Poznań Studies in Contemporary Linguistics 45(1), 2009, pp. 1–31

doi:10.2478/v10010-009-0002-x

HYPOTHESES OF NATURAL PHONOLOGY

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ABSTRACT

Natural Phonology characterizes production and perception of speech in terms of a set of universal phonetically motivated phonological processes. Before their first words, infants identify some processes as inapplicable in their language, which narrows their perceptual universe to its phonemic system and enables them to hear the intention rather than the actuation of speech. They then gradually inhibit the inapplicable processes to achieve mature pronunciation. If some inhibitions are not fully mastered, the child's speech seems to have a sound change, or perhaps a variable pronunciation, or a speech deficit. Processes that remain active govern allophony, variation, automatic alternations, one's native "accent", and one's "foreign" accent in second-language learning. Inactive processes may (re-)emerge to cope with stresses like injury or fatigue. This paper surveys some of the principal hypotheses of Natural Phonology, and we briefly compare them with Optimality Theory and recent neo-empiricist phonology. We argue that abstraction from actions to intentions is fundamental to learning and understanding language at every level from phonetics to pragmatics.

KEYWORDS: Perception; intention; phonemes; phonetics; optimality.

For Ulli Dressler, and his students

Phonology is the study of the categorical discrepancies between speech as it is perceived and intended, and speech as it is targeted for actuation. The theory of natural phonology[1] takes the discrepancies to be due to the operation of natural processes, cate-

[1] Some papers and discussion in this volume describe Natural Phonology as being "against" generative linguistics, formalism, and abstractness, or "for" external evidence, or phonetic explanation. We reject such statements. A theory may be right or wrong. It is not "for" or "against" anything. We also reject confusions of Natural Phonology with "natural generative phonology", as presented in Vennemann (1974) or [Bybee] Hooper (1976), or with the straw man refuted in "Why phonology isn't natural" (Anderson 1981).

gorical mental substitutions, each of which responds in real time to an innate limitation of the human faculty for fluent speech perception and production. It takes *non*-discrepancies to be due to inhibitions of those processes – inhibitions that are mastered in acquiring the pronunciation of a particular language. Since all languages and individuals have the same processes, the phonology of a speaker of a particular language consists entirely of these inhibitions. The processes are universal.

Phonological processes operate on a real-time mental prosodic representation of the features of the *intended* utterance, and their output, though it may differ considerably in content, is of the same kind: a real-time prosodic mental representation of the features of the *actual* utterance. When we speak here of *sounds*, or *kinds* of sounds, like vowels or consonants, we are speaking of their mental representations.

1. Fortitions enhance clarity. Lenitions enhance fluency.

The active (non-inhibited) processes operate in two blocs: first, Fortitions apply to enhance the divisions of the prosodic score and the clarity of intended sounds, and then Lenitions apply to enhance the fluency of the sequence of sounds. Fortitions make sounds more like themselves and less like adjacent sounds; lenitions make sounds more like their adjacent sounds, sometimes to the point of identity.

Processes have purely phonological and prosodic conditions, and when they are context-sensitive they govern the alternations that Baudouin de Courtenay (1895) called "divergences" (i.e. divergent from the intended sound). Sapir (1921, 1925) called these "mechanical", and Bloomfield (1933: 211) called them "automatic". They apply unwilled and unconsciously to any intended configuration of sounds that a speaker has not learned to pronounce, to provide an alternative target that is identical save for the unpronounceable feature value. For example, there is a lenition that nasalizes sounds next to nasals. Speakers of English from their earliest words nasalize vowels before nasals at least in the fall ("rhyme") of a syllable, as in [sɔ̃ŋ] *song* or [bræ̃nd] *brand*. This is not some parochial rule for the realization of English phonemes: it is not English but the speakers of English who do this, and they nasalize non-English nonnasal vowels before nasals, as in French [lyn] *lune* 'moon', and they nasalize before non-English nasals, as in Polish [ˈpoznɑɲ] *Poznań*. Rather, nasalization is a fluency-motivated process that spreads a certain feature value (nasal) through a string of otherwise similar sounds. In this case the string of similar sounds is the class including both vowels and nasals, namely sonorants, e.g. [n ɾ l r w j i u ... ɑ], etc., as is evident from examples like [ɑ̃ə̯̃r̃n] *iron* or [ɛ̃ɫ̃m] *elm*.[2] In more relaxed styles, like any as-

[2] This formalizes the "similarity" principle in assimilation (e.g. Zwicky 1972a; Hutcheson 1973). The failure of [ɾ] to nasalize in [ˈbæɾ.ĩŋ] *batting* (which would converge with [ˈbæ̃ɾ̃.ĩŋ] *banning*) is because in *batting* [ɾ] is a derivative of /t/, and anticipatory sonorant nasalization is limited in English just to nonderivatives (Sec-

similation, nasalization may widen its rhythmic domain, to a whole syllable [br̃ǣnd], or a "foot" [ɔˈr̃ɑ̃ĩ̯.ə̃n] *Orion*, or a word, [ɔ̃ˈr̃ɑ̃ĩ̯.ə̃n]. And it may also apply progressively over the fall of a foot, as in [ˈæd.m̃r̩̃.ə̃ɫ̃] *admiral*, [j̃ũˈnɑ̃ẽ̯r̃.ə̃d] *united* (often misspelled *uninted*).

It is clear that English speakers are unaware of this nasalization. Asked to say the vowel in [sǣŋ] *sang*, they say [æ], never [ǣ]; they hear the nasalization as being on the nasal stop. The fact that nasalization is redundant or predictable in vowels adjacent to nasals doesn't explain this: after all it isn't redundant or predictable in [sǣk] *sank*, with its nasal stop elided. Clearly, nasalized vowels are not perceivable as such by English speakers, and as one observes, e.g. in Hindi classes, even when English speakers learn to hear intended nasal vowels distinct from nonnasal vowels, they often still denasalize them in pronunciation.

In natural phonology this is attributed to a fortition that denasalizes all vowels (indeed, it denasalizes all continuants, and in a few languages that lack even nasal stops, all sounds). Clarity-motivated processes do not apply to the result of fluency-motivated processes ("Fortitions first, lenitions last", in the slogan of Donegan and Stampe 1979): it would defeat the function of assimilatory nasalization to denasalize all secondarily nasalized vowels. A context-free process like denasalization, in a language where it is obligatory, imposes a constraint on possible perceptions and therefore on possible intentions in speech production: if no continuants are perceived as nasal, then no lexical entries or morphological rules will be created containing nasal continuants. The process is covert in production until a speaker, having learned to perceive nasal vowels in phonetic or second language instruction, also attempts to produce them.

"Unilateral implicational laws" (Jakobson 1942) like "nasal vowel phonemes imply non-nasal vowel phonemes, but not the converse", are reflections of the existence of a natural process denasalizing all continuants but no natural process nasalizing all continuants. It is the process, not the law, that is universal. A child learning a language in which vowel nasalization is not merely derivative, as in French [nɔ̃] *non* 'no' or Hindi [hãː] 'yes' can pronounce them only when she overcomes the denasalization process. Thus, phonemic perception is natural. (See Section 10 below.)

Fortitions and lenitions are mental embodiments of the contrary forces of Clarity vs. Ease of the great nineteenth-century pioneers of phonological phonetics. They are reconciled by the "Fortitions first, lenitions last" principle: Fortitions limit basic representations, requiring, for example, that all vowels be perceived and intended as nonnasal, while lenitions govern derivative representations, requiring that sonorants in nasal contexts are nasalized.

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tion 8). Contrast the nasalization of intended /ɾ/ in stage pronunciations of [bɑ̃ɾ̃n] *barn* or [ˈbǣɾ̃.ə̃n] *baron*. The "counterfed" status of anticipatory nasalization casts doubt on Cohn's (1993) contention that it is purely phonetic in English (Section 12).

2. Processes are "of the speaker". Rules are "of the language".

Structural phonology – whether at Geneva, Copenhagen, Prague, Yale, London, Harvard, or MIT – focused mainly on describing the language-particular discrepancies between ideal and actual speech, with statements classing mutually predictable sounds into phonemes, or conversely, stating the realizations of phonemes in different contexts. Even at MIT, where the discrepancies are stated in terms of phonetic "natural classes", they were still widely regarded merely as conventions of the language. Some of the discrepancies were said to be "natural" or "phonetically motivated", because they arose as gradual mechanical changes became perceptible (Anderson 1981; Ohala 1990; Blevins 2004, 2006). Others appear "crazy" (Bach and Harms 1972) because the origin of the mechanical changes has been obfuscated by subsequent changes. And it is true that phonetic explanations of alternations like *loaf/loaves*, or *keep/kept* belong to history – children assume these are *loafs* and *keeped*, and must learn the "accepted" forms – because the alternations live on only as conventions. But they are conventions of grammar, *not* phonology: they are not discrepancies between intended vs. actual speech at all, but between distinct *intentions*.

Historical and generative phonology have focused on morphonology, the regular or near-regular alternations that account for morphological forms. Morphonology deals with stem formation and word formation, derivation and inflection, foreign and native word-stocks (lexical strata), etc. In some phonological descriptions, only alternations of phonemes are accounted for ("structure preservation"), and allophonic changes and variation are not specified.

The alternations described in morphonology often appear to be based on features – e.g. the voiceless/voiced pairings of θ/ð, f/v, s/z, etc., in alternations like *breath/breathing, life/living, house/housing*), but the effects of these changes are often limited to occurrence at certain boundaries, or with particular morphemes, or in particular lexical strata (e.g. only in native vocabulary). English now allows intervocalic voiceless fricatives, e.g. *nothing*, *lithium*, and it permits exceptions to voicing, as in *loaf (v.)/loafing, mouse/mousing*, etc., even with the same affixes that sometimes require it. The voicing process that created these alternations is no longer phonetically motivated. Although some forms still display the alternations, the process is dead in English. Conventional alternations may show their phonetic origins, as this one does, if there has not been enough other change since the phonetic process "died" to obscure the phonetic motivation. (This doesn't necessarily imply recency.)

But phonetic motivations can be obscured. Compare the "long/short" pairings of the English vowel shift rule in *divine/divinity, serene/serenity, sane/sanity*, etc. No simple feature combination can be offered to describe the alternating pairs here, because the long and short vowels have changed in a variety of unrelated ways. The "long" vs. "short" vowel pairings may still exist in English, but they are just that – phonemic pairings without any consistent feature relationships.[3] The "long" vowels no longer have any clear phonetic relationship to their "short" counterparts, and we would not expect a change that affects /ɪ, ɛ, æ/ to have any effect on /ɑi̯, i(i̯), ɛi̯/, or vice versa. And indeed, when /æ/ becomes /eə̯/ in some US Northern Cities dialects or /ai̯/ in the US South, this has no consequences for its counterpart /ɛi̯/ as in *sane*. Or if /ei/ (or /ɛi̯/) becomes [ai̯] in Australian English, this has no consequences for /æ/. Further, the "long" and "short" vowels no longer even form phonetic natural classes – not even diphthong-vs-monophthong, since the "short" vowels have diphthongal variants (/ɪə̯, ɛə̯, æə̯/) in many dialects.

Morphonological rules specify alternations of phonemes particular to certain morphosyntactic situations. Thus such rules are conventional and lack synchronic phonetic motivation. They might not even be correctly described in terms of so-called "phonological features". In short, morphonological rules – even quite productive rules, rules that might expand their lexical or grammatical domain as umlaut did in German – are part of morphology. A variety of devices are required to describe morphonological rules in terms of quasi-phonetic features (such devices range from lexical strata to opaque and transparent segments to "true" and "fake" geminates, etc.). It may be that such devices are required because the rules no longer apply in terms of featural or phonetics-based representations. The irregularities or sub-regularities may simply be the result of layers of historical phonological change.

This problem is not limited to derivational phonologies. Optimality Theory attempts to base phonological alternations on the interaction of universal constraints, which have communicative motivations. (Well-Formedness constraints have phonetic motivations and Faithfulness constraints preserve lexical information.) But morphological conditions and exceptions have required the introduction of numerous additional mechanisms to OT, as well.

While rules may depend directly on morphology (morpheme boundaries, word classes, lexical strata, etc.), and indeed (as in the Celtic mutations) even on syntax, processes operate on purely phonological (featural and prosodic) conditions. While both processes and rules may produce regular patterns in the language, processes are first encountered as one's own limitations, and they remain one's own even though other speakers share them; their violations require special motivation. For example, flapping and other processes make word pairs like *kitty* vs. *kiddie*, or phrases like *he cán eat it* vs. *he cán't eat it* homophonous in many American dialects, and avoiding this takes special attention and effort. Rules often allow exceptions that do not require such effort: names like *Boston* and *Sefton* are violations of the pattern of the *t*-deletion rule of *soft/soften, moist/moisten*, but they present no particular production difficulty.

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[3] The /æ/ vowel is neither short nor lax in American English. It is long in *bad* and tense relative to the lax front vowel [aː] of Boston *bard*, or southern U.S *bide*. The tensing of /æ(ə̯)/ in northern cities of the US is usually raising of the vowel to [eə̯] (Donegan 1978).

Because of such differences, generative phonology has had to draw a distinction between lexical and post-lexical rule applications, but it has treated automatic phonological processes as a sort of postlexical afterthought, not distinguished in kind from conventional (lexical) rules. But in talks and courses in the 1960s, Stampe had already proposed that phonological processes, as opposed to conventional rules, are natural responses to limitations of the unpracticed human speech capacity, limitations that can be overcome in learning a language, if the language requires it, but which otherwise remain as the true phonology of the language. The theory came to be called Natural Phonology, since it treated of "natural processes" (processes which are innate in the sense that "natural classes" of sounds are innate) as opposed to conventional rules imposed by the language.[4] These automatic processes not only govern automatic alternations or add allophonic features. Together with the prosody, they account for the native "accents" of speakers, they constrain the perception and pronunciation of second languages, and they are the basis of systematic variation and change.

3. Phonological processes are "innate" substitutions in pronunciation.

Phonological processes are innate and universal – not in the sense of "Universal Grammar", but rather in the sense that they are natural responses to the phonetic difficulties encountered in speaking. They are universal because the human vocal and perceptual apparatus is universal – not because they are somehow part of the human brain. They may be discovered by the child in the process of using his vocal tract – during vocalization, crying, or babbling – and still we call them "innate", since their origins and motivations are innate. Rules must be learned by observing other speakers.

The *innate* elements in phonology are the phonetic forces (processes, constraints, or preferences) that press toward optimization and motivate substitutions. Optimization can take place along two dimensions: (a) paradigmatic: optimizing individual segments, particularly at prosodic peaks and edges; and (b) syntagmatic: optimizing sequences of segments over prosodic divisions. The *learned* elements in phonology are the speaker's

[4] Some writers object to the name "natural", saying that it suggests that other phonology is "unnatural" or "artificial". The term "natural" was applied to natural classes by Halle (1962) and to natural rules and representations by Postal (1968: Ch. 2) and by Chomsky and Halle (1968: Ch. 9), before it was first adopted by Stampe (1969) to distinguish the natural and universal ("process") component as distinct from the conventional and language-specific ("rule") part of the overly inclusive version of phonology that had developed in generative grammar. It was perhaps a bad choice. Because of the generative view that language acquisition involved an "evaluation measure", the term "natural" was interpreted as an evaluation measure. This view survives in generative theory, European naturalness theory, and Optimality Theory, but it was rejected by Donegan and Stampe (1978, 1979), citing Baudouin's view that in correlations (rules), "phonetic plausibility" matters not at all. In morphological theory, the semiotic criteria of Dressler, Mayerthaler, and Wurzel on "natural morphology" seem more appropriate. As for evaluation in phonology proper, it would be (trivially) possible to count inhibitions, but we think that a more promising program is to explore the influence of prosody on the kinds of inhibitions that are favored (Donegan and Stampe 1983, 2004).

acquired *inhibitions* that let him achieve (a) the phoneme inventory and (b) the phonetic realizations that he perceives as the communicative and cultural and stylistic requirements of family and community. English speakers could say /səˈrinɪti/ for *serenity*, but convention demands /səˈrɛnɪti/ . In contrast to this, we say [səˈrĩn] *serene* and [səˈrɛ̃nɪti] *serenity* with nasalized vowels, because we have not been required to learn to exercise enough timing control to say *[səˈrin] and *[səˈrɛnɪti].

4. Phonological processes apply to features within prosodic domains.

Processes can be stated entirely in terms of configurations of phonetic features and real-time rhythmic domains (e.g. syllables, feet, phonological words and phrases), and their natural subdivisions (beginning, rise, peak, fall, end). For example, in English, regressive sonorant nasalization may affect a stretch of [+sonorant] within a variable domain. It is obligatory at least within the syllable fall ("rhyme"), as in *swallowing* [ˈswɑl.ɔ.wĩŋ], but usually it spreads over sonorants in the whole syllable [ˈswɑl.ɔ.w̃ĩŋ] (cf. *sworn* [sw̃ɔ̃r̃n]), and may extend over the fall of the foot [ˈswɑ̃l̃.ɔ̃ṷ̃.ĩŋ], or the whole foot [ˈsw̃ɑ̃l̃.ɔ̃ṷ̃.ĩŋ]. From the impossibility of *[swɔr̃n], with just one segment nasalized, and of *[ˈswɑl.ɔ̃.w̃ĩŋ], with just two syllables nasalized, as would be expected if whole-syllable nasalization "iterated" segment-by-segment through syllables, we see that the process applied over its whole domain at once.

The distinct treatment of the divided /ɔ͡u/ phoneme in [ˈswɑl.ɔ.w̃ĩŋ], as opposed to the variant [ˈswɑl.ɔṷ.ĩŋ], shows that processes are not restricted to apply to phonemes. Rules on the other hand treat /ɔ͡u/ as atomic, with alternations like /ɔ͡u/ : /ɑ/ in *tone* : *tonic*. The phoneme may be spelled as /ɔ/ or /o/ plus /u/ or /w/, but vowel phoneme surveys that list English has having /ɔ/ and /u/ or /w/ and do not include the unit /ɔ͡u/, are certainly misguided. Speakers asked to say *coat* /kɔ͡ut/ in reverse say [tʰɔṷk], never *[kʰṷɔt], because in English [ɔṷ] represents an atomic phoneme /ɔ͡u/, just like /ɑ͡i/, /ɑ͡u/, /ɔ͡i/, /ʧ/, /ʤ/, etc.

However, once phonemes are mapped onto real time, it matters whether the beginning and end of the phoneme are phonetically distinct, as is clear from its Baltimore and British variety /ɛ͡u/, which fronts a preceding velar and backs a following one: compare the normal and reversed pronunciations of /kʰɛ͡ut/ *coat* [cʰɛṷt] and [tʰɛṷk]. In fact the pronunciation /ɛ͡u/ itself arose originally from the mutual dissimilation of the beginning and end of earlier English [oo̯] onto the sonority rise and fall at the peak of a foot: the rise became brighter in timbre (o > ʌ > ɛ) as the fall became darker (o̯ > ṷ).

Donegan and Stampe (1978, 1979 and subsequent talks) have claimed that if each process operates over rhythmically delimited strings which include both the causal and the affected elements and which are defined solely in terms of the phonetic features of that string, then direct reference to phonemes or even segments per se can be avoided – without such superstructures as "autosegmental tiers" (Goldsmith 1990), "long components" (Harris 1944), "prosodies" (Firth 1948), or "gestures" (Browman and Goldstein

1986). In an asegmental phonology like that which we have proposed, every feature is its own "tier" or "autosegment". Successive segments are differentiated from each other only by some feature difference or, as in the case of geminates or long vowels, by syllable positions or prosodic associations. (This accounts automatically for much of what the Obligatory Contour Principle (Goldsmith 1979) has been used to explain.)

Phonological processes make no reference to morphological information (word boundaries, lexical strata) that is not reflected in the prosody: e.g. *mis-time* [mɪsˈtʰɑi̯m] requires aspiration of its /t/ because a prosodic boundary precedes the /t/; the boundary results from a clear morpheme boundary, which is absent in words like *mysterious* [mɪˈstɪr.i.əs] or has been forgotten in *mistake* [mɪˈstei̯k].

5. Phonological processes are sensitive to implicational conditions on their application.

Phonological processes are universal in form because they are universal in phonetic motivation, but they do not apply universally. A process may be suppressed, or it may be deprived of input by an alternative process, or it may be limited in application to a subset of its possibilities. The universal form of a process includes a variety of conditions that favor or disfavor its application. Because of their phonetic nature, these conditions are implicational. A well-known example is the condition that makes back obstruents more susceptible to devoicing than front ones. This reflects the phonetic motivation of devoicing in the greater difficulty of maintaining the air flow across the glottis (which is required for glottal vibration) when the oral closure is closer to the glottis. Another example is the greater susceptibility of lower vowels to depalatalization or to unrounding (Donegan 1978). A third is the greater susceptibility of consonants to palatalization before more-palatal vocalics, so that [j] palatalizes consonants more freely than does [i], and [i] does so more freely than [e], and so on (Neeld 1973).

A process may be subject to more than one such condition, of course. Devoicing, for example, is especially applicable to back obstruents – and it is also especially applicable to long obstruents. Non-labial consonants are more susceptible to palatalization than are labial consonants. When a process is allowed to apply, a selected subset of its universal implicational conditions may determine its application. This subset is not the same in every language. Even within a language, the substitutions may vary, expanding or contracting their segmental and prosodic domains along the paths laid out by the universal implicational conditions, depending on speech rate, on formality, on the degree of attention paid to speech, etc. Various lenitions apply more freely in faster speech, and the application of lenitions may expand along any of their featural dimensions.

In Donegan (1978), evidence is presented for a variety of fortition processes that affect vowels. Each process is subject to a number of implicational conditions, and cases that exemplify these implicational conditions in child speech and sound change and as constraints on vowel systems in the world's languages are presented. Each condition may apply independently or in conjunction with other conditions. For example, depalatalization, if unrestricted, applies to all vowels in many beginning speakers and in a handful of the world's languages. But it may be restricted especially to lower vowels, or to lax vowels, or to labial vowels. So lax vowels may depalatalize ([a] → [ɑ], [ɛ] → [ʌ], [ɪ] → [ɨ]), or low vowels ([æ, a] → [ɑ]), or non-high vowels ([æ, a] → [ɑ] and [e, ɛ] → [ʌ]), or labial vowels may depalatalize ([y] → [u], [ø] → [o], [œ] → [ɒ]). Or a combination of these inhibitions may apply, e.g. only non-high labial vowels depalatalize ([ø] → [o], [œ] → [ɒ]).

6. Alternations can be morphologized; processes cannot.

Because processes may make allophonic substitutions, speakers may be quite unaware of their effects. Rules may be habitual and quite unconscious, but they never govern allophonic substitutions; they are acquired through the observation of linguistic differences, and speakers are usually unconscious of allophonic differences.

Rhymes also give evidence of the difference between phonemic and allophonic perception. The rhymes in /-æt/ in *The cat / that sat / upon the mat* are perfect even if each word has a different allophone of /t/, e.g. *The ca*[ʔ] *that sa*[ɾ] *upon the ma*[t]. And even words with distinct lexical representations rhyme if they are phonemically alike, as in the advertising jingle *Cheddar is better*, where flapping and voicing of /t/ in *better* [ˈbɛɾɚ] makes it phonemically perceptible as /ˈbɛdəɹ/, and it rhymes with *cheddar* even if *cheddar* is not also pronounced with a [ɾ] but with [d], either of which is perceived as the phoneme /d/ in the sense of autonomous phonemics (Stampe 1968, 1987).

In language change, allophones do not acquire morphological conditions or mark morphological differences; only phonemes do. And changes that are lexicalized by "lexical diffusion" always involve a change of individual words from one phonemic category to another. There is no evidence that such changes are ever allophonic. And it would be indeed be puzzling if speakers changed the lexical representations of words by changing features that are not part of those words' lexical representations.

Further, processes do not express semiotic differences, because even when they result in perceptible (phonemic) changes, they do so for merely phonological reasons. Rules, which exist only because they make a perceptible (phonemic) change for no apparent phonological reason, are therefore capable of expressing semiotic differences. In its inception as a process, palatal umlaut in German merely assimilated the frontness of a following high front vowel in its foot, sometimes within a stem e.g. *stain* → *stein* 'stone', *badi* → *bedi* 'bed', but sometimes between stem and suffix, e.g. *gast* 'guest' but plural *gast-i* → *gesti*, *mūs* 'mouse' but plural *mūs-i* → *mǖsi*. Later the causal *i* vowel began to be reduced to *e*, which had not caused fronting. The reduced *e* were still intended as *i*, but children could not guess that, and could only interpret the fronted vowels as intended (phonemic). Thus they could only understand this intentional alternation of back vowels in the singular and front vowels in the plural as a morphological expression of plurality, and it lived on as such in future generations, and extended its usefulness to many words that had never had *i*-plurals.

This a classic example of what is often called the "morphologization" of a phonological process. But it is not the *process* but the *alternation* that is morphologized . It took two (sets of) minds to do this – those of the speakers who produced an alternation due to an intended vowel that they had begun to reduce in actual speech, and those of the learners who because of that reduction could only interpret the alternation as being a direct morphological expression of the plural (see Nathan and Donegan, forthcoming). The palatalization process persisted, applying to new words in which *i* was not reduced. But even if it hadn't, it is wrong to say that the *process* had been morphologized. An alternation may be morphologized as a rule, but phonological processes can no more turn into morphological rules than frogs can turn into princes.

In general, only rules may have semiotic functions, but some rules may have no semiotic function at all, like the *t*-deletion in *soften*, *moisten*. Such rules exist purely by custom – as do many aspects of languages.

7. Processes apply in real time, and may depend on real-world conditions.

Processes apply to lexical representations, as mapped onto prosodic units, in real time. They apply during the construction of phrases, since they may apply across word boundaries, as in *ten people* [tɛ̃m pipəl], or *often go* [ɒfəŋ gou̯]. Rules typically apply within grammatical words.

Slips of the tongue give clear evidence that processes apply in real-time speech production: allophones are correctly substituted to such errors, even though the errors themselves must occur in real time. So, for example, in a spoonerism, *stale candy* might become [skɛi̯l tʰæ̃ndi], where the exchanged /t/ and /k/ have appropriate aspiration, but not *[skʰɛi̯l tæ̃ndi]. Or a blend like [mɛi̯stli] from *mainly* and *mostly* has appropriate nasalization (as would an alternative blend, [mõũ̯nli]). Errors like *[mɛ̃ĩ̯stli] or *[mou̯nli] do not occur.

Processes also apply to the output of language games – particularly those which infix or affix an element. A simple example is the English Pig-Latin pronunciation of *me*. When the initial consonant is moved to the end of the word, and the vowel [ɛi̯] is suffixed, [mi] becomes [ĩmɛi̯], with a nasalized vowel, on account of the following nasal. Rules do not apply to the deformed representations that result from speech errors or language games.

Because they apply in real time and are sensitive to speech rate and other real-world circumstances (like fatigue, drunkenness, objects in the mouth, injuries, etc.), processes are variable. Optional processes represent articulations over which the speaker has less-than-perfect control, so that special conditions – such as fast tempo, or lack of attention or care, or situations of high redundancy, or very frequent words – can affect their application. Inhibitions may be relaxed so that lenitive processes apply more freely.

(Stampe (1973) shows how very free applications of phonological processes can result in what Johnson (2004) calls "massive reduction" – as, for example, when *divinity fudge* is pronounced [dəvĩĩ̯ fʌʤ].)[5]

At very slow tempos or in especially careful or exaggerated speech, the inhibitions may be imposed more strictly, so that ordinary lenitions fail to apply. And fortitive processes that do not apply in ordinary speech may apply in exaggerated speech (see Donegan 1993). Not only may processes be optional, applying or failing to apply – they may increase or narrow their application in accordance with the implicational conditions mentioned in Section 5 (cf. Zwicky 1972b). Morphonological rules are not sensitive to such conditions. Their conventional nature exempts them from the phonetic pressures of style and tempo.

8. The ordering of speech production

The production flow Lexicon/Rules → Prosody → Processes (Fortitions → Lenitions) is functionally determined. The Lexicon and Rules provide the grammatical structures and tonal and intonational tunes that the Prosody sets to a real time rhythmic score, exactly as an improvised text is set to music (Stampe 1972–73, 1973c). The Processes operate on that song-like score: Specifically, the Fortitions make its sounds more salient and its divisions sharper, and the Lenitions assimilate these into a fluently performable stream (Donegan and Stampe 1978, 1979; Stampe 1973c; Donegan 1978; Stampe 1987).

We cannot discuss prosody here, but let us at least refer to the growing evidence of its pervasive role in the structure and drift of every level of language, including word order and grammatical typology (Donegan and Stampe 1983, 2004).

Fortitions all apply simultaneously, just once, so that their mutual relationship is both "counterfeeding" and "counterbleeding". Lenitions also apply simultaneously, and most apply simultaneously again until no obligatory changes are left undone. This means that no fortition can bleed or feed another fortition, that no fortition can be fed or bled by a lenition, and that lenitions cannot bleed each other, but can feed each other.

The single relationship that can be language-specific is that a particular lenition can be restricted not to iterate, in which case it cannot be fed by another process. For example, in Spanish, there are no aspirate phonemes: foreign aspirated stops are deaspirated and foreign /h/ is deleted, e.g. /enri/ *Henry*. But in some varieties of Spanish /s/ loses its oral closure in weak positions and is pronounced [h], e.g. [ohɔh] for /osos/ 'bears'. In the theory of Donegan and Stampe (1979), the "counterfeeding" of deaspiration would be expressed not as an ordering relation with *s*-aspiration but as a simple restriction on deaspiration that it may not iterate. This predicts that [h] derived from other phonemes,

[5] Occasional doubts about hypoarticulate speech (e.g. Householder 1979) are answered in Zwicky (1972), Shockey (2003) and Johnson (2004).

say /x/ as in /oxos/ *ojos* ‘eyes’, pronounced [ohɔh] in some Caribbean dialects, would also not be subject to deaspiration. The non-iteration restriction on deaspiration is relaxed to let derivative [h] delete in some dialects and styles, and the theory predicts that this would be true of [h] in similar contexts whatever its source.

(That deaspiration is a lenition is clear from its application in English. Although for typographic convenience we write them here as /p t ʧ k/, we regard the English voiceless noncontinuants to be underlyingly both voiceless and aspirated, i.e. allowing both fortitions [−voi] → [+asp] and [+asp] → [−voi] to apply, and we view the loss of stop aspiration, as in *atom* beside *atomic* and *scrunch* beside *crunch*, and the deletion of [h], as in *vehicle* beside *vehicular* as due to the application of deaspiration in noninitial positions, a characteristic lenitive context.)

9. Processes affect second-language pronunciation.

It is particularly clear that processes reflect real constraints on speaker abilities when an adult speaker of one language (L1) attempts to learn another (L2). The processes that apply in L1 typically apply in L2 as well, affecting both perception and production, at least until the learner learns to overcome them. Rules do not “transfer” in this way because they represent conventions that the L1 speaker has learned rather than constraints on his articulatory and perceptual abilities (Singh and Ford 1987; Dziubalska-Kołaczyk 1990, 1997; Singh 1991; Major 2001; Park 2005). Even processes that have no input in the L1 (like final obstruent devoicing in languages with no final obstruents) – and that thus could not be learned by observation of phonetic forms – also apply in the speech of L2 learners (Stampe 1969, confirmed by Flege and Davidian 1984 and many following studies). This is particularly strong evidence of their innateness.

10. Processes determine the “alphabet” of the lexicon and grammar.

Conflicting demands are mirrored in conflicting processes, of course. A speaker’s individual tendencies (toward process application) often conflict with language or community requirements (process suppression or limitation, or application of an alternative process). And linguistic optima may conflict with each other. Assimilation and reduction optimize sequences; thus, for example, sonorant nasal voiced stops spread nasality through adjacent sonorants and voiced stops, helping the soft palate keep up with the quicker articulators. Fortitions – also called “foregrounding” (see e.g. Dressler 1984, 1985) or “enhancement” (Stevens and Keyser 1989) – optimize individual segments, so for example, vowels denasalize context-freely because non-nasalized vowels are more sonorous and more distinguishable, and, even diphthongize into an oral vowel plus nasal consonant, e.g. dialectal French [bɑo̯ŋ] for standard [bɔ̃] *bon* ‘good (m.)’. There are alternative “optimizations”, e.g. [e] → [i] increases palatal color, but [e] → [ʌ] increases sonority; and [b] → [p] increases obstruency, but [b] → [ᵐb], or [b] → [ɓ] increase voicing – so that a variety of alternative substitutions can be motivated.

10.1. The phoneme is a unit of perception, mental representation, and intention.

Phonologists usually agree that English speakers don't have nasal vowel phonemes, but some authors (Vennemann 1974; Hooper 1976; Bybee 2001; Port 2007) take the contrary view that the perceived and intended forms of lexemes are identical to their phonetic form(s). But if a lexeme with a vocalism that is normally invariably nasalized, like *shine* [ʃɑ̃ĩ̯n], is spoken with its phonemes reversed, then anticipatory nasalization will be blocked and the basic nonnasal value of the vocalism will surface: [nɑi̯ʃ], a reversal of its three [sic] phonemes |ʃa͡i̯n|. Or if it is spoken in a language game that infixes /Vb/ before each vowel, making V a copy of the original vowel, *shine* is not *[ʃɑ̃ĩ̯bɑ̃ĩ̯n] but [ʃɑi̯bɑ̃ĩ̯n], with a non-nasal vocalism in the infixation, followed by nasalization of the vocalism before a nasal. Or if the prosodic domain of nasalization is broken up, as in the coda-less syllabication favored by singers, the basic nonnasal values of the normally superficially nasalized vocalisms of *shine* and *moon* are revealed in singing *Shi– ne‿on, shi– ne‿on, Harvest Moo– n‿up in the sky*.

Textbooks on linguistics still present phonology in terms of the structuralist analytic methodology: the distinct phonemes of a language are those sounds that distinguish utterances, and sounds that are in complementary distribution or free variation with those sounds are treated as their allophones. But if phonology had to be learned by children using the offline text- or wordlist-processing methods of structural and generative linguistics, it would be unlearnable (Donegan 1985, 1995).

Nevertheless, complementary distribution and phonetic similarity are still presented as the ultimate criteria for phonemic analysis, so investigators are often reluctant to attribute phonemic status to differences that do not distinguish utterances. But a method for discovering probable phonemic distinctions is not a definition of the phoneme. Nor is it an explanation of the existence of such units.

10.2. Phonemic representation results from the interaction of Fortitions and Lenitions.

Phonological processes are not merely post-lexical specifications of details. The application of processes actually accounts for the phoneme inventory of each language. Stampe (1968, 1987) presented arguments that the alphabet of the phonology and the grammatical rules is the inventory of phonemes of a language; he had discovered a way of accounting for the existence of phoneme inventories purely in terms of the interaction of context-free (usually fortitive) and context-sensitive (usually lenitive) processes.

Fortitions enhance the phonetic features of individual segments, and they may result in fewer categories, constraining the phoneme inventory:

(1a)	[V +pal] → [+high]	maximizes palatality (and eliminates /e ɛ æ a/).
(1b)	[+cont] → [−nas]	maximizes quality (eliminates nasal vowels etc.).
(1c)	[−son, −cont] → [−voi]	maximizes obstruency (and eliminates /b d g/).

Note that NP does not argue that fortitive processes optimize *contrasts*: the effect of a fortition may be to eliminate contrasts, as when (1a) merged the contrast of Middle English /eː/ (*reed*) vs /æː/ (*read*) as modern /iː/. We claim, instead, that speakers apply fortitions to exaggerate or enhance a *phonetic* property. The mechanism and motive for enhancement may be proprioceptively articulatory or it may be auditory, or both. The enhancement adds or increases a feature that presumably makes the sound seem *more like itself* – but not necessarily more distinct from other sounds in the system. This takes into account not only the usual "centrifugal" or "dispersion" aspects of fortitive processes, but also their ability to cause mergers.

Lenitions optimize sequences and, unless they happen to neutralize an opposition, they multiply the variety of output sounds. For example:

(2a)	[V] → [−high] / __ [−high]	creates [e o] in some contexts.
(2b)	[+son] → [+nasal] / [+nasal]	creates nasalized vowels in some contexts.
(2c)	[ ] → [+voi] / [+voi] __ [+voi]	creates [b d g] in some environments.

Lenitions include assimilation as well as "weakenings" of various sorts. They reduce the magnitude or number of articulatory gestures and may relax the timing requirements of the gestural score.

If both opposing processes (1a, 2a), or (1b, 2b), or (1c, 2c) apply, then:

(3a) */e/ is ruled out of the phoneme inventory, and [e] before a uvular is perceived and remembered as /i/. That is, [e] is an allophone of /i/.

(3b) Nasalized vowels are allophones of their plain counterparts.

(3c) */b/ is ruled out of the phoneme inventory, and [b] between vowels is perceived and remembered as /p/. That is, [b] is an allophone of /p/.

10.3. Fortition-Lenition interaction: A simple example

Continuant Denasalization (Denas), a fortition, creates in vowels a more-perceptible vowel quality, and Nasalization (Nas), a lenition, eases articulatory timing in sequences including vowels). Every speaker must learn to inhibit some processes, as his language requires. A child must learn *which processes to restrict* in what circumstances – and *how to restrict them* (in production) – that is, how to pronounce their input. Because the processes are innate, perceptual acquisition requires only that the processes that prevent utterances from being pronounced correctly would be flagged for inhibition (Donegan 1985, 1995).

Compare the application of these two processes in English, Hawaiian, Hindi, and French, as shown in Table 1.

Table 1. Four-way typology of application of contrary Fortitive (F) vs. Lenitive (L) processes, illustrated by Fortitive Denas and Lenitive Nas in vowels in four languages. "+" means that a process applies, "−" that it is inhibited, or flagged for inhibition by an infant. Representation statuses are "| |" lexical, "[ ]" allophonic, "/ /" phonemic (i.e. perceptibly nasal or nonnasal regardless of the lexical representation).

The languages are ordered in increasing phonetic difficulty left to right. −F means a lexical opposition for nasality (Hindi, French), −L means an invariance of the base vowel nasality (Hawaiian, French); thus French requires both processes to be flagged. +F+L means allophonic variation of nasality (English), which requires no processes to be flagged. −F+L means automatic phonemic alternation, with the lexical opposition neutralized in the lenition context (Hindi).

<table>
<tr><th></th><th></th><th>English</th><th>Hawaiian</th><th colspan="2">Hindi</th><th colspan="2">French</th></tr>
<tr><td>F (denas)</td><td>+cont → −nas</td><td>+</td><td>+</td><td colspan="2">−</td><td colspan="2">−</td></tr>
<tr><td>L (nas)</td><td>+son → +nas / __ +nas</td><td>+</td><td>−</td><td colspan="2">+</td><td colspan="2">−</td></tr>
<tr><td colspan="2">Phonological inventories:</td><td>|ɑ|</td><td>|ɑ|</td><td>|ɑ|</td><td>|ɑ̃|</td><td>|ɑ|</td><td>|ɑ̃|</td></tr>
<tr><td colspan="2">Allophonic/phonemic inventories:</td><td>[ɑ ~ ɑ̃]</td><td>[ɑ]</td><td>/ɑ ~ ɑ̃/</td><td>/ɑ̃/</td><td>/ɑ/</td><td>/ɑ̃/</td></tr>
</table>

In each case, the phoneme inventory is defined by the interaction of the universal constraints: the fortitions limit the set of possible sounds to a set of relatively optimal – intendable – segments, and the lenitions determine their pronunciation in context, sometimes creating "impossible" sounds (like [ɑ̃] in English) as modifications of the "possible" sounds. Since there is an advantage to process application, the learner assumes application unless the data require suppression. (That is why so many processes that are covert in the native language become overt when a foreign language is learned.) In principle, for a given feature, at most two forms are required for the learner to decide that a process does not apply (Table 2 overleaf) – though of course the learner really has access to much more.

Often a single form flags several processes, such as French [mɑmɑ̃] *maman* 'mother', where the [ɑ̃] flags Denas, and [ɑ] flags Nas.

10.4. False steps

False steps are possible. For example, if a French child encounters forms like [bɔ̃] *bon* 'good (m.)' or [matɛ̃] *matin* 'morning', he could assume that the vowel is nasalized by a

Table 2. Representative minimal data required to flag processes for non-application (−) and establish the phonetic and phonological values in Figure 1.

The −F+L type takes /ɑ̃/ as lexical |ɑ̃| except in lexemes where it is /ɑ/ in non-nasalizing contexts. Where invariant |ɑ̃m| is written *am* this is to save writing time.

	Phonetic data	Process Status	Inventory	
English	—	Fortitive Denas	|ɑ|	*|ɑ̃|
	—	Lenitive Nas	[ɑ ~ ɑ̃]	
Hawaiian	—	Fortitive Denas	|ɑ|	*|ɑ̃|
	[ɑmɑ] ‘outrigger float’	−Lenitive Nas	[ɑ]	
Hindi	[hɑ̃] ‘yes’	−Fortitive Denas	|ɑ|	|ɑ̃|
	—	Lenitive Nas	/ɑ ~ ɑ̃/	/ɑ̃/
French	[ɑ̃fɑ̃] *enfant* ‘child’	−Fortitive Denas	|ɑ|	|ɑ̃|
	[ɑm] *âme* ‘soul’	−Lenitive Nas	/ɑ/	/ɑ̃/

word-final nasal consonant that is simultaneously deleted, and that the speaker intends /bɔn/ or /matɛn/. But it will not be long before the child hears words like [bɔn] *bonne* ‘good, f.’ or [lyn] *lune* ‘moon’; words like these, where the vowel is *not* nasalized before a nasal, and the final nasal is *not* deleted, require him to flag both Nasalization and “Nasal-deletion” for inhibition. The child may still be unable to inhibit either process in production, and may therefore mispronounce *bonne* as [bɔ̃] and *lune* as [lỹ], but he now in effect knows that that is not what mature speakers do, and so when he next hears a word with a nasalized vowel, like [fɛ̃] *fin* ‘end’, he can now only perceive it as intentionally nasalized, i.e. /fɛ̃/. For the time being, the child’s lexical representations of *bon* and *matin* are wrong, but next time he hears either of them he will perceive them as /bɔ̃/ and /matɛ̃/, and the lexical representations will be corrected. No global search and replace operation for the lexicon is required. Nor is it required that the child actually inhibit the flagged processes. All the evidence we have suggests that children already know the phonemic representations of words in their language before they begin to use any words themselves, and that this is quite independent of whether the child can inhibit any of the processes that prevent him from pronouncing them as adults do (e.g. Stampe 1969; Smith 1973).

10.5. Context-free lenitions may also limit the inventory.

Fortitions are not the only source of limitations of the phoneme inventory. Lenitions are context-sensitive, but some, like deaspiration, can be effectively context-free because whole utterances are rarely aspirated.[6] An obligatory process that eliminates a sound value in all environments in effect removes that value from the phoneme inventory of the language. Speakers of the Munda language Sora, for example, deaspirate foreign words with /tʰ/ or /dʱ/ and delete [h], as in [dobbɑ] from Oriya [dʱobɑ] 'laundryman' or [insɑ] from Oriya [hinsɔ] 'plowshare'. A bilingual Sora may know that these words have aspirates, but in his Sora speaking register the aspiration is lost, and monolingual interlocutors have no way of learning his "occulted" intentions.

Similarly, as noted above, Spanish lacks /h/, but in some varieties coda /s/ optionally debuccalizes to [h], e.g. [ɛhˈtɑh] in *¿cómo estás tú?* 'how are you?'. This is explained in Natural Phonology by restriction of the deaspiration process to nonderivative forms. The two lenitions affecting *s* and *h* apply simultaneously: an intended /h/, e.g. in a foreign name like *Fatimah*, is lost, but [h] derived from /s/ is not. An optional relaxation of that restriction allows derivative [h] to be deleted as well, /ɛsˈtɑs/ → [ɛhˈtɑh] → [ɛˈtɑ].

11. Processes and phonotactics: Natural and conventional admissibility

Phonological processes are responsible for some phonotactic gaps, but the history of the language and, to some degree, chance are responsible for others. Phonotactic constraints reflecting automatic phonological processes may affect perception.

Some forms happen not to occur, although they are perceived with accuracy and are perfectly pronounceable. In English, /ɑi̯/ does not occur after /j/ or before palatals, and /au̯/ does not occur after /w/ or before labials or velars, and /oi̯/ does not occur after /j/ *or* /w/, or before palatals, labials, *or* velars. These impressive regularities date back to sound changes in very early English, and yet exceptions are still rare: besides *yikes*, *yoiks*, and *wow*, there are e.g. the past tense form *wound* (by analogy with *found*), spelling pronunciations of names like *Reich* and *Cowper* and *Wouk*, and loans like *trauma*. But the gap is no longer a phonological one: if people say tr/ɒ/*ma* instead of *tr*/au̯/*ma*, that is also due to spelling pronunciation, not phonological processes.

Most genuine phonotactic gaps arise from the dual effect of the prosody and obligatory phonological processes. The absence of monosyllabic words with obstruent clusters like */sd/ with mismatched voice, or */nm/ with mismatched place, etc., as in */sdanm/, is due to the prosody for putting this in one syllable, and to obligatory processes assimilating voice and place for changing the result to [stamm] = [stam], which can only be perceived as /stam/. One might ask how the prosody and lenitions like these could constrain lexical representations, given the natural order of operations. The answer is that although you can try to say anything, if it changes into something that is phonemically

[6] The late Ted Lightner, during the 1960s, sent Stampe a postcard noting that although *h*-deletion can be stated as context-free in many languages, it somehow feels context-sensitive.

distinct from your intention in all its occurrences, it is in effect impossible to say. The hedge "in all its occurrences" is necessary to allow for lexical representations of sounds that are in automatic alternation with other phonemes, e.g. it allows for German /hʊnt/ *Hund* 'dog' with final devoicing to be represented as lexical |hʊnd|, because it also occurs in /hʊndɛ/ *Hunde* 'dogs'. (The /d/ in /hʊndɛ/ cannot derive from voicing /t/ in /hʊnt/ before a voiced sound because that process is inactivated in German, e.g. /tɑntɛ/ *Tante* 'aunt').

Phonotactic limitations may affect perception. For example, Japanese lexical forms do not include coda consonants except /n/ or the first half of a geminate, but Japanese speakers devoice and delete vowels fairly often, so that consonant clusters and final consonants often occur in actual speech: /suki dɛsu/ 'likes' often becomes [ski dɛs]. But such illicit clusters are perceived as the results of vowel deletion, so [ski dɛs] is perceived as /suki dɛsu/, and the vowels are identified according to their deletability in Japanese, in descending order /u, i, ɔ, ɛ, ɑ/ or, in the orthogonal notation of Donegan (1978), [!+high], [!−low], [!−pal].[7] Foreign as well as native forms are perceived in terms of one's native phonological system – the system is not merely one's system for pronunciation but also, inductively, one's "theory" of the intentions behind the actual speech of others. So the Japanese speaker interprets "illicit" clusters, as in English [strɑik] *strike,* as reflecting Japanese vowel deletions from a phonotactically licit Japanese intention like /sutɔraiku/. The perception of the second syllable as /tɔ/ rather than the more reducible candidates /tu/ or /ti/ appears to be an exception to the hierarchy of deletability, but in Japanese these high vowels affricate /tu/ and /ti/ to [tsu] and [ʧi]; since the actual English form is neither [stsrɑik] or [stʃrɑik] but [strɑik], the perceptions /tu/ and /ti/ are eliminated, and the next most likely hypothesis is that the intended syllable is /tɔ/.

Ohso (1971) and Lovins (1974, 1975) first developed this view of Japanese loan phonology, showing that the monolingual natural phonology serves as a perceptual theory as well as a production system for *all* speech – even that of foreigners. They demonstrated the rational basis of the Japanese speakers' "wrong" hypotheses about the phonological intentions of English speakers. The understanding of second language phonology is in its way more difficult than even child or aphasic phonology because it involves two independent systems of speaking and perceiving. But it is rewarding in uncovering regularities like the devoicing of final obstruents by speakers of languages without final obstruents (Section 9) – regularities which could not be discovered either by learners or by linguists in the data normally encountered in monolingual language acquisition and use, and which therefore can only be explained as due to covert innate processes.

[7] The "!" is read as "especially if", thus: "especially if high", meaning that if a nonhigh vowel is affected by a process, a high vowel will be also.

12. Phonology is inseparable from phonetics.

In addition to defining a phoneme inventory, phonological processes, as noted above, play a crucial role in automatic alternations, in the native "accents" of speakers, in second-language perception and pronunciation, and in phonological variation and change. But the automatic alternation and variation that occur both within words and in larger domains which, though given lip service as "post-lexical phonology", are increasingly designated as "part of the phonetics" of a language, and are thus eliminated from phonological description. For example, Cohn (1993) argues that vowel nasalization in English belongs to the phonetic component, Zsiga (1995) claims that English postlexical consonant palatalization is phonetic, and Myers (1997) regards the morphology-insensitive place assimilation in phrases like *i*[m] *Baltimore* as a phonetic matter of gestural overlap.[8] Blevins (2004, 2006) appears to attribute variation and change entirely to phonetics (undershoot, overshoot, and (re)lexicalization of surface forms by learners). But, as Donegan (2002) has argued, natural phonological processes (non-morphologized, phonetically motivated, automatic substitutions) are not simply phonetics.

12.1. Phonology has a physical basis, and much of phonetics is mental.

Although textbooks may distinguish phonetics from phonology by the idea that phonetics studies the physical aspects of speech, and phonology, the mental, even morphonological substitutions that are synchronically clearly conventional are thought to have originated for phonetic reasons. Few would claim that automatic phonological substitutions have nothing to do with phonetic constraints. Living phonological substitutions often have quite obvious physical motivations. And since speakers of different languages may perceive identical phonetic stimuli differently, or may fail in different ways to perceive certain aspects of different stimuli, it is clear that perception is a mentally determined matter. For example, Park (2002) found that Korean speakers perceived an intervening vowel in stop plus nasal sequences, so that [bæd mæn] *bad man*, which in

[8] Ad Cohn, we respond that the slow onset of vowel nasalization would be due to the English process being limited to the syllable fall, which begins within the peak vowel (Donegan and Stampe 1978); if it is extended to the entire syllable, nasality begins after the first obstruent, as in French. Nasality in English crosses basic glottal stops (e.g. /ʔʌʔɔu̯/ *uh-oh!* is either all oral or all nasal) but not derivative ones, as in [bʌʔn] *button*; a counterfed process is surely a mental one.

Ad Myers, the place assimilation of /nb/ gives [n͡mb], which optionally feeds a decoronalization yielding [mb]; a nonterminal process is surely a mental one.

Ad Zsiga, lexical and rule-governed /ʃ/ as in *fish* or *mission* are often apical and rounded, while assimilations of laminal /s/ and /j/ as in *miss you* are laminal, and real neutralization in the latter seem likely to be due to subjects aiming at /ʃ/ rather than at /s/. The assimilations, as Donegan notes, can take several forms, palatalization [ʃj], assibilation [sʃ], or both [ʃʃ], as well as partial [sʃj], and the fact that all of them are optional does not bode well for their being facts of physical phonetics.

Korean would assimilate nasality, becoming [bæn mæn], was perceived as /bædə mæn/. And Dupoux et al. (1999) reported that Japanese speakers failed to distinguish the presence vs. absence of a vowel – forms like *ebzo* vs. *ebuzo* were hard for them to differentiate. On the other hand, French speakers, who distinguished the presence vs. absence of a vowel with ease, failed to distinguish between short and long vowels – *ebuzo* vs. *ebuuzo* – a distinction which was, of course, easy for the Japanese speakers. Such differences are clearly in the minds of the perceivers. Pronunciation is also mentally constrained. The most obvious evidence for this is that adjustments that are quite well motivated, like the nasalization of any stop before a following nasal stop, may apply obligatorily in one language (like Korean) but not at all in another (like English).

12.2. Phonetic representations are mental.

Speakers do not produce a sequence of phonemic targets by allowing the articulators to get from one to another as best they can. This is perhaps an extreme interpretation, of course, but the notion of phonemic "undershoot" (Lindblom 1963) or even that of "gestural overlap" (Browman and Goldstein 1989) might be taken to imply that much of coarticulation is "mechanical". The idea that articulators receive the same neural commands for a given phoneme but fail, for biomechanical reasons, to realize the intended gestures in particular environments or at particular tempos (as in Lindblom 1963) would predict that similar effects of tempo and context would occur in various languages.[9] For example, English /u/ shows a raised F2 between coronal consonants, presumably because the coronal consonants contribute to tongue fronting or conflict with tongue backing. But this effect is greater in English than in French, German, or Hindi (Flemming 2001; Oh 2002). If the raised F2 were simply a physical effect of context, all languages would show similar effects of that context, but they do not.

Phonological substitutions and the resulting phonetic representations are mental. Speakers make adjustments to make forms pronounceable. The activity of articulation is centrally planned, so that features spread (or do not do so) in phonologically regular ways. This planning differs from language to language in ways that require us to recognize its mental aspects. Moosmüller (2007) draws a clear distinction between the speaker's "intention", which a phonologist would refer to as the phonological representation, and the speaker's "target", the output of the phonological processes – the phonetic representation. This difference is often overlooked, and it is assumed that the target is the phonemic form. But Moosmüller adduces considerable evidence (from her own work and that of Flemming 2001; Oh 2002; Wood 1996) that phonetic undershoot is not sufficient as an explanation of coarticulatory phenomena. As Whalen (1999) puts it, coarticulation is largely planned.

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[9] Lindblom's later work (the Hyperarticulate and Hypoarticulate Speech model, as in Lindblom 1990) acknowledges that speakers have a choice as to whether to allow undershoot.

12.3. Phonetic gradience results from the interaction of discrete features.

Phonology is sometimes distinguished from phonetics with the claim that phonology involves discrete or categorical specifications of features, while phonetics is concerned with gradient values. For example, "phonetics involves gradient and variable phenomena, whereas phonology is characteristically categorical and far less variable" (Hayes 1997: 6). In contrast to this, Natural Phonology claims that (1) categorical processing is sufficient to account for the differences between phonological (lexical) representation and phonetic representation; (2) phonetic representation, like phonological representation, is categorical; and (3) gradience in the speech signal results from multiple interacting factors in the physical production of speech. These factors include feature combination within segments, particular segment sequences, segment position, prosody, and speech rate. (See Donegan (2002) for further discussion.)

Gradient phonetic effects need not require gradient specifications. Phonetic gradience results from simultaneous and sequential feature combinations and prosodic differences. For example, within a language, different prosodic contexts, different points of articulation, and different adjacent segments may affect the onset and duration of voicing (Westbury and Keating 1986; Keating et al. 1983). The specifications for place, voicing, etc., may be discrete, but their interaction may result in phonetic gradience in terms of degrees of voicing during a consonantal articulation.

Natural Phonology recognizes that the specific values of features depend on the values of other features occurring simultaneously and sequentially in speech, and on the prosodic pattern, as interpreted in real time (including speech rate, intonation, etc.). Examples include the following: other things being equal, a lower vowel is less labial than a corresponding higher vowel (i.e. [ɒ] is less labial than [o], and [o] is less labial than [u]). Similarly, a lower front vowel is less front than a higher front vowel. Voice onset time increases with the backness of the stop (Smith 1978; Sock 1981), so [k^h] will be more aspirated than [t^h] or [p^h]. Consonantal constriction is more extreme or has greater duration initially in a broader prosodic domain (e.g. Keating et al. 1999; Fougeron and Keating 1996). So a phrase-initial stressed [p^h] may be longer than a phrase-medial stressed [p^h]. Voice onset times for voiceless stops are longer in stressed syllables than in unstressed ones. Coronal stop releases may be slower before high vowels than before non-high vowels (leading to affrication before high vowels, as in Japanese or Canadian French). All of these comparisons refer to differences that are mutually independent; even though more-back consonants have greater VOT in the same prosodic circumstances than more-front consonants, [p^h] may have a longer VOT than [t^h] or [k^h] if the [p^h] is in a more strongly stressed syllable, phrase-initial, etc., while the [t^h] or [k^h] is less prominent prosodically. A key condition on such statements, of course, is "other things being equal".

Phonological processes are categorical, but they are sensitive to gradience in their phonetic inputs and outputs. This sensitivity is expressed in the implicational conditions that govern the application of phonological processes even at the deepest levels of phonology, and it is a reflection of the speaker's implicit knowledge of his or her own abilities and the lawful relationships between gesture and acoustic effect.

12.4. Variable degrees of coarticulation may result from non-application of processes.

Languages sometimes differ in the degree to which adjacent segments are assimilated or coarticulated, and this is sometimes attributed to rules which specify degrees of features. Hayes (1997), for example, observed that English speakers spread voicing from a nasal through 13%–60% of a following stop but maintain a voice distinction, while Ecuadorian Quechua speakers voice through the postnasal stop, losing the distinction. NP would say that Quechua speakers have a "natural" response to the difficulty of nasal-plus-voiceless-stop sequences: that is, they give up the voicing distinction in this position and voice the stop. English speakers resist this option and inhibit the voicing process. Even though English speakers cannot avoid some post-nasal voicing, it is not clear why a rule would be necessary to describe it; the degree varies greatly, but voicing is sufficiently inhibited to maintain a voiceless percept.

13. Processes and constraints – Optimality Theory and Natural Phonology

Optimality Theory (OT), as proposed by Prince and Smolensky (1993), is an attempt to account for phonological forms and alternations through the interaction of universal, phonetically-based constraints. Speakers select surface forms that show the fewest violations of higher-ranked universal constraints. The foundation of Optimality Theory is the idea that phonology is a system of universal phonetic constraints that a speaker brings to a language, rather than a system of rules that a learner must induce from the observation of surface forms. This is an important break from the position of structural and generative phonology, but it is one that Natural Phonology made long ago.[10]

13.1. Similarities between OT and NP

OT displays, of course, some similarities to Natural Phonology (NP). First, the universal Well-Formedness constraints of OT refer to the same phonetic difficulties as natural phonological processes do. OT constraints, like natural processes, are "violable": constraints may be outranked, as processes may be suppressed or limited. OT's Faithfulness constraints, which specify that the output should be the same in some respect as the in-

[10] Stampe (1973a: 46) said of natural processes, "if they applied freely they would reduce all phonological representations to [pa]", and Chomsky (1995: 380) said of optimality constraints "all lexical inputs yield a single phonetic output, whatever the optimal syllable might be (perhaps /ba/)".

put, function in the same way as do inhibitions or limitations of processes; if a Faithfulness constraint outranks a Well-Formedness constraint, the difficulty of the input form perseveres in the output. Constraint rankings constitute the language-specific part of phonology in OT, as do the inhibitions of processes in NP.

The initial high ranking of Well-Formedness constraints above Faithfulness constraints in children's speech (Gnanadesikan 1995; Smolensky 1996a, 1996b) corresponds roughly to the initial over-application of processes in children. The learning bias in favor of "markedness constraint dominance" corresponds roughly to the expectation in Natural Phonology that processes *apply*. The "demotion" of a Well-Formedness constraint below a Faithfulness constraint functions like process suppression or limitation. Incidentally, optimality theorists may refer to "omission" of processes in NP – but processes can only be inhibited, and the most solid inhibitions of features or domains may be relaxed in the pronunciation of commonplace phrases like [ˈpʰrɛzˌɲãẽ̯ˈstɛi̯ts] *President of the United States*, beside [ˈrɛzɨdə̃ɾ̃əðəjəˌnɑe̯ɾɨdˈstɛi̯ts] *resident of the United States*, or in hurried speech like [ˌtʰw̃ə̃ĩˈw̃ə̃ː ˌtʰw̃ə̃ĩˈtʰuː ...] *twenty-one, twenty-two, ...*, and similarly in fatigue, nervousness, physical interference [ˌʔaʔ ˈhəʔh] *that hurts!* (spoken to the dentist), babytalking [ˈpʰwɪdi ˌwɪdʊ ˈbʊdi] *pretty little birdie*, and in intoxication, degenerative diseases, and brain traumas.

OT constraints that are related by function can be described so as to replicate implicational conditions on phonological processes. OT instantiates phonetically motivated implicational conditions as sets of related Well-Formedness (a.k.a. Markedness) constraints with universal rankings (e.g. *[−son, +voice, Dorsal] >> *[−son, +voice, Coronal] >> *[−son, +voice, Labial], and a Faithfulness or "blocking" constraint can intervene in rank between the members of the set. Hayes and Steriade (2004) use the example of obstruent devoicing; they say that it is subject to two implicational conditions (place and length), resulting in a single scale: *[+voice]: {ɡː < dː < bː < ɡ < d < b}, where < means "is more marked than" (Hayes and Steriade 2004: 9). A Faithfulness constraint like Ident I-O (Voice) might allow all the segments "to its right" to surface, while segments "to its left" are ruled out. If the voicing-identity constraint is ranked between *[+VOICE]: [ɡ] and *[+VOICE]: [d], the language will allow surface [d] and [b], but not [ɡ] or long voiced stops. So a language that lacks [ɡ] will always lack long voiced stops as well.

Natural Phonology, since its inception, has referred to implicational conditions on process application; but NP takes the view that each condition is independent. For example, the delabialization process: [+syllabic, !+low, !−high] → [−labial] (to be read as "Vowels become non-labial, especially if [+low], especially if [−high]") expresses the implicational condition that if a higher vowel delabializes, a lower one, *ceteris paribus*, will delabialize as well (Donegan 1978). In OT this could be expressed as a universally ranked constraint set *[+syllabic +low +labial] >> *[+syllabic −high +labial] >>*[+syllabic +labial] , which could be limited by the interposition of a faithfulness constraint between any of the sub-constraints. The ranking *[+syllabic +low +labial] >> *[+syllabic −high +labial] >> Ident I-O (labial) >> *[+syllabic +labial] would allow high labial vowels to surface, but not low or mid ones. (See Lassettre 1995 for further discussion.)

13.2. Differences between OT and NP

There are, however, important differences between OT and NP. Perhaps most important, OT, like its generative forebears, attempts to deal with morphonological alternations using the same phonetically-based constraints as those that govern phonology. This leads to the same kinds of complications that have afflicted Lexical Phonology and its derivational relatives. Non-universal constraints such as *VkV "no vowel-k-vowel" or *ær]$_{\sigma}$ "no /æ/ before tautosyllabic r" (Kager 1999), and additional theoretical machinery such as multi-stratal OT, sympathy, local conjunction, and output-output constraints (Kager 1999) are among the patches used to cope with opaque and morphonological phenomena that are not accounted for in Prince and Smolensky's original theory.

OT focuses on articulatory and perceptual difficulties rather than on the processes that alter difficult forms. One problem with this is that many plausible "repairs" for those difficulties never seem to occur: for example, voicing is more easily maintained in coronals and labials than in dorsals, so changing [g] to [d] or [b] might make it possible to maintain voicing, but if this occurs it has not been discovered.

OT concentrates on the selection of surface forms; there are no limitations on inputs: "the set of *inputs* to the grammars of all languages is the same" (Smolensky 1996b, 3). This idea is referred to as "the richness of the base". In contrast, while NP also allows for any intention the speaker can concoct, it imposes limitations on lexical forms.[11] But these limitations are not stated independently as morpheme structure constraints or as an arbitrarily specified inventory of phonemes. Rather, lexical limitations reflect language-specific limitations on speakers' perceptions.

In both OT and NP, the "locus of explanatory activity" is in the constraints and processes, respectively, that determine surface forms. But in NP, the processes affect perception, as explained in Section 10: fortitive processes constrain the hearer's inventory of pronounceable and thus perceivable sounds, and lenitive processes allow the hearer to perform a causal analysis of sounds that do not belong to the inventory and to perceive them as variants of those that do belong. Fortition-Lenition interactions, as noted above, allow an NP account of phonemic perception. Insofar as (original) OT says anything about perception, it seems to assume that perception is entirely faithful to the phonetic output (Smolensky 1996a).

Although by adoption of "Stampean occultation" OT eliminates some potential lexical representations, without some device like NP's fortitive constraints on perception, it fails to eliminate subphonemic features. But there is considerable evidence (e.g. Sapir

[11] Lassettre and Donegan (1998) reject the OT claim that perception is perfectly "Faithful" (as in Smolensky 1996a), and propose an alternative OT interpretation.

1933; Dupoux et al. 1999; Aoyama 2003; rhymes as in Section 6, etc.) that perception is phonemic, language-specific, and not entirely faithful to the surface form. So inputs to perception are indeed unlimited, but linguistic perception is phonemic, and as a result, lexicalizations and linguistic "intentions" are limited. Birds don't say *bobwhite*, or *chickadee* or *quack-quack*, but if we hear them as speaking to us in English, that's what we hear them say (Donegan and Stampe 1977).

OT aims to eliminate long derivations, and all OT constraints apply simultaneously, although stratal OT allows multiple steps. In Natural Phonology, Fortitions apply simultaneously and Lenitions apply simultaneously. The two sets apply as consecutive blocs, and one bloc, the Lenitions, may iterate, at least in some cases. So long derivations are avoided, but NP's view of process application enables it to describe the opacity associated with "counterfeeding order" as a derivational constraint (Donegan and Stampe 1979, see Section 9), which is problematic for OT.

14. Conclusion

Natural Phonology holds that all infants, discovering the capacities of their bodies and their senses through vocalization and babbling, and listening to the stream of actual speech around them, arrive at a universal theory of the relationship between articulatory actions and their perceptual results (features), and also of the multi-dimensional hierarchies of difficulty that stand between intended actions and their actual results in the real time rhythm of speech (processes). And using this theory, even before they speak words themselves, infants learn to perceive what in the stream of speech is intended (phonemes), and what is just process-induced divergence. And when they begin to use words, they aim at what they have (usually) correctly perceived as the intention of adult speech, and the active processes they share with adults will take care of the details of its actuation.

Unfortunately many, or most, of the processes that they know to be inactivated by adults remain active in their own speech. Although they are aiming at the same forms as adults – which is rarely true of second-language learners – their pronunciations of those forms are often objectively far more divergent from native speech than are the pronunciations of foreigners. And yet, if children are consistent in their choice of mispronunciations, their interlocutors, who share the same intended forms, and the same body of hypotheses – the natural processes – about how speech might be mispronounced by a child, are usually able to understand most of their intentions.

The ability of the child and the adult to abstract away from actuations to intentions in terms of a common system of natural hypotheses makes it possible for them to communicate, and furthermore to adapt to each other as the child's pronunciation evolves, sometimes by leaps and bounds, and as the adult gradually ceases to use fortitive and simplified speech to the child. It is the shared system of natural processes, and the shared perception of intentions, that allow language to be learned and taught in the only way that it can be, by being used to communicate.

Baudouin's student Kruszewski, by publishing his 1881 thesis in German, gave western Europe a first glimpse of the phoneme as a unit of intended speech that is abstracted from the "divergent" sounds of actual speech, and also its vital role in the lexical and grammatical "correlations" of morphology. "Without the concept of the phoneme", Kruszewski (1881: 45)wrote, "it is impossible to study either phonetics or morphology". Now, as then, there are doubters, who believe that the phoneme is a delusion based on letters. But Kruszewski's thesis topic was *guṇa*, a part of the profound analysis of Sanskrit that the ancient Indian grammarians developed and passed down – not in writing but in speech, at a time when Sanskrit had no letters, but only phonemes.

Infants and adults alike abstract the essential from the accidental – whether it be a an oral vowel nasalized by a nasal, or a white flower shaded green by green foliage – and we do it so instinctively that it takes years of practice to transcribe the actual sound or paint the actual color, so that many of us depend on analysing visual recordings or color measurements, and most of us transcribe or paint by rule.

In our normal and effortless perception of utterances, we perceive not the actual sounds, nor the words or sentences that are said to us, or even their literal meanings, but what the speaker meant. We unconsciously discard what was caused by ambient noise and by natural processes and by lexical and grammatical conventions and conversational conventions, until we arrive at what it was that caused the utterance to be spoken. *Perception is not merely sensing, it is understanding*. Everything incidental to understanding is treated as mere formality, beneath the notice of anyone but linguists.

But for our science, whether we call it phonology or phonetics, it is what is meant that is the given, and how it is expressed that is the puzzle – why we speak with such unconscious and inadvertent noise, and why that noise, however massively variable, gradually reveals such lawlike regularities.

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