Lexical Phonology and the Problem of Variation
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Proceedings of the Nineteenth Annual Meeting of the Berkeley Linguistics Society: General Session and Parasession on Semantic Typology and Semantic Universals (1993), pp. 171-181

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The theory of lexical phonology (LP), as it has been developed over the last decade in works such as Kiparsky 1982, Mohanan 1986, and numerous others, postulates a fundamental distinction between lexical and post-lexical applications of rules. Several criteria distinguish between these two: one is the status of exceptions: lexical rules may have lexical exceptions and are often lexically specific, while post-lexical processes apply across the entire lexicon, without exception. Another criterion is the kind of conditioning the rules are sensitive to: lexical rule applications occur within the lexicon, in the course of a derivation, and therefore have no external context and cannot be subject to cross-word-boundary conditions of any sort; however, they do have access to morphological information about the internal structure of the word. Post-lexical operations, on the other hand, have the converse of these properties: operating on the surface phonology, they may apply across word boundaries and be subject to word-external constraints. However, they are predicted by the theory to be insensitive to the internal morphological structure of the word. This prediction follows from the principle of BRACKET ERASURE, by which morphological bracketing is erased at the end of each derivational level. Hence when a form exits the lexicon, there is no word-internal bracketing left in the representation for the surface phonology to make reference to. Post-lexical rules therefore can't have morphological conditioning.

A potential problem for this analysis arises in the study of variable phonological processes. There are a number of such processes that are well-known to be sensitive simultaneously to word-internal morphological conditioning and cross-word-boundary factors. An example is English coronal stop deletion, by which /-t/ and /-d/ are optionally deleted from word-final consonant clusters, especially in phrasal contexts like *wes' side* and *ol' man* (cf. Guy 1980, Labov 1989). This process operates in all dialects of English, subject to certain apparently universal conditions. These are illustrated in Table 1.

Across word boundaries, there is more deletion before a following obstruent than before a following vowel (*wes' side* is more likely than *wes' end*); this suggests that the rule operates POSTLEXICALLY.[1] But the process is also morphologically conditioned: there is significantly less deletion in past tense forms like *missed, packed* than in underived, monomorphemic forms like *mist, pact.* The irregular or semi-weak past tense forms, with both a vowel change and a final stop suffix, like *lose-lost, tell-told, keep-kept, leave-left* etc., fall at an intermediate position: less deletion than the monomorphemes and more than regular past tense forms. This systematic differentiation of morphological classes should imply that the rule applies IN THE LEXICON.

Two other characteristics of the rule are compatible with either lexical or post-lexical application. In 1.2 we see that the rule is conditioned by the preceding segment, with maximum deletion after obstruents and least after sonorants. And finally, there are no known lexical conditions on the rule.

Now are there three things about these results that are important to note: First, it is ONLY these three morphological classes that are significantly distinguished by this process; past participles, for example, undergo the rule at the same rate as their structurally equivalent past tense forms. Second, these results are very robust; the specific numbers in Table 1 are from a recent corpus of my own, but they have been replicated in over 20 different corpora by many different researchers. And third, these results present a serious question of explanation: why do we get these numbers, in this order, and not some other deletion rates or some other order of the three classes?

In any case, this is a rule that clearly shows both kinds of conditioning at the same time: cross-word-boundary and internal morphological. But lexical phonology predicts that this can't happen. And this is not an isolated instance. A number of such cases have been described in the variationist literature. For example, final -s deletion in Spanish is shown to be sensitive to the following (i.e. cross-word-boundary) phonological context, and to the morphological status of the segment as a plural marker, verbal inflection, or mere segment of a larger morpheme in studies of Panamanian Spanish (Cedergren 1973), Puerto Rican Spanish (Poplack 1980, Hochberg 1986) and several other varieties (e.g. Terrell 1979, 1981). In Brazilian Portuguese, a parallel process of final sibilant deletion with both kinds of conditioning is documented in Braga 1977, Guy 1981a,b, and Scherre 1988, and a doubly-conditioned process of final /r/ deletion is described in De Oliveira 1982. And Caribbean Spanish also shows deletion of final /n/ with both morphological and word-external phonological conditioning (Poplack 1978). Note that all of these cases involve deletion or weakening processes, targeting single final consonants that can occur as either part of a root morpheme or as an inflectional affix in the language in question. By way of contrast, Brazilian Portuguese has a rule of final vowel denasalization which appears to be only postlexical (Guy 1981a). It affects monomorphemes like *orfão, ontem* at the same rate as plural verbs like *falam, comem,* where the nasality of the final vowel (orthographically indicated by the letter *m*) represents plurality. But this rule targets a mere feature, not a separate segment. So there appears to be a valid generalization to account for: processes may be doubly conditioned if and only if they target final, potentially inflectional segments.

If these data are to be reconciled with LP, there are only two courses open to us. One would be to abandon the bracket erasure convention. This would be a fairly drastic step, because bracket erasure is important to the theory for several reasons: it restricts the power of the model, it allows for the elimination of the messy inventory of boundary types that were found in SPE-style representations, and it accounts for a variety of facts, like the strict sequencing of affix attachment, that suggest that derivational processes treat the units they operate on as unanalyzed chunks. (e.g. past tense of *operationalize* is not **operatedtionalize;* the process can't look inside and see a verb *operate* and work on it.) So bracket erasure has important status in the theory, and the consequences of eliminating it would be far-reaching. There may be arguments in favor of some modification of it as regards post-lexical rules, but I will not pursue this issue here.

Therefore, if we wish to preserve bracket erasure, there remains only one alternative: that is to postulate that coronal stop deletion has BOTH LEXICAL AND POST-LEXICAL APPLICATIONS. This is possible within the LP framework because of the convention that the pool of rules is unitary and a given rule can apply at more than one level in the derivation. So the morphological conditioning on -t,d deletion is taken as evidence that the rule applies within the lexicon, and the cross-word-boundary phonological conditioning is taken as evidence that the rule also applies postlexically. The surface observations reported in Table 1 then represent the accumulated effects of conditioning on several distinct levels of application of this rule. In principle, we are saying that the rule is available to operate at all levels of derivation.

This analysis neatly resolves the conditioning paradox in a way that is consistent with the LP framework. But it has one very important consequence. It implies that the rule could potentially apply more than once to a given form. The theory assumes multiple levels of derivation within the lexicon; minimally, there are two: the familiar level 1, where most derivational affixes and irregular inflection occurs, and level 2, where regular inflection and some derivation occurs. It is postulated that all lexical items pass through all the derivational levels en route to production, so if the rule operates at multiple levels, a given word would have several POTENTIAL exposures to it, at least two within the lexicon and one postlexically.

Now if we put this observation together with one other, we get a very interesting result. Note that in Table 1.3 the rate of deletion in each morphological class is correlated with the derivational depth of the target cluster. The monomorphemic forms that are subject to the rule have their final consonant clusters present underlyingly, from the beginning of a derivation. The irregular past tense forms, however, get their final stop attached at level 1, while the regular past tense forms acquire their final stop suffix at level 2, at the end of a derivation.

This suggests a very attractive explanation for the ordering of the deletion rates in the three classes. The classes with higher rates of deletion can be accounted for as a consequence of their having **more exposures to the deletion rule**. Since words like *mist* have their final cluster throughout the derivation, they are exposed to the rule on every pass through the rule system -- that is, once on each derivational level. If the final segment is not deleted on some pass, it is still potentially subject to deletion at a later level. Derived forms like *missed*, on the other hand, have their final clusters created by affix attachment late in the lexical derivation and hence have fewer exposures to the deletion rule. Therefore, in a population of words, a greater cumulative rate of deletion should be observed in the underived forms than in the inflected forms. Irregular inflected forms like *slept, told* will have an intermediate rate of deletion, because their final coronal stops are derived earlier than the regular past forms, but not present underlyingly.

This model implies several very strong and precise quantitative predictions. It is commonly postulated in variation studies (cf. Cedergren & Sankoff 1974) that variable rules have a fixed base rate of application, or p_0. In the model I am proposing, that means that the observed surface frequencies of deletion and retention of final stops in the various morphological classes should be exponential functions of p_0. Specifically, the fraction of stops retained (i.e. not deleted) for any given morphological class should be $(1-p_0)^n$ where n equals the number of passes through the rule system which the class sustains (i.e. the number of levels or strata in the derivation). Thus a rule that deleted half of all forms on each pass would leave half retained after one pass; then on the second pass it would delete half of those, leaving 1/4 retained (which is the square of 1/2); after three passes it would leave 1/8 (the cube of 1/2), and so on.

For coronal stop deletion, if we postulate just two lexical levels plus one postlexical level, we should find exactly three possible morphological classes, with the exponential relationship illustrated in 1. In the affixed (past tense) forms, I will assume that the cluster becomes eligible to undergo the rule when bracket erasure removes the boundary between root and affix. Therefore, monomorphemes will be exposed to the rule at levels 1, 2 and postlexically; irregular past tense forms exposed at level 2 and postlexically, and regular past tense forms only postlexically. Consequently, the frequency of retention in regular past tense forms (R) will be equal to ($1-p_0$), the frequency in irregular forms (I) will be the square of this value, and the frequency in monomorphemes (M) the cube of this value. this can be summarized by defining the probability of retention, p_r (equal to $1-p_0$): this should be equal to R, to the square root of I, and to the cube root of M:

1. The exponential model.

$M = R^3$ Underived forms retained at approximately the cube of level 2-derived (regular past tense) forms;

$I = R^2$ Level 1-derived (irregular past tense) forms are about the square of level-2 derived forms.

$p_r = R = \sqrt{I} = \sqrt[3]{M}$

This prediction of an exponential relation among deletion rates in the morphological classes is strong, unexpected, and easily testable. It also turns out to be true, or at least well supported by a number of data sets. Results for three of the largest corpora it has been tested on are given in Table 2: my own data set, Santa Ana's dissertation data (1991), and the preliminary results from Bayley's current research in San Antonio (1993). I've also tested it on published data collected in the 1960's by Walt Wolfram (cf. Guy 1992), and various other data sets. So far, all of these tests confirm the exponential model. Statistical findings for fitting the model to the data are given for two of these corpora in Table 2, and confirm a high-probability fit. In a previous paper (Guy 1991) I have compared this fit with the standard logistic analysis used in many variation studies, and shown that my model actually fit these data better, using fewer parameters. So it now appears that we can make a strong empirical statement that the rates of coronal stop retention in English morphological classes are exponentially ordered, within the usual limits of random sampling error. For a given speech community or speaker, we find figures like .8, .64 and .512, or .7, .49, and .343. But we do NOT find rates like .8, .7, .6, or .90, .50, .10. This empirical fact is a profound challenge to any model of phonology that does NOT involve integral iterations of a single rule with a fixed base rate of application.

Besides this overall relation among the morphological classes, the exponential model makes quantitative predictions about the other conditioning factors. These are summarized in 2.

2. Contextual constraints: predictions of the exponential model.
   - 2.1a. Internal constraints will show an apparent increase in magnitude for derivational classes exposed to multiple passes of the rule.
   - 2.1b. External constraints will have the same magnitude (i.e. the same range of factor weights) for all derivational classes.
   - 2.2a. Words with the same internal constraint will preserve the exponential relation. (e.g. $R = \sqrt[3]{M}$)
   - 2.2b. Words with the same external constraint will deviate from the exponential relation. When the external constraint promotes retention, $\sqrt[3]{M} < R$. When the constraint retards retention (i.e. promotes rule application) $\sqrt[3]{M} > R$.

Word-internal constraints on the rule will always be present whenever the rule applies, and therefore should iterate in the lexicon. This means two things: first, their effect should appear to be magnified on forms with more exposures to the rule, and second, each separate internal context should define a set of forms which preserve the exponential relationship across the several morphological classes. These predictions are confirmed in Tables 3 and 5. In 3 we see that the magnitude of the preceding factor effect is apparently greater for monomorphemic words than for past tense words (because it has been iterated in the lexicon for the former), and in 5 we see that the basic exponential model fits the subsets defined by the various preceding segments (remember: a high p-value equals a good fit; the model is not rejected for any of the preceding contexts.)

Word-external constraints, on the other hand, should affect the rule only in its final, postlexical operation. Therefore, their effects are NOT iterated in the lexicon. Hence they should be equal for all the morphological classes. Table 4 confirms that this is the case. Furthermore, each individual following context should define a set of words that do not neatly follow the exponential relationship. The direction of deviation from the exponential order will depend on whether the external context favors or disfavors retention. A favoring context for example exercises its favoring effect only once for all classes, so it is not squared and cubed for two and three applications. Therefore, in a context that promotes retention, the observed retention rate in the irregular verbs will be less than the square of the retention rate in past tense forms, and the retention rate in monomorphemic words will be less than the cube. The converse will be true of disfavoring contexts. Table 6 illustrates this effect in the data published in Wolfram 1969. In the retention favoring environment of a following non-consonantal, every one of his five social groups showed the retention rate in monomorphemes to be less than the cube of the retention rate in regular past tense forms, while in the disfavoring context of a following consonantal, the reverse is true. If these values were varying randomly, we would be extremely unlikely to find all ten of these inequalities going in the predicted direction.

Now, there are still two problems for this model, one empirical and one lexical. The empirical problem, illustrated in 8, is that words like *test* and *land* never surface with derived forms like *tessing and *lanned in place of testing and landed. But my model allows deletion to apply to them early in the derivation, before these affixes are attached, so forms like tessing should occur at least some of the time. The same is true of the other four processes I cited: Spanish *pan* and *paz* have plural forms of *panes* and *paces*, and never just **pas*, which would be generated if n and s deletion applied in a derivation before plural formation. Similarly Portuguese words like *rapaz* and *cor* always have plurals of *rapazes* and *cores*, and never **rapas* or **cos*.[2]

The theoretical problem arises from the principle of strict cyclicity: lexical rule applications are supposed to be limited to contexts that were derived on the current level, and not apply to underived material. This principle limits the power of the model, prevents excessively abstract analyses, prevents rules from undoing the work of other rules, and generally does a lot of desirable things. For my model, it would seem to limit the application of coronal stop deletion to one opportunity per lexical item: the first time the appropriate context is created. However, there are certain classes of rules that cannot be subject to this principle, mainly operations that define structure that is not present in underlying representations. For example, in an underspecified model, the default rules to fill in underspecified features will have to operate on underived material at some point. And more importantly, syllabification rules will need to build and rebuild syllables throughout derivations.

Now coronal stop deletion, and the four other cases that I mentioned from Spanish and Portuguese, all involve coda weakening processes affecting word final consonants, and all are disfavored by a following word that begins with a vowel. This is a context where the final consonant may be resyllabified rightward as the onset of the following syllable, and thus moved to a non-coda position out of the scope of the weakening rule. So, I suggest that the correct analysis of these rules is not that they delete segments directly, but rather they operate on the syllabification of these segments. The coronal stop deletion rule can be treated as delinking the final -t,d from the syllable to its left, or blocking its attachment to that syllable, thus rendering it extrasyllabic. If such a segment is subsequently licensed by rightward attachment as an onset, it will surface, but otherwise it will be removed by a general process of stray erasure. Treating the process in this way as a syllable structure operation removes the conflict with strict cyclicity. It also makes a prediction: that exponential iteration of rule effects will only be found for processes operating on syllabification. Happily, this explains why the Portuguese vowel denasalization rule does NOT have morphological conditioning. Since it's not a syllabification rule, it is subject to cyclicity, and can't iterate on the same form.

This treatment also explains the non-occurrence of inflected forms like **tessing* and **lanned*, and Spanish and Portuguese cases like **pas* and **cos.* Any final consonants which are rendered extrasyllabic by a coda weakening process early in a derivation, but subsequently have a vowel-initial suffix attached, will automatically be relicensed as onsets, and hence retained.

Finally, this analysis predicts that the following segment effect is basically a constraint on possible syllable onsets. For instance, rightward resyllabification should be possible before a following word beginning with /r/, because /tr-/ and /dr-/ are possible onsets in English. But it should be impossible to relink the coronal stop to a word beginning with /l/ because English disallows initial /tl, dl/. This prediction is also confirmed in my studies, as illustrated in Table 7. The probability of deletion in the 6 contexts distinguished there correlates with the possibility of the coronal stop becoming part of the onset. Following /l/ favor deletion at a high rate, like other obstruents, while following /r/ disfavors deletion modestly. Glides are intermediate, presumably because some stop plus glide onsets are possible in English and others rare or impossible.

CONCLUSIONS.

So, what can we conclude from all this? Let me start by reviewing the empirical facts. They are:

•First, it is clear there are variable phonological processes that show the characteristics of both lexical AND postlexical applications

•Second, the processes that do so all involve deletion of final consonants

•Third, such deletion processes are inhibited by rightward resyllabification of the consonant

•Fourth, the one such process examined in detail, English coronal stop deletion, distinguishes exactly three morphological classes, R, I, and M.

•Fifth, the order of retention in those three classes is R>I>M

•Sixth, the frequency of retention in those classes is exponentially related: R^2=I, R^3=M

•Seventh, internal and external constraints on the rule differ as predicted in 2.

How can these facts be accounted for? I have proposed that we can do so with a variationist version of lexical phonology. To get all these facts right would seem to require, at a minimum:

- iterated applications of variable processes,
- the number of such iterations to depend on derivation
- distinctive derivational histories for exactly the three classes mentioned, and no more.
- a contrast between lexical and postlexical processes.

The model I have proposed has all these things; it is hard to see how one could do without any of them and not stumble over the empirical facts. The exponential ordering of the classes is probably the toughest. For example, one might appeal to functional load to explain why there is more deletion of monomorphemes than of past tense forms: this correctly predicts the ordering of the three classes, but would be perfectly compatible with non-exponential retention frequencies, like 80%, 70%, 60%, which are in fact NOT found. Similarly, the standard variationist model of logistic constraints would predict the uniform magnitude of external constraint effects found in Table 4, but cannot account for the nonuniform results for internal constraints shown in Table 3.

Finally, the approach proposed here requires a suspension of the strict cyclity convention, but in a motivated way, for syllabification rules. This accounts for why it is only these resyllabifiable final consonants that show this kind of double conditioning. Other variable processes that don't affect syllabification, like certain feature assimilations for example, I would predict not to show this lexical/postlexical duality.

Therefore, at the present state of our knowledge, the model I have sketched correctly predicts all the facts, while the alternatives do not. Thus we might fairly say that lexical phonology no longer has a problem with variation, but rather offers a solution for it.

NOTES

1. The effect of a following pause (i.e. utterance final position) varies by dialect; cf. Guy 1980.

2. In both languages, final sibilant deletion can apply to the plural forms cited, leaving forms like *pane, pace, vece, rapaze, core,* but such forms all retain the final consonant of the root, and therefore apparently did not undergo deletion BEFORE affix attachment. They can be treated in this model as having lost the final sibilant in the postlexical phonology.

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Table 1. Constraints on English coronal stop deletion.

1.1. External phonological conditioning: following segment effect

	N	% Deleted
__##C	422	48.6%
__##V	293	15.0
__##	180	27.8

1.2. Internal phonological conditioning: preceding segment effect

	N	% Deleted
obstruent__	449	39.2%
nasal__	248	35.1
liquid__	198	18.2

1.3. Morphological conditioning: morphological class

	N	% Deleted
Monomorphemes (e.g. *mist, old*)	658	38.1%
Irregular Past (e.g. *lost, told*)	56	33.9
Regular Past (e.g. *missed, tolled*)	181	16.0

Table 2. The exponential relationship: -t,d retention in three data sets

	N	Observed % retained	Predicted exponential progression		Model-fitting
Corpus 1 (Guy 1991, 7 speakers)					
Monomorphemes	658	61.9	.614	(n=3)	Best-fit p_0 = .15
Irregular Past	56	66.1	.723	(n=2)	Chi-square = 1.28
Regular Past	181	84.0	.85	(n=1)	p=.55
Corpus 2 (Santa Ana 1991, 45 speakers)					
Monomorphemes	3724	42.1	.422		Best-fit p_0 =.25
Irregular Past	297	59.3	.563		Chi-square = 1.17
Regular Past	836	74.3	.75		p=.57
Corpus 3 (Bayley 1993, 18 speakers)					
Monomorphemes	2216	43.9	.439		Best-fit p_0 =.24
Regular Past	568	75.5	.760		

Table 3. Internal constraint -
Preceding segment effect on -t,d deletion:
Varbrul factor weights for separate analyses of morphological classes.
(Guy 1991 corpus)

	Morphological Class		
Preceding Segment	M		R
Sibilants	.66		.67
Obstruents (stops, nonsib. fricatives)	.49		.46
Nasals	.59		.41
Liquids	.27		.44
Range:	.39	>	.26

Table 4. External constraint -
Following segment effect on -t,d deletion:
Varbrul factor weights for separate analyses of morphological classes.
(Guy 1991 corpus)

	Morphological Class		
Following Segment	M		R
Consonants (incl. liquids and glides)	.73		.65
Vowels	.31		.24
Pause	.45		.63
Range:	.42	=	.41

Table 5. Internal constraint - Preceding segment effect:
Retention rates and estimates of p_r according to the exponential model.
(Guy 1991 corpus)

	Morphological Class					
		M			R	
Preceding Segment:	Ret/Tot	%	Est. p_r	Ret/Tot	%	Est. p_r
Sibilants	134/269	49.8	.7927	31/40	77.5	.7750
Obstruents	24/34	70.6	.8904	79/93	84.9	.8495
Nasals	133/214	62.2	.8534	16/19	84.2	.8421
Liquids	116/141	82.3	.9370	26/29	89.7	.8966

	Best p_r	Expected Ret.		Tot. Chi-sq.	p=
		(M)	(R)		
Sibilants	.790	132.6	31.6	.0835	.87
Obstruents	.865	22.0	80.4	.7050	.75
Nasals	.853	132.8	16.2	.0185	.94
Liquids	.932	114.2	27.0	.7318	.78

Table 6. External constraint - Following segment effect:
Estimates of p_r. (Wolfram 1969 corpus)

	Estimates of p_r by constant following context:					
	Following consonantal			Following non-consonantal		
Estimates based on:	$\sqrt[3]{M}$		R	$\sqrt[3]{M}$		R
Social Group:						
UMW	.695	>	.628	.960	<	.972
UMN	.595	>	.508	.918	<	.932
LMN	.510	>	.383	.828	<	.867
UWN	.402	>	.275	.702	<	.757
LWN	.300	>	.240	.653	<	.661

Table 7. Following segment effect on -t,d deletion - detail.
(Guy 1991 corpus)

Following segment	Prob. of deletion	Syllable onset conditions
obstruent	.66	*ts- *tk- *tn- etc.
/l/	.80	*tl-
glide	.57	tw- + front vowel, tyu- (some dialects)
/r/	.42	tr-
vowel	.19	ta-, etc.
pause	.37	