Chapter 18

An architecture for phonology

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1 Why and how

"Phonology" is construed here in a broad sense. It comprises the system of unpredictable ("distinctive") phonological properties of expressions, which may be called phonemics, and the system of phonetic properties that are only predictable in terms of a language's phonemics in conjunction with phonetic rules specific to the language (but not by a theory of universal phonetics alone). It also includes "morphophonology," which deals specifically with phonological phenomena that are observed when signs are components of larger signs.

An explicit empirical theory that is to integrate a subject as large and diversified as phonology[1] needs to be built on a very clear but highly expressive formal basis grounded in a theory of language. The formal theory of language and grammar developed in King (1989) and work that builds on it, essential aspects of which also underlie the HPSG theory of PS94 (i.e., Pollard & Sag 1994), is exceptionally well suited for this task. Moreover, the structure of signs (i.e., objects of sort *sign*) proposed in PS94 is an excellent point of departure for a theory of morphology that is to be able to interact naturally with morphophonology.

[§] *Editors' note:* This paper was originally published in Borsley, Robert D. & Adam Przepiórkowski (eds.). 1999, *Slavic in Head-Driven Phrase Structure Grammar* (Studies in Constraint-Based Lexicalism), 61–90. Stanford, CA: CSLI Publications.

[1] For information on phonology, useful recent reference works are available: for data and analytical ideas that have dominated discussions in (morpho-)phonology in the last decade(s), Kenstowicz (1994) and Goldsmith (1995b); and for phonetics, Ladefoged & Maddieson (1996) and Hardcastle & Laver (1997). Some information on formal phonology can be found in Bird (1995) and in Carson-Berndsen (1998).

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In the sections to come I will outline a frame of reference expressive enough to discuss empirical phenomena with a useful degree of explicitness, resulting in a simple architecture for phonology in the broad sense (summarized in §8). Some aspects of the architecture (and questions waiting to be explored) are illustrated with examples from Russian, German and Miwok. No originality is claimed in either respect. My intention, on the contrary, is to remind ourselves that a framework in which to do formal phonology, closely related to PS94, is at hand (even though the multistratality that I endorse here has routinely been rejected). I further believe that considerations from phonology can contribute to the efforts (e.g., in King 1999 and Pollard 1999) to explicate the meaning of grammars, and that the particular model-theoretic conceptions adopted here can in turn contribute to attempts to elucidate the relation between the grammar and physics of phonetics.

2 Segments and segmental strings

2.1 Signature

As in PS94, signs bear an attribute PHON(OLOGY). Its value is of sort *phon*. The structure of *phon* objects is described in Figure 1.

$$\begin{bmatrix} \textit{phon} & \\ \textsc{segmental-string} & \textit{listofsegment} \\ \textsc{hierarch} & \begin{bmatrix} \textit{hierarch} & \\ \textsc{syllables} & \textit{listofsyllable} \\ \textsc{feet} & \textit{listoffoot} \\ \textsc{phonwords} & \textit{listofnelofsegment} \end{bmatrix} \end{bmatrix}$$

Figure 1: Structure of *phon* objects

The S(EGMENTAL)-STRING value is a (possibly empty) list of segments, whose internal structure will be considered below. The string of segments is hierarchically ("prosodically") structured, minimally into syllables, feet and phonological words.

Although phonological words will play an important role in §7, the hierarchical structure shown in Figure 1 is provisional. Intuitively, one might expect that a phonological word is constituted by a sequence of feet, a foot is constituted by a sequence of syllables, and the s-string (i.e., the S-STRING value) is exhaustively syllabified. Then, the PHONWORDS value should be a list of *phonword* (rather than *nelofsegment*) objects, and the attributes SYLLABLES and FEET would be born by *foot* and *phonword* objects, respectively. But phenomena of extrasyllabicity (cf., e.g., Bagemihl 1991, Gussmann 1992, Hyman 1992) and extrametricality, as well as the mismatch of syllables and phonological words in (25) below, indicate that the relations between s-strings, syllables, feet, and phonological words can be far less simple. Thus, although it is obvious how members of SYLLABLES, FEET, and PHONWORDS values can formally be related to s-string members (cf. Mastroianni 1993 for syllables), there is a host of empirical questions that I will not enter into.

The structure of segments is determined by the inventory of non-atomic sorts and their feature declarations in (1) on the following page. Indentation indicates partitioning into subsorts; thus, e.g., *vowel* and *consonant* partition *segmproper*; *obstruent* and *sonorant* partition *consonant*; *fricative*, *affricate* and *plosive* partition *obstruent*; *nasalcon* and *liquid* partition *sonorant*; *lateral* and *rhotictrill* partition *liquid*. For *segmproper*, the attributes AIRSTREAM, VOICING, VELUM and TONGUE are appropriate; for *consonant*, CONSTRICTION is appropriate. Attributes appropriate for a sort are also appropriate for that sort's subsorts. Atomic sorts, for which no attribute is appropriate, are partitioned in (2).

(2) *achievement*: *full, reduced, zero.*
airstream: *pulmonic, ejective, implosive, click.*
lateralclosure: *sideslocked, sidesunlocked.*
listofplace: *elist, nelofplace.*
narrowing: *round, nonround.*
sideslocked: *grooved, nongrooved.*
sitecor: *upperlip, dental, alveolar, postalveolar, palatal.*
sitedors: *velar, uvular.*
sitelab: *upperlip, upperteeth.*
velum: *openvelum, closedvelum.*
vertical: *high, mid, low.*

List supersorts, such as *listofsegment* in Figure 1, are always partitioned analogously to *listofplace*. Construing a string of segments as a list of tree-like objects with some trees sharing some branches, as illustrated in Figure 2 below, is a straight explication of notions that can be found, e.g., in Clements (1985: 237); a difference being that Figure 1 (just like Scobbie 1997) does not provide for "autosegmental tiers" independently of the segmental string. In detail, there has been (and will continue to be) much discussion on the proper structure of segments; cf., e.g., Bird (1995: Chapter 4), Clements & Hume (1995), and Ladefoged (1997) for three different proposals. I cannot hope to discuss here all aspects of (1), (2). Certain aspects will be commented upon below.

(1)	*segment*	SEGMPROPER *segmproper*
	long, short	
	segmproper	AIRSTREAM *airstream*
		VOICING *voicing*
		VELUM *velum*
		TONGUE *tongue*
	vowel	AIRSTREAM *pulmonic*
	consonant	CONSTRICTION *nelofplace*
	obstruent	
	fricative	
	affricate	
	plosive	VELUM *closedvelum*
	sonorant	AIRSTREAM *pulmonic*
	nasalcon	VELUM *openvelum*
	liquid	
	lateral, rhotictrill	
	voicing	ACHIEVEMENT *achievement*
	voiced	
	normalvoice, breathy, creaky	
	voiceless	
	spreadgl, closedgl	
	tongue	VERTICAL *vertical*
		HORIZONTAL *horizontal*
	tense, lax	
	horizontal	NARROWING *narrowing*
	front, central, back	
	nelofplace	FIRST *place*
		REST *listofplace*
	place	ACHIEVEMENT *achievement*
	labial	SITE *sitelab*
	lingual	LATERALITY *lateralclosure*
	coronal	SITE *sitecor*
	apical, laminar, retroflex	
	dorsal	SITE *sitedors*
	pharyngeal	
	glottal	

2.2 "Underspecification" vs. total well-typedness

I adopt HPSG's standard assumption that the objects in a model of a grammar are "totally well-typed,"[2] hence each object bears all attributes that are appropriate for its sort (cf. PS94, 396). Although this assumption has first been explicitly introduced in King (1989), it is less than self-evident with respect to this theory's intended models. There are no obvious formal or ontological reasons for insisting on it. Dropping it would remove a "foundational problem" in PS94's theory of coordination (PS94, 203, note 39) and would be conducive to an attempt to formally reconstruct theories of phonemic "underspecification" that have loomed large in the eighties.

For an illustration, we may consider some data from §7. Slavic languages are known for a regressive voicing assimilation that affects obstruents at the end of words. In Russian, the assimilation is only triggered by obstruents, in which voicing is (mostly) distinctive, but not by vowels and sonorants, in which voicing is predictable. To capture the dependence of assimilation on distinctive voicing, Kiparsky (1985) and others suggest that phonemically, vowels and sonorants do not have any voicing properties (i.e., they do not bear a VOICING attribute), so that the assimilation is phonemically triggered just by segments that do have voicing properties.

Of course, *vowel* and *sonorant* objects that lack voicing properties cannot surface as such; they must map to corresponding objects that bear a VOICING attribute. We thus get configurations as schematically described in (3) for vowels:

[2] In the formal theory that I rely on (King 1989; cf. also King 1994 and note 16 below), a grammar G consists of a signature (such as PS94, 396–399) and a set of restrictions ("constraints/ principles/rules," such as PS94, 399 ff.), each of which is an expression of a formal description language. The description language of King (1989) has disjunction, classical negation, sort specifications, and path equations. Let U be a set that conforms to the signature in that the denotations of the maximally specific sort symbols partition U, and each attribute symbol denotes a partial function from U to U, respecting appropriateness. With total well-typedness, the function is total with respect to the denotations of the sorts that the attribute is declared to be appropriate for. There is a denotation function *D* from the set of description language expressions to the powerset of U. Thus, a description language expression denotes a subset of U. It can require (by a path equation) that on each member of its denotation, certain path values are token identical, but it cannot identify any particular member of U. U is a "model" of G just in case U = $\cap\{D(\delta) \mid \delta \in \text{Restrictions}\}$. Crucially, the relation of a grammar's models to a natural language is as lucid as it can possibly be: the members of the intended models are token linguistic objects. Specifically, for a grammar G, some natural language L is intended to be an exhaustive (i.e., maximally inclusive) model of G (King 1995; 1999).

(3) a. $$\begin{bmatrix} \varphi\ \pi_1 \begin{bmatrix}\sigma_2\\ \text{TONGUE}\ \boxed{1}\\ \text{VOICING}\ \textit{voiced}\end{bmatrix}\\ \pi_2 \begin{bmatrix}\text{PHON}\ \pi_3 \begin{bmatrix}\sigma_1\\ \text{TONGUE}\ \boxed{1}\end{bmatrix}\end{bmatrix}\end{bmatrix}$$

b. $$\neg\ \big[\pi_2 \big[\text{PHON}\ \pi_3 \big[\text{VOICING}\ \textit{voicing}\big]\big]\big]$$

The symbols σ_1 and σ_2 are meant to be variables over maximally specific subsorts of *vowel*; φ is a cover symbol for some phonological attribute (such as PHON or UTTERANCE, introduced below in (7)); the π_i are path variables. The descriptions in (3a) and (3b) are to be understood conjunctively: objects that satisfy (3a) also satisfy the negative description (3b). Thus, the π_3 value does not bear a VOICING attribute. Even if the attribute values of the π_3 value are identical to attribute values of the π_1 value, as shown for TONGUE, the π_1 value cannot be identical to the π_3 value, as only the former bears a VOICING attribute.

When total well-typedness is dropped, σ_1 and σ_2 can be identical; while with total well-typedness retained, they cannot. Sort identity probably conforms to the intuitions underlying underspecificational analyses better than nonidentity.

In southwestern variants of Polish, the word-final voicing assimilation is also triggered by vowels and sonorants; i.e., distinctiveness of voicing is not relevant there. This sheds doubt on the attempt to account for the situation in Russian by an ontological construct like underspecification.[3] For broader critical discussion, cf. Broe (1993: Chapter 9), Goldsmith (1995a), Calabrese (1995: §6), Zoll (1997: 370), and references therein.

On inspection, then, the supposed empirical virtues of allowing objects not to bear attributes they are allowed to bear typically turn out to be deceptive. Moreover, segments that cannot surface in principle would contradict what I regard as an important leading conjecture: all segments are physically interpretable. Physically uninterpretable segments should be admitted in the linguistic ontology only in the face of unequivocal positive evidence. No such evidence is known.

Independently of these empirical considerations, experience indicates that working with a fully explicit theory that forgoes total well-typedness gets unwieldy to an extent that outweighs any doubt about its being ontologically well-motivated. I thus see no reason to drop, but strong reasons to retain, total well-typedness.

[3] Historically, "underspecification" has more often been motivated by considerations of markedness. This motivation has been obsolete at least since Kean (1981) and Höhle (1982).

2.3 Some comments on the signature

According to (1), then, each *segmproper* object bears an attribute TONGUE whose value bears attributes indicating the horizontal and vertical tongue positions that characterize vowel gestures. I follow Odden (1994) in classing the narrowing of the frontal oral tract associated with "rounding" in vowels together with the horizontal specification.

Consonants in addition bear an attribute CONSTR(ICTION) whose value indicates one or more places of consonantal constriction. Thus, the CONSTR value is a list that is treated in such a way that the order of list members is immaterial. In this way, double articulation of stops and nasals – which may be phonemic or may result from contextually induced coarticulation – can be captured.

At the same time, consonants bear the tongue specifications that characterize vowels. This captures the fact that vowel gestures typically "act as a kind of background to the "figure" of the consonants" (Browman & Goldstein 1990: 354). It is exploited phonemically in languages that have distinctive secondary articulations, such as palatalization, velarization or labialization.

Tense vowels often differ from lax vowels by being articulated with the tongue root advanced. This is not necessarily true of low vowels, though. A more general (if more complex) characterization might be centralization in lax vowels. In consonants, the *tongue* subsort typically has no perceptually appreciable consequence. But in some languages, TONGUE values of sort *tense* and *lax* cooccur with a battery of different articulatory properties in consonants, cf. Local & Lodge (1996). Thus, the phonetic correlates of the subsorts of *tongue* are not fully universal and are in any case somewhat indirect.

Major class and manner distinctions (vowel vs. consonant, sonorant vs. obstruent, etc.) are captured in (1) by subsorts of *segmproper*. (Inclusion of *affricate* among the manner sorts is meant to be hypothetical; it raises questions that I cannot discuss here.) Non-atomic sorts can thus contribute to phonetic characteristics just like atomic sorts.

Considering the attribute ACHIEVEMENT that is born by *place* objects, there is evidence (mainly from stops) that the degree of constriction that is characteristic of consonants can be reduced under the control of the speaker, often leading to the perception of assimilation or loss; see, e.g., Nolan (1992), Barry (1991), Jun (1996). This can be captured by the ACHIEVEMENT value. While values of sort *full* and *reduced* should be unproblematic, the value sort *zero* points to an important topic of research.

Nolan (1992) classifies as "zero" consonant productions where no closure is measured (by the method used). Correspondingly, hearers under ordinary conditions typically do not perceive a closure in cases like this. The main difference with mere absence of closure lies in the fact that under favourable conditions, hearers do perceive a closure with more than chance frequency. Also, zero productions are typically found in free variation with reduced productions, which is natural if zero is understood as extreme reduction. Still, it is obvious that this concept is empirically difficult, and experiments need to be replicated under the most careful control of all potentially relevant factors. But I take it that at least some studies have made it plausible that zero closure, as distinct from absence of closure, is real.

In fricatives, reduced and zero achievements correspond to "approximant" and vowel-like degrees of constriction, respectively. A case in point might be the rhotic in Standard German, which is a fricative (or approximant) when in a syllable onset, as in [tiː.ʁə] *Tiere* 'animals', but vowel-like in a coda, as in [tiːʌ] *Tier* 'animal'. (Final obstruent devoicing is only observed with unreduced constrictions.)

Somewhat speculatively, I assume that the ACHIEVEMENT attribute is also appropriate for *voicing* objects. Its phonetic meaning differs slightly for *voiced* and *voiceless* objects. I follow Goldstein & Browman (1986) (and Ladefoged & Maddieson 1996: 49 ff.) in considering the state of the glottis to be the primary characteristic of systematically voiced vs. voiceless segments: in "voiced" segments, the vocal folds are adducted, which is just their neutral state in the speech mode; in "voiceless" segments of sort *spreadgl*, they are actively abducted. For there to be voice, transglottal pressure must in addition be kept sufficiently high. The ACHIEVEMENT value relates to the active gesture.

In a *voiced* object, a value of sort *reduced* or *zero* means that transglottal pressure is reduced. Thus, unvoiced word-initial plosives as in Standard German [d̥uː] *du* 'thou' can be analysed as having a VOICING value of sort *voiced* that has an ACHIEVEMENT value of sort *zero*, perceptually almost indistinguishable from the unaspirated [tuː] *tu* 'do' of Austrian German, which has a VOICING value of sort *spreadgl*. (Cf. Flege 1982 for English.)

In a *spreadgl* object, an ACHIEVEMENT value of a sort other than *full* means that the vocal folds are less than optimally abducted; in a *closedgl* object, it means that the vocal folds are not fully closed. If at the same time transglottal airflow happens to be large enough, sufficient transglottal pressure may build up to cause voice to be perceived.

2.4 On token (non-)identities

By using subsorts of *segment* to distinguish long from short segments, I try to forestall any temptation to view slots in a list of segments (i.e., individual *nelof*-

segment objects) as time units. A physically interpreted list of segments can be viewed to be a "timing tier" in two respects. First, the articulatory gestures that correspond to gesturally relevant components[4] of a segment overlap temporally. A segment thus corresponds to a constellation of gestures during a temporal interval. Second, the sequence of segments in the list corresponds to a temporal sequence of constellations of gestures. But the duration of temporal intervals corresponding to segments in a given list varies drastically in accordance with their position in syllables and other factors; cf., e.g., Smith (1991; 1995), and Browman & Goldstein (1988). Thus, there is no unit of time that could consistently be associated to slots in a given list. But consistent association is presupposed when a segment is explained to be long just in case it occupies two adjacent slots, as is usually done in "skeletal" theories. Otherwise this explanation is just a marking device for phonological length as phonetically arbitrary as any other.

The main phonological motivation for the double-slot analysis is the fact that phonotactically, long vowels often pattern with diphthongs and long consonants, with consonant clusters. Closer inspection, however, suggests that these phonotactical facts are more adequately captured by syllable theory in conjunction with a theory of phonological weight. (But I take the theory of weight to be a research topic rather than a fully developed theory; cf. Kenstowicz 1994: §8.4, Perlmutter 1995, and Hume et al. 1997 for overviews and discussion.)

I adopt a reformulated version of the "Sharing Constraint" in Scobbie (1997: 93, (3.13)):

(4) In a list of segments $\langle s_1, \ldots, s_n \rangle$, if a component *o* of s_1 that corresponds to an articulatory gesture is also a component of s_j, then *o* is also a component of every s_i with $1 < i < j$.

If one token gesture is overlapped by two constellations of overlapping gestures, it is overlapped by each such constellation in between.[5] Thus, (4) is necessarily true for physically interpreted lists of segments (UTTERANCE S-STRING values; cf. §4). I require not only all segments, but also all lists of segments to be physically interpretable, hence it must be true for all such lists. Thus, (4) is just a natural consequence of any empirically clear explication of autosegmental phonology, such as found, e.g., in Sagey (1988).

As both Sagey (1988) and Scobbie (1997) note, (4) is inconsistent with many uses the "Obligatory Contour Principle" and "autosegmental spreading" in non-concatenative morphology have been put to. The obvious conclusion, drawn in

[4] An object *o* is a "component" of an object *o'* just in case *o* is the value of a path on *o'*. (The path can be empty.)

[5] I assume physical events to be temporally connected by necessity. This assumption is rejected in Bird & Klein (1990: 41) and Bird (1995: 73).

both Sagey (1988: 115f.) and Scobbie (1997: 223ff.), is that "long distance" identities are not token but type identities.[6] One can expect to see direct evidence for type (vs. token) identity in particular with consonants, e.g., in reduplication and in Semitic biradicals. It is indeed well-known that long distance geminates are not true geminates at all. Cf. Scobbie (1997: Chapter 6), and Gafos (1998) for discussion of these and related facts.

One particularly important sort of long distance identity is found in vowel harmony. Formally, the geometry of (1) allows a TONGUE value component to extend over an unrestricted number of segments, and this seems indeed to be the case with lip rounding in the rounding harmony of Turkish vowels (Boyce 1990). But for several languages, there is evidence that, e.g., in a sequence such as [ipi], there are typically two tokens of the vowel gesture, rather than one token extending over the whole string (Gay 1981: 137, Bell-Berti & Harris 1981: 12, McAllister & Engstrand 1991), and there is no evidence that vowel harmony languages necessarily disobey this pattern. Rather, there is acoustic evidence that some obey it (Bessell 1998). Moreover, vowel harmony systems often include "transparent" vowels that allow harmony to operate across them even though they fail to have the harmonically relevant phonetic property. Thus, Scobbie (1997: 223) is clearly correct in assuming that vowel harmony deals essentially with identities of types rather than tokens.

2.5 Phonemic sorts

I posit phonemic sorts (similar to those in Mastroianni 1993) as partitionings of major class and manner sorts; individual languages may differ (to some extent) in their inventory of phonemic sorts. As an illustration, some (incomplete) partitionings for German are introduced in (5), with some of the attending restrictions given in (6). ('FIRST' and 'REST' are abbreviated FT, RT; other abbreviations are transparent.)

(5) *vowel*: *sort*_i, *sort*_ɪ, *sort*_u, *sort*_ʊ, *sort*_y, *sort*_ʏ, …
plosive: *sort*_k, *sort*_g, *sort*_t, *sort*_d, *sort*_p, *sort*_b.
nasalcon: *sort*_n, *sort*_m, *sort*_ŋ.

[6] Two objects are "type identical" if they have some significant property in common. An important case of type identity can be enforced by "sort equations": a description language expression of the form $\tau_1 \simeq \tau_2$ denotes the subset of U such that on each member, paths τ_1 and τ_2 are defined and the values of the paths are of the same maximally specific sort. (See §6 for an example.)

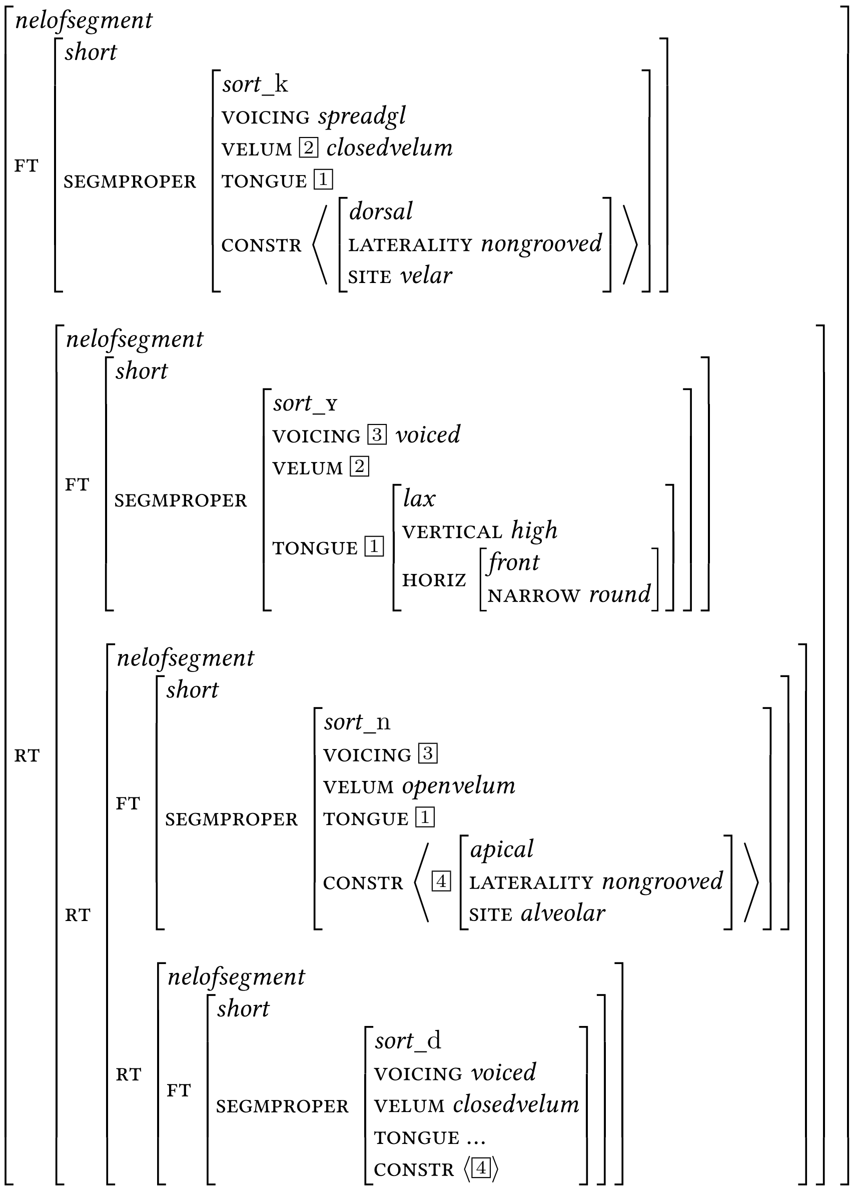

Figure 2: Phonemic structure of [kynd]

(6)

$$\textit{sort}\_\mathrm{i} \rightarrow \textsc{tongue} \begin{bmatrix} \textit{tense} \\ \textsc{vertical}\ \textit{high} \\ \textsc{horiz} \begin{bmatrix} \textit{front} \\ \textsc{narrow}\ \textit{nonround} \end{bmatrix} \end{bmatrix}$$

$$\textit{sort}\_\textsc{y} \rightarrow \textsc{tongue} \begin{bmatrix} \textit{lax} \\ \textsc{vertical}\ \textit{high} \\ \textsc{horiz} \begin{bmatrix} \textit{front} \\ \textsc{narrow}\ \textit{round} \end{bmatrix} \end{bmatrix}$$

$$\textit{sort}\_\mathrm{k} \rightarrow \begin{bmatrix} \textsc{voicing}\ \textit{voiceless} \\ \textsc{constr ft site}\ \textit{velar} \end{bmatrix}$$

$$\textit{sort}\_\mathrm{d} \rightarrow \begin{bmatrix} \textsc{voicing}\ \textit{voiced} \\ \textsc{constr ft site}\ \textit{alveolar} \end{bmatrix}$$

$$\textit{sort}\_\mathrm{n} \rightarrow \textsc{constr ft site}\ \textit{alveolar}$$

Sorts like these do not only serve to keep descriptions more compact, but play a useful role in enforcing type identities and in determining which components of segments are (not) free to subphonemic variation.[7]

A conceivable description of the initial four members of an S-STRING value for German [kʏndɪɡə] *kündige* 'terminate' is given in Figure 2. (I assume that in this configuration the tongue gestures of the vowels overlap the adjacent consonants and that with voiced obstruents a voicing gesture typically sets in.)

3 Phonetic strings

Phonetic strings may exhibit segmental phenomena that are not naturally captured by s-strings. A possible case in point are "transitional" segments. For instance, corresponding to the substring [ʏn] as described in Figure 2 there probably is a phonetic string where the velic opening gesture sets in before the alveolar constriction gesture does; this might be described as in Figure 3.

[7]In consonants whose CONSTRICTION value has more than one member, the role of phonemic sorts is formally nontrivial. The order of list members being immaterial, a voiced plosive with CONSTR value ⟨*dorsal*, *labial*⟩ can be of *sort*_b or of *sort*_g. In a language that has a phonemic double articulation sort such as *sort*_gb, a segment with the same CONSTR value could also be of that sort.

There may be further roles for phonemic sorts. Some speakers of Standard German progressively assimilate syllabic alveolar nasals to uvular [ʁ]: they have [tiː.ʁɴ] next to [tiː.ʁn] *Tieren* (dat. pl.). What sort should the uvular nasal belong to? There are several possible responses, one of them being that *sort*_n objects are not unconditionally required to be alveolar, as they are in (6), but only when they are in an environment that does not induce assimilation.

$$\begin{bmatrix} \text{FT SEGMPROPER} & \begin{bmatrix} \textit{sort\_}\text{ʏ} \\ \text{VELUM } \textit{closedvelum} \end{bmatrix} \\ \text{RT} & \begin{bmatrix} \text{FT SEGMPROPER} & \begin{bmatrix} \textit{sort\_}\text{ʏ} \\ \text{VELUM } \boxed{1} \end{bmatrix} \\ \text{RT FT SEGMPROPER} & \begin{bmatrix} \textit{sort\_}\text{n} \\ \text{VELUM } \boxed{1}\ \textit{openvelum} \end{bmatrix} \end{bmatrix} \end{bmatrix}$$

Figure 3: Transitional segment in [ʏʏ̃n]

As noted earlier, segments correspond to time intervals (of varying durations) of overlapping articulatory gestures. In this respect, transitional segments as in Figure 3 are no different from phonemic segments as in Figure 2. More particularly, in Figure 2 the alveolar closure of [nd] and the tongue characteristics of [kʏn] are both partially overlapped by the velar opening of [n]. The only new aspect in Figure 3 is the lack of alveolar closure in [ʏ̃]. There is thus no reason to exclude transitional segments from the universe of linguistic objects in principle.[8]

I assume that transitional segments do not "feed" morphophonological phenomena. It thus should be sufficient to associate strings as in Figure 3 with signs that are not embedded in another sign. Unembedded signs, which can be performed as (complete) utterances, need to be distinguished by a special sort for quite independent syntactic, semantic and pragmatic (e.g., illocutionary force) reasons. Adapting a proposal in Richter (1997: 134ff.), I partition the sort *phrase* and require unembedded phrases to bear a distinguished phonological attribute whose value hosts a non-empty list of segments:

(7) *phrase* …
  embedded-phrase
  unembedded-phrase UTTERANCE *phon*

(8) *unembedded-phrase* → UTTERANCE S-STRING *nelofsegment*

For ease of expression, I reserve the term 's-string' to PHON S-STRING values and call an UTTERANCE S-STRING value a "p-string." Figure 3 can now be understood

[8]On the face of it, transitional segments such as [ʏ̃] can be avoided by allowing values of paths on segments to be lists whose order of members is temporally interpreted. Thus, [ʏʏ̃] would be one segment with a VELUM value ⟨*closedvelum*, *openvelum*⟩. I prefer to eschew "contour" values like that, though: they complicate matters in that they, in effect, introduce something like segments within segments, yet do not, as far as I see, solve any problem that transitional segments might be attended with.

as (an informal rendering of) a description language expression that denotes (a set of) components of some p-strings.

In simple cases, a phrase's p-string may be identical to its s-string. In cases where transitional segments are to be components of signs, the p-string is related to the s-string in the way suggested by the relation of [ʏʏ̃n] to [ʏn]. In general, though, the relation is not necessarily that simple. For German [ɔʁ.dnə] *ordne* 'put in order', many speakers have an alternate pronunciation [ɔʁ.nə]. The plosive [d] cannot be overlapped by a lowered velum gesture, according to (1), hence it cannot appear as a member of the p-string in the latter case. The same is often observed with syllabic nasals, as in [leː.ŋ] next to [leː.gŋ] *legen* 'lay'. Similarly, [bə.am.tn] *Beamten* 'officials' has an alternate pronunciation [bə.am.pm], discussed in Kohler (1992), where the alveolar constriction of [tn] is not just overlapped, but in fact replaced, by the bilabial constriction from [m]. If these variations are to be accounted for by the relation of p-strings to s-strings, as seems reasonable, the relation cannot in general preserve segments or even phonemic sorts.

4 Physical interpretation

Intuitively, in a token *unembedded-phrase* object, components of its p-string are intended to correspond to (possible) physical events. As an explication, I propose there is a total bijective function Φ from the set of p-strings of language L to the set of u-equivalences of L, where the latter partitions the set of possible utterance events of L. To explain this, I temporarily suppose that a u-equivalence is just a singleton set. Thus, each p-string (a maximal *nelofsegment* object) is mapped to a complete utterance event (the member of a u-equivalence) such that each component of a gestural sort (e.g., *voicing*, *velum*, *place*, *lateralclosure*) is mapped to an articulatory gesture and each *segment* component, to a constellation of such gestures during a section of the utterance.

More exactly, for a given (token) p-string, I take there to be a choice among possible utterance events that differ along continuous dimensions that are considered to be "stylistic," i.e., linguistically irrelevant: loudness, pitch level, speaking rate, etc. Thus, a u-equivalence actually is a maximal set of stylistically alternative possible utterance events; it clearly is non-denumerable.

We need to have Φ in order to give an accurate empirical explication to our phonological notions. The apparatus sketched in the previous sections is unable to characterize well-known properties of gestures adequately. Velar closure events, e.g., differ considerably (in many languages) in accordance with adjacent (front or back) vowel gesture events; conversely, low vowel gesture events that overlap an alveolar constriction event are very different from the gesture events for the same vowel without alveolar overlap. That is, the notion of "gesture" that we have relied on is a highly abstract one; the precise properties of individual gesture events cannot be explicated without a detailed theory of the coarticulatory interaction of different gestures.

Any such theory must take seriously the fact that gestures are constituted by actions of spatiotemporal physical entities ("articulators" and air volumes) that change their location over time. To be adequate, such a theory – however abstract it might be – must have unrestricted recourse to the relevant physical theories and their attendant mathematical apparatus. For brevity, I call such a theory a "physical" theory.

One physical theory of that kind is known as "task dynamics." Cf. Saltzman (1995) for a general exposition, and Saltzman & Munhall (1989) for a detailed one; also McGowan & Saltzman (1995) for an extension. Adapting it to the present frame of reference (and simplifying somewhat), we can say that the physical theory defines a mapping from p-strings and their component objects to maximal sets of stylistically alternative possible physical events in accordance with an object's gestural properties and the influences of contemporaneous and immediately preceding physical events.[9]

I do not take models of grammars to include physical events. Rather, phonological linguistic objects are as abstract as any other linguistic object, and (sets of alternative) possible events constitute the interpretation (in the model-theoretic sense) of the relevant linguistic objects, with a physical theory defining the interpretation function, i.e., Φ.[10]

As we have seen in the previous section, and will see again later on, a component of an s-string is not necessarily also a component of a p-string. Although I consider it important that each (list of) segment(s) be physically interpretable in principle (cf. (4) above), there is no reason to insist that each of them is actually interpreted. The natural assumption is that with respect to the set of *nelofsegment* objects, Φ is partial in that it is only p-strings that are in its domain.

There are good reasons (in particular, from acoustically hidden articulatory

[9]To capture the role of syllable structure and stress for the temporal duration and phasing of gestures, the physical theory must access the full UTTERANCE value.

[10]I thus concur with Sagey (1988), Pierrehumbert (1990), Coleman (1998) and others that the relation of phonological linguistic objects to physical events is "semantic" in nature. I will not explore here the ontologically more parsimonious hypothesis that those objects are physical events themselves, so that some Φ' maps events as structured by sorts and attributes to the same events as structured by a physical theory.

gestures; cf., e.g., Browman & Goldstein 1990: 363ff.) to require (sets of alternative) articulatory events to be in the range of Φ. But in principle, the range might also include certain kinds of acoustic events (e.g., for vowels) that are only secondarily related to articulatory events, as argued for in Ladefoged (1990) and Perkell et al. (1995).

It seems clear that the defining characteristics of Φ can in large part be universal. The assumption that there is a strictly universal core to them is in fact a conceptual necessity if (at least major aspects of) (1) and (2) are to have the empirical import they are intended to have. But it seems equally clear that they are not fully universal. Thus, fine details of gestures in different languages just escape the categorial distinctions that can be adequately captured by sorts of linguistic objects (cf. Ladefoged 1980). Some details of Φ's characteristics apparently have to be learned for individual languages; but the learning theory for these details may be conceived to be quite weak.

According to Solé (1995), Spanish shows in vowels before nasal consonants significant anticipatory nasalization which is durationally constant across varying vowel durations in differing speaking rates. In American English, by contrast, anticipatory nasalization sets in at the beginning of the vowel (at the end of a preceding consonant), regardless of the vowel's duration. Solé (1995) suggests that the nasalization in English is "phonological," whereas in Spanish it is an "automatic phonetic" phenomenon.

We can reconstruct this intuition by assuming that in English, there is one fully nasal *vowel* object in the p-string, whereas in Spanish, there is no nasal vowel in it, not even a transitional one as in Figure 3. Rather, a transitional nasal vowel event is predicted by Φ. This is formally possible since the mapping from lists of segments to events may be less than trivially transparent. It is also compatible in principle with the fact that some languages otherwise similar to Spanish differ in details of nasalization (cf. Clumeck 1976), since we recognize that parts of Φ's characteristics can be learned.

This construal appears plausible. In English, the onset of velic lowering seems to be phased with respect to the offset of a consonant gesture preceding the vowel, and there does not seem to be a natural alternative way to express this. In Spanish, the constant phasing of the onset of velic lowering with respect to the onset of the nasal consonant gesture is in fact what we might expect of gestures that are coupled by a sort (subsort of *nasalcon*). Still, the present state of theorizing about Φ does not warrant the conjecture that transitional segments as hypothetically illustrated in Figure 3 are universally non-existent. (Cf., e.g., Mohanan 1986: 164 for a candidate example.)

According to Cohn (1993), the velocity of velic opening (or closing, in persevering nasalization) in predictably nasalized vowels adjacent to nasal consonants is (under most circumstances) much slower in English than it is in Sundanese. Although Cohn (1993) interprets this as a difference between "phonetics" and "phonology," it simply seems that in English, there is one (long, and hence, slow[11]) velic opening/closing gesture extending through the consonant and the vowel, whereas in Sundanese, there is a sequence of two (overlapping) velic gestures for the consonant and the vowel. If correct, this means that in Sundanese, but not in English, there are two different *openvelum* objects in adjacent p-string members. There are thus many more instances of type (vs. token) identities in strings of segments than assumed in much recent work. Cf. Saltzman & Munhall (1989: 362–365) for related considerations on phasing relations.

Just as with transitional segments, the question arises whether the work of ACHIEVEMENT values can and should be done by the definition of Φ. Two considerations might support this alternative. Reductions do not seem to play a role in phonemics;[12] this would follow from them not being accessible in s-string members. And when a *place* (or *voicing*) component of an s-string fails to be a component of the p-string, the ACHIEVEMENT value of that component may in many cases be spuriously ambiguous. On the other hand, languages are known to differ in the conditions and the extent to which reductions are used (cf. Jun 1996). Relegating them to Φ thus locates further aspects of linguistic knowledge outside the grammar and presupposes a rather strong learning theory for Φ's characteristics.

How the grammar of phonetics and the theory defining Φ interact is a large topic of research that can only proceed by working out detailed theories of both. The presence of the UTTERANCE and ACHIEVEMENT attributes is thought to be conducive to this enterprise.

5 Morphology: Four basic issues

For morphophonology, PS94's notion of signs is highly attractive in that both simple and complex signs bear a PHONOLOGY attribute. This fact by itself provides the multistratality needed to account for "postlexical" phonological phenomena

[11] In long consonants, the closing movement is much slower than in short consonants (Smith 1995: 217 ff.). This accords well with the assumption in Kröger (1993: 222) that articulator velocity is a function of the gesture's duration and amplitude.

[12] However, approximants and fricatives are reported to contrast phonemically in some languages (Ladefoged & Maddieson 1996: 76 and 324).

(e.g., sandhi). This notion, moreover, generalizes naturally to morphology such that words are built from smaller signs which, by bearing their own PHONOLOGY attributes, provide the strata that I hypothesize are necessary and sufficient to account for word-internal phonological alternations.[13] (See also Orgun (1996) for a vivid defense of the same view.)

Although many aspects of morphological theory can be left open for the purpose of morphophonology, four basic topics need to be commented upon: (i) lexical licensing, (ii) combinatorial properties of morphemes, (iii) phonological effects of morphological combining, (iv) the triggering of the phonological effects.

In natural languages the smallest signs are conventionalized tuples of (at least) semantic, phonological, morphosyntactic and combinatorial properties. To be able to account for the tuples being conventionalized (rather than for any formal reason), PS94, like most grammatical theories, requires the smallest signs in a model (in PS94: words, i.e., objects of sort *word*) to be "licensed" by "lexical entries." Although PS94 does not indicate how licensing is to be formally achieved, one obvious way (taken, e.g., in Pollard 1993) is to include a "Word Principle" of the form (9) among the restrictions of the grammar:

(9) $word \rightarrow (\mathrm{le}_1 \vee \ldots \vee \mathrm{le}_n)$

Thus, each word must satisfy one of *n*-many lexical entries le_i, each of which is a description language expression that denotes the set of objects that are "licensed" by that entry. The set of disjuncts in the consequent of (9), then, constitutes a "lexicon."

In a language with productive derivational morphology or/and compounding, the set of disjuncts in (9) would typically have to be infinite, which is impossible by the definition of the description language. The natural response (given, e.g., in Krieger & Nerbonne 1993) is to recognize formally that words can have smaller signs as components, and modify (9) accordingly.

Empirically, larger signs can also be conventionalized in that their properties do not fully derive from the properties of their component parts by general rule. This is sometimes seen in phrases, and often in complex words. To deal with cases like these, we would need to have a general formal theory of idioms. Although the theory of collocations sketched in Richter & Sailer (1999: §4) appears to be a promising basis to build such a theory on, I ignore these cases for the time being.

As for the second topic, minimal signs (morphemes) differ in their combinatorial properties just as words differ in theirs, except that the selectional mech-

[13]The way morphology and phonology interact here can be viewed as a straight explication of a core idea of "Lexical Phonology," e.g., in Mohanan (1986: 142 f.)

anisms for morphemes are considerably more powerful than those for words. Although there is no shortage of empirical research (e.g., Fabb 1988, Stonham 1994, and references therein), there does not appear to be a (successful) general formally explicit theory of selection.

Our primary interest is in the phonological effects on a parent of the combination of morphological daughters, i.e., the morphophonology. The simplest cases of concatenative morphology are similar to phrasal segmental phonology in that just the order in the parent of the daughters' concatenated S-STRING values must be specified, possibly including edge effects (sandhi). But sometimes, the resulting s-string must in addition conform to phonological rules (such as umlaut) that go beyond edge effects and may be specific to individual (classes of) daughters. In nonconcatenative morphology, the result of combination is nontrivial to begin with. The question, then, is how the particular phonological effects of combination are formally triggered by the elements combined. Given that the more complicated phonological effects on a parent are typically induced by affixes, one may expect this to be a consequence of the more powerful selectional mechanisms for morphemes.

In a sketch of inflexional morphology, Krieger & Nerbonne (1993) employs an unusually expressive way of lexical licensing. Words are supposed to contain a "stem" as value of a path MORPH STEM and an "ending" as value of a path MORPH ENDING. There is a lexicon for objects of sort *word* as indicated in (10a) (p. 105), and there appears to be a second lexicon for *word* objects as indicated in (10b) (p. 122):

(10) a. $word \rightarrow ([\text{MORPH ENDING } \mathrm{e}_1 \wedge \text{SYNSEM } \mathrm{es}_1 \wedge \mathrm{ed}_1] \vee \ldots$
$\ldots \vee [\text{MORPH ENDING } \mathrm{e}_m \wedge \text{SYNSEM } \mathrm{es}_m \wedge \mathrm{ed}_m])$

b. $word \rightarrow ([\text{MORPH STEM } \mathrm{s}_1 \wedge \text{SYNSEM } \mathrm{ss}_1 \wedge \mathrm{sd}_1] \vee \ldots$
$\ldots \vee [\text{MORPH STEM } \mathrm{s}_r \wedge \text{SYNSEM } \mathrm{ss}_r \wedge \mathrm{sd}_r])$

Thus, (10a) requires each ending e_i with $1 \leq i \leq m$ to cooccur with a certain SYNSEM value of the word, described by es_i, and with further (e.g., phonological) properties of the word or some part of it, described by ed_i; and (10b) requires the same of each stem s_i with $1 \leq i \leq r$.

In effect, then, the sets of disjuncts in (10a) and (10b) are lexicons for objects (endings and stems) that are proper components of a larger *word* object that satisfies the antecedent. Therefore, an embedded object can determine any property of the word it is a component of. Hence, lexicons like these can easily answer most questions of selection (including mutual selection of the components, if there is a pair of such lexicons) and can specify the effects of combination directly, thereby answering the triggering question. Thus, the four topics remarked upon above receive a formally simple homogeneous treatment, just by the particular way of lexical licensing. However, expressive though this approach is, it has its limitations, as will be seen in a moment.

For a sketch of word structure, we assume a simple extension of the sort hierarchy below *sign*:

(11) *sign* …
  phrase …
  word MORPH *morph*
  morph
    simplemorph
    complexmorph MHEAD *morph*
      MNONHEAD *morph*

This sketch is simplified in many ways; e.g., it only allows for morphologically endocentric structures. An example from German may illustrate structures motivated on morphological grounds and their ensuing complexities.

The adjective *prüfungslos* 'examinationless' in Figure 4[14] contains a suffix *-los* '-less' that derives adjectives from nouns. In it, the regular voicing alternation in German obstruents ([z $\sim$ s]) can be seen. I will not go into this; rather, the somewhat different alternation in Russian obstruents will be discussed in §7. *Prüfung* 'examination' is a noun derived from the free verbal stem *prüf-* 'examine' by the suffix *-ung* '-ation'. *-s-* is a "linking morpheme" (Fugenmorphem) that combines with a noun to the left to yield a bound complex that combines with certain suffixes, as in the present case, or with a free stem to the right. Thus, if being bound is analysed as a matter of selection, *prüfungs-* and *-los* must mutually select each other.

If the binary branching morphological structure assumed in Figure 4 is correct, the combinatorial properties of *-s-* cannot be captured by a set of lexicons for components of *complexmorph* objects in the manner of (10). A lexicon that contains (12a) (suitably enriched) as a member can account for *-s-* being bound to its left sister. But to capture the fact that its parent constituent is bound to its right sister, there would have to be another lexicon containing (12b) as a member. It surely is irritating that there should be two different lexical entries for *-s-*. But worse, the lexicon containing (12b) does not contain other members such that their disjunction could correctly capture the distribution of *-s-*.

[14]Here and later on, phonetic symbols that appear as (or in) list members are meant to informally indicate relevant properties of *segment* and *segmproper* objects. They do not indicate phonemic sorts. The attribute symbols MORPH, PHON(OLOGY) and S(EGMENTAL)-STRING are abbreviated M, P and S-S.

```
[ word
  P S-S ⟨p, ʁ, yː, f, ʊ, ŋ, s, l, oː, s⟩
  M [ complexmorph
      P S-S ⟨p, ʁ, yː, f, ʊ, ŋ, s, l, oː, z⟩
      MHEAD [ simplemorph
              P S-S ⟨l, oː, z⟩ ]
      MNONHEAD [ complexmorph
                 P S-S ⟨p, ʁ, yː, f, ʊ, ŋ, s⟩
                 MHEAD [ simplemorph
                         P S-S ⟨s⟩ ]
                 MNONHEAD [ complexmorph
                            P S-S ⟨p, ʁ, yː, f, ʊ, ŋ⟩
                            MHEAD [ simplemorph
                                    P S-S ⟨ʊ, ŋ⟩ ]
                            MNONHEAD [ simplemorph
                                       P S-S ⟨p, ʁ, yː, f⟩ ] ] ] ] ]
```

Figure 4: Morphological structure of *prüfungslos*

(12) a.
```
[ MHEAD [ simplemorph
          PHON S-STRING ⟨s⟩ ]
  MNONHEAD … ]
```

b.
```
[ MNONHEAD MHEAD [ simplemorph
                   PHON S-STRING ⟨s⟩ ]
  MHEAD … ]
```

Clarifying the interaction of lexical licensing, combinatorial properties of morphemes, and triggering the phonological effects of the combination of morphemes is thus left to future research. I henceforth concentrate on the effects themselves.

6 Nonconcatenative morphology

Sierra Miwok is known for its multiform nonconcatenative morphology; see Smith (1985; 1986), Sloan (1991) and references therein. Part of its inflexional verbal stem formation has also received an illustrative HPSG analysis in Bird & Klein

(1994) (based on Goldsmith 1990: 83–95).

For a typical derivational pattern, we consider (13) with the monomorphemic bases in (14), after Smith (1985: 376 f.):

(13) a. *ʔojsi-li:p-* 'quadruplets'
b. *mahko-lo:p-* 'quintuplets'
c. *naʔča-la:p-* 'ten at a time'

(14) a. *ʔojis:a-* 'four'
b. *mah:oka-* 'five'
c. *naʔa:ča-* 'ten'

The morpheme complexes in (13) conform to a template CVCCV plus a suffix 'lV:p', regardless of the form of the base, although the segmental substance is that of the base. The vowel of the suffix is type identical to the last vowel of the template. The third vowel of the base is elided, since it does not fit into the template.[15]

$$\begin{bmatrix} \textit{complexmorph} \\ \text{P S-S} \left\langle \begin{bmatrix}\textit{short}\\ \text{S } \textit{con}\end{bmatrix}, \begin{bmatrix}\textit{short}\\ \text{S } \textit{vow}\end{bmatrix}, \begin{bmatrix}\textit{short}\\ \text{S } \textit{con}\end{bmatrix}, \begin{bmatrix}\textit{short}\\ \text{S } \textit{con}\end{bmatrix}, \begin{bmatrix}\textit{short}\\ \text{S } ① \textit{vow}\end{bmatrix} \mid \boxed{2} \right\rangle \\ \text{H} \begin{bmatrix} \textit{simplemorph} \\ \text{P S-S } \boxed{2} \left\langle \begin{bmatrix}\textit{short}\\ \text{S l}\end{bmatrix}, \begin{bmatrix}\textit{long}\\ \text{S } ①\end{bmatrix}, \begin{bmatrix}\textit{short}\\ \text{S p}\end{bmatrix} \right\rangle \end{bmatrix} \\ \text{N} \begin{bmatrix} \textit{simplemorph} \\ \text{P S-S} \left\langle \begin{bmatrix}\textit{short}\\ \text{S m}\end{bmatrix}, \begin{bmatrix}\textit{short}\\ \text{S a}\end{bmatrix}, \begin{bmatrix}\textit{long}\\ \text{S h}\end{bmatrix}, \begin{bmatrix}\textit{short}\\ \text{S o}\end{bmatrix}, \begin{bmatrix}\textit{short}\\ \text{S k}\end{bmatrix}, \begin{bmatrix}\textit{short}\\ \text{S a}\end{bmatrix} \right\rangle \end{bmatrix} \end{bmatrix}$$

Figure 5: Morphophonological structure of *mahko-lo:p-*

Some aspects of the intended analysis of (13b) can be seen in Figure 5. (MHEAD, MNONHEAD and SEGMPROPER are abbreviated H, N and S.) Like Scobbie (1997: 224 f.), and unlike most work on nonconcatenative morphology, I see no reason to posit special attributes ("tiers/planes") just for consonants or vowels. The pair

[15]Elisions (and insertions of "default" vowels and consonants) are a well-known feature of Miwok morphology; cf. the references above. Ignoring this, Bird & Klein (1994: 468) asserts that "the phonology of a complex form can only be produced by either unifying or concatenating the phonologies of its parts."

of encircled tags, '①', indicates sort identity; in the present case, identity of the phonemic sort that [o] belongs to. For the reasons noted in the previous section, I leave open how the suffix (the H value) triggers the phonological form of its parent. We can see that the P S-STRING value is the CVCCV template, followed by the H P S-STRING value (tagged 2). The *consonant* objects of the template are *segmproper* objects of the N P S-STRING value, in left to right order; equally for the *vowel* objects.[16]

7 Morphophonology: Russian obstruents

7.1 Background

For an illustration of classical morphophonological considerations, we turn to the voicing alternation in Russian obstruents. This case is famous since Halle (1959: 21–24) used it in an argument against "empiricist" versions of phonology, effectively wrecking their distinction between phonemes and morphophonemes.

The case has gained additional fame through two kinds of ill-understood complications. First, the labiodental fricatives seem Janus-faced in that they partly pattern like ordinary obstruents, partly like sonorants (Jakobson 1956). Second, and somewhat similarly, a sonorant that immediately precedes an obstruent can, under certain conditions, pattern like the obstruent it precedes (Jakobson 1978). For attempts to capture the full range of data, see Wheeler (1988) and Kiparsky (1985: §2) (which both rely heavily on "underspecification"), and references therein.

Exciting though these complications are, I will disregard them and largely keep to the simplifying introductory description in Halle (1959: 22): "voicing is distinctive for all obstruents except /c/, /č/ and /x/, which do not possess voiced cognates. These three obstruents are voiceless unless followed by a voiced obstruent, in which case they are voiced. At the end of the word, however, this is true of all Russian obstruents: they are voiceless, unless the following word begins with a voiced obstruent, in which case they are voiced."

We thus find the voicing alternation at the end of the words in (15) (after Halle ib.) just like those in (16):

(15) a. *žeč li* [ʒetʃlʲi] 'should one burn?'
b. *žeč by* [ʒedʒbɨ] 'were one to burn'

[16]Here and throughout, the exposition of complex restrictions is highly informal. Explicit formulations would rely on the restricted theory of quantification and relations (based on King 1989) defined in Richter (1997: 22–35) and explored in Richter & King (1997). See also Richter (1999).

(16) a. *gorod Ufa* [gɔrətufa] '(the) town Ufa'
b. *gorod Baku* [gɔrədbaku]
c. *gorod* [gɔrət] (nom. sing.)
d. *goroda* [gɔrədə] (gen. sing.)

The affricate in (15a) as well as the alveolar plosive in (16a) are voiceless before the non-obstruent in the following word, but are voiced before the voiced obstruent in (15b), (16b). When nothing follows, as in (16c), obstruents are voiceless. Before a vowel in the same word, obstruents can be either voiced or voiceless, such as [d] in (16d) and [k] in (16b); but [dʒ, dz, ɣ] do not occur in this environment.

These regularities need to be detailed further in three respects (Halle 1959: 63f.). (i) By the "end of a word" is meant the end of a phonological word (a domain of accent rules). Most prepositions constitute a proper part of a phonological word; hence final obstruents in them are not devoiced when followed by a non-obstruent. (ii) By a "following word" is meant a following phonological word within the same "phonemic phrase." There is considerable freedom as to how many phonemic phrases any given utterance may contain. (iii) An "obstruent cluster," i.e., a sequence of consecutive obstruents, always conforms to the last obstruent in the cluster with regard to voicing. This observation applies to obstruent clusters within morphological signs and phonological words,[17] and is generalized in Halle (1959: 64) (following Jakobson) to clusters across boundaries of phonological words within a phonemic phrase.

To formally account for the fact that the s-strings of unembedded signs are articulated into phonological phrases, I hypothesize the feature declaration (17) and the restrictions (18) and (19):

(17) *unembedded-phrase* PHONPHRASES *nelofnelofsegment*

(18) In an *unembedded-phrase* object, the PHON S-STRING value is the concatenation of the members of the PHONPHRASES value.

(19) In an *unembedded-phrase* object, the last segment of a phonological phrase (i.e., a member of the PHONPHRASES value) is also the last segment of a phonological word (i.e., a member of the PHON HIERARCH PHONWORDS value).

[17] In a study of obstruent voicing assimilation in prepositions, Burton & Robblee (1997) has found overall acoustic evidence for regressive assimilation, but also subtle remnants of the underlying voicing properties. If these subtle effects prove to be reliable and significant, the question as to their articulatory cause arises. For present purposes I disregard them.

I thus assume that the end of a phonological phrase coincides with the end of a phonological word. In the illustrative partial analyses below, I will assume that in simple cases, a phrase's PWS (i.e., PHONWORDS) value is the concatenation of the PWS values of its daughters and a sign's s-string is a concatenation of the members of its PWS value, as in Figure 6 below. (The latter condition fails to be satisfied in cases of sandhi, as in Figures 7 and 8.) This is not the general rule in morphology, though, and it is of course not true in the daughters of prepositional phrases in Russian.[18] Although these cases would deserve a systematic discussion, I follow the literature in being inexplicit about non-trivial details. (Cf. Inkelas & Zec 1995 for some discussion.)

Among the phonemic sorts for Russian are the ones in (20), with some of the attending restrictions given in (21). The *affricate* subsorts *sort*_C and *sort*_Č as well as the *fricative* subsort *sort*_X are unrestricted as to voicing, so that, e.g., both [x] and [ɣ] are of sort *sort*_X.

(20) *fricative*: *sort*_S, *sort*_Z, *sort*_ʃ, *sort*_ʒ, *sort*_X, ...
affricate: *sort*_C, *sort*_Č, ...

(21) *sort*_S → [VOICING *voiceless*, CONSTR FT SITE *alveolar*]
*sort*_ʒ → [VOICING *voiced*, CONSTR FT SITE *postalveolar*]
*sort*_X → CONSTR FT SITE *velar*
*sort*_C → CONSTR FT SITE *alveolar*
*sort*_Č → CONSTR FT SITE *postalveolar*

7.2 Ordinary obstruents

As a first step, we consider a set of highly simplified rules that are close to Halle's (1959) introductory description:

(22) In a phonological phrase, the elements of an obstruent cluster C have the VOICING value of C's last element.[19]

[18] I suggest that the lexical entries of most prepositions require the s-string to be a proper prefix of the (single) member of the PWS value. In a PP headed by a preposition like that, the member of the preposition's PWS value is the concatenation of its s-string and the first member of the complement daughter's PWS value. Thus, the PP's PWS value is the concatenation of the head daughter's and the complement daughter's PWS values minus the latter's first member. The same sort of analysis can be applied to the indefinite articles *a* and *an* in English and also, probably, in morphology.

[19] The assumption that the VOICING values are token identical is a speculation. They might just be type identical, with the empirical consequence for the velocity of articulator movement noted in our discussion of Sundanese nasalization in §4.

(23) In a phonological phrase, an obstruent at its end is voiceless.

(24) In a phonological phrase, if an obstruent O that corresponds to an obstruent at the end of a phonological word is followed by a non-obstruent, O is voiceless.

The ground rule for the relation of a parent's PHON value to the PHON values of its daughters is of course that the values of corresponding paths in segments of parent and daughter are identical. To be able to work properly, (22)–(24) also presuppose that the ground rule is not obeyed when path values cannot be identical due to the demands imposed on the parent by a rule. Thus, the rules must be complemented by appropriate specifications of delinking, a task not undertaken here.

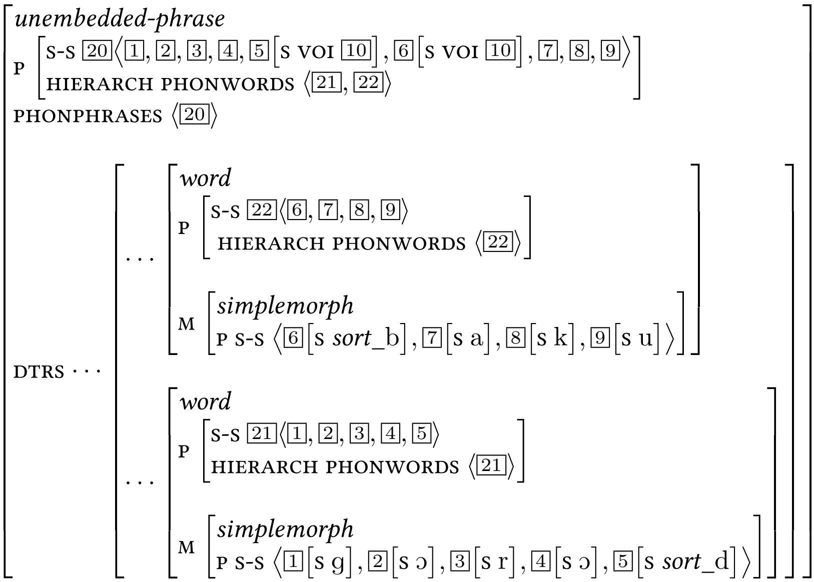

Figure 6: Morphophonological structure of *gorod Baku* (provisional)

Example (16b) is partially analysed in accordance with (22)–(24) in Figure 6. Vowel reduction is disregarded. I assume that *gorod*, *Baku* and *Ufa* are simple morphemes and hence licensed as such by lexical entries, and that (16a–c) can be performed as complete utterances.

In Figure 6, no rule requires that any path value in any segment of a parent be different from a corresponding path value in a daughter. The only relevant requirement is (22): the VOI(CING) values of the obstruents at the phonological word boundary (tagged [5] and [6]) must be identical. This is unproblematic, as they happen to be of the same sort anyway.

The rules (22)–(24) can claim to be "surface-true." Although this property is sometimes considered a merit in itself, (24) appears doubtful. Why should it be that obstruents are voiceless at the end of words whenever, of all segments, just a vowel or sonorant follows? Devoicing is often seen in codas. This could in fact be the relevant factor in (23); but in (24), there is no reason to expect an obstruent to be in a coda just when followed by a vowel. Actually, in (16a), the devoiced obstruent is not in a coda but in a syllable onset, according to Weisser (1987: 76):

(25) [gɔ.rə.tu.fa]

(If this is correct, the domain of syllabification rules is the phonological phrase, rather than some smaller unit.) In any case, the conditioning factor for devoicing is clearly the end of the phonological word, quite independently of whatever follows. That is, if a grammar is not just meant to reproduce the data in some fashion, but also to capture "natural" rules that constitute a speaker's knowledge, (24) must be replaced by (26). (Thanks to (19), this rule subsumes the effects of (23).)

(26) In a *word* object, an obstruent at the end of a phonological word is voiceless.

Rule (26) is of course no longer surface-true: an obstruent that is voiceless according to (26) surfaces voiced just in case a voiced obstruent follows in the phonological phrase. This fact suggests that the generalization expressed by (22) might be spurious and that it should be replaced by the less general cluster rule (27) and a sandhi rule (28):

(27) In a phonological word and in a *morph* object, the elements of an obstruent cluster C have the VOICING value of C's last element.

(28) In a phonological phrase, if an obstruent O that corresponds to an obstruent at the end of a phonological word is followed by a voiced obstruent B, O has the VOICING value of B.

With (26)–(28) replacing (22)–(24), Figure 6 is no longer correct, as shown in Figure 7 (indications of PWS values are simplified). By (26), the word *gorod* (tagged [21]) ends in a voiceless obstruent, and by (28), the corresponding obstruent in the phonological phrase is voiced.

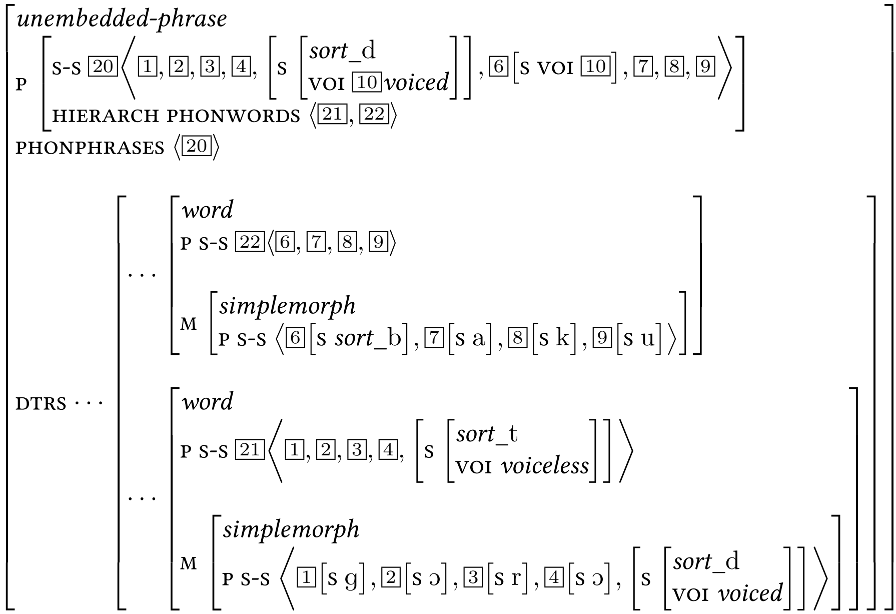

Figure 7: Morphophonological structure of *gorod Baku* (amended)

7.3 Obstruents with predictable voicing

The voice-unrestricted segment types x, c and č have been problematic for certain theories of phonemics. Within phonological words and *morph* objects, any such segment is voiceless if it precedes a non-obstruent. If it precedes an obstruent, it is subject to (27). If it is the last segment of a word, it is subject to (26). The situation at the end of morphemes is less obvious, as is shown in the partial analysis of (15b) in Figure 8.

In the phonological phrase, č (tagged $\boxed{7}$) is voiced, according to (28). At the end of the phonological word, č (tagged $\boxed{6}$) is voiceless, according to (26). Nothing prevents č in the morpheme (tagged $\boxed{3}$) to be voiceless too, so that possibly, $\boxed{8} = \boxed{9}$; but nothing enforces this identity either. The lexical entry for *žeč* should certainly not fix the sort of č's VOICING value. Neither can the ground rule and the delinking specifications attending the individual rules be balanced in such a way that necessarily $\boxed{8} = \boxed{9}$. (The same problem arises with obstruent clusters across morpheme boundaries within words.)

Naturally, no incorrect observational predictions ensue if this question is just

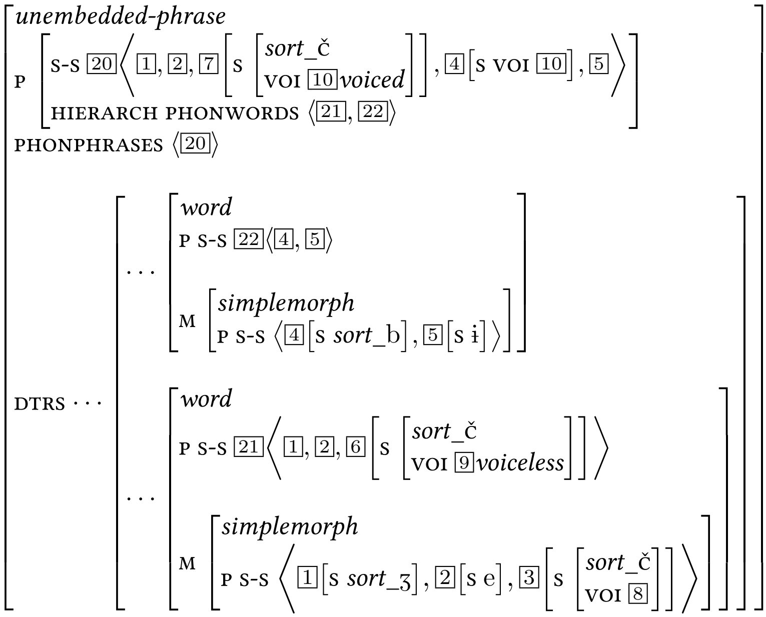

Figure 8: Morphophonological structure of *žeč by*

left open. But this (non-)decision forces upon us genuinely spurious ambiguities: for each word that ends in a voice-unrestricted obstruent sort, there are two candidate *simplemorph* objects that differ in the sort of the VOICING value of the morpheme-final obstruent. If a grammar is meant to capture the linguistic knowledge of speakers, nothing can justify an attribution to speakers of knowledge of such an ambiguity. Therefore, the rule for objects belonging to a voice-unrestricted sort is posited as in (29):

(29) In a *simplemorph* object, a P S-STRING value component of sort *sort*_c, *sort*_č or *sort*_x is voiceless if it does not precede an obstruent.

Given that the voicing of an obstruent at the end of a morpheme must in general be inferred on the evidence of the morpheme occurring before a vowel (or a sonorant) in a phonological word, (29) is perfectly natural. Thus, by (29), č in the morpheme *žeč* in Figure 8 is voiceless. By the ground rule, then, $\boxed{8} = \boxed{9}$ and hence, $\boxed{3} = \boxed{6}$.

7.4 Concluding considerations

According to the rule system (26)–(29), Russian has a special end-of-word rule (26), which is nothing unusual, and a sandhi rule (28) that is independent of the word-internal cluster rule (27). On comparative grounds, both rules are far more natural than (24). One can expect, then, that Slavic languages (whose obstruents show similar behaviour, by and large) vary (28) independently of (27). As we have noted in §2.2, this is just what happens in southwestern variants of Polish (cf. Bethin 1984, Gussmann 1992: 34 and 54, Rubach 1996: 72 and 82 f.): there, (27) and (26) are (basically) also in force, but in the counterpart to (28), 'obstruent B' is to be replaced by 'segment B'.

Moreover, it is possible that the sandhi rule (28) is actually not phonemic but phonetic in nature; cf. Kiparsky (1985) for references. This might mean that the VOICING ACHIEVEMENT values of obstruents, rather than their VOICING values, are critically affected by sandhi. It might also mean that (28) should actually regulate not s-strings but p-strings. This is suggested by the observation in Isačenko (1954/55: 415) (confirmed in Halle 1959: 64, note 15) that in examples such as *rež' bulku* 'cut the bread' the fricative typically sets in voiceless. This fact appears problematic upon (22) when the fricative is lexically voiced, but may be easier to understand upon (26) plus a modified version of (28). Conceivably, though, it is a rather direct consequence of there being just one long (hence, slow) voicing gesture throughout the obstruent cluster. To clarify these questions, more detailed data are required than are available to me.

In the discussion of Russian obstruents above, several noteworthy points should have become apparent. First, important questions of empirical detail notwithstanding, the requirements of lexical licensing and of rule naturalness strongly motivate non-trivial forms of multistratality. Second, although the relation of a parent's PHON value to those of its daughters (as envisaged in (26)–(28) in conjunction with the ground rule and the delinking specifications) is intuitively transparent, its logic is remarkably complex. Specifying it in full detail is some work even with the resources referred to in note 16 above. Third, the hierarchical structure imposed by PHONWORDS and PHONPHRASES values is non-trivial just in case it is not homomorphic to morpho-syntactic structure. But because of the lack of detailed research, we fail to have a general well-founded view of how to construe the relation explicitly for non-trivial cases.[20]

[20] To account for word order phenomena in Serbo-Croatian, Penn (1999) proposes a structure for signs that differs significantly from my highly conservative proposals (which can, in principle, be combined with the approach to linearization put forward in Richter 1997 or in Sailer 1997). Considerable exploratory work will be needed to assess the merits of either proposal.

8 Summary of architecture

A natural language is conceived to be a set of totally well-typed token linguistic objects. Among them, objects of sort *unembedded-phrase* are prominent in that they alone can be performed as utterances. They bear a distinguished phonological attribute UTTERANCE. Its value's S-STRING value (its "p-string") is mapped to a u-equivalence (a maximal set of stylistically alternative possible utterance events) by an interpretation function Φ.

Φ is defined by a physical theory that has a universal core, but allows certain details to be learned for individual languages. For a "grammar G of natural language L," L is (intended to be) an exhaustive model of G. Knowledge of L is thus partly embodied in G and partly, in the theory defining Φ.

An object's UTTERANCE S-STRING value is related, but not necessarily identical, to its PHON S-STRING value, providing room for phonetic regularities that are not captured by the PHON S-STRING value (or by Φ) alone. Components of PHON S-STRING values need not be physically interpreted, although they are required to be interpretable.

The PHON value of a sign is related to the PHON values of its component signs. Words embed (morphological) signs, which may again embed signs (recursively). The relation of a sign's PHON value to those of its component signs thus provides room (hypothesized to be both necessary and sufficient) for "postlexical" as well as "lexical" morphophonology.

"Long distance" identities in strings of segments are necessarily type (as opposed to token) identities. Identities in adjacent segments can (but need not) be token identities, since segments allow for massive gestural overlap. Notions from classical phonemics, which capture constant coupling of different gestural objects in segments, can be exploited (and explored) with the help of phonemic sorts (partitionings of major class and manner sorts).

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