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Phonetic linearisation of morpheme-internal phonological structure*

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ABSTRACT. This paper argues how phonological structure, which consists of head-dependency (asymmetric) relations between categories, phonetically manifests itself in the context of Precedence-free Phonology (Nasukawa 2014, 2017abc, Nasukawa and Backley 2015). In this model, as discussed in the syntax literature (Kayne 1994; Cinque 1993; Kural 2005; Abels and Neeleman 2012, Tokizaki 2013, 2018; Toyoshima 2013), precedence is solely the natural outcome of interpreting the head-dependency relations that hold between categories in hierarchical structure. In the case of English, for example, dependents (which display greater salience in terms of the degree of their carrier-signal modulations) manifest themselves first while heads (which are less salient) are phonetically externalised second at all levels of morpheme-internal phonological hierarchical structure. The mapping process for linearisation takes place at the highest head-dependency level, then moves down successively through the lower levels in a given structure.

Keywords: linearisation, head-dependency, prominence, precedence, Precedence-free Phonology

1. Mapping of linguistic structure onto phonetic outcomes

The phonetic externalisation of linguistic structure must be explained in terms of (i) quality, (ii) strength and (iii) precedence. Quality generally concerns contrastiveness in segments, which is typically expressed by *features* or other attributes of segmental structure. For example, features contribute phonetic properties such as frication or nasality. Strength refers to the strong-weak relation between units of all kinds. In stress assignment patterns, for example, one vowel is often said to be stronger than another vowel in the same domain. Precedence denotes the order in which units are phonetically realised. This remains an unresolved issue in the field of syntax, since precedence relations are not formally expressed in syntactic structure. To shed light on this issue, many different approaches to the linearisation process have been proposed (Kayne 1994; Cinque 1993; Kural 2005; Abels and Neeleman 2012, Tokizaki 2013, 2018; Toyoshima

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2013). In the study of morpheme-internal phonological structure, on the other hand, very few discussions on linearisation are to be found, even though linear ordering is considered to be an inherent characteristic of phonological structures, and thus, a fundamental issue in phonology.

Among the above three aspects of phonetic externalisation, the first two have been discussed widely in the phonology literature: for 'quality', the reader may refer to Kaye, Lowenstamm and Vergnaud (1985), Anderson and Ewen (1987), Harris (1994, 2005), Clements and Hume (1995), Harris and Lindsey (1995, 2000), Ewen and van der Hulst (2001), Backley (2011), Duammu (2016); and concerning 'strength', there are treatments in edited volumes such as Brandão de Carvalho, Scheer and Ségéral (2008) and Nasukawa and Backley (2009). By contrast, little work has been carried out on 'precedence' at structural levels lower than morphology; for this reason the present paper addresses the issue of linearisation (precedence relations).

The following discussion takes Precedence-free Phonology (PfP: Nasukawa 2011, 2014, 2015, 2016, 2017abc; Nasukawa and Backley 2015, Forthcoming) as its theoretical base. Unlike other theories of phonological representations (but like most syntactic theories), PfP assumes that no precedence relations between phonological units are specified in a structure. Rather, the linear ordering of segments, morphemes and words is a by-product of the phonetic externalisation of head-dependency relations between linguistic units (Nasukawa 2011; cf. Takahashi 2004). Focusing on morpheme-internal phonological structure (rather than on syntactic structure, which is addressed frequently in the relevant literature), this paper will argue how hierarchical structure is mapped onto a phonetic outcome consisting of linearly organised units.

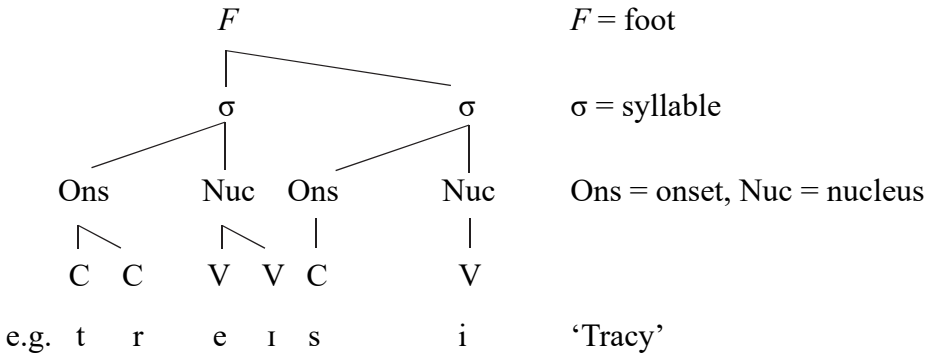
The structure of this paper is as follows. First, section 2 discusses the kind of phonological structure which is employed in the PfP approach to phonological representation, where the phonological component is presented as a strictly mono-stratal model. Then, focusing on morpheme-internal structure, section 3 argues how hierarchical structure comprising head-dependency relations is linearly externalised in the context of PfP. The discussion ends in section 4 by addressing the issue of 'contour' expressions, which are regarded as a means of improving the perceptibility of stops containing more than one specification for resonance. It is proposed that a 'contour' realisation makes multiple place cues more accessible to listeners.

2. Head-dependency relations in morpheme-internal phonology

2.1 A general view

Although variation exists between different theories, phonological structure within a morpheme is generally considered to show the following organisation.

(1) Morpheme-internal phonological structure



Segments are divided into two broad categories, consonants (Cs) and vowels (Vs), and the syllable constituents typically associated with these categories are *onset* (Ons) and *nucleus* (Nuc), respectively. A set formed by combining these constituents is referred to as *syllable* (σ). Two syllables then form another set called *foot* (*F*).

Like structures in other domains of linguistic structure, it is generally accepted that a set exhibits head-dependency relations between its constituents (Selkirk 1978, 1980; Anderson and Ewen 1987; Kaye, Lowenstamm and Vergnaud 1990; Harris 1994, 1997). Within a syllable, the nucleus is considered to be the head (as indicated by a vertical line) since it is obligatory, whereas the onset is optional (as shown by a slanting line). On this basis, therefore, a syllable appears to be a right-headed structure. (At this point, the term 'right' is used merely as an informal descriptive label.)

As depicted in (1), the right-headed structure is allowed only at the syllable level; at other levels, structures are left-headed. Unlike at the syllable level, there are no mandatory/optional relations between constituents within a foot, within a branching onset, or within a branching nucleus. Therefore, another means of determining head-dependency relations is needed here. One way of establishing structural head-dependency relations is to refer to differences in phonetic salience between constituents. In the case of English, for example, salience may be associated with the stronger energy found in stressed vowels (cf. their unstressed counterparts). And if this salience is automatically linked to head-dependency relations, then presumably this is done by assuming that the head has greater salience/energy than the dependent, which is

optional and may be targeted by phenomena such as vowel reduction (cf. Anderson and Ewen 1987, at passim).[1]

In phonology there is a tendency to equate sound energy with the sonority hierarchy: the more sonorous a segment is, the more prominent (stronger) its acoustic energy will be (Nasukawa 2017b: 129). On this basis, at the foot level a stressed syllable (leftmost in (1): /treɪ/ of /ˈtreɪ.si/) is deemed the head while an unstressed syllable (rightmost in (1): /si/ of /ˈtreɪ.si/) is the dependent. The same applies in a branching nucleus: the first member /e/ of the branching nucleus /eɪ/ in (1) is recognised as the head since it is typically more sonorous than the second member /ɪ/.

Branching onsets such as /tr/ are also assumed to be left-headed. In this case, however, the head /t/ in (1) is actually less sonorous than its dependent /r/. An explanation is therefore needed for why a branching onset patterns differently from a branching nucleus and a binary foot in terms of its head-dependency relations. Furthermore, we need to explain why the syllable constituent is right-headed (unlike the foot, the branching nucleus and the branching onset), even though the vowel in its head (nucleus) position is more sonorous than the consonant in the dependent (onset) position.

This state of affairs goes against current linguistic thinking, which favours generalisations over idiosyncrasies when it comes to characterising different levels/domains of the grammar. Following current trends, Nasukawa and Backley (2015) and Nasukawa (2017b: 136) takes the view that both heads and dependents generally exhibit similar characteristics across different structural levels.

2.2 An alternative view

To achieve a greater degree of uniformity across different levels, Nasukawa and Backley (2015) and Nasukawa (2017b) redefine the roles of heads and dependents in morpheme-internal phonological structure by referring to the sound energy of the modified carrier signal. This marks a deliberate departure from the more familiar approach in which sound energy is sonority-based (since this latter approach appears to have no advantages in terms of capturing uniformity, as explained in the preceding section).

According to Ohala (1992), Ohala and Kawasaki-Fukumori (1997), Traunmüller (1994, 2005) and Harris (2006, 2009), the energy associated with the carrier signal in spoken language makes it possible for linguistic messages to be heard, while the energy associated with

[1] In non-stress-accented languages, the head syllable of a foot is typically the one that displays no consonantal lenition (Nasukawa 1995, 2005; Harris 1997).

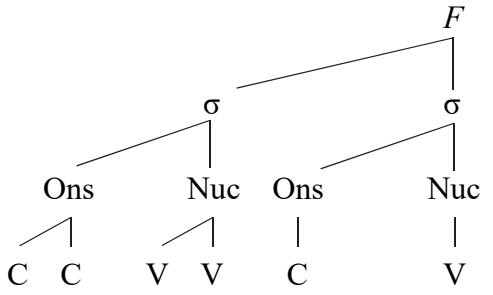
modulations to the carrier signal is linguistically significant in that it allows listeners (and also speakers, for purposes of self-monitoring) to recognise morphemes and words (Nasukawa 2017b: 129). The carrier signal itself serves as an acoustic foundation or baseline; it is periodic but contains none of the converging formants that characterise contrastive vowels. In phonetic terms, it appears as a schwa-like quality in the central region of the vowel space.

In the approach adopted here, modulations of the carrier signal are measured by the extent to which they deviate from the baseline with respect to acoustic attributes such as periodicity, amplitude, spectral shape, fundamental frequency and duration/timing (Harris 2009, 2012; cf. Nasukawa 2017b: 129). These measurements therefore serve as a means of identifying head-dependency relations between constituents, as shown below in the case of morpheme-internal phonological structure. Before proceeding with this, however, let us discuss head-dependency relations between constituents larger than morphemes.

As a result of analysing head-dependency relations at various morpho-syntactic levels, Nasukawa and Backley (2015) claim that heads are important in terms of structure-building but, contrary to the usual assumptions, are linguistically impoverished in terms of their ability to express lexical contrasts. On the other hand, dependents show the opposite tendencies: they are recast as being structurally weak (e.g. they are optional, rather than being structurally integral) and are seen as being informationally rich in the sense that they contribute to contrastiveness. Some straightforward examples are found at the level of affixation and at the phrasal level. In English, suffixes are analysed as heads because they usually determine the grammatical category of the suffixed form; and as heads they are structurally important, but at the same time they are semantically impoverished—they contribute little to the overall meaning of the resulting form. By contrast, bases/stems are grammatically and structurally less important but they are semantically rich. The distinction between heads and dependents is also reflected in their phonetic salience, where suffixes are typically unstressed whereas bases/stems receive primary stress, e.g. *púsh-es*, *háppi-ness*. Moreover, in terms of the degree of carrier-signal modulation, heads display smaller modulations than dependents. The same association between heads/dependents and the degree of carrier-signal modulation is found at the phrasal level too: in a phrase, the dependent shows a bigger modulation than the head (e.g., [VP[V *drink*][N *cóffee*]], [DP[D *the*][N *báckyard*]], [PP [P *in*][DP *the báckyard*]] (for more examples, see Nasukawa and Backley 2015).

Based the above analysis, Nasukawa and Backley (2015) also claim that heads at the foot level are structurally important yet linguistically impoverished, while foot-level dependents are structurally weak and should be reinterpreted as being informationally rich. On this basis, foot structure takes the form in (2).

(2) Proposed morpheme-internal phonological structure



Since the left-hand syllable /treɪ/ is stressed and shows bigger carrier signal modulations than the right-hand syllable /si/, it is regarded as a dependent at the foot level, while the unstressed syllable /si/ is the head. The same applies in the branching nucleus /eɪ/: the left-hand member /e/ is analysed as the dependent because it shows bigger carrier-signal modulations, while the second member /ɪ/ must be the dependent since it has smaller modulations.

Under this modulation-based analysis, the structure of a branching onset is explained in a similar way. As illustrated in (2), the first member /t/ of the branching onset /tr/ must be the head of the constituent because it involves relatively big modulations—in particular, the abrupt drop in amplitude associated with oral stops—while the second member /r/ has the characteristics of a dependent because its modulations are smaller (recent work in phonology has shown that /r/-type consonants form a natural grouping with the schwa-like carrier signal because of their acoustic similarities).

Although head-dependency relations at the syllable level are the same in (2) as they are in (1), a similar analysis holds with respect to the association between head/dependent relations and the degree of carrier signal modulation. That is, the nucleus is considered to be the head of the syllable because it displays bigger modulations than its dependent, the onset. And since this onset supports consonants—which are more salient than vowels in terms of the degree of carrier-signal modulation—it fits the expected profile of a dependent.

To summarise, under the carrier signal modulation approach described here, constituents at all levels of morpheme-internal phonological structure are characterised by right-headedness. This is illustrated by the structure in (2), which exemplifies morpheme-internal structure in languages such as English. The following section describes how the linear realisation of structures such as (2) is captured in formal terms.

3. Precedence relations between morpheme-internal constituents

3.1 The precedence-free model of phonological representation

In syntax, precedence relations between units are unspecified in representations. But in morpheme-internal phonology, which is independent of morpho-syntactic structure, it is standard practice to encode the linear ordering of segments in lexical forms; this linear ordering is then used to construct hierarchically-organised syllable/prosodic structure (Bromberger and Halle 1989, McCarthy and Prince 1986). In other words, precedence relations between segments are assumed to be integral to multi-stratal models of phonological representation.

On the other hand, pursuing a strictly mono-stratal model of the phonological component means that hierarchical (head-dependency) structure should be fully assigned in the mental lexicon (Harris 2004, Nasukawa 2011). In the model being described here, it is proposed that the relational property of head-dependency is sufficient to linearise phonological structure and to account for all properties relating to precedence (which are viewed as being representationally redundant). Precedence relations themselves are merely the natural result of interpreting the dependency relations which hold between units in a structure.[2] In the PfP approach introduced in section 1, the goal is to minimise the number of properties employed in linguistic representations, and furthermore, to ensure that representations on the competence side of the language faculty remain coherent throughout a derivation. To help achieve this, structural properties pertaining to phonology must resemble those that are present in other parts of the grammar. Next, I will focus on morpheme-internal structure and decribe how, in the context of PfP, the hierarchical structure derived from head-dependency relations is externalised as a linear string.

3.2 Dependent first, head second

It was argued in section 3.1 that dependents are more salient than heads in terms of the degree of carrier-signal modulation across all levels of morpheme-internal phonological structure. Described in informal terms, dependents are not only more salient but they are also realised first, while heads are not only less salient but are also phonetically externalised second. This works uniformly at all levels, as illustrated in (3).

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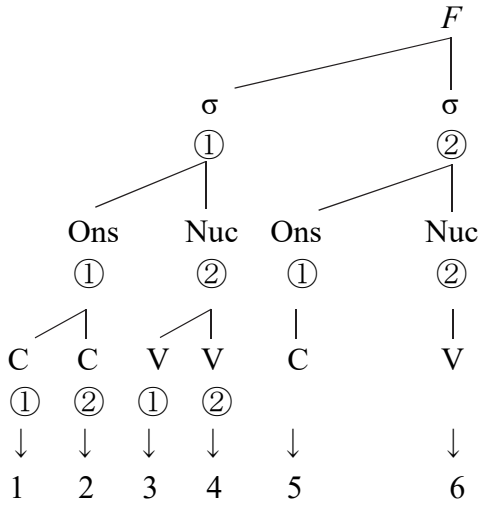
[2] There are also models which adopt the opposite strategy of specifying precedence relations between segments and eliminating hierarchical properties from representations (Scheer 2004, 2008; Samuels 2009).

(3) Precedence relations between phonological constituents



Assuming that (3) is a well-formed structure, it is natural to suppose that another structure which applies the linearisation process in the opposite direction is also possible. In fact, this case is found in languages such as Kaqchikel, Arrernte and Kunjen, where the dependent is phonetically preceded by the head. Readers may refer to Nasukawa et al. (2018) for a detailed discussion of this parametric mechanism.

Returning to the structure in (3), I suggest that the Sensory-Motor systems follow a particular path when interpreting the network of precedence relations holding at each level. This is a downward path in which the mapping process responsible for linearisation operates at the highest level of head-dependency then moves down successively through each level below. In this way, the linear ordering of segments is determined by the following calculation, where all possible sequences along the downward path are shown.

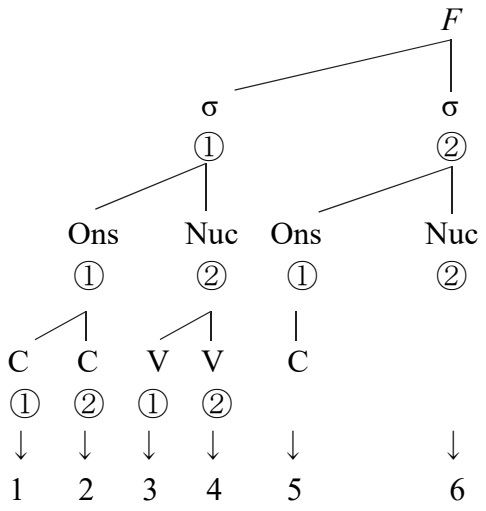
(4) Linearisation process

a.	i.	①→①→①	=	1st	/t/
	ii.	①→①→②	=	2nd	/r/
b.	i.	①→②→①	=	3rd	/e/
	ii.	①→②→②	=	4th	/ɪ/
c.		②→①→①	=	5th	/s/
d.		②→②→②	=	6th	/i/

The path ①→①→① in (4ai) is composed only of ①s and is phonetically realised first, while the path ②→②→② in (4d) is formed only of ②s and is pronounced last. As (4) shows, the linear orders of the other segments are determined by the tension between the number of ①s/②s and the level occupied by ①/②. Comparing ①→①→② in (4aii) with ①→②→① in (4bi), both have the same number of ①s/②s (two ①s, one ②) and ① occupies the first level of the path; however, they differ with respect to the level which ② occupies. Thus, the segment which is phonetically realised first is the segment with the greater number of ①s at the higher level. In this way, the whole structure comprising a network of head-dependency relations is ordered as shown and phonetically realised as the segmental string [treɪsi]. No matter how long or complex the structure is, the same mapping strategy applies.

We are now required to consider words ending with a consonant. Take the English word 'trace' as an example of a consonant-final word. In the Government Phonology approach (Kaye, Lowenstamm and Vergnaud 1990, Harris 1994, et passim), a domain-final consonant does not occupy a coda, but rather, is in the onset of the head syllable at the foot level. This onset is followed by an unspecified (melodically empty) nucleus, as depicted in (5).

(5) Precedence relations between phonological constituents



Although the foot-level head is an empty nucleus which is not phonetically realised (since it contains no melodic properties), the mapping strategy is the same. Following the Strict CVCV model of phonological representation (Scheer 2004, 2008), not only a domain-final consonant but also a domain-internal 'coda' is regarded as an onset followed by an empty nucleus. This

empty nucleus is phonetically silent in some contexts but audible in other contexts. The mechanism controlling the phonetic realisation of empty nuclei will not be described here since it is beyond the scope of the present topic, and moreover, it is subject to variation even within the Government Phonology literature. For further discussion the reader is referred to Harris (1994), Scheer (2004) and Nasukawa (2010).

4. Precedence relations between phonological primes

4.1 Segment-internal organisation

Up to this point the discussion has focused on linearisation within morphemes, where a dependent (segment) precedes a head when phonetically realised. We now turn to domains smaller than a segment.

In this paper, segment-internal structure is described using a set of six features called *elements* (Kaye, Lowenstamm and Vergnaud 1985, 1990; Harris 1990, 1994, 2005; Harris and Lindsey 1995, 2000; Backley 2011, et passim). These are given with their acoustic correlates in (6).

(6) Elements and their acoustic correlates (Nasukawa and Backley 2012, Nasukawa 2016, Nasukawa et al. 2018: 5)

elements	*abbr.*	*spectral shape*
|mass|	|A|	a mass of energy in centre of the vowel spectrum with troughs at top and bottom
|dip|	|I|	energy distributed to top and bottom of the vowel spectrum with a trough in between
|rump|	|U|	marked skewing of energy to lower half of the vowel spectrum
|edge|	|ʔ|	an abrupt and sustained drop in overall amplitude
|noise|	|H|	aperiodic energy
|murmur|	|L|	a broad resonance peak at lower end of the frequency range

In general, the first three elements |A|, |I| and |U| are associated with resonance characteristics in vowels and place properties in consonants, while the remaining ones |ʔ|, |H| and |L| capture laryngeal/source characteristics in consonants and to represent consonantal characteristics such as occlusion, aperiodicity and pitch/tone, as illustrated below.

(7) Elements and phonological categories (Nasukawa et al. 2018: 6)

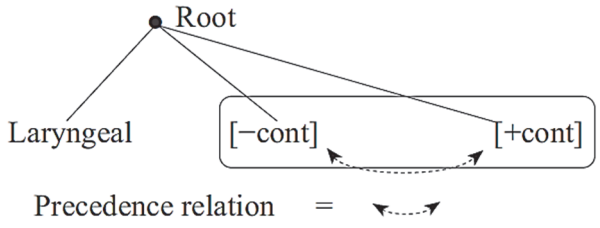
elements	*abbr.*	*consonant category*	*vowel category*
|mass|	|A|	uvular, pharyngeal place	non-high
|dip|	|I|	dental, palatal place	front
|rump|	|U|	labial, velar place	rounded
|edge|	|ʔ|	occlusion	creaky voice (laryngealised)
|noise|	|H|	aspiration, voicelessness	high tone
|murmur|	|L|	nasality, obstruent voicing	nasality, low tone

The same elements are present in all languages and can be identified by observing phonological phenomena. All elements are privative in terms of the way they express lexical contrasts; moreover, a single element can be pronounced on its own—it does not require the presence of other elements in order to be phonetically realised. For example, [a], [i] and [u] are the phonetic manifestations of |A|, |I| and |U| respectively. In most cases, however, segments are represented by compound expressions consisting of more than one element. For instance, an expression comprising |A| and |U| is phonetically realised as a mid rounded back vowel [o], the combination of |I| and |U| is phonetically realised as a high front rounded vowel [y]. For details, the reader is referred to Backley (2011).

4.2 'Contour' expressions

The question of precedence often arises in discussions of segment-internal organisation, particularly when it comes to the representation of 'contour' expressions of segments such as affricates such as /ʧ/ and prenasalised obstruents such as /^{n}d/. In Sagey (1986), for example, it is proposed that precedence relations are specified between the features [−cont] and [+cont] in the representation of affricates. This reflects the order in which the two features are phonetically realised.

(8) Precedence relations between features in an affricate (Sagey 1986, cf. Nasukawa and Backley 2008: 35)



However, in line with the preceding discussion on structural levels above the segment, this paper claims that, in a similar fashion, no precedence relations are specified within a segment. In fact, in recent years the formal status of contour expressions has been called into question in the phonology literature (Lombardi 1990, Schafer 1995, Scobbie 1997, Scheer 2003, Nasukawa 2005, Nasukawa and Backley 2008). At least the two questions arise regarding the validity of the representation in (8). First, if [+cont] can follow [−cont] then logically the reverse should also be possible, producing affricates such as *[ʒd]. However, there are no known languages which include such sounds in their segmental inventory, even though there is no obvious explanation for the absence of this reverse ordering. Second, there is no clear reason why affricates always contain exactly two sub-segmental timing slots; this restriction appears to be an arbitrary one.

Arguing that affricates are not contour expressions in a phonological sense, Nasukawa and Backley (2008) claim that affricate stops are phonologically the same as plain stops. For example, the English affricate *ʤ* is the phonetic manifestation of the expression |I A ʔ H| while the plain stop *d* is the phonetic realisation of |A ʔ H|. In their analysis, they propose that affrication should be regarded as a performance device for improving the perceptibility of complex-resonance stops (|I| and |A| in *ʤ*) by making multiple place cues more accessible to listeners; and to achieve this, the portion of the speech signal containing aperiodic noise energy (which is relatively rich in place cues) is acoustically enhanced. On the other hand, this is not necessary in the case of plain stops because they have only one resonance element (e.g. |A| in *d*). A similar argument is put forward in Nasukawa (2005) to account for the phonological structure of prenasalised obstruents.

Although the way in which PfP represents segment-internal structure is different in some of its details from the models used in Nasukawa (2005) and Nasukawa and Backley (2008), they are united by the fact that precedence relations are not encoded in representations. The reader is referred to Nasukawa (2014, 2016, 2017abc) and Nasukawa and Backley (2015, 2017, Forthcoming) for further details on the phonological hierarchical structure built from head-dependency relations between elements, where the same linearisation process is shown to operate at other morpheme-internal phonological levels.

5 Summary

In this paper I have proposed a way of formalising the linearisation process in morpheme-internal phonological structure by referring exclusively to the head-dependency relations existing between structural units. This has been done in the context of the PfP model of phonological representation. This approach assumes that dependents (which are more salient

in terms of the size of their carrier-signal modulations) are phonetically realised first, while heads (less salient) are pronounced second at all levels of morpheme-internal phonological structure. Linearisation takes place at the highest head-dependency level, then moves down successively through the lower levels of a structure. I look forward to developing this work in the future, in order to reveal the mechanism behind affrication and to explore further benefits of the PfP approach to phonological representations.

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