Deriving Abstract Representations Directly from the Level of Connected Speech[1]

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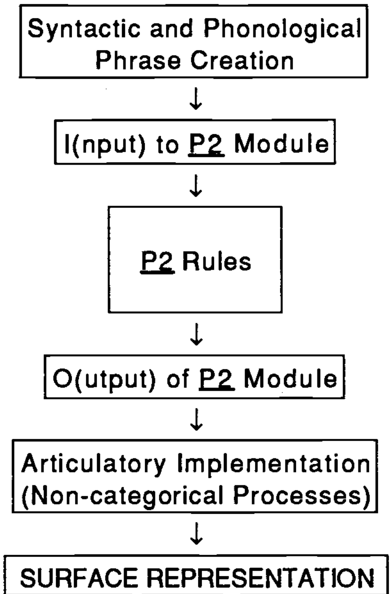
O. Introductory Remarks

My research concerns the featural properties of the levels of representation I and O, respectively in figure 1, for American English consonants:

(1)



Kaisse (1985) argues for a module of rules, hereafter P2, which immediately precedes articulatory implementation (where non-categorical processes such as degree of aspiration, degree of nasalization, and overall segment duration are relevant) and immediately follows syntactic and phonological phrase creation. In this conception of phonological organization, which I adopt, P2 rules represent the final set of operations whose application results in a categorical distinction of elements within the grammar. As a consequence of their position with respect to these other modules, the rules of P2 have the following properties: 1) they are non-cyclic; 2) they make no reference to morphological information, nor are they in principle limited in their application to any morphological domain; 3) they are exceptionless[2] ; 4) they are categorical operations describable in terms of phonological features.

I argue that P2 represents a very special module of the grammar from the perspective of a child learning its first language. P2 forms the locus of the first set of abstract (ie categorical) rules determinable directly from the surface phonetic string independently of any morphological, syntactic, or semantic structure. Thus, the discovery of P2 rules by a child requires no knowledge of the particular morphological, syntactic, or semantic details of the language. By exploring the consequences of discovering P2 rules, this research addresses and begins to answer the question of how much information about a phonological system can be learned independently of the structure of other independent modules of the grammar. I show that knowledge of the P2 rules of American English consonants results in a purely phonological distinction between the forms bin and pin. Thus the phonological, morphological, syntactic, and semantic distinction present in this minimal pair can be

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[2] There is a distinction between exceptionless and optional. Some P2 rules are optional and may or may not apply depending on the style of speech, however, if the P2 rule does apply, it applies in all environments without exception.

derived from the phonological system in the absence of morphological, syntactic, and semantic information about either of the two forms. This result suggests that acquisition of a phonological system is independent of acquisition of the independent modules of the grammar, and such acquisition may in fact reveal properties of these other independent modules.

Section 1. Background and Theoretical Issues

In this first section, I present the details of the theoretical perspective I adopt, outlining the general paradigm I have employed in conducting this research. I develop the Minimal Content Hypothesis, a principled algorithm for determining the necessary content of I, the level of representation input to P2. I show that the elements of this feature set E_I, when freely combined subject to a set of surface visible feature co-occurrance restrictions, are both necessary and sufficient to describe the segmental alphabets at the input to and output of P2. Further, I show that the Minimal Content Hypothesis produces an underspecified feature set E_I: for any feature f present in E_I, only one value of that feature αf is present in E_I.

1.1 Determining the Featural Content of Levels of Representation

P2 may be thought of as containing an output representation O and an input representation I, where I maps to O via a set of rules R relevant to that level. For example, American English voiceless stops present at the input to P2 are mapped to their aspirated counterparts (in certain environments) by the P2 rule of Aspiration (see section 2.1 for further details of this rule). In this section I introduce the Feature Admissibility Requirement and the Minimal Content Hypothesis. These two devices constitute a method through which the featural content of the input representation E_I of P2 can be determined. I show that this method determines an underspecified inventory E_I which is sufficient to determine the segmental inventory of both I, the input to P2, and O, the output of P2. Thus the Minimal Content Hypothesis derives both E_I and E_O.[3]

Let E_R represent the set of features required to specify the environments of the set of rules R relevant at P2. Assume also that a grammar requires positive evidence in the form of a phonological rule to admit a feature or feature value into E_R. I label this assumption the Feature Admissibility Requirement:

(2) The Feature Admissibility Requirement (FAR)

> The grammar of natural language requires positive evidence in the form of a phonological rule to admit a feature or feature value into E_R.

As an example of this, consider Aspiration. Aspiration affects voiceless stops in some prosodic domain, and thus Aspiration requires the features [-voice] and [-continuant] in its environment. Aspiration presents positive evidence for admission of [-voice] and [-continuant] into E_R. However, the operation performed by Aspiration inserts the feature [+spread glottis] into its environment. Because [+spread glottis] is inserted by rule, Aspiration yields no positive evidence that [+spread glottis] is present in E_R. By the FAR, [+spread glottis] is considered not to be a member of E_R.

Three relationships between the sets E_I and E_R are logically possible: $E_I < E_R$, $E_I = E_R$, $E_I > E_R$. I propose that only one of these relationships, that where the featural content of the input representation E_I is exactly equal to the featural content E_R required by the environments of the rules in R, exists in natural language at P2.:

(3) The Minimal Content Hypothesis (MCH)

> At P2, $E_I = E_R$.

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[3] Because the domain of this research has been limited to the P2 module, I cannot at this time conclude that this algorithm generalizes to any arbitrary level of phonological rules. This shall be a topic of future research.

Before discussing types of representations allowed by the MCH, I present details of the other two types of representations that the MCH rules out, $F_I < F_R$ and $F_I > F_R$.

$F_I < F_R$ could arise in the following situation. Consider a language L with distinctive voiced and voiceless stops but without distinctive aspirates. Let the language have a P2 rule that aspirates stops b, d, g when they follow i: $b \rightarrow b^h$, $d \rightarrow d^h$, $g \rightarrow g^h$. By the FAR, [-cont] and [+voice] are elements of F_R, as well as the features of i. Suppose that the language has an additional P2 rule that aspirated labials become voiceless $b^h \rightarrow p^h$. Therefore, although F_R also contains [+spread glottis], that feature need not be in F_I because [+spread glottis] is not distinctive. Thus, the learner would be faced with the task of learning not only the two rules, but also the crucial ordering relationship between them. In proposing the MCH, I claim that such a system would not arise in natural language.

$F_I > F_R$ could arise if a feature were present in F_I but never required by the environment of any P2 rule. For example, consider a language L which has a morphophonemic process (ie, one relevant to a more abstract level that P2) which refers to [+sonorant] in its environment. However, L contains no P2 rule which refers to [+sonorant]. In this case, a learner would not have access to the complete phonological feature system of L without knowledge of details of the morphological system of L. I claim that this system also does not exist as a system of natural language.

The MCH restricts the number of possible types of input and output representations which may exist in natural language. Specifically, it permits the existence of the two types of representations. Type I arises when the rules of R add no featural information (Aspiration would not fit in with this schema). Rules of this type spread or delink features when those features are present. In other words, Type I representations extend the number of possible feature combinations from I to O without increasing the number of features present in I and O. Type II arises when the rules of R add featural information, f_{rules}, not present in F_I. Rules of this type may spread, delink and also insert. In this case, F_O represents the union of the two sets F_R and f_{rules}. Aspiration is a rule of this type, since application of the rule inserts [+spread glottis]. Thus the output inventory F_O contains all of the features contained in F_R as well as features inserted by the rules of R.

I represent the two types of representations just described schematically in (4):

(4) Possible Types of Representation

I. $F_I = F_R = F_O$

II. $F_I = F_R$; $F_O = F_I \cup f_{rules}$

One other type of representation exists when the MCH is satisfied: $F_I > F_O$. This situation would arise if a feature were present in F_I which was deleted in all contexts by a rule in R. Thus, the input representation would be larger than the output representation. I predict that such a system requires a rule whose environment cannot be discovered at the surface, and would therefore be unlearnable. Thus, the model I propose requires that both F_I be a subset of F_O, and representations I and II of (4) be the only types available to natural language.

In this section I presented the Feature Admissibility Restriction and the Minimal Content Hypothesis as elements of an algorithm for determining the featural content F_I of I, the input to P2: F_I is equivalent to the set of features required by the environments of the rules R of the P2 module. I distinguished between features required by the environments of a rule F_R and those which are inserted by a rule itself f_{rules}. On the basis of this, I argued that the only types of output representations for a phonological module which may exist are those: I) where F_O is equivalent to both F_I and F_R, or II) where F_O is equivalent to the union of the two feature sets F_I and f_{rules}.

In the next section, I show that feature inventories derived via the FAR and MCH are both necessary and sufficient to derive segmental inventories at the input to and output of P2. I stress that the FAR and MCH derive inventories in the absence of morphological, syntactic, or semantic knowledge.

1.2 Featural Alphabets Derive Segmental Alphabets

Adopting the feature hierarchy of Sagey (1986), I show in Section 2 that the following features/nodes are required by those American English P2 rules which affect consonants:

(5) Features Relevant to American English Consonants

[-continuant]	[-voice]	[+consonantal]	[+nasal]
[+distributed]	[-back]	LABIAL	DORSAL

Figure (4) states that the featural content of the output representation is equal to the union of the featural content of the input representation and any features inserted by P2 rules: $\underline{F}_O = \underline{F}_I \cup \underline{f}_{rules}$. Anticipating the result of Section 2 that

$$\underline{f}_{rules} = \{[\text{+spread glottis}], [\text{+constricted glottis}]\}$$

for American English, and ignoring the contribution of $\underline{f}_{rules}$ at the moment for ease of exposition, the following figure illustrates the American English consonant segments which exist at O (I adopt the Kahn (1976) analysis of r̲ as a glide and therefore not [+consonantal]). This segmental inventory is determined by restricted free combination of the features of $\underline{F}_I$:

(6) Attested Segments at the Output of P2 (ignoring Aspirated and Unreleased Stops)

	p	b	f	v	m	m̥	t̲	d̲	θ	d̽	n̲	l̲	t	d	s	z	n	n̥	l	l̥	č	ǰ	š	ž	ñ	λ	k	k	g	g	η	h
[cons]	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+			+	+	+	+	+		+	+	+	+	+	
[vce]	-		-			-	-		-				-		-			-		-	-		-				-	-				-
[cont]	-	-			-	-	-	-			-	-	-	-			-	-	-	-	-	-			-	-	-	-	-	-	-	
[nas]					+	+					+						+	+							+						+	
[dist]							+	+	+	+	+	+																				
[back]																					-	-	-	-	-	-		-		-		
LAB	+	+	+	+	+	+																										
DOR																											+	+	+	+	+	

If exhaustive free combination of the eight features in (5) occurred, 256 segments would result ($2^8 = 256$). Figure (6) illustrates that there are only 32. Thus, some restriction of free combination is necessary in order to not overgenerate segments. Some features are never found to co-occur at the surface. These unattested combinations can be stated as a set of constraints following Archangeli and Pulleyblank (forthcoming). I propose that these constraints hold both at the surface and at all more abstract levels of representation:

(7) Constraints Restricting Free Combination

1. *[DOR, LAB]
2. *[-back, LAB]
3. *[+dist, LAB]
4. *[+dist, DOR]
5. $\begin{bmatrix}\text{+nasal}\\ \text{+cons}\end{bmatrix} \rightarrow \text{-cont}$; $\begin{bmatrix}\text{+nasal}\\ \text{-cont}\end{bmatrix} \rightarrow \text{+cons}$; $\begin{bmatrix}\text{+nasal}\\ \text{-vce}\end{bmatrix} \rightarrow \text{-cont}$
6. [LAB → +cons]
7. $\begin{bmatrix}\text{DOR}\\ \text{+cons}\end{bmatrix} \rightarrow \text{-cont}$; $\begin{bmatrix}\text{DOR}\\ \text{-cont}\end{bmatrix} \rightarrow \text{+cons}$

Constraints (7.1-7.5) are predicted to exist by the markedness theory of Pulleyblank (1989). Unmarked constraints permit only one node to be immediately dominated by PLACE unless positive evidence to the contrary is found (7.1-7.4). Other unmarked constraints relevant here include the three constraints on the co-occurrance of [+nasal] with other features (7.5).

Even given the constraints in (7), gaps still exist in the segments derived at O. These gaps are not ruled out in principle, but are accidental in nature. Accidental gaps include the lack of voiceless laterals and nasals at interdental ([+distributed]), palatal ([-back]), and velar (DORSAL) points of articulation. The environments for voiceless laterals/nasals arises when these elements are the second element of a cluster beginning with a voiceless consonant. Their absence is simply a result of the lack of clusters of this type in American English.

I now turn to the representation of I, the input to P2. This level of representation is still subject to the constraints of (7), with the addition that all of the segments (that is, certain combinations of features) which are predictable have been eliminated. Notice that voiceless nasals and laterals present in (6), in violation of an unmarked constraint *[+nas, -vce] of Pulleyblank (1989), are absent in (8): there are no voiceless nasals/laterals in I:

(8) Attested Segments at the Input to P2

	p	b	f	v	m	θ	ð	t	d	s	z	l	n	č	ǰ	š	ž	k	g	ŋ	h
[cons]	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	
[cont]	-	-			-			-	-			-	-	-	-			-	-	-	
[vce]	-		-			-		-		-				-		-		-			-
[nas]					+								+							+	
[dist]						+	+														
[back]														-	-	-	-				
DOR																		+	+	+	
LAB	+	+	+	+	+																

The voiceless nasals which appear in O appear in restricted, predictable environments. In fact, their existence is a result of the application of a P2 rule. With respect to the function of certain P2 rules, then, violation of the unmarked constraint *[+nas, -vce] at the surface appears to be re-established by the rule system in the abstract phonology. Although such conclusions are tentative at this preliminary stage of research, this result suggests that phonological rules are not entirely arbitrary processes. That is, the abstract phonology appears to derive from physiological principles[4] .

The representation in (6) describes all of the attested segments of the American English consonant system at the output of P2, while the representation in (8) describes all of the attested segments at the input to it. The segments of (6) and (8) are derived by combining the set of features presented in (5) restricted by the constraints in (7). Thus, the set of features in (5) is demonstrably sufficient to describe the attested segments of (6) and (8). Further, given that the constraints in (7) are operative, in a sense independently of a particular analysis, the removal of any one of the features in (5) would result in gross underdetermination of the attested segmental inventories of both (6) and (8). For example, consider the removal of the feature/node LABIAL. Free combination would generate DORSAL segments (as well as segments unspecified for PLACE), but could not generate the five LABIAL consonants of American English at either O or I. These segments could not be derived at O or I, and would therefore be predicted to be non-distinctive segments of American English. Since this is not the case (consider the trio pin kin tin), the set of features in (5) is demonstrably necessary to describe the attested segments of (6) and (8). This necessary and sufficient set of features in (5) is obtained by the FAR and MCH in the absence of any morphological, syntactic, or semantic information.

In this section, I proposed the Feature Admissibility Restriction and the Minimal Content Hypothesis as elements of an algorithm to derive the feature inventories both the input to and output of P2. I have presented the conclusions of this research, namely that a necessary and sufficient set of features relevant for American English consonants appears in (5), and these features combine to form the segmental inventory of American English at the input to and output of P2. Further, because the inventory in (5) consists of only eight feature values, this set is also underspecified.

In the next section, I motivated the features proposed in (5). To do this, it is necessary to examine in detail some of the P2 rules affecting American English consonants: Aspiration, Unrelease, Nasal Consonant Deletion, Vowel Nasalization, [-voice] Assimilation, PLACE Assimilation, Palatalization, Dentalization, and Flapping.

4 Similar conclusions in different phonological domains have been reached by Halle (1983) and Sagey (1986).

Section 2. Motivating the Featural Inventory of American English Consonants

I divide this section into two parts. The first subsection treats rules relevant to American English consonants in general. I show that the environments of the rules of Aspiration, Unrelease, Nasal Consonant Deletion, Vowel Nasalization, and [-voice] Assimilation motivate the features [-continuant], [-voice], and [+nasal]. The second subsection treats alternations specific to American English CORONAL consonants. Environments of the rules considered in this section, Place Assimilation, Palatalization, and Dentalization motivate the features [+consonantal], [+distributed], [-back] and the nodes/features PLACE, LABIAL, and DORSAL. I show that the grammar of American English is both simplified and more empirically adequate if CORONAL is unspecified at both I and O. Finally, I present a somewhat different analysis of the phenomenon of Flapping in American English.

2.1 General Consonant Alternations

I begin the discussion with American English rules which motivate the consonantal features [-voice], [-continuant], and [+nasal]: Aspiration, Unrelease, Nasal Consonant Deletion, Vowel Nasalization, and [-voice] Assimilation. Following the MCH, these features are present in E_I, the featural representation input to P2. Aspiration and Unrelease insert two features into the output representation E_O: [+constricted glottis] and [+spread glottis]. These two features comprise the set f_{rules}.

2.1.1 Aspiration

The phenomenon of interest here, commonly called Aspiration in the literature, concerns the breathy quality of the surface instantiations of American English voiceless stops when they occur in certain prosodic environments. The data below are representative of all voiceless English stops p t k:

(9) English Obstruent Data

a.	[p^h]anic	re[p^h]ort	s[p]ear	ras[p$^=$]
	iso[t^h]ope	mili[t^h]ary	s[t]ool	despi[t$^=$]e
	[k^h]reate	ana[k^h]onda	s[k]arred	stea[k$^=$]
b.	[b]ank	re[b]uke		Cale[b]
	[d]andruff	in[d]ecent		gla[d]
	[g]argle	a[g]hast		sla[g]
c.	[s]alamander			bu[s]
	[f]ather			rebu[f]
	[θ]eta			brea[θ]

The segmental content of the aspiration rule appears to be surrounded by little controversy: it targets the combination [[-voice] and [-continuant]] and inserts [+spread glottis].[5]

The rule of Aspiration (literally [+spread glottis] Insertion) is formulated below. To state this and other rules, I assume the rule formalism of Archangeli (1988).[6] Because this notation may be unclear to readers unfamiliar with it, I also present rules in the more familiar Chomsky and Halle (1968) (hereafter SPE) format.

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[5] This is not true of the particulars of the prosodic environment. Kahn (1976) and Hammond (1982) argue that Aspiration applies syllable-initally independent of the stress of the following vowel, while Kiparsky (1982) and Withgott (1982) argue for a syllable/foot based environment. For purposes of exposition, I assume the environment of Withgott (1982). Because I am concerned primarily with the segmental material present at this level of representation, and because all sources admit the necessity of the syllable in the environment, the particular choice of environment makes little difference with regard to the points being made here.

[6] The notation appears slightly altered from Archangeli (1988). The alterations I have made do not affect the theory associated with the source (personal communication).

(10) Aspiration (Kahn 1976)

Rule Name:	Aspiration
Operation:	Insert
Element:	[+spread glottis]
Environment:	featural: $\begin{bmatrix}\text{[-cont]}\\ \text{[-vce]}\end{bmatrix}$; prosodic: $[_\phi$ __ OR $[_\sigma$ __ $\acute{\mu}$

$$\begin{bmatrix}\text{[-cont]}\\ \text{[-vce]}\end{bmatrix} \text{ --> [+spread glottis]} / \left\{ \begin{array}{l} [_\phi \text{ ---} \\ [_\sigma\text{---}\ \acute{\mu} \end{array} \right\}$$

2.1.2 Unrelease

Another rule which affects voiceless stop consonants, this time in syllable final position, is Unrelease. Discussed in Kahn (1976)[7] , Withgott (1982), and Kaisse (1985), this process is responsible for the unreleased character present in voiceless stops in this position. Recall the data from (9):

(11) English Obstruent Data

a.	ras[p⁼]	b.	Cale[b]	c.	bu[s]
	despi[t⁼]e		gla[d]		rebu[f]
	stea[k⁼]		sla[g]		brea[θ]

I formulate Unrelease below, following Kahn (1976):

(12) Unrelease (Kahn 1976)

Rule Name:	Unrelease
Operation:	Insert
Element:	[+constricted glottis]
Environment:	$\left.\begin{array}{c} \overline{} \\ \text{[-cont]} \\ \text{[-vce]} \end{array}\right]_\sigma$

$$\begin{bmatrix}\text{[-cont]}\\ \text{[-vce]}\end{bmatrix} \text{ --> [+constricted glottis]} \Big/ \left.\begin{array}{c} \overline{} \\ \text{[-cont]} \\ \text{[-vce]} \end{array}\right]_\sigma$$

2.1.3 Nasal Consonant Deletion

Malécot (1960), Hooper (1977), and Kaisse (1985) discuss a rule of English which deletes a nasal consonant if it precedes a voiceless consonant in the same syllable. Data below, taken from Hooper (1977), Kaisse (1985), and my own pronunciation illustrate the effects of this rule[8] :

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[7] Kahn (1976) labels this rule Glottalization. I choose to identify it as Unrelease to avoid confusion of this rule, which concerns the unreleased nature of syllable-final stops, and another, separate phenomenon which allows syllable-final t to surface as glottal stop ʔ.

[8] The deletion of the nasal must crutcally follow Vowel Nasalization (see 2.1.4).

(13) Nasal Deletion (Malécot (1960); Hooper (1977); Kaisse (1985))

i. Nasal Deletion Before Voiceless Stops (Hooper (1977; fig. 5)

cap	[kæp]	bet	[bet]	back	[bæk]
cab	[kæ:b]	bed	[be:d]	bag	[bæ:g]
camp	[kæ̃p]	bent	[bẽt]	bank	[bæ̃k]
cam	[kæ̃:m]	bend/Ben	[bɛ̃:n]	bang	[bæ̃:ŋ]

ii. Kaisse (1985; ch. 2 fig.15) (schwa is hereafter represented as [@])

a. [sɛ́tr@l] < σ σ
/|\ /| |\
s ɛ n t r@ l

b. *[sɛ̃trǽl@Di] < σ σ σ σ
/|\ /| | /| /|
s ɛn t ræ l@ D i

iii. [ǽ̃kl̩] 'ankle'
[ǽ̃ŋgl̩] 'angle'

iv. Rule Name: Nasal Consonant Deletion
Operation: Delink
Element: ROOT linked to $\begin{bmatrix} +\text{nasal} \\ -\text{cont} \end{bmatrix}$
Environment: __ [-vce] $]_\sigma$

$$\begin{bmatrix} [-\text{cont}] \\ [+\text{nasal}] \end{bmatrix} \text{-->}\ \varnothing \,/\, \_\_\ [-\text{vce}]\ ]_\sigma$$

The data in (13ii) show both that the deletion must apply between two tautosyllabic segments, and that resyllabification (see Withgott 1982; Kaisse 1985) must precede application of both Aspiration and Nasal Consonant Deletion. The t in central is not aspirated, implying that it is neither foot-nor stressed syllable-initial. As Kaisse (1985) argues, it can therefore be resyllabified, becoming tautosyllabic with the preceding n which conditions deletion. However, in the derived form centrality, the stress shifts to the second syllable, and the t becomes aspirated. This t is therefore not subject to resyllabification, and Nasal Consonant Deletion cannot apply.

If resyllabification followed Nasal Consonant Deletion, then in central the t would be in syllable-initial position at the point in the derivation when Nasal Consonant Deletion was relevant, and it would not apply. Further, this would result in that t becoming aspirated, which is also not instantiated. Thus resyllabification must precede both Aspiration and Nasal Consonant Deletion. Because Aspiration and Nasal Consonant Deletion apply in different environments, no ordering relationship between them is necessary.

The forms ankle and angle in (13iii) show that the segmental environment for the application of this rule is [-voice]; the nasal can be deleted when it precedes k (in this case, k must have been previously resyllabified) but not when it precedes g.

A discussion of the properties of the rule itself is in order. As written, the rule is sensitive not only to [+nasal] but also [-continuant]. Both features are required, because as the data show, nasal vowels do precede [-voice] syllable internally. If the rule were sensitive only to [+nasal], the forms would incorrectly surface with neither a nasal consonant nor a nasalized vowel.

2.1.4 Vowel Nasalization

Another American English rule which constitutes positive evidence for the feature [+nasal] in FI is the obligatory rule which nasalizes vowels preceding nasals. Recall the data from Malécot (1960) which appears in figure (13i), and additional data below from Bauer et al (1980):

(14) Vowel Nasalization

[bĩỹm]	'beam'	[bĩn]	'bin'	[bẽỹn]	'bane'	[gãw̃n]	'gown'
[tɛ̃n]	'ten'	[bæ̃ŋ]	'bang'	[dũw̃n]	'dune'	[dõw̃m]	'dome'

Because all vowels are nasalized, the environmental target of this [+nasal] spreading process must be the moraic tier μ. If spread of [+nasal] were unconditioned, syllable-initial voiced stops [[+consonantal] and [-continuant]] preceding nasalized vowels would nasalize as well, since these two features can co-occur with [+nasal]. The data illustrate that long vowels (vowel-glide sequences) are nasalized (I follow the Borowsky 1986 analysis of glides as vowels which are not in syllable-head position), so the rule must be triggered only by the feature [+nasal] (recall that P2 rules apply whenever their domain is met, so if [+nasal] spread from a nasal consonant to a left-adjacent vowel, [+nasal] would still be in a spreading environment). I state the rule as follows:

(15)

Rule Name:	Vowel Nasalization
Operation:	Spread
Element:	[+nasal]
Environment:	μ ___

V --> [+nasal] / ___ [+nasal]

2.1.5 [-voice] Assimilation

Figure (16) below presents an exhaustive list of surface English onsets, and an exhaustive list of surface two consonant codas. Codas of up to four segments are possible in English, although the third and fourth members must be coronal consonants which agree in voicing.[9] Following Ladefoged (1982); Shriberg and Kent (1982), I indicate the devoicing of sonorants m, n, l, r, w, y which occurs when they follow a voiceless segment.

(16) [-voice] Assimilation

a. Possible English Onsets (Bauer et al (1980))

i. [-vce] [-vce]						ii. [+vce] [+vce]		
pl̥/spl̥		kl̥/skl̥	fl̥	sl̥		bl		gl
pr̥/spr̥	tr̥/str̥	kr̥/skr̥	fr̥ θr̥		šr̥	br	dr	gr
py̥/spy̥		ky̥/sky̥	fy̥		hy̥		dw	gw
	tw̥	kw̥/skw̥	θw̥	sw̥		by		
sp	st	sk sm̥	sn̥			my		

iii. [+vce] [-vce]	iv. [-vce] [+vce]
none found	none found

[9] Following Sagey (1986) I take interdentals d and θ to be coronals, as well as alveopalatals č, ǰ, š, ž.

b. Some Possible English Codas

i.	[-vce] [-vce] pt ft st kt sp sk tθ pθ	ii.	[+vce] [+vce] bz dz gz nd md gd bd
iii.	[+vce] [-vce] ns dθ mf ŋθ	iv.	[-vce] [+vce] none found

Both the devoicing of sonorants and the distributional gap of [-voice]...[+voice] clusters can be accounted for by proposing a rule which unconditionally spreads [-voice] rightward within the domain of the syllable. By proposing a constraint which prevents [-voice] from appearing in the head position of a syllable (reflecting the lack of voiceless vowels at the surface of American English): *[μ,-voice], rule application to vowels may be blocked. As a consequence, only syllable boundaries need be mentioned in the rule.

(17) [-voice] Spread

Rule Name:	[-vce] Spread
Rule Domain:	Strict Adjacency
Operation:	Spread
Direction:	Rightward
Iterativity:	Yes
Element:	[-vce]
Environment:	$[\ \_\_\ ]_\sigma$

Recall that one of the working assumptions in force here is the notion that one and only one value of a feature need be present at this level of representation, and that only the features present at this level are present at any more abstract level. Therefore, this treatment of voicing assimilation directly argues against treatments such as SPE, Kaisse (1985), Mohanan (1986), Borowsky (1986) which propose a rule which assimilates [+voice].

[-voice] Assimilation accounts for sonorant devoicing as well as the distributional gap in the surface syllable structure via one exceptionless and obligatory rule. Proponents of a [+voice] assimilation rule must account for why such a rule applies for morphological processes such plural formation ([kæts] 'cats' vs [dOgz] 'dogs') and verbal inflection ([wakt] 'walked' vs [wægd] 'wagged') but fails to apply in the nominalization process which takes wayd 'wide' to wɪdθ 'width'. Further, assuming that [+voice] assimilation would adequately describe the phenomena above does not account for the voicelessness of sonorants following voiceless sounds, nor does it account for the lack of [-voice]...[+voice] sequences in both onset and coda positions.

In this section I have motivated the following three features [-voice], [-continuant], and [+nasal] to be crucial to the environments of the five P2 rules of Aspiration, Unrelease, Nasal Consonant Deletion, Vowel Nasalization, and [-voice] Assimilation. These three features do not yet constitute a necessary and sufficient set of features to distinguish the segments of American English at either I or O. No PLACE features have been motivated, nor has the feature [+consonantal]. To motivate these features, I now consider alternations particular to CORONAL segments, although in fact I argue that such alternations are particular to CORONALS only because CORONAL is unspecified at I and O.

Alternations of Coronal Segments

2.2 Place Assimilation of Coronals

A number of alternations in American English involve the assimilation of place features by a CORONAL segment which is immediately to the left of a following segment. For example, the distribution of American English nasals is such that the clusters mp, ŋg, nt exist, as well as ms and ŋs, but there are no clusters *np, *ng. In parallel to this, obstruent clusters sk, sp, lk, lp exist, as well as ks, bz gl, bl, kt, bd but no corresponding *dg, *db, *tk or *tp. I argue that this distributional asymmetry is not the result of an accidental gap, but that this phenomena is due to a P2 rule which spreads the place features from a segment to a left-adjacent, non-continuant "CORONAL" consonant which has no place features. By examining the details of the environment of this rule from the perspective of a language learner, I argue that the node/features DORSAL and LABIAL are independently motivated.

A separate but related P2 rule of American English dentalizes a "CORONAL" stop preceding a dental ([+distributed]) segment: nθ → n̪θ, and yet another rule palatalizes a "CORONAL" consonant when that consonant precedes a palatal ([-back]) segment: dǰ → ǰǰ. I discuss each of these rules in turn and show that the grammar with respect to these three rules becomes simplified if CORONAL is unspecified at P2.

2.2.1 PLACE Assimilation

Data in figure (18) below concerning the place assimilation of nasals from Mohanan (1986) and my own investigation illustrate two relevant facts: (i) the process responsible for the place assimilation of nasals must be available at the P2 because it applies across word boundaries; and (ii) this process affects only the coronal nasal n. Data in (a) show n assimilating to the place of a following consonant, while data in (b) show that this is not found when a pause intervenes between the two words. Data in (c) illustrate the resistance of other English nasals ŋ and m to this process when no pause intervenes between words:

(18)

a.	Data	b.	Data	Gloss
	[tɛmb@ks]		[tɛn...b@ks]	'ten bucks'
	[tɛŋkɪŋz]		[tɛn...kɪŋz]	'ten kings'
c.	[seymkar]		*[seyŋkar]	'same car'
	[kɪŋpɪn]		*[kɪmpɪn]	'king pin'

The distribution of obstruent clusters sketched in the remarks introducing this section indicate that the process which assimilates place features to a preceding nasal is more general in character. Consider the attested vs unattested clusters in American English:

(19) Some Tautosyllabic Cluster Distribution Facts

Attested				Unattested	
pt	kt			tp	tk
bd	gd			db	dg
sp	sk	ps	ks		
lp	lk				

The lack of stop clusters with CORONALS as the leftmost element parallels the distribution of nasal clusters. However, the CORONAL continuant s and the lateral l do not participate in this alternation: lk and sp clusters are attested. If the two types of data in (18) and (19) are indicative of a single process, that process must target t d n while excluding s and l (due to an accidental gap, z is never found in the relevant environment). I consider that process sensitive to the common features of t d n: [+consonantal] and [-continuant]. Lacking the feature [-continuant] excludes the fricative s from satisfying the environment of the rule. By analyzing l as specified for the feature [-continuant] but not [+consonantal], l also fails to produce the necessary conditions to trigger application of this rule (the rules of Dentalization and Palatalization discussed later in this section verify this analysis of l as a non-continuant non-consonant).

Thus, this process spreads PLACE leftwards onto the combination [+consonantal] and [-continuant]. If CORONAL is assumed to be specified where this rule is relevant, the process must perform two operations: (i) spread PLACE, or some feature dominated by PLACE leftward onto an adjacent CORONAL; and (ii) delink/delete the already existing PLACE node dominating CORONAL, or CORONAL itself. By the evaluation metric presented in SPE (p. 334-5), such a formulation of a rule is not as highly valued as one which is formally simpler (ie, requires fewer symbols to state).

Underspecifying CORONAL and the PLACE node dominating it simplifies the rule in question. In this case, the rule may be stated as follows--following Archangeli and Pulleyblank (forthcoming), I assume that spread rules are blocked by the presence of a place node to the left unless such blocking is explicitly overridden in the formulation of the rule. Thus, the fact that only the CORONAL nasal n is found to undergo PLACE Assimilation is accounted for by principled means, namely that the rule is blocked from applying to LABIAL and DORSAL nasals m and ŋ because these segments are specified for a node dominated by PLACE:

(20) PLACE Assimilation

Rule Name:	PLACE Assimilation
Rule Domain:	Strict Adjacency
Operation:	Spread
Direction:	Leftwards
Iterativity:	No
Element:	PLACE
Environment:	[[-continuant] [+consonantal]] ; PLACE

As written, this rule targets PLACE. However, by my own hypotheses in Section 1, the rule does not motivate the presence of the node/features LABIAL and DORSAL which are dominated by PLACE, because they are not explicitly required in the environment of the rule. It is here that I look in detail at how this rule may be acquired by a child.

In the hierarchical arrangement of features which I adopt, the three articulation nodes LABIAL, CORONAL, and DORSAL determine point of articulation. LABIAL specifies labial or labiodental articulation for consonants, CORONAL determines the articulation of dentals, alveolars, and alveopalatals, and DORSAL specifies velar articulation. In this sense, these nodes are features in themselves--they localize articulation. Further segmentation of the articulation they describe is possible when these nodes dominate terminal features, the details of which are not necessary here. These three node/features are dominated by the node PLACE, which itself defines no articulation, forming an intermediate node between the ROOT node (which dominates at least the terminals [continuant], [consonant], [nasal]) and the articulator node/features.

Because PLACE is not a node specifying a locus of articulation, it cannot be terminal node: PLACE must always dominate a feature/node to be present in the structure. Thus, although the rule of (20) targets PLACE, implicit in the rule are the nodes which PLACE dominates, because the existence of PLACE depends upon the existence of one of the dominated nodes. I argue that the rule of (20) above, present in the adult grammar, is the result of collapsing two independent rules in a child's grammar, one which spreads DORSAL and the other LABIAL to the same target feature combination of [-continuant] and [+consonantal]. These two independent rules motivate the presence of LABIAL and DORSAL in the proposed analysis.

2.2.2 Dentalization

Having motivated LABIAL and DORSAL as independent constituents of F_I, the featural content of the input to P2, I turn now to a second type of assimilation affecting CORONALS. CORONALS t d n l become dentalized when they are found leftward-adjacent to the interdentals θ and ð. This assimilation affects l but does not affect s[10] (data from Bauer et al. 1980):

(21) Dentalization affects t d l n but not s

[eyt̪θ]	'eighth'	[wɪd̪θ]	'width'
[hɛl̪θ]	'health'	[tɛn̪θ]	'tenth'

[sɪksθ] 'sixth'

[10] z is not attested in the relevant environment due to an accidental gap.

Because t d n l dentalize, but s does not, t d n l form a natural class. I take this as support for the analysis that l is specified [-continuant], and formulate the Dentalization rule below:

(22) Dentalization

Rule Name:	Dentalization
Rule Domain:	Strict Adjacency
Operation:	Spread
Direction:	Leftwards
Iterativity:	No
Element:	[+distributed]
Environment:	[-continuant]

Following Sagey (1986), [distributed] is a feature immediately dominated by CORONAL, the same node which I argued above as unspecified at P2. However, consider that the critical descriptor of [distributed] articulation is [distributed] itself. Because [distributed] needs structure to dock into, the presence of [distributed] licences CORONAL, but the existence of CORONAL in this case is not independent of its terminal feature, but is part of the intervening structure between [distributed] and the ROOT. By the same argument used above regarding the dependence of PLACE on a dominated node, CORONAL is not independent here, and therefore it is not problematic to maintain its status as unspecified as an independent node/feature.

2.2.3 Palatalization

The final example of American English CORONAL sounds assimilating to a following consonant sound occurs when word-final t d n s z are adjacent to word-initial alveopalatals č ǰ š [11] without an intervening pause break. Consider the following data from Kaisse (1985, f. 26 e-h p.35), and notice that word-final l is not palatalized by this rule[12]:

(23) Palatalization affects t d s z n but not l

	pan shape [ñš]	(but [ñ...š])
e.	a bad joke [ǰǰ]	(but [d...ǰ] --Kaisse 1985)
f.	the worst joke [čǰ]	(but [t...č] --Kaisse 1985)
g.	whose shape [žš]	(but [z...š] --Kaisse 1985)
h.	worse shape [šš]	(but [s...š] --Kaisse 1985)
	full ship [λš]	(* [λš])

Palatalization selects t d n s z as a natural class, but excludes l. The only feature common to t d n s z is [+consonantal], and the only way to exclude l from this class is to not assign it the value [+consonantal] as well. I present the rule below:

---

[11] ž is not a possible word-initial segment in English (with the exception of foreign proper names such as Zsa Zsa, etc).

[12] The reader has no doubt noticed the omission of the more familiar rule of palatalization which involves y eg, [kUd...yuw] --> [kUǰuw] 'could you'. As Kaisse (1985) convincingly argues, this rule is in the process of being grammaticalized for most speakers (myself included), in that it is only the second person pronoun which triggers the rule: *[b@s...yɛlow] --> [b@šyɛlow] 'bus-yellow (the color of buses)'. Thus, this rule does not fit the three criteria in figure (2) to be considered relevant to P2.

(24) Palatalization

Rule Name:	Palatalization
Rule Domain:	Strict Adjacency
Operation:	Spread
Direction:	Leftwards
Iterativity:	No
Element:	[-back]
Environment:	[+consonantal]

Invoking the same argument as I used in Section 2.2.2, I claim that [-back] licences CORONAL as a docking node, but does not motivate CORONAL as an independent node/feature.[13]

In this section I motivated CORONAL as unspecified at P2. Rules of PLACE Assimilation, Dentalization, and Palatalization also motivated the node/features LABIAL and DORSAL, and the features [+consonantal], [-continuant], [+distributed], and [-back] as being crucially present in the level of representation input to P2. The move to underspecify CORONAL not only simplifies the grammar in a formally desirable way, but also explains the special behavior of CORONALS with respect to the widespread assimilation in which they participate, while segments at other points of articulation are not found to assimilate. The grammar need not stipulate CORONAL as a special target of assimilation because CORONAL attains special status through principled underspecification. Thus, the grammar is made more empirically adequate by the underspecification of CORONAL.

The environments of the P2 rules of Aspiration, Unrelease, Nasal Consonant Deletion, Vowel Nasalization, [-voice] Assimilation, PLACE Assimilation, Palatalization, and Dentalization have motivated the eight features of (5). Thus the task at hand has been completed. In the course of establishing these eight features, CORONAL was analyzed as unspecified at P2. I now present a somewhat different analysis to the phenomenon of American English Flapping, a rule which appears to target CORONALS exclusively, which is impossible in an analysis where CORONAL is not present.

2.3 Flapping is a Direct Result of CORONAL Underspecification

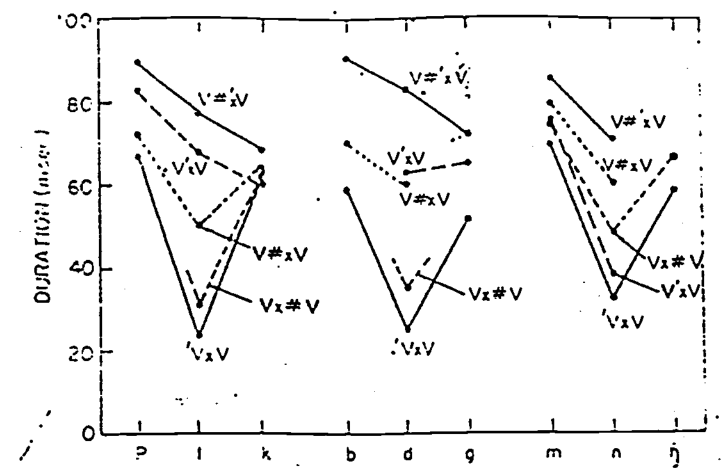
In this section I propose that Flapping is not a rule of the P2 module of the phonology, rather it is a consequence of CORONAL underspecification which persists through the articulatory implementation module. I argue that because Flapping follows the American English gradient (ie non-categorical) rule which lengthens vowels before voiced obstruents, Flapping itself must be a gradient rule, and thus must follow P2 in its application. I also present further, although not conclusive, support for CORONAL underspecification and hence Flapping based on perceptual experiments.

2.3.1 Umeda (1977): t d n Flap in Certain Prosodic Environments

Umeda (1977) presents results representing the duration of American English consonants in a number of phonetic environments. The data sample came from a single male speaker reading an essay of approximately 20 minutes duration. The data was analyzed by the use of spectrograms, where "...a phoneme boundary was determined at a discontinuity in excitation, formant structure, or both. (p 346)" Of interest to the discussion here is the duration of intervocalic CORONAL segments with respect to segments in the same environment but with different points of articulation. It is well known that in the environment v́cv, CORONAL stops t d n appear flapped, but this is not true of stops at other points of articulation. This data in this study bear out this observation:

[13] I note here that as written, the scope of Palatalization includes all bearers of [-back]. This set encompasses not just alveopalatals but also velars k g ŋ. Although I have no detailed analysis at this point, this rule may account for the palatal nature of k and g before [-back] vowels (compare keep with cap and geese with gas). Further research is necessary.

(25) Umeda (1977): Noncontinuant CORONALS flap



Data such as [wayDɛ́lɛf@nt] 'white elephant' and [mæ̀D@dOr] 'matador' show that Flapping is available within and across word boundaries, and thus available for application at P2. The analysis I propose, which underspecifies CORONAL at P2 based on assimilation facts presented in the previous sections, cannot account for a rule such as Flapping, which appears to specifically target CORONAL stops and not those at other points of articulation.

Such a rule is problematic since at P2 CORONAL consonants are not distinguishable from consonants at other points of articulation--no feature distinguishes them, rather, they are distinguished by lack of membership in any other class.

Based on the existence of Flapping, two options exist for its analysis: 1) weaken the analysis presented and specify CORONAL, complicating the grammar for PLACE assimilation facts but allowing Flapping to exist at P2; 2) Explore Flapping, and try to account for its effects while preserving the underspecification of CORONAL. Not surprisingly, I choose the second option. In the following two sections, I show that Flapping is more accurately represented as a process relevant to the articulatory implementation module which immediately follows P2, and although systematic, this phenomenon is not a rule changing CORONAL stops into flaps, but a direct result of implications of the underspecification of CORONAL in the grammar of American English.

2.3.2 Fox and Terbeek (1977): Flapping follows Vowel Shortening

2.3.2.1 Description of Experiment

Fox and Terbeek (1977) sought to determine the ordering relationship between the American English rule which lengthens vowels before voiced obstruents[14] and Flapping, the rule responsible for the flapped nature of CORONAL stops.

Twenty-one subjects (11 female and 10 male) read a list of 20 disyllabic word pairs. The list consisted of 14 five-word groups; the first and last word of each group were thrown out to minimize effects of list intonation on the data sample. Some list elements did not contain medial CORONALS, misdirecting subjects with regard to the purpose of the experiment. Many test forms were derived, thus the underlying nature of the medial CORONAL would be known to the speaker. The forms used in the experiment appear below (taken from Fox and Terbeek 1977; figure 1):

[14] In my terms, this rule shortens vowels before voiceless obstruents, since no evidence for [+voice] has been found present in the grammar at P2.

(26) Data from Fox and Terbeek (1977)

seater/seeder	writing/riding	tutor/tudor	bitter/bidder
putting/pudding	writer/rider	patty/paddy	coating/coding
waiter/wader	betting/bedding	latter/ladder	patting/padding
mottled/modeled	pouter/powder	petal/pedal	seating/seeding
coater/coder	butting/budding	otter/odder	waiting/wading

2.3.2.2 Description of Results

Results of the experiment appear below (p. 34):

(27) Results of Fox and Terbeek (1977)

(1) There was a significant durational difference between vowels preceding flaps with underlying /d/ vs flaps with underlying /t/.
(2) This difference is slight; all pre-flap vowels fall within the range of short vowels.
(3) The first vowel/second vowel ratios, as suggested by Sheldon (1973) is significantly higher in words with /d/-flaps as opposed to /t/-flaps.
(4) There was no significant duration difference in flap consonant itself linked to underlying segment identity.
(5) Though the majority of the flaps were voiced, 19% were voiceless.
(6) The actual voiced/voiceless character of the flap itself had no significant effect upon the duration of the preceding vowel.

Concerning these results, the study concludes, "(1) The vowel lengthening rule precedes the flapping rule, at least in the dialect investigated. (p. 34)." The study also mentions "...we know of no phonetic study which finds the reverse order to be valid...the question can be raised whether there is in fact a dialect which maintains the order F--VL [Flapping preceding Vowel Lengthening--T. B.] (p. 33)." Another conclusion implicit in the study which warrants exposition here, is that Vowel Lengthening is an obligatory operation.

2.3.2.3 Significance of Results

The conclusion that Vowel Lengthening precedes Flapping is very important to the framework of my treatment in this paper, because by its nature Vowel Lengthening is a gradient process: it fills in particular numerical values for the duration of a segment. According to the organization of the model which I adopt, gradient processes are present in the articulatory implementation module which follows P2. Thus, if Vowel Lengthening follows P2, and Flapping follows Vowel Lengthening, then Flapping must also be a gradient process (that is, not featurally based) and therefore not present in P2.

If Flapping is not present at P2 and not a featurally based process, what is it? I conclude, after Keating (1985), that Flapping provides more evidence that underspecification may persist into the phonetic implementation.

In order to clarify the point, consider the implications of underspecification of a feature--underspecification of a feature implies that that feature is not used by the grammar at any level more abstract than where that feature must be underspecified. From a production perspective I argued in section 2.2.1 above that CORONAL is unspecified at P2, the last level of abstract phonology before articulatory implementation. Therefore CORONAL is not used at any level more abstract than P2. At articulatory implementation, consonants not specified for PLACE are produced as CORONAL by default.

From a perceptual perspective, CORONAL is the point of articulation perceived by default, in the absence of other positive evidence for a different point of articulation. Extending this to the phonetic string itself, CORONALS in American English carry no point of articulation information to the hearer. No new information is gained by hearing CORONAL because it is assumed by default. Thus, the only information present in a CORONAL sound is information about the values of other features argued for above: [+cons], [-cont], [-voice] and [+nasal].

Given that Vowel Shortening is obligatory and applies to voiceless obstruents, information about the existence of [+cons] and [-voice] is already present in the vowel immediately preceding the CORONAL. [+nasal], if present, also appears on the preceding vowel due to an obligatory rule (not discussed in this paper) which nasalizes vowels immediately preceded by [+nasal]. The value of [continuant] is the only information crucially present in the CORONAL at this point.

I conclude from the above discussion that intervocalic CORONAL stops can appear flapped (ie, fast) on the surface because, by only communicating one bit of information to the hearer (the value of [continuant]), their recoverability is unproblematic to listeners.

2.3.3 Port (1979): LABIAL is perceived as CORONAL if Closure Duration is Short

Additional support for the conclusion that Flapping is the result of the default perception of CORONAL articulation by speakers of American English comes in the form of a result of the experiment conducted in Port (1979), which shows that LABIAL sounds are consistently interpreted as CORONAL sounds when their closure duration is shorter than 30 ms (recall from section 2.3.1 that the closure duration of unsynthesized flaps is around 30 ms).

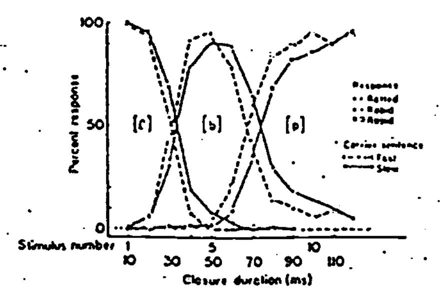
2.3.3.1 Description of Experiment

Research has shown that duration of closure of medial, post-stress English stops varies as a function of the voicing value of the stop (Lisker 1957; Port 1976), speaker tempo (Gaitenby, 1965; Port 1976), and point of articulation (Sharf 1962; Port 1976). In the Port (1979) experiment, the sentence frame "I'm trying to say rabid" was recorded at two tempos: careful (slow) and fast. The test word rabid was segmented at two points: immediately after the stop closure, and immediately before the stop release. The two syllables [ræb⁼] and [b@d], originally separated by a 70 ms voiced period, were recombined into 12 new forms separated this time by a voiceless period ranging from 10 ms to 120 ms. The novel forms were reintroduced into the appropriate sentence frames, and sixteen students of an introductory phonetics course at Brooklyn College were asked to make a forced choice by checking a response sheet as to whether the sentence they heard contained ratted, rabid, or rapid.

2.3.3.2 Description of Results

The figure below represents the results of the experiment. Of particular relevance to this discussion is that for stop closures of duration shorter than 30 ms, subjects perceived the phonetic identity to be flap [D]: underlying t. Subjects perceived CORONAL as opposed to LABIAL articulation despite the presence of transition and burst formants on vowels both preceding and following the stop closure, respectively; transition and burst formant information provides the main cue for place of articulation of a stop consonant.

(28)



Identification of stimuli as *ratted*, *rabid* or *rapid* plotted as a function of the duration of the silent closure interval between the first and second syllables in both fast and slow carrier sentences.

2.3.3.3 Significance of Results

Although the same study was not performed using forms with velar (DORSAL) articulation, this research suggests that speakers perceive CORONAL articulation (perhaps) when there is not sufficient time to make another perception. In terms of the theory I propose here, CORONAL is the default (unspecified) production articulation. Such underspecification would correspond to a strategy where CORONAL articulation is perceived by default unless positive evidence to the contrary is obtained.

Thus, the results of this study offer support, although certainly not conclusive support, for the underspecification of CORONALS presented here.

Section 3: Results, Conclusions, and Points Beyond

3.1 Results

Recall the Minimal Content Hypothesis, that the featural content of the input to P2 is defined by the environments of the rules at P2. In the previous sections I examined the following P2 rules of American English: Aspiration, Glottalization, Nasal Consonant Deletion, Vowel Nasalization, [-voice] Assimilation, PLACE Assimilation, Dentalization, and Palatalization. Determination of the environments of these rules motivates the set of features (from 5):

(29) Features Relevant to American English Consonants

[-continuant]	[-voice]	[+consonantal]	[+nasal]
[+distributed]	[-back]	LABIAL	DORSAL

These eight features, when combined freely subject to the restrictions in (7), all of which hold at the surface and at all more abstract levels of representation, are sufficient to generate the segmental alphabets present at both the input to and the output of P2.

The result of this research, that the features of (29) are present in the input to P2, coupled with the hypothesis that the surface constraints of (7) hold at all more abstract levels, produces a featural inventory at the input to P2 which is both necessary and sufficient to generate the (distinctive) segments present at that level. To illustrate this, consider the situation where fewer features were used. Free combination requires 5 binary features, since $2^4 = 16$ but $2^5 = 32$. However, exploiting free combination to this extent would require the relaxing of at least one of the surface constraints of (7), otherwise the resulting segmental inventory would underdetermine the necessary segments. By hypothesis, the surface constraints hold at more abstract levels, so relaxation is not possible. Thus, although in principle the number of features could be decreased and still generate an adequate number of segments, this option is not available to natural language, because it would produce abstract segments associated at best loosely with their articulatory instantiation. For example, consider the effects of eliminating the feature [+distributed] and relaxing the restriction of (7.1) *[LAB, DOR]. In this case, θ and $\overset{x}{d}$ would be represented abstractly as [+cons, -vce, LAB, DOR] and [+cons, LAB, DOR], respectively. however, these segments would have to be marked to have the combination [LAB, DOR] instantiated as [+distributed]. Such a theoretical move would make for a fairly large target of criticism.

Thus, the MCH generates a featural inventory both necessary and sufficient to describe the segments and processes at P2. Further, this inventory is underspecified. Underspecification was not an assumption of this analysis, rather it follows as a desirable consequence of the FAR: when positive evidence for a feature did exist, no positive evidence was found for more than one value of that feature as required by the environment of any P2 rule. It is important to point out that the type of underspecification derived is not the type of underspecification proposed in the theory of Radical Underspecification (RU) (Archangeli 1984; Pulleyblank 1986; Archangeli and Pulleyblank 1989). RU does not support free combination of features, rather RU requires that combination only be performed when it is necessary to distinguish between two segments in a representation. In this sense, RU presupposes segments and derives the featural representation of them, rather than presupposing features and deriving segments from them, as has been done in the above approach.

3.2 Learnability of this system

This research produces a result relating to the learnability of a phonological system. A learner presented with a surface representation can discover the rules of the P2 component (all of which are surface-visible), and from this derive a featural inventory F to be used by the grammar at more abstract levels of representation. Also, the learner discovers that pairs such as bat and fat differ from each other on purely phonological grounds! For example, based on the features required by the rules of Aspiration and PLACE Assimilation, a child may infer the 'phonemic' difference in the initial sounds of the words bat, pat, fat, vat, and mat:

b -> [+cons, -cont, LAB]; p -> [+cons, -cont, -vce, LAB] (note p will be found aspirated, b will not); f -> [+cons, -vce, LAB]; v -> [+cons, LAB]; m -> [+cons, -cont, +nasal, LAB].

3.3 Points Beyond

The analysis presented above asks a great many more questions than it answers. One such question concerns details of the syllable structure of American English, chiefly, the effects associated with palatals and coronals in coda position responsible for the contrast between plural forms such as cat/cats, dog/dogs, but witch/witches and bus/buses. Traditional analyses of American English have proposed that the feature [+strident] be present on coronal continuants and all palatal segments. Such analyses require this feature to account for the syllabification effects. The analysis presented above finds no evidence independent of plural formation for the existence of [+strident] in the grammar, and as such syllabic issues pose a possible falsification of both the FAR and the MCH. One assumption of this analysis is the existence of abstract prosodic constituents as well. To what extent are these motivated based on the FAR and the MCH.

This research makes profound claims about the nature of representations more abstract than P2. The FAR and MCH conspire to produce an inventory F_i, the content of which are the only features which the more abstract grammar can address. Therefore, issues about what the abstract phonology of American English look like extend well beyond questions of the existence of [+strident] to, for example, what the abstract representations of the pair divine divinity contain. Further, because this research derives a different type of underspecification than has been proposed in radical underspecification, the empirical and theoretical claims of each must be explored. As a final note, I have been loosely concerned with issues of learnability here. Thus, diachronic linguistics as well as language acquisition fall under the domain of the results presented here. Because these results touch on a number of issues, the theory presented here is highly testable from a number of different perspectives, which may (underscore may, of course) make the goal of understanding language all the more attainable.

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