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Chapter 3
Underlying representations that do not minimize grammatical violations*

Andrew Nevins and Bert Vaux

1. Overview

In this paper we review evidence from a variety of sources, including de-neutralization studies, that indicate that the choice of underlying representations is governed by causal reasoning, statistical inference, orthographic know-ledge, and hypercorrection, but rarely, if ever, by a principle of minimizing faithfulness violations.

2. What kinds of knowledge are used in inferring URs?

There is a well-known principle in OT which goes by the name of Lexicon Optimization. The classic definition, from Prince and Smolensky (1993), is reproduced in (1). Sharon Inkelas' adoption of the principle and definition are reproduced in (2).

(1) Lexicon Optimization.
"Suppose that several different inputs $I_1, I_2, \ldots, I_n$ when parsed by a grammar G lead to corresponding outputs $O_1, O_2, \ldots, O_n$, all of which are realized as the same phonetic form P – these inputs are all phonetically equivalent with respect to G. Now one of these outputs must be the most harmonic, by virtue of incurring the least significant violation marks: suppose this optimal one is labelled O_k. Then the learner should choose, as the underlying form for P, the input I_k." (Inkelas 1994: 209)

(2) "Given a grammar G and a set S = $\{S_1, S_2, \ldots, S_i\}$ of surface phonetic forms for a morpheme M, suppose that there is a set of inputs I = $\{I_1, I_2, \ldots,$Ij$\}$, each of whose members has a set of surface realizations equivalent to S. There is some $I_i \in$ I such that the mapping between

I_i and the members of S is the most harmonic with respect to G, i.e. incurs the fewest marks for the highest ranked constraints. The learner should choose I_i as the underlying representation for M." (Inkelas 1994)

Inkelas' idea is that, in the absence of any alternations to the contrary, a phonological form is stored identically to its surface form. The intuition here is one that many researchers consider to be the null hypothesis: that there is maximum transparency in the mapping of input to output forms, whenever possible.

Of course, in the face of alternations, such as Turkish [tat~tadɨ] (meaning "taste", in the nominative and in the accusative), there *is* no way to store an underlying form that is *maximally* transparent to both the nominative and accusative form. Storing the underlying form *tat* would be transparent for the nominative *tat* but unfair to the accusative *tadɨ*, while storing the underlying form *tad* would of course be transparent for the sake of *tadɨ* but would not lead to a transparent mapping for *tat*. In this case, Lexicon Optimization steps in, and says that the UR that will be chosen will be the one that minimizes the number of constraint violations that would be incurred. This is illustrated in the Tableau in (3).

(3) Comparative tableau, evaluated in parallel, to select most harmonic input

/tat/+/I/	*VOICED-CODA	IDENT-VOICE
Wrong output: [tatɨ]		
Right output: [tadɨ]		!*
/tad/+/I/	*VOICED-CODA	IDENT-VOICE
Wrong output: [tatɨ]		!*
Right output: [tadɨ]		

Result: **/tad/ chosen.**

Given the existence of final devoicing in Turkish, we know that *VOICED-CODA must outrank IDENT-IO-VOICE. Otherwise, there wouldn't be any devoicing at all. Hence, given that ranking, which any learner establishes based on hearing coda devoicing, we can compare how different possible URs would fare. As it turns out, storing the word as /tat/ leads to a completely gratuitous violation of Faithfulness in the output [tadɨ], so instead, /tad/ will be stored. The story is thus that URs are chosen so as to minimize grammatical violations. If Lexicon Optimization is right, learners will never store something like /tat/ as an underlying form for [tadɨ], because the choice of URs is governed by avoiding faithfulness violations.

The purpose of this paper is to show that learners do not respect Lexicon Optimization in a wide range of cases; rather, they seem to be going for underlying forms that flagrantly violate faithfulness constraints, when they could easily choose otherwise. After examining this behavior in detail, it becomes apparent that morphophonological knowledge, lexical statistics, segmental frequencies, and orthographic representations all play a role in constructing underlying representations, and that these factors *consistently* outweigh the desire to maintain maximal input-output transparency.

One of the best testing grounds for what kinds of underlying forms speakers come up with involves "deneutralization" phenomena. When learners hear a single output form, without hearing alternations, the expectation of Lexicon Optimization is that they will store that input form as faithfully as possible. Lexicon Optimization thus presents a new face on the intuition that was expressed by Paul Kiparsky's Alternation Condition (Kiparsky 1973): morphemes that don't alternate are stored in the maximally simple form. Kiparsky's Alternation Condition provided a guideline for what kinds of underlying representations could be assumed. After the seemingly heady days of SPE, where *nightingale* was stored with an abstract consonant in order to capture the fact that it resisted vowel shortening, Kiparsky's alternation represented a move towards anti-abstraction: why store phonological forms as any different from their surface form, if there is no alternation-based evidence to the contrary?

Our paper can thus be seen as not only a demonstration that Lexicon Optimization is empirically inadequate, but also that Kiparsky's Alternation Condition is too strong. Learners *do* go out of their way to construct "abstract" underlying forms in the absence of alternations, in the sense of "abstract" where it means "not identical to the surface". UR construction turns out to be a much more complicated procedure than can be computed by a Tableau-des-Tableaux. This finding may speak to Stig Eliasson's conclusion that not everything should be accounted for with the same grammatical machinery, and that some of the core acquisition mechanisms, in this case, the creation of inputs to the phonological computation, may lie outside the grammar proper.

3. Lexicostatistic influences on UR construction

One of the easiest examples to demonstrate this with at the outset occurs in Turkish. Consider a learner encountering a new word in Turkish in the nominative, a "wug" word, or nonce word, or novel form, as they are variously called. Suppose that the learner hears the word *nühüp*. Since Turkish has final devoicing, there are two choices for what the underlying form could be: *nühüp* or *nühüb*. Lexicon Optimization says, "Stop wasting my time! It will be *nühüp*! Why would anyone possibly choose otherwise?". The tableau for a lexicon-optimization based prediction for this scenario is given in (4).

(4) Comparative tableau, evaluated in parallel, to select most harmonic input

/nüüp/	*VOICED-CODA	IDENT-VOICE
Right output: [nühüp]		
Wrong output: [nühüb]	*	*
/nüüb/	*VOICED-CODA	IDENT-VOICE
Right output: [nühüp]		*
Wrong output: [nühüb]	*	

Result: **/nühüp/ chosen.**

Together with Beste Yolcu, a graduate student at Harvard University, we were able to ask 6 linguistically naive residents of Istanbul what the accusative form would be for this word (Nevins and Yolcu-Kamali 2005). Actually, we didn't ask them what the accusative would be. We asked them to fill in the blank in a sentence where the syntactic context demanded accusative case. As it turned out, 5 out of 6 of these speakers wrote down *nühübü*. This constituted a case of de-neutralization: since final devoicing *neutralizes* the contrast between voiced and voiceless stops, when a speaker *only* hears the voiceless form, he has to guess what the underlying representation actually is. By producing the accusative, we get direct access to what he chose for the underlying form, because the vowel ending of the accusative allows the underlying form to surface intact, it no longer being in the environment for final devoicing. Technically speaking, this is deneutralization because the UR could be either a /p/ or a /b/, and by producing the accusative, we get to see what the real underlying form is, outside of the neutralized environment in which the learner first encountered it.

A metaphor might help here. This is akin to the "blicket detector" task of Sobel, Tenenbaum, and Gopnik (2004). Children were introduced to a blicket-detecting machine that lights up and plays music when certain objects (blickets) are placed on it and were told that "blickets make the machine go". Sobel *et al.* studied 3- and 4-year old children's abilities to make a *backwards blocking* inference with the machine. In studies on backwards blocking, participants observe an outcome occurring in the presence of two potential causes (A and B). Participants then observe that event A independently causes the outcome. Participants are less likely to judge B as the cause of the outcome. In the task at hand, A and B are two blocks placed on the blicket detector together, which results in the machine activating. Subsequently object A is put on the detector alone, again resulting in activation of the machine. Children were then asked whether B was a blicket. 3-year old children's average percentage of responses that B was a blicket was 50%, while 3-year old children's average percentage of responses that B was a blicket was 12.5%.

Importantly the A and B backwards-blocking task is highly similar in structure to the coda deneutralization task we performed with nonce words in Turkish. Participants observed an outcome (e.g. [p] in final position) which occurs in the presence of two potential causes: the rule of coda-devoicing, or the existence of an underlying /p/. Much like the 3-year olds in Sobel et.al's experiment, once it is known that the presence of A alone is sufficient to trigger the outcome (in this case, that coda devoicing exists as a regular process in Turkish), then the likelihood that B is playing any role in the outcome plummets to 50%. Under the logic of rational parameter estimation models, such as the "Power PC" model of Cheng (1997), a blocked object in the backwards blocking paradigm has a strength parameter that is undefined, leading to complete uncertainty about the blickethood (or /p/-hood) of B.

In effect, in the backwards blocking condition of Sobel *et al.*, the blickethood of B is *neutralized* when it is placed on the blicket detector in the presence of A, a known blicket. When participants have to decide whether B is a blicket or not, they are forced to make a guess about the deneutralized likelihood of B's blickethood. This is entirely parallel to asking Turkish volunteers to form the accusative of nonce words they have only heard in the nominative.

We note briefly here that, for proponents of a theory in which there *are* no underlying forms, only Output-to-Output faithfulness relations with privileged bases, the lesson learned by these forms is the same. Thus, suppose that one wanted to deny underlying forms existed altogether, but claim that there is an Asymmetric Faithfulness relation required in the Accusative-to-Nominative mapping. The point is, in such a theory, freely choosing the Accusative *nühübü* when presented with the Nominative *nühüp* still flies in the face of grammatical pressure to minimize faithfulness violations. We will thus not consider such alternative models in further discussion, as the point remains the same: by choosing a voiced obstruent in the Accusative, speakers are demonstrating choice of a "base" of derivation that brings them away from a faithful mapping between forms.

In fact, the nonce word situation is not altogether different from the fate of loanwords. When the word *group* is imported to Turkish, it first undergoes epenthesis, yielding *gurup*. But for seemingly inexplicable reasons, its accusative form is *gurubu*. (Interested participants may wish to know that Google reveals 20,000 times more hits for *gurubu* than *gurupu*, although the latter does come up a handful of times, for reasons to become clear shortly.) Lewis (1967), in his grammar of Turkish, comments on the fact that polysyllabic loanwords are quite commonly adapted with underlyingly voiced final obstruents. This is thus a productive generalization, one which Lewis and subsequent scholars have characterized in terms of a morpheme-structure constraint: a constraint on what underlying forms can or should look like. Loanwords, however, as we know, enter the language in a variety of ways, and become "fixed" in their behavior relatively quickly. It is thus interesting to observe speakers' on-line behavior when immediately confronted with the task of deducing an underlying form.

Some of the results of our preliminary nonce-word study are included in the table in (5). In addition to these words, we randomly intermixed additional filler words, words with a seemingly exceptional voiced stop in the nominative, words which ended in sonorants, and monosyllabic words, to which we will turn in just a moment. (Note that Turkish velar stops are deleted between vowels, so we couldn't include those.) Here are the results for the number of speakers out of 6 who picked an underlying form that was voiced:

(5)

Voiceless Isolation form	Voiced UR, as shown by Acc	#/6
nühüp	nühübü	5
adip	adibi	4
gelep	gelebi	3
gotut	gotudu	3
rikep	rikebi	3
torsot	torsodu	3
ipanč	ipandʒi	3
sisap	sisabi	3
rutunk	rutungu	2
ongup	ongubu	2
südörp	südörbu	2
köbüt	köbüdu	0

One of the most obvious conclusions is that speakers do not behave uniformly. (Analysis of individual subjects reveals this as well; a single person is not "consistent" with respect to choosing all voiced or voiceless stops). Lexicon Optimization predicts that all of these should be stored as voiceless.

We are able to conclude based on this example that the driving force behind UR construction is *not* minimization of faithfulness violations.

Of course, there are alternatives to Lexicon Optimization that can be imagined and discussed here. In fact, Kiparsky's Alternation Condition, when dealing with Vowel Harmony, made the assumption that all alternating morphemes are stored with the *Marked* Value of the alternating feature. The idea was that neutralizing rules could delete structure, but not add structure. Now, we know that this is not generally true, due to the existence of neutralizing rules that yield the marked value, such as final *voicing*, even of underlyingly voiceless obstruents, as discussed for the Caucasian language Lezgian by Yu (2004). But suppose that it may be true on a language-particular basis. In that case, when faced with neutralized codas, learners might initially, in the absence of evidence to the contrary, store *all* such codas as underlyingly voiced, perhaps due to the evidence from existing alternations. In a recent paper by McCarthy (2004) on "free rides"[1], this intuition is echoed: in some situations, learners will adjust all of their underlying representations to be divergent from the surface form, based on more general evidence from morphophonemic alternations.

However, there are varying rates here as to how many speakers chose a voiced UR: none of them completely went for the Lexicon Optimization solution, and none of them completely went for the Store-as-Marked +Voice-solution. They seem eager to guess that *nühüp* comes from an underlying /nühüb/, but very hesitant to conclude that *köbüt* could come from underlying /köbüd/. What kinds of factors might play a role here?

Ernestus and Baayen (2003) in their study of nonce word production in Dutch deneutralization of coda devoicing note the role of sub-lexical factors in biasing learners towards postulating one or the other underlying representation.

One of the factors that Ernestus & Baayen (henceforth, "E&B") note that plays a role in whether an obstruent will be underlyingly voiced or not is its place of articulation. One model, for example, starts with the assumption that speakers know that there is neutralization in a certain position, and that they base their choice on whether an obstruent is underlyingly voiced (in a certain position) or not through their knowledge of the phonology of the language, so may decide to assign underlying [+voice] to those obstruents which are more robustly voiced *elsewhere*. For example, in Dutch, bilabial stops are more "robust" than alveolar stops, in the sense that they never undergo postlexical devoicing assimilation in function words. Crosslinguistically, bilabial stops are the most favored voiced obstruent, due to the following aerodynamic factors. Sustaining voicing requires that the oral pressure be lower than subglottal pressure. On the other hand, making an obstruent increases the oral pressure. So what to do in order to keep the subglottal-to-oral pressure ratio high enough to allow voicing? One option is to increase the volume of the oral cavity. A bilabial place of articulation allows this, and allows the cheeks to expand enough, allowing increased volume, which decreases the oral pressure. Ohala, Kingston, and others have thus reasoned that bilabial stops are more "eligible" for a [+voice] specification to begin with. Indeed, a brief inspection of our Turkish data does reveal that speakers as a pooled whole do prefer assigning [+voice] to the bilabial stop, so this type of explanation may play a role.

In Dutch, however, speakers showed a very different pattern, which turns out to be inconsistent with a "robustness" of [+voice] explanation. For nonce verbs such as *ik mip*, they overwhelmingly preferred the past-tense *mipte*. For nonce verbs with a final coronal stop, such as *ik nort*, they preferred the past tense *nortte*, with an underlying voiceless stop, though not to the degree of preference for underlyingly voicelessness observed for labial stops. Most

surprising were the results for nonce verbs with a velar fricative, such as *ik teeg* (in which the <g> is pronounced as voiceless [x]), for which subjects overwhelmingly preferred the voiced past-tense *teegde*.

E&B concluded that the most relevant factor in whether speakers will assign an underlying voiced or voiceless representation to a final obstruent for a given place of articulation is lexical statistics, and not the robustness of voicing or any phonological-strength-related factors. The velar fricative is not known for its robust compatibility with voicing. But in the Dutch lexicon, 97% of stem-final velar fricatives are underlyingly voiced.

E & B performed a database count, and found the following (6).

(6) Dutch obstruents in CELEX database

Place	Underlying [+voice]	Underlying [−voice]	Percent
Bilabial Stop	210	20	91% voiceless
Coronal stop	177	542	75% voiceless
Velar fricative	127	4	97% voiced

They conclude that "Speakers tend to choose that phoneme as the underlying representation that makes the morpheme resemble similar morphemes in the lexicon. That is, they are more likely to choose a given underlying representation when there are more similar words in the lexicon sharing this underlying representation. Speakers recognize that there is neutralization and base their choice for the underlying representation on the distribution of the underlying representations among existing morphemes, serving as exemplars." (E&B, p.7)

It is interesting to return to the Turkish pattern we have observed in our preliminary study, in which bilabials are the place of articulation with the greatest tendency for an underlying [+voice] specification in final position. If E&B are on the right track, perhaps the Dutch/Turkish difference in nonce-word formation is correlated with a difference in the lexical statistics of voicing specification in word-final position. A quick glance at an electronic Turkish database reveals that this is the case.

(7) Turkish obstruents in TELL database

Place	Underlying [+voice]	Underlying [−voice]	Percent
Bilabial Stop	431	56	85% voiced
Coronal stop	391	1224	75% voiceless

E&B note that the simple lexicostatistic of a predominance of underlying voiced vs. voiceless is one source of knowledge that speakers draw on in postulating the underlying representation for a novel word. We would like to point out here that this simple lexicostatistic *alone* cannot be the *whole* model for explaining our nonce word data, since speakers do not, on the whole, pick [b] exactly 85% of the time for nonce words. E& B point out other that factors can provide useful information about what to predict for the UR of an obstruent as well. For example, the quality of the vowel in the final syllable turns out to have an important information gain as to whether the final obstruent will be underlyingly voiced or not when a database is consulted, and indeed, E & B found that experimental performance correlated with this as well.

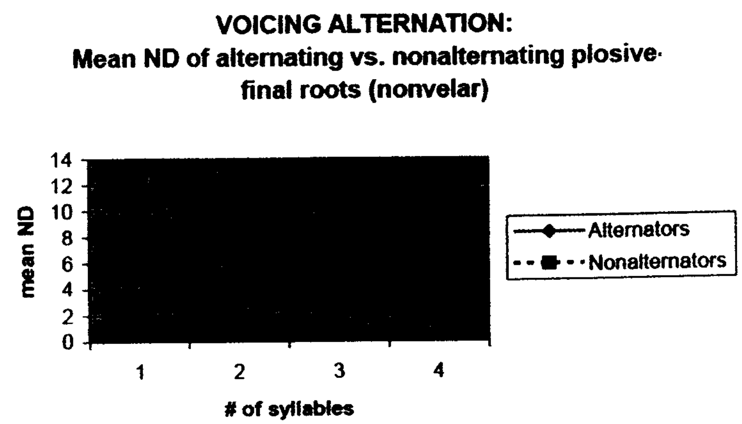
One of the factors that E & B note has very little predictive significance in Dutch as to whether a word will have an underlyingly voiced or voiceless obstruent is the length of the word. However, in Turkish, this factor turns out to be crucial. Monosyllabic loanwords such as *tube* are overwhelmingly adapted as underlyingly voiceless, yielding non-alternating nominative-accusative pairs, such as *tüp∼tüpü*. So there is a syllable-based generalization for Turkish; according to Inkelas, Pycha, and Sprouse (2004), while over half of Turkish polysyllabic obstruent-final words undergo voicing alterations, only one-fifth of monosyllabic obstruent-final words show alternation. In our nonce word study, we found a similar trend. The rates of adopting a UR with an underlying voiced stop were significantly lower for monosyllabic nonce words than in (5).

(8)

Voiceless Isolation form	Voiced UR, as shown by Acc	#/6
čič	čidʒɨ	0
rat	rat	0
münk	münk	0
šüt	šüt	0
sep	sep	1
üp	üp	1

As for why the monosyllabic vs. polysyllabic generalization should hold for Turkish, there are a variety of functionally-based speculations, but none are completely solid. Wedel (2002) suggested that monosyllabic words do not alternate – i.e, tend to be underlyingly voiceless – because they have a high neighborhood density. Neighborhood density measures the number of existing words in the lexicon that are one segment away. Wedel's idea is that CVC words are shorter, and have many more lexical neighbors. He notes that high neighborhood density slows down lexical access, which has been found by Luce and Pison (1998). His idea is that high neighborhood density makes lexical access tough especially when it is coupled with alternations, which he supposes make lexical access harder. (This latter fact, as far as we know, has never been demonstrated experimentally.) In any event, Inkelas, Pycha & Sprouse show that there *is* no such correlation in Turkish between lexical neighborhood size and whether or not a final obstruent alternates:

(9)



Perhaps the lexical neighborhood factor became grammaticalized, and perhaps not. Perhaps there is no principled reason why the voiceless tendency holds in monosyllables, and perhaps there is. Turkish speakers, however, have access to this lexical knowledge, and when constructing underlying representations, they make use of the fact that there is a monosyllabic vs. polysyllabic generalization: monosyllabic roots have final obstruents that tend to be underlyingly voiceless, and polysyllabic roots have final obstruents that tend to be underlyingly voiced. This productive generalization yields, oddly enough, loanword adaptations of *tube* and *group* as having the URs /tüp/ and /gurub/, completely the opposite of what a transparent surface mapping of the input would predict.

Why would natural language have such semi-productive tendencies to begin with? In other words, why should it be the case that the underlying voice specification of a final obstruent has some statistical correlation with unrelated phonological cues, such as the quality of the preceding vowel in Dutch, or the syllabicity of the word in Turkish? E&B make the suggestion that if the speaker forgets the underlying [voice] specification of a final obstruent (for an existing word in a neutralized context), he or she can deduce it from other morphemes in the lexicon and other sublexical cues. In other words, redundancy helps!

There are a variety of computational procedures that can model the experimental results we have been talking about, given knowledge of the lexicon and the statistical tendencies for voiced vs. voiceless specification, and our goal here is not to demonstrate which of the many computational models of analogy and nearest neighbor computations can best fit the experimental data. It seems when there are morpheme-structure-generalizations that act as cues, one of the more promising models for cases such as these, involves choosing URs based on an "exemplar set" of existing URs in the lexicon. One specific implementation involves the Analogy-Based modeling of Skousen (1989), where the analogical set contains words that share subsets of identical feature-values with the target word. A frequent argument against models of this type is the one embodied in the OT slogan "Knowledge is in the Constraints, not in the Lexicon", with the presupposition that it is computationally implausible to consult an analogical set of existing URs in the lexicon when deciding what the UR is for a newly-presented output form. However, a wide range of psycholinguistic evidence suggests that there *is* co-activation of similar-looking lexical candidates during lexical access.

We have thus considered the role of various grammatical pressures that contribute to construction of the UR for outputs that are neutralized due to coda devoicing. It turns out that the role of statistical frequency, and the desire to build URs that look the most like already existing URs in the Lexicon, plays a decisive role, and leaves little-to-no room for faithfulness-based optimization.

A similar situation, involving an altogether different process, involves Korean coronal fortition. This case is particularly interesting:

(10) a. Korean underlying /t t^h t' s s' c c^h c' h/ all neutralize to [t] word-finally (Ahn 1998; Iverson 1989)
b. Korean underlying /t/ is extremely rare (Sohn 2001; Kang 2003)

(11) a. English *internet* → [int^hənɛt],[int^hənɛsɨl]
b. English *Hamlet* → [hɛmnit],[hɛmnisɨl]

The suffixed object forms reveal the underlying form that Korean speakers have assigned to these words: both of them have an underlying /s/ as the final consonant. Since there are no constraints on underlying representations under Richness-of-the-Base, this fact is impossible to explain in terms of Lexicon Optimization. Why not just assign underlying /t/ for *internet*? McCarthy's Free Ride paper proposes a solution to this problem, within OT, one which was already anticipated in Harrison and Kaun (2000) which suggested the possibility of "Pattern-Responsive" Lexicon Optimization.

(12) "I will propose a learning principle according to which learners who have discovered the /A/ → [B] unfaithful map from alternations will attempt to generalize it, projecting /A/ inputs for *all* surface [B]s, whether they alternate or not. In other words, the nonalternating [B]s attempt to take a free ride on the independently motivated /A/ → [B] map."

The problem for this Pattern-Responsive generalization of unfaithful mappings for Korean, as pointed out by Idsardi (2005), is the following. Since all of the underlying phonemes in (10) exhibit unfaithful alternations, there is no way to know *which* underlying /A/ to pick. In other words, the Free Ride principle does not add anything new to the solution. It gives no way of knowing which of many possible URs a learner will choose; it merely re-describes the problem. However, lexical statistics go a long way towards understanding what Korean learners are doing. In a study of the SEJONG corpus performed by Albright (2005), it turns out that 56% of the morpheme-final coronals are /s/. Thus, rather than going for a maximally faithful underlying form, learners are using lexical statistics in constructing URs. This should not be overly surprising when viewed from a broader perspective on cognition. Randy Gallistel, a researcher on animal cognition, points out that when animals have to solve problems with incomplete knowledge, they frequently employ frequency matching as a strategy (Gallistel 1990).

Returning to the discussion of the blicket detector task of Sobel, Tenenbaum, and (Gopnik 2004), we turn to a discussion of their Experiment 3. In this experiment, they exposed kids to lots of objects before introducing them to the blicket detector. There were two conditions. In the "rare blicket" condition, 1 out of 10 of the objects they were exposed to beforehand were blickets. In the "common blicket" condition, 9 out of 10 objects were blickets. The children were then presented with the exact same task as before: seeing two objects, A and B, seeing that A lights up the blicket detector, and seeing that A and B together light up the blicket detector. The children were then asked if B was a blicket or not.

The children were remarkably sensitive to the *base rates* of whether something was a blicket or not as an independent fact about the world. The 4-year olds categorized B as a blicket on average 25% of the time in the rare blicket setup, but 81% of the time in the common blicket setup. Children's causal inferences about whether B was a blicket — which is logically indeterminate, given the backwards blocking scenario – depended on base rates. This is remarkably similar to the facts noted above: language users may be remarkably sensitive to the lexical statistics – the base rates – of underlying forms. Turkish speakers thus use the base-rate information of whether a word is likely to have an underlying /b/ or /p/ in making the decision of whether nonce words come from one or the other.

It is worth briefly noting here that Sobel *et al.* were not surprised that the children's outcomes – 81% response that B was a blicket given a 90% base rate, and 25% response that B was a blicket given a 10% response rate – did not match exactly the base rate. Bayesian inference models often recognize that individuals may use the base rates more conservatively than others, and do not expect a perfect match. The point is that the base rates make a difference, and that they make a difference in the right direction, with statistically reliable effects.

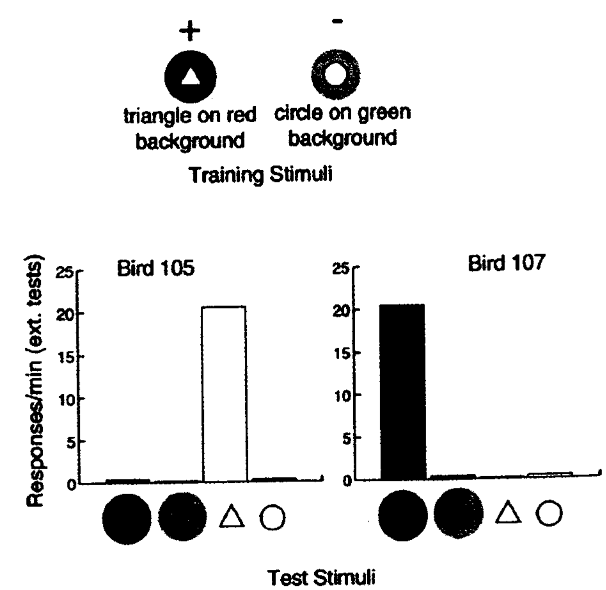
In more recent work, Inkelas (2000) has recognized the fact that lexicon optimization does not explain the behavior of speakers when they encounter new words and construct underlying representations for them. She tentatively suggests that learners "Sort underlying representations of lexemes by phonological specification and use analogy to come up with lexical representations for new lexemes for which the observed data doesn't yet force a particular underlying representation." (Inkelas: 2000).

This amounts to abandoning Lexicon Optimization, which says that when observed data doesn't force a particular underlying representation, the most transparent one is chosen. At this point we note, extremely briefly, that abandoning Lexicon Optimization will necessitate a reassessment of the widely-adopted RIP/CD algorithm for acquiring the order of constraints.

There remains the interesting question about what happens when there are inputs, say A and B, that both map to the output C, and the frequencies

of A and B are completely equal. Such a case is unknown to us, if attested at all in natural language. However, in his study of pigeon conditioning, G. S. Reynolds (1961) found that when both a triangle and a red circle were perfect predictors of the food response, certain pigeons would subsequently peck at equal rates for triangles alone and certain others for red circles alone. Both stimulus cues had 100% mapping to the desired output, and both stimulus cues had completely identical presentation rates during the conditioning process, so it seems natural to peck for either of them in subsequent trials. However, some of Reynolds' pigeons simply went for one of these stimulus cues and stuck with it, ignoring the other subsequently. In the figure below, Pigeon 105 consistently pecked at the triangle, ignoring the red circle as a predictor when presented alone. Pigeon 107, on the other hand, consistenly pecked at the red circle, ignoring the triangle as a predictor.

(13)



Gallistel (2003) interprets these outcomes as the result of redundancy reduction strategy: "Bandwidth reduction, a. k. a. parsimony applies: letting one of them do all the work maximizes the information conveyed per signal". It remains to be seen whether artificial language experiments can be designed which present two non-native phonemes in equal proportion, both of which neutralize to the same output. If so, such experiments would yield important insights into whether humans opt for deterministic behavior even in cases of perfect random choice.

A final case of interest that demonstrates the importance of segmental frequency trumping the principle of transparent URs comes from the study of Spanish rhotics. As pointed out in a series of papers by Jim Harris, Spanish neutralizes the contrast between the flap ⟨r⟩ and the trill ⟨rr⟩ in initial position: only the trill is possible in initial position. However, these two rhotics contrast intervocalically. (As a brief reminder, Spanish orthography uses one 'r' for the tap, and two 'rr's for the trill, while the IPA uses one 'r' for the trill.)

(14) Spanish trill contrastive intervocalically.

a. *pero* [peɾo] 'but' (flap)
b. *perro* [pero] 'dog' (trill)

An immediate question arises as to the representation of r-initial words, such as *rosa*, which have a surface trill. A completely transparent underlying form would be with the trill, of course. A much more abstract representation would be one with the flap underlying.

(15) Representation of [rosa] (surface trill)

a. /rosa/ (underlying trill)
b. /ɾosa/ (underlying flap) plus rule of initial trilling: ɾ → [r] in the environment: # _

The second analysis is of course much more complicated. Nonetheless, the rule of initial trilling (or its constraint-based equivalent) does represent a valid generalization about the language. This second analysis is ruled out, of course, by Kiparsky's alternation condition: there is no reason to specify /rosa/ as underlyingly [ɾosa] if there are no alternations to support this. However, we can begin to examine the lexical statistics of /r/, the trill, vs. /ɾ/, the flap. These can only be compared in intervocalic position, the position where they both are allowed. Harris (2001), examining the *Vox* Spanish dictionary, estimated 80% of intervocalic, morpheme-internal rhotics are the flap, while only 20% are the trill. If the preference to adhere to lexicostatistics for one segment versus another plays such a dominant role in UR construction, we might expect the drastic result that lexicostatistical preference overrides lexicon optimization here too. Note that there *is* no "free ride" to be taken here, as there are no alternations, morphological, postlexical, or otherwise, which turn an underlying flap into a trill in word-initial context. There are no morphological or phrasal concatenations that would suddenly make a non-initial rhotic into the initial segment of a word and thus trigger the context of the rule of initial trilling.

There is, however, one marginal process in Spanish, which does just what we are looking for: it moves an initial rhotic into a non-initial segment of the word. There is a language game that inverts the order of syllables, just like French *Verlan*. Thus, *casa* becomes *saca*, *gato* becomes *toga*, and so forth. What is important for our purposes is the output of the game for words like *rosa* (with an initial trill) and *reto* (meaning "challenge", also with an initial trill): it surfaces with an intervocalic flap.

(16) a. [rosa] → [saɾo] (surface transformation)
b. /ɾosa/ → [saɾo] (uderlying derivation to game output)

On the account in which *rosa* really is stored with a UR that contains an underlying flap in initial position, the game's result is expected. The flap is transposed to non-initial position: in other words, the game-transposition "bleeds" otherwise regular application of initial trilling.

However, on the account in which *rosa* is stored with an underlying trill, the output of the game is puzzling. Trills *are* allowed in intervocalic position. Learners are certainly not inventing a rule like "Trills become flaps in intervocalic position only when that results from Verlan-transposition". This rule is counter to the phonotactics of the language and therefore, without any evidence on which the learner could base it. The rule also requires access to the derivational history of its input, a "no-no" in all rule-based frameworks that ban "looking back", as well as in all existing versions of OT.

This language game, then, is a controlled experiment: it creates an environment in which we can see the "naked" underlying form of a rhotic, when it is transposed to a position where the rule of absolute neutralization can no longer apply. The result of the experiment shows that *rosa*, a non-alternating surface form with a trill in the output, is stored with an underlying flap instead. The explanation for this fact lies in the strong influence of segmental frequencies on UR construction, coupled with context-sensitive phonotactic knowledge.

4. Hypercorrection

In this next section, however, we will consider two additional considerations which can bias the choice of a UR in one direction or the other.

The first is hypercorrection. English flapping presents a case in which the two coronal stops /d/ and /t/ are neutralized to the flap [ɾ]. Nonetheless, since flapping is considered to be a casual speech rule, speakers are sometimes aware of the fact that an underlying /t/ should not be flapped in careful speech, and attempt to correct this mapping by pronouncing [t] where flapping otherwise yields [ɾ]. Speakers know that surface flaps may come from underlying /t/. Sometimes, they may "overdo" the application of this knowledge. It is interesting to observe that some speakers exhibit hypercorrection when it comes to "undoing" flapping. The second author's wife has yielded the following forms in careful speech (to be read in a slow "baby talk" register)

(17) enchilat^{h}a, chet^{h}ar cheese, somebot^{h}y

Interestingly, this speaker is systematic in producing no flaps in careful speech. And this tendency is not unique. Internet research reveals 25,000 Google hits for the spelling *sporatic*. An experimental study of repetition priming by McLennan, Luce, and Charles-Luce (2003) found that, in an experiment where subjects were exposed to both careful and casual speech, a casually-pronounced stimulus such as [koɾər] facilitated reaction time in repetition of both *coder* and *coater*, even though the latter is a highly infrequent word. They took the results to show that flapped stimuli are ambiguous and always activate both possible underlying representations. Lexicon Optimization, if it is the kind of thing that would make predictions about which underlying form is primed in lexical access, predicts that only the more harmonic *coader* will be activated. The Pattern-Responsive/Free-Ride theory, in its literal form (i.e. with the italicized universal quantification in (12)), predicts that only the unfaithful *coater* will be activated. Hypercorrective inferences about conversion from casual-to-careful speech, however, involve "undoing" phonological rules, however, and will choose the /t/ as a possibility in both perception and production.

In production sometimes, then, the desire to produce "careful speech" overrides even frequency biases for the input word, and has the effect of blocking the application of the optional rule of flapping, and when this happens, it reveals the true UR that speakers have adopted. On the assumption that the /d/-to-flap mapping is more faithful than the /t/-to-flap mapping by virtue of not changing [+voice] specifications, speakers who follow the hypercorrective impulse reveal a UR created at the expense of ignoring lexicon optimization.

5. Spelling

One of the most informative choices of a UR in the case of ambiguous neutralized input can come from orthographic knowledge. This follows a general theme we have been establishing: when speakers come across a neutralized output, they will use any information they can get their hands on in order to come up with a UR. They won't simply fall back on Lexicon Optimization. In fact, in any case in which they have any amount of knowledge to base a decision on, such as knowledge of alternations, segmental frequency and analogical exemplars, they'll use it. The same goes for knowing how a word is spelled. Orthographic knowledge plays an important role in phonological representations, particularly because in many writing systems, such as for English vowels, a morpheme retains the same spelling even when it undergoes drastic phonological alternations. Thus, it becomes a natural fallback of cognition to associate two distinct types of representations: the underlying form, which provides the same input to phonological derivations in a variety of alternating environments, and the orthographic representation (to be abbreviated "OR"), which retains the same representation in a variety of alternating environments.

Of course, mismatches exist in both directions, due to the fact that phonological systems change much faster than orthographic systems. But the association exerts a strong tendency in both directions. Sapir's informants, in his famous paper "The Psychological Reality of the Phoneme" (Sapir 1949) have their first experiences with writing systems. Sapir, who expected them to shape the OR based on the surface representations of morphemes, was surprised when he found that they decide to shape the OR based on their preexisting knowledge of the UR. In the cases we turn to now, subjects decide to base the UR, otherwise indeterminate, on their existing knowledge of the OR.

An initial example comes from vowel reduction in English. As noted by Michaels (1980), English orthography maintains distinct ways of writing unstressed vowels that are pronounced with identical surface form, such as the second vowel in *Néwton, Vénus, mámmal, Rússell.*

(18) a. Newton, Venus, mammal, Russell
b. [nuwtən, vijnəs, mæməl, rʌsəl]
c. *-ian* affixation

Michaels points out the effects of *-ian* affixation, which shifts stress to the immediately preceding syllable, even if it was a reduced vowel. The prediction of LO is that the underlying vowel is stored for these proper names as a central vowel, so under stress, the second vowel of *Newton* should become something like *Newtʌnian* – if speakers are using a "violation optimization" strategy for constructing URs, or even a "faithfulness maximization among affixed forms" strategy, they should be able to produce an affixed form with a stressed central vowel (the "caret"), no problem. However, speakers of English who know the orthographic representation for these words will tell you that the affixed forms are as follows:

(19) a. [nutonijən, vənuwšən, məmejlijən, rəsijlijən]
b. /nuton, vijnus, mæmejl, rʌsijl/

When speakers encounter an unstressed vowel and have no evidence for its underlying form, they thus use the following strategy: a vowel that is spelled ⟨o⟩" has the UR /o/, a vowel that is spelled ⟨u⟩ has the UR /u/, a vowel that is spelled ⟨a⟩ has the UR /ej/, and a vowel that is spelled ⟨e⟩ has the UR /ij/. (Michaels also notes that speakers know that a vowel that is spelled ⟨i⟩ has the UR /ɪ/, based on evidence from Dárwin-Darwínian.). Michaels notes the result of an experiment with adults asked to say the derived form of the name *Zinken*. They had no idea what to pronounce. He then showed them the spelling of the name, with the variant spellings and found their results were of course consistent with what the spelling told them.

(20) a. Zinken, Zinkan, Zinkun, Zinkon
b. ziŋkijnijən, ziŋkejnijən, ziŋkunijən, ziŋkonijən

Orthographic knowledge is further likely to play a similar role in UR construction for speakers of non-rhotic dialects. This may be of interest in light of the conclusions of Krämer (2005), who suggests that speakers may import an /r/ to follow the underlying representation of all non-high vowels, yielding an explanation for the so-called "intrusive r" that yields identity for

the following two sentences ((a) and (b) as in (c)).

(21) a. The tuna is here
b. The tuner is here
c. ðə tunəɹ ɪz hijə

We wish to bring into consideration some suggestive evidence from McCarthy (1992) on r-insertion. This evidence suggests that *-ic* affixation can reveal the underlying forms of words with final non-high vowels in non-rhotic dialects. Specifically, McCarthy notes that in his own Eastern Massachusetts English, the words *algebra* and *Homer* are produced with an identical final rime: they both end with a schwa. However, they behave differently under *-ic* affixation, yielding *algebraic* vs. *Homeric*.

(22) a. URs under Lexicon Optimization: /ældʒəbrə, homə/
b. URs under Free-Ride Extension of [r] to after non-high vowels: /ældʒəbrər, homər/
c. URs under orthographic knowledge of pre-neutralization source: /ældʒəbrej, homijɹ/
d. algebraic, Homeric

In accordance with Michaels' proposal, speakers will resort to the orthography when they cannot deduce a UR from the neutralized phonological output[2]. Of course, they can use knowledge from alternations they have heard from other speakers as well. This accounts for the lexical knowledge that accounts for the "linking" r found in the word *tuner*. As for the intrusive [r] in the word *tuna*, it may be possible that this word has been listed with an /r/ in its UR, as there are few alternations involving *tuna*. However, the fact that intrusive [r] shows up even in L2 pronunications, as noted by Jespersen (1909) who cites example of nonrhotic English speakers' attempts at German yielding *hatte[r] ich* and *sagte[r] er*, it is tempting to explain intrusive [r] as the output of an active phonological rule operating in URs constructed with the help of orthographic knowledge.

We end this paper with a discussion of the results of a study we are carrying out on European Portuguese (henceforth "EP"), with the help of Salvador Mascarenhas, a student at the University of Lisboa (Nevins, Mascarenhas, and Kilimangalam 2005). EP is known for its massive vowel reduction, which, esentially, turns all unstressed round vowels to [u], as discussed in the book the *The Phonology of Portuguese*, by Mateus and d'Andrade (2000).

(23) Eur. Port.: Unstressed /ɔ,o,u/ → [u]

Of additional interest is the process of vowel harmony that occurs in the third conjugation. In the first person singular and in the subjunctive, stems with an underlying mid vowel show up with a high vowel:

(24) a. /dormír/ 'to sleep'
b. [dormímos] 'we sleep'
c. [dúrmu] 'I sleep'
d. [dúrma] 'sleep 3SG. SUBJUNCTIVE'

The traditional wisdom, which we follow here, is that the stem vowel shows up as [u] in those contexts (e. g. 1. SG.)where the theme vowel is deleted for morphophonological reasons. We can call this harmony process "mid-vowel raising", since this is its effect, factoring out the triggering cause.

These two processes, unstressed vowel reduction, and mid-vowel raising, may combine to yield ambiguity for third conjugation stems. Consider the hypothetical verb stems 'gomir' and 'gumir'.

(25) a. /gomir/, /gumir/ → [gumír], by unstressed vowel reduction
b. /gumir/ → [gúmu] (1. SG.) inflection as usual
c. /gomir/ → [gúmu] (1. SG.) by mid-vowel raising

These verbs will have an identical infinitive pronunciation, and an identical first person singular pronunciation. They will diverge, of course, on the 2nd person singular, where mid-vowel raising can no longer apply:

(26) a. /gumir/ → [gúməs] (2. SG.) inflection as usual
b. /gomir/ → [góməs] (2. SG.) inflection as usual

We have conducted a wug-test survey of European Portuguese speakers, in which we present them with the infinitive *gumir* and the first person singular *Eu gumu*, and asked them to produce the second person singular. Our results thus far show fifty-fifty choice (27).

(27) No orthographic information. Subject hears *gumir. Eu gumu, Tu ...*"
a. [goməs] 3/6 speakers
b. [guməs] 3/6 speakers

In this experiment, we have an additional twist: after presenting each subject with 40 nonce verbs of this sort (suitably randomized and balanced with distractors), we then go back and ask them to go through the procedure again, but this time we show them the orthography. For 3 of the speakers, we have showed them the infinitive written as *gumir*, and for 3 of the speakers, we have showed them the infinitive written as *gomir*.

(28) a. *gomir* → Tu [goməs] 3/3 speakers
b. *gumir* → Tu [guməs] 3/3 speakers

It is striking to note the unanimity in responses among speakers when an orthographic form is shown, despite the fact that the same speaker may have produced the opposite result in the first half of the task with the same verb.

This experiment again shows that European Portuguese speakers rely on orthographic cues when they can, and when they can't, they go for probabilistic guessing of what the underlying form of the stem vowel is. If minimizing grammatical violations were all there was to the story, all 6 of the speakers should be choosing [guməs] when they hear *gumir* and *gumu*. As for what the exact factors are that bias them for choosing [o] or [u] for a given verb, we are awaiting the consultation of an electronic Portuguese lexicon to perform analyses of whether certain vowels are more probable between certain consonant clusters.

In closing, these results should not be too surprising, from a broader point of view. A long psycholinguistic literature has revealed the effects of orthographic knowledge in phonological tasks. Seidenberg and Tanenhaus (1979) found that speakers take longer to decide whether *pie* and *rye* rhyme than *pie* and *tie*, even though these tasks require only a phonetic judgement and are presented entirely auditorally.

Hallé, Chéreau, and Segui (2000) found that French speakers detect the phoneme /b/ more easily than the phoneme /p/ when they hear tokens like French word *absurde*, which is pronounced with a [p], due to voiceless assimilation, but not when they heard tokens like *rhapsodie*. This effect held up in a subsequent experiment even with non-words, so that *apsorie* yielded a high rate of /b/ detection, while *rapselg* did not. Hallé *et al.* concluded that French subjects perceived a [b] in *apsorie* but not in *rapselg* due to the similarity of the former to existing words in the French lexicon which are known to be morphologically and orthographically derived from the prefix *ab-*, with a [b]. They point out that a variety of models of real-time lexical access activate lexical neighbors, and that this sort of effect can overshadow the simplistic mechanism of isormorphism between the phonetic signal and the phonological representation. Yes, these speakers are using "higher-level, top-down" knowledge in making their automatic decision, but as we have seen throughout this paper, perhaps *everybody* is: it may be that reliance on lexical neighbors and orthographic cues is an inescapable urge for Man, the problem solver.

6. Conclusion

The ideal outcome of this paper would be that practising phonologists would simply stop believing that speakers ever use a principle like Lexicon Optimization, as there is no empirical evidence for its existence. It remains an interesting research challenge to see if there are *ever* any cases where the desire to minimize faithfulness violations takes precedence over the set of heuristics described here for UR construction.

Notes

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1. The term, incidentally, is originally due to Morris Halle, as acknowledged by Zwicky (1970) in a CLS paper on rule-ordering.
2. Note that *Homeric* is subject to trisyllabic laxing, of the form *serene–serenity*, so Michaels also correctly predicts the quality of its medial vowel given an underlying /ij/.

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