

Laryngeal dimensions, completion and enhancement

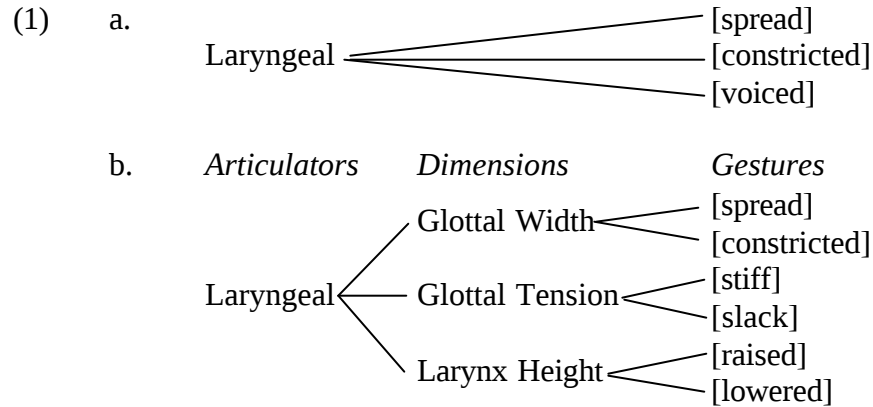
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1. Introduction

In this article we present a new model of phonological representations, concentrating on laryngeal systems. Our proposals are embedded in a theory of phonology in which representational economy is an axiomatic principle. Representational economy forces the phonology to be non-redundant in the sense that phonological representations are minimally specified. Deviations from the requirements of representational economy arise only in circumstances where independent complexity requirements force additional structure to be present. Apart from these cases, representations will always be specified only to the degree necessary to represent contrast within the system. This view of phonology must be contrasted with our view of the *phonetic* representations. Unlike the phonological representations, the phonetic representations are tremendously over-specified, containing information far beyond what is necessary for the simple maintenance of contrast. This extra information is useful, but it is not required from the point of view of the phonology. In our model the phonological system *per se* makes use of only very general phonetic information, indeed the features have a much more limited role in our system. The phonological representations provide specification for the phonetic *dimensions* and not for the phonetic *features* (modulo headedness, see §2.3). In §2 we will introduce our model of phonological representation and sketch our theory of phonetic implementation, using laryngeal systems as our focus. We illustrate various principles in §§3-5 with case studies of laryngeal systems: English, Japanese and Korean. In §6 we provide some conclusions and implications of our theory. Speculations regarding the rest of the feature geometry can be found in the Appendix.

2. Theoretical preliminaries

In (1) we contrast our model, (1b), with the current standard model of laryngeal organization, (1a) (as in Lombardi 1991 and others).



Because we depart from standard assumptions in several ways, we will explain the various aspects of the new organizational system, especially the extra layer of organizational structure.

As this paper is primarily concerned with laryngeal phonology, and indeed with only a subset of the laryngeal dimensions, we will restrict our attention to that system. Our speculations on the application of these principles of organization to the entire feature system are contained in the Appendix.

2.1. *Laryngeal motor instructions and gestures*

The terminal elements in (1b)—those enclosed in square brackets—are to be interpreted as motor instructions to the articulators. Thus, they share much in common with the *gestures* of Browman and Goldstein (1989), and so we will co-opt their term. They differ from Browman and Goldstein's gestures in that in our model the gestures play a very reduced role in the *phonology*, being in general absent from the phonological representation. In our view a gesture is the smallest independent articulatory action, the action of a single muscle

or muscle group. As Kim (1972: 338) states: “Speech production involves a large number of muscles, the majority of which are capable of independent control.”

We carry over the features for glottal adduction, [constricted], and abduction, [spread], from previous researchers.

The features [±stiff] and [±slack] were introduced by Halle and Stevens (1971). Criticisms of these features have often focussed on the over-generation in the theory with respect to the number of systems allowed using two binary features [±stiff] and [±slack] (Lombardi 1991; Keating 1988). The theory proposed here does not suffer from such shortcomings for two reasons: 1) the gestures are privative and 2) only *dimensions* can be contrastive in obstruents (discussed in §2.2). We are able to correctly constrain the number of phonological systems through the use of *dimensions*, discussed in §2.2. Furthermore, some of the criticism has clearly been misplaced. Halle and Stevens explicitly intend their system to also represent tonal features—high tone is [+stiff], low tone is [+slack]—and most of the criticisms do not weigh this extra explanatory power against the added complexity. We also believe that laryngeal features capture both phonation type and tone, for details see Avery and Idsardi (2000b).

Following Ladefoged (1973), we include the two phonetic gestures that control the height of the larynx. Although common in phonetic works, these features have been largely absent from phonological models. The gesture [raised] is operative in certain ejectives and raises F₀. The gesture [lowered] is the primary gesture for implosives and lowers F₀. We will ignore larynx height in the rest of this article, but we note in passing that there are two sources of tone in this model—glottal tension and larynx height. These issues are discussed further in Avery and Idsardi (2000b; in preparation).

2.2. *Laryngeal dimensions*

We go beyond previous models, however, in acknowledging explicitly that muscle groups form antagonistic pairs. This constitutes the

pre-terminal organization of the gestures, a layer that we will call the *dimensions*. Our inspiration for dimensions comes from more general studies of motor control (e.g. Sherrington 1947; Gallistel 1980; Zemlin 1998). Sherrington's crucial insight is that muscles are organized into antagonistic pairs:

"The muscles of the claw of *Astacus* are striated, and the case is interesting as one in which the co-ordination of action of two antagonistic muscles of the skeletal type is effected by the peripheral inhibition of one through the same nerve-trunk that induces active contraction of the other. But the similar co-ordination in the taxis of the skeletal musculature of vertebrates exerts its inhibition not at the periphery but in the nerve-centres. It occurs within the grey matter of the central nervous system." (Sherrington 1947: 85)

"A stimulus that excites a muscle on one side of a joint invariably inhibits excitation of the antagonistic muscle on the other side of the joint, and vice versa. Sherrington called this the principle of reciprocal inhibition." (Gallistel 1980: 58)

"... we shall be concerned chiefly with the actions of striated muscles. There are about 329 of them in the human body, and *all but two are paired muscles*. ... A muscle can exert a force in just one direction, and it is incapable of exerting any force in the opposite direction. Thus, either muscle in a functional pair may be the antagonist of the other." (Zemlin 1998: 18-27)

In our model the dimensions organize antagonistic pairs. The reciprocal antagonism of the muscles is modeled by restricting the dimensions to be non-branching. Thus, only a single muscle within a dimension can be active in any given speech sound. As stated previously, the gestures, which are the ultimate constituents of the phonological representation, do not bear the major contrastive burden and are in many ways unlike the features in traditional feature theory. They cannot be binary, as the muscle is either activated or inhibited by the activation of its antagonistic partner. For the most part, the phonology begins at one level removed from the gesture—the di-

mension, and this is the level that is largely responsible for contrast (see §2.3).

The laryngeal gestures are dependents of three dimensions: Glottal Width (GW), Glottal Tension (GT) and Larynx Height (LH).

The dependents of GW are [spread] and [constricted], which are familiar from most recent theories. Our theory, however, makes different predictions about the nature of the contrasts between GW segments. Other theories allow for a contrast between [spread] and [constricted] segments at the phonological level. We, on the other hand, do not allow for such a contrast. This necessitates a reanalysis of those systems that have been analyzed using [spread] and [constricted] contrastively, for example, Korean. In §5 we present a case study of Korean and show that the contrast of [spread] versus [constricted] is not basic but is instead derived in the phonetics. We will argue that the ‘tense’ consonants of Korean are in fact long segments that are enhanced with [constricted] in phonetic implementation. This is a case of phonetic over-differentiation where the underlying contrast is obscured by phonetic enhancement.

The dependents of GT are [stiff] and [slack]. Being mutually antagonistic, they cannot both be present in the same representation. Because obstruent contrasts are limited to dimensions (§2.3), we limit the number of potential contrasts, and in this way respond to criticisms of over-generation. Because GT is normally completed with [slack] (§2.4), the dimension node GT acts similarly to the feature [voice] in other theories. The principal difference is that we will allow more latitude in the phonetic implementation of GT.

The dependents of LH are [raised] and [lowered]. We will not consider this dimension in this article.

2.3. *Contrast*

We follow what we refer to as the Toronto School of Contrast (Dresher, Piggott and Rice 1995; Avery 1996). Under this view, contrasts are always of the type $\emptyset$ /Marked, so that in any two-term system there is an element that has no marking and an element that has

some specification. This means that for any contrasting pair, at the phonological level they differ only by the presence versus the absence of a single node.

In obstruents, only the dimensions are contrastive, not the gestures themselves. The contrastive use of gestures is severely limited. They contrast only when they are the designated articulator (the *head* of a segment), see §2.5 and §5.4. The dimensions are the primary interface between the phonology and the phonetics. Gestures are progressively added to the representations as they become more phonetic. All structure above the gesture is phonological and purely cognitive in nature.

Restricting ourselves to GT and GW systems, we predict that the basic two-way systems will involve a Ø/GT or a Ø/GW contrast. Of course, a length contrast is also available phonologically, and the dimensions can be combined. In (2) we outline the predicted systems which employ the GW and GT dimensions.

(2) Predicted phonological systems

	<i>Contrasts</i>	<i>Example</i>	<i>Typical characteristics</i>
a.	Ø	Tamil	no contrast
b.	Ø/GT	Spanish	fully voiced versus unmarked
c.	Ø/GW	English	aspirated versus unmarked
d.	Ø/GT/GW	Thai	fully voiced, aspirated and plain
e.	Ø/GT/GW /GT+GW	Hindi	full cross-classification including voiced aspirate

In other languages, such as Korean and Swiss German, length is also used contrastively. In more complex systems, such as Igbo, the LH dimension is recruited contrastively as well.

In §§3-5 we illustrate the workings of the theory through case studies of three rather different laryngeal systems: English, Japanese and Korean. It is in the study of these systems that the validity of our theoretical assumptions will be evaluated.

2.4. *Phonetic completion and enhancement*

Our theory of minimal contrast ensures that phonological representations are generally incomplete (i.e. underspecified). Thus, phonological representations are not by themselves pronounceable. In order to become pronounceable, the mapping from phonology to phonetics must add the missing gestural specifications. We will call this process *completion*. Bare dimension nodes are completed through the insertion of a dependent gesture.

We distinguish completion from *enhancement*. While completion merely involves the additions of gestural information to the already present dimensions, enhancement involves the addition of a dimension node, turning a phonological $\emptyset/X$ contrast into a phonetic equipollent (X/Y) contrast. Enhancement leads to the widely observed phonetic over-differentiation of contrast.

As the bare dimension nodes are generally the phonologically contrastive elements in the system, we must leave it to completion and enhancement to give the segment its phonetic content. Each bare dimension has a *default* completion, which is universal. For GT and GW the default completions are [slack] and [spread] respectively. This accords with the fact that in most languages with a two-way laryngeal contrast either a plain versus voiced distinction or a plain versus aspirated distinction is found. However, there are also context-sensitive completions, also universal, which are sensitive to inter-articulator phasing. One of the principles governing gestural completion is Kingston's Law, given in (3).

- (3) Kingston's Law: a gesture $\leftrightarrow$ phasing bi-directional relation
 - a. GW in phase with stop $\leftrightarrow$ [constricted]
 - b. otherwise (GW out of phase with stop) $\leftrightarrow$ [spread]

We draw here on the important research conducted by Kingston (1985, 1990) in specifying the relation between phasing and GW completion, though Kingston does not formulate a law in these terms. Kingston's Law is particularly prevalent in laryngeal completions. When GW is phased with the closure of a stop it is completed with

[constricted], otherwise it will be completed with [spread] (the default). This is in accord with Kingston's finding that aspiration is generally not associated with the closure of a stop but that glottalization is. Under special circumstances, such as assimilation (see §5.4) stops can become [spread]. In this case GW spreads until it is out of phase with the stop closure. Languages may also completely exclude the use of certain gestures, leading to language-particular violations of Kingston's Law. Japanese (§4) presents such a case, eschewing [constricted].

Our second principle, building directly on Vaux (1998), is Vaux's Law, (4).

(4) Vaux's Law: [fricative] → GW

Vaux's Law is not a principle of completion, but rather defines an obligatory enhancement relation. Recall that enhancement differs from completion in that enhancement adds a new dimension leading to phonetic over-differentiation. Vaux's Law ensures that fricatives are enhanced with GW whenever possible. If a system has a contrast between an unmarked fricative and a GT fricative, as in Japanese, then the unmarked fricative will be enhanced with GW. The net result is that the unmarked fricative will be completed with [spread]. If, instead, the contrast is between an unspecified fricative and a GW fricative, as in English, then the GW fricative is completed with [spread] and the unmarked fricative will not receive GW. That is, Vaux's Law is suspended in cases where GW is contrastive for fricatives. In general, enhancement is restricted to introducing non-contrastive dimensions. Consequently, the only systems in which we would expect to find true plain fricatives are those in which GW is not available for enhancement, i.e., systems that employ GW contrastively.

2.5. Heads

There are cases in which terminal gestures can be employed contrastively. Such cases can be succinctly explained, once the notion of *head* is introduced. Following Dresher and van der Hulst (1999), all segments have a head, which is the locus of greatest constriction in the segment. Thus, the notion “head” takes on the function of the “designated articulator” in other models (Sagey 1986; Halle 1995). As Dresher and van der Hulst document, heads can have greater structure than dependents. This implies that not only can heads contain more specification but also the corollary—dependents have less specification. Therefore, since in obstruents laryngeal dimensions are always dependents, the laryngeal dimensions must be less specified, and consequently there are no contrastive laryngeal gestures in obstruent systems. In segments containing only a laryngeal component, there is no oral constriction and thus the laryngeal dimension node must be the head. Heads must have at least a minimal amount of structure, and in this case the only available structure are the gestural dependents. When GW is the head, it must be specified for [spread] or [constricted], yielding the pure laryngeals /h/ and /ʔ/, respectively. Unlike GW, it is apparently the case that GT and LH cannot function as segmental heads. We know of no language that has independent segments that are only specified for GT or LH, but we must leave this question to further research.

3. English: GW invariance

In this section we establish two points: 1) the laryngeal contrast in English stops is of the Ø-GW type, and 2) English provides strong support for the claim that it is the *dimension* rather than the *gesture* that is contrastive. Space limitations prevent us from presenting more than a sketch of the laryngeal phonology of English, see Avery and Idsardi (in prep.) for details.

3.1. English as a Ø/GW system

Iverson and Salmons (1995) present both synchronic and diachronic evidence that the voicing contrast in Germanic languages is best analyzed as a two-way distinction between an unmarked segment and one that is commonly aspirated. We agree that the glottal opening gesture involved in making an aspirated segment signals the marked member of the contrast, but we propose that the contrast is at the level of the GW dimension node, rather than the [spread] gesture. Support for this claim can be found in English in the stability of the phonetic cues for the GW segments as opposed to the unmarked segments. We see this in the relative lack of consistent cues found in the unmarked (that is, the so-called voiced) segments and their phonological inertness (especially as assimilation triggers). These are the properties we take to be the hallmarks of the unmarked member of a contrastive pair and the central cues in acquisition. Clearly, phonological inertness must be a primary guide to the child in the setting up of underlying contrasts. If there is no phonological evidence for the presence of a feature through its activity in the phonological processes of the language, then there is no reason for the child to utilize the feature in constructing the inventory. While we believe that phonological inertness is a necessary condition for the unmarked status we are also convinced that inertness alone is not sufficient. The marked member of an opposition should also be relatively tightly distributed around a set of acoustic and auditory cues for the dimensional contrast: that is, the marked feature should display something that we refer to as *dimensional invariance*. This is not to deny that there could be contexts where contrasts are weakened or even completely neutralized, as clearly this is a common occurrence. Rather what we intend by this is that there will be contexts where the contrast is sharply indicated by the distributional properties of the acoustic and/or articulatory cues for the marked member of the contrast pair, and that such cues will be a signal to the contrastive *dimension*. Let us take for example the distinction between sounds such as /p/ and /b/ in English in onset position before a stressed syllable. In this case, the cues for the /p/ are consistent, the /p/ being marked by the

presence of aspiration. On the other hand, the /b/ is sometimes fully voiced, sometimes partially voiced, and sometimes completely voiceless. While there is no overlap between the two segments, the distribution of the /b/ is quite scattered as compared to the /p/ (for phonetic studies see Docherty 1992). It is this scattering that must be compared to the invariant cues that signal the marked member of the contrast.

3.2. *English fricatives*

The obstruents of English contrast unmarked segments with GW segments. We will justify this claim first with a brief examination of the fricatives. The primary evidence comes from phonetic studies of /s/ and /z/ but we are confident that these results extend to the other fricatives as well. Smith (1997) studied /s/ and /z/ in connected discourse (see also Scully 1971, 1979, 1992). She found that /z/ is variably realized as voiced or plain depending on surrounding phonetic context, while /s/ is consistently realized as voiceless. The oral airflow is consistently higher for /s/ than /z/, even when acoustically the distinction with the fricative is neutralized, e.g. bus/buzz (a “near merger” effect). This higher airflow of /s/ is best explained by a larger glottal opening, which is also confirmed from trans-illumination studies. This dimensional invariance of /s/ indicates it is underlyingly specified for the dimension node GW and subject to completion with the gesture [spread], the default GW completion. That /z/ varies is entirely consistent with the claim that it has no active laryngeal specification and thus receives *contextual voicing* (see Avery 1996).

In phonetic implementation, the plain fricatives of English do not acquire the gesture [spread] by Vaux’s Law because Vaux’s Law is suspended in cases where GW is the contrastive dimension. In general contrastive dimensions cannot be used for enhancement.

3.3. *English stops*

Of more interest to us is than the realization of the fricatives is the behavior of the stops. Like the fricatives, we find that it is the so-called ‘voiceless’ series that is always realized with the GW dimension, while the ‘voiced’ series varies depending on the surrounding segmental environment (again, see Docherty 1992 for a detailed review of the phonetics literature). What is most interesting in English, however, is the phonetic completion of the GW stops. In this case, they appear to be sensitive to phasing relations and thus subject to Kingston’s Law.

The basic facts are: 1) when GW stops are initial in an onset, they are aspirated and the peak of aspiration is coordinated with the release of the stop, devoicing any following sonorant, (5a-f), 2) in syllable final position, these stops are generally unreleased and glottalized, (5g-i). this aspiration is realized either on the offset of the stop or on a following sonorant.

(5) Syllable initial stops

- | | | | | | | | | |
|----|---------------------|--------|----|---------------------|--------|----|---------------------|--------|
| a. | [p ^h e] | ‘pay’ | b. | [t ^h i] | ‘tea’ | c. | [k ^h i] | ‘key’ |
| d. | [p ^h ɹe] | ‘pray’ | e. | [t ^h ɹe] | ‘tray’ | f. | [k ^h ɹe] | ‘cray’ |

Syllable-final stops

- | | | | | | | | | |
|----|---------------------|--------|----|---------------------|--------|----|---------------------|--------|
| g. | [hi ^ʔ p] | ‘heap’ | h. | [hi ^ʔ t] | ‘heat’ | i. | [hʊ ^ʔ k] | ‘hook’ |
|----|---------------------|--------|----|---------------------|--------|----|---------------------|--------|

Thus, when an obstruent stop is in a position that allows for release, as in onset position, it is completed with [spread]. This gesture is realized on the offset of the stop and may even overlap with a following onset consonant. If the stop is unreleased, as it often is in syllable final position, then the stop is completed with the gesture [constricted]. This is in accord with Kingston’s Law but most importantly from our perspective it shows that the dependents of the GW are not behaving contrastively. They are clearly alternate realizations of a single contrastive dimension.

3.4. Conclusion

In English we see two types of variable behavior in the stops. The unmarked stops are realized as voiced or voiceless depending on the precise phonetic context. On the other hand, the GW stops can be either aspirated or glottalized depending on phasing relations. Crucially, the bare GW dimension node in the representation of the GW stops of English allows us to account for the alternation between [spread] and [constricted], without any use of deletion processes. Also, by restricting contrast to dimension nodes we cannot create incompatible specifications which would then have to be identified and resolved through a constraint such as *[spread constricted].

As stated at the outset of this section, we are only presenting a thumbnail sketch of the English system as a full analysis would take us far beyond the concerns of this paper. We have ignored the status of foot-medial stops, flapping and reduction to glottal stop after glottalization. We must refer the reader to Avery & Idsardi (in prep.) for the full analysis of the English system.

4. Japanese: GW Enhancement of a GT system

In §3 we saw that GW is a contrastive dimension in English, marking the voiceless obstruents. In this section, we discuss the laryngeal system of Japanese in which GW is used as an enhancement.

In Japanese, the interaction between a phonological process known as *rendaku* (sequential voicing) and a morpheme structure constraint known as Lyman's Law (Lyman 1885, 1894; Mester and Itô 1986) demonstrates that the primary contrast must be Ø/GT. *Rendaku*, illustrated in (6), is a process by which the initial consonant of the second member of certain compounds becomes voiced.

(6) *Rendaku*

- | | | | | | |
|----|------------|---|----------|---|-------------------|
| a. | ori | + | kami | → | origami |
| | ‘fold’ | | ‘paper’ | | ‘origami’ |
| b. | yama | + | tera | → | yamadera |
| | ‘mountain’ | | ‘temple’ | | ‘mountain temple’ |

Rendaku is blocked by Lyman's Law, a constraint operating on the native vocabulary of Japanese that disallows the occurrence of two voiced obstruents in the same morpheme. Therefore, if the target morpheme already contains a voiced obstruent, the initial obstruent of the second member of the compound will not be voiced as illustrated in (7).

(7) *Rendaku* blocked by Lyman's Law

kami	+	kaze	→	kamikaze
'god'		'wind'		'divine wind'

The fact that *rendaku* creates voiced obstruents, and that it is blocked by the presence of other voiced obstruents in the same domain indicates that the voiced series is marked in Japanese. Therefore, *rendaku* is the insertion of a floating GT dimension node in conjunction with the compounding process. The floating GT is then associated with the initial consonant of the second member of the compound. The fact that *rendaku* requires grammatical information (i.e., that it is restricted to a particular type of compound), shows that *rendaku* is phonological rather than phonetic. This phonological evidence decides in favor of a Ø/GT system.

In Japanese, we also find a process of high-vowel devoicing. This involves the devoicing of a high vowel especially between two voiceless obstruents as shown in (8).

(8) a. [kɪppu] 'ticket' b. [kɪku] 'hear'

Tsuchida (1997) shows that vowel devoicing in Japanese is due to the presence of a [spread] gesture in voiceless obstruents, indicating the presence of GW phonetically (see also Varden 1998). EMG, glottographic and trans-illumination studies (Hirose and Ushijima 1978; Yoshioka, Löfqvist and Hirose 1982) confirm the presence of [spread] on Japanese voiceless obstruents. Thus, phonetically Japanese voiceless obstruents are [spread] not plain. However, we have argued above that the primary contrast, based on the phonology of

Japanese is Ø/GT. Our theory, constrained by the principle of *representational economy*, eschews phonological overdifferentiation, thus excluding an analysis in which the contrast in a two-way system is equipollent, GW/GT. We propose instead that the Ø/GT phonological system is enhanced by the insertion of the non-contrastive GW dimension, leading to the subsequent introduction of [spread]. GW will spread onto neighboring vowels to satisfy its phasing requirements, leading to vowel devoicing through trajectory smoothing. Our account agrees with Tsuchida's other findings, namely that vowel devoicing is highly variable, just as would be expected of a phonetic, rather than a strictly phonological process.

5. Korean: [constricted] is not distinctive

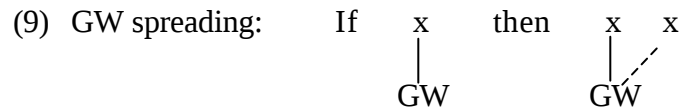
In Korean there is a three-way distinction among the stops. The series are traditionally described as plain voiceless, aspirated and tense (or fortis). The analysis of the tense series has long been controversial. Phonetically these segments have both a [constricted] gesture and long closure duration, making it unclear which aspect is the primary contrast, since in previous theories both length and [constricted] are available as distinctive properties. Thus, Lombardi (1991) has proposed that the feature [constricted] is present underlyingly on the tense series. Then, presumably, the length of the closure duration is supplied by a phonetic rule of Korean, though Lombardi does not discuss this. For others (e.g. Martin 1952) the difference between the tense consonants and the other series is length, an analysis that is also reflected in the Hangeul orthography.

Our theory prevents us from adopting Lombardi's analysis, as this would require a sub-dimensional contrast, something that is prohibited when the dimension is not the head. We are thus forced to look elsewhere for the contrastive property, and length is the obvious candidate. Moreover, there is striking phonological evidence confirming the primacy of length as the contrastive property when all of the relevant segments are considered. We begin by discussing the fricatives (§5.1) and then consider the stops (§5.2) and the interac-

tions with /h/ (§5.3). Taken together, the facts show that the length analysis is clearly superior to the [constricted] analysis.

5.1. Korean fricatives

Our analysis of the Korean fricative system owes a tremendous debt to Iverson (1983), which explains the phonetics and phonology of the fricatives very clearly. The fricative system is much simpler than the stop system, as Korean has only two fricatives (we ignore the palatalized allophonic variants). Phonetically, the Korean fricatives are aspirated, [s^h], and long [s:]. This is clearly an example of phonetic over-differentiation as the fricatives differ in *both* aspiration and length. Importantly, [s:] is *not* constricted, although its glottal width is about half that of [s^h] (Kagaya 1974; Iverson 1983). Spectrograms (Kagaya 1974, Lee 2000) show that the aspiration following [s^h] covers a substantial part of the following vowel. This is a general fact about aspiration in Korean, as there is also an inverse correlation between the length of aspiration and the length of the following vowel (Oh and Lee 1997; Roberts and Lee 1997). We conclude that GW is always bipositional in Korean, a fact that will be crucial in our analysis. Formally, this is a condition requiring that a singly linked GW node spread, as in (9).



Since fricatives normally receive GW through Vaux's Law, and we know of no phonetic reason for lengthening one of the fricatives, we analyze the phonological contrast in the fricatives to be one of length. Underlyingly, [s^h] is /s/, and [s:] is /s:/. The laryngeal properties of both segments follow from Vaux's Law, (repeated in (10)), GW spreading, (9), and GW completion, (11).

(10) Vaux's Law: [fricative] → GW

(11) GW completion: $GW \rightarrow GW$
⋮
[spread]

The underlying fricatives are shown in (12). (The C and V timing nodes are used here for expository purposes only. We also omit irrelevant intervening structure, in particular the Oral Place node).

(12) Underlying representations

a. [s^h] [fric] C V	b. [s:] [fric] / \ C C V
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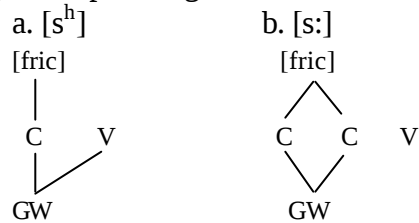
The application of Vaux's Law creates the structures in (13). Although GW is contrastive for Korean stops (see below), it is not contrastive in the fricatives. Therefore, Vaux's Law can apply in (13).

(13) Vaux's Law

a. [s^h] [fric] C V GW	b. [s:] [fric] / \ C C V \ GW
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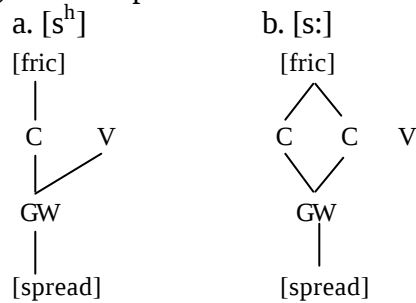
To meet the bipositional requirement, GW spreads in (14a) onto the following vowel position, ultimately devoicing the initial portion of the vowel. Since GW is already bipositional in (14b), no spreading is necessary.

(14) GW spreading



Finally, GW is phonetically completed with [spread] as in (15).

(15) GW completion

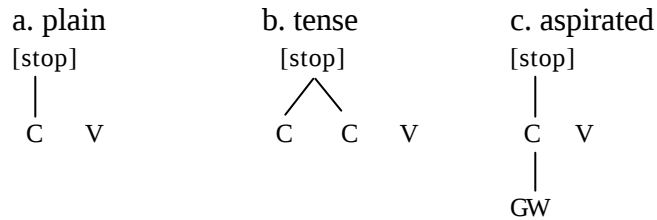


Notice that phonetically both the length of the [fricative] gestures and the relative timing of the [spread] gesture differ for the two fricatives and that this is captured representationally. Our analysis requires only a single statement that is specific to Korean: that GW must be bipositional. We now turn to the stops.

5.2. Korean stops

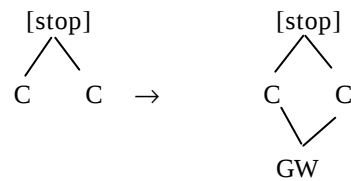
Given the existence of a length contrast in the simpler system of the fricatives, the most parsimonious analysis will also employ length in the stop system. Thus, we propose that Korean has the three-way contrast $\emptyset$ /long/GW as shown in (16).

(16) Underlying representations



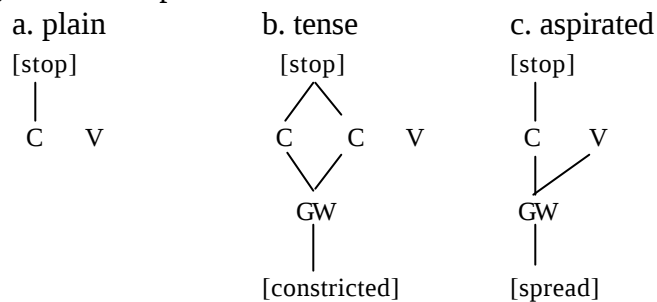
As noted above, phonetically the tense stops are both long and [constricted]. This property is specific to Korean, and not universal, as other languages, such as Italian, have plain long stops. So Korean contains a language-specific process which inserts GW onto bipositional stops, (17). This process also conforms to the bipositional requirement on GW, (9).

(17) GW insertion on long stops



Because the GW feature is in phase with the closure of the stop, Kingston's Law requires completion with [constricted]. The phonetic representation of the stops is given in (18).

(18) Phonetic representations



In (18a) the plain stop receives no additional features and is realized as plain. In (18b), the long stop receives GW, and is completed with [constricted]. In (18c) GW spreads onto the vowel, devoicing the initial portion of the vowel, yielding the “heavy” aspiration characteristic of Korean. We are thus able to derive the phonetic properties of the long stops from independent principles. We will now discuss additional support from the process of tensification.

5.3. Post-obstruent tensification

In Korean, plain obstruents become tense after another obstruent, as shown in (19). Because (19a) is a compound, an analogous monomorphemic example with /p^h + k/ is also provided.

- | | | | |
|------|--------------------------|----------------------|---|
| (19) | Cluster | Result | Example |
| | a. /k ^h + p/ | → [kp’] | /puΛk ^h patak / → [puΛkp’adək]
‘kitchen floor’ |
| | /p ^h + k/ | → [pk’] | /tΛp ^h kæ/ → [tΛpk’æ] ‘cover’ |
| | b. /k + p ^h / | → [kp ^h] | /cakp ^h um/ → [cakp ^h um] ‘a piece of work’ |
| | c. /k + p/ | → [kp’] | /kikpinca/ → [kikp’inja] ‘poor person’ |

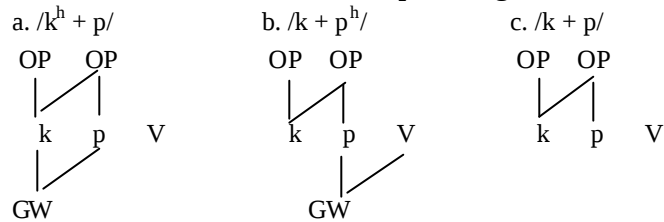
Tensification is the result of three more general processes—Oral Place spread, GW spread and GW insertion. We provide derivations below. The underlying representations are shown in (20).

- | | | | |
|------|-------------------------|--------------------------|------------|
| (20) | a. /k ^h + p/ | b. /k + p ^h / | c. /k + p/ |
| | OP OP | OP OP | OP OP |
| | | | |
| | k p V | k p V | k p V |
| | | | |
| | GW | GW | |

The obstruents come to share manner features through the spreading of the Oral Place node, which dominates the manner feature [stop] (see the Appendix). This, coupled with GW spreading, gives the re-

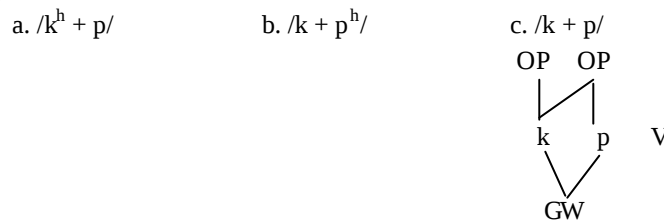
sults shown in (21). In other cases, such as /p + k/ the Oral Place node of the left-hand stop is then deleted, and the result is total æ-similation (see Iverson and Lee 1995).

(21) Oral Place and Glottal width spreading



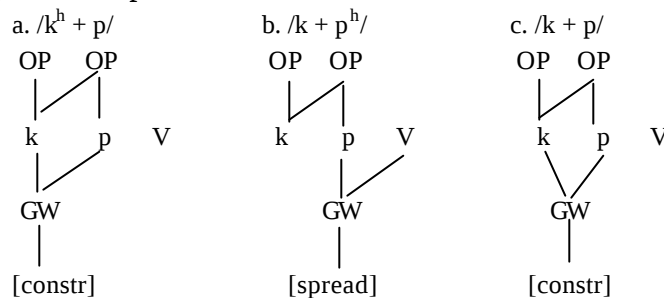
After OP spreads, [stop] will be shared, so the structural description for GW insertion, (17), is met in (21c).

(22) GW insertion



As GW is in phase with [stop] in (21a) and (22c), it is completed with [constricted]. In (21b), GW is out of phase with [stop], and therefore it is completed with [spread].

(23) GW completion

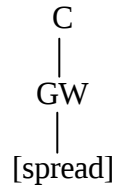


Note that our analysis requires no deletion whatsoever, only realization.¹ Korean shows the same result as in English, that the GW series can show up as either [spread] or [constricted] depending on its phasing relations.

5.4. Korean /h/

Our analysis receives striking support from the behavior of /h/ when it is in contact with obstruents (Oh 1997; Kang, Lee and Lee 1997). We will consider /h/ in two contexts: prior to fricatives and prior to stops. We show that the properties of /h/ follow from the fact that it is a GW-headed segment, and therefore is gesturally specified with [spread] underlyingly, as in (24).

(24) Representation of /h/



Now consider the realization of /hC/ clusters in Korean, (25).²

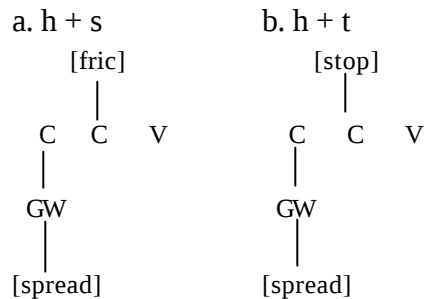
- (25) a. $h + s \rightarrow s$: /noh + sumnita/ $\rightarrow$ [nos:umnita] ‘put formal’
 b. $h + t \rightarrow t^h$ /coh + ta/ $\rightarrow$ [cot^ha] ‘good indic.’

Under the analysis we have so far developed, in both cases in (25) the feature [spread] has been retained. The underlying representations for these cases are shown in (26).

¹ We recognize that there must be word-final deletion in Korean to get the various neutralizations. All theories will have to posit multiple neutralization processes in word-final position. For further discussion see Avery and Idsardi (in preparation).

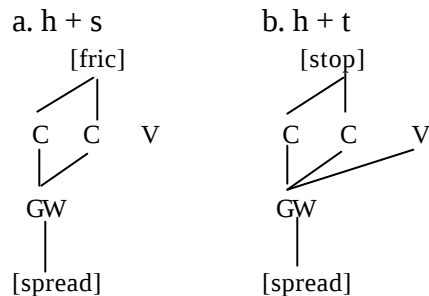
² Some speakers report additional variants of /h+s/ with [...ts:...]. Space considerations preclude discussion of this issue here.

(26) Underlying representations



Oral Place and GW spreading apply in both cases, (26). In (26b) this yields a [spread] gesture in phase with the [stop] closure, a configuration disfavored by Kingston's Law. Korean remedies this situation by spreading GW onto the vowel, so that [spread] will be out of phase with [stop].

(27) Oral Place and GW spreading, Kingston's Law



If /h/ did not have a GW dependent, then the GW dependent appropriate to the existing phasing relations would have been added, as with the aspirated stops, (23a). Notice that the aspirated stops do not contribute aspiration to the following stop in syllable contact, but /h/ does. So the aspirated stops are "less" aspirated than /h/ and we capture this by giving the stops a bare GW node, but giving /h/ both GW and [spread]. What is invariant in Korean is the presence of GW rather than one of its dependents. The gestures [spread] and [con-

stricted] are introduced to satisfy phasing requirements, and the gesture [spread] is maintained if it is underlyingly present.³

5.5. *Further work*

We acknowledge that the above analysis does not provide a complete picture of Korean laryngeal phonology. For instance, we have not provided an account of the neutralization of coda obstruents to stops in Korean. Most researchers claim that the final stops are plain and unreleased, but Baek (1992) claims that final stops are glottalized. Contrary to previous researchers, Kim and Jongman (1996) found that “83% of the word-final stops ... were followed by a brief burst.” More recently, Kim and Rhee (1997) extended the Kim and Jongman study, and found a smaller proportion of very weakly released stops. They interpret these as “inaudibly released” stops, and conclude that such release is phonologically irrelevant.

While the non-release of stops in phrase-final and pre-stop position may explain the *origin* of neutralization in Korean, there are two additional phenomena which favor a *phonological* neutralization to plain stops independent of phonetic release. First, final stops in the first member of a compound can become voiced when the second member begins with a sonorant: /pat^h + ilan/ → [padiran] ‘field-ridge’. Second, in verbs which take *-hata* the final obstruent becomes aspirated: /k’æk’is + hata/ → [k’æk’it^hada] ‘(be) clean’. Both of these changes point to an intermediate plain stage as the result of neutralization, as glottalized variants should not become either voiced or aspirated. Note, further, that the neutralized stops are, of course, phonetically released when followed by a vowel, as in these two cases.

We speculate that the laryngeal neutralization found in Korean is the result of the unavailability of GW spread in final position, given

³ Alternatives analyses of the Korean (Sohn 1987) which employ rule-ordering (with coda-neutralization feeding tensification) have to neutralize aspirated stops but not /h/ in syllable contact, a poorly motivated difference. For further discussion see Avery and Idsardi (in preparation).

the lack of a subsequent position at that point in the derivation. Conceivably, being unable to spread GW to be bi-positional would trigger deletion of the GW dimension as an alternative ‘repair’.

Another aspect of Korean neutralization is that both /s/ and /h/ become [t] in final position. Given the presence of [spread] on /h/ underlyingly, this neutralization strongly points to the deletion of either [spread] or GW in final position. The neutralization of /s/ also points to the loss of the [fricative] gesture word-finally. Finally, Kim (1997, 1999) has shown that Korean /c c' c^h/ are primarily affricates phonologically (and only secondarily palatal), and since they also neutralize to [t] word-finally, the word-final neutralization must also accomplish de-affrication.

We believe that the correct analysis will relate these disparate facts to the phasing of gestures and the bi-positional nature of GW in Korean. Such an analysis is similar to, but distinct from, aperture-based analyses. Word-finally, only a single position is available, and therefore GW is illicit in this position. Without the possibility of GW in this position, /h/ and /s/ are also illicit. By a corollary to Vaux’s Law, /s/ must lose [fricative] if it cannot have GW, turning into [t]. Similar considerations apply to /h/, which will then acquire the default Coronal place (Avery and Rice 1989).

6. Conclusion

We have seen that a model of feature organization that groups [spread] and [constricted] into a single GW dimension allows for a more explanatory account of the alternations observed between [spread] and [constricted] segments in the languages investigated thus far. Previously, such alternations were generally ignored and the intimate connection between the features [spread] and [constricted] was missed. Our theory of segment structure, in which antagonistic gestures are grouped into dimensions, allows us to revisit the connections between different gestural pairs. For us, non-contrastive variation between [spread] and [constricted] realizations is simply a matter of completing a bare GW dimension node. In theories where

[spread] or [constricted] is used to implement the contrast, languages such as English or Korean have to be analyzed as changing one feature, e.g. [spread] into a diametrically opposed feature.

Furthermore, because dimensions organize antagonistic gestures we have a direct structural explanation for impossible combinations. We do not require extrinsic filters such as *[spread constricted] as in Lombardi (1991).

We have seen in Japanese that enhancement can lead to phonetic over-differentiation but that phonological processes can provide the answer as to the true nature of the phonological contrast in the language. The child, in setting up the contrastive dimensions in the language then, draws not only on the phonetic information but also the phonological patterning of the language.

We have also demonstrated the necessity for both underspecification and for feature geometry. It is the underspecified dimension nodes that allow us to provide maximally simple analyses of laryngeal alternations in the languages investigated. Only through the employment of a hierarchically organized segment are we able to implement a theory of gestural completion that can make the right predictions about the behavior of laryngeal features.

The theory and analyses given above also offer strong support to a modular approach to the phonetics-phonology interface. Better explanations are achieved with our reticulated model, marshalling elements from both the phonetics and the phonology. At the same time sharp boundaries must be established between these two aspects of language, as it is the *phonological* contrasts not the phonetic manifestations that must be acquired by the child (Avery and Idsardi 2000a).

Appendix

In Figure 1 we give a speculative model of segmental organization based on the theory and ideas presented in this article. The organization suggested in Figure 1 gives the reader a flavor of the theory that we are assuming, although at this point many of the details follow from nothing more than a desire for symmetry throughout the system. At the terminal level are the motor instructions, actions that can be

executed by articulators. This includes the articulator-free gestures [stop] and [fricative], which plausibly involves antagonistic differences between ballistic and controlled movements in the closure and release phases (stops being ballistic in both phases, fricatives having a controlled closure and affricates having a controlled release). Antagonistic gestures are organized into dimensions, these features cannot co-occur in a single representation. There is minimal structure above this. Coronal. Antagonistic relations do not generally hold at the upper layers, for example [high front] is a valid gesture complex, though Curl and Groove may indeed be antagonistic. Groups of dimensions sharing the same articulator are grouped together into the organizational nodes Larynx, Dorsal, and Coronal. The Oral Place node provides the grouping for the dimensions and articulators of the mouth proper. These are the only gestures which can be performed with complete or near-complete closure, and thus correspond to the class of possible obstruents. For this reason, the gestures dealing with obstruency are dependents of the Oral Place node, and sounds will be sonorant unless specified for an obstruent gesture.

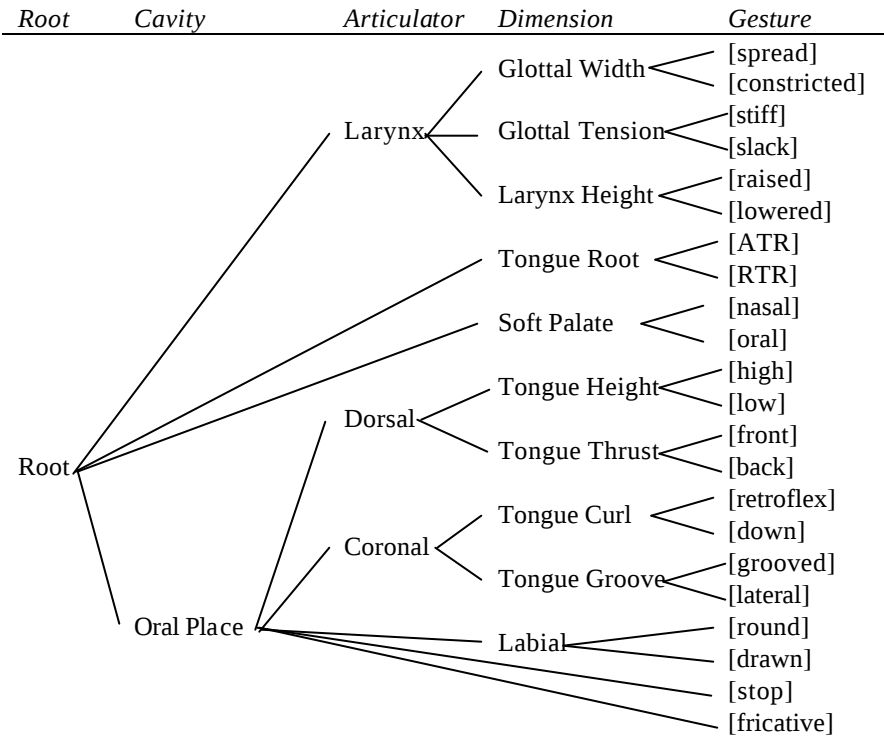


Figure 1. Segmental organization

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