23 Natural Phonology and Sound Change

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> If we turn now to the actuating principles that determine the general changeability of human speech habits, we shall find that the moving power everywhere is an impetus starting from the individual, and that there is a curbing power in the mere fact that language exists not for the individual alone but for the whole community. The whole history of language is, as it were, a tug-of-war between these two principles, each of which gains victories in turn (Jespersen 1964: 261).

Abstract

Phonological processes are phonetically motivated and universal, but their application is limited through language learning. As the inhibitions on processes change, pronunciations and speaker abilities change, leading to changes in learners' perceptions and representations. Natural Phonology accounts for the traditional notions of splits, mergers, rephonemicizations, chains, and typological changes through changes in these inhibitions.

1 Introductory remarks

Natural phonology (NP) views the phonology of a language as a system of subconscious mental processes that in real time mediate between intended but unpronounceable lexical forms of utterances and pronounceable surface forms. In production, the prosody maps lexical items in morphological and syntactic structures onto a real time rhythmic score. The scored sequence is submitted first to fortition processes that enhance the perceptibility of its rhythmic divisions (such as feet and syllables) and its phonemes, and

then to lenition processes that enhance the pronounceability of the sequences of sounds within their rhythmic domains.[1]

NP is a (primarily) non-structuralist theory of language structure, in which the nature of the phonological system is shaped by the nature of its users — human beings — and specifically by their speech-production and perception abilities. Essential works in natural phonology[2] include Donegan & Stampe 1979, 2009; Stampe 1979, 1987, Donegan 1985, 1993, Nathan 2008, 2009. Natural phonology's view of sound change is informed by its view of linguistic sounds. The sounds of each language are shaped by language-specific limits set on the natural pressures that the vocal tract and perceptual system impose on the humans who make use of them. For example, the vocal tract is configured so that voiced obstruents require complex physiological gymnastics to master. Polynesian languages, among others, lack these sounds, so their speakers have no need to master them. Speakers of Romance languages, on the other hand, must acquire the ability to perform these gymnastics, and so they overcome the inherent pressures against voiced obstruents.

Each pressure brings with it a 'solution' — a substitution that avoids the difficult sound (or class of sounds); this avoidance behavior is known in natural phonology as a process. Processes are motivated by our physiology, though they apply in speech planning. They are 'natural' (or 'innate') in the sense that they arise in response to the limitations of the human speech endowment[3]. They are not learned by observation and comparison of forms — though they may emerge as the infant learns to coordinate the

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1 The terms Fortition vs Lenition, adopted for the alliterative slogan 'Fortitions first, lenitions last' (Donegan & Stampe 1979, 153ff), apply to all classes of sounds, including vowels (Donegan 1978), not just relative to consonant 'strengthening vs weakening'. Earlier Stampe (1972, 584) had used the terms 'hyper- vs hypoarticulation', and subsequently Dressler (1985, 44-45) proposed 'foregrounding vs backgrounding'.

2 We refer here to what we might call the American (or 'classical') version of NP. We appreciate the many works on NP by European authors, but their versions may differ from ours in ways that we do not address here. References include, for example, Dressler 1984, 1985, Dziubalska-Kolaczyk, and Hurch & Rhodes 1996.

3 Note that this is a very different view of 'innateness' from Chomsky's, since it arises as the human organism learns about its capabilities while interacting with the environment, and is not directly given by its genetic endowment.

movements of the vocal tract and to associate articulatory gestures or configurations with their audible results. What is learned, in learning to pronounce a language, is to inhibit processes, or to inhibit them under certain circumstances, and thus to pronounce their potential inputs. In sound change, inhibitions on processes may be relaxed, so that additional processes apply, or particular processes apply more generally. With such changes, speakers' articulatory and perceptual abilities change, leading to splits, mergers, sound shifts and typological changes.

1.1 Phonology and morphonology

Natural phonology is a theory of the production and perception of speech sounds. In saying this, Natural phonology draws a crucial distinction between synchronic phonological processes — which are based in *mental* phonetics and inseparable from it, and morphophonological rules. 'Rules' describe alternations that may *appear to* refer to phonetic classes, but that should be treated, because of their conventional nature and morphological conditioning, as part of a language's morphology. This distinction of 'process' vs 'rule' is an old one, related to Baudouin's (1972/1895) distinction between divergence vs. correlation, Sapir's (1921, 1925) mechanical vs. grammatical processes, Bloomfield's (1933) and Wells' (1947) automatic vs. nonautomatic alternations, and Jakobson (1968) and Bazell's (1955) motivated and unmotivated alternations. In some important respects, this correlates quite closely with the traditional Neogrammarian contrast of sound law vs. analogy. Generative phonologists, beginning with Halle (1959) and continuing with Anderson (1981), rejected such a distinction. Lexical phonology (Mohanan 1986, Kiparsky 1982) reinstated a similar distinction, but the lexical vs post-lexical contrast coincides only in part with the rule/process contrast described above; lexical phonologists have continued to emphasize the study of morphophonological rules over post-lexical ones. Optimality theory seems to ignore the distinction.

The apparent phonetic conditioning of 'rules' is a byproduct of their origins in processes. But we cannot, strictly speaking, say that processes 'become' rules, because phonetically motivated processes represent constraints on speaker abilities, but morphophonological rules are conventions, part of the learned grammar of a language. Rules may govern speakers' behavior, but they are not constraints on their abilities. Thus, NP does not subscribe to the widespread view of a 'life cycle' of phonological rules,

where 'phonetic regularities' become 'phonologized' and then acquire morphological and lexical limitations. Natural phonological processes do not become rules. **Alternations** become rules.

The 'phonetic regularities' that underlie alternations do not just appear randomly – they arise in the requirements of the speaker & hearer. But neither are these regularities universal, as one might expect from the universality of the vocal and auditory apparatus. The phonetic difficulties that favor substitutions (either lenitive/assimilative or fortitive/dissimilative) *are* universal, but each language allows only some of the potential substitutions to apply. Language learners must learn to resist or suppress the application of the others.

The substitutions—or processes—are not mere physical slips or inaccuracies; they are centrally planned, and thus they are phonological *right from their beginnings* (in children's substitutions, in connected/casual speech, in exaggerated pronunciations, etc.). The processes mediate between the speaker's phonemic or lexical representation or *intention* e.g. English *can't* /kʰænt̚ʰ/ (which is fully specified in phonetic terms), and the speaker's *target* e.g. [kʰæ̃t̚ʔ], the representation after it has been adjusted by the processes – i.e. the phonetic representation. Note that the target is the phonetic *representation* – which is not identical with the actual physical output[4]. The 'phonetic regularities' are the result of the natural processes that apply.

If further processes are allowed to apply in the language, they may create unrecoverable opacity that completely obscures the phonetic motivation of older processes. E.g. If /bɛnt/ becomes [bɛ̃t], the opacity is recoverable: Nasalized vowels are absent from the inventory, but sonorants are nasalized before nasals, and nasal consonants are deleted in shortening (pre-fortis) environments – all of these processes are natural.

On the other hand, if vowels are (naturally) shortened in a particular prosodic environment (as in the earlier English process of trisyllabic laxing) and the long vowels change in quality (diphthongizing and raising, also natural) – and then, because of prosodic changes, the duration distinction is lost and the difference is reinterpreted as a quality distinction, the phonetic motivation and thus, the original intentions, are no longer recoverable. At this point, the quality alternation becomes conventional.

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[4] No two pronunciations of *can't* – even with the same target and by the same speaker – are likely to be in all details acoustically identical.

It is this conventionality that pushes the alternation into the grammar (the morphophonology), even if it remains 'productive' to some degree. In fact, alternations that become unrecoverably opaque often develop morphological conditions (so the alternation only applies with certain affixes, to certain word classes, at morpheme boundaries, etc.). But neither opacity alone nor morphological conditioning alone is the crucial distinction. Morphological conditioning is an *indicator* that an alternation is rule-governed rather than process-governed. Morphological conditioning is not definitional; conventionalness (absence of synchronic phonetic motivation) is.

1.2 The phonetic basis of processes

Processes have entirely phonetic motivations, but they are mental responses either to physiological limitations, such as the voicing/obstruence interaction, or to perceptual limitations (such as the fact that nasalization makes vowel contrasts more difficult to perceive). Some responses to perceptual and articulatory limitations enhance or optimize individual sounds, and they define for each language a set of sound elements traditionally called 'phonemes'. There is pressure towards stops rather than fricatives, toward front or rounded high vowels rather than central high vowels, and so on. The result of the application of these processes (called fortitions) is to limit the universe of intendable, perceivable sounds to a phoneme inventory, for each language – i.e. a set of perceptually idealized (prototypical) sounds (see Nathan 2007, 2008), an instance of prototypicality effects.

Responses to exclusively articulatory limitations on the other hand, usually associated with optimization of sound sequences, are known as lenitions; these result in fewer or weaker gestures performed by the vocal tract, or in relaxation of gestural timing requirements. Thus, obstruents are preferentially voiced between voiced sounds, and vowels, sonorants, or stop sounds are preferentially nasalized adjacent to nasal sonorants. While these universal processes may apply in all humans, each linguistic community 'selects' a set of processes to be suppressed. The child's acquisition task becomes one of learning not to apply the locally inappropriate set.

Because processes are based on universals of the articulatory and auditory systems, they appear at the earliest stages of language acquisition, and they recur in child language cross-linguistically (Jakobson 1968, Donegan 1985, MacNeilage 2008,

etc.). They also occur in unrelated adult languages around the world, as documented in the implicational universals of Jakobson (1968) and in more recent catalogs such as Ladefoged & Maddieson (1996). Processes are sensitive to implicational conditions (for example, vowel devoicing preferentially applies to higher, and intrinsically shorter, vowels). This indicates the essentially *phonetic* motivation of processes, though their categorical application in terms of classes of sounds indicates their *mental* nature. For example, the fact that high vowels often behave as a class, despite their radically different articulatory natures (e.g. tongue fronted, lips unrounded, vs tongue retracted and lips rounded) indicates the cognitive (even if unconscious) classification of these sounds, a classification system which underlies the concept of 'features'.

1.3 Processes as mental operations

Lenitions and fortitions are not to be understood as being implemented autonomously by the vocal tract — they are not simply accidental or unavoidable physical events. Rather, they are implemented by the mind, *on behalf of* the vocal tract and perceptual system. Their mental nature is evident from the fact that they do not apply universally, from their role in variation, from the evidence that they alter the targets of the articulators, and from counterfeeding applications (the cases that illustrate what is known in the phonological literature as 'opacity'). If processes were not (at least potentially) under mental control, we might expect them to apply equally in all languages, given equivalent inputs — but of course they do not. A language community may require that its speakers not apply a given process (consider, for example, obstruent devoicing and voicing) or it may allow its application to vary, depending on such social influences as formality, frequency, attention, and emphasis. A specific process--like flapping or vowel reduction in *Beddor*, or [t]-deletion in *Post*--can be temporarily suspended (as when dictating a name over the phone, or even when pronouncing an infrequent word); this requires that processes be mental events, not purely physiological ones. And finally and most obviously, a language community may require that its speakers not apply a given process. (Consider, again, that many languages do have distinctive voiced obstruents, and many do not voice obstruents allophonically.)

Because processes each respond to a given phonetic difficulty, alternative processes may resolve a given difficulty in different ways, and a speech community may

'select' from among alternative solutions. For example, Romance languages select the task of acquiring the ability to make voiced obstruents (thus suppressing the processes that would eliminate them). Some languages simply replace voiced with voiceless obstruents if necessary (for example, when borrowing); Hawaiian and Samoan illustrate this 'solution'. Vietnamese, on the other hand, replaces its voiced stops with implosives (Thompson 1965, 24), while Fijian replaces them with prenasalized voiced stops (Schutz 1985, 21); both of these options may involve more effort than merely voicing a stop, but enhance the audibility of the voiced quality.

2 What is a 'sound'?

To understand the natural phonology view of how sounds change, we need to consider both the representation and the realization of phonemes. 'Speech sound' is a term used of a recurring element in speech; sequences of such elements make up words. In natural phonology, phonemes are speech sounds – recurring units of perception, representation and intention. This contrasts with a number of alternative views that have had currency over the years, and with some newer views that are represented in this volume.

2.1 What phonemes are not

Phonemes in structuralist and generative phonology are ordinarily defined by the complementary distribution criterion, combined with a (somewhat ill-defined) notion of phonetic similarity. The structuralist and generativist views of the phoneme differ in important ways from NP's view, particularly in that the NP phoneme is not an abstraction. It is not a 'bundle of distinctive features' (Bloomfield (1933), Trubetzkoy (1939 [1969])), nor is it a column in a feature matrix or a root node in a feature tree. It is also not a small set of all and only the unpredictable feature specifications for a particular lexical entry (Halle 1964, Clements 1985, Archangeli 1988). Phonemes are not simply units that distinguish words, or keep them apart – they are the units that words are made of.

2.2. The nature of the phoneme

In NP, the phoneme is 'the mental image of a sound'. A 'sound' – a recurring element in speech – can be compared to a 'subroutine' in programming; it is called upon many times during the execution and interpretation of a larger units such as a words and sentences. An extensive discussion of this issue can be found in Nathan (2009), and a similar view is found in MacNeilage (2008) and in Lindblom's (1992) discussion of phonological acquisition.[5]

These recurring elements (phonemes) are the units of long-term mental storage of lexical forms. They are pronounceable — thus, they are units that morphology can manipulate. Being perceptible, 'graspable' units, they can differentiate meaning. It is for this reason that we can have minimal pairs — minimal pairs exist because phonemes are perceived as distinct.[6] And because phonemes are perceivable and intendable as themselves, non-automatic morphophonological substitutions ('divine ~ divinity', 't[ə]nir ~ t[j$\tilde{\varepsilon}$]nt'), which depend on morphological information, always involve the substitution of phonemes, so that 'structure preservation' is a characteristic of lexical (morphophonological) rules.

Phonemes are units, but they are interpreted phonetically, within the (natural) phonology. Phonological substitutions affect (and are conditioned by) phonetic features, which are the internal, mental mappings between physical gesture or configuration and its acoustic effect. Thus, [coronal] is a mapping between a tongue-front gesture and a specified set of formant transitions: the automatic mental equivalent of the thought process underlying this linking could be paraphrased as 'if I move my tongue this way, it sounds that way.'[7]

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[5] Lindblom's discussion of recurring elements rightly refers to the development of connections between articulatory gestures or configurations and their auditory results. He suggests that the early representations of speech units are syllables, emphasizing, at least in acquisition, the articulatory 'trajectory' associated with a sound sequence. NP would refer, instead, to the end points of such trajectories — so /ma/ is not just represented as the trajectory /ma/ but as the end points, /m/ and /a/.

[6] This is in some sense a reverse of the structuralist view that phonemes exist because there are minimal — or near-minimal — pairs.

7 This is not to suggest, of course, that such thought processes are conscious.

NP phonemes combine acoustic/auditory specifications with (simultaneous) articulatory specifications, and they are fully specified as pronounceable sounds, not underspecified abstractions. The fortitions that apply in a particular language 'cull' possible representations by eliminating dispreferred feature combinations from the inventory of intendable sounds. For example, if obstruent devoicing applies obligatorily and context-freely in a language, the language will ordinarily lack voiced obstruent phonemes, so no voiced obstruents are stored or intended. But in the same language, the application of a lenition like intersonorant voicing may allophonically introduce voiced adaptations of the intended voiceless obstruents. Lenitions adapt sounds to their environment or to a specific speaking style. Because hearers experience the same phonetic pressures that underlie speakers' adaptations, they can subconsciously undo the voicing substitution, and thus they normally perceive only the voiceless intention. This interaction between fortitions and lenitions thus results in an inventory of intendable, memorable, perceivable sounds — the 'recurring elements' of production and perception.

This view also contrasts with contemporary exemplar theory (e.g. Pierrehumbert 2002, 2003), according to which mental representations consist of sets of exemplars — exact memories of phonetic forms, both words and segments. 'According to exemplar theory, people have long-term memories of particular percepts, and these are stored as locations on the [perceptual] map. These are the 'exemplars' of the theory. Exemplars are categorized using [the set of labels associated with those percepts], and this has the result that each label is associated with a large set of remembered percepts. These implicitly define the region of the map which corresponds to that label.' (Pierrehumbert 2002:113).

A more moderate version is proposed by Bybee, who states 'a given linguistic category (say, /p/) will not have just one prototype, but may have several — one for each frequent context' (2001, p. 37). Because exemplars are apparently based on acoustic variation, sets of exemplars are required to allow not only for segmental environments, but also for slower or faster speech, varying styles, etc. Although there is no doubt that human mental storage is quite vast, the possibility that each lexical entry will have perhaps thousands of variants due not only to the segmental environment (e.g. adjacent voicing, nasalization etc.) but also to speech rate, speaking style, food in the mouth and other causes of variation seems unlikely, given that this would require that a speaker select among these thousands of stored variants in the ongoing process of speech

construction. NP's causal theory of speech perception, in which hearers perceive speakers' intentions in terms of their own limitations and habits, eliminates the need for separate representations for each speaking style for each segment for each speaker.

In contrast with usage-based models such as Bybee's, the NP phoneme is not a set of lexical connections or a repeated element used to construct a schema, where /b/ is the beginning of *big, bad, buy, believe*, etc[8]. Such a conception of the phoneme loses the connection between the syllable-initial [b] of such examples and the medial [b]'s of *rubber, baby, robin*, etc. and the final [b]'s of *rub, babe, rob*, etc. These medial [b]'s may be more weakly articulated, even spirantized, or the final [b]'s could in some varieties be glottalized, but these variations in articulation are governed by regular, phonetically-motivated processes, which allow the variations to be discounted, and the variants to be perceived as the same. The fact that these non-prototypical medial [β]'s surface as [b]'s if we sing, or speak syllable by syllable, or accidentally pronounce them out of place in a Spoonerism compels us to argue that they are true units of mental classification, and not merely the result of learning how to spell. We note further that this automatic variation occurs in speakers of languages that do not have orthographies, or have non-phonological ones, such as Chinese. Further evidence that speakers are, in general, completely unaware of this variation in /b/'s, is the ease with which children learn to spell the variants with <b>, as well as the training required for phoneticians to be able to hear the variation that usage-based models claim we store.

So, for example, if a fortition that delabializes low vowels applies in a language and [ɒ] unrounds to [ɑ] context-freely, the language will lack the phoneme /ɒ/, and speakers may perceive [ɒ] as /ɑ/, as in some varieties of English. But a language that lacks /ɒ/ may allow a lenitive assimilation process to labialize /ɑ/ between labial consonants, creating surface [ɒ]'s. Because the hearer shares both the fortitive limitation and the lenitive assimilation with the speaker, these [ɒ]'s will be perceived as /ɑ/'s which have undergone this assimilation. (Note that a hearer who has overcome the fortitive process that eliminates /ɒ/, will hear the [ɒ]'s as /ɒ/.)

[8] (See Bybee (2001, 22) "[b] is a possible syllable onset (in effect, [b] is a phoneme)." and also her figure 2.2 (23)).

3 How can ‘sounds’ change?

3.1 Processes ‘change’ sounds in speech[9]

In speech processing, lexical representations are altered, fortitively or lenitively, to become representation of the sounds speakers actually produce. What Baudouin called ‘divergences’ create differences between intention/memory and actual pronunciation. This is the essential problem of, and fact about, phonology.

The substitutions are phonetically motivated but they are mental, and thus humanly controllable — as we said above, they are not simply matters of physical undershoot or overshoot. In a given language, particular substitutions are allowed to apply, and consequently it is convenient to distinguish the speaker’s *intention* — the lexical representation — from the speaker’s *target* [10]— that representation as adapted, within the confines of the language, to the demands of speech. A speaker who intends *can’t be* /kænt bi/ may adapt that sequence of phonemes to an altered target, [kʰæ̃ʔpˉbi]. The hearer, knowing the processes of the language and their motivations, hears the acoustic effects that result from articulation of the target, and *undoes* these adaptations to arrive at the speaker’s intentions. The hearer perceives [kʰæ̃ʔpˉbi] as /kænt bi/ because he would pronounce /kænt bi/ as [kʰæ̃ʔpˉbi] himself.

3.1.1 Articulatory planning

Phonetic variability in the realization of lexical representations is not just a matter of random failures to achieve an articulatory intention, by overshoot, undershoot, accidental mistimings, etc. Evidence that substitutions are centrally coordinated comes, in part, from the fact that substitutions, though phonetically (and thus universally) motivated, are not instantiated in all languages. If speakers can learn to control process application, this indicates that such processing occurs in the central nervous system.

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[9] Changes in the lexical representations of words due to processes such as the analogy responsible for the /f/ in the Germanic word for ‘four’ from Indo-European *kʷetwores are not phonological processes and not addressed here, and of course other morphologically-motivated changes are not strictly speaking ‘sound changes’ either in this conception and are also not discussed here.

[10] The ‘intention-target’ distinction is clearly drawn in Moosmüller 2007.

An example of a supposedly unavoidable undershoot involves the fronting of back vowels in coronal environments. But the raising of F2, though appreciable in English (Stevens and House 1963, Hillenbrand 2001), does not occur equally in all languages. Flemming (2001) shows that F2 displacement (associated with this 'undershoot') does not occur equally in similar sequences in French, German, and Hindi. Furthermore, Labov (ms) shows that the application of this process in some dialects is variable, but is affected by standard phonological factors such as the adjacency of velarized /l/. If speakers have a choice in the matter of articulatory precision, then the undershoot or non-undershoot is controlled by the speaker and is "not the consequence of an inability of the articulators to reach their target" (Moosmüller 2007, note 4).

The precise timing of speech gestures would be impossible without central planning. Differences in inertia of different articulators, differences in conduction speeds of different nerves, etc., require central coordination. Speakers must plan articulations in ways that cope with and anticipate particular phonetic requirements. These phonetic requirements are those of the intention— some of which may not even appear in the phonetic representation, or target. The adjustments are to some degree independent of each other and occur simultaneously, but their coordination cannot simply be left to chance. Experimental evidence of many kinds (e.g. Whalen 1990, Boyce, Krakow, and Bell-Berti 1991, Kingston & Diehl 1994, Wood 1996, Moosmüller 2007, etc.) argues for central planning of phonetic details.

3.2 Diachronic phonetic change

Historical sound changes arise when a group of speakers begins to allow a process to apply where it had not applied before. Most, if not all, changes are motivated by the demands of articulation and audition; that is, they occur for phonetic reasons. The question of why a phonetic change — application of a previously suppressed or latent process — happens at a particular time in a particular place (the 'actuation problem') probably has no answer, but if a process *is* accepted (presumably under certain social conditions, giving rise to 'spread'), then the pronunciation in the community changes. There are undoubtedly many processes that are unsuppressed on an occasional, ad hoc basis, but do not get accepted, and hence the new pronunciation vanishes.

Sound change begins with the introduction of allophonic variants, or 'divergences' from the lexical representation. Phonological processes underlie such divergences: for example, a schwa vowel plus a sonorant consonant may become a syllabic consonant by assimilation ([bɑdl̩] 'bottle'), or a syllabic consonant may de-syllabify, as in a child's [blun] 'balloon'.

In child speech, processes are at first obligatory, and are gradually inhibited — to the limits of the community's tolerance. Within the adult speech community, processes (with the same phonetic motivation as in children[11] may first appear as optional or merely occasional substitutions, occurring only in limited contexts (phonological and stylistic), and perhaps only in particular lexical items. Bybee (2004, 40 ff.) shows a number of examples[12] in which apparently identical phonological environments do not condition identical substitutions: e.g. *every* must have two syllables, but *memory* may have two or three; *summary* may reduce to two syllables, but *summery* does not. The differences appear to be related to word frequency. Phonetic changes, particularly reductive ones, often appear to be more advanced in higher-frequency words, and resisted in less-frequent words, perhaps in aid of simpler recognition of rarer words.

Bybee interprets this as evidence that each lexical item has a particular set of lexical representations that depend on the item's use. But such differences in pronunciation need not imply different lexical representations; rather, such variation may instead reflect the sensitivity of process application to pragmatic facts of language use — process application may depend on factors like word frequency, redundancy (which may depend on particular interlocutors and their familiarity with a topic), degree of formality, tempo, etc. Thus, variable process applications are decisions based on a specific speaking situation.

Within a community, a process that is at first largely inhibited and applies only occasionally in adults may increase its frequency and range of application, generalizing its (phonological and 'usage-based') conditions for application. As the new divergence becomes accepted, learners may begin to allow the process to apply with diminishing

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11 Note that most well-studied instances of sociolinguistic variation, such as various American vowel shifts, AAVE consonant cluster simplification etc., are originally well-known processes.

12 Many of these examples were observed earlier by Zwicky (1972), who treated them as the result of application of optional fast-speech rules.

inhibitions. If the process becomes uninhibited or obligatory, it ultimately becomes an actual constraint on speaker abilities as, for example, unrounding of front vowels became obligatory in Early Modern English. More recently, in many varieties of English, /ɒ/ has unrounded to /ɑ/. Consequently, English speakers today cannot easily pronounce French, German or Chinese words with front rounded vowels, and California or Canadian dialect speakers who obligatorily unround low vowels find it hard to pronounce 'caught' differently from 'cot'. When a process becomes obligatory, speaker abilities have changed.

3.3 Variable process inhibition

The application of phonological processes is, as noted, related to redundancy, word frequency, style, and other factors.

3.3.1 Lenitions

Lenitions apply first, most frequently, and most generally to frequent items and set phrases; Stampe pointed out long ago (1979: 7–8) that while *I don't know* can reduce to [ão̯nõu̯], a similar phrase like *I dent noses* cannot so reduce, and while *think* as in *I think it's raining* can reduce to [ae̯ hĩŋk], it cannot in *I think, therefore I am*. Common usages like phatic phrases, anaphorics, clitics, or function words are particularly susceptible to lenitions. Glide loss is more likely in *I'll* [ɑl] than in *aisle* [ɑi̯l], and stopping of /z/ more likely in *isn't* [ɪdn̩t] or *doesn't* [dʌdn̩t] than in *pleasant* or *reason*. French *je suis* [ʒə sɥi] 'I am' and *je (ne) sais pas* [ʒə se pɑ] 'I don't know' can reduce to [ʃɥi] and [ʃepɑ], but *je saute* [ʒə sot] 'I jump' cannot reduce to *[ʃot].

3.3.2 Fortitions

Fortitions apply first, most frequently, and most fully to accented or emphasized forms, in situations that are susceptible to enhancement or exaggeration. They apply most often at the edges of phonological constituents, so initial stops may be aspirated or tensed, final stops may be glottalized or devoiced, etc. (See, for example, Donegan and Stampe 1978, Donegan 1986, compare Fougeron & Keating 1996.) Note that this does not necessarily mean that fortitions apply more to infrequent forms — fortition application is orthogonal to frequency, a point where NP differs from usage-based models. Consider,

for example the fronting of /ɔu/ to [ɛu̟] in some East Coast dialects (Philadelphia, Baltimore). With optional fortitions, all that seems to be required is some reason for emphasis. Thus, given equal emphasis, *nose* and *noes* (as in *The noes have it*) seem equally likely to front to [nɛu̟z] despite the radical difference in frequency of occurrence.

4 Changes in representations

Although the term 'sound change' may refer to the introduction of allophonic differences by process application, it is used more often to refer to changes in lexical representations. This could involve the introduction of new phonemes, loss of phonemes through mergers, and sound shifts. It may also be used of changes in the lexical representations of words without changes in the phoneme inventory. Phonetic changes do not necessarily change lexical representations, of course, in part because lenitive changes are often undoable, and transparent. Listeners subconsciously account for the actual occurrence of sounds that are eliminated by fortitions from their repertoires of intentions.

Lexical forms are susceptible to changes by fortition. If diphthongization of /e/ and /o/ to [ɛi̯] and [ɔu̯] becomes obligatory in stressed syllables, learners are likely to interpret the diphthongal variety as the underlying form and consequently, the unstressed or short variants ([e], [o]) will be reinterpreted as allophonic reduced forms. Or if /ɛi̯/ obligatorily dissimilates to [ai̯], [ai̯] will become, for learners, the lexical form. Obligatory fortitions can change lexical forms, even if they are context-sensitive. For example, the /əi̯/ which arose from Middle English /i:/ (the PRICE vowel) remained [əi̯] in some environments in a variety of English dialects (Canada, New England (now limited to the Massachusetts Islands), Maryland, Virginia, and some Irish dialects). In these dialects, only the (contextually) lengthened /əi̯/ was lowered to become /ai̯/. But this lengthened /əi̯/ was lowered obligatorily, and many of these dialects now show evidence of a phonemic /əi̯/-/ai̯/ difference, even though the two are nearly in complementary distribution (see, for example, Vance 1987b). The phenomenon known as 'Canadian Raising' may be, in some dialects, a result of this lowering.

4.1 New phonemes

The development of new phonemes is traditionally referred to as 'secondary split' (Hoenigswald 1960). The best understood instances of such changes involve the application of multiple processes, the first of which results in a conditioned substitution, and the subsequent substitution results in the disappearance of some (or all) aspect(s) of the conditioning environment.

Twaddell's classic 1938 paper on the split of plain versus umlauted vowels attempted to explain how Old vs Middle High German scribes wrote their language. Umlaut in Old High German fronted vowels before a high front vocalic, /i(:), j/, within the foot: *stain* > *stein* 'stone', *batti* > *betti* 'bed', *lamb-ir* > *lembir* 'lambs', *mûsi* [mu:s-i] > [my:si] 'mice'. Umlaut was thought to apply generally in OHG (authorities are cited in Twaddell 1938: note 1), but it was indicated only for short /ɑ/ (written *e*, e.g. *stein, betti*), which represented a primary merger with short /ɛ/, also written *e*, as in *weg* 'way', *geba* 'gift'). The rest of the umlauted vowels were written as umlauted only later, in MHG. Twaddell proposed that only in MHG was there a loss of the conditioning context for umlaut (by loss of unaccented /j/ and reduction or loss of final, unstressed /i/). With this loss, [y(:)] and [ø(:)] could no longer be perceived as assimilatively fronted allophones of /u(:)/ and /o(:)/, so they came to be perceived as distinct phonemes /y(:)/ and /ø(:)/, and consequently were written distinctly. Some authors (e.g. Janda 2003, Hooper 1976, Hyman 1976, Sapir 1921) find a logical problem in this account. Janda, for example (2003, 409ff.), claims that if the phonetic conditions for an allophonic variant are lost, the variant would no longer be produced, and thus, that 'phonemic split' must occur before the loss of the phonetic conditions for the variants — possibly because of phonetic distance between the two allophones.

But the question of how much phonetic distance is enough to cause rephonemicization creates problems. The requirement of phonetic distance is at best variable. For example, Japanese speakers have well-known difficulties distinguishing English /r/ and /l/, which do not present much difficulty for English speakers. Spanish speakers struggle to distinguish English /i/ vs /ɪ/, which do not cause much confusion in English. For speakers of English, [ɛi] and [ei] are virtually indistinguishable, but for speakers of the northern dialect of Pohnpeian, they contrast: e.g. */sɛysɛy/* means 'paddling' and /seysey/ means 'haircut' (Ken Rehg, p.c. 2009). If phonetic similarity were an absolute

requirement for the interpretation of sounds as allophones of the same phoneme, then the allophones of English /t/, which include such diverse forms as [tʰ] [t], [t̚] and [ʔ], would present a problem, as would the allophones of /oʊ̯/, which range from [o] in *notation* to [ɛʊ̯] or, in some British dialects, [ɛɤ̯] in *no*. Of course, without something like the phonetic similarity criterion, we might be left with cases like English [h] and [ŋ], which are in complementary distribution, but which do not seem to be allophones of a single phoneme. But as Bazell (1955) pointed out, it is not their lack of phonetic similarity that prevents these two sounds from being perceived as a single phoneme — it is the absence of any motivated substitution of one for the other that requires them to be perceived as distinct.

We need not resort to 'phonetic distance' to account for split. The claim that Twaddell's account is illogical ignores the existence of opaque forms. The umlaut split began with assimilative fronting of the OHG stressed vowel before a syllable containing a high palatal element. The lexical forms were constrained by the fortitive processes that eliminated labiopalatal vowels, so /y:/ was not a phoneme in OHG. The umlaut process made a vowel become palatal before a high palatal within the foot. Later, the umlaut assimilation began to be accompanied by loss of palatality in the unstressed 'trigger' or conditioning factor.

This loss of palatality, like umlaut itself, did not at first affect phonological representations. The fortitions eliminating labiopalatals continued to apply, so the lexical forms kept their back labial vowels. And the palatal reduction did not affect the lexical forms, so the umlaut palatalization could continue, creating opaque forms like [my:sɛ]. But *learners* who did not hear forms like [my:si], with unstressed high palatals, who heard only singulars like [mu:s] and plurals like [my:sɛ], could not account for the fronted labials as the result of assimilation. The reduced suffix they heard was insufficient to account for umlaut, so they had to assume that the labiopalatals were part of the speakers' intentions, and that the fortitions that would eliminate such vowels from the set of intendable sounds could not apply in the language they were learning.

So umlaut alternations were no longer phonetically motivated, as lenitions. The new vowels and the alternations were learned as conventional. Speakers became aware of them, so that scribes began to spell the umlaut vowels. Speakers also began to extend the alternation, now a morphological one, to cases where there was no original phonetic justification.

There are, of course, other examples in addition to umlaut. Having heard a nasal vowel without a conditioning nasal consonant, learners may construct a representation in which the nasal vowel is essential, rather than derived, as happened in French. (If the nasal consonant is restorable, the vowels may remain lexically non-nasal).[13] In cases like this, the more conservative speakers know that the conditioning feature is there, but they fail to produce it. The learner does not hear the intention but only the opaque result and thus arrives at a different representation from the older speaker.

Objections to Twaddellian accounts of re-phonemicization (where variants seem to become distinctive just when the conditioning environment is lost) seem to assume that allophones are purely mechanical or physical effects. If this were true, then loss of the trigger — the following palatal (in umlaut) or the conditioning nasal consonant (in nasalization) — would indeed imply loss of the assimilation. But both the assimilation and the loss of the trigger are processes that apply in speech planning, as argued above. They apply simultaneously[14], creating opaque phonetic forms in the speech of adults. Examples of such opaque phonetic forms that are clearly synchronic include cases like Japanese, where stops are affricated before /i, u/ as in /mat-u, mat-te, mat-imasu/, which are [matsu, matte, matʃimasu] '(forms of) wait'. When not adjacent to voiced sounds, short /i, u/ are often lost (e.g. /mat-u/ → [mats], but the affricates that are conditioned by the lost vowels do not revert to stops (Vance 1987a, Kumagai 1997).

Another classic case, involving what is clearly still a living process, is vowel nasalization in Sea Dayak (see Kenstowicz & Kisseberth 1979, McCarthy 2003 for theoretical discussion and N. C. Scott 1957 for the original data). Rightwards vowel nasalization is entirely allophonic, but there are cases where a nasal consonant comes to be adjacent to a vowel through the operation of an optional cluster simplification rule. For example, /naŋa/ 'straighten' is pronounced [nãŋãʔ], but /naŋga/ 'set up a ladder'

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[13] One might claim that the nasal consonant is restorable in some French words (determiner and adjective pairs like *un/une, fin/fine*). But the nasal is not restorable in other words (like *vin* or *tant* or *dont),* and this requires that the nasalized vowels must be admitted as phonemes in these words – and therefore can be perceived as phonemes in *un, fin*, etc.

14 Note that no ordering is required, except that lenitions follow fortitions. The environments for both lenitions – the umlaut assimilation and the unstressed vowel reduction – are present in the lexical form. So both processes (umlaut and palatal reduction, or vowel nasalization and nasal deletion) could apply simultaneously (cf. Donegan and Stampe 1978).

can be pronounced either [nãŋgaʔ] or [nãŋaʔ]. As in many cases of opacity, the lack of nasalization 'encodes' or marks the presence of an underlying consonant. To the extent that the oral member of the consonant cluster is still stored by speakers, the nasalization will continue to be allophonic, despite the surface 'contrast'.

Mielke et al. (2003), working within Optimality Theory, argue that opacity is an unnecessary concept if we assume instead that the vowel nasalization is lexicalized. While this is not impossible, neither is it necessary in a derivational model, even one without 'intermediate levels'. As long as cluster simplification is optional, and [nãŋgaʔ] varies with [nãŋaʔ], learners can know that the nasality-inhibiting stop is part of the speaker's intention, even if it is not part of the output.

Furthermore, this solution would lead to difficulties in other, similar cases. For example, as is well known, American English lengthens vowels before tautosyllabic final voiced consonants, *hat* [hæt] vs *had* [hæ:d]. Another, optional, process devoices final obstruents, at least before pause, yielding [hæt] vs [hæ:t]. This would lead to surface opacity where pairs like the preceding example would seem to be minimal pairs for vowel length. But while it is possible to get trained speakers to hear the length while focusing on it, it is very difficult to get introductory phonetics students to transcribe it consistently, while they have no problem transcribing the same pair as having contrasting final consonants, despite their surface neutralization.

Thus, NP can account for the changed interpretation of allophones as phonemes in the speech of learners, without resorting to a notion of phonetic distance as a criterion for phonemic split, and without requiring multiple lexical representations for variants.

4.2 Mergers

Languages can also 'lose' phonemes by merger. A phonological process may cause two formerly distinct phonemes to be pronounced identically. The classic synchronic example in well-known English dialects is the /ɒ/ ~ /ɑ/ merger in *caught* : *cot, dawn* : *Don*. Mergers often arise through fortitive processes. Lenitive processes may neutralize oppositions superficially, but since they are typically context-sensitive, they rarely merge sounds in all their occurrences, at least in languages that show many phonological alternations. For example, American English /nd/and /n/ in words like *bands* : *bans*, or *tends* : *tens*, neutralize only before /z/. Elsewhere, /nd/and /n/ have distinct realizations:

winnow : *window*, *band* : *ban*, *banded* : *banned*, *banding* : *banning*, so the underlying representations of *bands* and *bans* remain distinct. Context-sensitive neutralizations like this are usually only superficial neutralizations. Sounds become the same in certain contexts through a lenition process but remain distinct in other contexts, and the overall phoneme inventory of the language is thus unaffected.

Fortition processes, on the other hand, are often context-free, at least with regard to segmental context. When they apply obligatorily, they merge sounds in all their occurrences. Thus, the surface neutralizations they produce easily become mergers of underlying form, because they leave no surface alternations — as when, for example, /ɒ/ as in *caught, dawn* becomes /ɑ/ as in *cot, Don* in various North American dialects. Well-known historical examples include the Sanskrit merger of Indo-European *e and *o with *a (Burrow 1965:103ff.). This is an instance of merger by loss of color of mid vowels; Sanskrit short /ɑ/ was [ʌ], so *e, *o > [ʌ] (Allen 1953:58). The Eastern Yiddish mergers of /y/ with /i/ and /ö/ with /e / (Sapir 1915) also were the result of loss of vowel color — in this case, the unrounding of palatal vowels. But merger can also result from the addition of color, as when Gutob-Remo *ɨ became /u/ in the Mundlipada dialect of Remo, and /i/ in Gutob (Zide 1965:44). And the epenthetic or 'enunciative' vowel of Dravidian, elsewhere /ɨ/, becomes [u] in Kannada and Telugu, thus merging with original or underlying /u/ (Bright and Eastman 1975: 35-39).

The loss of a length distinction can of course result in mergers: as when Classical Latin short *a* and long *ā* merged as Vulgar Latin *a* (Romeo 1968:61) (although the distinctions between the other long and short Latin vowels were maintained as a tense/lax contrast in Late Latin). Perhaps the most famous example of wholesale merger — the Greek convergence of six different vocalisms (ι, η, ει, οι, υ, υι), as [i] (Sturtevant 1940:30) — was the result of a variety of processes (raising, monophthongization, etc.). Mergers may also occasionally result from lenitive processes, of course. If the glide of /ɑe̯/ assimilates to the nucleus, giving [ɑɑ̯] = [ɑː], the diphthong may merge with a monophthong /ɑː/ in the system. Or the nucleus may assimilate to the glide, as when /ɛi̯/ becomes /iː/.

Some mergers (like the English merger of /y/ with /i/) are problematic for theories that view dispersion — maximization of phonological distinctions — as the motivation for context-free changes because, of course, mergers eliminate distinctions. In NP, the motivations for changes are phonetic, not structural. Mergers may result when

processes exaggerate or maximize phonetic properties at the expense of phonological distinctiveness. So, for example, if /e/ undergoes raising, which exaggerates its palatal quality, it may merge with /i/. Or if /y/ unrounds to optimize its palatality, it may merge with /i/. The independence of each process (with its own set of phonetic causalities) underlies the existence of such mergers.

Mergers occur when a phonetically motivated process is accepted by a community in spite of the potential ambiguities that may result. But there seems to be a kind of 'natural selection principle', which makes such occurrences the exception rather than rule. We might perhaps more appropriately regard the principle as one of 'natural rejection': process applications (i.e. substitutions) which result in mergers are often — though not necessarily — rejected by the speech community. This is not a novel view, of course, as our epigraph from Jespersen indicates.

4.3 Direction and 'perceptual bias'

In the view of change presented by Ohala (1981, 1993) or by Blevins (2004), perceptual similarity between the phonetic forms of phonologically different segments presumably underlies sound change. But if the problem is simply that hearers cannot easily distinguish possible forms of, say, *input* – like [ĩnpʊt], [ɪn͡mpʊt], and [ɪmpʊt], what accounts for the directionality of the change? What accounts for the 'movement' from two distinct phonetic forms to two forms of which one is always mistaken for the other e.g. /i/ and /y/, where /y/ is always heard and reproduced as /i/ — but not vice versa? Similarly, while there are numerous cases of /θ/ > /f/, there are no known cases of the reverse direction, /f/ > /θ/, although a simple 'confusion' theory based solely on acoustic similarity would predict an equal number.

Blevins (2004: 286-8) refers to 'perceptual biases' as a possible factor governing the direction of phonological interpretation. Natural phonology attributes such biases to processes with both perceptual and articulatory motivations, and it thus constitutes a full-blown theory of 'perceptual bias'. 'Perceptual bias' may in fact be bias toward segments with better perceptual properties ([i] is more clearly palatal than [y]) or less demanding articulations (stops require less precision than fricatives), or toward sequences with less demanding articulations ([nk] requires two tongue gestures, while

[ŋk] requires only one, [ɑguɑ] requires full closure between vowels, while [ɑɣuɑ] does not).

Processes that optimize segments (e.g. Kannada [ɨ] becomes [i]) limit the phonological inventory, and those that optimize sequences (e.g. *tenth* /tɛ**n**-θ/ becomes [tɛ̃**n̪**θ]) account for the phonetic variants that occur in speech. The former constitute learner bias by requiring the learning of fewer segments; the latter contribute to bias by allowing more-optimal sequences within the limits of the allowed inventory.

5 System changes

If, as natural phonology claims, the motivations for sound changes are phonetic rather than structural, then what are we to make of changes that seem to affect entire systems in languages?

5.1 Chain shifts

Sound shifts — changes in the realization of entire systems of vowels or consonants — would appear to be somehow systematically motivated. Martinet (1955) and other structuralists emphasized the role that the entire system of oppositions might play in sound change, proposing push and drag chains, suggesting that a change in the realization of one phoneme might be the cause of changes in the realization of others. If, for example, voiced stops become voiceless, this seems to be an application of a single process, even though several sounds may be affected. But when voiceless stops become aspirated and voiced stops become voiceless, we suspect that something more systematic is at work. The changes look like a system-wide chain of events.

Two characteristics of chain shifts are definitive. First, the processes that underlie the shifts are usually not obviously 'conditioned' — that is, they appear to be 'context-free', involving fortitive rather than lenitive processes. If they show any conditioning at all, the conditioning is prosodic — it is a matter of length, or accent, or syllable structure, rather than the quality of adjacent segments. Second, the changes do not result in the degree of merger that one might expect. In a chain shift, /ɒ/ may become /ɑ/ and /ɑ/ may become /a/, and so on — but the /ɑ/'s from original /ɒ/ do not become /a/, so that, generally speaking, the set of distinctions is preserved.

The phonetic motivations of fortitive processes — even 'unconditioned' processes — are always present; speakers are always under some pressure to enhance the perceptibility of particular phonetic features. But these processes are held in check by the requirements of the community — some enhancements are acceptable, but others are rejected. An enhancement of a phonetic property (as when, for example, vowel raising enhances labiality or lowering enhances sonority) seems to be less welcome when it results in confusability — as when the /ɒ/ of words like *caught* becomes /ɑ/, as in *cot.* Such mergers may occur, of course, but the unrounding of /ɒ/ would be more acceptable if /ɑ/ has itself undergone a change. The change of /ɒ/ to /ɑ/ does not cause the change of /ɑ/ to /a/, nor does the change of /ɑ/ to /a/ cause that of /ɒ/ to /ɑ/. But it may be that /ɒ/ to /ɑ/ is more likely to be admitted when /ɑ/ has become /a/. The phonological principles of Jakobson and Martinet may play an important role in the occurrence of changes— but as constraints rather than as causes. Substitutions may fill holes in the phonological pattern or gaps in the phonetic space, where the same substitutions might be rejected if they caused mergers. So system gaps may seem to 'drag' elements of the system into new realizations, but the gaps themselves need not be seen as causal. If maintenance or increase of phonological contrasts were the motivation for changes, mergers would remain inexplicable, but the enhancement of a *phonetic* property can underlie either mergers or chains.

5.2 Changes in type

The notion 'language type' refers to a constellation of phonological, morphological and syntactic characteristics that seem to pattern together across languages. In phonology, we find that vowel reduction, diphthongization, tense-lax vowel distinctions, vowel and consonant shifts, contour tones, consonant clusters and complex syllables, and iambic or monosyllabic word patterns have a tendency to co-occur, while vowel harmony, monophthongal vowels, stable vowel and consonant systems, level tones, geminate consonants and simpler syllable canons, and trochaic or polysyllabic word forms often co-occur. Donegan & Stampe (1983, 2004) examined the case of Austroasiatic, where the western (Munda) and eastern (Mon-Khmer) branches of the family are typologically not merely different, but opposite. They noted the co-occurrence of the former cluster of phonological characteristics with VO and its associated word order tendencies, with

isolating or fusional morphology, with prefixing, and with rising phrase accent – and the co-occurrence of the latter phonological characteristics with OV and its associated word order tendencies, with agglutinative or even polysynthetic morphology, with suffixing, and with falling phrase accent. They proposed that the unifying force behind these co-occurrence tendencies is rhythm, that only a shift in rhythm could explain the wholesale quality of the changes, and that major changes in syllable type, word-shape, affixation, etc., which are sometimes viewed as typological indicators, can occur as a result of rhythmic change.

Changes in rhythm may include changes between falling and rising accent and changes in patterns of isochrony – shifts among mora, syllable, and stress timing. For example, Thurgood (1999) discusses change in type in Chamic languages, such that this branch of Austronesian has become atypically final-accented. And a series of changes in Old French diphthongized vowels in stressed open syllables, and reduced the vowels of unstressed syllables, suggesting a shift from the mora-timing of Latin toward a more stress-timed rhythm. A subsequent series of changes monophthongized the diphthongs and weakened or deleted syllable final consonants, leading to an open-syllable pattern that became the syllable-timed pattern of modern French. (See, e.g. Pope 1934:103, 190). Changes in rhythm can result in wholesale changes in the application of phonological processes because processes are sensitive to prosodic factors such as duration, accent, and syllabication.

6 A note on Lexical Diffusion

The variant forms of words or phrases need not be lexically specified, as Bybee (2001) would have it. Instead, variation in the applicability of a process can be specified on the process, rather than on the lexical item.

True 'lexical diffusion' refers to historical cases where a sound change affects only some instances of a sound in a given phonetic environment, and thus only a portion of the phonologically appropriate vocabulary – but the change does not appear to be optional or conditioned by prosodic or pragmatic factors. Lexical diffusion in this sense seems always to involve a phonemic difference. The well-known case of /æ/ vs /eə/ in U.S. cities (discussed extensively in Labov 1994, 2007 and elsewhere), for example, is

clearly a phonemic difference[15], and its lexical spread is consequently a matter of learners' exposure to individual forms. (So *banana* may be learned with the stressed vowel /eə/ of *m*[eə]*n* and *pl*[eə]*nning* and *D*[eə]*nny*, rather than with the /æ/ of *r*[æ]*n* and *pl*[æ]*net* and *D*[æ]*niel,* while *cabana* may be learned with stressed/æ/. This may be associated with frequency, with earlier vs later learning, or with other usage factors.) As a result of contact situations, the adoption of an alternative phonemic target may generalize to a broader set of inputs. Labov 2007 contains an extensive discussion of the results of patterns. The original phonemic splits themselves often seem to arise in language or dialect contact, but lexically diffusing changes may perhaps arise internally. If a process applies variably, and if its output is subject to an alternative phonemic interpretation, the lexical representations of similar items may change at different times.

7 Conclusion

The phonologies of languages are the result of natural processes constrained by speech-community-specific restrictions; they may be limited in feature-specific ways or suppressed entirely. Sound change is change in the restrictions a language community imposes. When Canadians or Californians merge /ɑ/ and /ɒ/, they have given free rein to a phonetically motivated process unrounding low vowels. As a consequence, they can no longer acquire new words with /ɒ/, nor do they even notice that east-coast Americans continue to maintain this distinction. Speaker abilities have changed.

Context-sensitive processes that apply in speech production may be undone in perception, so that contextual variants are not necessarily perceived at face value; hearers can interpret speakers' productions and arrive at their intended articulations. Alternative perceptions of the same acoustic configuration are an important element in sound change, but if an acoustic configuration is truly ambiguous, the directionality of change must be attributed to some articulatory or perceptual advantage.

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[15] The existence of minimal pairs (have [hæv] vs. halve [heə̯v], Cavs [kævz] vs calves [keə̯vz]), morphologically-dependent differences (ran [ɹæn] and swam [swæm] vs man [meə̯n] and ham [heə̯m]), and near-minimal pairs (sad [sæd] and glad [gleə̯d], lass [læs] and glass [gleə̯s], math [mæθ] and bath [beə̯θ]) allows no other interpretation.

Where new phonemes develop, they do so because learners are unable to attribute some feature of a sound to an aspect of its environment and must accept as an intention what is, for older speakers, a consequence of an intended but un-realized environment. Alternations fossilize when the motivation of a process is hidden by additional processes, so that learners can no longer attribute the alternants to phonetic adjustments, but instead come to perceive them as associated with morphological patterns.

Chain shifts arise from phonetic motivations. 'Holes' in the phonological pattern may *allow* the context-free changes that typify such shifts, but they do not *cause* the changes. Changes in type are often associated with changes in rhythm, which may affect whole constellations of processes, tilting the phonetic advantage in one way or another.

Our discussion has interpreted 'sound change' in a strict sense – we have not included the analogical generalization of an alternation to forms where it does not originate phonetically (as umlaut has generalized to new plurals), nor do we include 'lexical diffusion' – the gradual phonemic re-lexicalization of individual words. Regular, sound change, like synchronic phonological processing, involves the interaction of production and perception. It is motivated by phonetics and constrained by community consensus.

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