Precedence Graphs for Phonology: Analysis of Vowel Harmony and Word Tones.

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Contents

1 Introduction

The study of representations, their limits and capacities, is an indispensable part of the formal study of language. The representations are the limits of what can be stored and computed upon, and the details of a representation have a major influence on the details of any analysis.

More specifically the goal of this paper is to offer a lower bound of complexity for the phonological module. By exploring the capacities of a representation that I will argue requires fewer stipulations than anything offered so far, I will defend the claim that the freedom of this more powerful representation is just as powerful as morphology.

The ideas described in this paper are most obviously a development of the ideas expressed in Raimy (1999, 2000) in that it explores the full extent of the representational power of directed graphs in phonology, as the main data structure needed. But these ideas also draw from the insights of autosegmental phonology, particularly as it pertains to moving away from strings as a data structure and taking features to have an amount of independence from each others, forming independent autosegments. I also see this work as pushing the limits of underspecification theory, going as far as to suggest underspecification in linear order.

2 Precedence-Relation-Oriented Phonology

This section will introduce the theory of Precedence-Relation-Oriented Phonology (PROP). Because it derives mostly from the multiprecedence representation used in Raimy (1999, 2000), section 2.1 will summarize the theory of Multiprecedence and section 2.2 will distill the parts of Multiprecedence that will be used in the rest of this dissertation.

2.1 Raimy 2000

The basic point of departure that Raimy took away from standard phonology was to ask was what could happen if instead of using the string as our basic representation we used a structure with fewer stipulations: sets of pairs of segments in a precedence relation from the first to the second, bounded by a START point and and END point. He used this structure to derive morphophonological phenomena in a novel way that allowed him to account in a derivational theory for difficult phenomena in the interaction of regular phonology with reduplication and infixation. This section will cover the mechanics, some of the empirical facts that this representation could derive elegantly, and it will summarize some of the directions that have been explored by others working in Multiprecedence Phonology.

2.1.1 Precedence relations

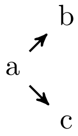
Consider a string like (1-a), the familiar way to think of what phonology operates over. An alternative way to encode that same information is in the form of a set of precedence statements like (1-b). For legibility the set of pairs in (1-b) can be represented in the form of a graph; adding the convention that of using # and % for the START and END symbols respectively we get the picture in (1-c). In general I will refer to this view as the **graph representation**.

(1) a. kæt
    b. $\{\langle START, k\rangle, \langle k, \text{æ}\rangle, \langle \text{æ}, t\rangle, \langle t, END\rangle\}$
    c. $\# \rightarrow k \rightarrow \text{æ} \rightarrow t \rightarrow \%$

The main difference between such a representation and a string-based one is that since the precedence pairs are all there is, there is no restriction as to what the set of them can be. For instance segments can be in precedence relations with multiple other segments as in (2), two segments can be in a precedence relation with each other as in (3), and segments can precede themselves as in (4).

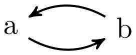
(2) a. $\{\langle a, b\rangle, \langle a, c\rangle\}$

b.



(3) a. $\{\langle a, b\rangle, \langle b, a\rangle\}$

b.



(4) a. $\{\langle a, a\rangle\}$

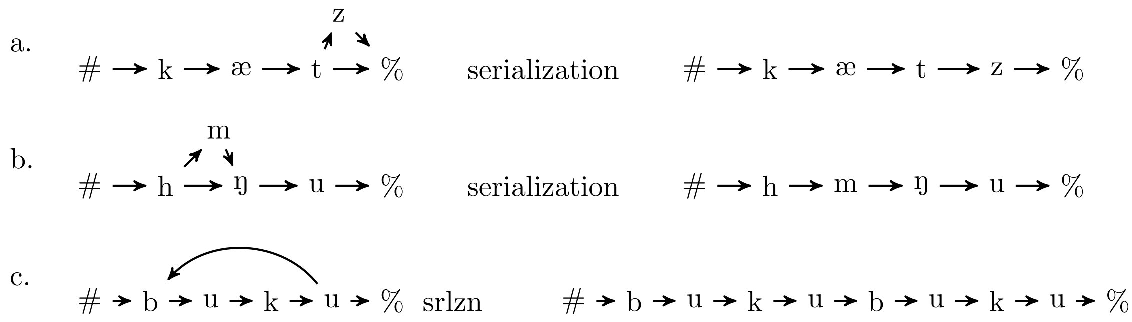
b.

In Raimy's system the geometrical possibilities of the representation end up carrying weight in describing the interaction of morphology and phonology. The goal of this paper is to show that the geometrical possibilities of multiprecendence go beyond loops and can serve to account for other phenomena of morphology and phonology.

2.1.2 Affixation and Reduplication

In this system all affixation involves adding precedence links and segments to a root. Suffixation looks like (5-a), which shows the English plural, and infixation like (5-b), which shows the Atayal animate action focus. Crucially, (5-c), which shows the Indonesian plural, is how to represent reduplication. All three of these structure have to be handled by a serialization algorithm, in order to be actualized by the motor system, which selects a path through the graph to be sent to the articulators. The details of such a serialization algorithm would take us too far astray, but the general intuition for now is that serialization attempts to traverse as many arcs of the graph as it can with as little redundancy as possible, hence why it follows the path with the affix in (5-a) and (5-b) rather than bypass it and why it takes the loop in (5-c) but does not loop more than once.

(5)



For Raimy, the multiprecedence structures on the left can be built either by vocabulary items or by readjustment rules specified to add structures like (6) to a root (7) to give the stem in (8). The moniker ”last segment” is an informal way to refer to that part of the affix that is responsible for attaching it to the stem in the right location. This was named a *sticky end* by Samuels (2009) and we will discuss this mechanism in 2.2.2.

(6) a. $\{\langle lastsegment, z\rangle, \langle z, \%\rangle\}$

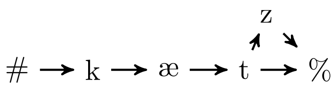
b. $lastsegment \rightarrow z \rightarrow \%$

(7) a. $\{\langle START, k\rangle, \langle k, \text{æ}\rangle, \langle \text{æ}, t\rangle, \langle t, END\rangle\}$

b. $\# \rightarrow k \rightarrow \text{æ} \rightarrow t \rightarrow \%$

(8) a. $\{\langle START, k\rangle, \langle k, \text{æ}\rangle, \langle \text{æ}, t\rangle, \langle t, END\rangle, \langle t, z\rangle, \langle z, END\rangle\}$

b.



Throughout his book, Raimy (2000) shows how this representation can generate a vast number of patterns from numerous languages as well as account for a number of over- and underapplication phenomena of phonology that McCarthy and Prince (1995) had claimed were not derivable in serial models.

Raimy also shows how multiprecedence is restrictive enough to predict the impossibility of some unattested patterns that competing theories can easily generate.

A crucial take-away of this theory is that according to it there is nothing special about reduplication as a morphological operation. Affixation is adding material onto a stem, and reduplication is the case where that otherwise unremarkable affixation creates a loop in the representation. There is therefore nothing morphologically or phonologically special about reduplication, except for the fact that the representation it creates has special effects due to its geometry. The link between the final /u/ an the intial /b/ in (5-c) is of the same nature as as the link between the /b/ and the /u/ that follows it. There is no special ”back arrow” symbol as suggested in Paschen (2018, p.3).

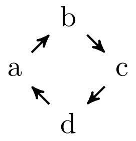
2.2 Detailed Mechanics

Before going beyond Raimy (2000), it is important that we take the time to examine the machinery of multiprecedence.

2.2.1 Start and End

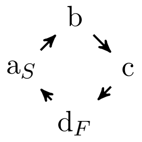
The Start and and End symbols are probably the most glaring difference between the graphs used so far and classical phonology based on strings. Those symbols are necessary in the multiprecedence model, because when loops are involved there is no way to know where to start without an explicit symbol. For instance in (9) it is impossible to decide where to start and end the loop; the only way is to mark segments as initial and final. There are multiple ways this could be done.

(9)



A simple way would be to directly mark it on the segments by augmenting the graph with a representation for initials and final states borrowed from Finite State Automatas as in (10).

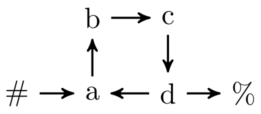
(10)



This makes it an information about the node itself whether or not it begins the word. One empirical problem with this approach is that the first and last segments of the out put form can change, e.g. through the addition of prefixes and suffixes.

Another possibility is to add a sort of empty segment as in (11).

(11)



This gets around the empirical problem, as material can be added between these empty segments and the overt phonological material of the stem.

One may be tempted to see this as a deficiency of the graph model, but phonological models based on strings also need boundary symbols, typically both marked with #, to which phonological rules may be sensitive. Even outside of the world of phonology having special start- and end-of-string characters are a common way to deal with strings in computer implementations of string, e.g. null-terminated strings in C. This is a case where multiprecedence is more explicit, not more complex. This is a distinction to which we will return in 2.3.1

2.2.2 Sticky-Ends

An important mechanic of Raimy's system is the *sticky end*, the part of the underlying form of affixes that allows them to attach onto a stem. The name "sticky-ends" is from Samuels (2009) and I will borrow it for this paper.

Sticky-ends are needed in this system for all affixes that attach to anything else than # or %. Because sticky-ends can attach to multiple roots, they cannot know in advance what segment they attach to, and as such they must specify their target intensionally through the target's feature and/or relation to other segments within the form.

For instance suffixes must be specified to precede %, but also to follow the last segment of the stem, as in (6) above. This is done through a sticky-end that picks out the last segment of a word. This can be defined intensionally by making the sticky-end seek a segment x satisfying the relation $x \rightarrow \%$. Thus (6) could be more properly represented as (12) with one sticky-end seeking a segment that precedes %, and one end that seeks %.

(12) $[\_ \rightarrow \%] \rightarrow z \rightarrow \%$

These sticky ends can also be specified to seek segments with particular features. Consider infixation in native roots in Tagalog as in (13)[1].

(13) Tagalog *um*-infixation (Kager (1999), citing French (1988))

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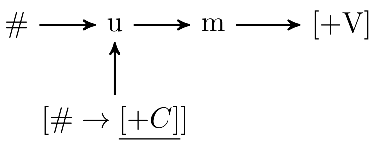
[1] Non-native roots, which may have onset clusters and have been reported to have variable realizations (e.g. Klein (2005), introduce some complications that would take us beyond the scope of this introduction.

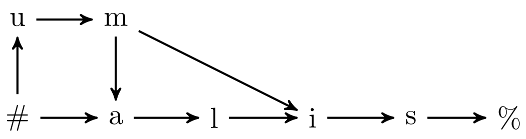
alis	um-alis	'leave'
tawag	t-um-awag	'rewarded'

This can be handled with the affix in (14). This affix has three ends. One simply targets the beginning of the word, then the sticky-end pictured to the right seeks segments that are vowels. And finally the sticky-end pictured at the bottom seeks segments that both follow the # and are consonants. Note that not every stem will have such a segment, e.g. vowel-initial roots, in which case that sticky-end will simply be unable to attach. This is in fact exactly what we see in the formation of *um-alis* in (15). The affix attached to # and to every vowel of the word, that is, it added an ordered pair between # and /u/, as well as an ordered pair between /m/ and each of the vowels of the stem. But there was no segment in the stem satisfying the conditions of the other sticky-end which therefore did not add any precedence pairs to the graph. The affix in (15) thus ends up following # and preceding /a/, because this order satisfies all the precedence relations stated in the graph, thus surfacing as a prefix.

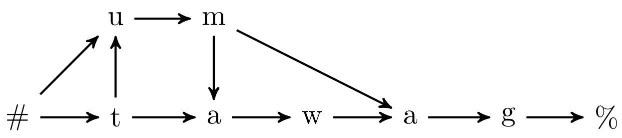
(14) Tagalog *um*-infix



(15) *um-alis*



(16) *t-um-awag*



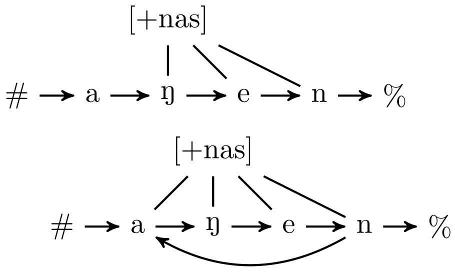
In the formation of *t-um-alis* in (16) on the other hand all ends of the affix manage to attach, adding a link from # to /u/, one from /t/ to /u/, and one from /m/ to every vowel of the stem. the affix -um- therefore ends up following /t/ and preceding the first /a/, because this order satisfies every ordering relation stated in the graph, and thus it surfaces as an infix between these segments.

I will use the square brackets for sticky-ends. This usage is closely related to the use of square brackets in classical phonological rules, in which forms like [+high, -back] are meant to capture not a segment, but a natural class, namely an intensional description. In fact the square brackets are ambiguous as they are also used to refer to segments. Here I will follow the convention of Bale et al. (2014) and reserve square brackets for intensional definitions (both in rules and in sticky-ends), and use curly brackets to refer to segments. Thus from now on, [+high, -back] refers the set of all segments that are supersets of the set {+high, -back}, whereas {+high, -back} refers to sets of features, namely segment.

2.2.3 Raimy (2000) is not PROP

Raimy's (2000) phonology contains more than the precedence relation introduced in 2.1. Raimy maintains autosegmental assumptions of layers of elements associated to each others, hence it relies on relation other than precedence. For instance the following isappears in his analysis of Malay nasal harmony.

(17) Autosegmental feature spreading in Raimy(2000,p.18)



2.3 Going Full PROP

2.3.1 Simplicity vs. graphics vs. power

I am claiming that the repsentational system in which (18-b) is represented contains fewer stipulations than one for (18-a). To understand this claim it is important to distinguish a) the fact that directed graphs are simpler than strings in the way mentioned above from b) the graphical conventions of our writing system that allows us to easily represent strings as left-to-right lists of symbols, and c) the richer set of structures allowed in graphs than

than in strings. a) is a mathematical fact about the properties of the data structure. Strings are graphs with a total order relation, namely the relation is total, transitive, and antisymmetric. A graph without these properties is a simpler mathematical object with fewer assumptions. It is true that thanks to b) we can represent strings in fewer symbols than graphs as in (18-a), but that is because our writing system implicitly packages all these stipulations, representing linear order in time as linear left-to-rightness on a the page. We should not allow this purely pictorial fact of writing to influence impressions about complexity. Strings do require a logical relation of precedence between pairs of elements as well as a notion of start and end; the graph notation is simply actually writing those down. The presence of arrows and special START and END symbols in (18-b) is explicitness, not complexity.

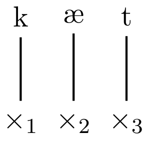
(18) a. kæt
b. # → k → æ→ t → %

And as said in c) it is true that we can do more with less stipulative graphs than with strings (since all strings are graphs but not vice versa). As seen above graphs can contain branchings, loops, and parallel paths that strings cannot represent. But this is representational power, not complexity. My claim is that talking about generic graphs rather than strings is making fewer assumptions about what phonology is and therefore it is a simpler claim. But one would be correct to think that that it is powerful. Simpler things often offer more possibilities. The point of this paper is to argue that this power matches very well with all the less string-like phenomena of phonology and morphology that are attested. This simpler-than-string phonology is powerful, and it seems to contain just the right power to do morphology.

2.3.2 complexity and power in phonological representations

It is already standard for phonology to be made more powerful than strings, thanks to autosegmental phonology, morphological planes, feature geometries, prosodic structures, and Optimality Theory correspondence relations. But all those approaches add this power by also adding stipulations to the representation, adding new relations, types, and restrictions, and therefore complexity in the above sense. For instance a representation like in (19-a) contains at least two types of relations: the more stipulative linear precedence relations between melodic segments and between timing slots, and the arcs connecting melodic segments and timing slots. This representation is at least as complex as (19-b-c), where P is the set of precedence statements and A is a set of autosegmental associations.

(19) a.

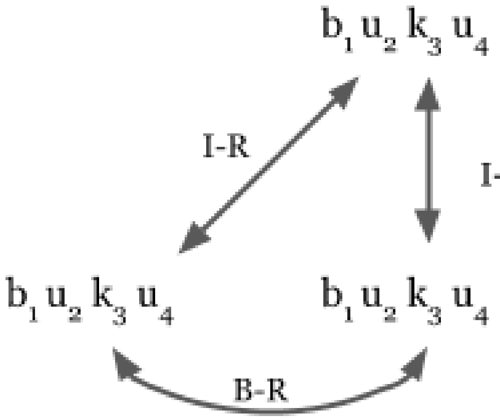


b. $\langle P, A \rangle$

c. $\langle \{ \langle START, k \rangle, \langle k, \text{æ} \rangle, \langle \text{æ}, t \rangle, \langle t, END \rangle, \langle START, \times_1 \rangle,$
$\langle \times_1, \times_2, \rangle, \langle \times_2, \times_3 \rangle, \langle \times_3, END \rangle, \},$
$\{ \langle k, \times_1 \rangle, \langle \text{æ}, \times_2 \rangle, \langle t, \times_3 \rangle \} \rangle$

Similarly a typical representation from Optimality Theory contains multiple types of relations between segments, including precedence and any graph-theoretic relations used above, but also the relations of correspondence including Input-Ouput (I-O), Base-Reduplicant (B-R), and sometimes Input-Reduplicant (I-R) . A basic reduplicated structure like (20-a) will therefore be computed over a representation as complex as (20-b) with a set of all the precedence relations in the input and output, the I-O correspondences, the B-R correspondences, and the I-R correspondences as a bare minimum, which can be expanded as (20-c), the actual representation over which correspondence theory needs to be computed (see Raimy and Idsardi (1997).

(20) a. OT correspondences



b. $\langle P, IO, BR, IR\rangle$

c. $\langle\{\langle START^{input}, b_1^{input}\rangle, \langle b_1^{input}, u_2^{input}\rangle, \langle u_2^{input}, k_3^{input}\rangle,$
$\langle k_3^{input}, u_4^{input}\rangle, \langle u_4^{input}, END^{input},\rangle, \langle START^{output}, b_1^{red}\rangle,$
$\langle b_1^{red}, u_2^{red}\rangle, \langle u_2^{red}, k_3^{red}\rangle, \langle k_3^{red}, u_4^{red}\rangle,$

$$\langle u_4^{red}, b_1^{base}\rangle, \langle b_1^{base}, u_2^{base}\rangle, \langle u_2^{base}, k_3^{base}\rangle,$$
$$\langle k_3^{base}, u_4^{base}\rangle, \langle u_4^{base}, END^{output}\rangle\},$$
$$\{\langle b_1^{input}, b_1^{base}\rangle, \langle u_2^{input}, u_2^{base}\rangle, \langle k_3^{input}, k_3^{base}\rangle, \langle u_4^{input}, u_4^{base}\rangle\},$$
$$\{\langle b_1^{base}, b_1^{red}\rangle, \langle u_2^{base}, u_2^{red}\rangle, \langle k_3^{base}, k_3^{red}\rangle, \langle u_4^{base}, u_4^{red}\rangle\},$$
$$\{\langle b_1^{input}, b_1^{red}\rangle, \langle u_2^{input}, u_2^{red}\rangle, \langle k_3^{input}, k_3^{red}\rangle, \langle u_4^{input}, u_4^{red}\rangle\}\rangle$$

As such, PROP representations like (21) are intended to be both more explicit about the information they contain, and simultaneously containing less information total.

(21) a. kæt

b. $\{\langle START, k\rangle, \langle k, \text{æ}\rangle, \langle \text{æ}, t\rangle, \langle t, END\rangle\}$

c. $\# \rightarrow k \rightarrow \text{æ} \rightarrow t \rightarrow \%$

In a way, the goal of this paper is to embrace the added power while rejecting the added complexity. All the phenomena that have led to doing phonology on graphs making a convincing case in favor of something more powerful than strings in phonology. But instead of gaining this representational power by adding machinery, I propose that we do it by relaxing the stipulations on the string machinery. If the limitations of strings can be circumvented either by adding complexity or by removing it, the latter is definitely a sensible direction to explore. Let's add power by simplifying.

2.3.3 THESIS: PROP is exactly what we need for language

The main thesis of this paper is this: the range of phenomena of morphology and phonology is exactly that which follows for free from the assumptions (or lackthereof) of PROP. The power of morphology and phonology reduce to the possible configurations of a PROP directed graph. The different geometrical configurations that a string cannot represent but that can be represented in PROP will capture exactly the range of non-concatenative morphology and non-linear phonology.

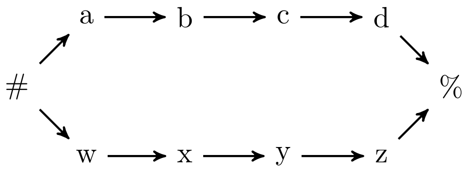
3 Tone and Harmony

In this section I will show that the representational power of PROP can derive phenomena of harmony and word-level tone from simple geometrical configurations made available for free by directed graphs.

3.1 Basic geometry

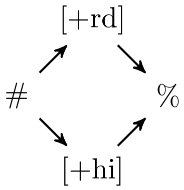
Expanding upon the representational possibilities of PROP, a geometrical pattern that can now exist is one containing separate streams, each of which contains phonological material. I will propose here that this representation is capable of accounting for tone spreading phenomena and harmony patterns.

(22)



For the case of graphs without loops like (22) in which the the relation described by the graph is a partially ordered set, I will refer to incomparable elements of the partial sets –those pairs x,y in the graph for which is is neither stated that x transitively precedes y nor that y transitively precedes x– as being in parallel. The assumption I propose to follow here is that parallel nodes can surface simultaneously as long as they are phonetically compatible, such that

(23) possible phonological form giving rise to surface {+rd,+hi}.



Intuitively, the claim is that the phonetic output of a graph like (22) is a surface form in which *abcd* is more or less coextensive in time with *wxyz*. The phonology does not transmit any ordering relation between the two to the articulators, and as such they are coextensive in time.

However coextensivity is too strong of a claim. A bit less restrictively, since the output of the phonology specifies nothing at all about the order it is up to the motor planning of the muscles involved in the realization of phonological material to produce an output that satisfies the input as they 'want'. In many cases the result will not be perfect simultaneity, as the motor movements of some features may be incompatible, or some motor movements faster or slower than others. If in (22) the features of *a* and *w* cannot be produced simultaneously, then one or the other will have to wait. We will come back to this discussion as we see more concrete examples.

3.2 basic examples

Since Leben (1973, 1978) nouns in Mende (Bantu) are commonly analysed as having one of five tone melodies, sequences of L(ow) and H(igh) tones, normally couched in Autosegmental Phonology[2].

(24)

pattern	σ	$\sigma\sigma$	$\sigma\sigma\sigma$
H	kɔ́	pɛ́lɛ́	háwámá
L	kpà	bɛ̀lɛ̀	kpàkàlì
HL	mbû	kényà	fémàlà
LH	mbǎ	nìká	ndàvúlá
LHL	mbǎ̂	nyàhâ	nìkílì

(from Odden, 1995)

The PROP analysis consists in seeing the tone melody as a parallel stream from # to %. This captures the notion of the independence of the tonal pattern from the segmental material behind the autosegmental analysis while using the simpler PROP representation. Intuitively we can see that once this type of graph is sent to the articulators, the segmental and tonal material are pronounced relatively independently.

(25) mbǎ̂

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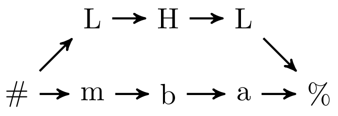
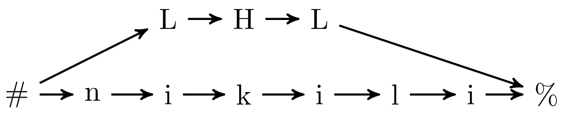
[2] Tones on a vowel V are notated as such:

- V́ = high tone
- V̀ = low tone
- V̌ = rising tone contour
- V̂ = falling tone contour
- V̌̂ = rising-falling tone contour



(26) nìkílì



All that the representation encodes is what precedes what. The melodic autosegments are ordered with regard to each others, and the tone autosegments are ordered with regard to each others, but the tones and the melodic autosegments are not explicitly ordered with regard to each others. What the representation says is that both of them must occur between # and %. This captures the relative independence of Mende tone patterns from their melody. This is enough to capture the set of contrasts in Mende. It is however *not* enough to completely derive the phonetics. For instance I have provided no explanation as to why none of the tones ends up surfacing on the /m/ of (25), which is perfectly plausible phonetically. We will come back later to how to add precedence information to a graph.

Beyond independence of some material, PROP also easily derives 'spreading' phenomena (here used in a descriptive sense). Consider Akan (Kwa) [ATR] harmony. The general pattern is for stems to be specified for [ATR] or not, which controls the form of both prefixes (27) and suffixes (28).

(27) Akan prefix harmony

	eat	be called
1s	mi-di	mɪ-dɪ
2s	wu-di	wʊ-dɪ
3s	o-di	ɔ-dɪ
1p	ye-di	yɛ-dɪ
3p	wo-di	wɔ-dɪ

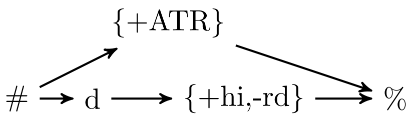
(28) Akan suffix harmony

wie	'to finish'
a-wie-i	'the end'
tɔ	'to fall'
a-tɔ-ɪ	'West'

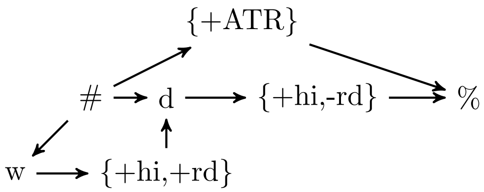
The forms in (27) show two roots that minimally differ in that the root for 'eat' is underlyingly +ATR and the root for 'be called' is underlyingly -ATR. The person agreement prefix agrees in ±ATR with the root. The forms in (28) show that the same harmony affects suffixes, demonstrated with the nominalizer.

This is easy to account for in PROP with roots specified for $[\pm ATR]$. For a root like eat (29) that is specified for $[+ATR]$ between and %, any prefix inserted between and the first segment will also be parallel to the $[+ATR]$ value ((30)).

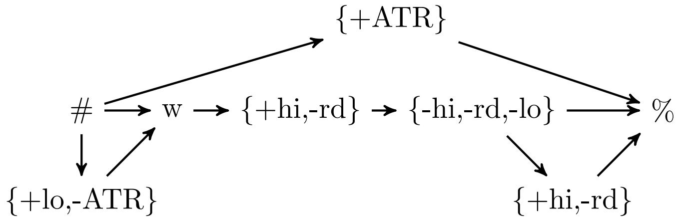
(29) $\sqrt{di}$



(30) wu-di



(31) a-wie-o



The reason the above graphs work is that the $[+ATR]$ feature, being specified only as following and preceding %, is parallel to everything that also occurs between those} symbols. In (30) we can see that there is a path from to % going via the $[+ATR]$ node and a completely separate path from to % going through the $[+hi, +rd]$ segment of the prefix. This gives us automatic bidirectional spreading.

Intuitively, the realization of this type of graph involves pronouncing a [+ATR] value throughout the word that will surface whenever it does not conflict with other features, e.g. those of the consonants. Motor planning is told to move the tongue root to produce [+ATR] in an event that follows the start of the word and precedes the end of the word. Since the two vowels are underlying underspecified for [ATR] the parallel [+ATR] value will surface during those. One can imagine each stream as a part in a musical ensemble. The $[+ATR]$ is "played" throughout on one part, while the other part "plays" the other segments. The analogy breaks when it comes to resolving conflicts between multiple streams. We will see how these are resolved.

It is worth noting that I am therefore defending a view of harmony patterns in line with Lightner (1965), what he calls harmony as a property of root-morphemes. It is a property of morphemes and their exact lexical specification that makes them cause harmony phenomena, not directly a property of the segments and features involved per se.

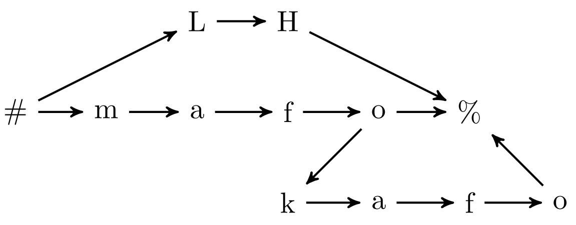
This simple type of spreading is more common with harmony patterns, but it is attested for tone patterns in James' (1994) analysis of Siane (Trans-New-Guinea) (cited in Cahill (2000)). In this language noun stems come with one of the tone patterns H, L, LH, HL, or HLH and the generalization is that the first tone is realized on the first syllable and the last one on the rest, including the suffixes. The exceptions are the case of HL words over four syllables in which case the two first syllables carry H and the rest L. and the case of bi-syllabic HLH words which seem to mostly surface HL-H rather than H-LH.

(32)

	noun stem	1p.poss.	defin	erg	gloss
H	kúlá	kúláté	kúlámá	kúlákáfó	’dog’
H	kétúfú	kétúfúté	kétúfúmá	kétúfúkáfó	’saliva’
L	mèinà	mèinàtè	mèinàmà	mèinàkàfò	’payment’
L	kòsìnà	—	kòsìnàmà	—	’sky’
LH	màfó	màfóté	màfómá	màfókáfó	’taro’
LH	kìlífú	kìlífúté	kìlífúmá	kìlífúkáfó	’trap’
HL	lónò	lónòtè	lónòmà	*lónókàfò*	’work’
HL	máfùnà	*máfúnàtè*	*máfúnàmà*	*máfúnàkàfò*	’owl’
HLH	kêfá	kéfàté	kéfàmá	kéfàkáfó	’meat’

The PROP analysis of this pattern combines the insights of Mende and Akan and starts with a parallel stream of tones for each root’s pattern with the suffixes added in parallel to those. The string of segments /mafokafo/ is being pronounced while the sequence of tone /HL/ is also being pronounced.

(33) màfókáfó



One may wonder why the contour tone is realized as it is with a low tone on one syllable and a high tone on three syllables. That is, why doesn’t the graph in (33) predict [màfòkáfó], with a low tone on two syllables and a high ton on the other two as in the HL case of [lónókàfò]. After all, if two tones have to be pronounced during four syllables, one could well think that they would get two tones each. However the formal system here makes no such claim. All that the graph says is that a sequence of tones /LH/ must be pronounced between the beginning and the end, and a sequence /mafokafo/ must be pronounced between the beginning and the end, nothing else. It might be that we need to formulate phonological rules that would add the required ordering relations, but ideally there is nothing more to say about how that happenes at the level of the phonology if it is resolved by phonetics and motor planning, acting without a notion of fairness towards the tone.

In other words I contend that the choice between all configurations of a sequence of /HL/ tones pronounced over four syllables is chosen for non-linguistic reasons in a motor-planning module. There are problems, such as how to get the tones to associate in the axact way they do. For instance why is the HLH form *kêfa* HL-H rather than H-LH *kèfǎ* The question of how this may be done is a topic for further research.

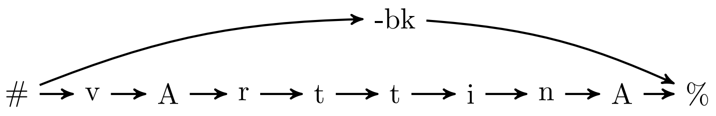
3.2.1 Transparent and opaque vowels

One assumption I made at the beginning of this section is that parallel segments are constrained by phonetic compatibility: two parallel segments will not be pronounced simultaneously if their features are incompatible. This is a bit loosely defined here, but it is this principle that allows me not to worry about vowel features and tones being pronounced during consonants in the examples above: if the consonant holds features incompatible with tone or vowel specifications, then those tones cannot be simultaneous to those segments.

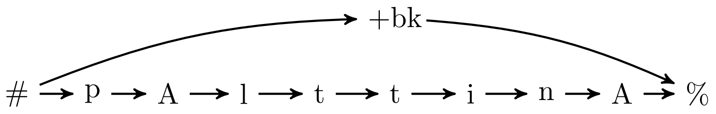
However one very strict and simple use of this principle is in the case of transparent vowels, vowels that are seemingly ignored by vowel harmony, where featural specifications of two segments in parallel can be explicitly contradictory.

Consider Finnish backness harmony as described in Hulst (1995). Roots are segregated into front vs. back, such as *värttinä* ‘spinningwheel’ vs. *palttina* ‘linen cloth’, which will surface respectively with front affixes, *värttinä-llä-ni-hän*, ‘with spinning wheel, as you know’, or back affixes, *palttina-lla-ni-han* ‘with linen cloth, as you know’. The underlying forms of these roots would be as in (34) and (35), where /A/ stands for a low vowel underspecified for backness[3].

(34) *värttinä*



(35) *palttina*



As expected the back feature will have ‘scope’ over suffixes and create

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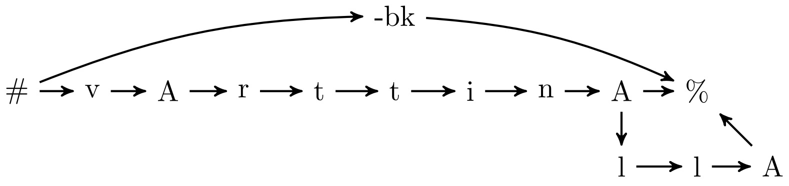
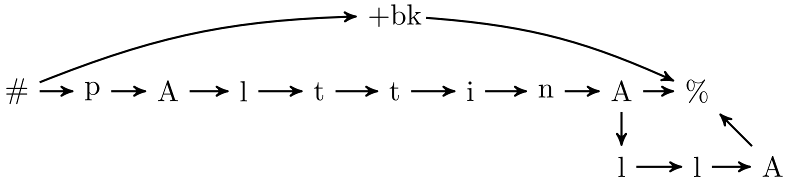
[3] I am not concerned here with the issue of underspecification, which may easily allow one of the two classes of Finnish words to be underspecified for backness and simplify the analysis.

the harmony pattern:

(36) *värttinä-llä*



(37) *palttina-lla*



Note that /i/ is unaffected by vowel harmony. This is easy to explain if we posit that Finnish /i/ is underlyingly -back. Because the +back autosegment and the -back /i/ cannot be coextensive, only one of them will surface at that point in time, here the segment's for a reason that will become clear.

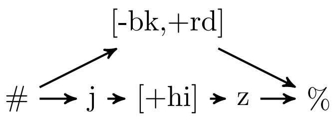
Now consider the case of opaque vowels, vowels that not only do not harmonize, but create their own domain of harmony. In the well known case of Turkish, vowels harmonize for backness and roundness, as shown in (38) with the genitive suffix *-in/-yn/-ɯn/-un*. The plural suffix *-ler/-lar* however assimilates only in backness. It is always -Round, but it is not transparent to roundness harmony; a genitive suffix following a plural suffix will surface as -round, regardless of the root and of how it surfaces in the singular genitive, as in the crucial case of *jyz-yn* vs. *jyz-ler-in* as opposed to **jyz-ler-yn*.

(38)

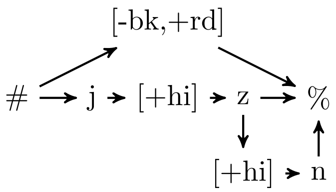
nom.sg.	nom. pl.	gen. sg.	gen. pl.	gloss
ip	ip-ler	ip-in	ip-ler-in	‘rope’
jyz	jyz-ler	jyz-yn	jyz-ler-in	‘face’,
kɯz	kɯz-lar	kɯz-ɯn	kɯz-lar-ɯn	‘girl’
pul	pul-lar	pul-un	pul-lar-ɯn,	‘stamp’

The PROP analysis of the roots and genitives is straightforward given what we have seen so far: the root must be specified to have parallel ± back and ± round features as in (39). The genitive is then added to such forms to give (40), and the underspecified vowel is pronounced with the values of the segment it is parallel to.

(39) $\sqrt{jyz}$

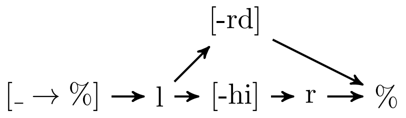


(40) *jyz-yn*

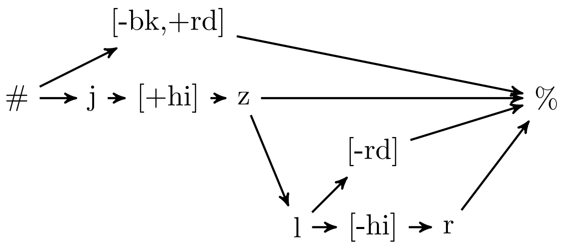


The plural introduces some complication: it contain a -round feature to ‘protect’ it from harmony as in the Finnish case above, but this -round feature must also be parallel as its roundness makes subsequent suffixes harmonize. It will therefore have the underlying form in (41), with its [–round] feature scoping over any further suffix. If affixed to a root $\sqrt{jyz}$ it will attach as in (42).

(41) *-lAr*

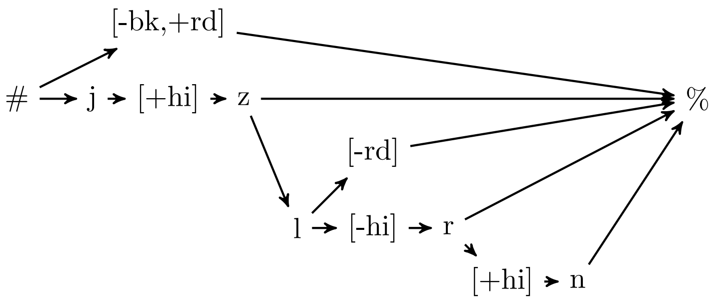


(42) *jyz-ler*



Finally to this form we can affix the genitive as in (43).

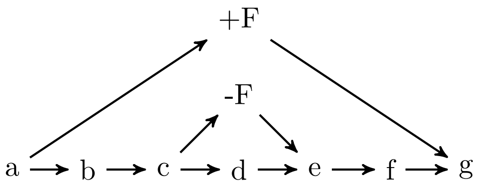
(43) *jyz-ler-in*



The graphs in (42) and (43) are starting to be complicated, but it is pretty straightforward: the [-bk,+rd] portion of the root emcompasses the whole form, and the [-rd] portion of the suffix encompasses everything after the /l/ of -lAr. But now we reach an issue of phonetic realization: at the point of pronouncing the [-hi] segment of the plural and the [+hi] segment of the genitive, these segments are parallel to *both* the [+rd] of the root *and* the [-rd] of the suffix, so why do they surface as [-rd]?

I propose that it is a general fact of the phonetic realization of parallel contradictory features that the "inner" one always wins. More precisely: if all the segments parallel to A are also parallel to B, but not vice versa, and A and B contain a feature with contradictory values then for the segments that are parallel to B it is B that will be pronounced in parallel. For instance in a configuration like (44), in which all the segments parallel to segment [+F] are also parallel to segment [-F] but not vice versa, it is [-F] that 'counts' during the segments parallel to -F, namely /d/, thus it will surface as in (45).

(44)



(45)

$$[\ \mathrm{a} \longrightarrow b_{+F} \longrightarrow c_{+F} \longrightarrow d_{-F} \longrightarrow e_{+F} \longrightarrow f_{+F} \longrightarrow \mathrm{g}\ ]$$

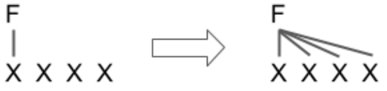
Importantly, the case of transparent segments discussed above is just the extreme case of this principle where there is no segment /d/ and the inner segment with a contrary feature surfaces on its own as in the Fiinnish example in (37). We therefore unify the 'independence' of transparent and opaque segments from harmony out of the same geometric principle. Or seen in another way opaque segments are nothing more than segments with both the property of having an 'inner' feature like a transparent segment, and the property of having this feature stretch to one edge of the word like a 'spreading' feature.

Ideally we should hope to derive this principle of phonetic realization independently, but this is beyond the scope of this paper.

3.3 Alternatives

One interesting aspect of this approach to vowel harmony and tone patterns is that it maximizes the use of representation in the explanation, as opposed to the existing approaches in terms of processes. Compare with an autosegmental analysis of harmony patterns requires an operation of spreading as in (46), which actively spreads a feature onto other segments, or a search-and-copy analysis which actively copies features from one segment to another as in the procedure copied from Nevins (2010) in (47).

(46)



(47) *Harmonic Search-and-Copy procedure, in two steps: (τ, δ, F)*

a. Find: $x =$ the closest τ to the recipient y in the direction δ

b. Copy: the value of F on x onto y, where x, y are segments, F is a feature, τ is a predicate over segments.

In contrast the parallelism analysis of vowel harmony and tone spreading presented here is representational and passive. Being pronounced across multiple other segments is a property of features being arranged in a specific way with regard to those segments. Harmony and tone 'spreading' as presented here are not *operations*, but at best terms of convenience for what are really patterns of representation.

3.4 Plugging-in

The parallel graphs in the preceding section were all underlyingly parallel, i.e. the underlying form of the root contained multiple streams. However we can define affixes that attach in parallel to a root.

3.4.1 Parafixes

I will use the terms *parafix* to refer to affixes added onto a stem in such a way that its segments are parallel to some or all the segments of the stem. The term has been used for instance in analyses of Semitic templatic morphology along the lines of McCarthy (1981) to refer to the morphological process that adds morphemes in parallel to CV templates. It is important to keep in mind that in the analysis here there is nothing different about the content of the affix itself or its affixation process that creates parafixation, but it is useful to distinguish the geometrical pattern created by adding material in parallel to other material.

For instance Nevins (2010, citing Akinlabi (1996)) discusses the example of Kanembu in which the completive is $[+ATR]$ and the incompletive is $[-ATR]$.

(48) Kanembu from Nevins (2010)

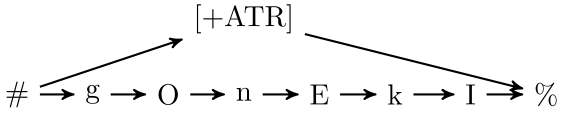
gɔnəkɪ	gonʌki	”I took / I am taking
dalləkɪ	dʌllʌki	’I got up / I am getting up’
barrɛnəkɪ	bʌrenʌki	’I cultivated / I am cultivating’

This can be accounted for in PROP with an affix like (49-a) attaching in parallel to roots underspecified for $[+ATR]$ as in (49-b) (where /O/,/E/,/I/ stand for segments underspecified for [ATR]), giving graphs as in (49-c) with a similar geometry as the Akan example above. We can see that affixes are in a way ‘plugged’ onto the graph of the stem.

(49) a. $/\# \rightarrow [+ATR] \rightarrow \%/$

b. $/\# \rightarrow g \rightarrow O \rightarrow n \rightarrow E \rightarrow k \rightarrow I \rightarrow \%/$

c.



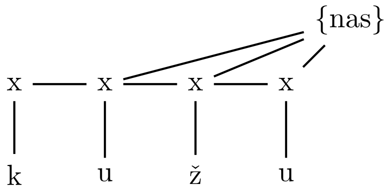
We saw in 2.2.2 that already for Raimy (2000) some affixes need to target segments other than at the edges of the form, e.g. for infixation and partial reduplication, by anchoring the affix to something other than # or %. As expected we can find cases where parafixes also target non-edge segments.

An important class of phenomenon that this kind of plugging in can easily derive is bounded spreading of certain features. Consider the regressive nasal spreading in Mixtec that Piggott (1992) calls a pseudo-harmony, triggered by the second person inflection.

(50) Mixtec regresive nasal spreading from Piggot (1992)

kũžũ	'you are diligent'
kĩʔvĩ	'you will be drunk'
kĩʔð̃ĩĩ	'you will get angry'
kaʔcẽ tã	'you will sing'
kotõ^{n}dɛ̃ɛ̃	'you will examine'
cikweʔcẽ	'you will complain'
koʔšõ	'you will fall'

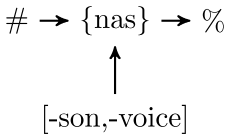
(51)



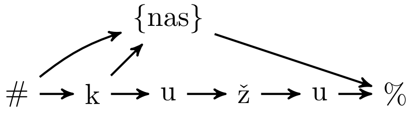
As shown in (50), the second person in Mixtec is marked by nasalization from the end of the word to the last voiceless obstruent. A straightforward autosegmental analysis of this pattern involves a second person suffix that spreads leftward until the a voiceless obstruent as in (51).

This can be handled in PROP with a second person affix underlyingly set to attach to voiceless obstruents as in (52). Note that the sticky-end here will seek *all* segments containing the features -Sonorant and -voice. When attaching to the root √*kužu* it will attach to the ends of the word, as well as to the /k/, thus the nas follows /k/ and precedes the end of the word, nasalizing everything in this span. In the case of √*cikweʔce* the resulting graph is more complicated, but the ordering relation is easy to interpret: the {nas} segment follows multiple consonants, but in particular it follows the last /c/ and therefore it will surface after it.

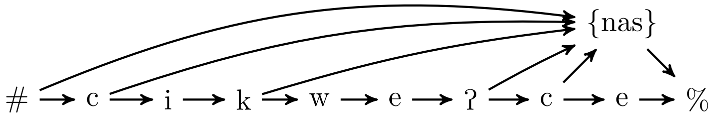
(52) Mixtec 2nd person affix



(53) kũžũ



(54) cikweʔcẽ



These very basic examples show that the power of PROP is at least sufficient to account for basic phonological patterns. The next section will push more on advantages of PROP over more traditional autosegmental accounts.

3.4.2 Tone Donation

The examples so far have been very basic phonological patterns that are also very well handled in autosegmental phonology. We will now turn to phenomena for which the PROP analysis is, I think, conceptually superior: cases where tones seem to need both a sort of independence from melodic content, and also some knowledge about linear order, giving rise to call the partial-independence problem: autosegmental theory allows only complete independence between autosegments or complete attachment. PROP on the other hand flexibly allows for intermediate levels of independence.

A relatively common phenomenon of tone phonology is donator morphemes. This phenomenon involves morphemes that contribute both a tone and segmental material, but the tone gets realized not on the segments it came with, but elsewhere on the final form, thus donating a tone to neighbours.

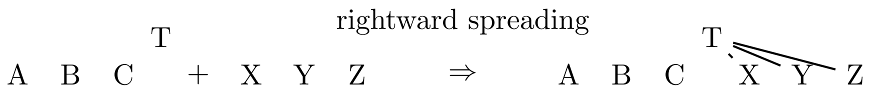
Consider KiYaka as described in Kidima (1991, p.19). Nouns that follow the class 7 prefix *kya* surface with a H tone on the stem-inicial syllable

(55) KiYaka donating tone

kya ndőongo	‘it’s of the needle’
kya ndoőngo	‘it’s of the palmwine’
kya zőba̋	‘it’s of the idiot’
kya ngoőmbe	‘it’s of the cow’
kya ka̋tíka	‘it’s of the liver’
kya he̋kó	‘it’s of the tsetse’

Before analysing this pattern it is worth bringing attention to a dangerous pitfall of autosegmental phonology when trying to deal with tone donation. Consider the abstract analysis in (56). It might look good at first, but it does not work: by autosegmental assumptions the tone /T/ and the segments /ABC/ it is floating over should be *unordered* with regard to each other. There is no sense in which /T/ could be to the right of /ABC/. illustrating /T/ slightly to the right of /ABC/ would be nothing but typesetting trickery.

(56) Bad autosegmental analysis of tone donation



A first lesson to draw here is a call back to the discussion in section 2.3.1 above: there is a danger to letting some important relations like precedence remain implicit in the representation, because then we might not realize when we are letting something back in where it shouldn’t be.

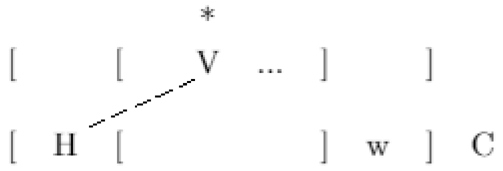
But to the point at hand, (56) cannot be the autosegmental analysis. Something has to force the floating tone to associate rightward.

Kidima’s analysis is with a process he calls H-Attraction (p.33) in (57).

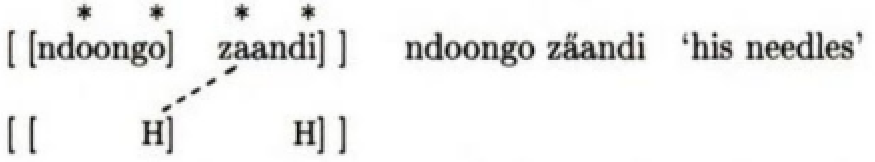
But it is not clear that this analysis should be allowed in autosegmental phonology. It requires a notion of floating tones being ordered with regard to material they are not associated with, which is obvious in examples such as (58) from Kidima (1990).

(57) Kidima's H-attraction rule

Associate a floating H to the first unlinked accented syllable to the right of its domain.



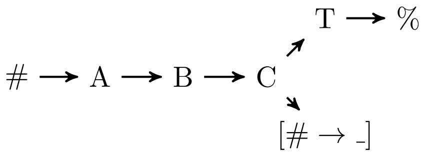
(58) Example of H-attraction from Kidima (1990)



What I want to argue from this example is that an analysis of tone donation needs a way to encode phonological material that is *both* relatively independent from other phonological material *and* linearly ordered with regard to it, simultaneously. Autosegmental representations can only have one or the other: two phonological tiers are either independent and unordered with regard to each other, or associated and ordered with regard to each other. There is no halfway.

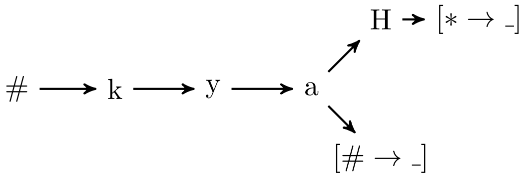
This is something that a PROP analysis does well. Consider the form in (59), which would accomplish what (56) purported to account for. Here I intend the notation [# → _] to stand for a sticky-end seeking a segment that has the property suchof following # (in the same way that traditional phonological rules use *A_B* to refer to a segment following A and preceding B). The advantage of this analysis is that it is possible to both maintain the independence of /T/ with regard to /ABC/, as well as order the two of them so /T/ is right of /ABC/.

(59) PROP version of (56)



With this kind of morpheme it is possible to account for the pattern in (55) as in (60)[4].

(60) KiYaka class 7 prefix



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[4] For simplicity's sake I omit here the fact that *kya* is taken by Kidima (p.19) to be a bi-morphemic combination of a class 7 prefix *ki-* and a morpheme *-a* whose role is unknown.

More complex phenomena of tone donation at long-distances are possible. And for this we will analyze the case of Digo in more details.

3.4.3 Digo Verbal Tonology

Digo is a language with complicated word- and phrase-level tone phenomena. The following analysis is based on the data from Kisseberth (1984), but the presentation does not go in the exact same order and does not address the historical justification for parts of the analysis.

Digo possesses two main kinds of roots, some that are are underlyingly toneless and some that have an underlying high tone. The two types can be exemplified with the infinitive form marked with *ku-*. As is common in Bantu language all indicative verbal forms have a final *-a* morpheme. The forms in (61) are toneless and the forms in (62) have an underlying high tone.

(61)

ku-changamuk-a	’to be cheerful’
ku-ambir-a	’to tell’
ku-dekez-a	’to spoil s.o.’

(62)

ku-furukŭt-â	‘to move restlessly’
ku-arŭk-â	‘to begin, start’
ku-bomŏr-â	‘to demolish’

(63)

ku-dunduríz-a	‘to place in reserve’
ku-furíz-a	‘to apply heat’
ku-koróg-a	‘to stir’

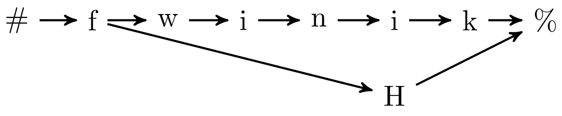
The presence of a high tone can manifest itself in one of two ways at the surface as seen in the difference between the rising-falling pattern in (63-a) vs. the high-low pattern in (63-b). This difference is predictable: the high-low pattern occurs when the final consonant of the root is a voiced obstruent (depressor consonant) and the rising-falling pattern occurs elsewhere. We can also observe the underlying unity of the two patterns for forms in which a suffix is added to the root and the final consonant is thus not from the root. The derivational extension suffix -ir for instance can be added to toneless roots without adding any new tone as in (64-a). When added to a high-toned root ending in something other than a voiced obstruent the tone occurs shifted onto the extension as in (64-b). Finally when added to a form ending in a voiced obstruent, the tone is also shifted, but it now takes the form that we expect from a form ending in something other than a voiced obstruent.

(64)	a.	ku-vugur-a	‘to untie’
		ku-vugurir-a	‘to untie for/with’
	b.	ku-fwinǐk-â	‘to cover’
		ku-fwinikǐr-â	‘to cover for/with’
	c.	ku-bundúg-a	‘to pound’
		ku-bundugǐr-â	‘to pound for/with’

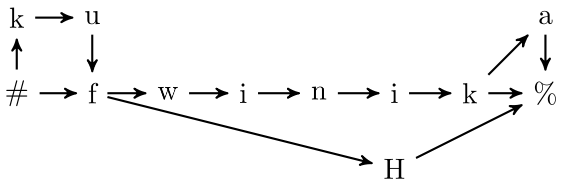
We can therefore conclude that all high-toned roots are underlyingly the same and a late effect causes the difference between the rising-falling and the high-low pattern to arise.

Underlyingly high-toned roots come with a H tone as in (65). Adding suffixes as in (66) and (67) puts them within the 'scope' of the high tone.

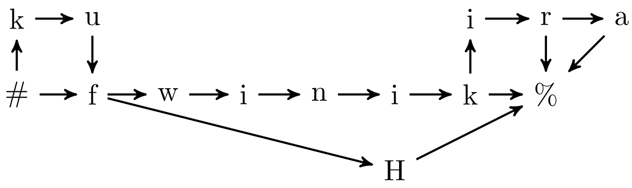
(65)



(66)



(67)



A process must then be responsible for narrowing down the H tone to the end of the word so as to create the high-low vs. rising-falling patterns (as in the Siane case in (33)). The details of this process do not matter much for the present discussion, but one possibility is to take advantage of the fact that voiced obstruents in Digo can be argued to carry an L tone, as is common throughout Bantu. If this is the case, and given a late process making tones that precede the end of the word precede the final vowel, the difference between the two final patterns can be ascribed to the difference between the schematic forms (68) and (69).

(68)

$$\begin{tikzcd}
 & & H \arrow[dr] & & \\
\cdots & V \arrow[r] & C \arrow[r] & a \arrow[r] & \%
\end{tikzcd}$$

(69)

$$\begin{tikzcd}
 & & H \arrow[dr] & & \\
\cdots & V \arrow[r] \arrow[dr] & C \arrow[r] & a \arrow[r] & \% \\
 & & L \arrow[ur] & &
\end{tikzcd}$$

Pushing the idea that motor planning can do part of the explanation, here is a simple account of this final pattern that follows from event timing. In (68) H must precede /a/. This can be done with the H pronounced with a peak on the consonant, which will mostly surface as rising-falling on the neighbouring vowels as in (64)[b]. But in (69) the H cannot be simultaneous with the consonant, as this consonant must already be simultaneous to a L tone, and it cannot be pronounced any later as it must precede the final -a, so it pronounced to peak earlier on the vowel, resulting in the high-low pattern of (64)[c]. This analysis is obviously very speculative. Again this is a promisory note, with the hope that phonetics can do part of the work for us without having to totally specify the linear order of segments.

The evidence that this process is late is that the final patterns can actually surface on a following noun in Verb-Noun VPs. A full analysis of full VPs would take us to far astray.

(70)

ku-onyěs-â	‘to show’
n-jira	‘path’
ku-onyes-a n-jĭrâ	‘to show the way’

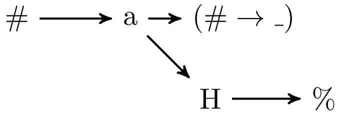
One thing worth appreciating here is that PROP allows such a thing as an analysis that is temporarily vague about the ordering of its material. A root can be introduced with an H between the beginning and the end, i.e. anywhere in the form, and remain incompletely specified until other affixes are added, after which a late process will narrow down the H tone to the end of the word (as opposed to having the whole form surfacing with a high tone as in the Mende and Siane examples discussed above). In a sense PROP brings underspecification to ordering. It is a theory in which order can be underlying underspecified.

Digo also has object prefixes and the plural object prefixes come with a H tone that surfaces at the end of the word. In the case of underlingly toneless words these forms surface with the same tone pattern as verbs whose roots have an underlying H tone as shown in (71).

(71)

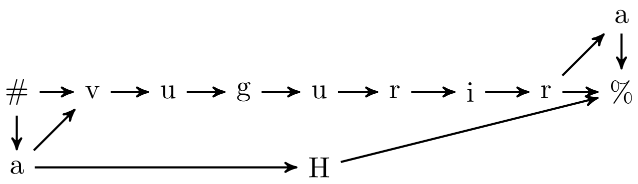
ku-vugurir-a	‘to untie for’
ku-ni-vugurir-a	‘to untie for me’
ku-ku-vugurir-a	‘to untie for you s.g’
ku-mu-vugurir-a	‘to untie for him/her’
ku-u-vugurĭr-â	‘to untie for us’
ku-a-vugurĭr-â	‘to untie for you pl.’

(72) Digo 1pl. object



The affix in (72) will attach to the root and also contribute an H tone parallel to the whole verbal complex. Assuming that the -*a* suffix is added first, at the point in the derivation after affixing the plural the stem looks like (73), very similar to the forms with a root H pictured above.

(73)



Interestingly, when this affix is added onto a root that does have an underlying H tone, the result is as one would expect from a word with a single of either of these tones. For instance the root *puput* has a high tone, as we can see in (74-a-d), since we saw in (71) that these object prefixes do not contribute a tone, so these tones must come from the root. But we also saw in (71) that the *u*- and *a*- object prefixes do contribute a tone, and yet the surface tonal shape of the word is unchanged.

(74)

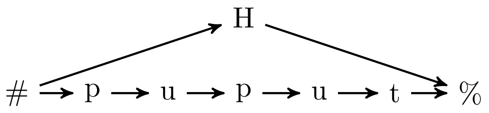
a. ku-pupŭt-â	'to beat'
b. ku-ni-pupŭt-â	'to beat me'
c. ku-ku-pupŭt-â	'to beat you sg.'
d. ku-mu-pupŭt-â	'to beat him/her'
e. ku-u-pupŭt-â	'to beat us'
f. ku-a-pupŭt-â	'to beat you pl./them'

A way we can conceive of what is going on for the sake of the discussion is that the tone contributed by the prefix is 'redundant': it will surface when it is alone in the form, but when added onto a graph that already contains a H tone it will not add to it.

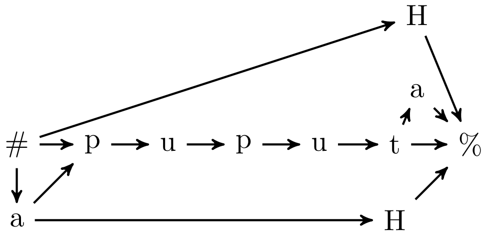
This follows from the way the object affix has been specified in (72) and from how H roots are encoded in (65). The root $\sqrt{puput}$ is as in (75). Once affixed with the verbal suffix and the object prefix, there is a step in the derivation where the form looks like (76). In this picture, the H on top of the image is the one contributed by the root. The one at the bottom is the one contributed by the object prefix. We can see that they run parallel to each other, which given the assumptions so far implies pronouncing them at the same time. Reasonably, since they are the excact same feature, for the segments that are parallel to both this is identical to having a single

H tone in the form, hence we derive that multiple H tones would have a 'redundant' behavior. And since both H's precede the end of the word, they will be equally targeted by the late process narrowing down the H tone to the end of the word.

(75) $\sqrt{\textit{puput}}$



(76) 2pl.obj+$\sqrt{\textit{puput}}$+mood



There are other sources of H tones in Digo verbs. An important one is subject prefixes, which appear outside of the tense prefix.

(77) Digo indicative verbal template

Subj.-Tense-(Obj.)-Root-a

(78)

a.	ni-na-tsukur-a	‘I am taking’
b.	ni-na-mu-tsukur-a	‘I am taking him/her’
c.	a-na-tsukǔr-â	‘he/she is taking’
d.	a-na-mu-tsukǔr-â	‘he/she is taking him/her’

As we can see in (78), $\sqrt{tsukur}$ is a toneless root and the singular third person subject prefix *a-* (as well as the third person plural *ma-* as we will see in (80)) carries a high tone that is realized as the now familiar final pattern, just like the first and second plural person prefixes *u-* and *a-*. We can therefore anticipate the underlying form of the third person subject prefixes to contain a similar donating H tone. However an interesting behavior arises when these new prefixes are added to a form that already has a H. Consider (79) which completes the paradigm in (78).

(79)

e.	ni-na-a-tsukǔr-â	‘I am taking them’
f.	a-na-á-tsúkúr-â	‘he/she is taking them’

(80)

a.	ni-na-pupǔt-â	‘I am beating’
b.	u-na-pupǔt-â	‘you sg. am beating’
c.	a-na-púpút-â	‘he/she am beating’
d.	tu-na-pupǔt-â	‘we are beating’
e.	mu-na-pupǔt-â	‘you pl. are beating’
f.	ma-na-púpút-â	‘they are beating’

The form in (79-f) shows that when both the subject prefix and the object prefix contribute a tone, all vowels between the tense prefix and the final vowel surface as H. Similarly we know from (74) that $\sqrt{puput}$ has an underlying H that surfaces without any of the tone-bearing prefixes, but (80) shows that with one of the third person prefixes the form also surfaces with all vowels between the tense prefix and the final vowel as H. The tense prefix *ka-* also behaves this way. (81) shows *ka-* on root we know to be toneless from (78) and (79). (82) shows what happens when *ka-* is prefixed to a root bearing a high tone.

(81)

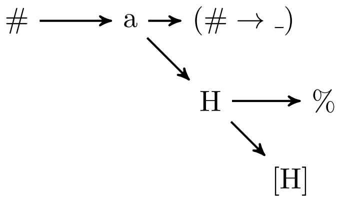
ni-ka-tsukǔr-â	‘I have carried’
u-ka-tsukǔr-â	‘you sg. have carried’

(82)

ku-kumbukǐr-â	‘to remember’
ni-ka-kúmbúkír-â	‘I have remembered’
u-ka-kúmbúkír-â	‘you sg. have remembered’

This new tone is therefore clearly not ‘redundant’ in the way I labelled the behavior of the tone of the object prefix. The tone of this new prefix, to the contrary, supplements whatever tone the stem already carries. Let us call this tone ‘supplementary’. We can characterize the behavior of this class of prefixes with ‘supplementary’ tones with underlying forms like the following.

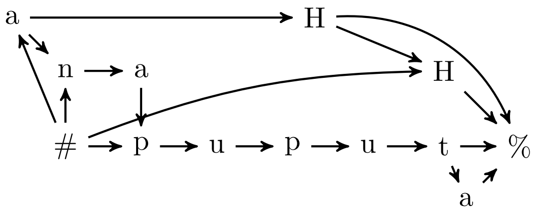
(83) Digo 3rd.sg. subject



This form only minimally differs from (72) in that it has an additional sticky end that seeks H tones if there are any. The result of this is that for a stem without any H tone, adding (83) will create the familiar pattern, but when added to a form that does contain a H of any origin, this new H has to precede it.

Consider the derivation of forms with a H tone from the root and one from a subject prefix as in (80)[c]. It starts with the root of $\sqrt{pupu t}$ as in (75) to which the tense and subject prefix are added, resulting in (84).

(84) 3s.subj+present+$\sqrt{puput}$+mood

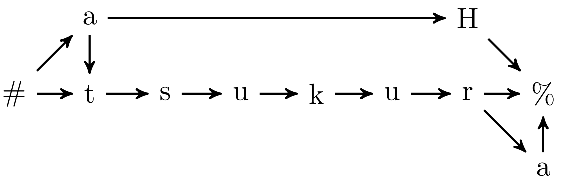


The graph in (84) crucially differs from (76) in that now the two H tones are not parallel anymore: the H introduced by the subject pronoun precedes the one from the root. As a result one H does not directly precede the end of the word. If the process restricting the pattern of tones to the end of the word is sensitive to this difference (e.g. targeting H that only precede % and nothing else) it follows that this H will not surface as one of the two final patterns, rising-falling or high-low, and it is expected that it will be realized on a greater portion of the word.

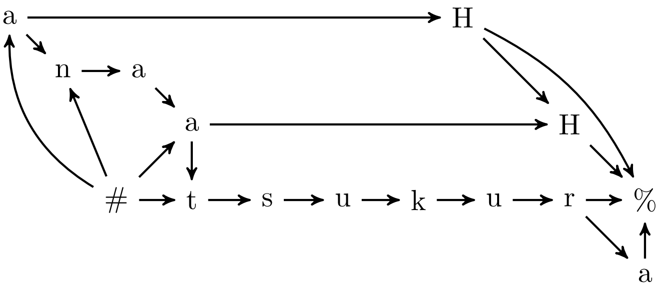
Simiarly the derivation of (79)[f] will start with the toneless root in (85), to which we add the 3p prefix as in (86), and the tense and subject prefixes as in (87). As in (84) we have a form where one of the H tone precedes the other, and hence will not be affected by the process restricting it to the end of the word.

(85) $\sqrt{tsukur}$

(86) 3p.-$\sqrt{tsukur}$-a



(87) 3s-pres.-3p-$\sqrt{tsukur}$-a



The only thing missing from (84) and (87) is something to restrict the non-final H to after the tense prefix. This could be as simple as a phonological rule adding a precedence link from the tense prefix to the H tones of the word. A plausible way to obtain this is to assume that the is a natural boundary after the object prefixes, in the form of a phonological cycle or a phase boundary, such that the subject prefix, the root and the mood suffix form a natural unit that the non-final H can target. Kisseberth (p.129) does argue in favor of such a unit which he calls the verbal complex. In any case this would manifest itself here as a precedence link from the tense affix to the tone added at some point in the derivation. I will not dwell into this aspect of the Digo tonology.

More interesting is the right-hand boundary of the 'supplementary' tone. Although the forms in (79) and (80) suggest that the 'supplementary' tone extends over the whole verbal complex, the data in (88) shows that it is more complicated than this. Crucially the tone does not extend to the right of voiced obstruents. Recall that in forms above the ‘supplementary’ tone spreads to the penultimate vowel and changes final rising-falling, which does not happen in (88).

(88)

a-na-gurǐr-â	‘he/she is buying for’
a-na-á-gurǐr-â	“he/she is buying for them’
a-na-demurǐr-â	‘he/she is scolding’
a-na-á-demurǐr-â	‘he/she is scolding them’

a-ka-ézěk-â	‘he/she has thatched’
a-ka-wézěk-â	‘he/she has enabled’
a-ka-súrúbǐk-â	‘he/she is strong/firm’
a-ka-ú-tógǒr-â	‘he/she has praised us’

There is a very natural way to describe what is going on here: the ‘supplementary’ tone of the tense *ka-* and the subject prefixes *a-* and *ma-* must precede voiced obstruents. The tricky part is that is that this seems to be true only when this tone is ‘supplementing’ another, not when it is the only tone of the word. E.g. in (89) the tone causes the regular final pattern despite it following a voiced obstruent.

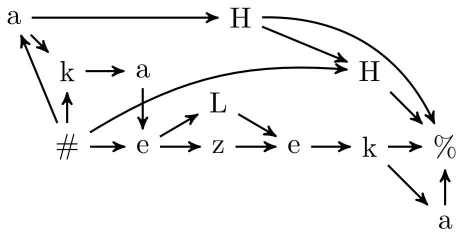
(89)

ku-togor-a	‘to praise’
ni-na-togor-a	‘I am praising’
u-na-togor-a	‘you sg. are praising’
a-na-togŏr-â	‘he/she is praising’
ma-na-togŏr-â	‘they are praising’

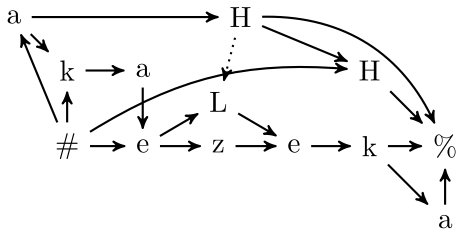
Given the assumption above that voiced obstruents have a L tone I propose that a phonological process like (90) is responsible for this, which adds a precedence link from an H to voiced obstruents if this H precedes another. Thus the form built in (91-a), similar to the form in (84), undergoes this process to give (91-b), with its ‘supplementary’ H restricted to precede /z/, or more accurately .

(90) If an H precedes an H, make the former also precede all L’s in the form.

(91) a.



b.



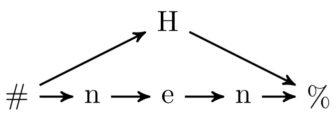
Consider now the exceptional behavior of some monosyllabic roots. Kisseberth notes that unlike polysyllables for which there are two behaviors, captured so far by positing H roots and underspecified roots, there are three behaviors for monosyllables, whose difference is visible when comparing the infinitive to the extended form. There are monosyllabic roots with the regular unspecified pattern as in (92-a), roots with the regular H tone pattern as in (92-b), and roots that are low-toned in isolation, but show the H tone pattern when the extension is present as in (92-c).

(92) Digo monosyllabic verbal roots

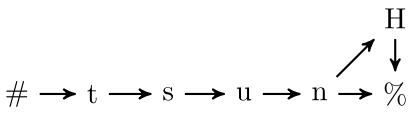
a.	ku-rim-a	ku-rimir-a	‘to cultivate’/‘to cultivate for’
b.	ku-nĕn-â	ku-nenǐrâ	‘to speak’/‘to speak for’
c.	ku-tsun-a	ku-tsunǐrâ	‘to skin’/‘to skin for/with’

One way to deal with this is to treat these cases as an instance of tone donation as San Miguel El Grande Mixtecan in the previous section, except here roots are donating. So while the regularly-behaving monosyllable roots have the form in (93), the roots whose H tone only appears on suffixes have a form like (94).

(93)

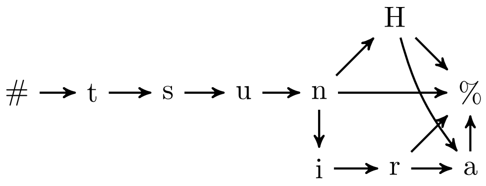


(94)



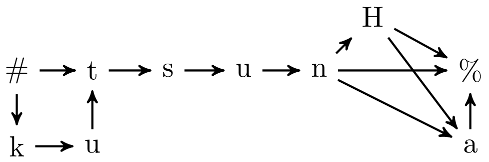
These forms, once suffixed with the extension *-ir* and the verbal suffix *-a* will surface with the expected final pattern

(95)



But without an extension the form will end up looking like (96). Given the reasonable assumption that H cannot be pronounced without being parallel to some vowel or consonant, the tone a form like (96) will not be able to surface phonetically, since H must follow /n/ but precede /a/.

(96)



And this concludes the analysis of Digo verbal tonology. We see that given PROP assumptions it is possible to make sense of complicated tone patterns like those of Digo. The analysis involves root which may contain an H from # to % or not, as well as donator prefixes. These donator prefixes are of one of two kinds, adding either a tone in parallel to tones already in the form, or adding them preceding other tones, giving rise to the ‘redundant’ and ‘supplementary’ patterns of behavior.

3.5 Summing up

The analyses in this paper brought us to recast a number of basic patterns and discover a number of principles. The account of parallel features developed here re-conceptualizes vowel harmony as a representational phenomenon involving features whose lexical entries make them span multiple segments. We also now have the simple but powerfully general nesting principle according to which incompatibility among features with incompatible features will be won by the ‘inner’ one, which we saw at work as an explanation of both transparent and opaque segments, and which we can hope to derive from more basic principles of motor planning organisation. We have a superior understanding of donator morphemes now that the representation allows features to be simultaneously independent and ordered with regard to each others, while autosegmental phonology allows only one or the other. And finally we have a novel understanding of Bantu depressor consonants that carry low tones and of how they may effect the phenomena we observe.

4 Conclusion

The goal of this paper was to explore the additional power granted by a representation like Multiprecedence, distilled to only precedence. We saw that the additional geometric freedom at our disposal allows us to account for a number of phenomena of vowel harmony and word tones, through the use of parallel streams of segments.

The gamble of PROP is that that all phenomena of non-concatenative phonology can be handled with it, and a careful study of these will therefore have to be done to complete the claim of this paper. Several challenges await, such as the issue of combining the analyses of harmony that take it for granted that the graphs of phonology are acyclic with the fact that this analysis was founded on positing cyclic graphs to handle reduplication.

An indispensable element missing from this analysis is a theory of phonetic implementation that can handle such structures and manifest all the assumptions I have made about it already.

However I hope that the analyses offered here gave hope that the PROP thesis is tenable and deserves attention.

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