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Phonetics in Phonology and Phonology in Phonetics*

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In this paper, I explore the relationships between phonology and phonetics and argue that there are two distinct ways that they interact. A distinction needs to be drawn between the way phonetics affects phonology–*phonetics in phonology*, and the way phonology affects or drives phonetics–*phonology in phonetics.* The former concerns the way that phonetic effects and constraints are reflected in the phonology, often referred to as *naturalness*. The latter is the mapping between the units of phonology and their physical realization. How is phonological knowledge realized in and extracted from the physical signal? In this case, the phonology emerges in the phonetics in the sense that phonological contrast is physically realized. These two facets of the relationship between phonology and phonetics are discussed in light of their implications for an understanding of phonology and phonetics and their relationship.

1. Introduction

The aim of this paper is to consider the different ways in which phonology and phonetics interact. Let us start by considering a fairly standard post-Sound Pattern of English (SPE, Chomsky and Halle 1968) view of the relationship shown in (1).

(1) The relationship between phonology and phonetics:

phonology	=	discrete, categorical
≠		
phonetics	=	continuous, gradient

It is widely assumed that phonology and phonetics are distinct and that phonology is the domain of discrete and categorical entities, while phonetics is the domain of the continuous and gradient. (For recent discussion see e.g. Keating 1996; Cohn 1998; also

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individual contributions in Burton-Roberts et al. 2000; and Hume and Johnson 2001). Yet much debate surrounds the relationship between phonology and phonetics. Questions such as the following continue to be asked: How strong is this correlation? How do phonetics and phonology interact? Are they in fact one in the same thing?

I argue that there are actually two distinct ways in which phonology and phonetics interact. A distinction needs to be drawn between the way phonetics affects phonology–what I term *phonetics in phonology*–and the way phonology affects or drives phonetics–what I term *phonology in phonetics*. This is a basic point, but one that I believe has been largely overlooked. Both of these facets of the relationship need to be addressed in reaching an understanding of the nature of phonology and phonetics.

In this brief discussion, I outline both facets of the relationship. In the first, the place of naturalness, as internal to the grammar, or outside of it, is central. In the second, the strength of the correlation suggested in (1)–that is, that phonology is discrete and categorical, while phonetics is continuous and gradient–is important. The evidence suggests that this correlation may not be as strong as often assumed. However, this does not necessarily lead to the conclusion that, therefore, phonology and phonetics are the same thing. Our discussion leads to a (re)consideration of certain fundamental assumptions, notably the role of modularity and the status of so-called duplication—cases where similar patterns are attributed to more than one domain of language, as well as a brief consideration of the nature of categories.

The structure of the paper is as follows. In §2, I discuss *phonetics in phonology* and in §3, I turn to *phonology in phonetics*. In §4, I consider the implication of these two facets of the relationship for a better understanding of the nature of phonology and phonetics. Conclusions and implications for future research are presented in §5.

2. Phonetics in phonology

As shown in the work of Ohala and others (e.g. Ohala 1990), a close parallel exists between phonetic patterns of coarticulation and phonological patterns of assimilation cross-linguistically. These widely observed parallels raise the question of why this should be the case. It is generally agreed that the phonetic patterns arise from

physical (articulatory, aerodynamic, acoustic and auditory) constraints. Patterns attributable to such factors are said to be *natural*. The close parallel between the phonetic effects and phonological patterns has led many to suppose that phonetic *naturalness* is a primary source of phonological patterns, that the phonology is *grounded* in the phonetics (e.g. Archangeli and Pulleyblank 1994). Yet there is much debate about where naturalness resides, within or outside the grammar. Naturalness is sometimes framed in terms of *markedness*. One's characterization of naturalness depends in large part on certain underlying assumptions about the nature of grammar and modularity as well as the nature of synchronic vs. diachronic systems. I briefly sketch out different approaches in §2.1 and then return to the parallels between coarticulation and assimilation and implications of these parallels in §2.2.

2.1 Why is phonology *natural*?

Much attention has been given to the question: Why is phonology *natural*? Different ideas about where naturalness resides have been espoused, depending in part on one's starting assumptions. I do not attempt here to resolve this complex question, but provide only a brief overview of the subject. (See Chitoran 2005; Chitoran and Cohn to appear; and Hayes and Steriade 2004, for recent discussion.)

Many understand naturalness to be part of phonology. The status of naturalness in phonology relates back to early debates in generative phonology about natural phonology and natural generative phonology (Stampe 1979 among others). This view is also foundational to Optimality Theory (e.g. Prince and Smolensky 2004), where functional explanations characterized in scalar and gradient terms are central in the definition of the family of markedness constraints. Contra views "where the principles that the rules subserve (the "laws") are placed entirely outside the grammar. . . A much stronger stance [, …,] is available. When the scalar and the gradient are recognized and brought within the purview of theory, Universal Grammar can supply the very substance from which grammars are built." (Prince and Smolensky 2004, p. 233-234.) Under such approaches the explanations of naturalness are connected to the notion of markedness. However, this does not offer an explanation without having an independently motivated theory of

markedness. (See Hume 2004 and Haspelmath 2006 for recent discussion of this issue.)

It is sometimes argued that explicit phonological accounts of naturalness pose a *duplication* problem. Formal accounts in phonological terms (often attributed to Universal Grammar) parallel or mirror the phonetic roots of such developments, thus duplicating the phonetic source or historical development driven by the phonetic source. This leads to a duplication of the explanation (see Przezdziecki 2005 for recent discussion). As discussed below, it doesn't necessarily follow that distinct representations and accounts of the patterns themselves (phonological assimilation and phonetic coarticulation) also result in duplication. If, as concluded below, assimilation and coarticulation are similar, but not identical, then treating them as the same thing is not empirically adequate. We need to draw a distinction between the duplication of the explanation and the source of the patterns themselves.

This view of naturalness' centrality in the synchronic grammar is the source of the *form* vs. *substance* debate as framed by Hale and Reiss (2000), where they argue for a complete separation of substance from form. They argue that phonology = grammar = formal and phonetics = substance = function. This approach is closely tied to assumptions about strict modularity, an issue to which we return below (§4.2).

Others understand naturalness to be expressed through diachronic change. This is essentially the view of Hyman (1976, 2001). Hyman (1976) offers an insightful historical understanding of this relationship through the process of *phonologization*, whereby phonetic effects can be enhanced and over time come to play a systematic role in the phonology of a particular language. Under this view, phonological naturalness results from the grammaticalization of low-level phonetic effects. This provides a diachronic explanation of these types of effects. While a particular pattern might be motivated historically as a natural change, it might be *un-natural* in its synchronic realization (see Hyman 2001 for discussion). Phonetic motivation is also part of Blevins (2004) characterization of types of sound change.

We are still left with the unresolved question: Is synchronic phonology independently constrained by principles of naturalness? This leads us to the still timely discussion by Anderson (1981) "Why phonology isn't 'natural'?" His figure in which he

characterizes the range of factors that impinge on phonology and considers what is specific to language itself is replicated here in Figure 1.

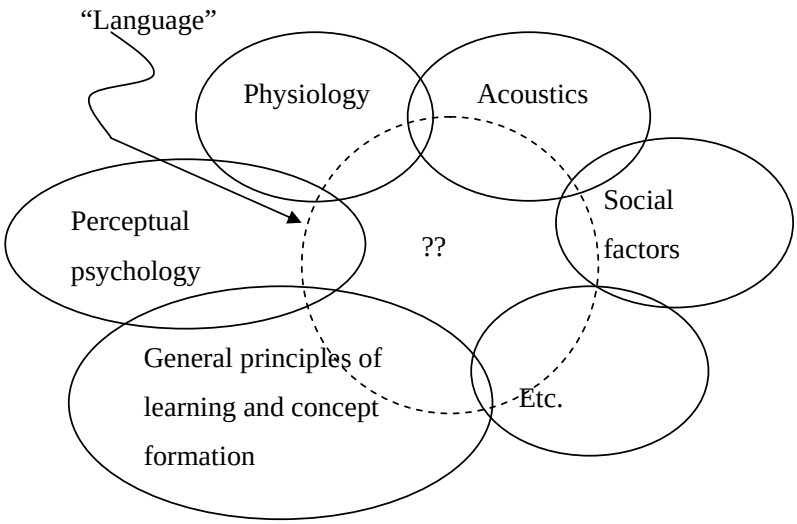


Figure 1: Following Anderson (1981, Figure 1, p. 494)

In this brief discussion, I will not attempt to resolve the debate about the sources of naturalness in phonology, however, Hayes and Steriade (2004) propose an approach offering middle ground between these opposing views worthy of close consideration. They argue that the link between the phonetic motivation and phonological patterns is due to individual speaker's phonetic knowledge. "This shared knowledge leads learners to postulate independently similar constraints." (p. 1). They argue for a deductive approach to the investigation of markedness and state:

> Deductive research on phonological markedness starts from the assumption that markedness laws obtain across languages not because they reflect structural properties of the language faculty, irreducible to non-linguistic factors, but rather because they stem from speakers' shared knowledge of the factors that affect speech communication by impeding articulation, perception, or lexical access. (p. 5)

There are two points for us to consider. First it is clear that these issues are part of the question of the relationship between phonetics and phonology. In this regard, we strive to understand the ways that phonetics shapes the phonology, what I have termed *phonetics in phonology*. Second, the issue of naturalness leads to the broader question of what is the domain of phonology proper? Some have suggested that no clear boundary exists between phonology and these other spheres, particularly phonetics, what I term *unidimensional* approaches. Others have suggested that certain principles – such as symmetry, productivity – are specific to the phonology. (See Hayes 1999 and Clements 2003 for recent proposals along these lines.) These questions lead us to the second facet of the relationship between phonology and phonetics: the realization of phonology in the physical signal, what I term *phonology in phonetics*. To understand this facet, we need first to understand the nature of the parallels between what have been understood to be phonetic patterns vs. phonological ones, e.g. coarticulation vs. assimilation. We turn to the nature of these patterns and the source of the similarity in the next subsection in anticipation of the question of whether phonology and phonetics constitute a single domain or two distinct domains.

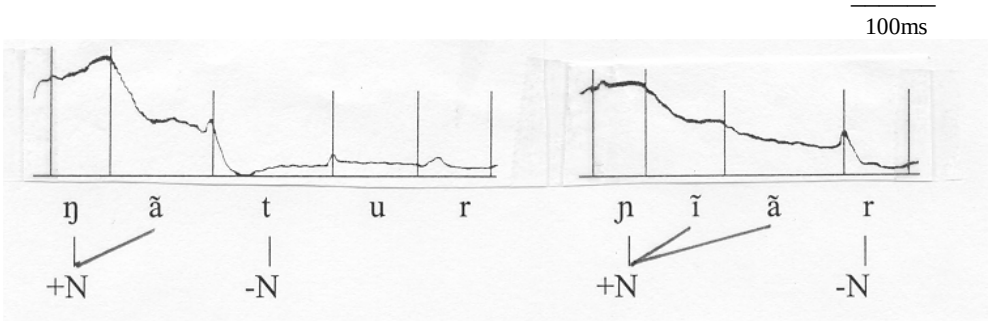
2.2 Similarity between coarticulation and assimilation

In comparing phonetic and phonological accounts of assimilation, Ohala (1990, p. 267) argues "For the sake of explaining natural sound patterns there are advantages to representations using phonetic primitives – advantages not found in other currently popular phonological representations." The view implies that in some sense coarticulation and assimilation are one and the same thing, since they are given the same

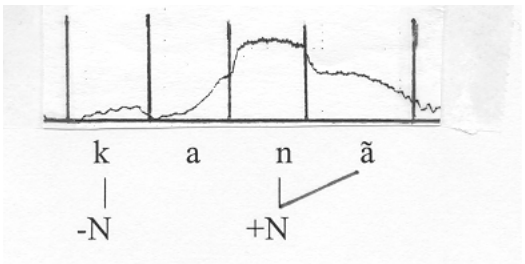
account. This then suggests that understanding these patterns as distinct is a source of *duplication*, that is, the distinction is not empirically motivated, but follows from our assumptions. The problem is that there is a conflation here between the *explanation of the source* of the patterns and the account of the *patterns themselves*. Because of the pervasiveness of this confusion, it is worth revisiting the evidence that coarticulation and assimilation are distinct. There is also an important methodological issue, which is that impressionistic data is often insufficient to investigate the differences between assimilation and coarticulation.

In Cohn (1998), where I argue that phonology and phonetics are distinct, I discuss a number of cases where phonological and phonetic effects are similar, but not the same. This is the fundamental character of what I term *phonetic and phonological doublets*, cases where there are parallel categorical and gradient effects in the same language, with independent evidence suggesting that the former are due to the phonology and the latter result from the implementation of the former. For example, this is seen in patterns of nasalization in several languages (Cohn 1990), palatalization in English (Zsiga 1995), and vowel devoicing in Japanese (Tsuchida 1997, 1998).

Take the example of nasalization in Sundanese, whereby a vowel or vowels (with possibly intervening laryngeals) following a nasal consonant is/are nasalized. In derivational terms, this is understood to be a lexical phonological rule, due to its interaction with morphology. This is shown in Figure 2, with representative nasal airflow traces, where nasal airflow is taken here as the realization of the feature [±Nasal]. There is robust nasal airflow during a nasal, as well as following vowel or vowels. This is seen in the vowels following the nasals in the forms (a) *ngatur* ‘arrange’ [Nãtur], (b) *nyiar* ‘seek’ [ɲĩãr] and (c) *kana* ‘for the purpose’ [kanã]. The nasal airflow during the nasals and following vowels is roughly characterizable as a plateau. In addition to this phonological pattern of nasalization, there is coarticulatory nasalization observed in the transition between oral and nasal events. This can be seen, for example, in the vowel preceding a nasal consonant in the first [a] in (c) *kana*, where a gradient pattern of nasal airflow is observed starting partway into the vowel in anticipation of the upcoming nasal.



a. *ngatur* ‘arrange’ [Nãtur] b. *nyiar* ‘seek’ [ɲĩãr]



c. *kana* ‘for the purpose’ [kanã]

Figure 2: Nasal assimilation and coarticulation in Sundanese a. *ngatur* ‘arrange’ [Nãtur], b. *nyiar* ‘seek’ [ɲĩãr], c. *kana* ‘for the purpose’ [kanã]

The differences between coarticulation and assimilation are also clearly demonstrated in work comparing vowel harmony with effects of vowel-to-vowel coarticulation, as shown in work on Turkish (Beddor and Yavuz 1995) and Yoruba (Przezdziecki 2005). Consider an example from Yoruba comparing three dialects where the phonological patterns of vowel harmony differ. In the Àkùré dialect, there is anticipatory [ATR] vowel harmony affecting both mid and high vowels; thus in a V_1CV_2 form, a mid or high V1 will agree in [ATR] with the following V2. In comparison, in the Mò**O**bà dialect, vowel harmony is active in mid, but not high vowels; and in Standard Yorùbá (SY), synchronically vowel harmony is no longer active.

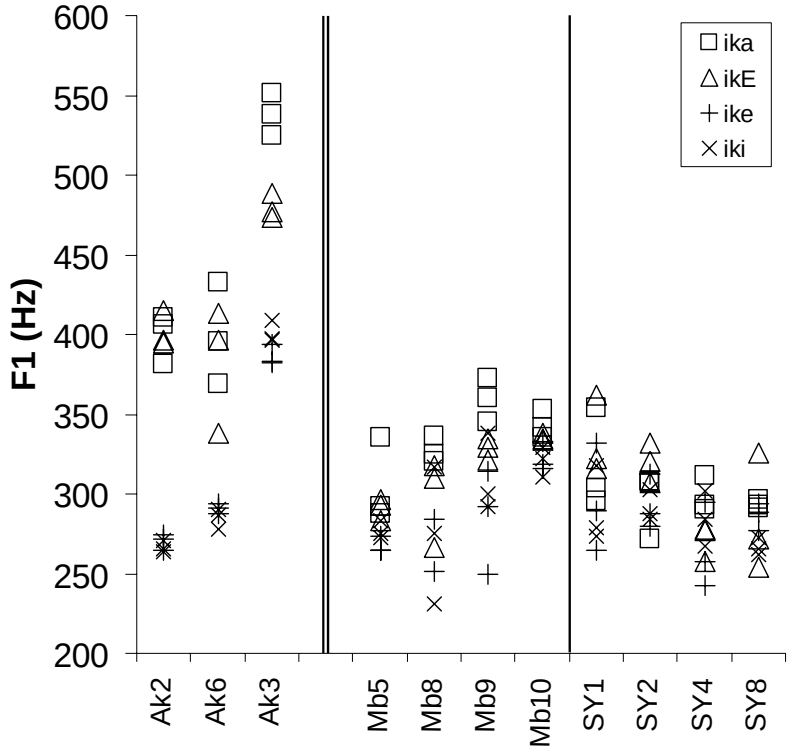


Figure 3: From Przezdziecki (2005, Figure 4.62, p. 225) "F1 values of /i/ measured in the middle of the first vowel (V1) in individual tokens of four VCV contexts: ika, ikẹ, iki in speakers of Àkùréọ, Mòọbà, SY"

The effects of vowels harmony can be seen in Figure 3 (from Przezdziecki 2005, p. 225), where for three Àkùré speakers, the F1 of the initial /i/ differs sharply depending on whether the V2 is [+ATR] ([i, e]) or [-ATR] ([a, ẹ]). Przezdziecki compares the effects of vowel harmony in high vowels in Àkùré with the effects of vowel-to-vowel coarticulation for four speakers in Mòọbà and four speakers of Standard Yorùbá (SY), where smaller differences going in the same direction are seen for some speakers, but the difference is not of the magnitude of that seen where vowel harmony is active in high vowels. Thus we see a difference between the realization of vowel harmony and effects of vowel-to-vowel coarticulation. In this case, the difference is between closely related dialects with different phonological patterns. In the case of nasalization in Sundanese, both manifestations were illustrated in the same language.

What these cases and many other cases have in common is that the patterns of coarticulation are similar to, but not the same as, assimilation and that both patterns co-occur in the same language. The manifestations are different, with the more categorical effects observed in what we independently understand to be the domain of the phonology and the more gradient ones in the phonetic implementation of the phonology. To document such differences, instrumental phonetic data is required, as impressionistic data alone do not offer the level of detail needed to make such determinations.

It is then the case that coarticulation and assimilation are the *same* thing, since these patterns are not identical and the coarticulatory effects are built on the phonological patterns of assimilation. It is an illusion to say that treating such patterns in parallel in the phonology and phonetics poses a *duplication problem*. Rather this is a case of parallel effects due indirectly to the ways in which phonology is *natural*, not directly in accounting for the effects through a single vocabulary or mechanism. Thus we need to draw a distinction between the source of the explanation, where indeed at its root some factors may be the same (see Przezdziecki 2005 for discussion), and the characterization of the patterns themselves, which are similar, but not the same.

Since assimilation and coarticulation are distinct, an adequate model needs to account for both of them. The view taken here is that while assimilation might arise historically through the process of phonologization, there is ample evidence that the patterns of assimilation and coarticulation are not reducible to the same thing, thus we need to understand how the more categorical patterns and the more gradient patterns relate. This brings us to the second facet of the relationship between phonology and phonetics, how phonological patterns are realized in the phonetics–what I term *phonology in phonetics*.

3. Phonology in Phonetics

Phonology is the cognitive organization of sounds as they constitute the building blocks of meaningful units in language. The physical realization of phonological contrast is a fundamental property of phonological systems and thus phonological elements are physically realized in time. How is phonological knowledge realized in the physical

signal? How is phonological knowledge extracted from the physical signal? Phonology emerges in the phonetics, in the sense that phonological contrast is physically realized. This then is the second facet of the relationship between phonology and phonetics: the relationship between these cognitive elements and their physical realization. The relationship between phonology and phonetics has been understood as a mapping between abstract phonological units (usually understood as features) and the physical signal.

Let's return to the correlation presented above in (1). Implicit in the realization of phonology is the division between categorical vs. gradient effects, since the phonology is understood to capture contrast that at the same time must be realized in time and space.

The correlations in (1) suggest the following relationships:

(2)

a. Categorical phonology	b. ~~Gradient phonology~~
c. ~~Categorical phonetics~~	d. Gradient phonetics

If the correlation between phonology and categoriality on one hand and between phonetics and gradience on the other were perfect, we would expect there to be only categorical phonology (a) and gradient phonetics (d). There are reasons why the correlation might not be perfect, but nevertheless strong enough to re-enforce the view that phonology and phonetics are distinct. On the other hand, perhaps there is in fact nothing privileged about this correlation. We need to review how robust the correlations are for categorical phonology and gradient phonetics. We need to consider evidence for gradient phonology and categorical phonetics and in light of such evidence, address the question of whether categorical phonology and gradient phonetics are somehow privileged. In §3.1, we review the evidence for categorical phonology and gradient phonetics. We consider categorical phonetics and gradient phonology in §3.2.

3.1 Categorical phonology and gradient phonetics

Following from basic tenets of Generative Phonology (Chomsky and Halle 1968), the phonology is understood as the domain of the qualitative and the phonetics as the domain of the quantitative. This is a modular view of grammar that frames our modeling of more categorical and more gradient aspects of such phenomena as belonging to distinct modules (e.g. phonology vs. phonetics). Intrinsic to this view is that lexical entries and phonological patterns are represented in terms of distinctive features, taken to be abstract properties, albeit defined phonetically. These are then interpreted in a phonetic component, distinct from the phonological one. I refer to this as a *mapping approach*. Following a mapping approach, categorical (steady state) patterns observed in the phonetics are understood to result from either lexical or phonological specification and gradient patterns are understood to arise through the implementation of those specifications.

Growing out of Pierrehumbert's (1980) study of English intonation, gradient phonetic patterns are understood as resulting from phonetic implementation. Under the particular view developed there, termed *generative phonetics*, these gradient patterns are the result of interpolation through phonologically unspecified domains. Keating (1988) and Cohn (1990) extend this approach to the segmental domain, arguing that phenomena such as long distance pharyngealization and nasalization can be understood in these terms as well. Within generative phonetics, the account of gradience follows from a particular set of assumptions about specification and underspecification.

For the sake of concreteness, consider an example of phonological patterns and their corresponding phonetic realization that are consistent with these correlations. In Figure 4, we see representative examples of the patterns of nasal airflow in French and English (as discussed in Cohn 1990, 1993). As above, nasal airflow is taken as the realization of the feature [±Nasal].

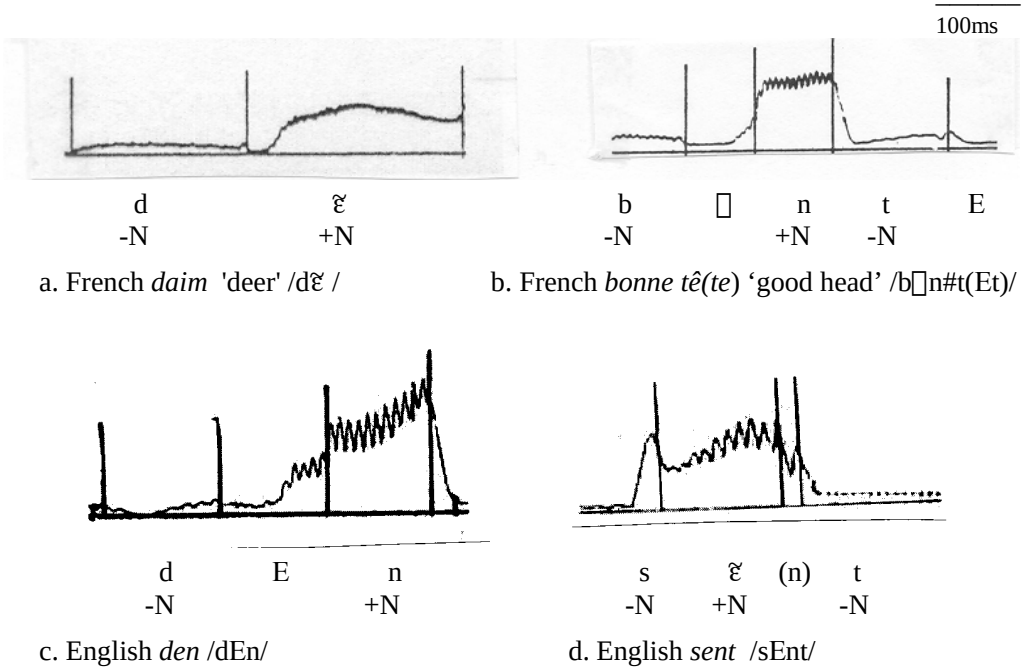


Figure 4: Examples of nasal airflow in French and English following Cohn (1990, 1993), a. French *daim* 'deer' /dɛ̃ /, b. French *bonne tê(te)* ‘good head’ /b□n#t(Et)/, c. English *den* /dEn/, d. English *sent* /sEnt/

In the case of a nasal vowel in French, here exemplified in the form *daim* ‘deer’ [dɛ̃] (Figure 4a), there is almost no nasal airflow on [d] and there is significant airflow throughout the [ɛ̃]. Here we observe *plateaus* corresponding to the phonological specifications, connected by a rapid transition. In English on the other hand, during a vowel preceding a nasal consonant, such as [E] in *den* [dEn] (Figure 4c), there is a gradient pattern—or a *cline*—following the oral [d] and preceding the nasal [n] (characterized by the absence and presence of nasal airflow respectively). This is quite different from the pattern of nasalization observed on the vowel in cases like *sent* [sɛ̃ t] (Figure 4d), in which case the vowel is argued to be phonologically nasalized (due to the deletion of the following /n/) and we observe a *plateau* of nasal airflow during the vowel, similar to the pattern seen in French. The observed differences between French and

English relate quite directly to the fact that French has nasal vowels, but English does not.

This case also provides a further example of the difference between assimilation and coarticulation. In French, in the realization of contrastive nasal vowels, there is nasal airflow resulting from the contrast and there is also nasal airflow resulting from coarticulatory patterns seen, for example, in the transition between oral vowels and nasal consonants. This is seen in presence of nasal airflow toward the end of the vowel [□] in *bonne tête* 'good head' /b□n#t(Et)/ (Figure 4b). While in the case of contextual nasalization in English, there are both long distance and more local effects seen in the physical patterns of nasal airflow. Following this approach, the cline seen in the vowel [E] in [dEn] in Figure 4b is interpreted as resulting from phonetic interpolation through a phonologically unspecified span.

The patterns of nasal airflow investigated in my dissertation lent themselves to a fairly straightforward interpretation of plateaus and clines. However, not all cases are so straightforwardly interpreted in these terms. Categoriality in the phonology can only be understood in rather abstract terms; there are many cases showing that a very literal interpretation of phonology as categorical will not work. This less-than-categorical realization follows largely from a gestural modeling of the phonetics. For one such approach, see the hybrid distinctive feature to gestural score approach proposed by Zsiga (1997).[1]

It is generally assumed that categoriality in the phonology also follows directly from the nature of perception and the important role of categorical perception. The specific ways in which perception constrains or defines phonology are not well

[1] Within the approach of generative phonetics, the relationship between phonology and phonetics was conceived in derivational terms and has been understood as a mapping between abstract phonological units (usually understood as features) and the physical signal. As argued by Cohn (1998) and Zsiga (2000), constraint-based approaches to phonology lead us to reconsider the nature of the phonetic component and its relationship to phonology. Rather trivially, we can understand the phonetic implementation of phonological representations in constraint-based terms. Many working within Optimality Theory, while taking Optimality Theory to be non-derivational and strictly bi-stratal, still assume that the output of the phonology feeds into the phonetics. That is, phonetic implementation is a distinct component from the phonology and this relationship is understood in derivational terms.

understood, although see Hume and Johnson (2001) for a series of recent discussions of the relationship between phonology and perception.

A modular mapping approach has been the dominant paradigm to the phonology-phonetics interface since the 1980's and such approaches have greatly advanced our understanding of phonological patterns and their realization. The intuitive difference between more categorical and more gradient patterns in the realization of sounds corresponds to the division of labor between phonology and phonetics within such approaches and this division of labor has done quite a lot of work for us. Such results are seen most concretely in the success of many speech synthesis by rule systems both in their modeling of segmental and suprasegmental properties of sound systems. (See Klatt 1987 for a review.) A modular approach accounts for the sense in which the phonetics, in effect, acts on the phonology. It also offers one possible account of so-called phonetic and phonological doublets, discussed above, since assimilation is accounted for in the phonological component and coarticulation in the phonetic implementation.

Such approaches predict categorical phonology and gradient phonetics, but do they fully capture observed patterns? What about categorical phonetics and gradient phonology?

3.2 Categorical phonetics and gradient phonology

I understand categorical phonetics to be periods of stability in space through time. I believe these result directly from certain discontinuities in the phonetics. This is precisely the fundamental insight in Stevens's (1989) Quantal Theory, where he argues that humans in their use of language exploit articulatory regions that offer stability in terms of acoustic output.[2] There are numerous examples of this in the phonetic literature. To mention just a few, consider for example, Huffman's (1990) articulatory landmarks in patterns of nasalization, Kingston's (1990) coordination of largyneal and supralaryngeal articulations (binding theory), and Keating's (1990) analysis of the high jaw position in English /s/.

[2] Pierrehumbert et al. (2000) make similar observations.

There are many ways to model steady-state patterns within the phonetics without calling into question any of the basic assumptions of the dichotomous model of phonology and phonetics. Just to mention one approach, within a target-interpolation model, phonetic targets can be assigned based on phonological specification as well as due to phonetic constraints or requirements. Such cases then do not really inform the debate about the gray area between phonology and phonetics.

The more interesting question is whether there is evidence for gradient phonology, that is, phonological patterns best characterized in terms of continuous variables. It is particularly evidence claiming that there is gradient phonology that has led some to question whether phonetics and phonology are distinct. The status of gradient phonology is a complex issue – and one that I explore in much greater detail in Cohn (2006). There, I take up this question by first attempting to define the various ways in which *gradience* has been used in the phonological literature. I then explore evidence for gradient phonology in the different aspects of what is understood to be phonology—contrast, phonotactics, morphophonemics, and allophony. I conclude that the answer depends in large part on what is meant by *gradience* and which aspects of the phonology are considered. The conclusions do suggest that strictly modular models involve an oversimiplification.

While modular models of sound systems have achieved tremendous results in the description and understanding of human language, strict modularity imposes divisions, since each and every pattern is defined as either X or Y (e.g. phonological or phonetic). Yet along any dimension that might have quite distinct endpoints, there is a gray area. For example, what is the status of vowel length before voiced sounds in English, *bead* [bi:d] vs. *beat* [bit]? The difference is greater than that observed in many other languages (Keating 1985), but does it count as phonological?

An alternative to the types of approaches that assume that phonology and phonetics are distinct and that there is a mapping between these two modules or domains are approaches which assume that phonology and phonetics are understood and modeled with the same formal mechanisms—what I term *unidimensional* approaches. A seminal approach in this regard is the theory of Articulatory Phonology, developed by Browman

and Goldstein (1992 and work cited therein), where it is argued that the domains that are often understood as phonology and phonetics respectively can both be modeled with a unified formalism. This view does not exclude the possibility that there are aspects of what has been understood to be phonology and what has been understood to be phonetics that show distinct sets of properties or behavior. This gestural approach has served as fertile ground for advancing our understanding of phonology as resulting at least in part from gestural coordination.

More recently, there is a significant group of researchers working within constraint-based frameworks pursuing the view that there is not a distinction between constraints that manipulate phonological categories and those that determine fine details of the representation, as argued recently by Steriade (2001), Kirchner (2001), Flemming (2001), and others. This then is another type of approach that assumes no formally distinct representations or mechanisms for phonology and phonetics, at least implying that phonology and phonetics are one and the same thing.

One type of argument in favor of this approach is that it offers a direct account of naturalness in phonology. The strength of the argument depends on one's view about the source(s) of naturalness in language, which, as discussed above in §2.1, is a controversial and complex question. An adequate theory of phonology and phonetics, whether modular, unidimensional, or otherwise, needs to be able to offer an account of not only phonetics in phonology, but also of the relationship between phonological units and physical realities, the ways in which phonetics acts on the phonology. We pursue this question further in the next section.

4. Are phonetics and phonology distinct?

While the existence of categorical phonetics might not be pivotal in resolving our understanding of the relationship between phonology and phonetics, the status of gradient phonology is quite crucial for our understanding of this relationship. It is worth spelling out more explicitly the implications. In this section, we first consider the implications of gradient phonology and whether categorical phonology and gradient phonetics are special, or whether they are just the end points along a continuum (§4.1); we then turn to

a consideration of modularity and duplication (§4.2), and the nature of categories and how they are learned (§4.3).

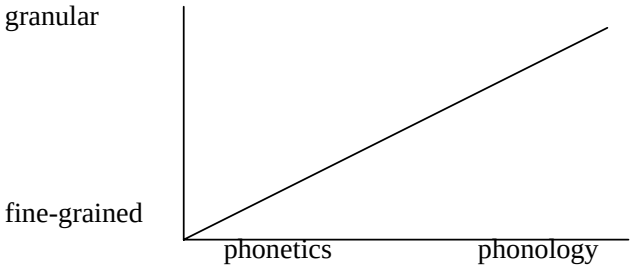
4.1 Implications of a continuum of granularity

As mentioned above, it is evidence suggesting that there is gradience in phonology that has led some to question whether phonetics and phonology are distinct. Pierrehumbert, Beckman, and Ladd (2000, p. 287) state the question in the following way:

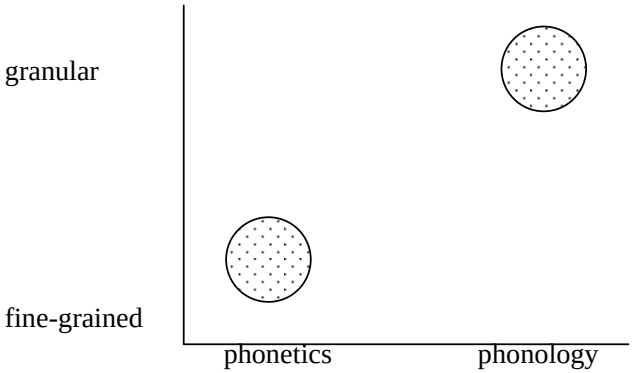
> …this assertion [that the relationship of quantitative to qualitative knowledge is modular] is problematic because it forces us to draw the line somewhere between the two modules. Unfortunately there is no place that the line can be cogently drawn… In short, knowledge of sound structure appears to be spread along a continuum. Fine-grained knowledge of continuous variation tends to lie at the phonetic end. Knowledge of lexical contrasts and alternations tend to be more granular.

The sound structure continuum is schematized in Figure 5a with phonetics vs. phonology on the x-axis and degree of granularity on the y-axis. Consider the schematic distribution of the data: A modular approach suggests a bimodal distribution such as that in Figure 5b, with little or no gray area. A unidimensional approach suggests a distribution such as that in Figure 5c, with little correlation between the two dimensions. Yet the evidence suggests that the distribution of data fall somewhere between these two views. How can we understand and model this distribution?

a. continuum of sound structure and granularity



b. modular view: bimodal distribution



c. unidimensional view: unimodal distribution

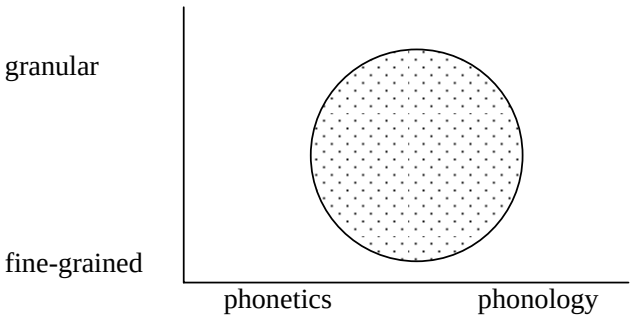


Figure 5: a. Continuum between phonetics and phonology (x-axis) and fine-grained and granular (y-axis) dimensions of speech, b. distribution of data, modular approach, c. distribution of data, unidimensional approach

First of all, it is important to realize that just because it is difficult to know exactly where to draw the line, this does not necessarily mean there are not two separate domains of sound structure. The fact that is difficult to draw a line follows in part from the conception of phonologization. Phonologization by its very nature is bound to result in indeterminate cases. As phonetic details are being enhanced, it will be difficult at certain stages to say that a particular pattern is *phonetic*, while another is *phonological*. For example, vowel lengthening before *voiced* sounds in English might be viewed as being in this gray area. Thus the existence of some gray area does not in and of itself resolve the question. Yet, at the same time, it is important that our understanding of the nature of this continuum is not predetermined by our theoretical assumptions.

4.2 Modularity, duplication, and redundancy

In understanding the continuum from categorical to gradient sound patterns, we need to be careful about how our assumptions color our interpretations. I consider briefly three issues in terms of how they frame these issues and may influence our evaluations of possible solutions: modularity, duplication, and redundancy.

Consider first the question of modularity. Hale and Reiss (2000, p. 162) state "The modular approach to linguistics, and to science in general, requires that we both model the interactions between related domains, and also sharply delineate one domain from another". But, we need to ask the question: Is there strict modularity? Does modularity entail sharp delineation? Could there be modularity that is not rigid? The lack of strict modularity is implicit in views that understand the relationships between linguistic domains through interfaces. If we do not subscribe to strict modularity between phonology and phonetics and between phonology and the lexicon, then it becomes an empirical question if drawing a distinction is useful. Does a division of labor contribute to both descriptive adequacy and explanatory adequacy?

It is important to think about so-called duplication problems and how these frame our understanding of similar patterns. As discussed above in §2.2, parallels between phonetics and phonology, particularly in assimilation and coarticulation, have been used as arguments to support unidimensional approaches. That is, the perceived cost of

duplication leads to arguments for reductionism to avoid duplication. But this conclusion is often based on the conflation of the explanations and the patterns themselves. Again, as discussed above, while there are close parallels, the evidence suggests that these systems are not the same thing (see e.g. Cohn 1998, Zsiga 2000 and Hyman 2001 for recent discussions). At the same time, the view that the explanation of naturalness may reside in the grammar does not in and of itself lead to a reductionist view. In discussing this question, Hayes and Steriade (2004, p. 5) state:

> The research presented here bears only on the possibility of systematically deducing the contents of phonological constraints from knowledge of grammar-external factors. This is not the same thing as deducing the grammar itself: on the contrary, structural properties of the grammar may well filter phonetic knowledge and limit the ways it is mapped onto grammatical statements…

In trying to reach an understanding of the nature of phonology vs. phonetics, we need to address the question of what needs to be explained empirically. We need to ask whether the mechanisms, properties, constraints, vocabularies, of phonology vs. phonetics are different.

Similarly, we need to understand empirically the respective contributions of the lexicon and phonology. Following most generative approaches to phonology, both rule-based and constraint-based, phonotactic patterns are captured with the same formal mechanisms as phonological alternations. Typically, phonotactic and allophonic patterns closely parallel each other, providing the motivation for such unified treatments. Similar to the issue of where naturalness resides, it has been argued that distinct treatments would result in a duplication problem (e.g. Kenstowicz and Kisseberth 1977). The degree to which evidence shows that some phonotactic patterns may reflect stochastic patterns in the lexicon suggests that this equation is also reductionist (see Hay et al. 2003 and Pierrehumbert 2003 for discussion). On the other hand, some psycholinguistic approaches can be criticized for over-attributing the contribution of the lexicon in offering an account

of not just lexical knowledge but abstract generalization, widely understood to be the substance of phonology.

Both in characterizing the nature of phonetics and phonology and phonology and the lexicon, we see that the relevant phenomena may be similar, but not the same. Reducing similar but different sorts of cases to a single mechanism misses subtle but important differences. This sort of oversimplification leads to a loss of insight. Rather than posing a duplication problem, such areas of similarity but non-identity highlight parallels and redundancy in language. Things can appear to be similar for a variety of different reasons, not necessarily because they are the *same* thing.

A related issue is the status of Occam's Razor, or the principle of parsimony—"All things being equal, the simplest solution tends to be the best one." (Occam's Razor, Wikipedia 2007). While generally understood as a heuristic, in linguistic arguments, Occan's Razor is sometimes promoted to a very central principle. Perhaps Occam's Razor does not play as central role in language as often assumed. There is redundancy in language. Redundancy is widely observed in the domain of phonetics in terms of multiple and varied cues to the realization of particular phonological structures. Even cases of what we understand to be a straightforward phonological contrast may involve multiple cues and are probably realized through cue weighting. Consider for example the commonly observed cross-linguistic contrasts between *voiced* and *voiceless*, which is cued by all or a subset of the following cues: low-frequency energy during closure, Voice Onset Time, duration of closure, duration of preceding vowel, F0, spectral tilt, and so forth (see Jessen 2001 for recent discussion).

Evidence suggests that lexical representations include multiple levels of detail, including the kind of sparse abstract representations widely assumed in generative phonology and much more fine-grained levels of detail. (See Beckman et al. 2004 for discussion and a specific proposal in this regard.) Not only is there redundancy within domains, but there appears to be redundancy across domains, so duplication is not a problem, but in fact an intrinsic characteristic of language. Recent work in psycholinguistics shows that speakers have access in at least some situations to very fine details including both speaker-specific and situation-specific information. (See Beckman

2003 and Pierrehumbert 2003 for reviews and discussion of this body of work.) However, just because we are sensitive to finer details does not mean that we cannot abstract across the lexicon. Pierrehumbert (2003, p. 191) argues that some phonotactic knowledge is, indeed, true abstraction across the lexicon. "In light of such results, I will assume, following mainstream thought in linguistics, that an abstract phonological level is to be distinguished from the lexicon proper." This suggests that we have access to both fine-grained and coarse-grained levels of knowledge and that they co-exist (Beckman 2003; Beckman et al. 2004).

Attempting to understand sound structure in only abstract categorical terms or in only gradient details, or trying to understand the nature of the lexicon in exactly the same terms that we try to understand phonology is insufficient. Similar issues are at stake in our attempts to understand the development and acquisition of sound systems, as compared to the competence or knowledge acquired and its use as part of a rich multifaceted communicative system.

4.3 Implications for learning

In advancing our understanding of the relationship between phonology, phonetics, and the lexicon, we need to a consider a point that is obvious to some, but largely ignored by others—that is, how we learn is not the same thing as what we know.

There has been interesting work on the nature of categorization and how categories are learned. This includes a large body of work on infant speech perception showing the shift from relatively language-independent perception to largely language-specific perception roughly between the age of 6-12 months. (See for example Best 1994, Kuhl et al. 1992, and Stager and Werker 1997). This work offers insight into the nature of human perceptual categories and the development of language-specific categories. While newborns are endowed with perceptual abilities and the ability to discriminate, this does not necessarily mean that specific linguistic categories are endowed. Certain aspects of speech perception may be *emergent*, in the sense that they can be learned from the ambient language. On the other hand, this does not answer the question of whether or not speech is special. (See Benson et al. 2001 for recent work on the subject.) Much work

remains to be done to tease apart the nature of the perceptual endowment.

This still leaves us with the critical question of *how* categories are learned. In recent work, Maye and others (notably Maye 2000 and Maye et al. 2002) have shown experimentally the ability of infants and adults to form categories based on distributional information (that is, input that is either unimodally or bimodally distributed). Such results suggest a possible mechanism for the acquisition of categories, which is fundamental to the notion of contrast. The mechanism involves statistical learning and might well work in ways not unlike an exemplar model (Johnson 1997, Pierrehumbert 2001, 2002). However, statistical learning does not exclude abstract generalization. Crucially, *how* we learn is not necessarily the same as *what we know*.

A nice example of an integrated approach to acquisition acknowledging the fundamental contributions of both statistical learning and abstract generalization is provided by Wauquier-Gravelines (2002) on acquisition of liaison in French. She argues that the observed patterns of acquisition support three stages: First, till about 2,0 years words and clusters are treated as global units. From about 2,0-3,6 years, during the development of linguistic prosodic structure, kids use variable strategies for resyllabification. It is at this stage that one sees the common strategy of consonant epenthesis [*le[n]elephant* for *le[z]elephants*] and indeed this pattern appears to match to some degree statistical distribution in the input. In a third stage, there is a disappearance of errors. This, Wauquier-Gravelines argues, results from morphological bootstrapping, with the accurate encoding of floating consonants in lexical representation. Neither a purely statistical or traditional generative account alone can account for the observed patterns. Both play a role and we need to focus more on the question of the ways these mechanisms work together. Beckman (2003, p. 122) reaches a similar conclusion: “The data seem to call for a model of acquisition which posits far less phonological structure in the initial state and far more phonological structure at the end… But the representations at the lower level are not discarded when the higher-order representations are formed. This is why the end-state grammar is robust.”

5. Conclusions

In this paper, I have considered a basic point, but one which is often overlooked: To reach a fuller understanding of the nature of phonology and phonetics, we need to consider *phonetics in phonology*–how phonetics is reflected in the phonology. Stated another way, this is the ways in which phonology is natural, whether understood as naturalness within the formal grammar or influences through diachronic change. We also need to understand *phonology in phonetics*, the way that phonological contrast and patterns are realized in the physical signal.

The relationship between phonetics and phonology is a multifaceted one. It includes phonetic constraints that have shaped synchronic phonological systems through historical change over time. Synchronically, phonological systems emerge as a balance between the various demands placed on the system, but the evidence suggests that phonology cannot be reduced to the sum of these influences.

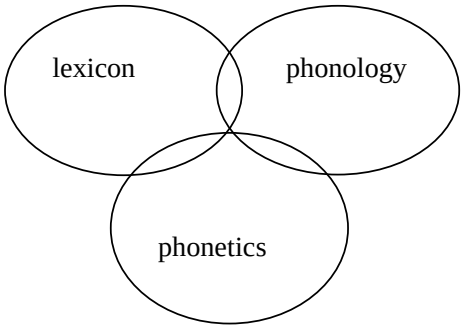
This led us to a consideration of the degree to which phonology is categorical and phonetics gradient. While there is some gray area along the continuum from categorical to gradient, this is expected since due to the very nature of phonologization, there will be indeterminate cases. The evidence suggests that despite the gray area, there is indeed a sense in which the end points of the continuum are privileged. This follows from the mechanisms of the realization of phonological contrast within a physical system continuous in time and space. Categorical phonology and gradient phonetics are privileged due to the central task of the phonology in the maintenance and realization of contrast and the fundamentally continuous nature of the physical realization of sound patterns.

The question of whether phonology and phonetics should be understood as distinct modules needs to be approached as an empirical question. What sort of approach gives us the best fit for the range of more categorical vs. more gradient phenomena, as well as for the gray area inbetween?

We also need to understand phonetics and phonology in relationship to the lexicon. The evidence suggests that there are parallels and overlaps between these three areas, but none of these areas is properly reduced to or contained in the others. Language

patterns are fundamentally fluid. There is evidence of phonologization, grammaticalization, lexicalization, and so forth. Similar patterns can be observed across these domains. This suggests the sort of relationship schematized in (3).

(3) The relationship between the lexicon, phonology, and phonetics



To reach a fuller understanding of the workings of phonology, phonetics, the lexicon, and their interactions, we need be willing to reconsider widely held assumptions and ask in an empirically-based way what is the connection between these domains of the linguistic system. What is called for are non-reductionist integrated approaches. Once we accept the profound complexity of what we are trying to describe and explain, we will discover that many of the contributions of generative linguistics and psycholinguistics often framed as being in opposition are in fact compatible and together offer an explanation of the nature of sounds systems, in terms of their mental representations, production, perception, acquisition, and use.

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