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Privativity, Underspecification, and Consequences for an Adequate Theory of Phonetic Implementation*

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The consequences of privative features for an adequate model of phonetic implementation are explored. First some background on recent theories of underspecification and privativity is presented. Then these issues are explored by examining the observed patterns of nasalization in French. First an account of the phonetic implementation of these patterns is sketched out assuming Nasal as a binary feature and then considering what would be required for Nasal to be interpreted as a privative feature. The results require a "smart phonetics" which has access to a wide range of information, not necessarily generally assumed to be part of a phonetic representation.

1. Introduction

The view of phonological representations as consisting of sets of feature specifications is one of the cornerstones of modern phonology. Recent proposals include the view that all phonological features are fully specified, as well as views of partial specification (falling as a class under the term "underspecification"). Closely related to the degree of specification is the issue of whether features are binary, as assumed in Chomsky and Halle (1968, hereafter SPE) or privative (building on Trubetzkoy's 1939 concept), as assumed more recently by a number of researchers. The nature of phonological representation, particularly the surface representation, has direct implications for our understanding of the relationship between phonetics and phonology and the question of phonetic implementation. In this paper, I would like to explore the nature of feature specification and its implications for the phonology-phonetics interface.

First in the remainder of this section, I review some issues about phonological specification, starting with the view espoused in SPE (§1.1) and then I briefly discuss the relationship between phonology and phonetics (§1.2). In §2, I explore the implications of privative features for an adequate phonetic implementation by looking at a specific case, the phonetic patterns of nasalization in French.

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1.1 Underspecification and Privativity

In SPE, an explicit distinctive feature theory is proposed, building on the seminal work of Jakobson, Fant, and Halle (1963). The SPE system has been enormously influential and serves as the foundation of many current assumptions, explicit or implicit, about the nature of phonological representations. Following Jakobson, Fant, and Halle (1963), in SPE phonological representation consisted of bundles of a limited number of binary features (with phonetic correlates). Full specification of all features was assumed within the phonology. Generalizations about markedness were captured in the lexicon, with a set of markedness conventions, but these were implemented prior to the input to the phonology. The input to the phonology, or the underlying representation, consisted of fully specified feature matrices. Following this assumption, all phonological rules were feature changing.

The advantages of the SPE system were that it offered a constrained and explicit theory of phonological structure. More recently, many arguments have been put forward in support of other views of feature structure and specification, claimed to offer a more insightful view of the phonology. I consider here two closely related proposals: underspecification and privativity.

Most recent work in phonology rejects the notion that there is full specification at the input into the phonology; rather it is widely assumed that there is at least some degree of underspecification of phonological representation (see Steriade 1987, Archangeli 1988, Mester and Itô 1989, and more recently Clements 1993, Steriade 1995). Two main views of underspecification have been dominant:

(1)
- Contrastive Underspecification = no redundant values, binary values in case of contrast (e.g. Steriade 1987, Clements 1988)
- Radical Underspecification = only a single value present underlyingly, unmarked values filled in (e.g. Kiparsky 1982, Archangeli 1984)

Contrastive and Radical Underspecification share the assumption that redundant information is excluded from underlying representations and may be filled in at some point in the phonological derivation. They differ in their treatment of contrastive "unmarked values", assumed to be present underlyingly in the case of Contrastive Underspecification, but absent in the case of Radical Underspecification, filled in by redundancy rules during the course of the derivation. Under a strong view of Radical Underspecification (e.g. Kiparsky 1982, Archangeli 1984), it is assumed that there is full specification at the output of the phonology, while Contrastive Underspecification is agnostic on this point. Evidence for these views of underspecification comes from behavior of morpheme structure constraints and phonological processes.

Another important source of evidence for the underspecification of phonological representations comes from what has been termed "phonetic underspecification" (Keating 1988), cases where patterns of phonetic realization are affected solely by the phonetic context and not the presence of a feature value. As argued by Keating (1988) and Cohn (1990), such cases provide independent support for the nature of phonological specification and also argue against the strong view of Radical Underspecification.

Several recent proposals suggest that many, if not all, distinctive features should be viewed as privative (e.g. Lombardi 1991, Steriade 1995). What does it mean for a feature to be privative? In contrast to binary features, where reference is made to both plus and minus values, phonological contrast is captured by the presence or absence of a particular feature. The strongest hypothesis would be that no need ever arises to refer to more than one value of a particular feature in the phonology.

The term "privative" comes from Trubetzkoy's (1939) use of the term in his system of oppositions. In particular, within his system distinctions are made between privative, equipollent, and gradual oppositions. Of interest to us here are privative vs. equipollent oppositions:

> a. *Privative* oppositions are oppositions in which one member is characterized by the presence, the other by the absence, of a mark. For example: "voiced"/"voiceless," "nasalized"/"nonnasalized," "rounded"/"unrounded." The opposition member that is characterized by the presence of the mark is called "marked," the member characterized by its absence "unmarked." . . .
>
> [*b. Gradual*]
>
> c. *Equipollent* oppositions are oppositions in which both members are logically equivalent, that is, they are neither considered as two degrees of one property nor as the absence or presence of a property. For example: German *p-t* and *f-k*. (Trubetzkoy 1939, translated by Baltaxe 1969, p. 75)

First, we note the importance of markedness in Trubetzkoy's definition. The presence of a mark— markedness—is defined based on language specific evidence, determined by neutralization. These terms are relative for Trubetzkoy and may be interpreted in a language specific manner; it is the structure and the function of the system that allows this determination. The same set of sounds may have a different status in two different languages, thus this notion of privative opposition is different from the current notion, where privative features are generally assumed to be universally defined as such. It is also important to remember that for Trubetzkoy these were oppositions within a phonological system and not distinctive features as such.

A number of different sorts of arguments have recently been put forth in favor of privative features. First, a privative feature theory can be argued to be more restrictive, as there are fewer possible representations. Unlike theories of underspecification where only one value is allowed at some point in the derivation, under a privative theory only one feature value is allowed ever. Second, a privative feature theory has been argued to be more empirically adequate. For example, very few convincing cases of [-coronal] have been identified, and this observation is part of the motivation for arguing that Coronal and the other basic places of articulation should be represented with articulator nodes, rather than with binary features (see Sagey 1986 and McCarthy 1988). Finally a privative theory has been argued to offer a more coherent theory of neutralization (Lombardi 1991). Such an approach avoids the problem where a minus value and an unspecified value represent the same thing, e.g. [-voice] and [Øvoice] for obstruents. It is important to note that it might be that some features are privative and others are binary.

To compare these differing views of feature specification, I take as an example English voicing specifications, as shown in (2).

(2) English voicing specifications

input	e.g.	full spec	contrastive	radical	privative
obstruents	t, s, č	-V	-V	ØV	
	d, z, ǰ	+V	+V	+V	V
nasals	n	+V	ØV	ØV	
liquids/glides	l, y	+V	ØV	ØV	
vowels	i, a, u	+V	ØV	ØV	
output		same	specs may be added	full spec by default	same

Under a view of full specification, all segments are underlyingly specified as [+voice] or [-voice] and remain specified throughout the phonological derivation. Any rules therefore involve features changing, e.g. voicing assimilation in clusters would involve a [-αvoice] specification becoming [αvoice] in a particular context. Under Contrastive Underspecification, both feature values would be underlyingly specified within the class of obstruents, but no specifications would be present underlyingly within the class of sonorants. These redundant values might or might not get filled in during the course of the derivation. Under Radical Underspecification, only the contrastive, marked values would be present underlyingly, that is, [+voice] in obstruents; both the unmarked [-voice] values in the obstruents and the redundant [+voice] values in the sonorants would be filled in by rule, required before any other rule could apply making references to those values. At the output of the phonology, the specifications under these three views might potentially be the same. A much sparser representation results if Voice is privative, underlyingly only the voiced obstruents would be marked as Voice (just like the case of Radical Underspecification), and under the strictest interpretation, this would be the case throughout the derivation, with no [-voice] values ever filled in.

One goal of an adequate phonological theory is to incorporate markedness. Such a theory should account not only for occurring vs. non-occurring structures, but should also inform us about common vs. uncommon structures. Both Privativity and Radical Underspecification claim to incorporate markedness. Privativity incorporates markedness in the most direct way, by saying that unmarked values do not exist. Within Radical Underspecification, markedness is achieved by relegating unmarked values to a secondary position. They are not present underlyingly, being assigned by rule in the course of the derivation. Additionally, unmarked values have been argued to be language specific; for example, Archangeli and Pulleyblank (1989) argue that the unmarked value in an ATR system is a language specific property. Privativity's position vis-à-vis markedness is clearly the stronger one.

An important question to ask is whether Privativity is substantively different from Radical Underspecification. Until the point at which unmarked values are filled in for a radically underspecified feature, Privativity and Radical Underspecification do not appear to be distinct. The real issue is whether the unmarked values are filled in at some point in the phonology. Radical Underspecification does not identify a specific point at which such values are filled in, while the strong version of Privativity asserts that such values play no role at any point in the phonology. Other versions of Privativity allow values to be filled in post-lexically or phonetically, making these theories more constrained than Radical Underspecification only in that an explicit point for feature fill-in is identified (see Lombardi, ms. for discussion of this point).

Recent research by Prince and Smolensky (1993) and McCarthy and Prince (1993) results in a rather dramatic rethinking of many basic assumptions of phonology. Following this view, phonology is no longer seen in derivational terms. One area that clearly requires rethinking is the nature of phonological specification. Theories of underspecification have largely been derivational theories, asking how information is filled in over the course of the derivation. Yet the goals of these theories—an account of empirical adequacy, markedness, contrast vs. redundancy—still need to be achieved. These issues need to be reconsidered in non-derivational terms. (See Clements 1993 and Steriade 1995 for discussion of related issues.)

Smolensky (1993) argues that Radical Underspecification is inadequate as a treatment of markedness. Optimality Theory offers a different view of markedness, literally, unmarked things have fewer marks or violations. (However, Lombardi to appear argues that certain features may indeed still be privative.) But what about underspecification more generally, should we return to the SPE view of full specification? The basic Optimality Theory position seems to be to assume full specification, unless there is evidence to the contrary; while the default derivational view has been to assume as little information as necessary. What should we take for evidence? Inkelas (1994) argues that underspecification is still required in certain cases of alternations in the shape of a morpheme and cases where three values of a feature appear to play a role. Similarly, evidence from phonetic underspecification also supports this conclusion. We might refer to these sorts of evidence as "empirically motivated" underspecification. There is also an important issue of a non-derivational view of contrastive vs. redundant information. Optimality Theory potentially offers other ways of capturing redundant vs. contrastive information besides, or in addition to, underspecification. Such differences might also be captured through underparsing and the relative ranking of parse constraints. Systematic discussion of these very important issues is beyond the scope of the present paper. Here, I will continue to use some derivational metaphors, but from time to time will step back and explicitly consider the consequences for Optimality Theory.

If some or all phonological features are indeed privative, this has important implications not only for phonological representations, but also for the relationship between phonetics and phonology.

1.2 The relationship between phonology and phonetics

A theory of privative phonological features has direct consequences for the phonetics-phonology interface. Before laying out this issue more explicitly, I start by characterizing the relationship between phonetics and phonology that I am assuming here.

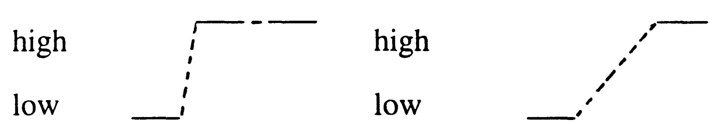
The phonology consists of abstract sound patterns, while the phonetics is the physical realization of these abstract patterns. In considering the relationship between phonology and phonetics, I make two important assumptions: (1) Both phonology and phonetics may be language specific and therefore constitute part of the linguistic grammar. (2) Phonology and phonetics are distinct, as the mechanisms are distinct—phonology manipulates discrete abstract units, while phonetics manipulates gradient quantitative structures. (See Cohn 1993b for discussion of these assumptions.)

I assume that the phonology-phonetics interface consists of translation of a static representation into a quantitative one, realized in both time and space. Following Pierrehumbert (1980), Keating (1985), and others, I assume a target-interpolation model of this relationship, whereby feature specifications leaving the phonology are translated into phonetic targets, such that a plus value translates to relatively more of the physical value that implements a particular feature than a minus value. The targets are then hooked up through phonetic interpolation. Based on empirical evidence, phonetic targets are argued to have inherent duration (Pierrehumbert and Beckman 1988, Huffman 1989). In the case of the feature Nasal, targets last for most of the duration of a segment (Cohn 1990). Furthermore, as discussed above, underspecification may persist into the phonetics (Keating 1988). In the case of Nasal, assuming for the moment that it is a binary feature, three possible values are present at the output of the phonology: +, -, Ø.

A schematic example of the mapping from the phonology to the phonetics for the feature Nasal following this view is given in (3).

(3) Phonological Output: a. -N +N +N b. -N ØN +N

Phonetic Targets: & interpolation



In (3a), we see an example where each segment is fully specified at the output of the phonology. Each segment has a target lasting for most of the duration of the segment and rapid transitions between the segments are expected. In (3b), we see a case where the first and third segments are specified, but the middle segment is unspecified at the output of the phonology. We expect the first segment to be oral for most of its duration and the third segment nasal, with the middle segment's pattern of nasalization being defined by the phonetic context, showing a clinelike pattern throughout the duration of the segment.

At this juncture it is worth asking whether Optimality Theory requires a rethinking of the phonology-phonetics interface. In one sense, the answer to this question is no: since it is the surface phonological representation that serves as input to the phonetics, it does not matter whether this representation has arisen as a final step in a traditional derivation or as the most harmonic member of a candidate set, generated by Gen and evaluated by a set of ranked constraints. However, recently generative phonetic analyses have been cast in rule based terms; this suggests a rethinking of the phonetics in non-derivational terms. We might define a non-derivational phonetics as a set of quantitative constraints, resulting from articulatory, aerodynamic, and perceptual requirements, evaluated in light of phonological structure. A non-derivational phonetics is compatible with many of the assumptions already made within generative phonetics. First it is generally assumed that there should not be any intrinsic ordering of rules within the phonetics. Implementation is necessarily constrained, both by the representation it is implementing and certain independent requirements of phonetic well-formedness. And in this sense, it seems straightforward to recast the notion of phonetic implementation in terms of constraints. (For fuller discussion of these issues, see Cohn 1995.)

With this brief review of issues of underspecification and privativity and the nature of the relationship between phonology and phonetics, I would like to explore the implications of privative features for the phonology-phonetics interface: the question to ask is how would the phonetics implement a privative feature (as opposed to a binary one). If we assume "weak privativity", whereby a privative feature becomes binary later in the phonology, there are really no implications for the phonetics distinct from the implementation of binary features, since by the output of the phonology, there will be both plus and minus values referred to. The substantive question to ask, then, is what are the consequences of "strong privativity": if the output of the phonology, that is, the input to the phonetics, consists of only privative feature specifications, what would the phonetics have to look like?

As noted by Keating (1991), common phoneticians' practice interprets [ØF] as distinct from [-F]:

(4) [+F] - do some specific thing
[-F] - do the opposite specific thing
[ØF] - do nothing with passive dependence on context

Keating notes that this results in a paradox: "If [-F] is collapsed with [ØF] because it seems phonologically invisible, then it cannot be visible later on to block phonetic interactions." Can we fully maintain a privative phonetics, with no distinction between [-F] and [ØF] and at what cost?

2. Implications of privative features

In this section, I explore the implications of privative features for the phonology-phonetics interface by looking at the phonetic realization of patterns of nasalization in French. I start in §2.1, by considering the phonological evidence for the feature Nasal as a privative feature, as well as the feature Voice, since this will be relevant to the phonetic implementation of Nasal. I then turn to the study itself in §2.2 & §2.3 and the implications for privativity §2.4.

2.1 The features Nasal and Voice

A number of recent proposals argue that some if not all features may be privative; we consider here the proposals and evidence for Nasal and Voice.

Several researchers have recently argued that the feature Nasal is privative (see, e.g. Itô and Mester 1989, Steriade 1993a, b, Trigo 1993). Steriade (1993b) discusses the observed patterns of markedness and notes that Nasal is a case of what she terms "context free markedness": "If a language possesses a [+nasal] series of sounds then it will possess the corresponding [-nasal] series." (Steriade 1993b, p. 334). Conceptually Nasal fits the criterion laid out by Steriade for a privative feature.

One set of proposals assumes a representation, where the feature Nasal is dominated by a soft palate node (see e.g. Itô and Mester 1989, building on the structure proposed by Sagey 1986), as shown in (5).

(5) A representation of Nasal as a privative feature

SoftPalate
|
Nasal

As Yip (1989) argues, there are a number of reasons to find this representation undesirable; basically it just encodes a binary distinction through an extra dummy feature, which has no phonetic content of its own. A more substantive proposal for Nasal as a privative feature comes from Steriade's work within her aperture node theory (Steriade 1993a, b). Steriade argues that [-continuant] segments are phonologically characterized by both a closure and release phase. Her proposed representations for plain, prenasalized, and postnasalized nasals are sketched out in (6).

(6)	<u>nasal stop</u>	<u>prenasalized stop</u>	<u>postnasalized stop</u>
	[nasal]	[nasal]	[nasal]
	/ \	|	|
	A_0 A_{max}	A_0 A_{max}	A_0 A_{max}
e.g.	[m]	[^{m}b]	[b^m]

This leaves us with the empirical issue of accounting for putative cases of reference to [-nasal] within the phonology of any language. As argued by Steriade, there are few convincing cases spreading [-nasal] and a clear asymmetry exists in that no long distance cases of [-nasal] spreading exist. The main use of [-nasal] is in the representation of pre- and post-nasalized stops. Steriade's representations obviate the need for reference to [-nasal] for these segments, as shown in (6) and also capture an important asymmetry, not predicted in other representations, that only noncontinuants can be contour. The case for Nasal as a phonologically privative feature is quite strong. There are, however, a few problematic cases which require attention. These include a local [-nasal] spreading rule in Sundanese, shown by Cohn (1993a) to be phonological and cases of references to three values of Nasal, as seen, for example, in Tucano (see Noske 1993).

A number of researchers have also argued that the feature Voice is privative (see, for example, Mester and Itô 1989, Cho 1990, Lombardi 1991). In discussing the status of Voice, it is important to note that what is meant is a widely assumed post-SPE version of the feature (following e.g. Clements 1985), where it is the presence or absence of voicing which is the phonetic correlate, not the position of the vocal cords (as argued in SPE). Mester and Itô and Cho argue for Voice as privative, while Lombardi and Steriade (1994) argue that the laryngeal features as a class are privative. (The evidence for both Spread Glottis and Constricted Glottis as privative is quite convincing, but will not concern us here.) Here too the observed patterns of markedness are consistent with Steriade's criterion: "the presence of a voiced obstruent series implies the presence of the corresponding voiceless series, but not vice versa." (Mester and Itô 1989, p. 263, following Maddieson 1984a).

There is a large set of putative cases of phonological reference to [-voice] (as discussed by Mester and Itô 1989, Cho 1990, Lombardi 1991, Kenstowicz 1994). One such class of cases is symmetrical spreading rules: [voice] —> [αvoice] / _____ [αvoice]. The solution proposed by a number of researchers is that these cases really consist of two distinct rules, one of delinking and the other of spreading. Such analyses make a clear prediction that the voiced sequences, but not the voiceless ones, constitute linked structures. We therefore might expect to see integrity effects in the former, but not the latter structures, but I do not know of any such cases that have been discussed in the literature. Another class involves cases where what was assumed to be [-voice] is argued to be something else, e.g. "voiceless nasals" as being [+Spread Glottis] (see e.g. Cho 1991). Still other cases can be argued to be the result of phonetic implementation and not the phonology. Sonorant Devoicing in English might be such a case. As has been widely observed, a sonorant following a voiceless stop is devoiced, e.g. *play* [pl̥ey]. Under the view that Voice is privative, the explanation cannot be that [l̥] is [-voice]. It has been suggested that this is due to a phonological assimilation rule, whereby [+SG], rather than [-voice] is spread to the liquid (see Iverson and Salmon 1994 for such an account), though the timing facts may be more complex than would be predicted following this view. On the other hand, it is quite likely that this is really a question of phonetic implementation and interpolation of voicing through an unspecified span (as argued by Cohn 1990).

Yet other cases of phonological [-voice] specifications and redundant [+voice] in sonorants have led some researchers to propose what I will term "weak privativity", whereby at a later point in the grammar a privative feature becomes binary. Cho (1991) suggests that phonologically Voice is privative, but that phonetically distinctions are made between [+voice] and [-voice]. Lombardi (ms) has suggested that there may be post-lexical reference to [-voice]. These proposals are in a sense variants of Radical Underspecification, but more constrained in that such values only become available at a recognized point in the grammar. Central to this approach is the claim that such rules always apply late in the grammar. Another type of solution to difficult cases of characterizing sonorant voicing vs. obstruent voicing is to propose that sonorant and obstruent voicing are distinct features, see Rice (1993) and Steriade (1995) for proposals along these lines.[1] While many researchers hold to the view that Voice is phonologically privative, this is clearly a complex question and one that I believe has not been fully resolved.

2.2 The phonetic realization of patterns of nasalization in French

In this study, nasal airflow was taken as a measure of the phonetic output for the feature Nasal. Data from a wide range of phonological contexts was examined for two speakers. There were five repetitions of each utterance, said in a frame /dit _____ dø fwa/ *dites_____ deux fois* 'say ______ twice'. The results were quite consistent across repetitions for both speakers. (See Cohn 1990 for a fuller discussion of the methodology used in the study.)

It is the feature specifications at the output of the phonology, which serve as input to the phonetics. Assuming for the moment Contrastive Underspecification, both [+nasal] and [-nasal] specifications are present in the case of contrast, that is, for both [-continuant] consonants and vowels. Where Nasal is redundant, in the case of [+continuant]

[1] Note that the two features in these sorts of solutions are distinct from the two features Stiff and Slack proposed by Halle and Stevens (1971), which between them define a continuum.

consonants, I assume that no values are specified. This results in three possible values, [+nasal], [-nasal] and [Ønasal] at the output of the phonology.[2] This is summarized in (7).

(7) French phonological specifications

specification	class	abbreviation	example
[+nasal]	nasal consonants	N	n
	nasal vowels	Ṽ	ɛ̃, ɔ̃
[-nasal]	voiceless stops	T	t
	voiced stops	D	d
	oral vowels	V	e, o
[Ønasal]	continuants	L	l

The question we need to address is how are patterns of nasal airflow realized for each of these classes of sounds — oral, nasal, and unspecified — in a range of contexts. In §2.3, I first consider a range of patterns of nasal airflow in French and present an analysis assuming Nasal as a binary feature, with [+nasal], [-nasal] and [Ønasal] values at the output of the phonology. Then in §2.4, I turn to the issue of how we might account for the observed patterns with Nasal as a privative feature, excluding [-nasal] values.

2.3 Patterns of nasal airflow, Nasal as a binary feature

The patterns of nasal airflow presented here are part of a larger study, reported in Cohn (1990). In our discussion, I focus on a subset of the patterns and abstract away from many of the finer details of the airflow patterns. I consider here a range of sequences of oral, nasal, and unspecified sounds, by looking at representative examples of nasal airflow traces.

I start by considering the realization of oral segments followed by nasal segments. Assuming phonological feature specifications are mapped to targets lasting most of the duration of the segment, we would expect to see the pattern of phonetic implementation schematized in (8), where the oral segment is fully oral, the nasal segment nasal, with a rapid transition in between.

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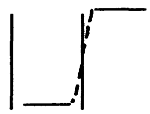
2 Optimality Theory may lead to a rethinking of some of these assumptions, particularly with respect to the treatment of redundant specifications. The different status of contrastive vs. redundant information might be treated by relative ranking of Parse constraints, with ParseContrastive outranking ParseRedundant. These are issues for further research, but here I will continue to assume that redundant values are unspecified, unless there is empirical evidence to the contrary.

(8) -N +N

Phonological output:

```
  x     x
  |     |
 -N    +N
```

Phonetic implementation:



Consider now the representative examples of this pattern involving both [-continuant] consonants and vowels, shown in Figure 1.

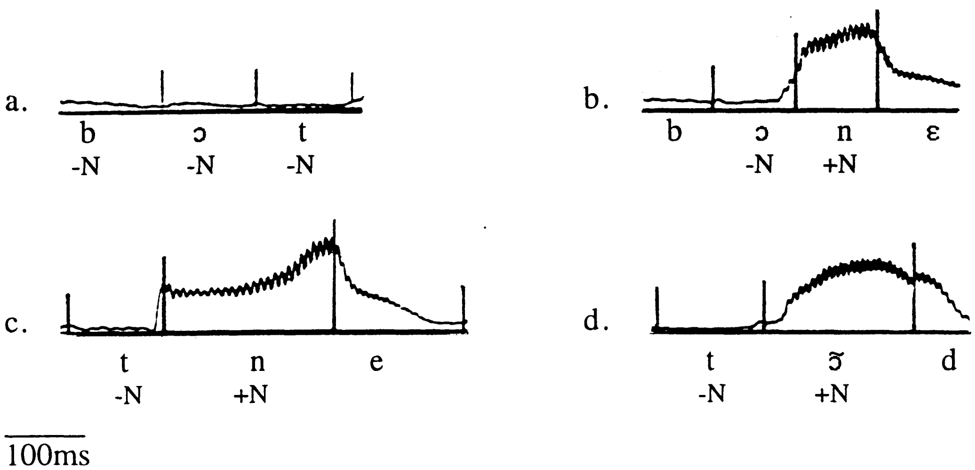


Figure 1. Representative examples of nasal airflow in [-nasal] [+nasal] sequences, a. DVT *botte* /bɔt/ 'boot'; b. VN *bonnet* /bɔnɛ/ 'bonnet'; c. TN *(di)tes nez* /t#ne/ 'say nose'; d. TṼ *thon (deux)* /tɔ̃#d/ 'tuna'.

In Figure 1a, a sequence of oral segments is shown. Here virtually no nasal airflow is observed. This example sets an effective baseline for the other cases. In Figure 1b, we see an example of an oral vowel followed by a nasal consonant. The vowel is oral for most of its duration, followed by a rapid transition into the nasal consonant, which is fully nasal for its duration. In Figure 1c, we see an oral stop followed by a nasal consonant, again with a rapid transition between the fully oral stop and fully nasal consonant. In Figure 1d, we see a similar pattern of an oral stop followed by a nasal vowel. Here the transition, again rapid, occurs after the release of the stop. (In Cohn 1990, an explicit analysis of the patterns of transitions is given, where it is shown that different segments control the transition to various degrees. I abstract away from these issues here.)

To generalize across these patterns, we see that the oral segments are characterized by a lack of nasal airflow for most of their duration, while during the nasal segments, both consonants and vowels, significant nasal airflow is observed for most or all of their duration, with rapid transitions in between, like the pattern schematized in (3a). These patterns of nasal airflow in French allow a direct interpretation of the phonological feature specification of Nasal. Those segments phonologically characterized as oral, which I assume to be specified as [-nasal] at the output of the phonology, show no significant nasal airflow, while those which are phonologically nasal ([+nasal]) show significant nasal airflow both temporally and spatially. Such segments are nasalized for most or all of their duration and the patterns of nasalization are seen to be quite plateau-like, not gradient or transitional.

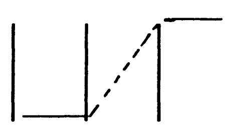
Let us now compare these patterns with a sequence of an unspecified segment followed by a nasal consonant. The predicted pattern of phonetic implementation is schematized in (9).

(9) (-N) ØN +N

Phonological output:

```
x    x    x
|         |
-N        +N
```

Phonetic implementation:



In this case we expect to see the preceding oral segment be fully oral, the following nasal segment fully nasal and the unspecified segment partially nasalized due to the context, with a cline-like pattern of increasing nasal airflow throughout the duration of the segment. Let us consider the representative examples of this pattern presented in Figure 2.

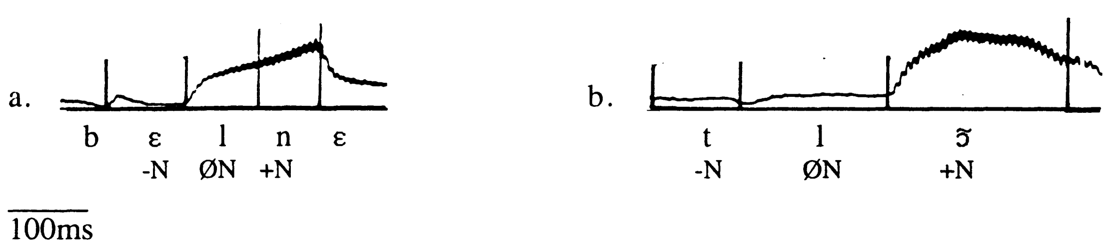


Figure 2. Representative examples of nasal airflow in [Ønasal] [+nasal] sequences, a. VLN *belle Ne(l)* /bεl#nε/ 'pretty Nell'; b. TLṼ *(di)tes long* /t#lɔ̃/ 'long'.

In Figure 2a, we see that the preceding oral vowel is fully oral, the following nasal consonant fully nasal and intervening [l] shows increasing partial nasalization throughout its duration. This is quite different from the pattern seen for an oral vowel or stop before a nasal consonant, illustrated in Figure 1. Here the [l] appears not to contribute an oral target of its own, consistent with the assumption that it is phonologically unspecified. This pattern is accounted for in my analysis as interpolation through an unspecified span, resulting in a pattern that looks like the schematic example, shown above in (3b).

But not all [l]'s (or [+continuant] consonants more generally) are the same. In Figure 2b, the [l] is fully oral. This difference appears to be due to syllable position. An [l] in the onset of a syllable behaves as if it were [-nasal]. In Cohn (1990), I propose a phonological rule which assigns [-nasal] to an onset otherwise unspecified for Nasal in order to account for these sorts of cases. This could also be treated non-derivationally. Intuitively, what is at issue here is that fuller specification is required in onset position, resulting in the unmarked [-nasal] specification in the absence of any other specification.

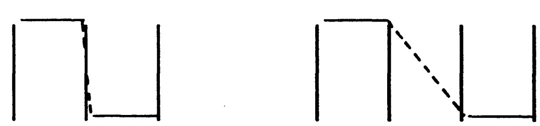
In these cases then, we see evidence for three classes of segments—[+nasal], [-nasal], [Ønasal]—at the output of the phonology, as well as a rule or constraint requiring specification of the feature Nasal in onset position. Now let us turn to carryover cases of +N-N and +N ØN -N. The predicted patterns for these cases—the mirror images of -N+N and -NØN+N—are schematized in (10) and representative examples are presented in Figure 3.

(10) +N-N and +N ØN -N

Phonological output:

x	x	x	x	x
|	|	|		|
+N	-N	+N		-N

Phonetic implementation:



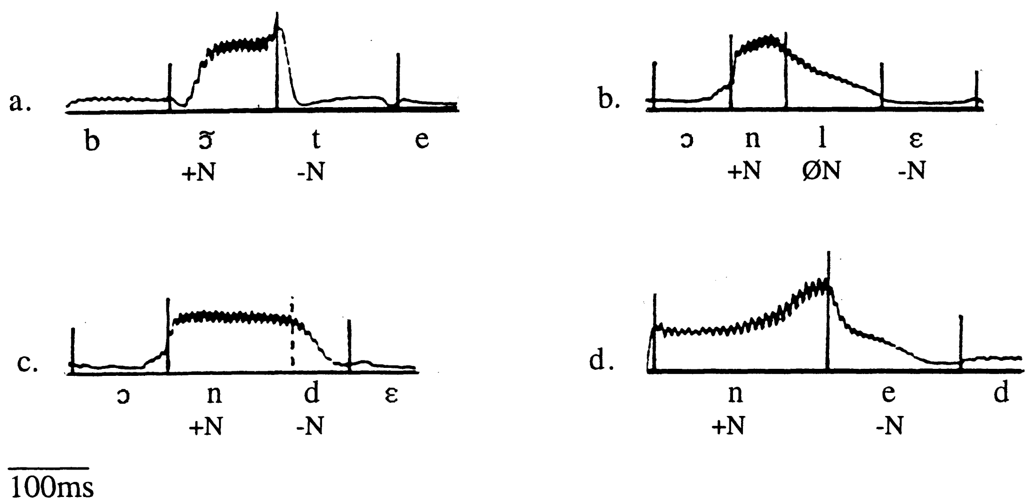


Figure 3. Representative examples of nasal airflow in [+nasal][-nasal] and [+nasal][Ønasal][-nasal] sequences, a. ṼT *bonté* /bɔ̃te/ 'goodness'; b. NLV *(b)onne let(tre)* /ɔn#lɛ/ 'good letter'; c. ND *(b)onne de(tte)* /ɔn#dɛ/ 'good debt'; d. NV *nez d(eux)* /ne#d/ 'nose twice'.

In Figure 3a, the pattern of a nasal consonant followed by an oral (voiceless) stop is what we would predict, with the former being fully oral and the latter fully nasal, with a rapid transition in between. In Figure 3b, with an [l] following a nasal consonant, we find a clinelike pattern throughout the [l], again what we would expect for an unspecified segment. (Note, however that the [l] is in onset position, but nevertheless seems to be unspecified.) But the patterns in Figure 3c & d, which we would a priori expect to look like the pattern in Figure 3a, are very different. In both of these cases, the segment following the nasal consonant, an oral voiced stop or vowel, appears to be unspecified for Nasal in this context, exhibiting a clinelike pattern of nasalization, just like [l]. In Cohn (1990), I propose a rule of [-Nasal] Delinking, whereby the [-nasal] specification of a voiced segment is deleted following a [+nasal] specification. Intuitively, what is happening here is that the nasal specification is spreading to the right, resulting in a phonetic effect of nasalization, and this spreading overrides the presence of a [-nasal] specification. The result of this is distinct behavior of voiceless and voiced oral segments, yielding an asymmetrical pattern for voiced stops and vowels preceding and following nasals.

In (11) I summarize the observed patterns of nasal airflow.

(11) Patterns of nasal airflow in French

N, Ṽ	always nasal, independent of context
T	always oral, independent of context
L	oral, or a cline, dependent on context and syllable structure
D, V	asymmetrical behavior, oral before +N, partially nasal after +N

Nasals and voiceless stops exhibit consistent patterns of airflow independent of context, while voiced stops, continuant consonants, and oral vowels all exhibit patterns dependent on context. In addition, the pattern for oral stops and vowels is different from that seen for [+continuant] consonants. Thus we see several distinct patterns of behavior among those segments which are not [+nasal].

In Cohn (1990), a systematic comparison of nasalization in French and English is presented. Here, I focus on the contexts most relevant to our discussion; the VN and NV contexts in English are exemplified in Figure 4.

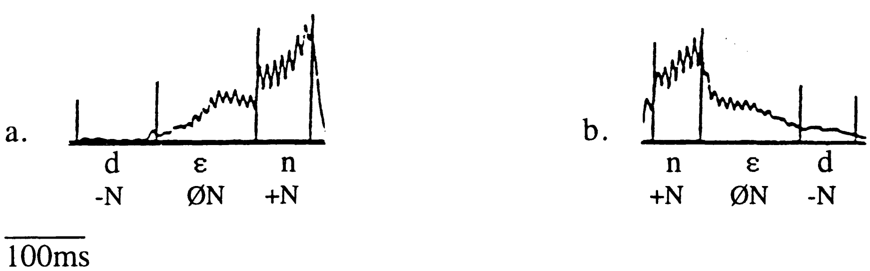


Figure 4. Representative examples of nasal airflow in VN and NV sequences in English, a. DVN *den* /dɛn/ b. NVD *Ned* /nɛd/.

The VN pattern in English looks like the French LN pattern, seen above in Figure 2a. In Cohn (1990, 1993b), I argue that this is because vowels in English are unspecified for Nasal, due to lack of contrast; thus the clinelike pattern results from interpolation through an unspecified span. The NV pattern in English is very similar to that seen above for French. This is again due to the lack of specification in English, resulting in a symmetrical pattern in the VN and NV cases in English, in contrast to the asymmetrical pattern observed in French. Within a binary system of feature specification of Nasal, the language specific differences between French and English follow from the difference in feature specification, directly reflecting the difference in contrast between the two languages.

While D, V, and L appear to contribute nothing in terms of orality following a nasal consonant, when we look at the most restrictive context, an oral segment between two [+nasal] segments, we see that subtle, but significant, differences emerge. The predicted realization of +N-N+N and +NØN+N patterns is schematized in (12) and representative examples are presented in Figure 5.

(12) +N -N +N and +N ØN +N patterns

Phonological output:

x	x	x		x	x	x
+N	-N	+N		+N		+N

Phonetic implementation:

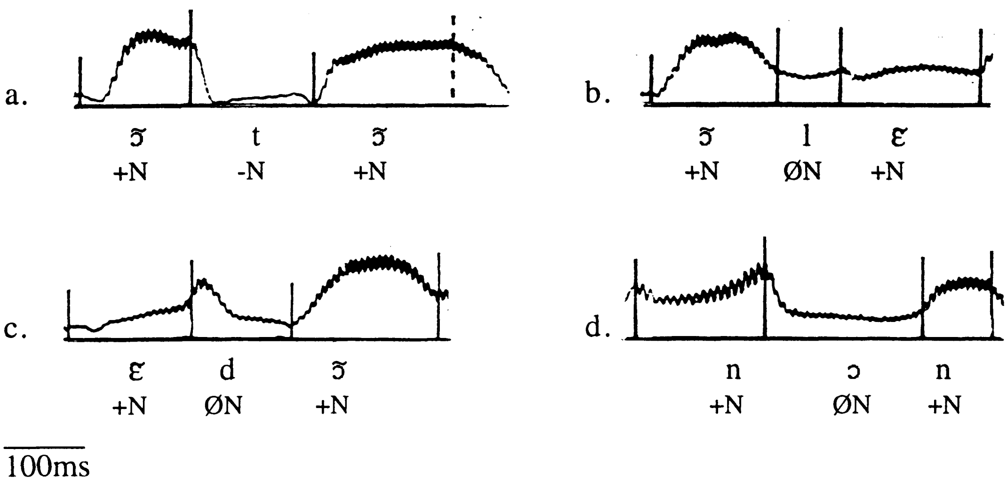


Figure 5. Representative examples of nasal airflow in [+nasal][-nasal][+nasal] and [+nasal][Ønasal][+nasal] sequences, a. ṼTṼ *(b)on thon* /ɔ̃#tɔ̃/ 'good tuna'; b. ṼLṼ *(b)on lin* /ɔ̃lɛ̃/ 'good flax'; c. ṼDṼ *(d)indon* /ɛ̃dɔ̃/ 'turkey'; d. NVN *nonne* /nɔn/ 'nun'.

In Figure 5a, we see that [t] is still fully oral and in Figure 5b, we see that [l] is nasalized throughout, imposing no orality of its own.[3] These are the expected patterns for a [-nasal] and [Ønasal] segment respectively in this context. However the patterns with D and V are different from what we saw above in Figure 3. In Figure 5c, we see that D imposes some orality; it is not fully nasalized and therefore not fully unspecified. Similarly in Figure 5d, while the "oral" vowel is nasalized throughout, it exhibits a low level of nasalization, not the degree of nasalization expected of a fully nasalized vowel with the same quality (such as

[3] The difference in level of nasal airflow between [ɔ̃] and [ɛ̃] seen in these examples is the result of an impedance effect, due to the differing degree of oral openings in these two vowels. I abstract away from these differences in this discussion.

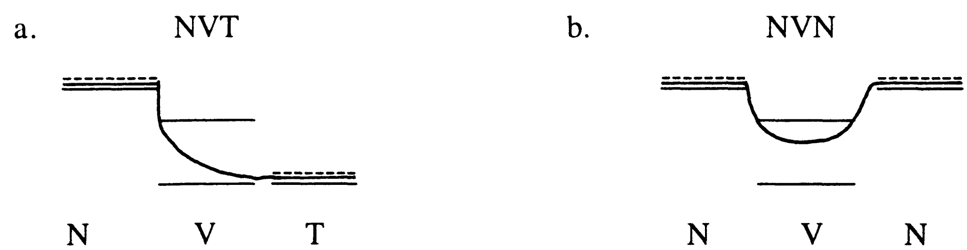
seen in Figure 5a). Thus D and V impose certain weak phonetic requirements. Different classes of segments appear to impose distinct phonetic requirements or conditions on phonetic well-formedness of a segment. These are precisely the sorts of quantitative constraints that we would expect in the phonetics.

As we have seen, the phonetic requirements of voiced and voiceless stops are different. Phonetically, voiced stops minimally have oral releases, whereas voiceless stops must be oral for most of their full duration. We might account for this difference through reference to closure and release, that is, voiced stops are amenable to having their closure portion nasalized (in effect becoming a prenasalized stop) while voiceless stops are not. This difference is schematized in (13).

(13) Phonetic requirements of voiced and voiceless stops

We can account for the behavior of oral vowels, following Keating's (1990) Window Model, assuming that the target for an oral vowel is not necessarily complete orality, but rather constitutes a limited range in space between fully oral and partially nasal, while a nasal vowel has a range of values falling within a range of full nasalization. As schematized in (14), this would account for the apparent lack of target of an oral vowel in the context following a [+nasal] segment, but preceding a [-nasal] one (14a), compared with the case between two [+nasal] segments (14b).

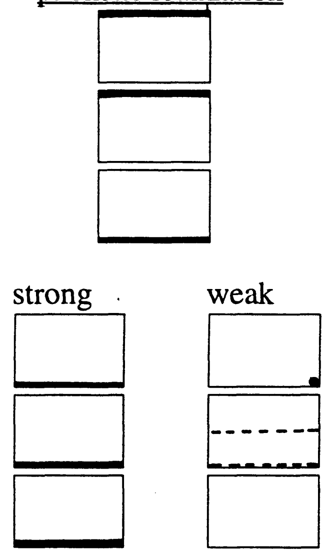
(14) Phonetic requirements of vowels



In (15), I summarize the phonological specifications and phonetic requirements of each class of segments.

(15) Phonological specifications and phonetic requirements

		phono spec	phonetic realization
a.	Nasal consonants	[+nasal]	
	Nasal vowels	[+nasal]	
	Voiceless stops	[-nasal]	
b.	Voiced stops	[-nasal]	
	Vowels	[-nasal]	
	/l/	[Ønasal]	



In (15a), the patterns of phonetic realization reflect direct interpretation of what I have assumed to be the phonological specifications of these classes of segments. As noted above, for these classes of sounds, the pattern of phonetic implementation is independent from phonetic context. The situation in (15b) is more complex. For these sounds, the pattern of realization is dependent on context and shows a stronger or weaker requirement depending on the phonetic context. Voiced stops and oral vowels are fully oral preceding a [+nasal] segment, but impose only weak constraints after a [+nasal] specification. [+continuant] consonants, exemplified by [l], impose no requirements, except in onset position before a [+nasal] specification. I believe that these well-formedness requirements follow from articulatory (aerodynamic) or perceptual requirements, but I state them here as descriptive requirements based on empirical observations of the patterns, since clearly more work is needed to fully understand the nature of these requirements.

Under an analysis assuming Nasal is a binary feature, an account of these facts is fairly straightforward. The independent patterns seen in (15a) follow directly from the target-interpolation model assumed here. In the cases in (15b), it is assumed that segments may have phonetic well-formedness conditions, weaker than the effect of a phonological specification, that emerge in certain contexts. In a binary account, the difference between the strong vs. weak requirements is due to the presence or absence of a [-nasal] specification. In Cohn (1990), I assume that this is due to the deletion of a [-nasal] specification in certain contexts. In non-derivational terms this could be accounted for as the relative ranking of Parse[-nasal] and phonetic permeation of nasalization.

2.4 The phonetic consequences of Nasal as privative

The importance of phonetic requirements in accounting for the observed patterns leads directly to the question of whether we can account for these patterns WITHOUT reference to [-nasal]. In other words, can the observed patterns be accounted for without making a distinction between [-nasal] and [Ønasal], thereby avoiding Keating's paradox. In (16), I summarize the work that the [-nasal] vs. [Ønasal] distinction is doing in the analysis.

(16) Uses of [-nasal] vs. [Ønasal]

a. Contrast between T, D, V vs. L
b. Context dependence of D and V
c. Orality in syllable onsets for L
d. Differences between French and English

First a three-way contrast was assumed, between nasal segments, oral ones (T, D, V), and unspecified ones (L), to account for the distinct behavior of each of these classes of sounds. Additionally direct reference was made to [-nasal] both in accounting for the context dependent pattern of realization in D and V and in accounting for the sensitivity to syllable structure in characterizing the realization of L. Further, certain language specific patterns, such as the difference between VN in French (seen above in Figure 1b) and in English (seen in Figure 4a), where a clinelike pattern is observed, is straightforwardly accounted for by making a distinction between [-nasal] in the French case and [Ønasal] in the English case.

In order to account for the observed patterns without reference to [-nasal], the phonetics has to be enriched in a number of ways: (1) the assignment of phonetic targets would have to be based on reference to other feature values and context; (2) reference to syllable structure would have to be made; (3) reference to a rest or neutral position would be necessary; (4) language specific patterns of implementation would be required.

The assignment of phonetic targets to segments specified as [+nasal] would be straightforward, but in order to know how to interpret the pattern of nasalization for a segment unspecified for Nasal, reference would have to be made to other feature specifications besides Nasal. It would be necessary to distinguish between vowels and consonants, between continuants and noncontinuants, and between voiced and voiceless stops. This strategy for phonetic implementation of privative features is suggested by Keating (1991) and would work in cases where the required information would also be present under a privative feature theory. But the situation for the difference between voiced stops and voiceless ones becomes very tricky. Whether we characterize this difference phonologically (with a rule spreading nasalization to the closure of voiced stops) or phonetically (through phonetic requirements), these segments differ only in their voice specification, thus it appears that reference would need to be made to [+voice] vs. [-voice]. And it is the class of [-voice] segments which impose the more stringent requirements. If we maintain the view that Nasal is privative, this suggests that Voice is not privative, at least not by the input to the phonetics (consistent with "weak privativity", as proposed by both Cho and Lombardi). Other evidence, such as the phonetic evidence from tone splitting and tonogenesis (as discussed by Hombert et al. 1979 and others), also supports this conclusion. What is found is that voiced consonants lower the pitch of the beginning of the following vowel, while voiceless consonants raise the pitch (rather than being neutral). These effects cut across obstruent and sonorant voicing, as discussed by Maddieson (1984b) in the case of Burmese.

The assignment of phonetic targets to oral segments would also have to be sensitive to context, in order to account the pattern of VN vs. NV. This difference is not just due to the window effect, since in the VN case, basically the strong requirement is required. Under a binary analysis, this is due to the presence of a [-nasal] specification in the VN case. Such a solution is not available under the privative view. Thus in order to account for the assignment of phonetic targets, not only is reference to the Nasal feature specifications needed, but access to both paradigmatic and syntagmatic information is required.

Direct reference to syllable structure in the phonetics would also be required. Under a binary view, the transparent behavior of [l], except in syllable initial position, was accounted for with a phonological assignment of [-nasal] syllable initially. If Nasal is privative, the phonetic requirements of [l] would have to be sensitive to syllable structure. Phonetic requirements would be assigned based both on inherent featural content of segments as well as syllable structure. In addition, here too syntagmatic information would be required, since the presence of a preceding [+nasal] specification overrides the effects of syllable structure.

There would also need to be a notion of rest or neutral position, to account for the fact that spans of segments unspecified for Nasal are not just nasalized throughout. Here different classes of segments show distinct behavior. An [l] in a N__N environment is indeed nasalized throughout, but other classes of segments are not. In the case of D, the contextual effects of nasalization are quite local, limited to the closure of the segment, with the release being oral. In the case of NVD, the D is fully oral, even though we might expect the closure portion to be amenable to nasalization. To account for the locality of these effects, reference to rest position is needed, that is, after a certain duration (perhaps defined quite abstractly) the velum reverts to rest position. Articulatorily the velum shows a speech ready position (raised), distinct from breathing position (lowered), so reversion to the speech ready position is not implausible, but how is this mechanism integrated to the phonetics and constrained in its behavior?

Finally, phonetic implementation of feature specifications would have to be language specific to account for the observed differences in French and English. Under a privative view, this difference could not be due to a phonological difference in specification, between [-nasal] and [Ønasal] and it could not be due to differences in window sizes, since the NV cases are quite similar in the two languages. This would require not only language specific, but again context dependent, phonetic interpretation. Good evidence of the language specific nature of phonetic implementation exists, but in this case the phonetics would be required to implement a difference that stems directly from the nature of phonological contrast in the two systems.

In summary then, the consequences of a privative phonological theory are the following. While the basic patterns in French can be accounted for without phonological reference to [-nasal], this can only be done by making the phonetics quite powerful. It requires what we might term "smart phonetics". The absence of Nasal is interpreted through other features, including Voice as a binary feature, and through context, thus requiring both paradigmatic and syntagmatic information. Additionally reference to syllable structure and rest position would be necessary and all of this would have to be language specific to account for differing patterns in e.g. French and English. Whether we interpret this as a desirable result depends in large part on the degree to which there is independent evidence that the phonetics needs to be able to refer to these sorts of information.

3. Conclusions

In the above discussion I have explored the consequences of privative features in the phonology for an adequate model of phonetic implementation. I considered these issues by examining the observed patterns of nasalization in French, sketching out first an account of the phonetic implementation assuming Nasal as a binary feature and then considering what would be required for Nasal to be interpreted as a privative feature. The results require a "smart phonetics" which has access to a wide range of information, not necessarily generally assumed to be part of a phonetic representation. The result is to turn the traditional (SPE) view of language specific phonology and universal phonetics on its head, with much of the language specific work being done in the phonetics. The viability of this approach depends on independent evidence that the phonetics should have access to this range of information.

While it seems possible to implement Nasal as a privative feature, one of the consequences seems to be to keep Voice a binary feature. This leaves us with the question of how different Voice and Nasal are as features. This in turn has implications for our understanding of markedness. Can we distinguish in a principled manner between features like Nasal and Voice? Steriade (1995) suggests that there are two different kinds of features, those which are privative and characterized by having a neutral position and those which are equipollent, not showing the same asymmetries. Yet as seen above, those arguing for Voice as privative make arguments about markedness similar to those for Nasal, so is there a real difference?

Finally, I have mentioned a number of issues concerning feature specification and the nature of underspecification within a non-derivational view of phonology. Much work remains to be done on issues of feature specification and its relationship to phonetics.

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