is icy in the present context. Because constraints may refer exclusively to heads, it seems plausible that these constraints might be able to capture the icy target pattern, which is what happens in BDT.

Several different feature domain theories have been proposed. The most established ones are: Optimal Domains Theory (Cassimjee & Kisseberth 1989; Kisseberth 1994; Cole & Kisseberth 1995a,b; Cassimjee & Kisseberth 1998), Span Theory (McCarthy 2004), and Headed Domains Theory (Smolensky 2006; my designation). These theories differ slightly from one another, but not in a way that would be relevant to icy targets. Hence, I will illustrate the treatment of icy targets using only one theory, and the conclusions are valid for the other.

BDT and feature domain theories assume feature heads, and propose constraints that refer to them. Smolensky (2006:621ff.) makes use of the general markedness constraint *Head (≡ Assign a violation mark for every root node that is a head) and Local Conjunction (Smolensky 1993, 1995, 1997; Baković 2000; Łubowicz 2002a,b, 2005) with another constraint. Such a conjoined constraint cannot be violated outside of a head. This generalization interacts with another restriction of the theory, which is that each domain has exactly one head. That is, *Head&$\mathbb{C}$ cannot only be violated maximally once per head but also maximally once per domain, since no domains have multiple heads.

As we have already seen in (5), non-conjoined constraints cannot generate an icy target candidate, and this is also the case for feature domain theories. However, these theories also allow faithfulness and markedness constraints that refer to heads, which seems a reasonable approach to capture icy targets. In Smolensky's approach, these constraints are formally conjunctions. I present the effect of five conjoined constraints in the tableau in (37). The original notation is retained: each domain is between a pair of parentheses, and heads are underlined. For each form, we see three rows. The top row contains a segmental string, complemented by domains and heads of the feature [round]. The third row for every candidate shows the feature specification of the feature [low]. For example, candidate (37-a) has two domains: the first one, ($\underline{\text{a}}$), is limited to a single segment. This domain is [−round], which can be seen in the second row, where a minus is aligned with ($\underline{\text{a}}$). Since every domain is headed, the first vowel is also a head, and hence underlined. The second domain in candidate (37-a) has two round vowels, of which the final one is headed. In this theory, heads are determined by alignment and other constraints, and here I am assuming that heads are aligned to the right edge of a domain.[16] Four candidates are considered: (a) contains an icy target, (b) has no assimilation, (c) has total assimilation and (d) total unrounding. The icy target candidate (a) is harmonically bounded.

(37) Icy targets harmonically bounded

/ a a ʏ / [r] − − + [l] + + −	*Hd&*[+r]	*Hd&*[−r]	*Hd&*[+l]	*Hd&*[−l]	*Hd&Id(r)
a. ☹ ($\underline{\text{a}}$) (œ $\underline{\text{ʏ}}$) [r] − + + [l] + + −	1	1	1	1	
b. (a $\underline{\text{a}}$) ($\underline{\text{ʏ}}$) [r] − − + [l] + + −	1	1	1	1	
c. (œ œ $\underline{\text{ʏ}}$) [r] + + + [l] + + −	1	L	L	1	
d. (a a $\underline{\text{ɪ}}$) [r] − − − [l] + + −	L	1	L	1	1 W

The reason why the icy target candidate (37-a) cannot win in an approach based on headed feature domains is because of the restrictions on possible domains. In particular, each domain has exactly one head (Smolensky 2006:624). This means that the constraints on heads apply to maximally one segment per domain. If we look at (37), candidate (c) harmonically bounds the icy target (a). In candidate (c), the first and the second [œ] have equal status and do not violate any constraint on heads. This differs from BDT, where the candidate with total rounding is not harmonically bounded, as shown in (20-c). As we have seen, BDT allows for multiple heads within a sequence of segments that are associated with some feature. Candidate (20-c) has a head on the second [œ], which is not present in the icy target candidate (20-a).

[16]The consideration of other kinds of head distributions would also yield comparable results.

We can conclude that Smolensky's approach fails to predict the candidate with icy targets. The same is true for all other feature domain theories. The failure stems from the theories' restriction on exactly one head per domain. Even if we allow a modification of feature domain theories to allow multiple heads per domain or overlapping/recursive domains, the distribution of heads would have to be identical to BDT.

7.2 Non-iterativity

In this section, I compare icy targets with non-iterativity. I demonstrate that the constraints non-iterative spreading is a pattern district from icy targets.

Non-iterative spreading has exactly one target, which seems to be similar to icy targets. For example, Icelandic u-umlaut involves rounding of exactly one /a/, whereas all other potential targets are normally not affected. On the face of it, non-iterativity could also account for icy targets.

The distinction between iterative and non-iterative spreading can be captured in either a rule- or constraint-based grammar. Here, I will take on the latter approach, because it allows for a direct comparison with icy targets in BDT. The distinction between non-iterative and iterative patterns is standardly attributed to an OT constraint. As to what this constraint is, at least three variants are found in the literature.

The first option is a constraint that penalizes singly associated segments. For example, the constraint *MonoF[eature]D[omain] requires that a feature domain contains at least two segments/moras/syllables (Cassimjee & Kisseberth 1998). This constraint is satisfied by any spreading. Faithfulness or other markedness constraints prefer spreading to fewest segments, which results in spreading to one target. In short, the first proposal imposes a limit on the fewest number of segments associated with a feature. The second proposal is a constraint that is satisfied only when the relevant feature is associated to *exactly* two segments. Example of this kind are SpanBin[f] (Becker 2007; Key 2007) and Binary[f] (Uffmann 2005). The third proposal, on the other hand, imposes a limit on the highest number of segments that can be associated with a feature. For example, Local (Myers 1997; Yip 2002) is violated by shifting or spreading to a segment/mora/syllable that is non-adjacent to the trigger. A very similar constraint is BinaryAssociation[f] which I will use below.

Even a short overview of the three approaches reveals a common property, which is a constraint designed specifically for non-iterative spreading (even though there seems to be some disagreement as to what exactly this constraint is). Any of these constraints predict non-iterative spreading, and there is no reason to assume they would differ in their treatment of icy targets. Thus, it seems reasonable to look at a single constraint and generalize the findings for all other similar constraints.

I will consider a constraint that makes a restriction on the maximum number of segments associated with a feature—BinaryAssocation[+round]. The definition is in (38).

(38) BinaryAssociation[+round] (adapted from Topintzi & van Oostendorp 2009)
The feature [+round] can be associated with maximally two segments.

In Icelandic, this constraint interacts with the general ranking of Align-L[+round] $\gg$ DepLink[+round]. When BinaryAssociation[+round] is ranked above the alignment constraint, non-iterative spreading is preferred. Tableau (39) shows the Icelandic icy target pattern in roots without reduction. Candidate (c) with total spreading is ruled out by the binarity constraint, while delinking of [+round] found in candidate (d) violates the high ranked faithfulness constraint MaxLink[+round]. Of the remaining constraints, Align-L[+round] prefers the icy target candidate (a) over the faithful candidate (b).

(39) Icy targets predicted under non-iterativity

[+rd] / a a y / [+lo][+lo]	MaxLink[+rd]	BinAssoc[+rd]	Align-L[+rd]	DepLink[+rd]	*œ
a. ☞ [+rd] a œ y [+lo] [+lo]			1	1	1
b. [+rd] a a y [+lo] [+lo]			2 W	L	L
c. [+rd] œ œ y [+lo] [+lo]		1 W	L	2 W	2 W
d. a a i [+lo] [+lo]	1 W		L	L	L

The basic icy target pattern is predicted by a constraint that prefers non-iterative spreading. However, this approach cannot see which segments are triggers and which are targets. In particular, BinaryAssociation[+round] prefers non-iterative spreading regardless of the vowel quality of the trigger. The problem becomes apparent when we consider the trigger /œ/. Tableau (40) shows the incorrect prediction for the form [amœba] 'amoeba'. Candidate (b) best satisfies both binarity and alignment. The intended winner (a) fatally violates alignment.

(40) Non-iterative spreading is preferred regardless of the trigger

[+rd] / a m œ b a / [+lo] [+lo] [+lo]	BinAssoc[+rd]	Align-L[+rd]	DepLink[+rd]	*œ
a. ☹ [+rd] a m œ b a [+lo] [+lo] [+lo]		1		1
b. ☞ [+rd] œ m œ b a [+lo] [+lo] [+lo]		L	1 W	2 W

To sum up, icy targets are a pattern distinct from non-iterativity. While icy targets involve a restriction on spreading of one feature due to another feature, non-iterative spreading has no such restriction.[17]

[17] A separate, but perhaps even more serious question is whether non-iterativity is found in assimilation at all. See Kaplan (2008) for further discussion.

7.3 Positional licensing

Positional licensing capitalizes on the idea that prominent positions bear more contrast than non-prominent positions (Steriade 1995; Zoll 1998a,b; Piggott 2000; Walker 2001, 2004, 2005, 2011; Kaplan 2008). A feature realized in a prominent position has a different status than one realized in a non-prominent position. In terms of constraints, positional markedness constraints require a feature to be associated with a prominent position. This is directly relevant to Icelandic u-umlaut, where [+round] spreads from a suffix until it reaches a low vowel. This holds for roots without reduction (the first target satisfies the requirement and spreading is terminated) and for roots with reduction (subsequent targets are raised and spreading continues until an low vowel is reached). From the perspective of positional licensing, [+round] spreads until it reaches a prominent feature, [+low]. This can be formalized in terms of a positional markedness constraint (41).

(41) License([+round], [+low]) (adapted from Walker 2005:941–942)
An output [+round] must be associated with an [+low] vowel.

The constraint License([+round], [+low]) is satisfied by spreading to a [+low] vowel. This effect is shown in (42). The icy target candidate (a) wins when the licensing constraint outranks DepLink[+round]. Candidate (b) violates the licensing constraint, because it lacks an [œ]. Candidate (c) shows total spreading, and violates DepLink[+round] twice, while candidate (d) violates the highest ranked Max[+round].

(42) Icy targets surface under positional licensing

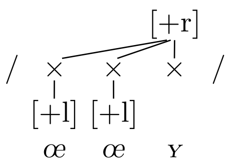
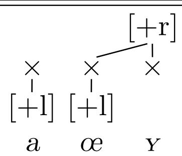
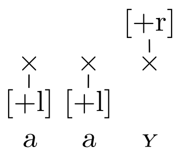
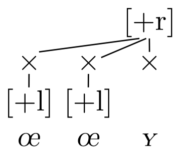
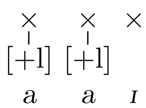
/ a[+l] a[+l] ʏ[+r] /	Max[+rd]	License([+rd],[+lo])	DepLink[+rd]
a. ☞ a[+l] œ[+l] ʏ[+r]			1
b. a[+l] a[+l] ʏ[+r]		1 W	L
c. œ[+l] œ[+l] ʏ[+r]			2 W
d. a[+l] a[+l] ɪ	1 W		L

At first it appears that positional licensing can successfully capture icy targets, rendering the current approach based on substantial representational modifications unwarranted. However, at a closer examination, it turns out that positional licensing has several severe disadvantages.

Tableau (42) represents an evaluation of an input with [+round] linked to a single root node. Given Richness of the Base, inputs with multiple links must also be considered. In particular, even when [+round] is linked to multiple segments in the input, the output must map to an attested output in Icelandic. In BDT, such inputs surface with an icy target [œ], because constraints on heads prefer delinking. More specifically, a head on the icy target segment [œ] is deleted under the pressure of *[+ROUND +low]. Consequently, the candidate with only one target [œ] (which is not a head of the feature [+round]) surfaces, as expected.

The positional licensing approach, however, cannot replicate this effect, as shown in (43). The positional markedness constraint never forces delinking of the relevant feature, because the feature [+round] linked to a single low vowel—as in candidate (a)—satisfies the constraint just as well as when [+round] is linked to multiple low vowels—as in candidate (c). The latter surfaces because it is most faithful to the input. The problem is that candidate (c) is not attested.

(43) The Richness of the Base argument

	MAX[+rd]	LIC([+rd],[+lo])	DEPLINK[+rd]	MAXLINK[+rd]
a. ☹ 				1
b. 		1 W		2 W
c. ☞ 				L
d. 	1 W			1

Another argument against the positional licensing approach stems from forms with reduction, but without an output [œ]. As we have seen, reduction raises [œ] to [ʏ]. When there are no further targets, a derived [ʏ] surfaces without any preceding [œ]. The positional licensing constraint LICENSE([+round], [+low]) (41) is violated in such forms, because no [œ] is associated with [+round]. Hence, there is no incentive to spread in the first place, and low ranked faithfulness constraints prefer no spreading at all.

The problem is illustrated in (44). The reduced form *ˈh*[ɛ]*r*[ʏ]*ˌð*[ʏ]*m* 'district' has a single available target. Reduction needs a separate account and I follow Crosswhite (2001) by using a constraint that penalizes unstressed low round vowels, *UNSTRESSED/œ (≡ Assign a violation mark for every unstressed [œ]). This constraint dominates the licensing constraint, since no reduction would have applied otherwise. The actual winner is candidate (a), which contains a reduced [ʏ]. However, this candidate is harmonically bounded to the faithful candidate (b) because spreading [+round] to any other vowel but [œ] does not satisfy the licensing constraint. Candidate (c) fatally violates the high ranked *Unstressed/œ.

(44) ˈhɛrʏˌðʏm 'district'

[+r] / ˈh ɛ r a d ʏ m / [+l] [+l]	*Unstr/œ	Lic([+rd],[+lo])	DepLink[+rd]	Max[+lo]
a. ☹ [+r] ˈh ɛ r ʏ d ʏ m [+l]		1	1	1
b. ☞ [+r] ˈh ɛ r a d ʏ m [+l] [+l]		1	L	L
c. [+r] ˈh ɛ r œ d ʏ m [+l] [+l]	1 W	L	1	L

The reason why the reduced candidate (a) does not win is not due to the licensing constraint per se. Instead, it is attributed to the fact that alignment has to be ranked below DepLink[+round], otherwise total spreading would be preferred in all forms.The ranking in BDT is revered, and the alignment constraint prefers total spreading, and blocking is enforced by a high ranked constraint on heads (21).

I have now shown that an analysis based on positional licensing fails to fully account for icy targets. The representational solution of BDT thus seems to be the only viable solution so far.

7.4 Sequential Markedness Constraints

Sequential Markedness Constraints (henceforth, SMCs) are constraints against a sequence of segments with a particular feature combination: *[αF][βG]. While SMCs are widely used in the literature, the designation comes from Mahanta (2008), who uses these constraints for vowel harmony.

Recall that in Icelandic u-umlaut, [+round] and [−back] spread from /ʏ/ to a preceding /a/. The prohibited sequence in Icelandic is [aʏ], which violates the SMC *aʏ, as defined in (45).

(45) *aʏ

$$*\begin{bmatrix} -\text{front} \\ -\text{round} \\ +\text{low} \end{bmatrix}\begin{bmatrix} +\text{front} \\ +\text{round} \\ -\text{low} \end{bmatrix}$$

The constraint in (45) is violated by any sequence in which [a] in one syllable is followed by [ʏ] in an adjacent syllable. To make the best case of SMCs, let us consider the effect of *aʏ in combination with other constraints that are also active in Icelandic. The faithfulness constraint Dep[+round] (and Dep[+front], omitted) is ranked below *aʏ, while the high ranked MAX[+round] assures that [+round] is not deleted. The ranking is shown in (46). The candidates are parallel to the ones in tableaux (37), (39) and (42).[18] The winning candidate (a) violates solely DEP[+round], as opposed to candidate (b) that additionally violates *aʏ, and candidate (d) that also violates MAXLINK[+round]. The remaining candidate (c) incurs two violations of DEP[+round]. On the face of it, the SMC *aʏ has the desired effect and can capture the icy target pattern.

(46) Icy targets correctly predicted

/a a ʏ/	MAX[+round]	*aʏ	DEP[+round]
a. ☞ a œ ʏ			1
b. a a ʏ		1 W	L
c. œ œ ʏ			2 W
d. a a ɪ	1 W		L

However, SMCs come with their own set of problems. Here I discuss three of these patterns. First, SMCs refer to two adjacent vowels, ignoring any intervening consonants. On the one hand, the constraint *aʏ is violated by the string [aʏ], but not by [ai̲ʏ]. On the other, the constraint *aʏ is *not* violated by [ak̲ʏ], [aθ̲ʏ] or [ar̲ð̲ʏ]. The necessary assumption is that consonants lack any value of the features [back], [round] and [low]. This indicates that spreading of these features from a consonant to a vowel (and vice versa) is excluded. However, such patterns are attested.

Second, SMCs produce pathologies. These pathologies are particularly severe when SMCs are highly ranked. Consider for example the ranking *aʏ ≫ DEP[+round] ≫ MAX. The following two patterns are predicted. An input /a ʏ/ maps to an output with an epenthetic vowel rather than spreading, as shown in (47). However, an input /œ ʏ/ can surface faithfully, as shown in (48). The pattern in which two unlike vowels show epenthesis (but two like vowels do not) is unattested. This pathology is an instantiation of the too-many-solutions or too-many-repairs problem (see Pater 1999; Wilson 2000, 2001; Steriade 2001, 2001/2008; Blumenfeld 2006; Baković 2007 for related cases). What makes this pathology a too-many-solutions problem is that a markedness constraint can be satisfied by several candidates, a subset of which is actually attested. Nothing in BDT has the same effect.

(47) Epenthesis with dissimilar vowels

/a ʏ/	*aʏ	DEP[+round]	MAX
a. ☞ a ə ʏ			1
b. a ʏ	1 W		L
c. œ ʏ		1 W	L

[18]These faithfulness constraints are not used by Mahanta (2008), who uses IDENT(f) constraints instead.

(48) No epenthesis with similar vowels

/œ ʏ/	*aʏ	Dep[+round]	Max
a. ☞ œ ʏ			
b. a ʏ	1 W		
c. a ə ʏ			1 W

A third problem is that the approach based on SMCs entails a much larger set of constraints. The SMC *aʏ in (45) refers to three features and two segments that have exactly the opposite feature specification. One can easily imagine a number of very similar constraints. When two or more features are relevant for each segment, the number of constraints grows exponentially. For example, for n binary features, $16n^2(n-1)^2$ constraints of the type *[f g][h i] are possible. Just 10 binary features yield 129,600 constraints. Furthermore, nothing restricts an even greater number of features or a greater number of segments in SMCs, consequently generating many more constraints. Constraints on heads in BDT, on the other hand, can never generate such a large number of constraints, because any constraint on heads only refers to two unary features. For n binary features, only $2n(2n-1)$ constraints of the type *[F g] are possible; 10 binary features allow maximally 380 different constraints. In this paper, five such constraints were mentioned or discussed: *[+ROUND +low] (19) and *[−BACK +low] in Icelandic, *[−ANTERIOR −continuant] (27) and *[−DISTRIBUTED −continuant] in Sanskrit, and *[+NASAL −continuant] (34) in Ikwere.

In short, SMCs predict icy targets, but can additionally generate many other unattested patterns. From the viewpoint of assimilation, SMCs are not restrictive enough, whereas BDT perfectly predicts icy targets without excessive overgeneration.

8 Conclusions

The contribution of this paper is two-fold. The empirical contribution is in identifying a new, previously unreported class of segments, named icy targets. The theoretical contribution is an account of icy targets by modifying some fundamental assumptions regarding feature spreading.

Icy targets are both targets and blockers of assimilation. Under the traditional assumptions about assimilation, icy targets are surprising, because the sets of targets and blockers are normally disjunctive. No known theory predicts icy targets. In response to this challenge, I propose a modification of the feature spreading mechanism. In a nutshell, all branching is maximally binary. Similar proposals have been set forth by some early autosegmental literature. Binary Domains Theory (BDT) revives such models and incorporates binarity, headedness, and recursion into a new theory of autosegmental spreading.

The main advantage of BDT is a formal distinction between headed and non-headed segments. The distribution of heads is predictable: all but the final target contain a head. Heads are marked structures that can be referred to by OT constraints on heads. Such constraints are always satisfied by a final target, which is what effectively terminates further spreading.

In short, BDT takes on representations of Metrical Theory and applies them to feature spreading. The advantage of this approach is a unified account of segmental and prosodic phenomena. Even though there are significant differences between prosody and assimilation, their common properties suggest that feature spreading and prosody are much more similar to each other than previously assumed. More broadly speaking, the solution offers insight into how association lines work, and provides support for the claim that representations play a crucial role in phonological theory.

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