Restricting Multi-level Constraint Evaluation:
Opaque Rule Interaction in Yawelmani Vowel Harmony

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This paper presents an analysis of vowel harmony in Yawelmani and its interaction with vowel epenthesis and lowering, within the non-derivational, constraint-based model of Optimal Domains Theory (ODT). Kisseberth's (1969) analysis of the Yawelmani system, formulated within classical generative phonology, demonstrates an opaque rule interaction among the rules governing vocalic phonology, and was taken as an important piece of evidence for the notion of rule ordering in generative theory. The challenge in providing a non-derivational analysis of Yawelmani lies in accounting for conditions on vowel harmony which factor in phonological structure that is "inserted" in surface form, as well as structure that is "deleted" from underlying form. This paper presents a restricted means of bringing together information from underlying and surface representations in a theoretical framework that eschews intermediate representations, through the use of abstract (ie., unrealized) feature-domain structure. We discuss problems that arise under an alternative approach in which individual constraints are able to freely inspect structure at both underlying and surface levels of representation.

1 Yawelmani Round Harmony

Yawelmani displays a system of vowel harmony in which a suffix vowel agrees in backness and roundness with the stem vowel (Archangeli 1984, Kenstowicz and Kisseberth 1979, Kisseberth 1969, Newman 1944). The surface vowel inventory contains the short vowels [i,u,e,o,a] and the long vowels [e:,o:,a:].[2] The interesting properties of the harmony system stem from a condition that requires the trigger and targets of harmony to be of identical height. Thus, the high stem vowel [u] conditions harmony on high suffix vowels, as in (1a), while the low stem vowel [o] conditions harmony on low suffix vowels, as in (1b). In forms where the stem vowel and suffix vowels differ in height no harmony obtains, as in (1c). A suffix vowel which differs in height from the preceding vowel actually blocks any subsequent suffix vowels from undergoing harmony as well, as seen in (1d).

(1)	a.	xil-hin	'tangles, non-future'
		dub-hun	'leads by the hand, non-future'
	b.	xat-al	'might eat'
		bok'-ol	'might find'

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[2]Despite the transcription, Newman (1944) describes the vowels [e:,o:] as phonetically low. We maintain the transcription [e:,o:] to facilitate cross-reference with the sources cited above.

c.	xat-hin	'eats, non-future'
	bok'-hin	'finds, non-future'
	xil-al	'might tangle'
	dub-al	'might lead by the hand'
d.	bok'-k'o	'find (it)!'
	bok'-sit-k'a	'find (it) for (him)!'

The height condition on round harmony has the result that, in the simplest cases, the trigger and targets of harmony are identical in surface form, bearing a uniform specification for height, round and back features. Thus, we refer to the height condition in Yawelmani as a **Uniformity** condition.[3]

The vowel harmony pattern is obscured in some words that contain long stem vowels. Consider the following examples.

(2)

	passive aorist	
a.	me:k'-it	'swallow'
b.	?o:ṭ'-ut	'steal'
c.	do:s-it	'report'
d.	ta:n-it	'go'

Comparing examples (2b) and (2c), it appears that some instances of surface [o:] exceptionally trigger harmony on a following high suffix vowel. Surface [o:] in the same stems also fails to trigger harmony on a following low suffix vowel, as shown in (3).

(3)

	precative gerundial	
a.	me:k'-?as	'swallow'
b.	?o:ṭ'-?as	'steal'
c.	do:s-?os	'report'
d.	ta:n-?as	'go'

Kisseberth (1969) argues that instances of surface low vowels [o:,e:] which pattern with the high vowels in their harmonic behavior actually derive from the high vowels /u:, i:/, respectively, in underlying representation.[4] A context-free rule of lowering maps /u:,

[3]For further discussion of harmony systems governed by Uniformity (termed *parasitic* harmony in some earlier work), see Halle 1995, Cole and Trigo 1989, and Steriade 1979. Uniformity functions in many of the round harmony systems found in Turkic languages as well, where it may govern the height and/or palatality of vowels in a round domain (Cole and Kisseberth 1995). In some of the Turkic harmonies, the Uniformity condition does not render all harmonizing vowels identical, as in Yawelmani; for this reason we formulate Uniformity in terms of individual features and not as a constraint on full featural identity.

[4]Kisseberth (1969) and Kenstowicz and Kisseberth (1979) provide a wealth of additional arguments

i:/ onto their non-high counterparts, and also accounts for the near absence of the long high vowels [u:,i:] in surface forms. Kisseberth's lowering rule is ordered after harmony, with the result that surface instances of [o:,e:] that are the output of Lowering will not trigger harmony on a following low vowel, as seen above.[5]

The round harmony system is further complicated through its interaction with vowel epenthesis. The maximal syllable in Yawelmani is bimoraic: CV: or CVC. An epenthetic high vowel is inserted to break up unsyllabifiable consonant clusters. As seen in (4), if the preceding vowel is high, round [u], the epenthetic vowel (in boldface) undergoes round harmony and surfaces as [u]. Furthermore, a medial epenthetic vowel blocks harmony between low vowels, as shown in (5c). The effect of epenthesis on the harmony system is transparent in surface forms, since the height of the epenthetic vowel clearly plays a role in determining the extent of the harmony domain.

(4)

	non-future	
a.	?il**i**k-hin	'sings'
b.	?ug**u**n-hun	'drinks'
c.	log**i**w-hin	'pulverizes'
d.	pa?**i**ṭ-hin	'fights'

(5)

	precative gerundial	
a.	?il**i**k-?as	'sing'
b.	?ut**u**y-?as	'fall'
c.	log**i**w-?as	'pulverize'
d.	pa?**i**ṭ-?as	'fight'

In Kisseberth's generative analysis, the interaction between the subsystems of harmony, epenthesis and lowering is accounted for by ordering epenthesis before the harmony rule, and harmony before lowering, as in (6). Under this order, the Uniformity condition on harmony can factor in the presence of the epenthetic vowels that appear in surface structure, and the [high] feature of underlying /u:,i:/ that appears in underlying structure.

(6) Epenthesis >> Harmony >> Lowering

It is important to note that the Uniformity condition on harmony cannot be correctly imposed or evaluated on the basis of either underlying or surface structure alone. Underlying structure is crucial to block harmony in a form like /?u:ṭ-?As/, which surfaces as

in support of the analysis that posits underlying /u:,i:/ in roots like /?u:ṭ-/, based on phonological patterns that are independent of harmony.

[5] Note that when Lowering applies to the front vowel, it derives the mid vowel [e:], which is not an independently contrastive vowel in the system.

ʔo:ṭ'as and not **ʔo:ṭ'os* (3b). Surface structure is crucial to block harmony in a form like /logw-ʔAs/, which surfaces as *logiwʔas* and not **logiwʔos* (5c). The rule ordering solution in effect posits a third level of representation, intermediate between underlying and surface representations, in which all and only those vowel structures relevant to the determination of the Uniformity condition are present. These customized representations arise automatically from the architecture of classical generative theory, in which rules apply sequentially; the output of each rule application is an intermediate representation that defines the input for the next rule.

The problem addressed in this paper is how to get at the information encoded in the intermediate representations of Kisseberth's analysis, while maintaining a non-derivational theory which eschews intermediate representations. Stated generally, the problem that Yawelmani presents, and which is encountered in a variety of other phonological systems as well, concerns the manner in which a phonological grammar can establish links or dependencies between elements in the phonological expression of morphemes, when those elements (eg., features) don't appear together in the same representation. In Yawelmani, the necessary dependency relates height and round features that appear in underlying and surface representations. Similar problems arise in other languages when dependencies relate structure contained in distinct words that stand in paradigmatic relation, giving rise to cyclicity and analogical levelling, among other phenomena (Cole 1995, Kraska-Szlenk 1995).

2 Multi-level constraint evaluation

In this section we explore two possible approaches to modelling cross-representational dependencies in non-derivational phonology. We consider first an analysis developed in Goldsmith (1993), adopting a three-level theory of phonological representation, and then go on to consider a straw-man proposal that we sketch for the implementation of multi-level constraint evaluation in Optimality Theory.

2.1 The Harmonic Phonology model

The possibility of representations intermediate between underlying and surface forms is not unique to the derivational model. Goldsmith (1993) presents an account of Yawelmani harmony that manages the interaction between harmony, epenthesis and lowering through the use of intermediate structures, in a non-derivational analysis that shares much in common with the rule-ordering analysis. Goldsmith develops his analysis in the framework of Harmonic Phonology, a model of phonology in which phonological constraints define mappings between structure at three levels of representation: M(orphophonemic)-level, W(ord)-level, and P(honetic)-level.[6] In addition to inter-level constraints, there are intra-level constraints, which apply persistently to a single level of representation, inducing modification of structures at that level until a "harmonic" (or "optimal") output

[6]Slightly different formulations of three-level phonology are developed in Lakoff 1993 and Wheeler and Touretzky 1993.

state is achieved.[7] This model builds in a limited number of intermediate representations between underlying (M-level) and surface (W-level), and thus provides a way for constraints like the Uniformity constraint in Yawelmani to evaluate a representation that combines aspects of underlying form with some (but not all) inserted structure.

Goldsmith demonstrates how the three-level model is sufficient to account for the interaction between harmony, lowering, and epenthesis in Yawelmani. As diagrammed in (7), Epenthesis governs the mapping between M-level and W-level representations, Harmony is an intra-level constraint on W-level representations, and Lowering governs the mapping between W-level and P-level.

(7) Yawelmani in a three-level model

M-Level	
$\Updownarrow$	$\leftarrow$ Epenthesis
W-Level	$\leftarrow$ Harmony
$\Updownarrow$	$\leftarrow$ Lowering
P-Level	

The result of this grammar organization is that Harmony evaluates W-level representations that encode epenthetic vowels, but with their underlying height specifications intact. Lowering evaluates W-level *output* representations, which have already undergone harmony. The model succeeds, but only at the expense of allowing five distinct structures to be subject to constraint evaluation: Input M-level (for M-M intra-level constraints), Output M-level (for M-W constraints), Input W-level (for M-W and W-W constraints), Output W-level (for W-P) constraints, and Input P-level (for W-P and P-P constraints). The details of each type of constraint evaluation and their interaction are not our primary concern here, but the analysis of Yawelmani under this model is of interest to us for its use of intermediate representations. It demonstrates that the key to resolving the opaque rule interaction in Yawelmani lies in the possibility of composing structure from underlying representation with derived structure, which is independent of the implementation of the model as derivational or non-derivational.

2.2 Multi-level evaluation in OT

In contrast to Goldsmith's model, Optimality Theory (OT) (Prince and Smolensky 1993) recognizes at most two distinct representations—underlying form (input) and surface form (output). All constraints apply in parallel, and with the exception of Faithfulness constraints, all constraints evaluate surface representations.[8] So, the challenge in de-

[7]Because the inter-level constraints induce modification of a string, the resulting framework is not wholly non-derivational; but it uses a restricted type of derivation, since explicit ordering relations among constraints are not possible.

[8]Under correspondence theory (McCarthy and Prince 1995), Faithfulness constraints evaluate the correspondence between elements in surface and underlying form. The special behavior of Faithfulness constraints are considered further below.

veloping an OT account of Yawelmani round harmony lies in establishing the necessary dependencies between elements of underlying and surface form without introducing novel intermediate representations.

One way of giving constraints access to information contained in underlying representation is to allow certain constraints to directly evaluate underlying rather than surface representation. Unfortunately, such a simple solution is insufficient for Yawelmani, since as shown above, the Uniformity condition must consider underlying structure (for lowered vowels) *and* surface structure (for epenthetic vowels).

A second, less restrictive type of solution approach would be to allow constraints to evaluate structure in both underlying and surface representation simultaneously. Under this scenario, a constraint is satisfied if it can find the appropriate structure in either surface or underlying form. An analysis of Yawelmani under this approach would allow the Uniformity condition to evaluate the height specification of all surface vowels, as well as the height specification of vowels in underlying representation. As long as Uniformity is satisfied at one of the two levels, harmony can apply. This approach yields satisfactory results for examples like *ʔo:ṭ'-ut* (2b), where Uniformity is satisfied at the underlying representation, thereby licensing harmony.

(8)	underlying:	?u:ṭ'-It	Uniformity: yes
	surface:	?o:ṭ'-ut	Uniformity: no; Harmony: yes

But this approach does not account for the failure of harmony in forms where a lowered vowel is followed by a low suffix vowel, as in *ʔo:ṭ'-as* (3b). Here, Uniformity should apply, since it is satisfied at the surface level.

(9)	underlying:	?u:ṭ'-?As	Uniformity: no
	surface:	?o:ṭ'-?as	Uniformity: yes; Harmony: no

This approach also fails in words containing epenthetic vowels, such as *logiw-as* (5c), where the failure of Uniformity at the surface level blocks harmony, even though Uniformity is satisfied in underlying representation.

(10)	underlying:	logw-As	Uniformity: yes
	surface:	logiw-as	Uniformity: no; Harmony: no

To summarize, we have seen that restricting constraint evaluation to surface level alone (as in the formulation of OT in Prince and Smolensky 1993) is not sufficient for the Uniformity constraint in Yawelmani. Some underlying structure must be factored in. Unrestricted multi-level evaluation, in which both underlying and surface levels can be subject to independent evaluation, also does not succeed in accounting for the facts. What is needed is a restriction to the effect that constraints on surface form may *under certain conditions* access information in underlying form. More precisely, for Yawelmani, the Unformity constraint *must* consider the underlying height specification of any vowel for which there is a discrepency between surface and underlying height specifications, ie., lowered vowels. If there is no discrepency, then surface height features alone suffice. Epenthetic vowels have no underlying specification at all, therefore they do not countenance an underlying-surface discrepency, and so it is their surface height feature (ie., their only height feature) that is counted.

This more restricted method of multi-level evaluation provides a successful means of establishing a cross-representational dependency in Yawemani. But the restriction is absolutely critical; unrestricted multi-level evaluation yields a potential pathological result. In the unrestricted version, Uniformity is satisfied in all the cases shown in (8-10), which means that harmony would take place not only in *ʔoṭ'-ut* (8), but also in surface forms like *ʔo:ṭ'-ʔos* (cf., (9)) and *logiw-os* (cf., (10)). The pathology in the system arises because a lowered vowel functions both as a high vowel and as a low vowel in harmony contexts. We are not aware of any harmony system (or any other kind of phonological system) in which a segment patterns simultaneously as a member of two lexically contrastive feature classes *with respect to a single constraint.*

The harmony pattern that results from multi-level evaluation in this hypothetical case is particularly puzzling because it suffers a degradation of the Uniformity condition to no apparent benefit. In the real Yawelmani system, the Uniformity condition is not perfectly upheld in surface forms, as seen by the behavior of lowered vowels. But the very occurrence of harmony in forms such as *ʔo:ṭ'-ut* provides a way of preserving the underlying, contrastive High specification of the stem vowel. The behavior of the lowered vowel exactly mimics the behavior of High vowels. We suggest that the real Yawelmani system tolerates harmony in contexts where Uniformity is violated, but only for the purpose of preserving contrast. This is the kind of situation that OT handles very well—a tradeoff between conflicting grammatical constraints. In contrast, in the hypothetical system, with unrestricted multi-level evaluation, Uniformity is similarly violated (witness the non-uniform height in the harmony domains of putative *ʔo:ṭ'-ut* and *logiw-os*), but in this case the harmony pattern does not consistently reflect the underlying height feature of the lowered vowel. The behavior of the lowered vowel doesn't exactly match that of either high or low vowels outside of lowering contexts. Thus, by allowing Uniformity free access to both underlying and surface information, the surface round domains are degraded (non-uniform), and in lowering contexts, serve to further obscure the underlying height specification of the lowered vowel.

From consideration of this straw-man proposal for unrestricted multi-level evaluation, we conclude that the task at hand is to provide a principled restriction on the conditions under which underlying structure can be evaluated. In the next section, we develop an account of Yawelmani in which information about the underlying height specification of a vowel is preserved in surface structure, even when the underlying feature cannot be phonetically realized. The presence of unrealized underlying structure in surface form is not guaranteed in all situations (ie., it does not follow from a principal of Containment), but is shown to be a necessary component of grammars in which phonological constraints come to assume some of the function of Faithfulness constraints.

3 The ODT approach

Optimal Domains Theory (ODT) is a theory of the realization of segmental features based on OT. It adopts from OT the view that phonological grammars consist of a ranking over a set of universal constraints on well-formedness, and that all constraints are in principle violable. A constraint will be violated in a surface form if it stands in conflict with a higher-ranking constraint; if there is no candidate surface structure which can satisfy both constraints, it is the lower-ranking constraint which will be violated. Constraint violation arises frequently when phonological constraints come into conflict with the Correspondence constraints, which require the underlying and surface representations of a form to be fully identical. The Correspondence constraints are divided into the following two sets (McCarthy and Prince 1995):[9]

(11) MAX: Every element of the input has a correspondent in the output. (Prohibits phonological deletion.)

(12) DEP: Every element of the output has a correspondent in the input. (Prohibits phonological epenthesis.)

ODT defines a set of well-formedness constraints governing the extent and composition of structures in which distinctive features can appear in surface form. ODT is developed in Cole and Kisseberth (1994a,b,c, 1995) as the basis for a constraint-based, non-autosegmental account of harmony systems.[10]It also serves as the basis for the analysis of tonal phonology in Cassimjee (1995), and Cassimjee and Kisseberth (in prep.).

3.1 F-domains and alignment

The central claim of ODT is that distinctive features (ie., substantive features that give rise to articulatory and acoustic events) in underlying representation are parsed into feature domains, or **F-domains**, in surface representation. In other words, the F-domain serves as the surface correspondent for an underlying feature specification, as required by MAX. Whereas features are sponsored by individual segments in underlying form, F-domains may span one or more segment positions, and thus mark the duration of

[9]We have generalized the statement of MAX to refer to every *element* of the input, as opposed to every *segment*. Featural correspondence arises in our system from the family of MAX-F constraints, which play a similar role to the IDENT-F identity constraint in McCarthy and Prince 1995. We do not explore potential differences between the MAX-F and IDENT-F constraints here (but see Cole and Kisseberth 1995).

[10]ODT is non-autosegmental in that it does not make use of the key concepts that define autosegmental analyses of harmony. In particular, ODT does not model harmony as autosegmental spreading, and does not appeal to the NoCrossing constraint to derive transparency or opacity. In fact, the ODT analysis does not require any explicit representation of autosegmental association.

the feature in surface form. The F-domain is an abstract structure, on par with other structural units such as the syllable or foot, and constitutes a formal notation for encoding the feature-class membership of a segment. The F-domain can also be viewed as the structural analogue of a *plan* for the execution of a phonetic event. F-domains in ODT take over much of the role of the autosegment in Autosegmental Theory.

F-domains are the only legal structures into which distinctive features may be parsed, and so there is no contrast in surface representation between features in F-domains and features outside of F-domains. Having an F-domain correspondent in surface structure is a necessary (but not sufficient) condition for the phonetic realization of an underlying feature. F-domains are included in the set of categories governed by Alignment Theory, and so can be aligned with other structural units, including the segment, syllable, foot and prosodic word. ODT recognizes the special function of two alignment constraints: BASIC ALIGNMENT aligns an F-domain with the segment that sponsors the feature in underlying representation; WIDESCOPE ALIGNMENT aligns an F-domain with a larger prosodic constituent, such as the prosodic word.

WIDESCOPE ALIGNMENT is responsible for the extended feature domains that characterize harmony. In order to have a wide F-domain in surface form, it is necessary to rank the relevant WIDESCOPE ALIGNMENT constraint above the corresponding BASIC ALIGNMENT constraint. Yawelmani Round Harmony is rightward within words, and so WIDESCOPE ALIGNMENT for the feature Round aligns the right edge of every Round domain with the right edge of the Prosodic Word, as in (13)

(13) WIDESCOPE ALIGNMENT (WSA): Align(Rd-domain,R; PrWd,R)

BASIC ALIGNMENT is formulated in (14), and the rankings over the F-domain alignment constraints which are necessary to get rightward harmony in Yawelmani are shown in (15).

(14) BASIC ALIGNMENT (BA): Align(Rd-domain, R/L; Sponsor, R/L)[11]

(15) Some rankings for harmony

a. WSA-RIGHT(Rd-domain, PrWd) >> BA-RIGHT(Rd-domain, Sponsor)

b. BA-LEFT(Rd-domain, Sponsor) >> WSA-LEFT(Rd-domain, PrWd)

c. BA >> WSA, for all other F-domains

The ranking in (15a) yields rightward harmony, (15b) prohibits leftward harmony, and (15c) is a general statement about the alignment of all other feature domains to the effect that no other feature exhibits harmony.

[11] BASIC ALIGNMENT functions as member of the family of Faithfulness constraints in ODT. It keeps the domain of a feature local to the underlying sponsor, which guarantees preservation of contrast. Thus, like other Faithfulness constraints, BASIC ALIGNMENT evaluates correspondences between underlying and surface structures, in this case by picking out feature sponsors.

3.2 Feature specification and grounding constraints

A few comments are in order about the specification of features in the underlying representation of harmony targets. The results of this section provide some technical detail and constraint rankings to support the ensuing analysis, but do not constitute the important part of the analysis of opacity, which is the focus of this paper.

Suffix vowels may be unspecified for Round, since the surface value is always dependent on instances of Round in the stem.[12] The feature Back may also be omitted from the underlying specification of suffix vowels, since it can be determined on the basis of Round and High. The grounding constraints (Archangeli and Pulleyblank 1994) that govern the co-occurrence of the features Round and Low with the feature Back are formulated in (16). These constraints are undominated, and account for systematic gaps in the vowel inventory. The grounding constraints and WIDESCOPE ALIGNMENT both outrank the Faithfulness constraint DEP for the feature Back, with the effect that a segment which acquires Round through the harmony-inducing domain alignment constraints will also acquire the feature Back.

(16) Grounding constraints

ROUND → BACK (RD/BK):	Requires all round vowels to bear the feature Back. Yields the harmonizing vowels [u,o].
LOW → BACK (LO/BK):	Requires low vowels to be back Yields [a] in words with no Round Harmony.

If a suffix follows a stem with no round vowel, then no round harmony takes place, in which case the suffix vowel surfaces as Back if it's Low ([a]) and Front if it's High ([i]). The appearance of Back on suffixal [a] is guaranteed by the grounding constraint LOW/BK.[13] The appearance of Front on suffixal [i] arises due to the ranking of DEP-BACK over DEP-FRONT: when there's no pressure from the presence of the feature Round, it's better to insert Front as the backness specification on an unspecified vowel. In addition, underlying

[12] Underspecification is not a crucial assumption for the analysis, however, by the same argument put forth in Itô, Mester and Padgett 1994: any underlying specification for Round or Back would be effectively over-ridden in favor of the specification that satisfies the highly ranked harmony constraints and grounding constraints on feature co-occurrence. ODT does not exploit the possibility of underspecified representations to account for opacity or transparency in harmony systems.

[13] The LOW/BK grounding constraint is violated in the case of [e,e:], which derive from underlying /i:/ through Lowering (and Shortening, which we do not discuss here). When Lowering applies to underlying /u:/ it yields surface [o:], thereby neutralizing the underlying contrast between /u:/ and /o:/; but Lowering of the front vowel /i:/ does not lead to a parallel neutralization of the contrast between /i:/ and /a:/. To account for this difference, we appeal to an explicit constraint prohibiting neutralization, PRESERVE CONTRAST (Cole and Kisseberth 1994c, Homer 1995), which is ranked above LOW/BK, with the result that the combination of [Low, Front] is tolerated as a means of satisfying Lowering, since the alternative structure [Low, Back] would lead to violation of PRESERVE CONTRAST. Neutralization of the back vowels seems unavoidable, since the closest lowered variant of /u:/ is low [ɔ:] (mid back vowels simply never appear).

specifications for Round, High, and Low are never affected by harmony, which requires ranking the relevant MAX constraints above the Rd-domain alignment constraints and UNIFORMITY (see below).[14]

3.3 Expression

Thus far, we have developed the following points in the ODT treatment of harmony: (i) the surface correspondent for an underlying feature specification is the F-domain, and therefore an F-domain is required to satisfy MAX; and (ii) F-domains are aligned with a single segment or with a larger prosodic constituent. The final piece in the ODT analysis is the Expression constraint, which states that every segment within the abstract structure of the F-domain must phonetically realize the feature [F]. To continue the plan analogy, while the F-domain constitutes the plan to realize the feature [F], expressing the feature on elements in the F-domain constitutes the execution of that plan. Just as every action presupposes a plan, every phonetic manifestation of a feature presupposes a corresponding F-domain in the surface representation. Expression is formulated as follows:

(17) EXPRESSION: The feature [F] must be expressed on every element in an F-domain.

The distinction between a feature domain and the expression of the feature within its domain provides a way of accounting for transparency in harmony systems. Briefly, transparency arises as a violation of EXPRESSION, under pressure from a higher-ranked constraint that prohibits the realization of a feature [F] on some segment or segments in the F-domain. For example, in Yawelmani the grounding constraint (18) prohibits the realization of Round on consonants, and for this reason consonants are transparent to round harmony.

(18) *[RD,C]: Round → NOT Consonantal

EXPRESSION must dominate DEP-RD in order for vowels in a Rd-domain to acquire the feature Round, but the *[RD,C] grounding constraint must in turn dominate EXPRESSION in order for the consonants to be transparent. The tableau in (19) demonstrates the constraint rankings among the Rd-domain alignment constraints, EXPRESS, DEP-RD, and *[RD,C], given the input form /dub-hIn/, with Round specified in the underlying form of the stem vowel. Parentheses are used to delimit Round domains.

[14]Round is contrastive only on the initial root vowel, which can be accounted for by ranking the positionally defined MAX-RD (STRONG) over *ROUND, while ranking *ROUND over the more general MAX-RD constraint. See Cole and Kisseberth (1994b).

(19)

input:	dub-hIn [Rd]	WSA -RT	*[RD,C]	EXPRESS	DEP -Rd	BA-RT
output:						
→ a.	d(ub-hun)			***	u	bhun
b.	d(ub-hin)			**** !		bhin
c.	d(u)b-hin	b!hin				
d.	d(ub^w-h^wun^w)		*!**		u	$b^w h^w u n^w$

The optimal candidate satisfies WSA-RT by extending the Rd-domain from the sponsoring vowel rightward to the end of the word, and satisfies *[RD,C] by not expressing Round on consonants in the Rd-domain. It is better than the (b) candidate, which fails to express Round on even the vocalic element in the Rd-domain. The undominated constraint *[RD,C] will be left out of the remaining discussion and tableaux, since its effects will always be entirely parallel to those shown in the above tableau.

The next section continues the ODT analysis of Yawelmani round harmony by developing a formal account of the Uniformity condition. But before moving on, there is one point to be made concerning the structures that derive transparency in ODT. We have seen that transparency arises through the violation of Expression, due to higher-ranking constraints governing feature distribution. Well-known examples of transparency in harmony systems involve cases where a potential target fails to undergo harmony, yet allows harmony to "pass through" it, inducing harmony on subsequent targets. Thus, the typical transparency configuration is $...\alpha_F...\beta...\gamma_F...$, where only α and β bear the harmony feature, $[F]$. Given the analysis of transparency in ODT, it should be clear that there are a larger range of potential "transparency" structures. Transparency arises by a violation of Expression, for which all that is needed is a single element in an F-domain that fails to express the feature [F]. It is in principle possible for "transparency" to arise at the edge of an F-domain, as in $(...\alpha_f...\beta)$, or $(\beta...\gamma_f...)$, or even in a domain containing only the single element (β) which fails to express the feature [F]. Of course, cases such as the last three are not typically referred to as involving "transparency" in autosegmental accounts of harmony, but they must be seen as instances of the same phenomenon in the ODT analysis. Below we will see evidence for the single-element transparent domain in the analysis of Lowering, providing important empirical support for the treatment of transparency in ODT.

3.4 Uniformity

Now it is time to work the Uniformity condition into the ODT analysis of harmony. Abstracting away from the effects of Lowering for the moment, Uniformity requires monotonicity within the harmony domain; transitions from high to low, or from low to high, are prohibited. Monotonicity is achieved only if the elements that express the harmony feature are of the same height. Since in Yawelmani there are only two independent degrees of contrast, height and backness/roundness, the end result of Uniformity is that the output of harmony will be sequences of fully identical vowels: [u...u] or [o...o].

(20) Uniformity (UNIFORM): The harmony domain must be monotonic: High or Low.[15]

The Uniformity condition has a blocking effect on harmony, as seen by examples like *bok'sitk'a* (1d), which means that UNIFORMITY must dominate WSA-RT. This ranking is illustrated in the evaluation of *bok'sitk'a* from underlying /bok'-sIt-k'A/ in (21). As shown, the optimal candidate in (a) satisfies UNIFORMITY, albeit in a vacuous manner, since the harmony domain stops short of the first potential target. It does, however, fare better than any of the competing candidates, which fatally sacrifice UNIFORMITY in order to satisfy WSA-RT.

(21) Uniformity as a blocking condition on harmony

input:	/o...I...A/	UNIF	WSA-RT	EXPRESS
→ a.	(o...)i...a		!i,...,a	
b.	(o...i...o)	*!		*
c.	(o...u...o)	*!		

The epenthetic high vowel functions just as underlying high vowels in blocking harmony, as seen above in (5c), which is, however, consistent with the interpretation of UNIFORMITY as a constraint on harmony domains in surface representation.

3.5 Lowering and the opacity problem

The final element in the ODT analysis of Yawelmani round harmony concerns the treatment of Lowering. Lowering can be viewed as an optimizing constraint that increases the sonority of bimoraic vowels. This is a case of the strong (in terms of weight) becoming stronger (in terms of peak sonority). LOWER is formulated in (22).

[15] An interesting question concerns the status of consonants in round harmony domains. A transparent consonant does not bear the High or Low feature shared by vowels in the same harmony domain. Thus, under at least one interpretation, the consonant should incur a violation of UNIFORMITY. The conflict arises between UNIFORMITY and *RD/C on the one hand, and WSA on the other hand. For consonants, we want to say that WSA and *RD/C outrank UNIFORMITY. But, as shown below, the opposite ranking is required in the case of non-uniform vowels. To block harmony in a sequence /o...I...A/ or /u...A...I/, it is necessary to rank WSA under UNIFORMITY, rendering violations of WSA with non-uniform vowel sequences. A way around the ranking paradox is to formulate UNIFORMITY in such a way that it applies only to vowels, excluding sequences like /u...o/ or /o...u/. This can be done by formulating UNIFORMITY as a negative constraint against High-Low or Low-High transitions within a harmony domain, in which case the consonants become irrelevant, lacking any height specification at all.

(22) Lowering (LOWER): $V_{\mu\mu} \rightarrow$ [Low]

The effect of LOWER is that long vowels are realized as Low, which entails the insertion of Low-domains in the surface representation of underlying High, long vowels. With the Low-domain in place, the feature Low can be expressed.[16] To achieve these results, LOWER must be ranked above DEP-LOW.

(23) Inserted Low-domains in the optimal candidate
Notation: { } = Low domain, ( ) = High domain

input:	u:	LOWER	DEP-LO
→ a.	{o:} Lo		*
b.	(u:) Hi	*!	

Examples such as *ʔo:ṭ'-ut* (2b) and *ʔu:ṭ'-ʔas* (3b) were noted above as showing that a lowered High vowel nonetheless is counted as a High vowel by the Uniformity condition on harmony. The dual behavior of lowered vowels can be accounted for in ODT through the use of domain structure. Even though underlying /u:, i:/ cannot realize their High feature due to the effect of the undominated LOWER constraint, it remains possible for the underlying High feature to be parsed in a High-domain. The surface representations of lowered vowels can encode both a High-domain that satisfies MAX-HIGH, and a Low-domain that satisfies LOWER. Then the issue becomes which domain wins the Expression battle. By definition, High and Low are opposing gestures which cannot be simultaneously executed, and so under the assumption that Gen produces only those structures that have a *potential* realization, there will be no candidate which expresses both High and Low on the same vowel. The surface candidates for an underlying /u:/ are indicated in the tableau in (24).

[16] In attributing the surface lowness of lowered vowels to a surface level Low feature and Low-domain, we are adopting the restrictive position that *every* feature which is phonetically realized must exist within a corresponding feature domain in surface realization. The evidence for the phonological status of lowered vowels, then, is simply their phonetic realization. An alternative analysis which treats the surface lowness of lowered vowels as simply a phonetic manifestation of a phonologically High vowel simply shifts the burden of explanation to principles governing phonetic realization. The ODT position is to keep phonetic interpretation as transparent as possible, and deal directly with patterns of alternation in the constraint grammar. It is our view that this position affords the greatest opportunity for the maximal integration of phonetics and phonology.

(24) Evaluation of /u:/

Notation: { } = Low domain, ( ) = High domain

input:	u:	LOWER	MAX-HI	EXPRESS-HI	DEP-LO
a.	(u:)	*!			
b.	({u:})	*!			
→ c.	({o:})			*	*
d.	{o:}		*!		*

Candidate (a) is the most faithful to underlying featural specification, but fails on LOWER. Candidates (b) and (c) have co-extensive Low- and High-domains, but since LOWER requires *realization* of [Low] on bimoraic vowels, only (c) satisfies that constraint.[17] Candidate (d) yields the correct phonetic form, but fails on MAX-HI. By ranking LOWER and MAX-HI over EXPRESS-HI, candidate (c) emerges as the winner, and by virtue of the "empty" High-domain, provides the information necessary for UNIFORMITY to correctly evaluate this vowel as High.

The analysis is not yet complete, though, and two issues remain to be considered. The first issue concerns how to determine which of two competing domain structures is counted by UNIFORMITY, because while it is true that the surface form of an underlying long, high vowel contains a High-domain, as in (24c), it also contains a Low-domain. The second issue concerns what factors motivate the presence of abstract, ie., unexpressed, domain structure. We would like to know when it is reasonable to expect a "deleted" feature or segment to maintain its presence in surface form through the use of unexpressed domain structure. We return to this second issue below, and continue here with the reformulation of UNIFORMITY.

On a superficial level, there appears to be a competition between the conflicting domain structures for the features High and Low. The Low-domain wins the Expression battle, as shown above, but it is the High-domain that wins the battle with respect to UNIFORMITY. We could complete the analysis rather quickly by simply stipulating that in the case of conflicting domains, UNIFORMITY counts a High-domain, but we seek a more principled understanding of what factors are involved in resolving the UNIFORMITY conflict in favor of High-domains. What is going on in Yawelmani is that the Uniformity condition on harmony provides an opportunity for the unexpressed High feature to emerge and have an impact on the surface realization of the word. It's a kind of weak Faithfulness effect, in that a feature can play a role in surface representation through its domain structure, if not through its phonetic expression. Thus, we suggest that the competition is not between a High-domain and a Low-domain *per se*, but rather between

[17] For the purposes of linear representation, the High-domain is arbitrarily designated "outermost" in (24b,c), but the two height domains are in fact fully overlapping. Specifically, the linearized representation does not encode any hierarchical relation between the two domain structures.

a domain that parses an underlying feature (expressing information about contrast and class membership) and a domain which does not. In short, in case of conflict, UNIFORMITY counts the *faithful* domain.

UNIFORMITY is reformulated in (25), and requires two enrichments to the theory. First, faithful domains, or those that parse underlying features (ie., satisfy "lexical" constraints), must be distinguished in surface representation from domains which are required solely for the satisfaction of phonological constraints. Second, individual phonological constraints must be able to exploit that distinction, by choosing under certain circumstances to focus attention on the faithful domain. In the case of UNIFORMITY, the faithful domain is evaluated when there are conflicting domains.

(25) UNIFORMITY (revised): The harmony domain must be monotonic: High or Low. If conflicting High and Low domains are present, the faithful height domain is counted.

Formulated in this way, UNIFORMITY will always count the lowered vowels as High, since it is the High-domain and not the Low-domain that parses the underlying feature. Under the analysis given above, the High-domain is guaranteed to be present in the surface representation of lowered vowels because it serves to satisfy MAX-HI. The ranking MAX-HI >> EXPRESS-HI delivers this result. Of crucial importance, UNIFORMITY is not restricted to evaluate *only* faithful domains. In the case of epenthetic high vowels, for which there is no faithful domain, UNIFORMITY evaluates the inserted High-domains—the only domains present that are relevant to UNIFORMITY.

At this juncture, we pause to reconsider the role of unexpressed domain structure in our analysis, and to consider more generally the sort of conditions that must exist in a phonological system in order for unexpressed domains (or empty structure of any sort) to occur in surface forms at all. First of all, we note that unexpressed F-domains, crucial to the proposed analysis of Yawelmani, are incompatible with the notion stated above (fn. 16) that phonological surface forms should be maximally isomorphic with their corresponding phonetic form. Let's refer to this as the principle of Output-Phonetic Form Isomorphism, or OP-Isomorphism.[18] By OP-Identity, the only F-domains present in surface structure will be those in which [F] is physically realized in the domain.

In the analysis of Yawelmani proposed above, the ranking MAX-F >> EXPRESS-F gives rise to an empty domain structure for a deleted feature [F]. Thus, to ban empty structures altogether it is necessary to impose the opposite ranking EXPRESS-F >> MAX-F: it's a worse violation to have an unexpressed domain than to have no domain structure at all for an underlying feature [F]. We claim that the latter ranking is the universally preferred one, because it helps satisfy OP-Isomorphism. Since the constraints of ODT allow the possibility of empty domain structure, the question for ODT is the following: under what conditions can a language employ the marked ranking, allow-

[18] This principle is consistent with correspondence theory, in which there is genuine deletion, but not with the earlier theory of OT which adopts the principle of Containment (Prince and Smolensky 1993).

ing unexpressed F-domains to appear in surface structure, in the absence of any direct phonetic evidence for such domains?

A possible answer might be that empty domain structures will emerge whenever there is a constraint that requires faithful domains to be evaluated. After all, there would be little point specifying that a constraint should look for faithful domains, if no unexpressed faithful domains appear in surface form. In the case of Yawelmani, if unexpressed domain structure were not present in surface form, then UNIFORMITY would encounter no conflict between unexpressed Hi-domains and expressed Lo-domains, in which case there would be no cause to encode a conflict clause in the formulation of UNIFORMITY. But as a general justification for empty structure, this account is not wholly satisfying. A deeper understanding of the conditions which lead to empty domain structure can be reached through further consideration of what it means for a constraint to be looking for faithful domains.

In Yawelmani, the UNIFORMITY constraint, by looking at faithful domain structures, provides an opportunity for unexpressed features to nonetheless have an impact on surface representation. In other words, UNIFORMITY is functioning in a weakly faithful capacity. Faithfulness in ODT has three components:

- MAX-F, satisfied by the presence of an F-domain;
- DEP-F, satisfied by the absence of inserted F-domains; and
- EXPRESS-F, satisfied by the realization of [F] on elements within the F-domain.

We propose that for Yawelmani a faithfulness role is extended to the phonological constraint UNIFORMITY. Perfect faithfulness to an underlying feature [F] is achieved only by satisfaction of the three primary faithfulness constraints above; in particular, it requires expression of [F] in the F-domain. But when EXPRESSION is blocked by a higher-ranked constraint (e.g., LOWER in Yawelmani), weak faithfulness can be still be achieved if the grammar extends the faithfulness function to an independent phonological constraint. For Yawelmani, it will suffice to say that UNIFORMITY is a weak enforcer of height faithfulness. This does not mean that UNIFORMITY will evaluate underlying forms; the role of epenthetic vowels in blocking harmony makes that an untenable analysis, as shown above. It means just that UNIFORMITY must take into account underlying height features when evaluating surface representations, and in particular, that it must count an underlying height feature whenever it differs from the expressed height feature. With this interpretation of faithfulness, we present our final formulation of UNIFORMITY in (26).

(26) UNIFORMITY (final): The harmony domain must be monotonic:
High or Low. **Faithful(High/Low)**.

Now we can return to the question posed above about the conditions which give rise to unexpressed F-domains in surface structure. Empty domains arise from the marked ranking Max-F >> Express-F. We propose that the unmarked ranking Express-F >> Max-F is subverted whenever a phonological constraint is called into faithfulness duty. More precisely, subjecting a constraint to the faithfulness condition **Faithful ([F])** automatically entails the marked ranking scheme: Max-F >> Express-F. The opposite, unmarked ranking simply would not allow the constraint to assume its faithfulness role.

With this final development of the analysis, we now have a complete account of the opaque behavior of lowered vowels in Yawelmani. Lowered vowels function as high vowels in the harmony system because Uniformity is a weak faithfulness constraint for the feature High. The Faithful(High) condition on Uniformity has the result that any deleted High feature will maintain a presence in surface form through an empty High-domain. Empty High-domain structures are guaranteed through the marked ranking of Max-High >> Express-High, which is required by the Faithful(High) condition on Uniformity.

We close this section by providing a complete tableau illustrating the evaluation of surface correspondents for an underlying sequence /u: ... I/, as in *ʔo:ṭ'-ut* from /ʔu:ṭ'-It/, in which both Lowering and Harmony take place. The first four candidates demonstrate various structures possible with widescope Round-domains; the second set contains four parallel candidates but with narrow Round-domains.

(27) Evaluation of *ʔo:ṭ'-ut* from /ʔu:ṭ'-It/
Notation: { } = Low domain, ( ) = High domain, [ ] = Round domain

input:	u:...I	Max-H	Lower	Unif	Expr-H	WSA-rt
a.	[(u:)...(u)]		*!			
b.	[({u:})...(u)]		*!			
→ c.	[({o:})...(u)]				*	
d.	[{o:}...(u)]	*(!)[19]		*(!)		
e.	[(u:)]...(i)		*!			*
f.	[({u:})]...(i)		*!			*
g.	[({o:})]...(i)				*	*!
h.	[{o:}]...(i)	*!				*

In the output candidates a-h, the vowels [u,i] express High, while the vowel [o] expresses Low. The winning candidate is in the first set, with a widescope Round-domain that satisfies Uniformity, and height domains that satisfy both Lower and Max-H. The

[19] It is not clear which of the two highly-ranked constraint violations is fatal for candidate (d), an uncertainty which is noted here by placing two fatal marks in parentheses.

empty High-domain allows satisfaction of UNIFORMITY while complying with the requirements of LOWER.

The constraint rankings employed in this tableau, along with other crucial rankings motivated in the preceding discussion, are summarized here.

- LOWER >> EXPRESS-H; which prohibits the realization of High on bimoraic vowels;
- MAX-H >> EXPRESS-H; which guarantees that even unexpressible underlying High features are parsed in surface High-domains;
- UNIFORMITY >> WSA-RT; which blocks a widescope Round domain that isn't monotonic in height (deferring to faithful H-domains);
- WSA-RT >> BA-RT; requires the widest (possible) Round-domains (see tableau in (19)).
- WSA-RT, EXPRESS-R >> DEP-RD; vowels must undergo harmony, and will not be transparent or opaque (see tableau in (19));
- WSA-RT, EXPRESS-R, RD/BK >> DEP-BK; vowels that are Round, including those that undergo harmony, must be Back.
- MAX-LO, LO/BK >> DEP-BK; vowels that are Low will also be Back.

4 Conclusion

The distinction in ODT between an F-domain and the expression of [F], a necessary ingredient for the analysis of transparency in harmony systems, admits the possibility of surface-level F-domains that are completely unexpressed. Under the principal of output-phonetic form isomorphism, such empty domain structures are not tolerated in optimal surface forms. Simply put, no structure is better than phonetically empty structure. We argue, however, that there are situations when empty domain structure serves a useful function in surface form, a situation that obtains whenever an empty F-domain serves to preserve information about underlying contrast.

We have demonstrated an analysis of round harmony in Yawelmani in which empty F-domains appear in surface representation as a minimal manifestation of underlying features that cannot be phonetically realized. These empty, faithful domains do not yield a phonetic interpretation, but have an important impact on surface forms, where they are critically evaluated by the UNIFORMITY constraint on harmony domains. In this way, the UNIFORMITY constraint takes on the auxiliary function of a Faithfulness constraint, preserving contrastive features, and establishing a correspondence between surface and underlying features. The effect of the empty F-domains on harmony structures makes the harmony system surface opaque, in the sense of Kiparsky (1973). We argue that while empty domain structures are not typically encoded in surface structure for every deleted element, they will necessarily appear whenever a phonological constraint, like UNIFORMITY, serves in a Faithfulness capacity.

The theory developed here, incorporating the notions of F-domains and the extension of Faithfulness to ordinary phonological constraints, provides a restricted role for underlying structure in constraint evaluation. We argue that a theory in which constraints can freely access underlying and surface information is too powerful, and gives rise to an unattested kind of phonological element—a trans-categorical segment that behaves for the purposes of a single phonological constraint as though it belongs to two contrastive segment classes. Under the ODT analysis, opacity has a natural and restricted characterization, as a phenomenon that arises when Faithfulness to underlying contrast is maintained in the face of constraints that lead to the loss of contrast in surface representation.

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