Phonological evidence for segmental structure: insights from vowel reduction

Kuniya Nasukawa
Tohoku Gakuin University

Phillip Backley
Tohoku Gakuin University

ABSTRACT. Vowel reduction patterns can shed light on the internal structure of their target vowels. This is evident in an element-based approach to representations, where abstract phonological elements are defined using phonological evidence such as that gleaned from vowel reduction processes. In Precedence-free Phonology, an extension of Element Theory, elements combine into hierarchical structures via head-dependency chains; only the most deeply embedded elements in these chains are targeted by vowel reduction. The reduction process itself operates blindly and uniformly on any target structure, thus allowing its original (full vowel) structure to be established by observing the phonological characteristics of its reduced form. The model succeeds in conflating centripetal (centering) and centrifugal (dispersing) vowel reduction into a single pattern. Also, by proposing that different varieties of a language have minimally different hierarchical representations for the ‘same’ sound, it accommodates the variation we observe in vowel reduction patterns between those varieties.

Keywords: Element Theory, Precedence-free Phonology, vowel reduction, vowel system typology, head-dependent relations

1. Introduction

The paper argues that segmental weakening is best analysed as a structural process. That is, when a segment weakens in a given context, it loses part of its representational structure. This loss of structure then has a direct effect on the way the segment is phonetically realized. The approach that this paper pursues is a unified one, in that it attempts to account for all forms of weakening, in consonants and in vowels, using just a single general operation. It is argued that this is achievable if the weakening process itself is made formally simple, so that any typological variation in weakening effects must be accounted for by differences in the original structures of the target vowels.

The following discussion employs a Precedence-free Phonology (PfP) approach to segmental structure (Nasukawa 2014, 2015, 2016, 2017; Nasukawa and Backley 2017), which is a recent development of the Element Theory model (Harris and Lindsey 1995; Cyran 2010; Backley 2011). In PfP, elements combine into complex expressions by forming chains of head-dependency relations; these chains are depicted as hierarchically organized structures which capture different forms of segmental weakening including vowel reduction effects. It will be shown how the phonological process of segmental weakening serves as a useful source of phonological evidence to support the postulation of particular element structures in consonant and vowel representations. The paper is organized as follows. Section 2 discusses the nature of segmental weakening and introduces the notion of a unified process for all instances of weakening. Section 3 describes the theoretical framework for analyzing vowel reduction, focusing on PfP as an extension of Element Theory. Section 4 then outlines the proposed analysis of vowel reduction using illustrations from Bulgarian, English, and other languages. Finally, section 5 summarizes the main points.

2. Strength in phonology

2.1 Segmental weakening

The term ‘weakening’ suggests that strength is an inherent characteristic of segments. We may also infer that different segments display different degrees of strength, so that statements such as ‘segment A is stronger/weaker than segment B’ can be made on a language-specific basis or even universally. To make this possible, however, we require a clear definition of segmental strength; and as yet, phonologists have not reached a consensus on this point.

At least three problems stand in the way of such a consensus. The first stems from the fact that
most definitions of strength are not sufficiently general: that is, they focus on consonants whilst ignoring vowels. This bias towards consonants is understandable, given that it is possible to describe strength-related properties in consonants by referring to tangible or easily observable measurements such as sonority and vocal tract width. The issue, however, is that these are physical properties; and this raises the question of how they relate to phonological patterns such as segmental distribution. Moreover, by referring to these consonantal properties, scholars reinforce the (erroneous) idea that strength is relevant to consonants but not to vowels. The second problem concerns the use of sonority as a tool for explaining phonological behavior; as Harris (2006) has shown, sonority is a notoriously difficult concept to define. The third problem concerns the fact that the physical properties which have been used to measure segmental strength apply to some differences (e.g. the difference between stops and fricatives) but not to others (e.g. the difference between oral and glottal sounds). And this issue becomes even more apparent in the case of vowels: there appears to be no reason why, for example, a central vowel should be deemed weaker than a peripheral vowel.

2.2 Weakening as a structural effect

In view of the problems associated with a sonority-based approach to weakening and also with an approach based on the physical properties of segments, this paper pursues an alternative approach which focuses on representational structure. Specifically, it employs hierarchical representations of the kind used in Precedence-free Phonology (Nasukawa 2014, 2015, 2016; Nasukawa & Backley 2017). Precedence-free Phonology or ‘PfP’ is a development of the Element Theory framework, in which weakening involves a loss of elements from a segment’s structure. In Element Theory, a segment’s representation may be simplex or complex: simplex expressions contain just a single element, whereas complex expressions consist of two or more elements combined. Moreover, simplex and complex expressions show different patterns of distribution, such that simplex structures have a relatively free distribution whereas complex structures are generally restricted to prosodically strong positions. When a complex expression occurs in a weak position, therefore, it may weaken to a simplex expression by losing one or more of its elements. Following element loss, any remaining element structure is pronounceable as a weakened segment. The effects of weakening are thus twofold, as shown in the following examples. (The elements will be described in section 3.1.)

\[
\begin{align*}
(1) & \quad \text{stop} \rightarrow \text{fricative} \quad [g] \ H U \quad \rightarrow \quad [ɣ] \ H U \\
& \quad \text{mid} \rightarrow \text{high} \quad [e] \ A I \quad \rightarrow \quad [i] \ A I
\end{align*}
\]

First, because elements are lost from a segment’s structure, the phonological properties of the segment will inevitably change and the segment will come to represent a different phonological category, e.g. in (1a) a stop becomes a fricative. Second, the phonetic realization of the segment will also change, since the loss of an element incurs the loss of the phonetic properties associated with that element, e.g. in (1b) the mid-vowel [e] has a complex structure consisting of the elements |A| and |I|, and when it is targeted by weakening the |A| element is lost to leave just |I|, which is pronounced as a high vowel [i].

Assuming that weakening does involve element loss, the question arises as to which elements are lost and which are retained. At first glance, the choice appears to be a random one. Compare, for example, vowel weakening in Bulgarian and Belarusian, illustrated in (2).

\[
\begin{array}{|l|l|l|l|}
\hline
\text{Bulgarian} & \text{full V} & [e] & |A I| & s[ɛ]lu \ ‘village’ \\
& \text{weak V} & [i] & |(\wedge) I| & s[i]lə \ ‘villages’ \\
\hline
\text{Belarusian} & \text{full V} & [e] & |A I| & r[ɛ]ki \ ‘rivers’ \\
& \text{weak V} & [a] & |A (i)| & r[a]kə \ ‘river’ \\
\hline
\end{array}
\]

Although both languages display the effects of vowel weakening, the outcome is different in each.
In Bulgarian, [e] weakens to [i], which involves the loss of the |A| element. By contrast, in Belarusian the same target vowel [e] weakens to [a], which requires the loss of |I| rather than |A|. Evidently, the weakening process can take different forms depending on the language. How then can this variation be encoded in the grammar?

2.3 Weakening as a single process

The proposal here is that segmental weakening takes just one basic form in the grammar: it is a single operation which applies blindly and uniformly to any target structure. Given this, it follows that any variation we find in the outcome of weakening must be encoded by some aspect of language knowledge which lies outside the phonological grammar. In fact, we claim that this variation is expressed by differences in the way the original target segment is represented in the lexicon. Thus, to reflect the differences shown in (2) between Bulgarian and Belarusian, for example, it is proposed that [e] has (minimally) different representations in the two languages.

To illustrate the point further, consider accent variation in English. The English /t/ sound can have a range of realizations when it stands between sonorants (e.g. better, bottle), depending on the accent. This is shown by the realizations of the English word better in (3).

(3) realization description example accent
a. [ˈbɛtə] released RP (standard British English)
b. [ˈbɛʔə] glottalized Cockney (London English)
c. [ˈbrɔʔə] tapped Australian English
d. [ˈbɛɹə] rhoticized Tyneside English (North-East UK)

If we are correct in claiming that the weakening process always takes the same form, then presumably, the four accents of English in (3) all have different ways of representing /t/ in lexical forms. The next section describes how the ‘same’ segment can be represented in more than one way by using element-based representations in which the elements are arranged into hierarchical structures following the PfP approach.

3. Representations
3.1 Elements

The PfP model is an extension of the Element Theory approach and uses the same six elements that are found in standard versions of element-based phonology. Like features, elements represent the contrastive properties of speech sounds; but unlike features, they are associated with properties of the acoustic speech signal (cf. features, which mostly reflect aspects of articulation). The acoustic signatures of the elements are described in (4). (For a summary of the reasons why elements are grounded in the acoustics of speech, see Backley (2011: 2ff.).)

(4) Vowel (resonance) elements

<table>
<thead>
<tr>
<th>element</th>
<th>pattern</th>
<th>acoustic properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>[A]</td>
<td>mass</td>
<td>central spectral energy mass—F1-F2 convergence</td>
</tr>
<tr>
<td>[I]</td>
<td>dip</td>
<td>low F1 with high spectral peak—F2-F3 convergence</td>
</tr>
<tr>
<td>[U]</td>
<td>rump</td>
<td>low spectral peak—lowering of all formants</td>
</tr>
</tbody>
</table>

Consonant (laryngeal) elements

<table>
<thead>
<tr>
<th>element</th>
<th>pattern</th>
<th>acoustic properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ʔ]</td>
<td>edge</td>
<td>abrupt and sustained drop in amplitude</td>
</tr>
<tr>
<td>[H]</td>
<td>noise</td>
<td>aperiodicity, noise</td>
</tr>
<tr>
<td>[L]</td>
<td>murm</td>
<td>periodicity, nasal murm</td>
</tr>
</tbody>
</table>

In addition to being associated with the acoustic signal, elements also represent segmental
categories. That is, like features, they function as units of melodic structure. As shown in (5), however, the categories they represent do not necessarily match those that are defined by traditional features. For example, the element \(|H|\) is associated with aperiodic noise energy, which is an acoustic property that inheres in fricatives and in the release phase of oral stops. The implication is that \(|H|\) defines a natural class comprising fricatives and released stops—something which is not predicted in standard feature-based approaches. To take another example, the element \(|U|\) represents a formant pattern in which sound energy is concentrated at low frequencies. This pattern is common to labials, velars and rounded vowels; and again, the claim is that these sounds form a natural class. In Element Theory, evidence for class membership comes from the acoustic signal and also from the observation of phonological behavior.

(5)

<table>
<thead>
<tr>
<th>resonance</th>
<th>nuclear</th>
<th>non-nuclear</th>
</tr>
</thead>
<tbody>
<tr>
<td>(</td>
<td>A</td>
<td>)</td>
</tr>
<tr>
<td>(</td>
<td>I</td>
<td>)</td>
</tr>
<tr>
<td>(</td>
<td>U</td>
<td>)</td>
</tr>
<tr>
<td>laryngeal</td>
<td>non-nuclear</td>
<td>nuclear</td>
</tr>
<tr>
<td>(?)</td>
<td>oral/glottal occlusion</td>
<td>laryngeal/creaky voice</td>
</tr>
<tr>
<td>(</td>
<td>H</td>
<td>)</td>
</tr>
<tr>
<td>(</td>
<td>L</td>
<td>)</td>
</tr>
</tbody>
</table>

3.2 Element expressions

A single element can be pronounced on its own; for example, the simplex expression \(|H|\) is realized as \([h]\). But usually, elements combine to form complex expressions. In PfP, element combinations are always asymmetric. That is, they combine by forming head-dependent relations. Note that the formation of head-dependent relations operates recursively to produce structures consisting of chains of asymmetric relations; therefore, the more complex the expression (i.e. the greater the number of elements), the more levels of embedding the structure will have. Below it will be argued that the hierarchical organization of PfP representations facilitates our understanding of weakening effects. Some examples of vowel structures are given below. For a description of how these have been constructed, the reader is asked to consult the references given in section 2.2.

(6)

\[
\begin{align*}
|A| & |I| & |I| & |I| \\
[a] & [e] & [æ] & [œ]
\end{align*}
\]

The main difference between PfP and standard versions of Element Theory is that in PfP some of the elements have a dual function. That is, they represent segmental properties in the usual way, but in addition they can function as prosodic constituents. Specifically, it is the resonance elements \(|A|, |I|\) and \(|U|\) which have this prosodic function. So, \(|A|, |I|\) and \(|U|\) not only carry information about lexical contrasts in vowels, they also project to higher prosodic levels and form head-dependent relations with one another. In effect, they take the place of traditional prosodic constituents such as ‘nucleus’, ‘syllable’, and ‘foot’. Of particular relevance to this discussion of vowel weakening are the properties of \(|A|, |I|\) and \(|U|\) when they function as nuclei. This is because, as (7) shows, their phonetic realization differs depending on whether they are present as nuclei or as units of segmental structure.
The structure in (7a) is maximally simple, in that it contains only a head element |A|. In effect, this |A| takes the role of a nuclear position. It is pronounced as a weak/default vowel [ə] because there are no dependent elements associated with it. In PfP it is dependent elements, not heads, which provide segmental/contrastive properties; so, without any dependents, a head behaves as if it were an empty nucleus. Compare this with (7b), which has a head |A| and a dependent |A|. Because dependents contribute lexical information, the whole expression is realized as a full (contrastive) vowel [a] (i.e. the ‘strong’ realization of |A| when it is present as a dependent). In (7b) the acoustic properties of the head |A| are inaudible, since they are masked by those of its dependent. By contrast, (7a) has no dependent elements to mask the phonetic properties of the head; this leaves the head exposed, and it is perceived as a non-contrastive vowel [ə].

From the preceding discussion it emerges that the roles of heads and dependents in PfP differ markedly from their roles in other models of segmental representation (Nasukawa & Backley 2015). It is traditionally assumed that structural heads are more prominent than dependents, and therefore, that they carry more linguistic information. In PfP, however, the opposite is true. To illustrate this, let us compare the structures for [e] and [æ] in (7), both of which have |A| and |I| as dependent elements. It can be seen that the more deeply embedded an element is, the more prominent it is: in [e] the lowest dependent position is occupied by |I|, making it acoustically close to [i], whereas in [æ] the most deeply embedded element is |A|, which ensures that the whole expression is realized as a low vowel. In fact, it is a general characteristic of PfP that dependent structural units carry more phonological (e.g. lexical) linguistic information than head units.

### 3.3 Default vowels

In (7) it was shown that if an expression has dependent elements, then these will determine the phonetic realization of the whole structure. But if there are no dependents, then there is nothing in the structure to mask the acoustic properties of the head, and consequently, the head element’s phonetic properties become audible. Note that, because the head behaves as a prosodic constituent, it has no segmental/contrastive properties of its own, so it is pronounced as a default vowel.

But what determines the precise phonetic quality of this default vowel? Language typology surveys show that default vowel quality varies from one system to another: in most varieties of English the default vowel is [ə], but in other languages it may be any vowel sound within the range [ə]–[i]–[u]. In PfP this variation is accounted for by proposing that each language selects its head or ‘base’ element from the set of resonance elements |A|, |I|, |U|, and that the choice of base element determines the default vowel quality. The structures for the default vowels [ə], [i], [u] are given in (8). The vowel qualities are illustrated using loanwords in the relevant language, which often reveal the phonetic quality of a language’s default vowel—and thus, the identity of its base element.

```
(8)   |A|      |I|      |U|
      |A|      |I|      |U|
[ə] (English)     [i] (Chilungu)     [u] (Japanese)
e.g. Cnut [kənjuːt] e.g. n-ku-ful-a [iŋkulufa] e.g. game [ɡeːmu]
```

By itself, the base element provides a phonetic baseline, and it is onto this baseline that the acoustic patterns of dependent elements are superimposed. As already noted, in the absence of dependent
elements this baseline resonance is exposed and the base element can be heard. To reiterate, the representations in (8) are minimal structures, and as such, they resemble empty nuclei. (For further discussion of the characteristics of empty nuclei, see Charrette 1991; Harris 1998; Kaye 2000; Cyran 2010; Scheer 2004; Živanović & Pöchtrager 2010).

Besides appearing in loanwords, the default vowels [ə], [ɨ] and [ɯ] also occur in weak syllables. This is readily observed in languages with vowel reduction, such as English, where lexical contrasts are often suspended in prosodically weak positions, and in place of contrastive vowels we find the default vowel for the language in question. Furthermore, there is a clear affinity between these prosodically weak contexts and the weak acoustic patterns that characterize default vowels. In PfP the inherent weakness of [ə], [ɨ] and [ɯ] is captured by assuming that these default vowels are weak realizations of the three full vowels that are phonetically closest to them—namely, [a], [i] and [u] respectively. The distinction between the full forms [a], [i], [u] and the weak forms [ə], [ɨ], [ɯ] manifests itself both structurally and acoustically.

In structural terms, the members of each weak-strong pair are similar in that they have the same element in their representation: however, in weak vowels this element is present only as a head, whereas in strong forms it exists as a dependent, as illustrated in (7) above—recall that dependent elements have greater prominence, and also, they have the ability to convey lexically contrastive information. In acoustic terms too there is a difference between the weak and strong realizations of the same element. This can be seen by comparing the spectral patterns in (9a) and (9b).

\[
\begin{align*}
(9) & \quad a. \quad |A| \text{ as } [\bar{a}] \quad |I| \text{ as } [\bar{i}] \quad |U| \text{ as } [\bar{u}] \\
 & \quad b. \quad |A| \text{ as } [a] \quad |I| \text{ as } [i] \quad |U| \text{ as } [u]
\end{align*}
\]

In each case the strong (full vowel) realization has a spectral profile in which its identifying pattern is an exaggerated version of the corresponding pattern in the weak (default vowel) realization. For example, the ‘mass’ pattern (see (4) above) represented by the element |A| is characterised by F1-F2 convergence, and this pattern is more prominent in [a] (9b) than in [ə] (9a) since the F1 and F2 energy peaks are closer together—that is, they fully converge. Turning to strong [i] versus weak [ɨ], the difference again comes down to the prominence or salience of the relevant acoustic pattern. The ‘dip’ pattern associated with |I| is marked by a high F2 peak, which creates a trough or dip between F1 and F2. The trough in [i] is visibly deeper and more prominent than in [ɨ], and for this reason it may be understood as an exaggerated form of ‘dip’. Finally, [u] and [ɯ] both display the ‘rump’ pattern associated with |U|, in which acoustic energy is concentrated at low frequencies. This produces a falling spectral shape which is sharper and more exaggerated in strong [u] than in weak [ɯ].

4. Vowel reduction
A model of vowel structure must represent not only lexical contrasts but also phonological behavior such as vowel reduction. Crosswhite (2001) describes two types of vowel reduction: centrifugal systems, which have weak vowels occupying the periphery of the vowel space (usually [a], [i], [u]), are driven by contrast enhancement, while centripetal systems, which have central weak vowels (typically [ə]), strive for prominence reduction. In this paper, however, we challenge Crosswhite’s approach, and instead, follow Harris (2005) in claiming that it is neither necessary nor desirable to distinguish between the two types. Rather, we aim for a unified analysis of vowel reduction in which just one general mechanism is involved—namely, the loss of elements in weak positions. The following paragraphs demonstrate how this is achieved using PfP’s hierarchical element structures.

We propose that segmental reduction operates by targeting and suppressing the lowest element(s) in a structure, after which, speakers pronounce any remaining elements. This renders the reduction process formally simple. Moreover, we assume that it applies blindly and uniformly to any target structure. Note that this proposal is intended as a general description of segmental weakening, so in principle the target could be either a vowel or a consonant, though in the present discussion the focus is on vowels. Assuming that vowel reduction works in this way, then it follows that the outcome of reduction must depend on the internal structure of the original target vowel. That is, typological variation of the kinds illustrated in (2) and (3) above must be determined by the structural properties of the original representations. These properties will refer not only to the elements present but also to the head-dependent relations between them.

Recall from (2) that Bulgarian and Belarusian both display vowel reduction: in Bulgarian [e] reduces to [i], while in Belarusian [e] reduces to [a]. The question is how to formalize these two different patterns. If vowel reduction targets the lowest element in a structure, then the remaining elements above it will be pronounced as a reduced vowel. In Bulgarian the reduced vowel is [i], so the [I] element must remain while the [A] element below is lost. By contrast, in Belarusian the head-dependent relation between [A] and [I] is reversed: the lowest element must be [I], not [A]; then following the loss of [I], the remaining dependent [A] is realized as the low vowel [a]. The relevant structures are given in (10).

(10) Bulgarian [e]~[i]    Belarusian [e]~[a]    English [a]~[ə]

|A|    |I|    |A|    |A|    |A|    |A|    |A|
|A|  |I|    |A|  |A|     |I|

It should be pointed out that, in the Element Theory model, there is no anomaly in the fact that Bulgarian [e] and Belarusian [e] have similar pronunciations despite having different representations. This is because element-based structures are primarily a reflection of a segment’s phonological properties rather than its phonetic properties. It is therefore possible for phonetically similar sounds to have different representations. The principal reason for positing different representations is that the two sounds in question show different phonological behaviour—and this is precisely what we have just observed in their vowel reduction patterns.

Bulgarian and Belarusian are both centrifugal vowel reduction systems. So, to illustrate how a centripetal system can be analyzed in the same way, let us consider vowel reduction in English. In the strong-weak alternation *drama*-dr*ama*tic, the full vowel [a] has a head [A] and a dependent [A] in its structure. In an unstressed position, however, [a] undergoes reduction and dependent [A] is lost, leaving just the head element [A]. Recall that the head functions as a prosodic constituent—in effect, an empty nucleus—which is realized as baseline resonance. In English, baseline resonance has the quality of a central [ə]. The English reduction effect is also shown in (10).

5. Summary
In PfP, vowel reduction is a general process which applies blindly and uniformly to any target structure. Its effect is to suppress the most deeply embedded level of a vowel’s representation. It may be noted that this approach is in keeping with the overall assumption in Element Theory that representations are relatively abstract entities. For example, Bulgarian and Belarusian both have the vowel [e], which is phonetically similar in the two languages but which, arguably, is represented differently in each. Claims such as this are made not on the basis of pronunciation, but rather, by referring to the phonological behavior of the relevant segments under vowel reduction. This suggests that phonological structure and phonetic realization are related only indirectly—something that Element Theory has always maintained. Element expressions are mental objects, so there is no precise correspondence between elements and the physical (e.g. articulatory) properties of speech. To determine a vowel’s element structure, it is necessary to focus on its phonological behavior, not on its phonetic properties. As we have attempted to show, processes such as vowel reduction can shed light on phonological representations, no matter how those representations are phonetically realized.

Notes
* This paper was first presented at the Phonology Forum 2018, Higashiyama Campus, Nagoya University, Japan, on 29 August 2018. We thank the participants for their feedback and two anonymous reviewers for their helpful comments on an earlier draft. This work was supported by the following grants: Grant-in-Aid for Scientific Research on Innovative Areas, the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of the Japanese government, no. 18H05081; Grant-in-Aid for Scientific Research (B), the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of the Japanese government, no. 26284067; Grant-in-Aid for Scientific Research (C), the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of the Japanese government, no. 15K02611.

References