Non-iterativity, Icy Targets, and the Need for Non-linear Representations in Feature Spreading

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1 Introduction

Vowel and vowel-consonant harmonies have been central to much linguistic theorizing over the last century (Harris 1944; Lightner 1965; Clements 1980; Goldsmith 1985; McCarthy 2004; Jurgec 2011; Walker 2011). One prevailing theme in this work is the need for non-linear representations. Concerning the analysis of ATR harmony in Akan, Clements (1981:164) writes:

> Thus by virtually any metric of 'simplicity' or 'learnability' one might want to propose, the nonlinear analysis proves to be the more highly valued. There is every reason to believe that *even if phonological theory does not exclude linear analyses of unbounded processes like vowel harmony in principle*, in cases like Akan the language learner will select the nonlinear analysis with little hesitation. [emphasis in original].

Clements argues for the superiority of non-linear representations for the analysis of unbounded patterns. He makes no claim concerning bounded harmonies, harmonies in which some elements undergo but do not propagate the harmonic feature. One might wonder if non-linear representations impart any advantage for the analysis of bounded pattern. Jurgec (2011) argues this very point, developing a metrical theory of feature spreading in Optimality Theory (OT; Prince & Smolensky 2004) to account analyze the behavior of elements that undergo but do not propagate the harmonic feature, what he calls *icy targets*. In this paper I modify and extend Jurgec's analsyis to account for a larger class of bounded harmonies. Like Jurgec, I call the analysis developed below metrical because the hierarchical representations invoked are structurally akin to those employed in the literature on metrical stress. Moreover, I use these representational structures without yoking a theory of feature spreading to stress or feet. The proposed analysis focuses on rounding harmony in Central Crimean Tatar, ATR harmony in Bangla, and ATR harmony in Iny, demonstrating that a metrical analysis can account for a larger class of bounded harmonies than is discussed in previous proposals.

2 Bounded harmonies

Before entering into the constraint-based analysis, it is paramount to define the analytical categories relevant to the argument. Three terms are central to the harmony-related distinctions laid out below. *Triggers* are elements that initiate the harmony pattern. Triggers are to be distinguished from *outputs* and *propagators* of the pattern. Outputs are simply the alternating surface elements produced by the harmony, and propagators are outputs that are also able to further spread the harmonic feature. While all three categories are important, the third is central to understanding boundedness in harmony. Two binary parameters are sufficient to characterize bounded and unbounded patterns, as well as key subtypes, shown in (1).

(1) Questions for the typology of bounded and unbounded harmonies
    a. Are propagators a strict subset of outputs?
    b. Do the sets of triggers and outputs intersect?

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These two questions yield a four-way typology for harmony. First, if propagators are a strict subset of outputs (1a), the harmony will be bounded because some elements will undergo but fail to spread the harmonic feature further within the relevant domain (2a,b). Of the two subtypes of bounded harmonies below, we can distinguish non-iterativity from the disjoint patterns that Jurgec (2011) analyzes. In truly non-iterative harmony the sets of triggers and outputs intersect, while in the class of patterns analyzed in Jurgec (2011) the set of triggers and outputs do not intersect (1b). Intersection thus distinguishes between disjoint patterns (2b,d) and intersecting patterns (2a,c). As noted at the outset, I focus on bounded harmonies in this paper, i.e., those in (2a,b), but will briefly comment on unbounded disjoint patterns in Section 4.5.

(2) a. Non-iterative harmony
    i. Are propagators a strict subset of outputs? Yes
    ii. Do the sets of triggers and outputs intersect? Yes
    ex. rounding harmony in Central Crimean Tatar (McCollum & Kavitskaya to appear)

b. Bounded disjoint harmony
    i. Are propagators a strict subset of outputs? Yes
    ii. Do the sets of triggers and outputs intersect? No
    ex. ATR harmony in Bangla, Sanskrit nati, Icelandic u-umlaut, nasal harmony in Ikwere (Jurgec 2011), rounding harmony in Mayak (Andersen 1999)

c. Iterative harmony
    i. Are propagators a strict subset of outputs? No
    ii. Do the sets of triggers and outputs intersect? Yes
    ex. rounding harmony in Turkish, ATR harmony in Assamese (Mahanta 2008), nasal harmony in Sundanese (Cohn 1990)

d. Unbounded disjoint harmony
    i. Are propagators a strict subset of outputs? No
    ii. Do the sets of triggers and outputs intersect? No
    ex. -ATR harmony from dominant enclitics in Liko (De Wit 2015)

3 Data

3.1 *Non-iterative harmony*

Non-iterative harmony is the most familiar type of bounded harmony. Despite the different intensional characterizations of non-iterative patterns in rule- and constraint-based analyses (McCollum & Kavitskaya to appear), the parametric characterization in (2a) captures the crucial facts – triggers and outputs intersect, and not all outputs of harmony may propagate it. This type of pattern is attested in a handful of languages, the most well-discussed of which is rounding harmony in the Central Crimean Tatar (Sevortjan 1966; Kavitskaya 2010; 2013; Kavitskaya & McCollum to appear; McCollum & Kavitskaya to appear). In this dialect, rounding harmony affects a single high vowel to the right of an underlying trigger, as in (3). Observe that only one alternating suffix undergoes rounding.

(3) a. /tuz-lɯq/ [tuz-luq] 'salt-NMLZR'
b. /tuz-ɯ/ [tuz-u] 'salt-POSS.3S'
c. /tuz-lɯq-ɯ/ [tuz-luɣ-ɯ] 'salt-NMLZR-POSS.3S'
d. /aʧ-uv-ɯ/ [aʧ-uv-u] 'open-GER-POSS.3S'

3.2 *Bounded disjoint harmony*

This type of harmony differs from non-iterative harmony due to the non-intersection of triggers and outputs. In Bangla (Mahanta 2008), ATR harmony is initiated by [+hi, +ATR] vowels, but in the absence of underlying /ɪ ʊ/, targets only the mid vowels /ɛ ɔ/. In this language, mid vowels are not licit triggers or propagators of harmony. As a result, only a single preceding mid vowel may assimilate to [+ATR], illustrated in (4).

(4) a. /ɔʃɔt/ [ɔʃɔt] “dishonest”
b. /ɔʃɔti/ [ɔʃoti] “dishonest.FEM”
c. /pɔtro/ [pɔtro] “letter/document”
d. /pɔtrika/ [potrika] “horoscope”

3.3 *Iny* One language that exhibits an interesting pattern of bounded harmony is Iny (Ribeiro 2002; 2012). Although this language has been called Karajá in previous literature, Ribeiro (2012: 7-8) notes that this term is likely a racial epithet. As such, I use the endonym Iny throughout. In Iny, mid vowels behave quite regularly for ATR harmony; [e o] trigger the pattern and are outputs of /ɛ ɔ/ when followed by a [+ATR] trigger. Further, surface [e o] propagate the harmonic feature leftward. These characterizations suggest that harmony is iterative among the mid vowels, (5). In (5a), a mid vowel triggers assimilation of multiple preceding mid vowels. In (5b), harmony propagates leftward up to the low vowel, which blocks spreading. In (5c), observe that regressive harmony is capable of assimilating an underlying high vowel to [+ATR].

(5) a. /dɛbɔ d-e/ [debo d-e] ‘parrot REL-wing’
b. /Ø-r-a-kɔhɔØɗɛ=r-e/ [r-a-kohoɗe=r-e] ‘3-CTFG-INTR-hit=CTFG-IMPERF’
c. /Ø-r-ʊ-bɛhɛ=r-e/ [r-u-behe=r-e] ‘3-CTFG-INTR-go.down=CTFG-IMPERF’

In (6), we see that [+hi, +ATR] vowels may also trigger harmony on both mid (6a) and high vowels (6b,c). I will not address the apparent interaction of nasality and ATR, although it is relevant to the larger analysis of the pattern.

(6) a. /brɔrɛ-dĩ/ [brore-ni] ‘deer=similar.to’
b. /hãdɪ-dĩ/ [hãdi-ni] ‘jacu (a fish species)=similar.to’
c. /rɨ-dĩ/ [rɨ̞-ni] ‘cari (a fish species)=similar.to’

Crucially, derived [+hi, +ATR] vowels may not propagate ATR leftward. So while [+hi, +ATR] vowels are outputs of harmony, they are not propagators of the harmonic feature, (7). Observe in (7a) that high vowels may trigger and undergo harmony, but derived [u] may not propagate [+ATR]. In (7b), underlying /ɪ/ is output as [i], but again, does not propagate [+ATR] leftward. Finally, in (7c), the [+ATR] enclitic triggers assimilation of two mid vowels, both of which propagate [+ATR] leftward. However, the underlying high vowel only undergoes harmony, without further spreading the feature. Note, Ribeiro (2012:108-109) reports optional harmony of mid vowels before derived [i ɨ̞ u] in some morphological contexts.[1]

(7) a. /kɔɗʊ-dĩ/ [kɔɗu-ni] ‘turtle=similar.to’
b. /r-ɛ-hɪ=r-e/ [r-ɛ-hi=r-e] ‘CTFG-1.TRANS-drive.away=CTFG-IMPERF’
c. /r-ɛ-hʊkɔɗɛ=r-e/ [r-ɛ-hukoɗe=r-e] ‘CTFG-1.TRANS-lend=CTFG-IMPERF’

The particular parameterization of harmony types proposed in (1-2) renders the Iny pattern a type of non-iterative harmony, (8). Since propagators are a strict subset of outputs, and the sets of triggers and outputs intersect, the harmony pattern is classified like the Crimean Tatar pattern in (3). This is similar to the computational characterization of the pattern in Burness et al. (2021).

(8) Iny
Vowel inventory {i, ɨ̞, u, e, ɘ, o, ɪ, ɨ, ʊ, ɛ, ɔ, a, ĩ, ə̃, õ, ã}
Triggers {i, ɨ̞, u, e, ɘ, o}
Outputs {i, ɨ̞, u, e, ɘ, o}
Propagators {e, ɘ, o}
Are propagators a strict subset of outputs? Yes
Do the sets of triggers and outputs intersect? Yes

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[1] Ozburn & Leduc (2022) suggest a different characterization of the pattern, where derived [+hi, +ATR] vowels can propagate [+ATR] to preceding high vowels, but not to preceding mid vowels. It is unclear from Ribeiro’s grammar which characterization is most appropriate.

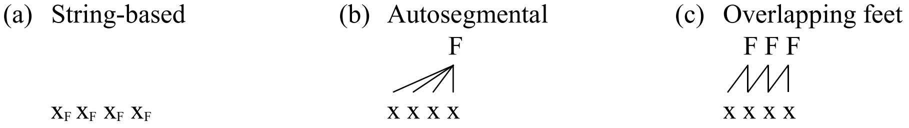
When viewed this way, we should be able to analyze Iny and Crimean Tatar with the same formal tools. In actuality, a slightly modified version of Jurgec's (2011) metrical analysis of feature spreading is able to account for all three of the languages discussed in this subsection.

4 A metrical analysis

4.1 *Assumptions* The development of hierarchical metrical structures, either as trees or as grids, influenced analyses of vowel harmony in the late 1970s and early 1980s (Vergnaud 1977; 1980; Halle & Vergnaud 1981; Steriade 1981; Kaye 1982; Leben 1982; Poser 1982). Among the various types of metrical structures proposed in the expansive literature Jurgec (2011) discusses recursive and overlapping metrical structures, although he chooses to implement his theory with recursive spreading domains. He however comments that overlapping metrical domains are also a plausible formulation of his core claim – that the representational structure necessary to analyze bounded spreading is metrical (2011:101). In this paper I use overlapping metrical feet to analyze harmony, partly for typographic reasons, but also to more straightforwardly connect with other work that has employed overlapping metrical feet (Hyde 2002; 2016; Key & Bickmore 2014).

Various representational systems are compared in (9). In a string-based representation (9a), the surface structure does not distinguish between triggers, outputs, and propagators. The autosegmental representation in (9b) provides no more information, although it is capable of distinguishing between harmony via spreading, depicted below, and harmony via feature copying. The representational structure with overlapping feet in (9c) can however capture the ternary distinction between triggers, outputs, and propagators.

(9) Leftward spreading in /x x x x_F/



(a) String-based (b) Autosegmental (c) Overlapping feet

As in Hyde (2002), the metrical representations here encode the distinction between heads and non-heads – heads are associated with [F] via vertical lines while non-heads are associated with [F] via diagonal lines. With this in mind, an output is an element associated with [F] via a diagonal line, i.e., a non-head. A propagator is an element associated with [F] via both a diagonal line and a vertical line, i.e., a head and non-head. Thus, a propagator is an element that is simultaneously a head of one metrical domain and non-head of another. Finally, a trigger is an element that is a head only. As noted above, these structures are metrical in the sense that they are commonly used to analyze metrical patterns, but structural prominence here is detethered from concepts like stress or accent (Hyde 2002).

4.2 *Constraints* With this representational structure in mind, we can now define a set of constraints necessary to describe the harmony pattern in Iny. First, we need a constraint to motivate harmony, and following Jurgec (2011), I use an alignment constraint, defined in (10).

(10)	ALIGN-L-[V, +ATR, PRWD]	assign a violation to every vowel that precedes [+ATR] within the same prosodic word and is not affiliated with some token of [+ATR].

Further, languages often exhibit restrictions on what elements may occupy prominent positions. For instance, a language may allow only certain kinds of syllables to occupy stressed positions (de Lacy 2006). In much the same way, this analysis depends on a set of positional markedness constraints to restrict the class of licit metrical heads. For Iny, we need a constraint that bans high vowels heading [+ATR] domains, (11).

(11)	*HD[+HI, +ATR]	assign a violation to every [+hi] vowel that is the head, i.e., trigger or propagator, of a [+ATR] domain.

In addition to the positional markedness constraint on domain heads, languages often impose restrictions on the size of metrical domains. Binary domains are often exploited in the analysis of rhythmic stress, among other phenomena. Jurgec (2011) excludes larger domains by constraining Gen to produce only binary domains. Here I transfer the responsibility for binarity from Gen to Con. To do so, I utilize a constraint enforcing binary domains from work in Span Theory (McCarthy 2004; Key & Bickmore 2014) as well as earlier work (McCarthy & Prince 1986; Prince & Smolensky 2004).

(12) SpanBin[+atr] assign a violation to every [+atr] domain that is not binary.

4.3 *Iny* With these three constraints and a basic faithfulness constraint, Ident-[ATR] we can account for all of the Iny data. For the sake of space, [+ATR] domains are indicated with [+] in the tableaux below. First, let us consider the easiest of cases, a word with only mid vowels and a [+ATR] trigger. In (13) we see the necessary ranking of Align-L >> Ident, which motivates harmony. The presence of SpanBin in the tableau prefers harmony via binary domains over autosegmental spreading.

(13)

[+] | /dɛbɔ d-e/	SpanBin[+atr]	Align-L-[+atr]	Ident-[atr]	
[+] | dɛbɔde		*!*		*no harmony*
[+] /| dɛbode		*!	*	*partial harmony*
☞ [+][+] /\/| debode			**	*full harmony via local spreading*
[+] //| debode	*!		**	*full harmony via non-local spreading*

To see the import of *Hd, observe a word with a mid vowel trigger and a high vowel output (14). In words with only partial harmony, the ranking of *Hd and SpanBin over Align-L is evident. Since both SpanBin and *Hd outrank Align-L, partial harmony is preferred in words with derived [+hi, +ATR] vowels.

(14)

[+] | /r-ɛ-hɪ=r-e/	SpanBin [+atr]	*Hd [+hi, +atr]	Align-L-[+atr]	Ident-[atr]	
[+] | rɛhɪre			**!		*no harmony*
☞ [+] /| rɛhire			*	*	*partial harmony*
[+][+] /\/| rehire		*!		**	*full harmony via local spreading*
[+] //| rehire	*!			**	*full harmony via non-local spreading*

In all of the bounded disjoint patterns that Jurgec (2011) analyzes, the relevant *Hd constraint outranks Align. That same ranking accounts for words like (15), but thus far the significance of shifting binairty from Gen to Con is not fully evident. In (13-14), SpanBin forces harmony to operate via local, binary, overlapping domains. However, SpanBin can also motivate harmony from a [+hi, +ATR] trigger; in (15), a high vowel triggers harmony on a preceding high vowel. Without SpanBin, the analysis predicts the faithful candidate is optimal because *Hd[+hi, +atr] does not assign violations to [+hi, +ATR] vowels that do not trigger harmony (Jurgec 2011).

(15)

[+] | /kɔɗʊ-dĩ/	SpanBin [+atr]	*Hd [+hi, +atr]	Align-L-[+atr]	Ident-[atr]	
[+] | kɔɗʊni	*!		**!		*no harmony*
☞ [+] /| kɔɗuni		*	*	*	*partial harmony*
[+][+] /|/| koɗuni		**!		**	*full harmony via local spreading*
[+] //| koɗu-ni	*!	*		**	*full harmony via non-local spreading*

The fact that SpanBin motivates harmony from an underlying [+hi, +ATR] vowel also accounts for iterative harmony in words like [brore-ni] 'deer=similar.to' (6a). If binarity is encoded in Gen only, high vowels are predicted to be inert as triggers. By moving binarity from Gen to Con, and specifically by ranking SpanBin >> *Hd the analysis is able to account for the Iny data.

4.4 *Bangla and Crimean Tatar*

4.4.1 *Bangla*

The analysis developed for Iny easily extends to the harmony patterns in Bangla and Central Crimean Tatar from Sections 3.1-3.2. Recall that ATR harmony in Bangla is triggered by [+hi, +ATR] vowels only and outputs [-hi, +ATR] vowels only – mid vowels are outputs but not propagators of harmony. The only modification to the constraint set necessary is the addition of a constraint penalizing heads of [+ATR] domains that are [-hi], *Hd[-hi, +atr], as demonstrated in (16).

(16)

[+] | /ɔʃɔt-i/	SpanBin [+atr]	*Hd [-hi, +atr]	Align-L-[+atr]	Ident-[atr]	
[+] | ɔʃɔti			**!		*no harmony*
☞ [+] /| ɔʃoti			*	*	*partial harmony*
[+][+] /|/| oʃoti		*!		**	*full harmony via local spreading*
[+] //| oʃoti	*!			**	*full harmony via non-local spreading*

Note that I have proposed two complementary markedness constraints on heads of [+ATR] domains, one that penalizes [+hi, +ATR] heads in Iny and one that penalizes [-hi, +ATR] heads in Bangla. This is to some degree undesirable, but not entirely stipulative. As extensively noted by Rod Casali (Casali 2003; 2008; 2016; 2017; see also Rose 2018), there is a strong correlation between the vowel inventory and the activity of [ATR]. In general, high vowels are preferred triggers of ATR harmony in 7- and 9-vowel inventories. However, given that the structure of the inventory is a key diagnostic, and the Iny inventory is so drastically different from the typical vowel inventories found in African ATR systems, the existence of a constraint penalizing high vowel heads in Iny might not be so outlandish.

4.4.2 *Central Crimean Tatar* As for the Central dialect of Crimean Tatar, the metrical analysis is able to offer a new intensional characterization of non-iterative rounding harmony that unifies the analysis of non-iterativity with bounded disjoint harmonies. In a rule-based framework, the extent of rounding harmony in Central Crimean Tatar depends on a rule that is either tagged as [-iterative] or rightward directional rule application (Anderson 1974; Kenstowicz & Kisseberth 1977; McCollum to appear). In a recent OT analysis, McCollum & Kavitskaya (to appear) develop an autosegmental analysis of harmony that crucially relies on a constraint banning non-adjacent elements linked to a single autosegment. While this constraint is capable of capturing non-iterativity, it cannot account for the Iny pattern. The extent of [+ATR] spreading in Iny is not confined to two syllables. Yet, the unity of these two patterns in Section 3.3 suggests a unified account is possible.

If the behavior of high vowels for rounding harmony in Central Crimean Tatar is viewed in the same way as the behavior of high vowels for ATR harmony in Iny, i.e., they are outputs but not propagators, we only need the constraint *HD[+HI, +RD] to analyze this type of rounding harmony pattern. Typologically, such a constraint is well-supported, given that the activity of high vowel triggers for rounding harmony often implies the activity of mid vowel triggers (Kaun 1995, 2004; McCollum 2017, 2018). In (17), SPANBIN demands spreading from a high vowel trigger, but prohibits further propagation from a high vowel output.[2]

4.5 *Unbounded disjoint harmony* Recall the four-way typology laid out in (2). Of the basic types of harmony patterns laid out there, I have shown that the metrical analysis can account for non-iterative and bounded disjoint patterns. It should be easy to see from the analysis of Iny that a grammar with a low-ranked *HD constraint can generate iterative spreading. Of the four categories in (2), three are straightforwardly handled within this approach. However, the fourth, unbounded disjoint harmony, deserves some discussion. Recall Bangla, where [+ATR] spreads from high vowels to mid vowels, but mid vowels cannot propagate [+ATR]. In a language like this, the string /ɔʃɔti/ will be output [ɔʃoti] with a two-syllable domain for [+ATR] harmony due to the restriction on mid vowel propagators. In an unbounded disjoint pattern, input /ɔʃɔti/ would be output as [oʃoti] with unbounded spreading. In this sort of pattern, as in Bangla, a highly-ranked *HD constraint must prevent mid vowels from triggering or propagating harmony. In addition, such a pattern demands a low-ranked SPANBIN so harmony will spread from trigger /i/ left to a potentially unbounded number of potential target /ɔ/ vowels. As a result, the structure generated by the grammar here is no longer binary and local. Instead, the grammar generates an autosegmental pattern with direct linkage from the trigger to all possible outputs, as seen in the schematic example in (18). Although Halle & Vergnaud (1981) treat autosegmental and metrical representations as fundamentally distinct, using each to account for dominant-recessive and directional harmony respectively, the theory developed here can account for both.

Unbounded disjoint harmonies serve to demonstrate the flexibility of the analysis. Both local spreading via overlapping (or recursive) metrical structures and non-local autosegmental spreading can be generated. At the empirical level, I do not know of any patterns that are unequivocally unbounded disjoint. However, I do know of several that have many of these characteristics, suggesting that this is a worthwhile category to entertain and theorize about.

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[2] If a constraint on overlapping domains, *OVERLAP, is included in the analysis, a second characterization of non-iterativity is possible, with high-ranking SPANBIN and *OVERLAP (Key & Bickmore 2014).

(17)

[+] │ /tuz-lɯq-ɯ/	SPANBIN [+RD]	*HD [+HI, +RD]	ALIGN-R- [+RD]	IDENT- [RD]	
[+] │ tuzlɯɣɯ	*!		**!		*no harmony*
☞ [+] │╲ tuzluɣɯ		*	*	*	*partial harmony*
[+][+] │╲│╲ tuzluɣu		**!		**	*full harmony via local spreading*
[+] │╲⟍ tuzluɣu	*!			**	*full harmony via non-local spreading*

(18)

[+] │ /ɔʃɔti/	*HD [-HI, +ATR]	ALIGN-L- [+ATR]	SPANBIN [+ATR]	IDENT- [ATR]	
[+] │ ɔʃɔti		*!*			*no harmony*
[+] ╱│ ɔʃoti		*!		*	*partial harmony*
[+][+] ╱│╱│ oʃoti	*!			**	*full harmony via local spreading*
☞ [+] ⟋╱│ oʃoti			*!	**	*full harmony via non-local spreading*

In Liko (de Wit 2015), [+ATR] spreads bidirectionally from [+ATR] morphemes (19b). However, there is a set of dominant [-ATR] enclitics that spread [-ATR] to preceding non-high vowels (19c). All the triggers of this pattern are [-low] while all the outputs are [+low], and multiple outputs may be controlled by a single trigger. In (19c) the root /ɓin/ spreads its [+ATR] value to the left (one syllable), but does not spread rightward because of the influence of the negation enclitic /gʊ/, which affects both of the preceding low vowel suffixes. As discussed in de Wit (2015), this particular pattern does affect preceding high vowels (19d), and there are no [+low] morphemes that trigger [-ATR] harmony. Thus, accounting for such a pattern with highly-ranked *HD[+LO,-ATR] and lowly-ranked SPANBIN[-ATR] predicts autosegmental spreading as in (18).

(19)	a.	/na-jɪɓ-ag-a/	[ná-jìɓ-ág-á]	'1S-tear-PLR-FV'
	b.	/na-ɓin-ag-a/	[nó-ɓín-óg-ó]	'1S-dance-PLR-FV'
	c.	/na-ka-ɓin-ag-a=gʊ/	[ná-kó-ɓín-ág-á=gʊ]	'1S-NEG-dance-PLR-FV=NEG.'
	d.	/Ø-ka-ɪ-su^{m}b-ɪ=gʊ/	[Ø-ki-su^{m}b-i=gʊ]	'3S-NEG-REFL-burn-FV=NEG'

Thus, some patterns appear to require metrical representations while others require direct linkage between the initial trigger and all potential outputs. The theory developed here is capable of generating both, as well as all four types of harmonies outlined in (2).

5 Alternatives

As has been noted in a range of work, the sort of enriched representations employed herein, all else being equal, increases the expressivity of the theory (for some recent computational work, see Chandlee & Jardine 2019; Jardine 2019; Burness et al. 2021). It is therefore necessary to consider a range of alternatives that employ simpler representational structures. Throughout this section I focus on the analysis of Iny, commenting on issues related to Bangla and Crimean Tatar where applicable.

5.1 *String-based representations* Strings form the simplest, and probably the most commonly employed representations in phonology (see Heinz 2018 for discussion). If we adopt Mahanta's (2008) analysis, a sequential markedness constraint *[-ATR][-HI,+ATR] is necessary to motivate iterative regressive spreading from mid vowels in Iny. However, an additional markedness constraint is needed to compel harmony from an underlying [+hi, +ATR] vowel but prevent it from a derived [+hi, +ATR] surface vowel. Since markedness constraints cannot refer to input values, this is a significant problem. An analysis like Mahanta's cannot capture the fact that high vowels simultaneously trigger but do not propagate harmony. With a simple set of two constraints, one can account for the behavior of output [+hi, +ATR] vowels (20) but not for their activity as triggers (21). In (21), the faithful candidate with no harmony is wrongly selected because there is no constraint to compel harmony before a high vowel. Such an analysis cannot elegantly account for the facts in Iny.

(20)

/r-ɛ-hɪ=r-e/	*[-ATR][-HI,+ATR]	IDENT-[ATR]	
rɛhɪre	*		*no harmony*
☞ rɛhire		*	*partial harmony*
rehire		**!	*full harmony*

(21)

/kɔɗʊ-di/	*[-ATR][-HI,+ATR]	IDENT-[ATR]	
💣 kɔɗʊdi			*no harmony*
kɔɗudi		*!	*partial harmony*
koɗudi		*!*	*full harmony*

Constraint conjunction offers one way to solve this problem and define the extent of harmony (Smolensky 1993; 1995; Łubowicz 2005). A conjoined constraint composed of a faithfulness and sequential markedness constraint, IDENT-[ATR] & *[+ATR][+HI,+ATR], though, does not induce actual spreading and instead prefers faithfulness to harmony because the locus of violation of a sequential markedness constraint is a span of two syllables. In order to restrict the locus of violation, we must revise the definition of the markedness constraint (Pulleyblank 2002). Consider the constraint defined in (21), whose locus of violation is a single [+hi, +ATR] vowel rather than a sequence of two syllable-adjacent vowels. Underlining indicates the locus of evaluation. The inclusion of the conjoined constrain in (22) obviates the need for the sequential markedness constraint above, which is replaced by a more general alignment constraint in (23-24).

(22) *[+ATR][+HI, +ATR] assign a violation to every [+hi, +ATR] vowel that is preceded by a syllable-adjacent [+ATR] vowel.

(23)

/r-ɛ-hɪ=r-e/	IDENT-[ATR] & *[+ATR][+HI, +ATR]	ALIGN-L[+ATR]	IDENT-[ATR]	
rɛhɪre		**!		*no harmony*
☞ rɛhire		*	*	*partial harmony*
rehire	*!		**	*full harmony*

(24)

/kɔɗʊ-di/	IDENT-[ATR] & *[+ATR][+HI, +ATR]	ALIGN-L[+ATR]	IDENT-[ATR]	
kɔɗʊdi		**!		*no harmony*
☞ kɔɗudi		*	*	*partial harmony*
koɗudi	*!		**	*full harmony*

Problematically, even though such a grammar can generate the Iny pattern, it is not *eventually idempotent,* a key computational trait of classical OT grammars (Moreton 2004; Tesar 2014). In a classical OT grammar, if the output of the grammar is fed back into the grammar, after some finite number of reapplications, the grammar will eventually select the faithful candidate. The grammar in (23-24), however, is not eventually idempotent. To see this, consider an input /ɪ…ɪ…ɪ…i/. This input is output as [ɪ…ɪ…i…i], with one preceding high vowel undergoing harmony (25). If we take this output and feed it back into the grammar, harmony will spread one syllable leftward, yielding [ɪ…i…i…i] (26). If we feed that output back into the grammar, harmony spreads one more vowel leftward, outputting [i…i…i…i] (27). At the fourth iteration, the grammar finally selects the faithful candidate (28). Crucially, since at each iteration the grammar drives spreading one syllable leftward, the number of iterations is equal to the length of the string.

Consider a phrasal variant of ATR harmony in Iny. Further, consider an unboundedly long phrase with no non-high vowels; in this string of high vowels, the last high vowel is [+ATR] and all preceding high vowels are underlyingly [-ATR]. Since the length of this string is unbounded, it will take an unbounded number of steps of the above process to reach a state where the optimal output is identical to the input. For this reason, such a grammar is not eventually idempotent, and as a consequence does conform to Moreton's (2004) definition of a classical OT grammar. More generally, an analysis predicated on sequential markedness constraints and conjoined constraints "really seems to miss the point of OT" (McCarthy 2004:15), since the number of constraints increases exponentially, as does the stipulativity of the analysis.

(25)

/ɪ…ɪ…ɪ…i/	ID-[ATR] & *[+ATR][+HI, +ATR]	ALIGN-L[+ATR]	ID-[ATR]
ɪ…ɪ…ɪ…i		***!	
☞ ɪ…ɪ…i…i		**	*
ɪ…i…i…i	*!	*	**
i…i…i…i	*!*		***

(26)

/ɪ…ɪ…i…i/	ID-[ATR] & *[+ATR][+HI, +ATR]	ALIGN-L[+ATR]	ID-[ATR]
ɪ…ɪ…ɪ…i		**!*	*
ɪ…ɪ…i…i		**!	
☞ ɪ…i…i…i		*	*
i…i…i…i	*!		**

(27)

/ɪ…i…i…i/	ID-[ATR] & *[+ATR][+HI, +ATR]	ALIGN-L[+ATR]	ID-[ATR]
ɪ…ɪ…ɪ…i		*!**	**
ɪ…ɪ…i…i		*!*	*
ɪ…i…i…i		*!	
☞ i…i…i…i			*

(28)

/i…i…i…i/	ID-[ATR] & *[+ATR][+HI, +ATR]	ALIGN-L[+ATR]	ID-[ATR]
ɪ…ɪ…ɪ…i		*!**	***
ɪ…ɪ…i…i		*!*	**
ɪ…i…i…i		*!	*
☞ i…i…i…i			

A different analysis is proposed in Ozburn & Leduc (2022), based on contrast preservation. However, the analysis in Ozburn & Leduc (2022) requires the grammar to evaluate contrast over the inventory, a significant departure from most work in OT.

5.2 *Autosegmental representations* As mentioned above, the key to McCollum & Kavitskaya's (to appear) autosegmental account of rounding harmony in Crimean Tatar is an adjacency constraint that bans non-local linkage (29). A grammar with highly-ranked ADJACENCY can account for the Central Crimean Tatar pattern only because the set of propagators is empty. In Iny, an adjacency-based analysis wrongly predicts a two-syllable domain for harmony in all cases since ADJACENCY penalizes all sequences of non-adjacent elements linked to the same autosegment. Since the set of propagators is not empty in Iny, i.e., mid vowels are propagators, this wrongly predicts partial harmony in (30).

(29) ADJACENCY[+ATR] given a string Y consisting of $V_1 \ldots V_n$ and a [+ATR] autosegment, assign a violation to every token of [+ATR] that is linked to non-adjacent vowels, e.g. V_y and V_{y+2}; V_{y-2} and V_{y+2} ; V_{y-1} and V_{y+1}.

(30)

[+] | /dεbɔ d-e/	ADJACENCY [+ATR]	ALIGN-L-[+ATR]	IDENT-[ATR]	
[+] | dεbɔde		*!*		*no harmony*
[+] 💣 /| dεbode		*!	*	*partial harmony*
[+] //| debode	*!		**	*full harmony*

One possibility is to replace ADJACENCY with a variant of a CRISPEDGE constraint that assigns a violation to every [+hi, +ATR] vowel that is not leftmost in a [+ATR] domain (Itô & Mester 1994; Walker 2011). This correctly generates full harmony among mid vowels, and generates partial harmony when a [+hi, +ATR] vowel is output by harmony, in (31).

(31)

[+] | /r-ε-hɪ=r-e/	CRISPEDGE-L [+HI,+ATR]	ALIGN-L-[+ATR]	IDENT-[ATR]	
[+] | rεhɪre		**!		*no harmony*
[+] ☞ /| rεhire		*	*	*partial harmony*
[+] //| rehire	*!		**	*full harmony*

However, this set of constraints incorrectly predicts no harmony from a [+hi] trigger since CRISPEDGE >> ALIGN-L, seen in (32); the faithful candidate is preferred over the attested output, [broreni].

(32)

[+] | /brɔrɛ-dĩ/	CrispEdge-L [+hi,+atr]	Align-L-[+atr]	Ident-[atr]	
[+] 💣 | brɔrɛni		**		*no harmony*
[+] /| brɔreni	*!	*	*	*partial harmony*
[+] //| broreni	*!		**	*full harmony*

To solve this issue, it is possible to introduce a constraint banning monosyllabic domains, *Mono[+atr], based on work in Optimal Domains Theory (Cassimjee & Kisseberth 1998). If this constraint is undominated, it will compel harmony from a high vowel trigger. This set of constraints rightly predicts full harmony in (33) and partial harmony in (34), like the metrical analysis developed above.

Given that both of these analyses can account for the data, the question is now which of the two is superior on theoretical grounds. There are at least two reasons to prefer the metrical analysis. First, the *Hd constraints in the metrical analysis do not need any directional specification, but the set of CrispEdge constraints in the autosegmental analysis must be duplicated for rightward spreading patterns. Second, *Mono in the autosegmental analysis exists solely to initiate spreading from a high vowel trigger. There is no independent motivation for this constraint in the language or within the larger theory. Such a constraint exists solely to compel bounded harmony. In contrast, its counterpart in the metrical analysis, SpanBin, dictates the size of spans more generally, parallel to its function for foot-based analyses of stress.

(33)

[+] | /brɔrɛ-dĩ/	*Mono [+atr]	CrispEdge-L [+hi,+atr]	Align-L- [+atr]	Ident- [atr]	
[+] | brɔrɛni	*!		**		*no harmony*
[+] /| brɔreni		*	*!	*	*partial harmony*
[+] ☞ //| broreni		*		**	*full harmony*

(34)

[+] | /kɔɗʊ-di/	*Mono [+atr]	CrispEdge-L [+hi,+atr]	Align-L- [+atr]	Ident- [atr]	
[+] | kɔɗʊdi	*!		**		*no harmony*
[+] ☞ /| kɔɗudi		*	*	*	*partial harmony*
[+] //| koɗu-di		**!		**	*full harmony via non-local spreading*

5.3 *Headed Spans* Autosegmental-style spreading has been modelled in OT using spans (McCarthy 2004; Smolensky 2006). The biggest representational difference between these theories and classical autosegmentalism is the delineation of heads.[3] In work by McCarthy and Smolensky, though, triggers may be heads, but not propagators since spans do not overlap (cf. Key & Bickmore 2014). This is crucial – as such, heads may only define what may trigger, and in the case of Span Theory, what must block harmony. These theories do not have internal devices with which to define how far harmony may extend. Without these devices, the types of constraints used above, like *MONO and CRISPEDGE may be used, and are faced in the same challenges discussed above.

5.4 *Shortcomings* Throughout the previous two subsections I have discussed the descriptive and theoretical issues for string-based, autosegmental, and span-theoretic alternatives. To be fair, it is necessary to indicate one key shortcoming of my hierarchical analysis, which is also shared by the autosegmental alternative sketched in Section 5.2. My analysis depends on a highly-ranked SPANBIN constraint to motivate harmony from an underlying [+hi, +ATR] vowel. While this successfully generates bounded leftward spreading in words like /kɔɗʊ-dĩ/ [kɔɗu-ni], the proposed constraint set also predicts *rightward* spreading to satisfy SPANBIN. Consider the data in (35). In each, leftward harmony is blocked, either because there are no vowels to the left of the trigger (35a) or because the preceding vowel is [+low], systematically blocking harmony (35b). For words like this my analysis wrongly predicts rightward harmony to satisfy SPANBIN (36).

(35)				
	a.	/ritʃɔrɛ/	[ritʃɔrɛ]	‘offpsring’
	b.	/wa-ritʃɔrɛ/	[waritʃɔrɛ]	‘1-offspring’

This pathological prediction is serious; there is no evidence that harmony in Iny ever spreads rightward. In my analysis, SPANBIN is the culprit, but the same pathological prediction is generated by *MONO. Thus, the issue is not restricted to my analysis only, but rather is characteristic of both the autosegmental and metrical analyses because each uses a constraint like *MONO or SPANBIN. While much of this issue is directly related to the particular constraints invoked to regular span size, this is another instance of the much larger “too many solutions” problem (Steriade 2001).

(36)

[+] | /ritʃɔrɛ/	SPANBIN [+ATR]	*HD [+HI, +ATR]	ALIGN-L-[+ATR]	IDENT-[ATR]	
[+] | ritʃɔrɛ	*!				*no harmony*
💣 [+] |\\ ritʃorɛ		*		*	*partial rightward harmony*
[+][+] |\\\|\\ ritʃore		*		**!	*full rightward harmony*

6 Conclusion

The vowel harmony patterns in Iny, Bangla, and Central Crimean Tatar all exhibit a shared property – boundedness. By this I mean that the extent of harmony is not always definable in terms of some well-motivated morphological or prosodic boundary, or the set of sounds that may undergo harmony. In these languages, the extent of harmony depends on the (in)ability of some segments to propagate the harmonic feature. While previous analyses fail to adequately account for these patterns (e.g., Jurgec 2011; McCollum & Kavitskaya to appear; Ozburn & Leduc 2022), the proposed metrical analysis provides a superior analysis

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[3] However, starred representations in Goldsmith (1976) could be treated as such, as noted by Leben (1982).

of these patterns. In a rule-based theory, Clements (1981) argues that unbounded harmony patterns demonstrate the necessity of non-linear representations. In this paper, I have argued that the analysis of bounded harmonies in OT supports a similar conclusion.

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