RESEARCH

Consonant harmony in Nilotic: contrastive specifications and Stratal OT

Sara Mackenzie
Memorial University of Newfoundland, St. John's, Newfoundland, Canada
sjmackenzie@mun.ca

Through analyses of dental harmony in four Nilotic languages, this paper argues both for contrastive representations and for a stratal version of Optimality Theory. Dholuo, Päri, Shilluk and Anywa all have dental harmony patterns which bar the co-occurrence of dental and alveolar segments. Details of the dental harmony patterning vary between languages and are tied to contrasts in the inventory. In Anywa, harmony is non-structure-preserving and an allophonic dental nasal surfaces in harmonic forms. This pattern can be analyzed in a stratal model of OT but leads to a ranking paradox if only a single level of evaluation is used. Further support for a stratal analysis can be found in the interaction between harmony and consonant mutation processes in the four languages. In Dholuo, harmony applies at the stem level and consonant mutation results in disharmonic surface forms in morphologically complex words. In Anywa, harmony applies later, at the word level, and words formed through consonant mutation must obey the dental harmony restrictions.

1 Introduction

This paper argues for the integration of contrastive specifications with a stratal version of Optimality Theory through analyses of dental harmony in Nilotic languages. The proposal that features needed to contrast members of a phonemic inventory are also those features which are active in phonological processes has played a central role in a variety of theoretical frameworks (e.g. Steriade 1987; Archangeli 1988; Avery & Rice 1989; Dresher 2009). While some notion of contrast remains central in a range of phonological literature, interest in modeling contrast through feature specification and underspecification has declined since Optimality Theory (Prince & Smolensky 1993) has become the dominant model of phonological formalisms. The OT principle of Richness of the Base excludes language-specific restrictions on input representations, a traditional method of representing contrastive specifications in pre-OT theories. Previous work (e.g. Mackenzie & Dresher 2004; Dresher 2009) has demonstrated that contrastive specifications can be achieved as outputs of OT grammars using markedness and faithfulness constraints. While these works have shown that contrastive specifications consistent with a principled definition of contrast can be achieved in OT without compromising Richness of the Base, they have generally failed to show how constraint rankings which determine contrastive specifications should be integrated with constraint rankings which motivate phonological processes. This paper demonstrates that contrastive representations as outputs of OT

grammars can be integrated into a stratal model of OT in which serial evaluation is limited to three levels (e.g. Kiparsky 2000; Bermúdez-Otero 2003).

The Nilotic languages Dholuo, Päri, Shilluk, and Anywa all have dental harmony in the form of morpheme structure constraints which bar the co-occurrence of dental and alveolar stops. The details of the harmony vary between languages as does the size and shape of the consonant inventory. Previous analyses (Mackenzie 2009; 2011) have argued that the connection between inventory shape and the patterning of dental harmony in Nilotic languages provides evidence for a theory of contrast in which features are hierarchically ordered with some features taking scope over others (Dresher 2003; 2009). The theory of the contrastive hierarchy ties contrastive specifications to inventory shape while allowing variation between languages with similar inventories. I follow the contrastive hierarchy analysis of Nilotic dental harmony here and show that the necessary contrastive specifications can be obtained through constraint ranking in a stratal model of OT. While evidence for the contrastive hierarchy is found in the connection between inventory shape and the patterning of dental harmony, evidence for a stratal analysis comes from a ranking paradox that arises in the analysis of Anywa harmony if only a single level of evaluation is used.

Two claims follow from this analysis. First, accounting for the differences in the patterning of dental harmony in Dholuo, Anywa, and Päri requires a serial, stratal version of OT. That is, while contrastive specifications can be achieved in OT, explanatory use of such representations is not consistent with the single level evaluation model of classic OT. Secondly, contrastive representations can be integrated with independently motivated levels of stratal OT. For contrastive specifications to play an explanatory role in accounting for phonological processes, it is not necessary to achieve contrastive representations prior to all other phonological generalizations. Rather, these representations can be achieved as outputs of the stem level and constraints achieving contrastive representations can be integrated with constraints which motivate stem-level processes. This analysis makes predictions about the interaction of harmony and morphological processes. Specifically, non-structure-preserving harmony, as in Anywa, is predicted not to occur at the stem level.

The paper is organized as follows. Section 2 provides an introduction to the theory of the contrastive hierarchy and a method for converting contrastive feature hierarchies to OT constraint rankings. Section 3 provides a brief introduction to Stratal OT. Section 4 gives analyses of Dholuo and Päri, demonstrating the crucial role of contrast in accounting for differences in the patterning of dental harmony in the two languages. This section also provides an analysis of Shilluk dental harmony and its interaction with consonant mutation processes. The analyses of Dholuo, Päri, and Shilluk show that the constraints which motivate harmony can be integrated with the constraints necessary for determining contrastive specifications. Section 5 provides an analysis of dental harmony in Anywa. While the harmony process in Anywa is highly similar to that found in the other languages, harmony in Anywa is non-structure-preserving and leads to a ranking paradox in a classic OT account. The analysis presented here shows that this problem can be resolved in a multi-stratal version of OT with dental harmony in Anywa occurring at the word level and contrastive specifications determined at an earlier, stem-level evaluation. Taken together, these analyses demonstrate that differences in harmony patterning between languages can depend both on differences in contrastive specifications and differences in the level at which harmony applies. Section 6 concludes.

2 The contrastive hierarchy and Optimality Theory

The analyses of dental harmony presented in the following sections provide evidence for the theory of the contrastive hierarchy (Dresher 2003; 2009). The theory of the contrastive hierarchy provides an explicit definition of contrast in which features are hierarchically ordered with some features taking scope over others. The order of features in the hierarchy can vary between languages, allowing for crosslinguistic variation in feature specifications, even between languages with similar inventories. Empirical consequences of the contrastive hierarchy are necessarily dependent on the notion that feature activity in phonological processes is tied to contrasts in the inventory. This "contrastivist hypothesis" is defined as follows in Hall (2007: 20):

> "The phonological component of a language L operates only on those features which are necessary to distinguish the phonemes of L from one another."

As Hall (2007) discusses, this formulation is open to interpretation, given the ambiguity of what it means for a feature to distinguish phonemes from one another and the range of proposals concerning the nature and definition of contrast. Taken together with the theory of the contrastive hierarchy, however, the contrastivist hypothesis predicts that only features that are formally deemed contrastive by the theory will be active in phonological processes.

According to the theory of the contrastive hierarchy, contrastive specifications are determined by a series of binary divisions of the inventory. This is formalized as the Successive Division Algorithm (SDA).

(1)   Successive Division Algorithm (Dresher 2009: 16)
   a. Begin with *no* feature specifications: assume all sounds are allophones of a single undifferentiated phoneme.
   b. If the set is found to consist of more than one contrasting member, select a feature and divide the set into as many subsets as the feature allows for.
   c. Repeat step (b) in each subset: keep dividing up the inventory into sets, applying successive features in turn, until every set has only one member.

The feature selected first will be contrastive for the entire inventory whereas lower ordered features will be contrastively specified only for those subsets of the inventory which require the feature in question in order to be uniquely specified.

The contrastive hierarchy is a theory of phonological representations. As such, it is, in principle, orthogonal to computational questions such as whether phonological patterns arise from parallel evaluation and constraint ranking as in OT, or from the application of sequentially ordered rules, as in SPE. Although the emphasis on representations and inventory structure, which is central to the theory of the contrastive hierarchy, is generally associated with derivational theories, previous work has demonstrated that contrastively specified representations can be achieved as outputs of OT grammars. Mackenzie and Dresher (2004) provide an algorithm capable of converting any contrastive hierarchy to an OT constraint ranking. This algorithm was revised in Dresher (2009) and Mackenzie (2013).

(2)   Converting a contrastive hierarchy to a constraint ranking (Mackenzie 2013: 305)
   a. Select a faithfulness constraint MAX[F]$_i$, where [F]$_i$ is the highest ordered contrastive feature for which MAX[F]$_i$ has not yet been ranked. Rank MAX[F]$_i$ below any MAX[F] constraints ranked by prior application of step (a) and above all other MAX[F] constraints. If there are no more contrastive features, go to (d).

b. Above this faithfulness constraint, rank any co-occurrence constraints of the form *[αF_i, Φ]$_{\text{Segment}}$, where Φ consists of features ordered higher than F_i and where contrastive specification of F_i is excluded in segments specified for Φ.

c. Go to (a).

d. Rank the constraint *[F] below all constraints ranked in steps a-c and end.

In step (a), a contrastive feature hierarchy is converted into a corresponding ranking of feature-specific faithfulness constraints. Faithfulness constraints are of the form Max[F] and are violated if a feature specification, either [+] or [-], present in the input is absent from the output. Step (b) provides a ranking of feature co-occurrence constraints which ensures that each feature will only be specified for those subsets of the inventory in which the feature is contrastive. Constraints of the form *[αF_i, Φ]$_{\text{Segment}}$ exclude the specification of any value of the feature F_i for a segment which has the specification, or set of specifications, Φ where Φ consists of higher ordered feature specifications. These markedness constraints have the effect of limiting the scope of a feature by restricting the set of segments which will be specified for that feature. Steps (a) and (b) are repeated until faithfulness constraints referring to all features in the contrastive hierarchy have been ranked along with the markedness constraints which limit the scope of those features. In the final step, the constraint *[F] is ranked below the constraints ranked in steps (a) and (b). *[F] assigns a violation mark for each feature specification in a representation and reflects a preference for representations to be minimal. Although all feature specifications incur a violation of *[F], contrastive specifications will surface faithfully due to the high-ranking of faithfulness constraints referring to contrastive features determined by step (a). Faithfulness constraints referring to non-contrastive features will be ranked below *[F]. This algorithm is capable of converting any contrastive hierarchy into an OT constraint ranking.

The theory of the contrastive hierarchy is a theory of phonological representations. The contrastive hierarchy provides an explicit definition of contrast, which, in concert with the contrastivist hypothesis, makes predictions about the relation between inventory shape and feature activity and the range of variation we expect to find in this relation across languages. The algorithm in (2) will take any contrastive hierarchy and convert it to an OT constraint ranking. The theory of the contrastive hierarchy proposes that only constraint rankings consistent with (2) will be found crosslinguistically and thus imposes restrictions on the set of possible OT grammars.[1]

The following example illustrates how the contrastive hierarchy and the algorithm for converting a contrastive hierarchy to a constraint ranking work. Consider a simplified inventory of coronal segments consisting of /t, d, n/. This inventory contains three segments and two contrastive features will be needed for each member of the inventory to be uniquely specified. Assuming the relevant features are [voice] and [nasal], we have two possible contrastive hierarchies, illustrated below.

---

[1] The theory of the contrastive hierarchy has implications for theories acquisition and learnability but is not itself a theory of language acquisition. The algorithm in (2) converts contrastive hierarchies to constraint rankings and the theory of the contrastive hierarchy predicts that all (stem-level) grammars will be consistent with such rankings. Theories of learnability and acquisition are needed to address the issue of how such rankings are acquired. See Mackenzie (2013) for additional discussion of this point.
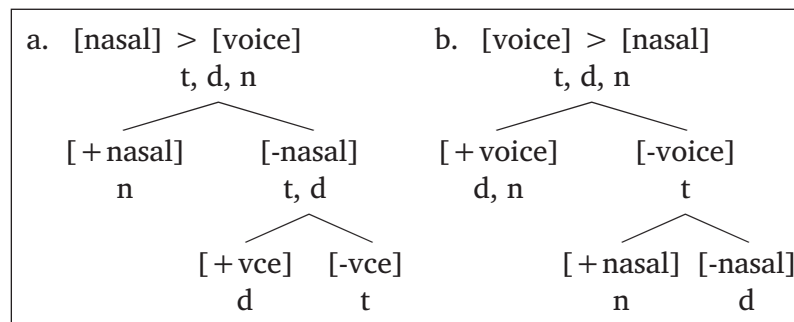
```
a.  [nasal] > [voice]              b.  [voice] > [nasal]
           t, d, n                            t, d, n
          /       \                          /       \
   [+nasal]    [-nasal]            [+voice]       [-voice]
      n           t, d                d, n             t
                 /    \                            /      \
          [+vce]   [-vce]                   [+nasal]  [-nasal]
             d        t                         n         d
```

Figure 1: Contrastive hierarchies for [voice] and [nasal].

In the hierarchy in (a), the feature [nasal] is ordered above the feature [voice]. All members of the inventory are specified for the feature [nasal]. Being the only [+nasal] member of the inventory, /n/ is uniquely specified at this point and does not receive any additional contrastive specifications. The two [-nasal] members of the inventory, /d/ and /t/, are specified as [+voice] and [-voice] respectively. After the feature [voice] is assigned, each member of the inventory is uniquely specified and there are no more contrastive features. The hierarchy in (b) represents the other possible order of features. Here, [voice] is ordered first and the inventory is divided into [+voice] and [-voice] sets. /t/ is the only member of the [-voice] set and is uniquely specified. The feature [nasal] differentiates the [+voice] segments /d/ and /n/.

Although the hierarchies illustrated in Figure 1 (a) and (b) have the same set of segments in the surface inventory, they have different feature specifications which result from different orderings of features in the contrastive hierarchy. We might expect these systems to pattern differently in the phonology. In the system in (a), we may expect /d/ and /t/ to pattern as similar to one another and to interact in processes to the exclusion of /n/. Examples of this type of patterning are common, as in cases where obstruents, such as /d/ and /t/, interact in voicing assimilation and sonorants, such as /n/, are neutral (e.g. Russian). In the system illustrated in (b), on the other hand, we may expect /d/ and /n/ to interact in processes to the exclusion of /t/. Such patterns are also attested, as in cases of long-distance nasal harmony in Bantu where /d/ and /n/ interact and /t/ is neutral (e.g. Hyman 1995).

Any contrastive hierarchy can be converted to an OT constraint ranking using the algorithm in (2). To take the hierarchy illustrated in Figure 1 (a) for example, step (a) of the algorithm requires us to select the faithfulness constraint referring to the highest ordered feature in the hierarchy, in this case MAX[nasal], and rank this constraint above any featural faithfulness constraints that have not yet been ranked. Step (b) requires a markedness constraint of the form *[αF_i, Φ] where Φ consists of features ordered higher than [F_i] to be ranked above MAX[nasal]. However, since [nasal] is the highest ordered feature this step cannot apply and we return to step (a), ranking the faithfulness constraint referring to the next ordered feature, MAX[voice], below MAX[nasal]. Again, we turn to step (b) and this time this requires us to rank the constraint *[αvoice, +nasal] above MAX[voice]. This markedness constraint will be violated by any [+nasal] segment which is specified for any value of the feature [voice]. At this point, faithfulness constraints referring to all contrastive features have been ranked and we proceed to step (d), ranking the general markedness constraint *[F] below all the constraints ranked by application of previous steps of the algorithm. The ranking produced by applying the algorithm for converting a contrastive hierarchy to a constraint ranking to the contrastive hierarchy in Figure 1 (a) is shown in (3), below.

(3)   MAX[nasal] >> *[αvoice, +nasal] >> MAX[voice] >> *[F]

With this ranking, any fully specified input will map to a contrastively specified output consistent with the proposed contrastive hierarchy. For example, the tableau below considers an input containing a nasal specified as [+voice, +nasal].

(4)

n [+voice] [+nasal]	MAX[nasal]	*[αvoice, +nasal]	MAX[voice]	*[F]
a) n [+voice] [+nasal]		*!		**
b) ☞ n [+nasal]			*	*
c) n [+voice]	*!			*

The input in (4) is fully-specified with respect to the two features under consideration. According to the proposed contrastive hierarchy, however, the nasal is not specified for the feature [voice]. The faithful candidate in (a) is eliminated due to violation of the constraint *[αvoice, +nasal]. This constraint penalizes any specification for the feature [voice] in a segment specified as [+nasal]. Candidate (b) is optimal. This is the contrastively specified candidate, according to the feature hierarchy in Figure 1 (a). The [+voice] specification in the input is absent from this candidate leading to a violation of MAX[voice]. MAX[voice] is ranked below the markedness constraint against specification of [voice] in [+nasal] segments, however, and the candidate is optimal. The candidate in (c) is specified only for [voice]. This candidate thus violates highly-ranked MAX[nasal] and is eliminated.

As illustrated above, rankings produced by the algorithm for converting a contrastive hierarchy to a constraint ranking produce contrastively specified representations from fully-specified inputs. One additional mechanism is needed, however, in order to ensure that contrastively specified representations are achieved in a manner that is truly compatible with Richness of the Base. The faithfulness constraints used in the algorithm are MAX[F] constraints. MAX is used, rather than IDENT, in order to penalize outputs which lack feature specifications which are present in the input. That is, MAX[F] militates against underspecification relative to the input. The MAX[F] constraints also penalize feature value mismatches between input and output. If a [+F] input specification maps to a [-F] value in the output, this violates MAX[F] because a positive feature value in the input is absent from the output.[2] MAX[F] constraints, however, only penalize the absence of feature specifications which are present in the input. If underspecified inputs are considered, MAX[F] constraints will do nothing to ensure that outputs are sufficiently specified to be consistent with the theory of the contrastive hierarchy.

As discussed in previous work on the contrastive hierarchy and Optimality Theory (Dresher 2009; Mackenzie 2013), additional constraints requiring feature specification in output forms are necessary in order to ensure contrastive representations and to be consistent with the premise of Richness of the Base which allows input representations to

---

[2] Under this view, feature value mismatches between input and output will also necessarily violate DEP[F] constraints. If a [+F] segment in the input maps to an output segment specified as [-F], both MAX[+F] and DEP[-F] are violated. DEP[F] constraints will not be shown here for reasons of space and economy.

be free. Dresher (2009) proposes the use of constraints of the form Spec[F] which require features to be present in output forms, regardless of their presence or absence in input forms. With respect to the algorithm for converting a contrastive hierarchy to a constraint ranking, Spec[F] constraints referring to contrastive features must be ranked above the general constraint against feature specification,*[F], and below any contextual markedness constraints of the form *[αF$_i$, Φ]$_{Segment}$ which refer to the feature in question and prevent specification of non-contrastive features.[3] Use of such constraints in conjunction with the other constraints needed to convert a contrastive hierarchy to a constraint ranking will ensure, not only that input features deemed redundant by the contrastive hierarchy will be eliminated from output representations, but also that features which are deemed contrastive by the feature hierarchy will be present in output representations, even if they are absent from inputs. Although the use of Spec[F] constraints adds additional complexity to the mapping of contrastive hierarchies to constraint-rankings, the need for Spec[F] constraints is not a result of the theory of the contrastive hierarchy but is a consequence of the principle of Richness of the Base. If inputs are truly free, any model of OT will require constraints which demand feature specifications in outputs even in cases where such features are absent from input representations.[4] Ranking of Spec[F] constraints will not be illustrated here but these constraints will play a role in the analysis of dental harmony in Anywa in later sections.

The theory of the contrastive hierarchy is motivated in part by theoretical considerations about what it means to be contrastive and what constitutes a logical theory of contrast (see e.g. Dresher 2009). A large part of the motivation for the theory of the contrastive hierarchy is, however, empirical. Crosslinguistic data provide evidence that features which are active in phonological processes are those features which are contrastive as defined by the theory of the contrastive hierarchy. Empirical arguments for the contrastive hierarchy are necessarily tied to the contrastivist hypothesis (Hall 2007) which holds that the phonological computation operates only on contrastive features.

If contrastive representations are achieved from a rich base via constraint interaction, and the constraints which determine contrastive representations are integrated with other constraints in the phonological grammar, it is unclear how it can be assured that only contrastive features are referred to in phonological processes. Some previous works using the theory of the contrastive hierarchy within the framework of OT have avoided this problem by assuming that the evaluation which results in contrastive specifications operates at a level prior to evaluations leading to phonological processes in a multi-level version of OT (e.g. Dresher 2009). These works have remained vague with respect to what the level that determines contrastive specifications is and what independent theoretical motivation it may have. These works have thus not truly integrated the theory of the contrastive hierarchy into a theory of constraint interaction. Data presented here will show that a single-level of OT evaluation is not sufficient to account for phonological patterning and that contrastive specifications must be determined prior to phonological processes, in

---

[3] Dresher (2009) states that all Spec[F] constraints can be ranked as a block above *[F] and below all contextual markedness constraints limiting the scope of feature specifications. Such ranking will, indeed, ensure that underspecified inputs map to contrastively specified outputs. Nothing prevents individual Spec[F] constraints from being ranked higher, however. The analysis of the interaction of dental harmony and consonant mutation in Shilluk in Section 4 proposes that each Spec[F] constraint is ranked above the corresponding Max[F] constraint.

[4] As pointed out by an anonymous reviewer, restricting inputs to fully specified forms is consistent with ROTB as long as there is no variation in inputs across languages. Although this is a potentially attractive alternative to considering underspecified inputs, I will not pursue the possibility here due to the range of works making use of input underspecification in OT (e.g. Inkelas 1994; Harrison & Kaun 2001; Colina 2013).

some cases. The goal of this paper is to provide an integrated theory of contrastive specifications and constraint interaction and to address the question, what is the level at which contrastive specifications are determined?

3 Stratal Optimality Theory

In Stratal Optimality Theory (Kiparsky 2000; Bermúdez-Otero 2003; Rubach 2003 among others), the phonological grammar consists of an ordered series of OT evaluations. Stratal OT limits the set of distinct parallel evaluations to three, the stem, word, and phrase levels. In accordance with Richness of the Base, inputs are free at the initial level of evaluation. This is the stem level and constraint ranking here determines the segmental inventory as well as morpheme structure constraints. The output of the stem level serves as the input to the word level evaluation. The output of the word level, in turn, serves as the input to the phrase level.

Considered in light of the theory of the contrastive hierarchy, Stratal OT requires that contrastive specifications be determined at the stem level along with other aspects of inventory structure. The accounts of dental harmony argued for here attribute differences between languages both to differences in their respective hierarchies of contrastive features and to differences in the level at which harmony applies. Crucial reference to differences in constraint ranking between levels is needed specifically to account for non-structure-preserving harmony in Anywa. The arguments made here are similar to those in Bermúdez-Otero's (2007) analysis of voicing assimilation in Catalan where he shows that non-structure-preserving neutralization processes can result in ranking paradoxes in classic, single-level OT. The principle of structure preservation prohibits processes in the lexical phonology from creating structures that are not part of the phonemic inventory (Kiparsky 1982; 1985). Structure preservation played an important role within the theory of Lexical Phonology, imposing limitations on rule ordering and aiding in the learnability of rules. While structure preservation has no direct analogue in Optimality Theory (see e.g. McCarthy 2007: 43), the analysis that follows demonstrates that the absence of certain non-structure-preserving processes from stem-level phonology follows from the basic architecture of a Stratal OT grammar in combination with the principle of Richness of the Base and the theory of the contrastive hierarchy.

4 Dental harmony in Nilotic

Western Nilotic languages have a system of dental consonant harmony (Hansson 2001; 2010; Rose & Walker 2004). These languages have a phonemic contrast between stops at the dental and alveolar places of articulation. Harmony bars the co-occurrence of dentals and alveolars, requiring all coronals to agree in dentality.

Many cases of consonant harmony are discernable only as morpheme structure constraints that hold within roots and not as active alternations (Hansson 2001; 2010; Rose & Walker 2004) and some of the Nilotic dental harmony cases fall within this description. In a stratal OT analysis, morpheme structure constraints are determined at the stem level. Incorporating stratal OT with a theory of contrastive specifications thus requires the constraints that motivate harmony which is discernible only as restrictions on the form of roots to be integrated with the constraints that determine contrastive specifications.

The following analyses of Dholuo, Päri, and Shilluk show that constraint rankings responsible for determining contrastive specifications can be integrated with constraint rankings which motivate harmony. Differences between the patterning of harmony across languages provide evidence in support of a theory in which the contrastive status of features is influenced by the size and shape of the phonemic inventory.

4.1 Dholuo

Dholuo (Western Nilotic) has a contrast between dental and alveolar stops. This contrast is present among voiceless, voiced, and prenasalized stops but absent among nasals.

(5)   Dholuo coronal stops (Tucker 1994: 30)

	Voiceless Stops	Voiced Stops	Prenasal Stops	Nasals
Alveolar	t	d	ⁿd	n
Dental	t̪	d̪	ⁿd̪	

As illustrated in (6) below, voiced and voiceless stops participate in dental harmony in Dholuo (a) but the nasal is neutral (b) and alveolar nasals appear with both dental and alveolar stops (Yip 1989; Tucker 1994; Hansson 2001; 2010).

(6)   Dholuo dental harmony (Tucker 1994)
    a. t̪ed̪o   'to forge'
        d̪ɔd̪ɔ   'to suckle'
        ⁿd̪id̪o   'to feel pins and needles'
        tedo   'to cook'
        diedo   'to balance'
        ⁿdede   'purse'
    b. t̪uno   'breast'
        t̪ʊɔn   'brave man'
        dino   'deaf, to be stopped up'
        tɪn   'small'

Previous work (Mackenzie 2011) provides an analysis of Dholuo dental harmony within the framework of the contrastive hierarchy. In this account, [distributed] is the feature which contrasts dentals and alveolars and, hence, the harmonic feature. The nasal's neutrality with respect to dental harmony can be accounted for with a contrastive hierarchy in which the feature [distributed] is ordered below manner features [sonorant] and [nasal].
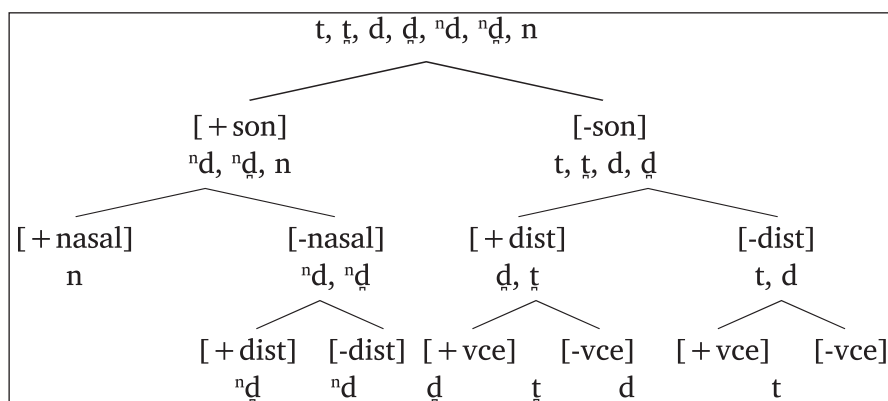

Figure 2: Dholuo feature hierarchy: [sonorant] > [nasal] > [distributed] > [voice].

The tree diagram in Figure 2 illustrates the operation of the contrastive hierarchy. We begin by considering the coronal inventory as a whole. The highest ordered feature is [sonorant]. The inventory is split into two sets, a [+sonorant] set and a [-sonorant] set. The feature [nasal] is ordered next. The [+sonorant] set is divided into [+nasal] and

[−nasal] subsets.[5] At this point, the nasal /n/ is uniquely specified and will not acquire additional contrastive specifications. Within the [-sonorant] set, there are no nasal segments. The feature [nasal] cannot serve to further subdivide the [-sonorant] set and therefore cannot be contrastively specified. The next ordered feature is [distributed]. The set of [-sonorant] segments and the set of [+sonorant], [-nasal] segments are now further subdivided into [+distributed] and [-distributed] sets. The feature [voice] is assigned last and differentiates the voiced and voiceless alveolar and dental stops. At this point, each segment is uniquely specified and no further contrastive features are assigned.

The contrastive hierarchy proposed for Dholuo results in specifications in which voiced, voiceless, and prenasalized stops are contrastively specified for [distributed] but the nasal is not. With these specifications, dental harmony in Dholuo can be motivated by a constraint that bars segments with distinct specifications for [distributed] from co-occurring within a form.

(7)   *[αdist] [−αdist]: distinct specifications of [distributed] are banned within a
         form

The constraint in (7) will be violated by forms that contain both alveolar and dental oral or prenasalized stops but will not be violated by nasals occurring with either [+distributed] or [-distributed] segments. This is a basic feature co-occurrence restriction, akin to the OCP constraints in Suzuki (1998) but penalizing distinct feature specifications as opposed to identical ones. As in other consonant harmony systems, segments which interact in Dholuo dental harmony need not be adjacent to one another. The issue of locality in harmony systems has received significant attention in the literature (Gafos 1996; Rose & Walker 2004; Kimper 2011 among many others) and the relation between contrast and locality has been explored in previous work (e.g. Avery & Rice 1989; Shaw 1991; Hansson 2001; 2010). The analysis of dental harmony advocated here relies on contrastively specified outputs. In such an approach, certain aspects of locality will be captured using the simple feature co-occurrence constraint in (7). Only segments with contrastive specification in the harmonic feature have the potential to violate the harmony-driving constraint. Other segments are irrelevant, regardless of their location relative to segments interacting in the harmony process.

Segments which interact in consonant harmony patterns tend to be highly similar and a requirement for interacting segments to share certain feature specifications is built into various proposals regarding the mechanisms of consonant harmony (e.g. Hansson 2001; 2010; Rose & Walker 2004). Although no explicit reference to similarity is present in the analysis proposed here, some of the similarity effects observed in previous work arise from contrastively specified outputs consistent with the theory of the contrastive hierarchy. Segments are contrastively specified for a specific feature only if that feature serves to differentiate members of an inventory not already distinguished by a higher ordered feature. If major place features are ordered above a feature like [distributed], this feature

---

[5] I am assuming that prenasalized stops are non-nasal sonorants, as argued in Piggott (1992) and Rice (1993), among others. For the purposes of the analysis of dental harmony, nothing crucial hinges on this assumption. The following analysis would hold if prenasalized stops were specified as [+nasal] or if they were, in fact, specified as [-sonorant]. Prenasalized stops pattern with sonorants in Dholuo in failing to undergo final devoicing but pattern with obstruents with respect to other processes such as formation of the imperative. Regardless of specification for manner features such as [nasal] and [sonorant], the Dholuo prenasalized stops will be contrastively specified for [distributed] as there is a minimal contrast between dental and alveolar prenasalized stops.

can only be contrastive within the set of [+coronal] segments. Even within the set of segments which share a major place class, some members of the set may not be contrastively specified for [distributed], depending on the structure of the inventory and the hierarchy of features. Similarity between segments is thus expected in a contrastive hierarchy analysis, even without any reference to similarity or shared features in the formulation of the harmony-driving constraint. As the feature hierarchy may vary between languages, this approach predicts variation between languages in terms of which segments will interact in harmony processes.

The contrastive specifications proposed for Dholuo can be achieved as output representations with the constraint ranking shown in the Hasse diagram in figure 3.

MAX[son], *[αnasal, -son]

MAX[nasal] *[αdist, +nasal]

MAX[dist] *[αvoice, +son]

MAX[voice]

*[F]
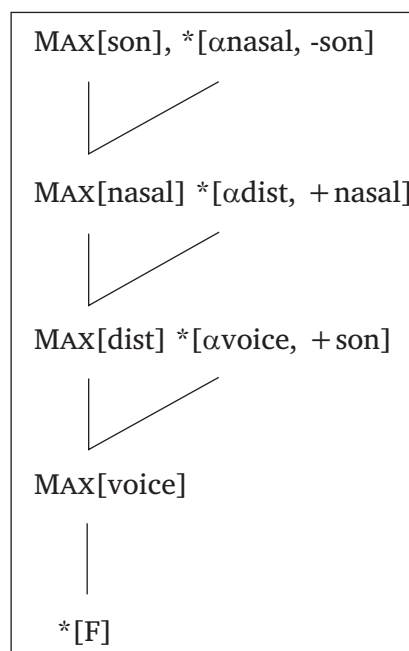
Figure 3: Dholuo constraint ranking for contrastive specifications.

The ranking above is determined in accordance with the algorithm for converting a contrastive hierarchy to a constraint ranking given in (2). The faithfulness constraint referring to [sonorant], the feature ordered highest in the contrastive hierarchy, is ranked first. [nasal] is the next highest ordered feature and the faithfulness constraint MAX[nasal] is ranked next. Above this faithfulness constraint, is ranked the contextual markedness constraint *[αnasal, -sonorant]. This constraint is violated by any specification for the feature nasal for a segment that is specified as [-sonorant]. Since it is ranked above MAX[nasal], it will eliminate outputs containing obstruents which are specified as [-nasal]. MAX[distributed] is the next ranked faithfulness constraint but above this constraint is ranked the markedness constraint *[αdistributed, +nasal]. This markedness constraint will eliminate nasals specified for any value of the feature [distributed] from surfacing. The constraint *[αvoice, +sonorant] will eliminate sonorants from surfacing with a voicing specification. And, finally, below MAX[voice], the constraint *[F] will eliminate any specifications for features that are not part of the proposed contrastive hierarchy.

With this ranking, any fully specified input will map to a contrastively specified output. The tableau below illustrates an evaluation of a fully specified nasal.

(8)　　　Dholuo: fully specified alveolar nasal input

n [-dist, +son, +nas, +vce]	MAX [son]	*[αnasal, -son]	MAX [nasal]	*[αdist, +nasal]	MAX [dist]	*[αvce, +son]	MAX[voice]	*[F]
a)　　　n [-dist, + son, +nas, +vce]				*!		*		****
b)　　　n [-dist, +son, +nas]				*!			*	***
c)　　☞ n [+son, +nas]					*		*	**
d)　　　d [-dist, -son, +vce]	*!		*					***

In tableau (8), the faithful candidate is eliminated due to a violation of the markedness constraint *[αdistributed, +nasal]. Candidate (c) is the contrastively specified candidate and the optimal one. This candidate lacks the specifications for [distributed] and [voice] that are present in the input and thus incurs violations of MAX[distributed] and MAX[voice]. This, however, allows the candidate to satisfy the markedness constraint *[αdistributed, +nasal]. An additional relevant candidate is illustrated in (d). This candidate retains specification for [distributed] and [voice]. It differs from the input in that it lacks specification for [nasal] and the [+sonorant] specification in the input has been changed to [-sonorant]. Since it has no specification for [nasal], this candidate avoids violating the markedness constraint *[αdistributed, +nasal]. However, it violates high-ranking faithfulness constraints MAX[nasal] and MAX[sonorant] and is eliminated. Note that, although the candidate in (d) is specified for the feature [sonorant], a [+sonorant] specification in the input is absent from the output leading to a violation of MAX[sonorant].

In addition to ruling out representations that are inconsistent with the contrastive hierarchy, this ranking will also eliminate dental nasals from surfacing, thus restricting outputs to members of the inventory. The evaluation of an input dental nasal is illustrated in (9), below.

(9)　　　Dholuo: fully specified dental nasal input

ṉ [+dist, +nasal, +vce]	MAX [nasal]	*[αdist, +nasal]	MAX[dist]	*[αvoice, +nasal]	MAX [voice]	*F
a)　　　ṉ [+dist, +nas, +vce]		*!		*		***
b)　　　ṉ [+dist, +nas]		*!			*	**
c) ☞ n [+nasal]			*		*	*
d)　　　ḏ [+dist, -nas, +vce]	*!					***

In the tableau above, the dental nasal, which is the faithful candidate in (a), is specified as both [+distributed] and [+nasal] thus violating the markedness constraint *[αdistributed, +nasal]. The winning candidate in (c) is specified only for the feature

[+nasal]. This is consistent with the contrastive representations proposed for the Dholuo inventory. Tableaux (8) and (9) demonstrate that inputs consisting of either a fully specified alveolar nasal *or* a fully specified dental nasal will map to outputs consisting of a nasal that is not specified for any value of the feature [distributed].

The harmony-driving constraint in (7) can be integrated with the Dholuo constraint ranking which ensures that output representations are contrastively specified. If the harmony-driving constraint is ranked above MAX[distributed], input forms containing oral stops with distinct specifications for [distributed] will map to harmonic output forms.

(10)   Dholuo: dental harmony among oral stops

t̪edo	*[αdist][−αdist]	MAX[dist]
a) t̪edo	*!	
b) ☞ t̪ed̪o		*
c) ☞ tedo		*

In tableau (10), the input contains a [+distributed] /t̪/ and a [-distributed] /d/. Faithful candidate (a) thus violates the harmony-driving constraint *[αdistributed][-αdistributed] which militates against the co-occurrence of segments with distinct specifications for the harmonic feature. Because dental harmony in Dholuo doesn't lead to alternations, there is no evidence about whether a disharmonic input would map to a harmonic form with dentals, as in candidate (b), or a harmonic form with alveolars, as in candidate (c). Both harmonic candidates violate MAX[distributed]. The input has a [-distributed] feature which is absent from candidate (b) and a [+distributed] feature absent from candidate (c).[6] What is crucial here is that a disharmonic input will map to a harmonic output.

Unlike inputs with multiple oral stops, a disharmonic input with a nasal and an oral stop will surface faithfully. Regardless of whether or not the input nasal is specified as [−distributed], the optimal output will contain a nasal that is unspecified for that feature and thus satisfies the harmony-driving markedness constraint.

(11)   Dholuo: disharmonic form with alveolar nasal

t̪ʊɔn [-dist]	*[αdist][−αdist]	MAX[nasal]	*[αdist, +nasal]	MAX[dist]
a) t̪ʊɔn [-dist]	*!		*!	
b) t̪ʊɔn̪ [+dist]			*!	*
c) ☞ t̪ʊɔn				*
d) t̪ʊɔd̪		*!		*

Tableau (11) shows an input in which a nasal specified as [-distributed] co-occurs with a [+distributed] voiceless stop.[7] Faithful candidate (a) violates both the harmony-driving

---

[6] As mentioned in footnote 2, these candidates will also violate DEP[dist] since the change of value in [distributed] means that they contain [distributed] specifications absent from input candidates. DEP[F] constraints could play a role in choosing between harmonic candidates with dentals and harmonic candidates with alveolars.

[7] For reasons of space and readability, not all feature specifications are indicated in input and output forms. Features are shown only when the presence vs. absence of that feature is used to distinguish between competing output candidates. In tableau (11), the feature [+distributed] is specified for /t̪/ in the input and in all competing output candidates. This feature is therefore not included in the tableau.

constraint, *[αdistributed][-αdistributed], and the markedness constraint which penalizes nasals specified for [distributed], *[αdistributed, +nasal]. In candidate (b), the input alveolar nasal has mapped to an output dental nasal. This results in a harmonic form which satisfies *[αdistributed][-αdistributed]. The nasal in this candidate, however, is still specified for the feature [distributed] and is eliminated due to violation of *[αdistributed, +nasal]. Candidate (c) is optimal. The nasal in this candidate is not specified for any value of the feature [distributed]. This specification is consistent with the proposed contrastive hierarchy and results in a candidate which vacuously satisfies the harmony-driving constraint. Candidate (d) contains only oral, dental stops. This candidate satisfies the harmony-driving constraint and contains only contrastively specified segments. However, the mapping of the input nasal to an oral stop in the output results in a violation of MAX[nasal] and the candidate is eliminated.

In this analysis of dental harmony in Dholuo, a contrastive hierarchy in which [nasal] is ordered above [distributed] results in specifications in which the nasal is not specified for [distributed]. The constraint *[αdistributed][-αdistributed] drives harmony and is violated by forms containing multiple oral stops that differ in the dental/alveolar distinction. Forms containing a dental oral stop and an alveolar nasal, however, do not violate the constraint because the nasal is unspecified for the harmonic feature. Representations consistent with this analysis can be achieved using the algorithm for converting a contrastive hierarchy to a constraint-ranking. The harmony-driving constraint *[αdistributed][-αdistributed] can be integrated with this ranking. The resulting constraint hierarchy can account for contrastive representations and dental harmony in a single level of evaluation.

The proposed constraint ranking for Dholuo is summarized in figure 4, below.
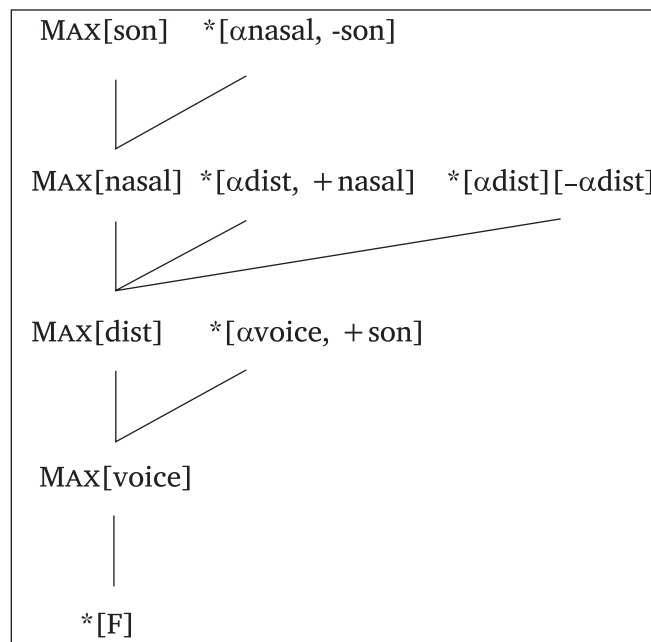

Figure 4: Dholuo constraint ranking.

4.2 Päri

Päri is another Nilotic language with a dental/alveolar contrast among coronals and with consonant harmony barring dentals and alveolars from co-occurring (Andersen 1988; Hansson 2001; 2010; Rose & Walker 2004). Unlike Dholuo, the Päri inventory is symmetrical with the dental/alveolar contrast present among voiced, voiceless, and nasal stops.

(12)   Päri coronal stops (Andersen 1988: 66)

	Voiceless Stops	Voiced Stops	Nasals
Alveolar	t	d	n
Dental	t̪	d̪	n̪

Päri also differs from Dholuo in that nasals participate in dental harmony.

(13)   Päri harmony (Andersen 1988)
    n̪ɔ̀t̪   'sucking'   *nɔ̀t̪
    d̪á:n̪-ɛ 'person (ergative)'   *d̪á:n
    àtwá:t'adult male elephant'

Because there is a minimal contrast between dentals and alveolars for each set of coronal stops, any ranking of features in a contrastive hierarchy will result in contrastive specifications for the harmonic feature within the set of nasals. A possible contrastive hierarchy for Päri using the same hierarchy of features used in the analysis of Dholuo is illustrated in figure 5, below.[8]
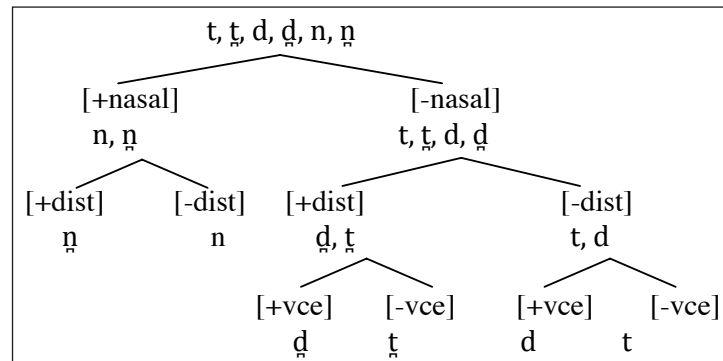
Figure 5: Päri feature hierarchy: [nasal] > [distributed] > [voice].

Although the proposed order of features in the contrastive hierarchy is the same in the two languages, the OT constraint ranking must differ in order to derive the differences in the inventory. The constraint ranking resulting from applying the algorithm in (2) to the hierarchy of features proposed for Päri is illustrated in figure 6.
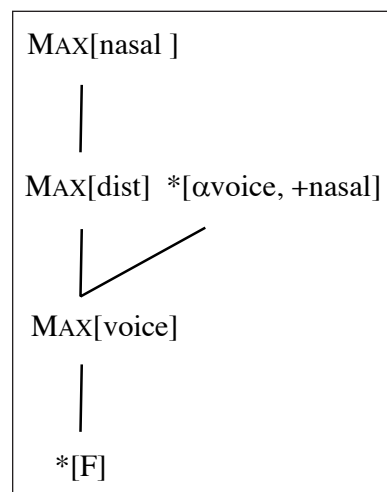

Figure 6: Päri constraint ranking for contrastive specifications.

---

[8] This hierarchy differs from that shown in the analysis of Dholuo in that the feature [sonorant] is not shown here. The Päri coronal inventory lacks prenasalized stops and is hence simpler than the Dholuo inventory. Only one of the features [nasal] and [sonorant] is necessary to distinguish all members of the coronal inventory in Päri.

Because the Päri inventory does contain a dental nasal, the constraint *[αdistributed, +nasal], which played a role in Dholuo, is not highly ranked in Päri. The only relevant contextual markedness constraint is *[αvoice, +nasal] which prevents specification for the feature [voice] in [+nasal] segments.

If the harmony-driving constraint is integrated into the Päri constraint ranking, nasals, like all other coronal stops, will be subject to harmony.

(14)   Päri: nasals participate in harmony

not̪	*[αdist][−αdist]	Max [nasal]	Max [dist]
a) not̪	*!		
b) ☞ n̪ot̪			*
c) ☞ not			*
d) d̪ot̪		*!	*

The tableau above contains a disharmonic input with a [-distributed] alveolar nasal and a [+distributed] dental voiceless stop. The faithful candidate is eliminated due to violation of the high-ranking constraint against forms containing segments with distinct values for [distributed]. Candidates (b) and (c) are both harmonic and are able to satisfy this constraint. They both violate Max[dist]. In candidate (b) this violation results from the fact that the [-distributed] value specified for the nasal in the input is absent from the output and in candidate (c) the violation results from a [+distributed] value on the voiceless oral stop in the input being absent from the output.

At this point, determining which of the candidates which satisfy dental harmony is selected as optimal is not crucial. What is important is that a disharmonic form containing a dental nasal and an alveolar dental will map to a harmonic output form. Nonetheless, data showing the interaction of dental harmony and consonant mutation processes suggest that a disharmonic form containing a combination of dentals and alveolars will surface as a form containing only dental stops. The following data show the possessive marker which involves the addition of a final vowel as well as mutation in which final liquids are realized as nasal-stop clusters. The final consonants created through mutation are subject to harmony.[9]

(15)   Päri (Andersen 1988)
         dè:l   'skin'   dè:nd-á   'my skin'
         t̪ùol   'snake'   t̪ùon̪d̪-à   'my snake'

In the analysis of Päri, the constraint driving dental harmony can be integrated into the constraint ranking which determines contrastive specifications. Because the inventory of Päri contains both a dental and an alveolar nasal, any hierarchy of features will result in contrastive specification for the feature [distributed] in the nasal set. The nasals thus specified for the harmonic feature also participate in harmony.

The proposed constraint ranking for Päri is summarized in figure 7.

---

[9] The fact that final nasal-stop cluster in 'my snake' is dental could be evidence of a preference for harmony to the positive value of [distributed] or could follow from mechanisms enforcing left-to-right directionality.
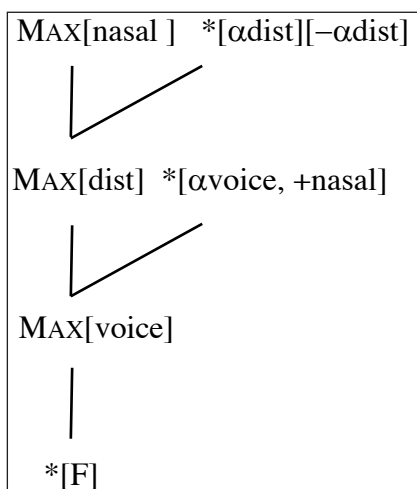
MAX[nasal]　*[αdist][−αdist]

MAX[dist]　*[αvoice, +nasal]

MAX[voice]

*[F]

Figure 7: Päri constraint ranking.

4.3 Shilluk[10]

Like Päri, Shilluk has an inventory of coronal stops which is symmetric with respect to the dental/alveolar contrast. Dental and alveolar stops contrast among the voiced, voiceless, and nasal stops.

(16)　　Shilluk coronal stops (Gilley 1992: 23)

	Voiceless Stops	Voiced Stops	Nasals
Alveolar	t	d	n
Dental	t̪	d̪	n̪

Also as in Päri, the dental nasal participates in harmony in Shilluk.[11]

(17)　　(Gilley 1992: 142)

　　　t̪î̪n̪　‘small’　t̄ı̄n　‘today’
　　　àd̪út̪　‘stinger’　dút　‘loin cloth’

With respect to the structure of the inventory and the basic patterning of dental harmony, Päri and Shilluk are alike. Dental harmony in Shilluk can therefore be accounted for using the same contrastive feature hierarchy and constraint ranking proposed in the analysis of Päri. Discussion of Shilluk is nonetheless included here because of differences between Shilluk and Päri found in the interaction of dental harmony and consonant mutation processes. As mentioned in the preceding section, consonant mutation feeds harmony in Päri. If a root-final liquid is realized as a nasal-stop cluster as a result of mutation, the cluster must harmonize with coronal stops elsewhere in the word (e.g. [t̪ùol] ‘snake’, [t̪ùon̪d̪-à] ‘my snake’). In Shilluk, mutation also feeds harmony but, unlike in Päri, it is the alveolar of the derived consonant that imposes harmony on coronal stops elsewhere in a form. Example (18) shows a verb ending in a labial stop where, in addition to the suffixation of a vowel, the instrumental is formed through the addition of mid tone, vowel length, the

---

[10] Thanks to an anonymous reviewer for raising the issue of Shilluk consonant mutation and its interaction with harmony.

[11]　Shilluk dental harmony is discussed in Gilley (1992) and Hansson (2001; 2010). No mention of harmony is made in Remijsen et al. (2011) and disharmonic forms are included in the data in this source. The following analysis relies on data from Gilley (1992) and assumes the description of dental harmony given there.

vocalic feature expanded pharynx (indicated with underlining), and voicing of the final stop. The data in (b) show that when a root ends in an /l/ and there is no other coronal in the form, the mutation process causes the lateral to be realized as an alveolar stop. In (c), we see that an alveolar stop derived from an /l/ via mutation causes a preceding dental to be realized as an alveolar, satisfying the dental harmony constraint. This pattern is illustrated with the instrumental and antipassive forms of the verb 'to cook'.

(18)   (Gilley 1992)
         a. yep   'open'   yē̱:bā   'open (instrumental)'
         b. kyel   'fry'   kyē̱:dā   ' fry (instrumental)'
            wa:l   'boil liquid'   wā̱:dā   'boil (instrumental)'
         c. ṱal   'cook (transitive)'   ṱā̱:ḏ-ā   'cook (instrumental)'   *ṱā̱ḏ-
                                             ṱa̱:t   'cook (antipassive)'   *ṱa̱ṱ

As discussed above in relation to Päri, the constraints motivating harmony and determining contrastive specifications are not, in and of themselves, sufficient to determine which value of the harmonic feature will surface in optimal forms when a disharmonic input is evaluated by the grammar. Determining whether the harmonic form which surfaces contains only [+distributed] or [-distributed] segments will fall to other constraints, markedness constraints which differentiate between dentals and alveolars, DEP[F] constraints which penalize the insertion of [+distributed] or [−distributed] feature values, or other mechanisms which determine directionality of assimilation. What is of particular interest in the Shilluk data is the fact that the lateral /l/ is not itself contrastively specified for the harmonic feature. As the transitive form of 'cook' in (18) illustrates, alveolar /l/ freely occurs with dental stops in Shilluk. In this respect, Shilluk is like other Nilotic languages where the liquids /l/ and /r/ are neutral with respect to dental harmony. There is no alveolar/dental contrast among liquids and I assume that the manner feature distinguishing liquids from coronal stops is ordered above the feature [distributed] in the contrastive feature hierarchies of all languages considered here. This results in representations in which the liquids lack specification for the feature [distributed] and, as a result, fail to participate in harmony. A proposed hierarchy of features for Shilluk is illustrated in figure 8, below, with the entire inventory of coronals. The order of features is identical to that proposed in the analysis of Päri but with the addition of the feature [approximant], used to differentiate between liquids and stops.
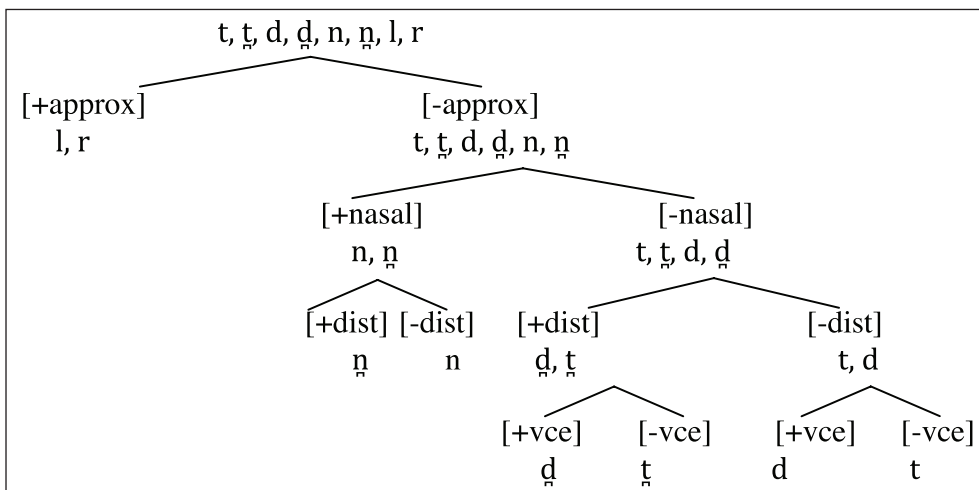

Figure 8: Shilluk feature hierarchy: [approximant] > [nasal] > [distributed] > [voice].

The constraint ranking resulting in outputs consistent with this hierarchy is shown in Figure 9, below. Again, this is identical to the ranking shown for Päri but with the

inclusion of constraints Max[approximant], *[αnasal, +approximant], *[αdistributed, +approximant], and *[αvoice, +approximant], needed to account for the specification of the liquids.

Max[approx], *[αnasal, +approx]

Max[nasal] *[αdist, +approx]

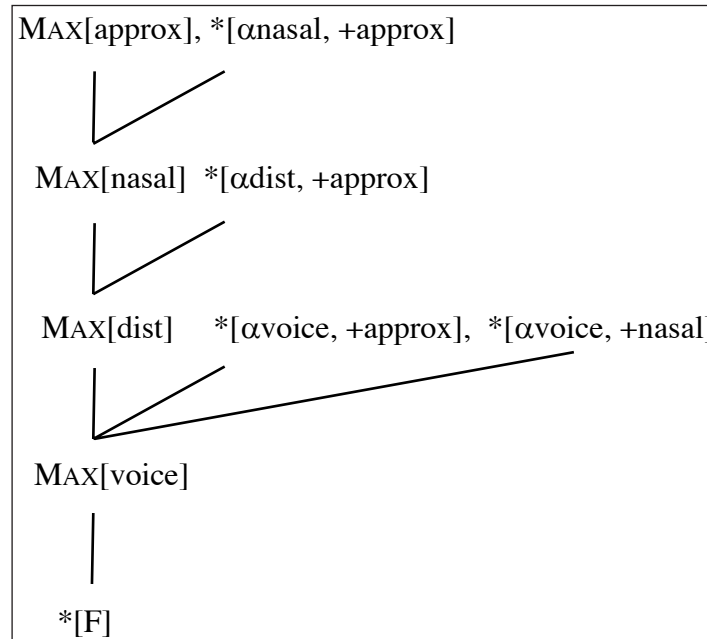Max[dist]   *[αvoice, +approx], *[αvoice, +nasal]

Max[voice]

*[F]

Figure 9: Shilluk constraint ranking for contrastive specifications.

With this constraint ranking, voiced and voiceless stops will be contrastively specified for the feature [distributed] but liquids will not be. A fully specified input containing an alveolar liquid and a dental stop, as in the form [t̪al], 'to cook', will map to a contrastively specified output with the feature [distributed] specified for the stop but not the /l/. This is illustrated in the tableau below.

(19)   Shilluk: dental stop cooccurs with alveolar liquid

t̪ a l [+dist][-dist]	Max[approx]	*[αdist, +approx]	Max[dist]	*[F]
a) t̪ a l̪ [+dist][-dist]		*!		**
b) t a l			**!	
c) ☞ t a l [+dist]			*	*
d) t̪ a t̪ [+dist][-dist]	*!			**

The tableau above shows the evaluation of an input with a dental stop and an alveolar lateral, both specified for the feature [distributed]. The faithful candidate is eliminated due to a violation of the constraint banning specification of the feature [distributed] in [+approximant] segments. Candidate (b) has eliminated [distributed] specifications for both the oral stop and the lateral, thus incurring two violations of Max[dist]. The second of these violations is fatal because optimal candidate (c) satisfies the highly ranked constraints demanding faithfulness in [approximant] and penalizing [distributed] specifications in [+approximant] segments while incurring only a single violation of Max[dist]. Candidate (d) satisfies Max[dist] and *[αdist, +approx] by changing the lateral to a stop

but is eliminated due to violation of highly ranked MAX[approximant]. Note that, although the constraint motivating harmony is not shown here, such a constraint will be vacuously satisfied by the winning candidate in (c) and will not affect the outcome of the evaluation.

Now consider the formation of the instrumental. A full analysis of the mechanisms that drive mutation is beyond the scope of this paper and I will not address changes in tone, vowel length, or vocalic features. For our purposes, it is sufficient to accept that the instrumental morpheme requires the final consonant of the root to be realized as a voiced stop. What will be addressed in this analysis is the feature specifications of the stop which surfaces in the instrumental forms. Leaving aside the issue of dental harmony for the moment, let us consider the evaluation of the instrumental form of [kyel], 'fry', in tableaux (20). This form has no coronals other than the one affected by mutation and will thus not be subject to dental harmony. The input shown is contrastively specified with no [distributed] feature present on the lateral. While all output candidates shown end in a voiced coronal stop, they vary in the feature specifications of that final stop. The constraint ranking is the same as that given above with the inclusion of an additional constraint, SPEC[distributed]. As discussed in section 2, constraints requiring specification in contrastive features must be included in the constraint set in order to deal with underspecified inputs. In all cases, achieving contrastive representations in output forms requires such constraints to be ranked above the constraint *[F] and below contextual markedness constraints limiting the scope of contrastive feature specifications. Although SPEC[F] constraints and MAX[F] constraints do not usually conflict, I will rank each SPEC[F] constraint above the corresponding MAX[F] constraint, for reasons to be discussed below. SPEC[distributed] is shown with this ranking in the following tableau.

(20)   Shilluk: instrumental of *kyel* 'fry'

kyel + instrumental	Spec[dist]	Max[dist]	*[F]
a) k y e̱: d ā	*!		
b) ☞ k y e̱: d ā [-dist]			*
c) ☞ k y e̱: ḍ ā [+dist]			*

With the constraints shown in (20), candidate (b), with a [-distributed] voiced stop, and candidate (c), with a [+distributed] voiced stop, are equally optimal. Crucially, candidate (a), with a final coronal unspecified for [distributed], is eliminated due to fatal violation of SPEC[distributed]. The constraint ranking is determined by the contrastive hierarchy proposed for the language. This ranking ensures that only contrastively specified members of the Shilluk inventory will be selected as optimal. In this example, the input correspondent of the voiceless coronal stop is a lateral unspecified for the feature [distributed]. The constraint ranking, however, requires that this output be specified for [distributed], as all coronal voiceless stops are in the language.

The use of SPEC[F] constraints ensures that underspecified inputs map to contrastively specified outputs and requires a /d/ derived from an input /l/ to be specified for [distributed]. As noted in section 3, the principle of structure preservation as developed in the theory of lexical phonology (e.g. Kiparsky 1982; 1985) has no direct analogue in OT grammars. The fact that there are no language specific restrictions on inputs, as required by the principle of Richness of the Base, undermines the notion of a basic inventory of structures for a given language. It is nonetheless worth noting that in the analysis proposed here, the requirement that output coronal stops be specified for distributed is both consistent with the principle of structure preservation and illustrates additional implications that structure

preservation holds in combination with Richness of the Base. In a discussion of English voicing, Kiparsky (1985: 92) states that structure preservation 'not only blocks voiceless sonorants from appearing in underlying representations and lexical derivations but also blocks the redundant specification [+voice] from being assigned to sonorants in lexical derivations.' The Shilluk example shows that OT implementation of the contrastive hierarchy results in constraint rankings which not only prevent specification of redundant features, such as [−distributed] in [l], but also requires specification of contrastive features, such as [−distributed] in [d], even in cases where such features are absent from inputs.

Both dental and alveolar stops are part of the inventory of Shilluk and the ranking shown above requires all coronal stops to be specified for [distributed], even in the absence of input specification. This ranking is not, however, sufficient to determine which value of [distributed] will be specified on a coronal stop when the input lacks specification in this feature. In Shilluk, the coronal stops derived from liquids via consonant mutation are realized as [-distributed] alveolars. I propose that this is motivated by ranking DEP[+distributed] above DEP[-distributed]. The constraint SPEC[distributed] will require specification if it is ranked above some constraint penalizing feature insertion. If the constraint penalizing insertion of positive feature values, DEP[+distributed], ranks above the constraint penalizing insertion of negative feature values, DEP[-distributed], input liquids unspecified for [distributed] will map to output stops with [-distributed] specifications in mutation contexts, as illustrated in tableau (21), below.

(21)   Shilluk: instrumental of *kyel* 'fry'

kyel + instrumental	DEP[+dist]	SPEC[dist]	MAX[dist]	*[F]	DEP[−dist]
a) k y ẹ̄ː d ā		*!		*	
b) ☞ k y ẹ̄ː d ā [-dist]				*	*
c) k y ẹ̄ː ḍ ā [+dist]	*!			*	

The tableau above is identical to previous tableau (20), but with inclusion of constraints DEP[-distributed] and DEP[+distributed]. DEP[+distributed] must outrank DEP[-distributed] in order to ensure the [-distributed] value of the stop derived through mutation. SPEC[distributed] must outrank DEP[-distributed] in order to ensure that underspecified inputs map to outputs specified for [distributed] in accordance with the proposed contrastive hierarchy.

If the constraint motivating harmony is integrated into the ranking in Figure 9, derived alveolar stops in instrumental forms will trigger harmony, as illustrated in tableau (22), below.

(22)   Shilluk: dental harmony in instrumental of *ṭal* 'cook'

ṭ a l + instrmntl [+dist]	*[αdist] [−αdist]	DEP[+dist]	SPEC[dist]	MAX[dist]	*[F]	DEP[−dist]
a) ṭ ā̰ː d ā [+dist]			*!		*	
b) ṭ ā̰ː d ā [+dist] [-dist]	*!				**	*
c) ṭ ā̰ː ḍ ā [+dist] [+dist]		*!			**	
d) ☞ t ā̰ː d ā [-dist] [-dist]				*	**	*

The winning candidate in (22) is the attested form which satisfies the dental harmony constraint by mapping the input dental stop to an alveolar. The candidate with a final stop unspecified for the harmonic feature, candidate (a), is eliminated by SPEC[distributed] and the candidate which satisfies dental harmony through [+distributed] specifications on both stops is eliminated due to violation of DEP[+distributed]. The winner violates MAX[distributed] because the [+distributed] value of the initial stop in the input is absent in the output. SPEC[distributed] and DEP[+distributed] are ranked above MAX[distributed], however, and this candidate surfaces as optimal. This is the case where MAX[distributed] and SPEC[distributed] conflict, motivating the ranking between them.

The analysis outlined here shows that dental harmony can be triggered by final coronal stops derived from liquids, even if the liquids themselves lack contrastive specification in the harmonic feature. The constraint ranking that ensures outputs are restricted to contrastively specified members of the Shilluk inventory requires output oral stops to be specified for [distributed] regardless of input specification. High-ranking DEP[+distributed] prevents [+distributed] dentals from surfacing in the absence of input [+distributed] specifications.

This proposal has implications for the analysis of dental harmony in Shilluk. Instrumental forms such as [ṱāːd-ā] 'cook', from [ṱal], are discussed in Hansson (2001; 2010) who interprets these data as evidence that dental harmony in Shilluk is right-to-left. The analysis proposed here does not rely on any mechanisms associated with directionality of harmony systems and suggests, instead, that Shilluk dental harmony is a dominant-recessive system with [-distributed] being the dominant feature value. Instrumental [ṱāːd-ā] is consistent with both analyses. The two proposals make distinct predictions if harmony occurs with prefixing mutation where an initial liquid is realized as a stop and a dental occurs later in the form. Under these circumstances, the right-to-left directionality account predicts that the [+distributed] value of the dental on the right will persist in cases where the form undergoes harmony whereas the analysis proposed here predicts that the [-distributed]
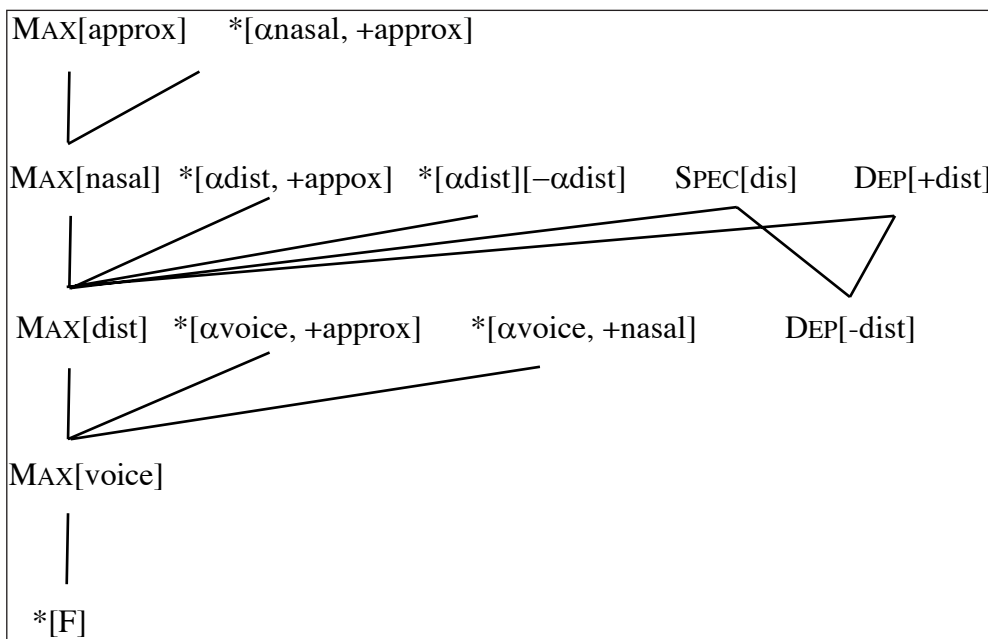

Figure 10: Shilluk constraint ranking.

value of the derived alveolar on the left will trigger a change to [-distributed] in a following stop. Alternatively, a dental stop created through word-final mutation would also be expected to pattern differently according to the two approaches, with the directional analysis predicting harmony to [+distributed] for all stops and the analysis given here predicting the dental created through mutation be realized as a [-distributed] alveolar if an alveolar stop occurs elsewhere in the form. To my knowledge, no mutation of initial segments is found in Shilluk. Although some plural forms include final dental stops created through mutation (e.g. [yoː] 'road', [ye̞ːt̪] 'roads'), none of the examples of this type in Gilley (1992: 86) have preceding alveolar stops. This leaves us without empirical evidence discriminating between the two interpretations of the data. The analysis proposed here requires all disharmonic inputs to surface as forms containing only [-distributed] segments. Forms with multiple dental stops surface only as outputs of input forms containing multiple dentals.

The complete constraint ranking proposed for the Shilluk inventory and dental harmony is summarized in the Hasse diagram in figure 10.

5 Dental harmony in Anywa: non-structure-preserving harmony

The analysis of dental harmony in Dholuo, Päri, and Shilluk illustrates the connection between inventory shape, contrastive specifications, and phonological activity. In Dholuo, the inventory is asymmetric, lacking a dental/alveolar contrast among nasals. In Päri and Shilluk, the inventory is symmetrical. Nasals contrast along the dental/alveolar dimension, as do other coronal stops. If all of these languages have a feature hierarchy in which the feature [nasal] is ordered above [distributed], the nasal will be unspecified for [distributed] in Dholuo but will be specified for this feature in Päri and Shilluk. When the contrastive hierarchy is converted to a ranking of OT constraints in Dholuo, output forms with co-occurring dental oral stops and alveolar nasals fail to violate the constraint barring segments with distinct specifications of [distributed] and the nasal fails to participate in harmony. In Päri and Shilluk, on the other hand, the nasal is specified for [distributed] and the constraint ranking achieving this specification also requires the nasals to participate in harmony. In these cases, dental harmony, contrastive specifications, and the phonemic inventory can be achieved in a single OT evaluation.

Differences between Dholuo, Päri, and Shilluk result from differences in the inventory. The hierarchy of features is alike in these languages but Dholuo differs from Päri and Shilluk in that Dholuo has only a single alveolar nasal in the inventory and Päri and Shilluk have both a dental and alveolar nasal. The theory of the contrastive hierarchy, however, allows the hierarchy of features to vary, even between languages with similar inventories. This predicts the possibility of a language with an asymmetric inventory like Dholuo, but with the nasal contrastively specified for the feature [distributed]. In such a case, the nasal is expected to be subject to harmony, even though there is no dental nasal in the inventory. The following analysis proposes that Anywa is such a language.

5.1 Anywa contrastive hierarchy

Anywa is another Western Nilotic language with a dental/alveolar contrast among coronals and harmony barring dentals and alveolars from co-occurring (Reh 1996; Hansson 2001; 2010; Rose & Walker 2004). Like Dholuo, Anywa has only a single coronal nasal.

(23)   Anywa coronal stops (Reh 1996: 23)

	Voiceless Stops	Voiced Stops	Nasals
Alveolar	t	d	n
Dental	t̪	d̪	

Unlike in Dholuo, however, the nasal participates in harmony in Anywa and dental nasals surface allophonically in harmonic forms. Outside of forms showing evidence of dental harmony, such as those below, dental nasals do not appear in Anywa.[12]

(24)   Anywa: nasals participate in harmony (Reh 1996)
         n̪ùd̪ò   'to lick'
         ōd̪óòn̪   'mud'
         t̪ùd̪   'ropes'
         núudó   'to press something down'
         dīn   'to thrash something'
         tūud   'pus'

The possibility of a pattern like that of Anywa is predicted by the theory of the contrastive hierarchy. If contrastive specifications depend, not only on the phonemic inventory, but also on the hierarchy of features, the scope of the harmonic feature may vary between languages resulting in different representations. In Anywa, the feature [distributed] is ordered high, resulting in contrastive specification for the nasal in the harmonic feature. Note that the dental nasal is not included in the phonemic inventory shown above. The process leading dental nasals to surface in harmonic forms is addressed later in this section, in the analysis of dental harmony. What is crucial here is that, with the feature [distributed] ordered high, the /n/ is contrastively specified for the harmonic feature even though there is no minimal contrast between dental and alveolar nasals in the phonemic inventory. This is illustrated in the contrastive hierarchy in figure 11.
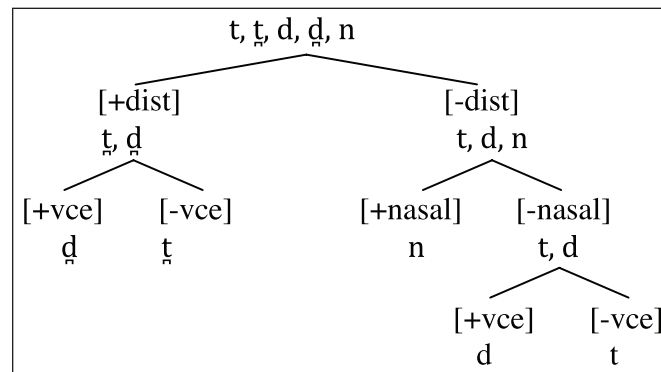

Figure 11: Anywa feature hierarchy: [distributed] > [nasal] > [voice].

Using the algorithm in (2), the Anywa contrastive hierarchy above can be converted to the following constraint ranking:

---

[12] Although geminate dental nasals occur as a result of mutation in morphologically complex forms, as discussed in relation to the process derivation in 5.3.
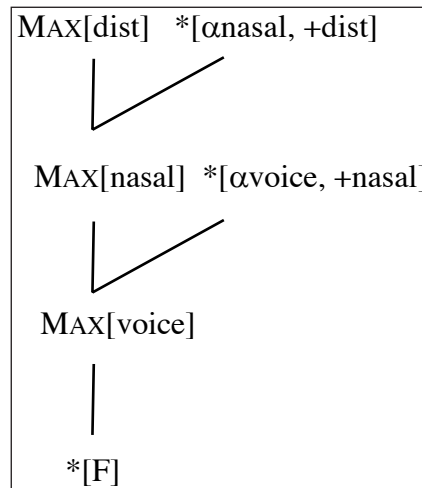
Figure 12: Anywa constraint ranking for contrastive specifications.

5.2 Anywa dental harmony: a ranking paradox

As in the analysis of Dholuo, Päri, and Shilluk, if the harmony-motivating constraint is integrated into the Anywa constraint ranking in Figure 12, the evaluation will rule out disharmonic forms as well as segments that contain non-contrastive feature specifications. However, the attested forms with allophonic dental nasals will not surface. The same ranking which eliminates dental nasals from the inventory results in disharmonic inputs containing nasals surfacing as harmonic forms containing dental obstruents.

(25)   Anywa: evaluation of harmonic form with dental nasal

n̪ùd̪ò	*[αdist][−αdist]	MAX [dist]	*[αnasal, +dist]	MAX [nasal]
a) ☞ n̪ùd̪ò			*!	
b) nùd̪ò	*!	*!		
c) ☜ d̪ùd̪ò				*

In the tableau in (25), the input consists of a form that obeys the dental harmony process and contains a dental nasal. The faithful and attested candidate in (a) is eliminated due to a violation of the markedness constraint *[αnasal, +dist]. This constraint rules out any specification for the feature [nasal] in segments that are specified as [+distributed] and is responsible for preventing dental nasals from surfacing in the inventory in general. The Anywa grammar must allow input dental nasals to surface as some other segment found in Anywa in order to account for the inventory. As illustrated in the tableau above, such an input-output mapping will also be available to satisfy the need for forms to obey dental harmony. The optimal candidate in (c) contains two dental oral stops. This candidate obeys dental harmony and also obeys the markedness constraint against dentals with specification for [nasal]. This candidate violates the constraint MAX[nasal] but this faithfulness constraint must be ranked below the constraint *[αnasal, +dist] in order to account for the Anywa inventory and the proposed contrastive specifications.

   The ranking paradox illustrated above is one example of a more general problem with modeling non-structure-preserving processes in OT. As discussed in the analysis of consonant mutation in Shilluk, the principle of structure-preservation (e.g. Kiparsky 1982; 1985) loses coherence in a framework that rejects language-specific restrictions on input forms. The principle is largely rejected in OT works, even in those arguing for a stratal

version of OT (e.g. Roca 2005; Bermúdez-Otero 2013). Working within the framework of the contrastive hierarchy, Hall (2007) addresses this issue in an analysis of Czech voicing assimilation and shows that contrastive specifications can be integrated with analyses of at least some non-structure-preserving neutralization processes if the markedness constraints which penalize non-contrastive feature specifications are reformulated as constraints which penalize the alignment of feature values. In the present case, such an approach would involve redefining markedness constraints such as *[αnasal, +distributed] such that they do not penalize the co-occurrence of [nasal] specifications and [+distributed] specifications per se but only penalize the co-occurrence of these features if they are identically aligned. If we adopt a theory of assimilation which involves multiply-linked features, a form like [n̪ùd̪ò] would avoid violation of such a constraint if the form contains only a single [+distributed] feature linked to both consonants. In such an analysis, the features [+nasal] and [+distributed] co-occur on the segment [n̪] but they are not identically aligned. The [+nasal] feature occurs only on [n̪] whereas the [+distributed] feature is multiply-linked and is associated to both the [n̪] and the [d̪]. The harmonic form thus satisfies the constraint against identical alignment of [+nasal] and [+distributed] and the harmonic form with the allophonic dental nasal would be evaluated as optimal. A dental nasal occurring outside of a harmonic context would have [+nasal] and [+distributed] specifications which *are* identically aligned and would correctly be ruled out by the relevant markedness constraint.

The ranking paradoxes illustrated in the analysis of Anywa, above, and in Hall's (2007) analysis of Czech voicing assimilation directly follow from the proposed hierarchies of features and the algorithm for converting a contrastive hierarchy to a constraint ranking. The difficulty that non-structure-preserving neutralization poses for Classic OT, however, is more general. Bermúdez-Otero (2007) addresses the issue of non-structure-preserving neutralization in the context of voicing neutralization in Catalan. Without assuming any particular theory of contrastive specification, Bermúdez-Otero demonstrates that processes which affect both contrastive and redundant feature specifications can lead to a ranking paradox. In Catalan, processes of voicing neutralization can result in surface [v] as an allophone of /f/, although [v] is absent from the phonemic inventory. As is the case for the dental nasal in Anywa, in Catalan, the allophone [v] cannot be ruled out from the input due to the principle of Richness of the Base. Rankings which allow input [v] to surface as some actual member of the Catalan inventory in the general case will also be available in contexts of voicing neutralization. Evidence from loanword adaptation suggests that a mapping from input [v] to output [b] is available and that output [b] is also expected to be preferred in voicing assimilation contexts. Bermúdez-Otero (2007) points out that the ranking paradox that arises in this case is similar to problems that arise in the analysis of opacity. He argues for a solution within the framework of stratal OT in which markedness constraints against the allophone [v] are ranked high at the stem level but demoted at higher levels of evaluation.

The proposal that follows advocates an analogous solution to the analysis of Anywa dental harmony and provides independent evidence that multiple levels of evaluation are needed. The analysis put forward here does not, however, require all non-structure-preserving processes to be absent from stem-level evaluations. A number of arguments in favour of stem-level, non-structure-preserving processes have been put forward in the stratal OT literature (e.g. Ito & Mester 2001; Roca 2005; Bermúdez-Otero 2013). Only those processes which are both allophonic and neutralizing are precluded at the stem-level by rankings required by the contrastive hierarchy. In Anywa, dental harmony leads to allophonic variation in the nasals but among the other coronal stops, the dental/alveolar

contrast neutralized by harmony is phonemic. In these cases, the contrastive hierarchy needed to ensure contrastive specification of the segments participating in harmony, specifically the nasal in Anywa, results in a ranking paradox if the neutralizing process takes place at the earliest level of evaluation.

5.3 Dental harmony at the word-level

The ranking paradox illustrated in the analysis of Anywa above arises if dental harmony, the phonemic inventory, and contrastive specifications are determined in a single level of evaluation. There is evidence, however, that dental harmony occurs at a later level of evaluation in Anywa than does dental harmony in Dholuo.

In Anywa, a variety of word-formation processes involve consonant mutation. In the examples below, a detransitivizing morpheme changes stem-final coronal sonorants to oral stops.

(26)   Anywa: words formed by consonant mutation undergo harmony (Reh 1996: 59)

			Detransitived
a.	d̪īr	'to jostle sth.'	d̪ìd̪ò
	t̪ōor	'to finish sth.'	t̪òod̪ò
b.	dɔ̄l	'to fold sth.'	dùdò
	tīir	'to adjust sth.'	tíidó

The transitive forms in (26) all end in the coronal sonorants /l/ or /r/. There is no dental/alveolar contrast among sonorants in Anywa and the sonorants do not participate in dental harmony. In the detransitivized forms, these sonorants become oral stops through the process of consonant mutation. The underived forms in (a) contain dental stops and mutation leads the stem-final coronal sonorants to become dental stops. The forms in (b) contain alveolar stops and mutation leads the sonorants to be realized as alveolar stops. In other words, Anywa consonant mutation feeds dental harmony.

This contrasts with the patterning of consonant mutation in Dholuo. Although Dholuo does not have exactly the same type of consonant mutation as Anywa, a relevant process is found in pluralized forms. One type of pluralization in Dholuo results in final coronal sonorants being realized as prenasalized stops.

(27)   Dholuo mutation creates exceptions to harmony (Tucker 1994: 557–603)

Singular		Plural
t̪ʊɔn	'brave man'	t̪uoⁿdi
t̪uol	'snake'	t̪uoⁿde

Recall that the Dholuo inventory has a dental/alveolar contrast among prenasalized stops and prenasalized stops participate in dental harmony. The disharmonic plural forms in (27) would be ungrammatical in monomorphemic forms.

I propose that dental harmony in Anywa occurs at the word level along with, or subsequent to, word-formation processes which trigger mutation. In Dholuo, on the other hand, dental harmony occurs at the stem level and word-level consonant mutation results in exceptions to harmony.

In Anywa, harmony is not determined in the same evaluation as contrastive specifications. At the stem level, the inventory and contrastive representations are determined. The input to the word level consists of contrastively specified outputs of stem-level evaluations.[13]

---

[13] As pointed out by an anonymous reviewer, non-contrastive representations could, in theory, occur in inputs to word-level evaluations through the addition of word-level affixes, an issue noted in McCarthy (2007). Buckler and Bermúdez-Otero (2012) address this issue by proposing that word-level affixes pass through stem-level evaluations.

The stem-level ranking for Anywa is the ranking proposed in the previous section as determined by the algorithm for converting a contrastive hierarchy to a constraint ranking. Unlike proposed rankings for Dholuo, Päri, and Shilluk, however, the constraint that drives harmony, *[αdistributed][-αdistributed], is ranked low, as illustrated in figure 13.

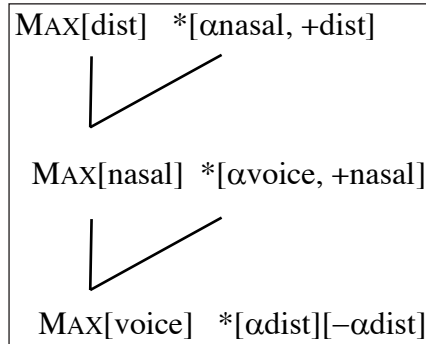$$\begin{array}{cc} \text{MAX[dist]} & *[\alpha\text{nasal, +dist}] \\[2.2em] \text{MAX[nasal]} & *[\alpha\text{voice, +nasal}] \\[2.2em] \text{MAX[voice]} & *[\alpha\text{dist}][-\alpha\text{dist}] \end{array}$$

Figure 13: Anywa stem-level constraint ranking.

This ranking will map any input segment to a contrastively specified member of the Anywa inventory. The fact that the harmony-driving constraint is ranked below faithfulness constraints referring to contrastive features means that this ranking does not enforce dental harmony and disharmonic forms are possible outputs of the stem level.

(28)   Anywa: stem level evaluation of disharmonic input form

nùḍò [-dist] [+dist]	MAX [dist]	*[αnasal, +dist]	MAX [nasal]	*[αdist][−αdist]
a) ☞ nùḍò [-dist] [+dist]				*
b) n̪ùḍò [+dist] [+dist]	*!	*!		
c) ḍùḍò [+dist] [+dist]	*!		*	
d) nùḍò [+dist]	*!			

In the tableau above, the faithful and disharmonic candidate in (a) is optimal. This candidate satisfies all faithfulness constraints. It also satisfies the markedness constraint *[αnasal, +distributed] which militates against [+distributed] segments with any specification for the feature [nasal]. This candidate does violate the constraint which motivates dental harmony, *[αdistributed][-αdistributed], but this constraint is low-ranked and the form is selected as optimal. The candidate in (b) has a dental nasal as the output correspondent of the input alveolar nasal. This form is consistent with dental harmony. However, a [-distributed] value in the input is absent from the output candidate in (b) leading to a violation of the constraint MAX[distributed]. This candidate also violates the constraint against dentals specified for the feature [nasal] and the candidate is eliminated. Candidates (c) and (d) are forms which satisfy dental harmony without containing a dental nasal. In candidate (c), the input alveolar nasal has mapped to a dental oral stop. This candidate also violates MAX[distributed] in addition to MAX[nasal]. Candidate (d) contains a nasal that is underspecified for the feature [distributed] and hence

satisfies the dental harmony constraint vacuously. However, the [-distributed] specification on the nasal in the input is absent from this output leading to a fatal violation of MAX[distributed].

The output of the stem-level evaluation will serve as the input to the word-level evaluation. At the word level, dental harmony is enforced by high-ranking *[αdistributed] [-αdistributed]. Both *[αdistributed][-αdistributed] and MAX[nasal] must outrank the constraint penalizing dental nasals in order to allow input-output mappings in which dental nasals surface in forms with dental harmony. The proposed word-level ranking is shown below.

MAX[nasal]   *[αdist][−αdist]

MAX[dist]   *[αnasal, +dist]
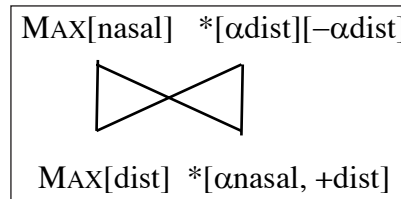
Figure 14: Anywa word-level constraint ranking.

The contrastively specified, disharmonic output of the stem-level evaluation in (28) serves as the input to word-level evaluation in the following tableau.

(29)   Anywa: word level evaluation of disharmonic input form[14]

nùd̪ò [-dist] [+dist]	*[αdist][−αdist]	MAX [nasal]	*[αnasal, +dist]	MAX [dist]
a) nùd̪ò [-dist] [+dist]	*!			
b) ☞ n̪ùd̪ò [+dist] [+dist]			*	*
c) d̪ùd̪ò [+dist] [+dist]		*!		*

In (29), the faithful candidate is eliminated due to violation of *[αdistributed][−αdistributed]. The optimal candidate in (b) satisfies dental harmony and contains an allophonic dental nasal. This candidate violates the constraint against dentals specified for the feature nasal, *[αnasal, +distributed]. At the stem level, this constraint played an important role in preventing dental nasals from surfacing as part of the inventory. At the word-level, this constraint is ranked below the constraint that enforces dental harmony and below the faithfulness constraint MAX[nasal]. The candidate in (c) also satisfies dental harmony but the input alveolar nasal has mapped to a dental oral stop. Such a candidate was problematic in (25) where we attempted to derive dental harmony, contrastive specifications, and the surface inventory of Anywa in a single level of evaluation. Here the candidate is eliminated due to violation of the faithfulness constraint MAX[nasal]. At the word level,

---

[14] The analysis given here does not account for the fact that inputs containing both [+distributed] and [-distributed] segments map to outputs that harmonize to all [+distributed] segments. Different ranking of faithfulness constraints referring to positive and negative feature values are needed to account for the dominance of [+distributed] in these cases. Either DEP[+distributed] and DEP[-distributed] must be ranked separately with DEP[-distributed] being ranked higher (opposite to the proposed analysis of Shilluk) or the MAX[distributed] constraint must be divided into distinct constraints for positive and negative values with MAX[+distributed] ranked higher.

faithfulness to nasality is ranked above faithfulness to [distributed] and the markedness constraint against dentals specified for the feature [nasal], allowing the dental nasal to surface.

There is a relevant candidate, not shown in (29), that requires consideration. A candidate which satisfies the dental-harmony driving constraint through underspecification would be optimal given the constraints shown, analogous to the winning candidate in the proposed analysis of Dholuo. The tableau in (29) is repeated below but with the problematic candidate included.

(30)   Anywa: evaluation of disharmonic input with underspecified candidate

nùd̪ò [-dist] [+dist]	*[αdist][−αdist]	MAX [nasal]	*[αnasal, +dist]	MAX [dist]
a) nùd̪ò [-dist] [+dist]	*!			
b) ☞ n̪ùd̪ò [+dist] [+dist]			*!	*
c) d̪ùd̪ò [+dist] [+dist]		*!		*
d) ☜ nùd̪ò [+dist]				*

In tableau (30), candidate (d) has a nasal unspecified for the feature [distributed] as the output correspondent of the [-distributed] nasal in the input. Faithfulness constraints like MAX[F] militate against underspecification relative to the input. The MAX[F] constraints also penalize feature value mismatches between input and output because positive and negative feature values are understood as distinct entities. If a [+F] input specification maps to a [-F] value in the output, this violates MAX[F] because a positive feature value in the input is absent from the output. It is this equivalence between a change in feature value and elimination of a feature value that leads to the problem in tableau (30). The underspecified candidate in (d) violates MAX[distributed] just as the candidate which contains the dental nasal does. The candidate with the dental nasal in (b) is the attested one but it ties with the underspecified candidate with respect to the faithfulness constraint referring to [distributed] and violates the markedness constraint against [+distributed] segments specified for the feature [nasal]. If only these constraints are considered, the underspecified candidate will win regardless of constraint ranking.

In order to address this issue, and to successfully model Anywa dental harmony, we need a markedness constraint which penalizes the absence of a feature. Constraints of this type were introduced in the discussion of converting a contrastive hierarchy to a constraint ranking in section (2). The markedness and faithfulness constraints included in the algorithm for converting a contrastive hierarchy to a constraint ranking successfully map fully-specified inputs to contrastively specified outputs. Constraints of the form SPEC[F] are needed to ensure that underspecified inputs will also map to contrastively specified outputs. Use of SPEC[F] constraints was also illustrated in the analysis of Shilluk consonant mutation. In the ranking determined by the algorithm for converting a contrastive hierarchy to a constraint ranking, SPEC[F] constraints are ranked below markedness constraints, such as *[αnasal, +distributed], which limit the scope of contrastive features. This ranking, however, is only required to determine the inventory and ensure

contrastive representations in the initial stage of evaluation, at the stem level. At later levels, constraint rerankings are necessary to model non-structure-preserving processes. The constraint SPEC[distributed], independently needed to ensure contrastive representations at the stem level, can be added to the hierarchy shown in tableau (30) and prevent the underspecified candidate from winning. The use of SPEC[F] provides the crucial distinction between mappings which change the value of a feature specification, which violate MAX[F], and mappings which result in the absence of any specification at all for the relevant feature. In cases where the relevant feature is specified in the input, such mappings violate both MAX[F] and SPEC[F].

As illustrated in the following tableau, SPEC[distributed] must be ranked above the markedness constraint *[αnasal, +distributed] at the word-level in Anywa in order to ensure that the need for dental harmony is not satisfied via underspecification of the harmonic feature.

(31)   Anywa: word-level ranking including SPEC[distributed]

nùd̪ò [-dist] [+dist]	*[αdist] [−αdist]	SPEC[dist]	MAX [nasal]	*[αnasal, +dist]	MAX [dist]
a) nùd̪ò [-dist] [+dist]	*!				
b) ☞ n̪ùd̪ò [+dist] [+dist]				*	*
c) d̪ùd̪ò [+dist] [+dist]			*!		*
d) nùd̪ò [+dist]		*!			*

In (31), SPEC[distributed], MAX[nasal], and the constraint driving dental harmony, *[αdistributed][-αdistributed], are all ranked above the constraint which penalizes specification of the feature [nasal] in [+distributed] segments. This allows the attested candidate in (b), containing the allophonic dental nasal, to surface as optimal.

The analysis of Anywa dental harmony requires the markedness constraint against dental nasals, *[αnasal, +distributed] to be ranked lower at the word level than at the stem level, relative to the constraint which drives dental harmony. The constraint requiring output segments to be specified for [distributed], SPEC[distributed], must also outrank *[αnasal, +distributed] at the word level. Additional evidence that the constraint against dental nasals is demoted at the word level comes from consonant mutation processes in which geminate dental nasals surface outside of harmonic contexts. The data in (32) illustrate the addition of a process morpheme which gives verbs an inchoative meaning. A stem-final dental stop becomes nasalized when the process morpheme is added, leading to a dental nasal on the surface, even though there is no other dental in the form.[15]

(32)   Anywa (Reh 1996)
        pɔ́ɔd̪ 'be smooth'   pòon̪n̪ 'become smooth'

_____
[15] A number of phonological changes take place in the process derivation, in addition to nasalization of the stem final consonant. These include a change in tone, gemination of the final consonant, and a change in the [ATR] value of the stem vowel. See Trommer (2011) for additional details of the process derivation.

In Anywa, the detransitivized forms in (26), e.g. detransitived [d̪ìd̪ò] from [d̪īr] 'to jostle sth.', may be formed at the stem level or at the word level. If the detransitizing morpheme is added at the stem level, harmony will not determine the [distributed] value of a coronal stop derived from a liquid, as the harmony-driving constraint is low ranked in the stem-level grammar. Harmony will be enforced when the form undergoes word-level evaluation where the harmony-driving constraint, *[αdist][-αdist], is highly ranked and rules out disharmonic surface forms. The process derivation illustrated in (32), however, must take place at the word level. Stem-level constraint ranking will rule out dental nasals from surfacing, even if a [+distributed] feature is present in the input, as illustrated in the analysis of dental harmony. The existence of word-level processes that can lead to dental nasals appearing in surface forms, outside the context of dental harmony, leads support to the proposal that the constraint which penalizes dental nasals is ranked lower at the word level than at the stem level. The proposal that the process derivation is word-level is contrary to Trommer's (2011) analysis in which the process/inchoative derivation is attributed to the stem-level. Trommer distinguishes word-level from stem-level processes partly on the basis of the degree of morphophonological interaction with stems. For example, the coda-condition can be violated by word-level affixation but not by stem-level affixation. His analysis of Anywa does, however, include underspecified word-level affixes which cause gemination and do not result in coda-condition violations (e.g. the 2PL suffix). It is not clear that the process derivation is incompatible with the stem-level ranking. I therefore take the contrastive hierarchy analysis here as a provisional argument in favour of a ascribing the process derivation to the word level, with further consideration of the issue within the context of Anywa morphophonology left to future research.[16]

5.4 Disharmonic prefixes

The previous section has shown that a successful analysis of dental harmony in Anywa requires reference to a multi-level evaluation. In order to avoid the ranking paradox that results from an attempt to model non-structure-preserving harmony in a single evaluation, the analysis presented here proposes that dental harmony in Anywa is enforced at the word level, after stem-level evaluation has filtered the rich base to include only contrastively specified members of the Anywa inventory. Data from the interaction of harmony and consonant mutation provides further support for the word-level analysis of Anywa dental harmony.

It is not the case, however, that Anywa dental harmony holds throughout all morphologically complex forms. While coronal stops and nasals created through mutation processes are subject to harmony, harmony does not extend to regular segmental prefixes, as shown in the following agentive nouns formed with the prefix /dì-/.

(33)   Anywa prefixed disharmonic forms (Reh 1996: 60)
        dì-t̪òod̪ì   'marksman'
        dì-bìd̪ì   'fisherman'

Disharmonic compounds are also permitted.[17]

(34)   Anywa disharmonic compounds (Reh 1996: 60)
        ā-d̪ὲ-gōod   'elephant snout' (*lit.* that with the mouth bent)
        d̪ὲ-ɔ́tɔ̄   'door' (*lit.* mouth of the house)

---

[16] Thanks to an anonymous reviewer for pointing out the necessity to ascribe the process derivation to the word level.

[17] Reh (1996: 60) also notes the exceptional disharmonic form /d̪àanɔ́/ 'person' and states that this form is a compound historically.

If forms like those in (33) and (34), above, are subject to the evaluation with the proposed word-level ranking in Figure 14, they are expected to undergo harmony. However, Trommer (2011), provides evidence that both prefixes and roots in compounds constitute distinct prosodic words in Anywa, whereas suffixes form a single prosodic word with the preceding root. The disharmonic forms in (33) and (34) are consistent with the proposed analysis if dental harmony is bounded by the prosodic word, as are other phonological processes in Anywa, such as high tone spread (Trommer 2011: 167).

6 Conclusion

This paper has provided an analysis of dental harmony in the Nilotic languages, Dholuo, Päri, Shilluk, and Anywa. All have a contrast between dental and alveolar coronals and all have a system of dental harmony which bars the co-occurrence of dentals and alveolars. Details of the patterning of dental harmony and the structure of the coronal inventory vary between languages. According to the analysis proposed here, differences between the languages follow from three distinct aspects of the phonological grammar; differences in the shape of the inventory, differences in the hierarchy of features according to the theory of the contrastive hierarchy (e.g. Dresher 2009), and differences in the level at which harmony applies within a stratal model of OT (e.g. Kiparsky 2000; Bermúdez-Otero 2003).

Differences between Päri and Shilluk, on one hand, and Dholuo and Anywa, on the other, follow from the structure of the inventory. In Päri and Shilluk, the inventory contains two coronal nasals which minimally contrast in [distributed]. The feature [distributed] is contrastive among nasals, regardless of the ordering of features in a contrastive hierarchy, and the nasals participate in dental harmony. The inventory of Päri and Shilluk thus differs from that of Anywa and Dholuo, both of which have only a single coronal nasal. Anywa and Dholuo, have inventories which are alike in relevant respects. In both languages, the dental/alveolar contrast which is present among coronal stops is lacking in the nasal series. The grammars of Anywa and Dholuo differ in two ways. First, they have different feature hierarchies. In Dholuo, the feature [nasal] is ordered above the feature [distributed] and in Anywa the order of these features is reversed. As a result, the nasals are contrastively specified for [distributed] in Anywa but not in Dholuo.

The proposed contrastive specifications are not themselves sufficient to model crosslinguistic differences in dental harmony in an explicit theory of phonological operations. In addition to differences in the feature hierarchy, Dholuo and Anywa differ in the level at which harmony applies in a stratal model of OT. In Dholuo, harmony applies at the stem level whereas in Anywa harmony applies at the word level. Although these languages differ with respect to the level at which harmony applies, differences in the feature hierarchy remain crucial to the analysis. If Anywa had a feature hierarchy like that of Dholuo, the input to the word level would contain nasals unspecified for [distributed], the harmony-driving constraint would be vacuously satisfied, and allophonic dental nasals would fail to surface.

This analysis makes typological predictions about the range of harmony patterns expected to be found crosslinguistically. In Dholuo, harmony occurs at the stem level, as shown by the existence of disharmonic forms arising through mutation processes at the word level (35).

(35)   Dholuo (Tucker 1994)
         ṱuol   'snake'   ṱuo^{n}de   'snakes'

In Shilluk, consonant mutation feeds harmony, as illustrated in (36) (repeated from (18). The analysis proposed in Section 4.3 accounts for this pattern of mutation and dental

harmony in a single level of evaluation. This is the stem level. Word-level affixation results in disharmonic forms, as shown with the suffix –ání, 'this', in (37).

(36)   Shilluk harmonic forms with mutation (Gilley 1992)
        ṭal   'cook (transitive)'   ṭā:d̪-ā   'cook (instrumental)'   *ṭā̪d-, *ṭ̪ād-
                                    ṭa̪:t   'cook (antipassive)'   *ṭat̪, *ṭ̪at

(37)   Shilluk disharmonic forms with affixation (Gilley 1992)
        d̪ɔ̀ŋɔ̀   'basket'   d̪ɔ̀ŋ:ání   'this basket'   * d̪ɔ̀ŋ:áṇí
        wât̪   'bull'   wá:ṇání   'this bull'   * wá:ṇáṇí

Both Dholuo and Shilluk have structure-preserving dental harmony at the stem level. However, a language with structure-preserving harmony but with harmony occurring at the word-level is predicted to be possible. Such a case is found in the Nilotic language Mayak (Andersen 1999; Hansson 2001; 2010) where harmony applies to regular segmental affixes leading to alternations. As in Dholuo and Anywa, the coronal inventory of Mayak contains only a single, alveolar nasal. The nasal does not participate in harmony, as in Dholuo, but harmony optionally applies to affixes showing that it is active at the word-level, as in Anywa.

(38)   Mayak: optional dental harmony in /-Vt̪ / singulative suffix (Andersen 1999,
        cited in Hansson 2010: 60–61)
        a. leɣ–it̪   'tooth'
            gim–it̪   'cheek'
        b. wʌd̪–it̪   'buttock'
            tid–ʌt̪ ~ tid–ʌt   'doctor'
            tuɣ–it̪ ~ tuɣ–it   'back of head'

(39)   Mayak: /n/ is neutral
        a. ʔin–ʌt̪   'intestine'
            kan–ɪt̪   'torch'
        b. di:n–ɛt̪ ~ di:n–ɛt   'bird'
            kɛt–ɪn–ɛt̪ ~ kɛt–ɪn–ɛt   'star'

The data above illustrate alternations in the singulative suffix. If there is no coronal stop in the stem (38), the suffix is realized as /-Vt̪ /, with a final dental stop. When the suffix is added to a form containing a coronal stop, dental harmony optionally extends to the suffix leading the suffix-final stop to be realized as alveolar if a /t/ or /d/ precedes (38). If the stem contains an /n/, however, there is no optional harmony in the suffix, showing that the nasal fails to participate in harmony (39). The nasal, in fact, patterns as transparent, allowing the suffix coronal to harmonize with alveolar stops which precede the nasal (39).

  Suffixes optionally undergo dental harmony but roots in Mayak are obligatorily harmonic. This indicates that, although harmony is active at the word level, there is some difference in constraint ranking between the stem and word levels. The relevant point of this example is simply that structure-preserving harmony can occur at the word level. Although harmony in Dholuo and Shilluk is restricted to the stem level, there is nothing in the analysis which precludes structure-preserving harmony from occurring at later levels of evaluation, as in Mayak. The analysis in Section 4.2 demonstrates that it is possible to analyze the Päri inventory, contrastive specifications, and dental harmony in a single level of evaluation, as is the case for Dholuo and Shilluk. Unlike Dholuo and Shilluk, however, there is nothing in the analysis that *requires* harmony to be determined at the same level of evaluation as the inventory and feature specifications in Päri. The following

examples show the possessive marker which involves the addition of a final vowel as well as mutation in which final liquids are realized as nasal-stop clusters. The final consonants created through mutation are subject to harmony. This is consistent with harmony being active at the stem level with the possessive form also created at the stem level. These data are also consistent with harmony applying later, at the word level, subsequent to stem-level morphological processes.

(40)   a. Päri (Andersen 1988)
            dèːl   'skin'   dèːnd-á   'my skin'
            t̪ùol   'snake'   t̪ùon̪d̪-à   'my snake'

The proposed analyses of dental harmony allow for structure-preserving harmony to occur at the stem level, as in Dholuo, or at the word level, as in Mayak. Non-structure-preserving harmony, as in Anywa, however, is predicted to be impossible at the stem level where a ranking paradox arises if harmony, the inventory, and contrastive specifications are modeled with a single constraint ranking. The ranking needed for the nasal to partici-pate in harmony, and for allophonic dental nasals to surface, must apply after contrastive specifications have been achieved. To my knowledge, this prediction is correct. There are no attested cases of non-structure-preserving dental harmony applying at the stem level within Nilotic.

This paper has demonstrated that contrastive specifications consistent with the theory of the contrastive hierarchy can be achieved as outputs of OT grammars with no restric-tions on the set of possible inputs. However, in order to analyze non-structure-preserving harmony, as in Anywa, a multi-level evaluation, as in Stratal OT, is required. Challenges that non-structure-preserving processes pose for Classic OT have been recognized in pre-vious work. The arguments for a serial evaluation presented here closely resemble those of Bermúdez-Otero (2007). His analysis of Catalan voicing assimilation also shows the need for a multi-level evaluation and draws a connection between challenges that the analysis of opacity poses for Classic OT and challenges posed by non-structure-preserving processes. This paper makes similar arguments from the analysis of dental harmony in Nilotic but, unlike Bermúdez-Otero (2007), the distinction between contrastive and redun-dant features relied on here is determined on the basis of an explicit theory of contrast that allows for differences in contrastive specifications between languages with similar inventories. An analysis of non-structure-preserving voicing assimilation in Czech is pro-vided in Hall (2007). This analysis is undertaken within the framework of the contrastive hierarchy and uses a single-level evaluation in OT. Hall avoids the ranking paradox that arises in the analysis of non-structure-preserving assimilation by reformulating feature co-occurrence constraints which limit the scope of non-contrastive features as constraints which limit identical alignment between particular features. Such constraints are not vio-lated by the co-occurrence of relevant features if the features do not have the same span, for example, if one feature is linked to multiple segments as a result of assimilation. This approach is able to adequately model non-structure-preserving harmony but fails to make any predictions about the interaction of phonological processes, such as harmony, with word-formation processes. In contrast, the stratal OT analysis here relies on the theory of the contrastive hierarchy and predicts that non-structure-preserving harmony, as found in Anywa, cannot be restricted to the stem level, as is the case for structure-preserving harmony in Dholuo.

The proposed analysis of dental harmony in Anywa, Dholuo, Päri, and Shilluk demon-strates that, while a multi-stage version of OT is necessary in order to achieve contrastive specifications as outputs, this does not require reference to any additional level beyond

the stem, word, and phrase levels proposed in theories of Stratal OT. Rather, contrastive specifications are achieved at the stem level of evaluation along with the surface inventory and other aspects of the grammar associated with restrictions on the shape of underlying representations in derivational theories. This approach captures the relationship between inventory shape and the patterning of harmony in addition to making predictions about how different types of harmony patterns interact with morphological processes.

Acknowledgements

Competing Interests

The author declares that she has no competing interests.

References

Andersen, Torben. 1988. Consonant alternation in the verbal morphology of Päri. *Afrika und Übersee* 71. 63–117.

Andersen, Torben. 1999. Consonant alternation and verbal morphology in Mayak (Northern Burun). *Afrika und Übersee* 82. 65–97.

Archangeli, Diana. 1988. Aspects of underspecification theory. *Phonology* 5(2). 183–207. DOI: http://dx.doi.org/10.1017/S0952675700002268

Avery, J. Peter & Keren Rice. 1989. Segment structure and coronal underspecification. *Phonology* 6(2). 179–200. DOI: http://dx.doi.org/10.1017/S0952675700001007

Bermúdez-Otero, Ricardo. 2003. The acquisition of phonological opacity. In Jennifer Spenader, Anders Eriksson & Östen Dahl (eds.), *Proceedings of the Stockholm conference on variation within Optimality Theory*, 25–36. Stockholm: Department of Linguistics, Stockholm University.

Bermúdez-Otero, Ricardo. 2007. Marked phonemes vs marked allophones: segment evaluation in Stratal OT. Handout from Workshop on Phonological Approaches to Opacity, GLOW XXX, Tromsø.

Bermúdez-Otero, Ricardo. 2013. The stem-level syndrome. Paper presented at the University of Pennsylvania.

Buckler, Helen, & Ricardo Bermúdez-Otero. 2012. Word-level affixes trigger stem-level cycles: evidence from German dorsal fricatives. Handout from the 20th Manchester Phonology Meeting.

Colina, Sonia. 2013. Galician geada: In defense of underspecification in Optimality Theory. *Lingua* 133. 84–100. DOI: http://dx.doi.org/10.1016/j.lingua.2013.04.003

Dresher, B. Elan. 2003. *Contrast and asymmetry in inventories. Asymmetry in grammar: Morphology, phonology, acquisition.* Amsterdam: John Benjamins.

Dresher, B. Elan. 2009. *The contrastive hierarchy in phonology.* Cambridge: Cambridge University Press. DOI: http://dx.doi.org/10.1017/CBO9780511642005

Gafos, Adamantios. 1996. *The articulatory basis of locality in phonology.* Baltimore: Johns Hopkins dissertation. Published 1999, New York: Garland.

Gilley, Leoma G. 1992. *An autosegmental approach to Shilluk phonology.* Dallas; Arlington, TX: Summer Institute of Linguistics.

Hall, Daniel Currie. 2007. *The role and representation of contrast in phonological theory.* Toronto: University of Toronto dissertation.

Hansson, Gunnar. 2001. *Theoretical and typological issues in consonant harmony.* Berkeley: University of California dissertation.

Hansson, Gunnar. 2010. Consonant harmony: Long-distance interaction in phonology *(UC Publications in Linguistics)*. Berkeley: University of California Press.

Harrison, K. David & Abigail Kaun. 2001. Patterns, pervasive patterns, and feature specification. In T. Alan Hall (ed.), *Distinctive feature theory*, 211–236. Berlin: Mouton de Gruyter. DOI: http://dx.doi.org/10.1515/9783110886672.211

Hyman, Larry M. 1995. Nasal consonant harmony at a distance: the case of Yaka. *Studies in African Linguistics* 24(1). 5–30.

Inkelas, Sharon. 1994. The consequences of optimization for underspecification. In Jill Beckman (ed.), *Proceedings of the 26th annual meeting of the North East Linguistic Society*, 287–302. Amherst Massachusetts: GLSA.

Ito, Junko & Armin Mester. 2001. Structure preservation and stratal opacity in German. In Linda Lombardi (ed.), *Segmental Phonology in Optimality Theory: constraints and representations*, 261–296. Cambridge: Cambridge University Press.

Kimper, Wendell A. 2011. *Competing triggers: transparency and opacity in vowel harmony*. Amherst: University of Massachusetts dissertation.

Kiparsky, Paul. 1982. Lexical phonology and morphology. In In-Seok Yang (ed.), *Linguistics in the Morning Calm*, vol. 2, 3–91. Seoul: Hanshin.

Kiparsky, Paul. 1985. Some consequences of lexical phonology. *Phonology* 2. 85–138. DOI: http://dx.doi.org/10.1017/S0952675700000397

Kiparsky, Paul. 2000. Opacity and cyclicity. *The Linguistic Review* 17. 351–365. DOI: http://dx.doi.org/10.1515/tlir.2000.17.2-4.351

Mackenzie, Sara. 2009. *Contrast and similarity in consonant harmony processes*. Toronto: University of Toronto dissertation.

Mackenzie, Sara. 2011. Contrast and the evaluation of similarity: Evidence from consonant harmony. *Lingua* 121(8). 1401–1423. DOI: http://dx.doi.org/10.1016/j.lingua.2011.03.004

Mackenzie, Sara. 2013. Laryngeal co-occurrence restrictions in Aymara: contrastive representations and constraint interaction. *Phonology* 30(02). 297–345. DOI: http://dx.doi.org/10.1017/S0952675713000146

Mackenzie, Sara & B. Elan Dresher. 2004. Contrast and phonological activity in the Nez Perce vowel system. *Proceedings of the twenty-ninth annual meeting of the Berkeley Linguistics Society*, 283–294.

McCarthy, John J. 2007. *Hidden generalizations : phonological opacity in optimality theory*. (Advances in Optimality Theory). London: Equinox.

Piggott, Glyne L. 1992. Variability in feature dependency: the case of nasality. *Natural Language & Linguistic Theory* 10. 33–78. DOI: http://dx.doi.org/10.1007/BF00135358

Prince, Alan & Paul Smolensky. 1993. *Optimality Theory: constraint interaction in generative grammar*. Ms, Rutgers University & University of Colorado, Boulder. Published 2004, Malden, Mass. & Oxford: Blackwell.

Reh, Mechthild. 1996. *Anywa language: description and internal reconstructions*. Cologne: R. Köppe.

Remijsen, Bert, Otto G. Ayoker & Timothy Mills. 2011. Shilluk. *Journal of the International Phonetic Association* 41(01). 111–125. DOI: http://dx.doi.org/10.1017/S0025100310000289

Rice, Keren. 1993. A reexamination of the feature [sonorant]: the status of "sonorant obstruents." *Language* 69(2). 308–344. DOI: http://dx.doi.org/10.2307/416536

Roca, Iggy. 2005. Strata, yes; structure preservation, no: evidence from Spanish. In Twan Geerts, Ivo van Ginneken & Haike Jacobs (eds.), *Current Issues in Linguistic Theory*, vol. 270, 197–218. Amsterdam: John Benjamins Publishing Company.

Rose, Sharon & Rachel Walker. 2004. A typology of consonant agreement as correspondence. *Language* 80(3). 475–531. DOI: http://dx.doi.org/10.1353/lan.2004.0144

Rubach, Jerzy. 2003. Polish palatalization in derivational Optimality Theory. *Lingua* 113. 197–237. DOI: http://dx.doi.org/10.1016/S0024-3841(02)00054-2

Shaw, Patricia. 1991. Consonant harmony systems: the special status of coronal harmony. In Carole Paradis & Jean-François Prunet (eds.), *The special status of coronals: internal and external evidence*, 125–157. (Phonetics and Phonology Series). San Diego: Academic Press.

Steriade, Donca. 1987. Redundant values. In Anna Bosch, Barbara Need & Eric Schiller (eds.), *Proceedings of the Chicago Linguistic Society*, vol. 23, 339–362. Chicago: Chicago Linguistic Society.

Suzuki, Keiichiro. 1998. *A typological investigation of dissimilation*. Tucson: University of Arizona dissertation.

Trommer, Jochen. 2011. *Phonological aspects of Western Nilotic mutation morphology*. Leipzig: Leipzig University Habilitation thesis.

Tucker, Archibald N. 1994. *A grammar of Kenya Luo (Dholuo)*. Köln: Rüdiger Köppe.

Yip, Moira. 1989. Feature geometry and cooccurrence restrictions. *Phonology* 6(2). 349–374. DOI: http://dx.doi.org/10.1017/S0952675700001068