Explaining universal tendencies and language particulars in analogical change

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1 Introduction

It is well known that members of morphological paradigms exert an influence over one another, and forms are occasionally rebuilt to create more coherent and consistent paradigms. For example, in early New High German, the singular forms of verbs with *eu* ∼ *ie* alternations (strong class II) were rebuilt to contain *ie* throughout, as in (1) (Paul, Wiehl, and Grosse 1989, §242):[1]

(1) Loss of /iu/∼/ie/ alternations[2] in early New High German

'to fly'	Middle High German		Early New High German		New High German
1sg	*vl**iu**ge*	>	*fl**eu**ge*	⇝	*fliege*
2sg	*vl**iu**gest*	>	*fl**eu**gst*	⇝	*fliegst*
3sg	*vl**iu**get*	>	*fl**eu**gt*	⇝	*fliegt*
1pl	*vliegen*	>	*fliegen*	>	*fliegen*
2pl	*vlieget*	>	*fliegt*	>	*fliegt*
3pl	*vliegen*	>	*fliegen*	>	*fliegen*

In other verbs, singular∼plural vowel alternations were not lost, but were simply rearranged. For example, in strong verbs like *hëlfen* 'help', *nëmen* 'take', and *geben* 'give' (classes IIIb, IV and V, respectively) the 1sg form was rebuilt to match the plural, as in (2a) (*ibid.*, §242). The result was a new alternation within the present tense paradigm, parallel to a separate pattern of alternation known as *umlaut*, seen in the verb *graben* 'dig' (2b):

[1] I use the following orthographic conventions: X∼Y represents synchronic alternations between X and Y within a paradigm; X→Y represents a synchronic morphological or phonological rule changing input X to surface Y; X>Y indicates regular sound change from X to its expected outcome Y, while X⇝Y indicates that form X has been replaced by an analogically rebuilt form Y. Analogically rebuilt forms are also underlined in tables, to highlight which parts of the paradigm underwent changes. In all of the cases discussed here, the term 'paradigm' refers to the set of inflected forms which share a single lexical stem (the set of case forms of a noun, the various person, tense and number inflections of a particular verb, etc.).

[2] This alternation was produced by regular sound changes affecting the Proto-Germanic diphthong **eu*. Specifically, when *eu* preceded a syllable containing a high vowel, it raised to *iu*, and otherwise it lowered to *eo* and subsequently dissimilated to *io* > *iə*. Since the present singular suffixes all had high vowels (*-u*, *-is*, *-it* and the plural suffixes all had non-high vowels (*-êm*, *-et*, *-ant*), this resulted in singular ∼ plural alternations (Paul, Wiehl, and Grosse 1989, §35).

(2) Rearrangement of /i/∼/ë/ alternations in early New High German

a.	'to give'	MHG	Early NHG		NHG	b.	Following pattern of 'to dig'
	1sg	*g**i**be*	*g**i**be*	⇝	*gebe*		*grabe*
	2sg	*g**i**best*	*g**i**bst*		*gibst*		*gräbst*
	3sg	*g**i**bet*	*g**i**bt*		*gibt*		*gräbt*
	1pl	*gëben*	*geben*		*geben*		*graben*
	2pl	*gëbet*	*gebt*		*gebt*		*grabt*
	3pl	*gëben*	*geben*		*geben*		*graben*

Although the changes in (1) and (2) yielded different patterns of alternation, what they have in common is that some members of the paradigm have been rebuilt to match other forms (*paradigm leveling*) or to differ systematically from another form (*analogical extension*, or *polarization*; Kiparsky 1968). The form that determines the shape of the rebuilt paradigm is traditionally referred to as the *base*, or *pivot* of the change.

A long-standing issue in the study of analogy is the question of which forms act as bases, and which are rebuilt. Typically, this is cast as a typological question: are there certain forms that tend to serve as bases, and other forms that tend to be rebuilt? Careful inspection of many cases has revealed numerous tendencies: analogy tends to be based on frequent forms, shorter forms, "unmarked" forms, and so on (Kuryłowicz 1947; Mańczak 1958; Bybee 1985; Hock 1991). These tendencies are often taken to be primitives of historical change: change tends to eliminate alternations by replacing less frequent alternants with more frequent ones, marked forms with unmarked ones, and so on.

Much less attention has been devoted to explaining the language-particular aspects of analogy. Why does analogical change favor a particular base in a particular language? Why are alternations sometimes leveled, and sometimes extended? The typological approach makes only weak predictions about the particulars of individual cases: certain changes are universally more or less likely, and the fact that a particular language underwent a particular change is in some sense a statistical accident. To the extent that individual changes obey the typological tendencies, they can be seen as reasonable and "natural", but analyses of analogical change seldom commit to the claim that an attested change was the only analogy that could possibly have occurred.

In Albright (2002), a model is proposed that makes precisely this claim. Specifically, it is hypothesized that learners select base forms as part of a strategy to develop grammars that can produce inflected forms as *reliably* or as *confidently* as possible. In order to do this, learners compare different members of the paradigm, using each to attempt to predict the remainder of the paradigm with a grammar of stochastic rules. The part of the paradigm that contains as much information as possible about how to inflect the remaining forms is then selected as the base form, and a grammar is constructed to derive the rest of the paradigm. In this model, analogical change occurs when the resulting grammar derives the incorrect output for certain derived (non-basic) forms, and these errors come to replace the older, exceptional forms. Thus, all analogical change is viewed as (over)regularization, echoing earlier proposals by Kiparsky (1978) and others. Since the procedures for base selection and grammar induction are both deterministic, this model makes strong predictions about possible analogical changes: they must be based on the most informative form in the paradigm, and the only possible "analogical errors" are those that can be produced by the grammar. I demonstrate that these are correct in several typologically unusual cases.

The goal of this paper is to show that a confidence-based model can make correct predictions not only about individual cases, but also about the typology of analogical change. It is organized is as follows: first, I provide a brief overview of tendency- vs. structurally-based approaches to analogical change, summarizing the major generalizations that have been uncovered, and situating the current work in an area that has been approached from radically different perspectives. Next, I present an overview of the synchronic model developed by Albright (2002). I show first how the synchronic confidence-based approach can explain the direction of analogy in individual cases, and then move on to explore its typological implications. I consider first some apparent counterexamples to the confidence-based approach, showing that in at least some cases where analogy has seemingly favored an uninformative member of the paradigm, that form is not nearly as uninformative as it might appear. In other words, many apparently unusual cases are not as surprising as they would seem based on schematic presentations. I then consider how token frequency may effect the calculation of confidence, favoring the selection of more frequent forms as bases. An exploration of the parameter space of the model reveals that even without an explicit bias to select more frequent forms, they are nonetheless selected as bases under most conditions. Thus, a model of grammar induction that aims to construct accurate and reliable grammars is able to derive the observed typological tendencies without any built-in bias specifically designed to favor more frequent forms as bases.

2 Background: two approaches to analogical change

2.1 The typological approach

Starting with the neo-grammarians, formal analyses of language change have divided changes into two types. On the one hand, there is phonetic sound change, which is said to be regular and law-abiding, in the sense that it is (in principle) exceptionless, and can be described formally as the operation of rules. On the other hand, there are non-phonetic changes, such as analogy and reanalysis, which are claimed to be sporadic, unpredictable, and describable only by tendencies, not laws.

A consequence of this division is that there is a sharp difference in how universals and the relation between synchrony and diachrony have been approached in the two domains. For phonetic change, it is generally accepted that there a close relationship between synchrony and diachrony, even if the exact nature of the relationship is debated. Diachronic change creates synchronic alternations, and synchronic forces such as articulation and perception motivate diachronic change. Furthermore, since phonetic pressures are at least in some respects universal, it is intuitively clear that some sound changes should be more common or "natural" than others. As a result, changes should go in some directions but not others. Explanation consists of uncovering the universal pressures, determining whether they are diachronic or synchronic in nature, and modeling them with the most restrictive possible theory that captures both the language-particular and typological patterns.

For non-phonetic changes like analogy, on the other hand, the situation is quite different. Whereas phonetic change is rooted to a large extent in physical and perceptual pressures, analogy is driven by more abstract cognitive considerations, such as reducing alternations within paradigms, or reducing the number of patterns in the language. Traditionally, these pressures have held no formal status in synchronic grammar,[3] but are seen as a diachronic force

[3] A recent exception is the reliance on *paradigm uniformity* or *uniform exponence* constraints in Optimality Theory (Burzio 1994; Kenstowicz 1997a; Steriade 2000; McCarthy 2005).

or acquisition bias that gradually eliminates alternations and restores regularity. Since these pressures do not place any restrictions on *how* regularity is achieved, analogical change may proceed in many different directions, and it is often difficult to classify one change as more or less natural than another competing possibility. Continuing with the example from above, in Middle High German, many verbs exhibited vowel alternations between the plural and some or all of the singular, as in (3a). In Modern German, these alternations have been retained in some cases (e.g., 'know', (3b.i) and most of the modal verbs), lost in others (e.g., 'fly', (3b.ii)); in yet other verbs such as 'to give', (3b.iii), the alternation was retained in just some forms (the 2,3sg), as shown in (2) above.

(3) Paradigmatic changes in early New High German

a. Alternations in Middle High German present tense paradigms

	i. 'know'	ii. 'fly'	iii. 'give'
1sg	*we**i**z*	*vl**iu**ge*	*g**i**be*
2sg	*we**i**st*	*vl**iu**gest*	*g**i**best*
3sg	*we**i**z*	*vl**iu**get*	*g**i**bet*
1pl	*w**i**zzen*	*vl**ie**gen*	*g**ë**ben*
2pl	*w**i**zzet*	*vl**ie**get*	*g**ë**bet*
3pl	*w**i**zzen*	*vl**ie**gen*	*g**ë**ben*

b. Modern German paradigms (analogically changed forms are underlined)

	i. 'know'	ii. 'fly'	iii. 'give'
1sg	*we**i**ß*	*fl**ie**ge*	*g**e**be*
2sg	*we**i**ßt*	*fl**ie**gst*	*g**i**bst*
3sg	*we**i**ß*	*fl**ie**gt*	*g**i**bt*
1pl	*w**i**ssen*	*fl**ie**gen*	*g**e**ben*
2pl	*w**i**sst*	*fl**ie**gt*	*g**e**bt*
3pl	*w**i**ssen*	*fl**ie**gen*	*g**e**ben*

The change from (3a) to (3b) represents a modest simplification or regularization: singular∼plural alternations have mostly been eliminated except in a few high frequency verbs (such as *wissen*), leaving just two general patterns (non-alternation, and raising in the 2,3sg). Logically, there are many other possibilities that seem just as natural, however. Could analogical change have gone further, eliminating alternations in *all* verbs? Or could it have gone in a different direction, yielding paradigms like *fl**eu**ge, fl**eu**gst, fl**eu**gt, fl**eu**gen, fl**eu**gt, fl**eu**gen,* or perhaps *fl**ie**ge, fl**eu**gst, fl**eu**gt, fl**ie**gen, fl**ie**gt, fl**ie**gen*?

Under the traditional view of analogy, the answer is affirmative: changes in any direction are possible. Nevertheless, it is commonly accepted that some changes are more likely than others. Analogical changes are often based on the shortest, or "least suffixed" member of the paradigm (Mańczak 1958; Hayes 1995, Bybee 1985, pp. 50-52), the "least marked" member of the paradigm (Jakobson 1939; Greenberg 1966; Bybee and Brewer, 1980; Tiersma 1982; Bybee 1985), and the member of the paradigm with highest token frequency (Mańczak 1980, pp. 284-285). In many cases, all three of these factors converge, yielding a base form that is frequent, unmarked, and unsuffixed (such as a nominative singular, or a third person singular present form). At the same time, there are many cases in which these factors do not converge, and a subsequent change obeys one trend at the expense of others. Even more troubling, there are analogical changes that

apparently violate all of these tendencies, rebuilding paradigms on the basis of a less frequent, more marked, suffixed base form (Hock 1991, chap. 10).

A well known example of analogy based on a marked form involves the loss of final devoicing in Yiddish (Sapir 1915, p. 237; Kiparsky 1968, p. 177; Sadock 1973; Vennemann 1979, pp. 188-189; King 1980). In its earliest stages, Yiddish, like Middle High German, had final devoicing of obstruents (seen here in alternation betwee sg. *vek* and pl *vegə* in (4a)). However, in many dialects of Yiddish, final devoicing was subsequently "lost", and the voicing value of the plural was reintroduced to the singular, leaving paradigms with [g] throughout as in (4b). (The change of the plural suffix from ∅ to -*ən* is irrelevant for the point at hand.)

(4) Loss of final devoicing in Yiddish

'way'	a. MHG		b. Earlier Yiddish		c. Modern Yiddish		
	sg.	pl.		sg.	pl.		sg. pl.
Nom., Acc.	*vek*	*vegə*	>	*vek*	*veg*(ə)	⇝	*veg* *vegən*
Gen.	*vegəs*	*vegə*	>	*vegəs*	*veg*(ə)		
Dat.	*vegə*	*vegən*	>	*veg*(ə)	*vegən*		

We can confirm that the change from *vek* to *veg* is due to the voicing in the plural form, and not to a separate process of final *voicing*, by comparing voiceless-final stems and observing that they remain voiceless (5).

(5) Voiceless-final stems remain voiceless

'sack'	a. MHG		b. Earlier Yiddish		c. Modern Yiddish		
	sg.	pl.		sg.	pl.		sg. pl.
Nom., Acc.	*zak*	*zekə*	>	*zak*	*zek*(ə)	⇝	*zak* *zek*
Gen.	*zakəs*	*zekə*	>	*zakəs*	*zek*(ə)		
Dat.	*zakə*	*zekən*	>	*zak*	*zekən*		

As Sapir first noted, this change is a paradigmatic one: words with [g] in the plural generally had [g] restored in the singular as well, while words with no plural form (such as the adverb *vek* 'away') did not change.[4] Thus, it appears that in this case, paradigms have been leveled to the form found in the plural, in spite of the fact that plurals are more marked and less frequent than singular forms.

Cases of leveling to "marked" forms are not uncommon in the literature, and the usual response has been to claim that the direction of analogy reflects general typological tendencies, but is not governed by any hard and fast rules (Kuryłowicz 1947; Mańczak 1958; Hock 1991). This position is summed up succinctly by Bybee and Brewer (1980, p. 215):

> A hypothesis formulated in such a way makes predictions of statistical tendencies in diachronic change, language acquisition and psycholinguistic experimentation. It cannot, nor is it intended to, generate a unique grammar for a body of linguistic data.

Although this is a reasonable approach to finding and testing descriptive hypotheses, it is unsatisfying from an explanatory point of view. As an account of language change, it tells us what changes are likely in general, but it cannot tell us why a particular language changed in a particular way at a particular time. As an account of language acquisition or experimental

[4]The details of the loss of final devoicing are considerably more complex than what is described here; see King (1980) and Albright (in prep.) for an overview.

results, it tells us what types of errors or results we might expect of humans in general, but it cannot explain why speakers of different languages behave differently in the types of errors they make or in their responses to psycholinguistic experiments. In order to explain data from speakers of individual languages, we need a synchronic, language-particular understanding of how paradigms are organized, and why analogy takes place.

2.2 The grammatical approach

It has been noted at least as far back as Hermann Paul that analogical change is quite plausibly rooted in the way that children learn language, and the (sometimes incorrect) analyses that they impose on it (Paul 1920, chap. 5). Early generative approaches to language change attempted to formalize this intuition, proposing that analogy might be best explained not by examining the surface patterns before and after the change, but rather by comparing the change in the underlying grammatical analysis. Kiparsky (1968) and King (1969, chapter 5.3) advanced the hypothesis that analogical change serves to simplify grammar, either by removing rules from the grammar (rule loss), simplifying their environments (broadening, or generalization), eliminating opacity (maximizing transparency), or removing exceptions. For example, the loss of final devoicing in Yiddish may have involved analogy to a marked base form on the surface, but the resulting grammar was simpler: the final devoicing rule, which had become opaque due to the counterfeeding apocope rule, was lost. The intuition is that analogical changes have a *structural* motivation, which can be viewed perhaps as a learning bias for transparent rule orderings, or for grammars that use as few rules as possible.

The idea that analogy always results in grammar simplification is tantalizing, but unfortunately, there are many changes that cannot be straightforwardly analyzed as simplification. Naturally, whether or not a particular change can be viewed as simplification depends crucially on the grammatical analyses employed, but in many cases the resulting grammar is not obviously any simpler than the original one—see, e.g., King (1969)and Vennemann (1979) for discussion. To take just one example, the change in the 1sg of the verb *geben* in German from *gibe* to *gebe* ((2) above) does not eliminate the need for an *e*∼*i* vowel alternation rule, or simplify its environment—in fact it arguably makes it more complex, by trading in a sg./pl. alternation for an alternation between the 2,3sg. and all remaining forms. Thus, it is not possible to maintain a strong version of the hypothesis that analogy is always grammatical simplification.

Nonetheless, as Vennemann points out, there are structural considerations other than simplification that could play a role in determining the direction of analogy. Returning to the example of the loss of final devoicing in Yiddish, let us compare the actual outcome ((4) above) with a hypothetical version of Yiddish with leveling to the singular form:

(6) Hypothetical extension of final devoicing in Yiddish

'way'	a. Earlier Yiddish		b. Hypothetical development	
	sg.	pl.	sg.	pl.
Nom., Acc.	*vek*	*veg*	⇝ *vek*	*<u>vek</u>*(*ən*)

Vennemann notes that although the hypothetical analogy in (6) employs an unmarked base, it would actually represent a rather unusual change. The reason is that analogy to the singular would eliminate the phonemic opposition in final position between underlying /k/ (that is, words like *zak* with [k] in both singular and plural) and underlying /g/ (like *veg*, with [k] ∼ [g] alternations). He hypothesizes that analogy characteristically preserves phonemic distinctions: "Sound change neutralizes contrasts, analogy emphasizes contrasts by generalizing them" (p.

189). Vennemann calls this the *predictability principle*, and he observes that the desire to maintain contrasts can override the tendency to level to unmarked base forms.

In Albright (2002), I proposed that the urge to maintain contrasts is more than a mere tendency that influences the direction of analogy; in fact, it forms the basis of how learners approach the problem of learning paradigms. The premise of this approach is that speakers (ideally) need to be able to correctly understand and produce inflected forms of their language. In order to do this, they cannot wait around to hear and memorize all forms of all words, since there are many forms that they will simply never encounter (particularly in a highly inflected language). Thus, learners need to make inferences about the phonological and morphological properties of words based on incomplete information. The proposal, then, is that learners adopt a strategy of focusing on the part of the paradigm that contains the most contrastive information, and allows them to project the remaining forms as accurately or as confidently as possibly—that is, the most informative, or predictive part of the paradigm. This form is chosen as the base of the paradigm, and a grammar is constructed to derive the remaining forms.[5] I will refer to this strategy as *confidence maximization*, since its goal is to allow the learner to infer properties of words as confidently as possible.

On the face of it, a confidence-based approach appears to suffer from as many counterexamples as any of the tendencies discussed above. For example, a famous analogy in history of Latin eliminated a stem-final contrast between [r] and [s]: *honōs* ∼ *honōris* 'honor-NOM./GEN.' ⇝ *honor* ∼ *honōris*, on analogy with underlying /r/ in words like *soror* ∼ *sorōris* 'sister-NOM./GEN.' (for discussion, see Hock 1991, pp. 179-190; Barr 1994, pp. 509-544 ; Kiparsky 1997; Kenstowicz 1998; Albright 2005, and many others). Such cases are not necessarily a problem if predictability is viewed as just one more factor that can compete or conspire to determine the direction of analogy, but they are a challenge to the idea that bases are *always* the most predictive form. Why does analogy sometimes wipe out distinctions, if bases are always chosen to be maximally informative?

I hypothesize that the reason why analogy sometimes eliminates contrasts is that learners are restricted in the way that bases are chosen, and cannot always select a form that maintains *all* of the contrasts that are displayed in their language. In particular, I propose that there is a *single surface base* restriction: learners must choose a surface form as the base, and that the choice of base is global (that is, the same for all lexical items). When there is no single form in the paradigm that preserves all distinctions for all lexical items, the learner must choose the form that maintains distinctions for as many lexical items as possible.[6] In the case of Latin, the contrast between [r] (*soror*) vs. [s] (*honōs*) was neutralized to [r] in oblique forms (*sororis*, *honōris*). This neutralization affected relatively few forms, however, compared to neutralizations in the nominative caused by cluster simplification and morphological syncretism; thus, the globally best choice of base form in Latin would have been an oblique form, even if it neutralized the rhotacism contrast. Thus, we see that the single surface base restriction can result in certain contrasts being lost in the base form; when this happens, they will be open to analogical leveling. For example, in Latin, the minority [r] ∼ [s] alternation with the more regular [r] ∼

[5] This search for contrastive information is similar to the way in which generative phonologists usually assume that underlying forms are discovered; for discussion of the parallels and differences, see Albright (2002a).

[6] All of the cases discussed here involve a single base form within a rather limited "local" paradigm (one tense of a verb, singular and plural forms of a noun, etc.) An important question not addressed here is whether larger paradigms, with multiple tenses, aspects, etc., might involve multiple "local" bases—perhaps along the lines of the traditional principle parts analysis of Latin or Greek verbs. The question of what considerations might compel learners to establish multiple base forms is a matter of on-going research; some examples are discussed in Albright (2002a), §6.3

[r] pattern. Leveling, under this approach, is not a *grammatical* simplification, but rather *lexical* simplification, eliminating exceptions and replacing them with grammatically preferable regular forms.

It should be emphasized that nothing in this system *requires* that overregularization/leveling must take place; as long as learners have sufficient access to input data, there is always the potential to learn and maintain irregularity in derived (=non-basic) forms. The model does not make specific predictions about *when* leveling will occur, except that we would obviously expect it when input data about exceptional forms is reduced, such as in low frequency words, reduced input because of bilingualism or language death, etc.; see also (Kuryłowicz 1947), (Bybee 1985), (Barr 1994), and Garrett (this volume) on this point. In fact, I am largely in agreement with Garrett's claim that the morphological change is driven diachronically by inaccurate or incomplete transmission of the full set of inherited forms. The current model differs from his account, however, in positing a cognitive constraint on the form of possible grammars: namely, that all morphological rules refer to the same base form as their input. This restriction is what allows the model to make strong predictions about directionality: when change occurs, it should always involve replacing an exceptional non-basic form with an innovative regularized form. Although this restriction is not a logically necessary part of the formalism, it receives empirical justification from the fact that analogy is overwhelmingly unidirectional, to a far greater extent than token frequency, memory failings, and chance would predict. In Classical Latin, nominatives were rebuilt on the basis of an oblique form, while in English, preterite forms were always rebuilt on the basis of presents (Garrett, this volume, p. xxx) and in Ancient Greek, presents were rebuilt on aorists (ibid., p. xxx), and so on.[7] I take such asymmetries to be the fundamental explicandum of analogical change.

Unlike the tendency-based approach, the confidence-based explanation of analogy aims to capture the directionality of *all* cases of paradigmatic change—a steep task, given the typological diversity of attested changes. In Albright (2002a), I examined several typologically unusual analogies, showing that they were indeed based on the most predictive, or informative member of the paradigm. In order to demonstrate the validity of this approach in general, however, two questions must be answered. The first is a question of coverage: are all analogical changes really based on the most predictive member of the paradigm, or are there cases in which analogy favors a less predictive member of the paradigm, contrary to the predictions of confidence maximization? The first goal of this paper is to examine one class of apparent counterexamples, using data from an analogical change currently underway in Korean. I will show that even though a form may appear to be radically uninformative when viewed schematically, it may actually be the most predictive form when we consider the language as a whole. Thus, some apparently exceptional changes need not be seen as a counterexamples at all, once we have a suitable understanding of the factors that play a role in the calculation of confidence.

The second question that must be answered is a typological one: can a confidence-based approach explain why certain types of analogy are extremely common, while others are relatively rare? In general, such questions play a secondary role in structural analyses; as long as the predicted patterns are a good match to the attested patterns, the question of why some are chosen more frequently is often ignored (though see, e.g., Harris (this volume) for one possible line of explanation). Nonetheless, the fact remains that analogy is very often based on unmarked or frequent members of the paradigm, and this fact demands some sort of explanation. The second goal of this paper, then, is to explore the behavior of the model when exposed to a

[7] See Garrett's treatment of apparent counterexamples in Greek (p. xxx), and also Tiersma (1982), Bybee (1985), for discussion of factors that might reverse the ordinary directionality of a change.

large range of possible input languages. I will show that because of the way that confidence is calculated, the model does indeed select bases with high token frequency a majority of the time; less frequent forms are chosen as bases only under somewhat extreme conditions, mirroring the observed typology.

Before we can answer these typological questions, however, it is first necessary to provide an overview of the synchronic model of base selection and grammar acquisition.

3 A synchronic model of paradigm acquisition

For languages with even a modest amount of morphological complexity, learners face a number of difficult tasks in learning to accurately understand and produce paradigms of inflected forms. They must learn what inflectional categories are marked in the language, what the relevant markers are, which words belong to which morphological classes, and which words exhibit irregularities or alternations that cannot be predicted by rule. Furthermore, if there is neutralizing phonology (as is often the case), the learner must be able to compare related forms, determining where in the paradigm one must look in order to discover the "true" form of certain segments. What makes the task especially hard, though, is that this must all be done on the basis of incomplete learning data; waiting around to hear and memorize every form of every word would be impractical at best, and outright impossible in most cases. It seems safe to say that human learners must bring a number of different resources to the task: exquisite memories for storing minute details of the learning data, an ability to find and compare the relevant pairs and discover the patterns that are present in the data, a means of evaluating competing patterns to learn which are productive, an urge to generalize and project beyond the data, and a set of principles that govern how generalization proceeds.

To date, no model has been implemented that can take on the whole problem, even with idealized learning data consisting of complete paradigms. In this section, I outline a model of one piece of the larger problem: it compares different parts of the paradigm to figure out which is most revealing about the properties of words, and develops a grammar of morphological and phonological rules to project the rest of the paradigm. This model assumes that the learner has already performed tasks such as segmenting the speech stream into words, representing words in some type of phonemic representation, and arranging the words into sets of forms that are hypothesized to be morphologically related.[8] In addition, it assumes that the learner has already performed some preliminary phonological learning, in the form of discovering that certain sequences are non-occurring (surface illegal) in the language.[9]

In order to understand how the model calculates predictiveness and constructs grammars, it is useful to start with a schematic example.

[8]Some models that take on the task of word segmentation include Allen and Christiansen (1996), Brent and Cartwright (1996) Cairns, Shillcock, Chater, and Levy (1997), and Brent (1999). The task of finding pairs of words that are hypothesized to stand in a morphological relationship is less well understood, though see Baroni (2000) and Goldsmith (2001) for unsupervised approaches to morpheme discovery.

[9]A number of studies have shown that infants acquire some knowledge about sequence probabilities as early as eight months—well before they know words or morphemes (Jusczyk, Friderici, Wessels, Svenkerud, and Jusczyk 1993; Friederici and Wessels 1993; Jusczyk, Luce, and Charles-Luce 1994)). It is not unreasonable to suppose that this knowledge is brought to bear on the task of learning alternations between morphologically related words; see Hayes (2004) and Tesar and Prince (2004) for specific proposals along these lines.

3.1 Searching for contrastive information within paradigms

Learning to produce inflected forms of words would be a relatively easy task if all lexical items took the same sets of endings, there were no exceptional irregular forms, and phonology never acted to neutralize surface contrasts. In such a language, the learner would simply need to compare related forms of a few words in order to ascertain the suffixes. For example, faced with the paradigms in (7) (based on a simplified version of Middle High German), the learner could infer that the nominative singular suffix is null, the genitive singular suffix is *-es*, and the nominative plural suffix is *-e*.[10]

(7) Paradigms with no alternations

Nom. sg.	Gen. sg.	Nom. pl.	Gloss
jar	jares	jare	'year'
kil	kiles	kile	'quill'
sin	sines	sine	'sense, mind'
arm	armes	arme	'arm'
ʃreɪ	ʃreɪes	ʃreɪ	'cry, shout'

Actual languages can, of course, be more complicated: phonology may act to neutralize surface contrasts in some parts of the paradigm, words may fall into different inflectional classes, and there may be irregular exceptions that fail to follow any of the major patterns. Consider the following sets of forms (again, based loosely on Middle High German), in which some forms show voicing alternations in the stem-final consonant (8a), while others do not (8b).

(8) Phonological neutralization

a. Stems with voicing alternations

Nom.sg.	Gen.sg.	Nom.pl.	Gloss
tot	todes	tode	'death'
nit	nides	nide	'enmity'
helt	heldes	helde	'hero'
sant	sandes	sande	'sand'
tak	tages	tage	'day'
tswik	tswiges	tswige	'branch'
diŋk	diŋges	diŋge	'thing'
vek	veges	vege	'way'
briəf	briəves	briəve	'letter'
kreɪs	kreɪzes	kreɪze	'circle'
lop	lobes	lobe	'praise'

b. Non-alternating stems

Nom.sg.	Gen.sg.	Nom.pl.	Gloss
mut	mutes	mute	'courage'
ʃrit	ʃrites	ʃrite	'step'
knext	knextes	knexte	'servant'
geɪst	geɪstes	geɪste	'spirit'
nak	nakes	nake	'nape'
blik	blikes	blike	'glance'
druk	drukes	druke	'pressure'
lok	lokes	loke	'lock (hair)'
ʃif	ʃifes	ʃife	'ship'
slos	sloses	slose	'lock'
ʃimpf	ʃimpfes	ʃimpfe	'taunt'

The data in (8) suggest that the language has a phonological process (such as final devoicing) which neutralizes the contrast between voiced and voiceless obstruents word-finally. In order to discover this, the learner must make two types of comparisons. First, by comparing nominative *tot* with genitive *tod-es*, it can be seen that some sort of process is operating to create voicing

[10] I leave aside the possibility that all nouns end in *-e* and that the nominative singular shows truncation, with *-s* and ∅ as the gen. sg. and nom. pl. suffixes, respectively. Such parsing problems can be non-trivial, however. For example, given just the first set of forms (*jar*, *jares*, *jare*), the learner might be uncertain about whether the *r* is part of the stem or the suffix. The procedure described below operates under the assumption that if material is shared by all morphologically related forms, it is part of the stem—that is, *jar-∅*, *jar-es*, *jar-e*.

alternations. Second, by comparing *tot* ∼ *todes* with *mut* ∼ *mutes*, one can infer that it is a devoicing process, and not a voicing one (or else we would expect genitive singular **mudes*). This is the basic logic behind many phonology problems: noticing that rules must operate in one direction rather than vice versa, because there is an unpredictable opposition which is neutralized in some forms but not in others. Furthermore, having discovered this, the learner also now knows that the nominative singular form is not a reliable source of information regarding the voicing of stem-final obstruents; for this, one must look to a suffixed form.

In addition to phonological neutralizations, the learner must also contend with the possibility of inflectional classes, which are not always distinct in all forms. For example, alongside the forms in (7) and (8), the language may have words like those in (9), which differ by changing their vowel in the plural form, or by taking a different suffix, or both.

(9) Stems in different inflectional classes

Nom.sg.	Gen.sg.	Nom.pl.	Gloss
sak	sakes	seke	'sack'
korp	korbes	kœrbe	'basket'
rok	rokes	rœke	'coat'
lip	libes	liber	'body'
vort	vortes	vort	'word'
liət	liədes	liəder	'song'
lant	landes	lender	'land'

The problem of discovering inflectional classes is usually treated as a separate problem from that of finding phonological contrasts, but the considerations are the same: an unpredictable difference seen in one part of the paradigm (here, the plural) may be neutralized in another part of the paradigm (i.e., the singular), forcing learners to look to a particular part of the paradigm for the crucial distinguishing information.

The task, then, is to discover that a contrast seen in form A in the paradigm is neutralized in form B. One possible approach would be to establish correspondences between every segment in form A and form B, checking to make sure that the relations were always one-to-one bijections (*x* always mapped to *y*). If a many-to-one relation is discovered (*x* maps to *y* in one word and to *z* in another), then we could infer that a contrast between *y* and *z* is neutralized to *x* in some environment. This is shown schematically in (10).

(10) Establishing correspondence between segments in related forms

a. One-to-one relation

$a_1 b_2 \mathbf{x}_3$ ∼ $a_1 b_2 \mathbf{y}_3$-suffix (tak ∼ tag-es)

$c_1 d_2 \mathbf{x}_3$ ∼ $c_1 d_2 \mathbf{y}_3$-suffix (tswig ∼ tswig-es)

b. One-to-many relation

$a_1 b_2 \mathbf{x}_3$ ∼ $a_1 b_2 \mathbf{y}_3$-suffix (tak ∼ tag-es)

$c_1 d_2 \mathbf{x}_3$ ∼ $c_1 d_2 \mathbf{z}_3$-suffix (druk ∼ druk-es)

This approach will discover neutralizations in any part of the paradigm, but it has one unappealing trait as a learning procedure: it presupposes that the learner is certain about the morphological analysis (*aby*-suffix, and not, say, *ab*-*y*suffix). The question, essentially, is whether the learner can be sure that *y* and *z* actually stand in a correspondence relationship with one another, or whether they belong to different morphemes that happen to put them in the same position in the word. Unless the learner can be sure that both segments belong to the same morpheme, it is impossible to infer that the opposition represents a phonological contrast that is neutralized elsewhere.

A different approach, which avoids this problem and mirrors the way that phonology students are often guided to the right solution, is to use an error-driven strategy: if adding a suffix to *abx* yields *aby*-suffix, then we incorrectly predict that adding the same suffix to *cdx* should yield **cdy*-suffix. For example, on the basis of forms like [jar] ∼ [jare] and [nak] ∼ [nake], we might expect the plural of [tak] to be *[take]. Since it is not, we know that something additional must be learned. There are numerous possibilities:

1. The difference between *y* and *z* is due to a doubly-conditioned phonological process, caused by *b* or *d* on the left and (at least some part of) the suffix on the right
2. The difference between *y* and *z* is underlying, and a phonological process neutralizes them to *x* word-finally
3. One of the outcomes is due to an irregular morphophonological process that affects only some words (in practice, this explanation is often handled in the same way as (2)
4. The segments *y* and *z* actually belong to two different suffixes, and the words belong to distinct inflectional classes

The plausibility of one hypothesis over another typically depends on considerations such as the number of words involved, the naturalness of the change, and so on. In the hypothetical example in (7)-(9), a phonological final devoicing analysis seems persuasive because of the number of words (and different segments) involved, the fact that the alternation cuts across different inflectional classes, and the naturalness of final devoicing as a phonological process. In order to conclude this with certainty, however, we need data from more that just a few words. Informally, analysts typically seem to assume that learners must entertain a number of hypotheses simultaneously, until there is enough data available to make one seem more likely than the others. In the next section, I outline a computationally implemented model that tries to do just this, bootstrapping preliminary information about morphology and phonology to evaluate competing hypotheses about how to account for apparent unpredictability.

3.2 Discovering contrastive information algorithmically

The premise of the current approach is that learners direct their attention to the part of the paradigm that provides as much information as possible about how to inflect words accurately—that is, avoiding errors like **heltes* for *heldes*, or **sake* for *seke* by learning that the former has an underlying /d/, and the latter is an umlauting (vowel-changing) stem. The procedure described in this section attempts to learn both phonological and morphological contrasts simultaneously, starting with a first-pass analysis of the morphological changes involved, attempting to learn some phonology, and using this to improve its morphological analysis. Finally, since it does not know where in the paradigm contrastive information may occur, it does this starting from every part of the paradigm, in order to determine which one yields the most accurate generalizations.

The input to the model is a set of paradigmatically related forms in phonetic transcription, such as the ones in (7)-(9) above. In order to permit generalizations about phonological environments, the model is also provided with a matrix of phonological feature values for the sounds of the language (that is, knowledge of phonological features is assumed to be "innate"). In addition, the model is provided with knowledge about sequences that are surface illegal in the language, in the form of a list of non-occurring sequences. In the case of a language with no word-final voiced obstruents, this list would include sequences like [b#], [d#], [g#], etc.

As discussed above, a key observation in discovering neutralizations is the simple fact that neutralizations lead to ambiguity, and thus, potential uncertainty. For instance, given a nominative singular form [mut], the learner is not certain whether the plural should be [mute], [mude], or even [myte], [myde], or some other form. Thus, if one were to construct a grammar that used the nominative singular as its input and tried to generate nominative plurals by rule, there would be some indeterminacy concerning both voicing and also the correct suffix to use. In such a case, the grammar might pick one of these outcomes as the regular outcome (for example, simply adding *-e* with no voicing or vowel change), but this would leave unaccounted for many "irregular" forms that took other patterns. Going from the plural to the singular, on the other hand, there is no ambiguity concerning final obstruent voicing: when the suffix is removed and the obstruent is put into final position, it must be devoiced.[11]

It is important to recognize that frequently, the seriousness of an ambiguity can be mitigated by means of clever and detailed rules that capture sub-generalizations about the patterns involved. In the sample data in (9), for example, we see that final obstruents are never voiced when they follow a fricative (pl. [knexte], [geɪste], but no forms like *[bexde], *[meɪsde]). At the same time, it happens that in this set of forms, [t] always voices after [n] ([sande], [lender] but no hypothetic *[bente], *[menter]). Stem-final [p] always voices ([lobe], but no *[rope]), while stem-final [pf] never does ([ʃimpfe], but no *[dimbve]). These small-scale generalizations (dubbed "islands of reliability" in Albright (2002b)) have the potential to recover a good deal of information about a contrast that has been neutralized. Furthermore, there is a growing body of experimental evidence showing that speakers are actually sensitive to such patterns (Zuraw 2000; Albright, Andrade, and Hayes 2001; Albright 2002b; Albright and Hayes 2003; Ernestus and Baayen 2003). Therefore, any attempt to estimate the seriousness of a neutralization must explore the possibility of "predicting one's way out of it" by means of such small-scale generalizations.

The Minimal Generalization model of Albright and Hayes (2002) is a model of grammar induction that is designed to do precisely this. It takes pairs of morphologically related forms and compares them, attempting to find the most reliable generalizations it can about the mapping from one form to the other. It starts by taking each data pair and comparing the input and output, to determine what has changed, and what is constant. The result is expressed as a word-specific rule, describing the mapping involved for just this one datum. For example, given the nominative singular and plural forms in (7)-(9), the Minimal Generalization algorithm would start by factoring each pair into a changing and non-changing portion, thereby determining that several changes seem to be involved. This is shown, for a subset of the data, in (11). At a first pass, the changing portion corresponds roughly to the affixes, and the constant portion can be considered the stem, though in cases where the voicing of the final obstruent is altered, we see

[11] Note that whichever direction is chosen, there may still be ambiguities concerning root vowel alternations—for example, singular [a] could correspond to plural [a] or [e], while plural [e] could correspond to singular [e] or [a]—though even here, the plural→singular mapping is less ambiguous (singular [u] may correspond to plural [u] or [y], but plural [y] almost always corresponds to singular [u]).

that this is also included as part of the change in this initial parse.

(11) Factoring the input data into change and context

Input	Output	Restated as a word-specific rule
mut	mute	∅ → e / mut ___ #
ʃrit	ʃrite	∅ → e / ʃrit ___ #
knext	knexte	∅ → e / knext ___ #
geɪst	geɪste	∅ → e / geɪst ___ #
jar	jare	∅ → e / jar ___ #
ʃreɪ	ʃreɪe	∅ → e / ʃreɪ ___ #
tot	tode	t → de / to ___ #
nit	nide	t → de / ni ___ #
helt	helde	t → de / hel ___ #
tak	tage	k → ge / ta ___ #
vort	vort	∅ → ∅ / vort ___ #

The next step is to generalize, by comparing word-specific rules that involve the same morphological change. For example, comparing the word-specific rules for *mut* ∼ *mute* and *ʃrit* ∼ *ʃrite*, the model posits a new rule added *-e* after any stem that ends in a [t] preceded by a high vowel:

(12) Generalization over pairs of related rules

Change	Residue	Shared features	Shared segments	Change location	Shared segments
∅ → e	m	u	t	___	#
∅ → e	ʃr	i	t	___	#
∅ → e	X	[+syllabic, +high]	t	___	#

The precise generalization scheme is as follows: moving outward from the change location, any strictly identical segments are retained in the generalized rule, in the "shared segments" term. Upon encountering a pair of mismatched segments, the model compares them to determine what feature values they have in common; these are retained as the "shared features." Finally, if either of the rules under comparison has additional material left over, this is converted to a free variable (here, 'X'). The search for shared material is carried out symmetrically on both the left and right sides. Here, the fact that the change is word-final is indicated by means of a shared word-edge symbol ('#'), but it could also be indicated simply by the lack of a free variable on the right side (meaning no additional material can be matched on this side).

The comparison in (12) happens to yield a rule that is scarcely more general than the word-specific rules that spawned it. When the process is iterated over the entire input set, however, much broader generalizations can emerge through comparison of heterogeneous input forms, including even context-free generalizations. One pathway to context-free *-e* suffixation is shown in Figure 1.

The goal of generalization is not merely to discover which contexts a change applies in, but also to discover where it applies reliably. This is assessed by keeping track of a few simple statistics. For each rule, the model determines how many forms in the input data meet the structural description of the generalization (data it tries to take on = its SCOPE), along with how many of those forms actually take the change required by the generalization (data it actually works for = its HITS). For example, consider the rule affixing [-e] after the sequence of a high

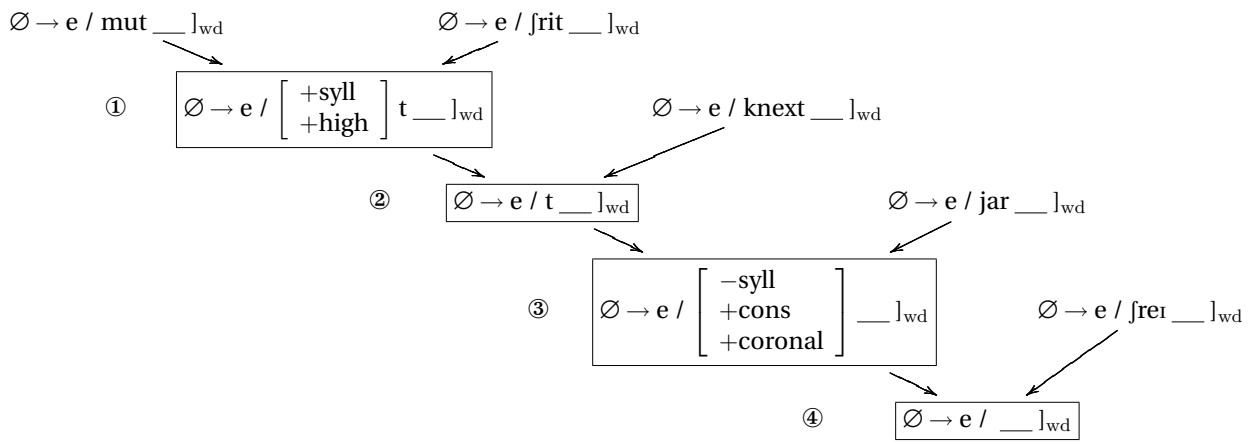

Figure 1: Iterative comparison yields broader generalizations

vowel followed by [t]: ∅ → e / [+syll, +high] t ___ #. Among the forms in (7)-(9), four contain high vowels followed by [t] ([nit], [mut], [ʃrit], and [liət], provided we treat the diphthong [iə] as high), so the scope of the rule is 4. Only two of these words form their plural by simple [-e] suffixation, however ([mute], [ʃrite]), while [-e] suffixation incorrectly predicts *[nite], *[liəte] instead of correct [nide], [liəder]; so, the [-e] suffixation rule has two hits, and two exceptions. The RELIABILITY of a rule is the proportion of its hits to its scope: here, 2/4 = .5. By comparison, the rule changing [t] → [de] could potentially cover 11 of the forms in (7)-(9) ([tot], [nit], [helt], [sant], [mut], [ʃrit], [knext], [geɪst], [vort], [liət], [lant]), but only 4 of them actually have voicing alternations, so this rule would have a reliability of $4/11 = .36$.

A model that values reliability above all else would try to find generalizations that have as few exceptions as possible—even if this meant carving the data up into a patchwork of small, independent generalizations to avoid admitting a few exceptions. In reality, we want to strike a balance between analyses that are accurate, and those that are general enough to capture the data insightfully and can extend the patterns correctly to novel items. This is achieved in the Minimal Generalization model by adjusting reliability values downward using lower confidence limit statistics, to yield a **confidence** score (Mikheev 1997). The result of this adjustment is that generalizations based on smaller amounts of data receive lower confidence scores: 2/2 = reliability of 1, confidence of .52, 5/5 = reliability of 1, confidence of .83, 20/20 = reliability of 1, confidence of .96, etc.[12] The relationship between the size of the generalization and the resulting confidence adjustment can be seen in Figure 2. By relying on confidence rather than on raw

[12]The lower confidence limit of a reliability ratio is calculated as follows: first, the reliability (probability) ratio, which we may call $\hat{p}$, is adjusted to avoid zeros in the number or denominator, yielding an adjusted value $\hat{p}^*$: $\hat{p}^* = \frac{hits+0.5}{scope+1}$. This adjusted value is then used to calculate an estimate of the true variance of the sample:

$$\text{estimate of variance} = \sqrt{\frac{\hat{p}^* \times (1-\hat{p}^*)}{n}}$$

This value is then used to calculate the lower confidence limit (π_{Lower}), at a particular confidence value α:

$$\pi_{Lower} = \hat{p}^* - z_{(1-\alpha)/2} \times \sqrt{\frac{\hat{p}^* \times (1-\hat{p}^*)}{n}}$$

The confidence value α ranges from $.5 < \alpha < 1$, and is a parameter of the model; the higher α is, the greater the penalty for smaller generalizations. In the simulations reported here, I will always assume an α of .75. The value z for a particular confidence level α is found by consulting a standard statistics look-up table.

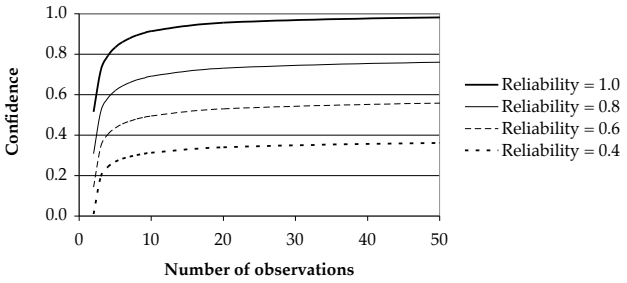

Figure 2: Relationship between amount of data and confidence limit adjustment

reliability, the model is able to favor broader generalizations (i.e., ones with more observations in their scope), even if they involve a few exceptions. As we will see in section 4.1, this adjustment also plays a crucial role when different amounts of data are available from different parts of the paradigm.

The process described thus far yields a rather uninsightful analysis of voicing alternations—namely, that words with voicing alternations constitute a separate inflectional class which take a different set of suffixes (sg. *-t*, pl. *-de*). The learner arrives at this analysis because the initial parse of the morphology occurs prior to any learning of phonological alternations, so there is no way of knowing that the [t] $\sim$ [d] alternation could be explained on phonological grounds. During the course of assessing the reliability of generalized rules, however, there is an opportunity to improve on this analysis, in the following way: when the model discovers that a form meets the structural description of a rule but does not obey it, an error is generated, which can be inspected for phonotactic violations. If the incorrectly predicted form contains an illegal sequence, then there may be a phonological rule involved, and the model attempts to posit a rule that fixes the incorrect form, transforming it into the correct, observed one.

To take an example, when evaluating the morphological rule $\varnothing \rightarrow$ e / [+syll, +high] t ___ # discussed above, the model observes that the rule correctly generates the forms [mute] and [ʃrite] (two hits), but it incorrectly predicts the forms *[nite] and *[liəte] (for [nide] and [liəder], respectively). There are two possible reasons why the rule generates the wrong outcome: either it doesn't apply to these words, or it does apply, but an additional phonological rule is needed to yield the correct surface output. Put more concretely, although the output *[nite] is incorrect, if the language had a process of intervocalic voicing, this would explain why the observed output is actually [nide]. The viability of an intervocalic voicing rule is tested by consulting the list of illegal sequences to see whether intervocalic [t] is known not to occur. In this case, we find that the hypothetical rule is not viable, since intervocalic [t] is fine in this language (in fact, it occurs in forms like [ʃrite]). Thus, we correctly discover that if we take the nominative singular as our starting point, there is no more insightful analysis to be had; all we can say is that there is an irregular competing process that sometimes changes [t] to [d].

Let us now contrast this with an analysis using the nominative plural as an input. Here, the changes that we observe include removing a suffix (e.g., [e] $\rightarrow \varnothing$), and removing a suffix with a concomitant voicing readjustment (e.g., [de] $\rightarrow$ [t], as in [tode] $\rightarrow$ [tot]). As above, iterative generalization discovers a range of possible contexts characterizing the two changes, and the model evaluates the reliability of all of these generalizations. Now the context-free rule for [e] $\rightarrow \varnothing$ makes the correct prediction for forms like [mute] and [ʃrite], but for plural [tode], [nide], and [tage], it incorrectly predicts singular *[tod], *[nid], and *[tag]. This time, the incorrect predictions could be fixed by a rule of final devoicing. When the erroneous predictions are

compared against the list of illegal sequences, we find that final voiced obstruents are in fact illegal, and a final devoicing rule is viable. With a phonological devoicing rule in place, forms like [tot] and [nit] can be derived by the simpler [e] → ∅ rule, and the reliability of this rule improves. Thus, by taking the plural as a starting point, the learner is able to come up with a unified analysis of the voiced and voiceless-final stems in (8).

We see from this example that when a form suffering from neutralizations is used as the input to the grammar, the resulting rules are less accurate and less reliable, since they have to make guesses about essentially unpredictable properties. This suggests a straightforward strategy for discovering which form in the paradigm exhibits the most contrasts: simply take each form in the paradigm and try learning grammars that derive the remaining forms from it. The slot in the paradigm that yields the most accurate, most reliable grammars is then chosen as the base of the paradigm, and the remaining forms are derived from it by means of morphological and phonological rules. Thus, the base form is chosen in order to maximize confidence in the remainder of the paradigm.

As noted in section 2.2, the confidence maximization approach has the potential to explain why analogical change sometimes takes the typologically unusual step of rebuilding more frequent, less marked forms. In the current example, based on Middle High German, we see that final devoicing made the nominative singular a relatively unpredictive form, while the number of different plurals suffixes would have made encouraged selecting a plural form as a base. This prediction seems to be borne out for real Middle High German: both Modern German and Yiddish show leveling of vowel length from the plural form (Paul, Wiehl, and Grosse 1989, §23), while Yiddish and some Bavarian dialects show the additional leveling of final obstruent voicing, discussed in section 2 above.

3.3 The single surface base hypothesis

In the example in the previous section, all phonological and morphological contrasts were aligned so they were most clearly visible in the same part of the paradigm (the plural). Often this is not the case, however. In fact, different parts of the paradigm frequently maintain different information, since phonological and morphological neutralizations can theoretically target any slot within the paradigm. For this reason, it is generally assumed that learners are able to compare multiple forms of inflected words to arrive at their lexical representation (Kenstowicz and Kisseberth 1977).

In Albright (2002a), a more restrictive model of acquisition is proposed: when no single part of the paradigm maintains all contrasts, the learner is forced to choose the single form that is generally most predictive, even if this means losing information about certain contrasts. This constraint can be called the **single surface base hypothesis**, since it requires that all paradigms of all words be organized around the same base form.

To see how the single surface base constraint works, let us consider some additional data from the history of German. At some point in Old High German or early Middle High German, the phoneme [h] (from older [χ] or [x]) was lost intervocalically (Braune and Mitzka 1963, §152b; Paul, Wiehl, and Grosse 1989, §111, §142). This created paradigmatic alternations, still seen in Modern German *hoch* [hoːx], *höher* [hœːɐ], *am höchsten* [hœːçstən] 'high/higher/highest'. It also created alternations in noun paradigms, since [h] deleted in forms with vowel-initial suffixes, such as the plural:

(13) Stems ending in (older) [h] ∼ [x]

Nom. sg.	Nom. pl.	Gloss
ʃux	ʃuː(w)e	‘shoe’
rex	reː(j)e	‘deer’
flox	flœːe	‘flea’

This change created a neutralization in the plural with nouns that did not have historical /h/:

(14) Stems without historical /h/

Nom. sg.	Nom. pl.	Gloss
kuː	kyːe	‘cow’
weː	weː(j)e	‘woe’

Furthermore, an independent change of older [k] > [x] in Old High German also worked to create a neutralization in the singular, with non-alternating [x] nouns:

(15) Stems without historical /k/

Nom. sg.	Nom. pl.	Gloss
bux	byxer	‘book’
bax	bexe	‘stream’
pex	pexe	‘pitch’
kox	kœxe	‘cook’

Such nouns went against the overall trend for contrasts to be preserved more faithfully in the plural; in fact, in each part of the paradigm, there is one contrast and one neutralization (the NEUTRAST configuration; Kager, in press). In order to learn whether a word had stem-final /h/ or not, learners would have had to compare also the nominative singular for this set of words.

For a learner operating under the single surface base restriction, however, such a strategy is not possible. Since the nominative plural form is most informative about the majority of other contrasts in the language, it must serve as the base for these words, as well.[13] As a consequence, this class of words must be stored without the [x] or /h/. Furthermore, since Middle High German had so few words with historical /h/, the rule “restoring” it in the nominative singular (e → x / [+syll] ___ #, producing derivations like [ʃuːe] → [ʃux]) would have had extremely low confidence. Thus, under this restriction, the grammar of MHG could not possibly have generated forms like [ʃux] or [flox] productively with high confidence rules. The only way to produce such forms would have been to memorize them as irregular exceptions, in order to block the grammatically expected forms [ʃuː], [reː], [floː].

The single surface base restriction seems drastic, but it makes the right prediction. If we assume that errors (by children or by adults) are overwhelmingly overregularizations (that is, replacement of irregular forms by grammatically expected regular forms), then we predict that older /h/ words should have lost the [x] in the nominative, as innovative regularizations ([floː]) gradually replaced the older irregulars ([flox]). We do not predict the converse changes of importing [x] to the plural (on analogy with [kox] ∼ [kœxe]) or deleting the [x] in historical /k/ words ([kox] ∼ [kœe], on analogy with [flox] ∼ [flœe]). Under this model, the failure of [flox]-type words to interact with [kox]-type words is due to the simple fact that historical /h/ and /k/

[13] This discussion is predicated on the (almost certainly true) assumption that words ending in obstruents outnumbered words ending in historical /h/ in Middle High German.

words remained distinct in the plural ([flœe] vs. [kœxe]). And in fact, this prediction is borne out: words like [ʃux], [rex] and [flox] lost their [x] by analogy (Paul, Wiehl, and Grosse 1989, §25c, p. 44; Molz 1906, p. 294), and are pronounced [ʃu:], [re:], and [flo:] in Modern German, while historically vowel-final and *k*-final words remained unchanged.

This example shows how the current approach can make very specific predictions about particular instances of analogical change. It predicts not only which form in the paradigm will be affected (non-basic forms, which are open to rebuilding if they cannot be generated correctly by grammar), but also which direction the change will go in (regularization to the lexically dominant pattern). By using a synchronic model of paradigm acquisition to predict asymmetries in possible errors, we are able to achieve a more constrained and explanatory theory of the direction of analogy.

This model has been shown to work in several other unusual cases of analogy, as well. In Albright (2002a), I showed that it made the right predictions for three typologically unusual paradigmatic changes. The first was a case of across-the-board leveling to the 1sg in Yiddish verbs, in violation of the tendency to level to the 3sg. In this case, the advantage of the 1sg appears to be due to the devoicing or even total loss of stem-final obstruents which occurs in the 2sg/3sg/2pl, together with the fact that the 1sg maintains a contrast in stem-final schwas which is sometimes difficult to recover from the 1pl/3pl/infinitive. Since the 1sg is the only form that maintains all of these contrasts, it is the most predictive, and is (correctly) chosen to serve as the base.

The second unusual change involved the elimination of [s] $\sim$ [r] alternations in Latin (the famous *honor* analogy), in which the nominative singular form of noun paradigms was rebuilt on the basis of an oblique form. As with the MHG case discussed here, the preference for a suffixed form in Latin seems to be due to phonological processes that affected word-final obstruents. The details of the change, which affected only polysyllabic non-neuter nouns, are also correctly predicted by a model that uses probabilistic rules to capture lexical tendencies in different contexts.

The final case involved an analogical change in Lakhota verbs which appears to have been based on the 2sg. In this case, the neutralizations involved were both more complex and more symmetrical, but the advantage of the 2sg seems to have come from the fact that it maintained the contrast between two large classes of words which were neutralized elsewhere in the paradigm. For details on all of these changes, the reader is referred to Albright (2002a).

The upshot of this section is that the proposed model makes advances in explaining the "language particulars" of analogical change. What remains to be shown, however, is whether it has anything to say about universal tendencies.

4 Typological tendencies: exploring the parameter space of the model

The model laid out in the previous section makes a strong claim about base forms in paradigms. It posits that bases play an integral role in the synchronic organization of grammar, and that they are chosen in order to facilitate, or optimize, the resulting grammar. A base form is considered optimal in this system if it contains enough information to reliably predict the remaining forms in the paradigm, by preserving contrasts and lacking neutralizations. This procedure for selecting base forms seems rational as a theory of how synchronic grammars are organized, and also makes the correct predictions for individual cases which are typologically unusual. In this section, I show that this procedure also makes the correct typological predictions.

There are two distinct issues that must be addressed in assessing the typological predictions of the model. The first is the issue of empirical coverage: are there attested analogies which run counter to the hypothesis that base forms are always the most informative form? The second issue is one of relative frequency: in principle, contrasts could be maintained anywhere in the paradigm (1sg, 2sg, 3sg, etc.), and in many cases, contrasts are maintained equally well by multiple forms. Why is there a strong tendency for analogy to be based on the most frequent or least marked forms?

I will consider each of these questions in turn.

4.1 Leveling to "uninformative" base forms

A common criticism of proposed principles of analogy is that there always seem to be exceptions: even if analogy usually extends the most frequent, the least marked, or the unsuffixed form, occasionally it goes in the opposite direction, extending a less frequent, more marked, suffixed form. Under a tendency-based approach, such exceptions are not a necessarily problem, since the goal is to explain only what is *likely*, not what is *possible*. The current model makes a stronger claim, however, that the direction of analogy should be predictable in all cases. The question immediately arises, therefore, whether there are exceptions to the informativeness-based account of analogy, just as there are exceptions to every other proposed tendency.

There are in fact a number of well-known examples of analogies based on pivot forms that appear to involve massive neutralizations. One case that is often cited comes from Maori (Hohepa 1967; Hale 1973; Kiparsky 1978; Hock 1991, pp. 200-202; Barr 1994, pp. 468-477; Kibre 1998). In Maori, passives were historically formed by adding a vowel-initial suffix (generally *-ia* or *-a*) to the verb stem: *awhit* → *awhit-ia* 'embrace', *hopuk* → *hopukia* 'catch', and so on. Subsequently, word-final stops were deleted (*awhit* > *awhi*) creating alternations within verb paradigms:

(16) Unpredictable consonants in Maori passive

Verb	*Passive*	*Gloss*
awhi	awhi**t**ia	'embrace'
hopu	hopu**k**ia	'catch'
aru	aru**m**ia	'follow'
waha	waha**ŋ**ia	'carry on back'
mau	mau**r**ia	'carry'
wero	wero**h**ia	'stab'
hoka	hokaia	'run out'
patu	patua	'strike, kill'

What makes the Maori case notable is the fact that the passive suffix has apparently been reanalyzed as a set of competing consonant-initial suffixes (*-tia*, *-kia*, *-mia*, *-ŋia*, *-ria*, *-hia*, etc.), and the *-tia* and *-a* suffixes have gradually been replacing the remaining allomorphs: for example, newer *wahatia*, *wahaa* alongside older *wahaŋia*. In other words, passive forms are being analogically rebuilt on the basis of the unsuffixed stem, even though it lacks information about unpredictable final consonants.

A similar change is underway in present-day Korean, in which noun paradigms are being rebuilt on the basis of unsuffixed (isolation) forms, even though these forms suffer from drastic

coda neutralizations. In Korean, all obstruents are realized as unreleased stops in coda position; thus, for example, underlying /nat/ 'grain, kernel', /nat^{h}/ 'piece', /nas/ 'sickle', /nac/[14] 'daytime', and /nac^{h}/ 'face' are all pronounced [nat̚]. In suffixed forms, however, stem-final consonants are intervocalic, and underlying contrasts are generally preserved in conservative speech and in standard Korean orthography (e.g., accusative [nad-ɨl], [nat^{h}-ɨl], [nas-ɨl], [naj-ɨl], [nac^{h}-ɨl]). The result is that noun paradigms frequently contain alternations:

(17) Alternations in Korean nouns (conservative pronunciation)

Unmarked	Accusative	Gloss
nat̚	nadɨl	'grain'
nat̚	nat^{h}ɨl	'piece'
nat̚	nasɨl	'sickle'
nat̚	najɨl	'daytime'
nat̚	nac^{h}ɨl	'face'

These underlying contrasts are gradually being lost in present-day Korean, but interestingly, the change has gone in the direction of replacing all stem-final coronals with /s/ or /c^{h}/: older [nat^{h}-ɨl] ⇒ newer [nac^{h}-ɨl], [nas-ɨl] (Ko 1989 [cited by Kang 2002]; Hayes 1995, 1998; Kenstowicz 1997; H. Kim 2001, p. 104; Y. Kang 2002, 2003; Davis and H. Kang 2003; H. Ko, in press; Sohn, n.d.; Lee, in progress; and many others).

(18) Analogical innovations in suffixed forms

Unmarked	Conservative acc. form	Newer acc. form	Gloss
k'ot̚	k'oc^{h}-ɨl	k'oc^{h}-ɨl, k'os-ɨl	'flower'
pat̚	pat^{h}-ɨl	pat^{h}-ɨl, pac^{h}-ɨl, pas-ɨl	'field'
cət̚	cəj-ɨl	cəj-ɨl, cəs-ɨl	'milk'

It appears that the [t̚] ∼ [s] and [t̚] ∼ [c^{h}] alternations are being analogically extended, and that the pivot, or base of the change is the unmarked form ending in [t̚].[15] Similar changes are also taking place at other points of articulation, with [p] and [k] gradually replacing [p^{h}] and [k^{h}]. Like the Maori example, this analogy appears to be based on a far *less* informative base form.

What are we to make of such exceptions? One possibility would be to concede that informativeness, like frequency, markedness, and so on, is just one of many factors that determine the direction analogy, and that it, too, has exceptions. I believe this conclusion is premature, however, and that even these apparent counterexamples can be handled within an informativeness-based approach. In this section, I will show that when the informativeness of the various Korean noun forms is calculated, it turns out that unmarked forms are, surprisingly,

[14] The precise realization of the obstruents conventionally transcribed as [c], [c^{h}], [c'] (〈ㅈ, ㅊ, ㅉ〉) is subject to a fair amount of individual and dialect variation. They are considered by some to be alveolar affricates (Cho 1967, p. 45; H. Kim 1999), by others to be postalveolar or palatal affricates (Kim-Renaud 1974; Ahn 1998, p. 55), and by yet others to be palatal stops (e.g., Sohn 1999, p. 153); see Martin (1992, pp. 28-29) for discussion. I follow majority opinion in calling them [−anterior] affricates, but nothing in the discussion that follows depends on their exact featural representation. I will (non-standardly) use [j] to indicate the intervocalically voiced counterpart of lax [c].

[15] An alternate possibility, advocated by H. Kim (2001), is that the change from [t, t^{h}, c, c^{h}] to [s] is simply a phonetic sound change. Kang (2002) provides detailed empirical evidence showing that although the change to [s] is most advanced in environments where it is phonetically natural, it is also taking place in other, unnatural environments. (See also (Comrie 1979) and Garrett, this volume, on the related issue of natural alternations resisting analogical change.) Furthermore, a purely phonetic account could not explain why the change to [s] is restricted to nouns.

Table 1: Korean obstruent inventory

		Labial	Coronal	Velar
Stops	Unaspirated (lenis)	p	t	k
	Aspirated	p^h	t^h	k^h
	Tense (fortis)	p'	t'	k'
Affricates	Unaspirated (lenis)		$\widehat{tʃ}$	
	Aspirated		$\widehat{tʃ}^h$	
	Tense (fortis)		$\widehat{tʃ}$'	
Fricatives	Unaspirated (lenis)		s	
	Tense (fortis)		s'	

more informative than suffixed forms. The reason is twofold: first, the coda neutralizations shown in (17) actually cause very little ambiguity in practice, due to statistical asymmetries in the lexicon of Korean. Second, unmarked forms are overwhelmingly more frequent than suffixed forms, so learners receive much more learning data about them. Once the lexical statistics of Korean and the relative availability of forms are taken into account, it emerges that the isolation form is actually the most reliable base form for Korean.

4.1.1 Neutralizations affecting Korean noun paradigms

Korean nouns are marked for case, as shown in (19). The case markers (referred to variously as suffixes or as particles in the literature) correspond roughly to functions such as nominative, accusative, dative, etc., though their distribution and syntax differ considerably from their equivalents in Indo-European languages (Sohn 1999, pp. 231f, pp. 326-350). In addition, case marking is often optional, and nouns may occur in unmarked (bare) forms. Finally, many cases have separate markers for consonant- and vowel-final nouns, such as nominative *-ka* (after consonants) vs. *-i* (after vowels). Partial paradigms for representative consonant and vowel final nouns are given in (19).

(19) Korean case marking for consonant- and vowel-final nouns (partial list)

	/k^hoŋ/ 'bean'	/k^ho/ 'nose'
Unmarked	k^hoŋ	k^ho
Nominative	k^hoŋ-i	k^ho-ka
Accusative	k^hoŋ-ɨl	k^ho-ɾɨl
Dative/Locative	k^hoŋ-ey	k^ho-ey
Genitive	k^hoŋ-ɨy	k^ho-ɨy
Topic	k^hoŋ-ɨn	k^ho-nɨn

Noun inflection is complicated by the fact that Korean has a number of phonological processes that give rise to alternations within the paradigm. Perhaps the most salient of these is the neutralization of all obstruents to unreleased stops in coda position. The obstruent inventory of Korean, which is shown in Table 1, contains several different manners (stops, affricates, and fricatives), as well as three different laryngeal settings (plain unaspirated [C], aspirated [C^h], and tense, or fortis [C']). Among labials and velars, this results in a three way contrast (/p, p^h, p'/, /k, k^h, k'/), while among coronals, there are eight different phonemes: /t, t^h, t', $\widehat{tʃ}$, $\widehat{tʃ}^h$, $\widehat{tʃ}$', s, s'/.

Word-initially, all of the laryngeal and manner distinctions are contrastive. In coda position, however, only unreleased stops are allowed: [p̚, t̚, k̚]. As as result, when a noun is unmarked for case, the final consonant of the stem is subject to neutralization. For example, the three-way contrast between /k/, /kʰ/, and /k'/, which is maintained in suffixed forms (at least in conservative speech), is neutralized to [k̚] in unsuffixed forms (20a). The same is true in principle for the labial stops /p/, /pʰ/, and /p'/, although in practice there seem to be no noun stems ending in /p'/ (20a).

(20) a. Neutralization of /k/, /kʰ/, and /k'/ in unmarked forms

UR	Unmarked	Nominative	Accusative	Gloss
/cʰuək/	cʰuək̚	cʰuəg-i	cʰuəg-ɨl	'reminiscence'
/puəkʰ/	puək̚	puəkʰ-i	puəkʰ-ɨl	'kitchen'
/pak'/	pak̚	pak'-i	pak'-ɨl	'outside'

b. Neutralization of /p/ and /pʰ/ in unmarked forms

UR	Unmarked	Nominative	Accusative	Gloss
/ip/	ip̚	ib-i	ib-ɨl	'mouth'
/ipʰ/	ip̚	ipʰ-i	ipʰ-ɨl	'leaf'

Among coronal obstruents, coda neutralization is even more severe, as the [nat̚] example in (17) above shows. In this case, however, the full set of underlying contrasts is not visible in the nominative either, due to an additional process of palatalization before the high front vowel [i]. This palatalization changes /t/ and /tʰ/ to [c] and [cʰ], respectively, before [i] in derived environments.

(21) Neutralization of coronals in unmarked and nominative forms

UR	Unmarked	Nominative	Accusative	Gloss
/nat/	nat̚	nac-i	nad-ɨl	'grains'
/nac/	nat̚	nac-i	nac-ɨl	'daytime'
/natʰ/	nat̚	nacʰ-i	natʰ-ɨl	'piece'
/nacʰ/	nat̚	nacʰ-i	nacʰ-ɨl	'face'
/nas/	nat̚	naʃ-i	nas-ɨl	'sickle'

From the distribution of contrasts in (21), we see that stem-final [t, tʰ, c, cʰ, s][16] are completely distinct only when the suffix begins with a vowel other than [i], such as in the accusative. Therefore, as far as final obstruents as concerned, it appears that the accusative would be the most reliable source of information about the properties of a Korean noun, even though it is suffixed, less frequent (see below), and more marked.

There are several reasons why this picture of Korean noun paradigms is incomplete, however. First, the coda neutralizations in (20)-(21) are not nearly as serious as they appear. In principle, coda [t̚] could correspond to any of [t, tʰ, t', t͡ʃ, t͡ʃʰ, t͡ʃ', s, s']. In practice, however, most of these are rare or unattested word-finally. In (22), corpus counts are given from the 43,932 nouns in the Sejong project corpus[17] (Kim and Kang 2000). These counts may be taken to represent an older stage of Korean, since nouns in the corpus are listed in standard Korean orthography, which is relatively conservative in representing final obstruents.

[16] There are no noun stems ending in the tense coronal obstruents [t', c', s'].

[17] http://sejong.or.kr

(22) Distribution of final obstruents

a. Labials

p	1360
p^h	64
p'	0

b. Coronals

t	1
t^h	113
t'	0
c	17
c^h	160
c'	0
s	375
s'	0

c. Velars

k	5994
k^h	18
k'	6

These counts reveal several important facts. First, obstruent-final nouns are somewhat underrepresented, accounting for total of only 8,108, or roughly 18% of Korean nouns. This can be compared with 17,344 vowel-final stems (39%), and 18,477 sonorant-final stems (42%). Within the obstruents, there are drastic asymmetries between different places of articulation. First, coronals are relatively underrepresented in comparison to the other places of articulation.[18] Furthermore, among labials and velars, plain (unaspirated) stops are most common stem-finally, particularly among velars. By contrast, among coronals, [t] is virtually unattested, while almost 80% of the stems end in /s/ or /c^h/.

These facts conspire to make final segments far more predictable than the examples in (20)-(21) would suggest. For the 80% of the vocabulary which ends in vowels or sonorant consonants, the final segment surfaces faithfully in all parts of the paradigm, including the unmarked form. For labial and velar obstruents (17% of the vocabulary), [p̚]/[k̚] in the unmarked form corresponds to plain [p]/[k] in suffixed forms 99% of the time. The only nouns for which the unsuffixed form is truly uninformative are those that end in [t̚] (just 1.5% of the vocabulary), and even here, chances are high that the stem ends in [s] or [c^h] in suffixed forms.

In order to confirm the fact that final segments are, by and large, predictable in Korean, I carried out a simulation using the minimal generalization learner to learn Korean noun paradigms. Nouns from the Sejong corpus were romanized using the HCode Hangul Code Conversion software (Lee 1994), and then converted to a broad phonetic transcription using the set of phonological rules outlined by Yoon, Beckman, and Brew (2002) for use in Korean text-to-speech applications. Finally, input files were created containing the 200 most frequent nouns, in their unsuffixed, nominative (-i/-ka), and accusative (-il/-ɾil) forms. The minimal generalization learner was then trained on the task of predicting accusative forms on the basis of either unmarked or nominative forms.

Unsurprisingly, the results show that it is easier to predict the accusative form using the nominative (suffixed) form than the unsuffixed form, because there are fewer neutralizations involved. It is worth noting, however, that the difference is extremely small, owing to the small number of words that are actually affected by these neutralizations, and the possibility of guessing strategically based on the neighboring segmental context. The numbers in (23) confirm the claim that suffixed forms of Korean nouns are extremely predictable no matter what form is used as the base: no matter which direction is chosen, it is possible to learn a grammar that predicts the correct outcome over 97% of the time, employ rules that have very high confidence

[18] The magnitude of this difference is somewhat smaller if Sino-Korean items are excluded, since Sino-Korean final [p] and [k] were borrowed faithfully, but final [t] was adapted as [l]. There is no reason to exclude these items from discussion (since the changes discussed here happened well after the influx of Sino-Korean borrowings), but even if they are excluded, it still appears to be the case that coronals are surprisingly underattested.

values attached to them (>.97 out of 1). Virtually identical results were obtained using input files of different sizes (the 100, 500, and 1000 most frequent nouns).

(23) Relative informativeness of unmarked vs. nominative forms

	Accuracy of Grammar	Mean Confidence
Unmarked → Accusative	97.5%	.971
Nominative → Accusative	98.6%	.986

Finally, it is necessary to consider the informativeness of the accusative form as a potential base, since it preserves all obstruent contrasts, and thus appears to be even more informative than the unmarked or nominative forms. As it turns out, this is not true when we consider the lexicon as a whole, rather than just obstruent-final nouns. The reason is that accusative marker has two shapes: *-ɨl* after consonants, and *-ɾɨl* after vowels. The two liquids [l] and [ɾ] are in allophonic distribution in Korean: [l] occurs in coda position, and [ɾ] occurs intervocalically. Thus, when a noun ends in the consonant /l/, it takes the *-ɨl* allomorph of the accusative marker, and the stem-final /l/ becomes [ɾ]: /il-ACC/ 'work' → [iɾɨl]. However, this is the same result that one would get from a vowel-final stem followed by the *-ɾɨl* allomorph: /i-ACC/ 'teeth' → [iɾɨl]. As a consequence, accusative forms ending in [ɾɨl] are potentially ambiguous: they could be parsed as an /l/-final stem with the *-ɨl* allomorph, or a vowel-final stem with the *-ɾɨl* allomorph.[19] Furthermore, this situation could arise quite often. Counts from the Sejong corpus show that 17,344 out of 43,932 nouns (39%) end in vowels, while 3,472 (8%) end in /l/. This means that up to 47% of accusative forms end in *-ɾɨl*, and are thus ambiguous with respect to how the remainder of the paradigm should be formed.

The relative unreliability of the accusative as a base form was confirmed by carrying out learning simulations in the accusative→unmarked and accusative→nominative direction, again on the 200 most frequent words in the Sejong corpus. As the table in (24) shows, using the accusative to project the unmarked and nominative forms does lead to more mistakes and more uncertainty than the other way round, because of *-ɨl*/*-ɾɨl* ambiguities. It might also be noted that in spite of these errors, overall performance is nonetheless quite good. This is an example of what Hayes (1999) calls *multiple predictability*: all of the forms in the paradigm are mutually predictable to a greater extent than is logically necessary.

(24) Relative informativeness of unmarked vs. nominative forms

	Accuracy of Grammar	Mean Confidence
Accusative → Unmarked	93.0%	.929
Accusative → Nominative	93.5%	.932

The overall informativeness of the unmarked, nominative, and accusative forms is summarized in Figure 3, which shows the average confidence with which each form may be used to predict the remaining two forms. The graph serves to reiterate the point that once we move beyond just obstruent-final nouns and look at the language as a whole, the unmarked and nominative forms are actually more informative than the accusative, even though they appear at first glance to suffer from more serious neutralizations. This finding is significant for two reasons: first, it is a vivid demonstration of how "informativeness", in the sense that I am using it

[19] Likewise [pʰaɾɨl] from /pʰa/ 'green onion' or /pʰal/ 'arm', [naɾɨl] from /na/ 'I' or /nal/ 'day', [saɾɨl] from /sa/ 'four' or /sal/ 'flesh', [maɾɨl] from /ma/ 'the south' or /mal/ 'horse', and many others. It should be noted that Korean orthography does differentiate stem-final vs. suffix-initial /l/, but this is a purely morphemic (and not phonetic) distinction.

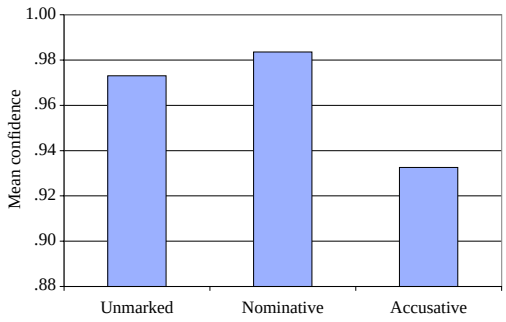

Figure 3: Relative informativeness of Korean noun forms, as measured by mean confidence in projecting the remainder of the paradigm

here, is difficult to intuit on the basis of schematic data, and can be calculated for certain only by running simulations on representative learning data. More important, this result brings us one step closer to understanding the Korean change, since it reveals that although the unmarked form is not the *most* informative form, it is extremely close (a 1% difference).

One fact that we have not yet considered is the relative token frequency of the various noun forms in Korean. Token frequency does not play any direct role in the model, as it was described in section 3. However, token frequency can play an important indirect role in determining what data a learner is likely to encounter. In the following section, I will show that differences in token frequency make the unmarked form a more reliable base form in Korean, in spite of the fact that it is slightly less informative.

4.1.2 Availability of forms: the influence of token frequency

The simulation results presented in the previous section assume that all words are equally available to the learner in all forms (unmarked, nominative, accusative, etc.). In real life, however, learners plainly do not have equal access to all forms. For more frequent parts of the paradigm, lots of input data will be available, including forms of both common and rare lexical items. For less frequent parts of the paradigm, however, less input data is available, and on average, only the more common words will have been encountered.

In Korean, the frequency difference between the various inflected forms is striking. Case marking is often omitted, particularly on accusative nouns. The relative token frequency of unmarked, nominative-marked, and accusative-marked nouns taken from counts of child-directed speech is given in (25). (Counts from non-child-directed speech show a similar, but slightly less drastic frequency difference.)

(25) Relative frequency of Korean nouns forms in child-directed speech (I. Lee 1999)

Form	Approximate % of all tokens
Unsuffixed	75%
Nominative	20%
Accusative	5%

The relative lack of data for forms like the accusative has an indirect impact on its reliability as a base form. Recall from Fig. 2 above that in the rule evaluation scheme employed by the

minimal generalization learner, there is a statistical confidence adjustment that rewards rules based on more data. The effect of this adjustment is to penalize rules that have been tested against just a few forms. Its main purpose is to reward patterns that are well-instantiated, by giving them slightly higher confidence, and hence a greater productivity. A side-effect of this adjustment, however, is that it rewards parts of the paradigm that are well-instantiated, since their grammars are based on more data, and thus receive overall less downward adjustment. Might this penalty be sufficient to tip the scales in favor of selecting a slightly less informative, but more frequent form as a base?

In order to test this, another simulation was performed, this time taking token frequency into account. Starting once again with the 43,932 nouns in the Sejong corpus, a simulated "Parental Locutionary Device" was constructed, which randomly produced inflected noun forms, chosen in Monte Carlo fashion according to both their lexical frequency and the relative frequency of the inflection. The probability of choosing a particular inflected form was calculated as in (26):

(26) $P(\text{inflected form}) = P(\text{lemma}) \times P(\text{inflection})$

The simulated parent produces common words more often than uncommon words, and frequent parts of the paradigm more often than infrequent parts of the paradigm. When asked to produce 1000 tokens of Korean nouns, on average it produces 750 unmarked tokens, 200 nominative tokens, and 50 accusative tokens, respecting the relative frequencies in (25). Many words happen to be produced in both unsuffixed and nominative forms, since these are both relatively frequent parts of the paradigm. The probability of producing the same word in both the unsuffixed and accusative forms, on the other hand, is much smaller (since accusative forms are simply not produced very often), and the probability of producing the same word in both the nominative and accusative is even smaller. Of course, the simulated parent also sometimes produces duplicate tokens, repeating the same form of the same word two or more times in the space of the same 1,000 word "text". Duplicate tokens were not counted as separate learning data (i.e., the text was converted to types for morphological learning.)

Since chance can produce radically different results on different occasions, the simulated parent was used to produce 10 different texts of 1,000 tokens each. These sets of forms were then used as learning data for the minimal generalization learner, in ten "simulated childhoods". Recall that the question of interest here is whether the relative frequency of unmarked forms over nominative ones is enough to render it a more reliable base form. The results of these simulations, given in (27), show that the frequency difference is more than sufficient to produce the desired result: the nominative form receives significantly lower scores, even though it is slightly more revealing about underlying phonemic contrasts.

(27) Average scores for unmarked and nominative forms, taking token frequency into account

	Mean Confidence	Average Winning Margin
Unmarked → Accusative	.795	.812
Nominative → Accusative	.461	.475

The upshot is that once token frequency is taken into account to provide more realistic learning data, the most reliable base form in Korean is in fact the unmarked form. This result contradicts initial impressions of Korean noun paradigms based solely on schematic data, and is due to three separate factors. The first is the relative rarity of stem-final coronal obstruents in the lexicon, meaning that the phonological rule of coda neutralization affects far fewer words than one might expect. Second, forms without coda neutralization suffer from their

own, independent neutralizations (such as palatalization, or the *-ɨl*/ *-tɨl* ambiguity). Finally, the extreme frequency difference between unmarked and marked forms makes data about suffixed forms quite sparse for the learner.

The Korean case is illustrative in two respects: first, it shows that informativeness about phonological and morphological properties is complex to evaluate, and typically requires quantitative assessment of competing processes. Second, it shows that the assessment of reliability is based on more than just simple informativeness; a good base form must be not only informative, but also adequately *available*. I conjecture that this example is typical, and that when analogies appear to employ uninformative base forms, those forms are more informative than it seems, and are often substantially more frequent than the rest of the paradigm.[20]

The claim that there is a bias towards using more frequent forms as bases is certainly not a new one. It echoes suggestions by Mańczak (1958), Bybee (1985, 2001) and others, who point out that frequent forms are often the pivots for analogical change. The current model differs from previous proposals in the explanation for this bias, however. According to Bybee, token frequency plays a direct role in determining the organization of paradigms: as certain forms of the paradigm that are heard and used more often, their lexical strength increases, and this makes them more influential and more "basic" (Bybee 1985, p. 117). By contrast, in the current model the grammar does not care about token frequency *per se*, but only about confidence of mappings. The relative token frequency of forms is not encoded anywhere in the grammar, nor does the model have any explicit bias to select frequent paradigm members as bases. The learner simply wants to select a base form that preserves as many contrasts as possible, but occasionally, the ideal form is so infrequent that it is impossible to evaluate its true reliability. In such cases, a more frequent, but slightly less informative form may yield more reliable grammars, and is selected as the base.

The results in (27) show that even this modest, indirect sensitivity to token frequency is enough to bias the learner towards selecting a more frequent form as the base when there is only a small difference in informativeness. This naturally raises the question: what is the trade-off between frequency and informativeness? How likely is the model to select the most frequent form over the most informative form as a base? Can it correctly predict the typological bias for analogical change to be based on frequent forms? In the section that follows, I attempt to answer these questions, by exploring the parameter space of the model.

4.2 The typological bias for frequent base forms

In the previous section, I showed that two factors play a role in favoring a less informative base form in Korean. First, the neutralization affects a small number of lexical items—only 1 or 2% of the nominal vocabulary, in fact. Second, the more informative forms have low token frequency (a greater than 50% difference). But how great must the frequency difference be, and how small the informativeness difference, in order for the model to choose a more frequent form over a more informative one?

In order to investigate this question, a series of artificial languages were constructed in which the most frequent member of the paradigm suffered from a neutralization (final obstruent devoicing), while the next most frequent member faithfully preserved all underlying contrasts.

[20] In the case of Maori, the first part of this claim seems to be true. Sanders (1990) found that over 70% of Maori verbs take either *-a* or *-tia* in the passive, and the choice of *-a* vs. *-tia* is itself somewhat predictable (Blevins 1994; de Lacy 2003). I have no information about the relative frequency of Maori verb forms to assess whether the second part of this claim also holds in the Maori case.

These languages varied along two dimensions: (1) the seriousness of the neutralization, and (2) the frequency difference between the most frequent paradigm member and the most informative one.

The seriousness of the neutralization was manipulated by varying the number of artificial stems that ended in obstruents: in a language with no final obstruents, the final devoicing does not lead to any ambiguity, while in a language where half of the words end in voiced obstruents, final devoicing neutralizes contrasts in 50% of the vocabulary. The artificial languages were constructed probabilistically by algorithm, and the percentage of voiced and voiceless stem-final obstruents was then checked using Microsoft Excel, in order to ensure that they did indeed display the intended frequencies. Six degrees of "seriousness of neutralization" were considered, ranging from 0% to 50% at 10% intervals.

The second factor that was manipulated was the difference in token frequency between the most frequent form and the most informative form. This difference varied from nearly equal frequency (50% vs. 45% of all tokens) to extremely unequal frequencies (90% vs. 5% of all tokens). When crossed with the different degrees of neutralization, this yielded a total of 6×9, or 45 artificial languages (one for each combination of neutralization vs. frequency difference).

In order to make the artificial languages resemble an actual language, pseudo-lexicons, containing 44,000 words each, were generated by computer. Since words in natural languages vary considerably in their token frequency, the lexical items in the artificial languages were assigned relative frequencies mirroring nouns in an actual language (Korean, as represented in the Sejong corpus). As a result, the artificial languages had a realistic profile of high- and low-frequency words. As an example, (28) shows the dozen most frequent words in the artificial language designed to have neutralizations in 50% of its lexicon.

(28) 50% Neutralization in the nominative (ambiguous forms in bold)

Nom.	Acc.	Dat.	Freq. (per million wds.)
pip	pipa	pipi	9289
lew	lewa	lewi	7990
bagmoj	bagmoja	bagmoji	5868
ran	rana	rani	5346
zol	zola	zoli	4624
vifdoj	vifdoja	vifdoji	4295
lak	laga	lagi	3753
lep	lepa	lepi	3231
ras	rasa	rasi	3009
zik	zika	ziki	2928
etc.			

As with the Korean simulations above, input data for the learner were drawn from these artifical lexicons, Monte Carlo style. A learning trial consisted of 1000 tokens of inflected forms, drawn randomly in proportion to the relative frequency of both the lexical item and also the inflection (see (26) above). On average, high frequency lexical items were produced more often than low frequency items, and frequent paradigm members were produced more often than infrequent ones. Continuing with the example from (28), when the frequency difference between nominatives and datives is 70% vs. 25% (the remaining 5% of the tokens being dative), a sample learning trial might look like (29). The token counts in (29) show that collectively, these twelve most frequent words were produced 67 times; the remain 933 tokens were forms of less frequent words.

(29) Most frequent words in a learning trial for the language in (28)
(Nom:Acc:Dat ratio = 70:25:5)

Nom.	Nom. tokens	Acc.	Acc. tokens	Dat.	Dat. tokens
pip	14	pipa	1	pipi	1
lew	6	lewa	6	lewi	1
bagmoj	6	bagmoja	2	bagmoji	1
ran	5	rana	1	rani	0
zol	3	zola	1	zoli	1
vifdoj	5	vifdoja	0	vifdoji	0
lak	1	laga	0	lagi	0
lep	2	lepa	0	lepi	0
ras	0	rasa	1	rasi	0
zik	1	zika	3	ziki	0
mos	3	moza	0	mozi	0
mut	1	muda	1	mudi	0
etc.					

Ten learning trials were carried out for each artificial language, in order to ensure that the results were not distorted by a particularly deviant random sample. As for Korean, accuracy and confidence were calculated for each paradigm member in each trial, and the results for each language were averaged across each of the ten trials.

The outcome of these simulations are summarized in Figure 4. In this graph, the two axes represent the two competing factors that can affect reliability of grammars: the seriousness of the neutralization, and the frequency difference between the paradigm members. The darkness of the shading indicates the degree to which the model prefers the more frequent form (the nominative) as the base; the spot at which this preference becomes positive (nominative is actually chosen) is indicated with a solid line. We see that even though the less frequent accusative form was more informative in all of these simulations, the model nonetheless has more confidence in the nominative form a fair proportion of the time. In particular, when the neutralization affects just a few words (seriousness is low) or when the frequency difference is great, the models confidence in the accusative form suffers, and the nominative is chosen as the base.[21] What this graph shows is that even when the more frequent paradigm member is less informative, it is chosen as the base under certain conditions: in particular, when the frequency difference is great, or when the seriousness of the neutralization involved is below a certain threshhold (roughly, affecting less than 5 to 10% of the lexicon). In the previous section, we saw that Korean fits both of these criteria: the coda neutralizations that occur in unsuffixed forms affect surprisingly few words, and there is a substantial frequency difference between unsuffixed forms and the remaining members of the paradigm, putting Korean at the extreme lower right of Figure 4.

The less frequent paradigm member, on the other hand, is chosen only when it is sufficiently frequent—even half as frequent may be sufficient—and when the benefit of choosing it is non-

[21]The chart is "bumpy" rather than a perfectly smooth contour because it is based on randomly sampled input data, with statistical properties that varied slightly from the controlled properties of the artificial languages. Such anomalies are particularly noticeable towards the right side of the graph, where the frequency difference is great, and the probability of producing accusative forms is low. Such sampling fluctuations appear to be responsible for the curious "rounding" at the top of the chart at a frequency difference of 50-60 percent (i.e., the nominative region juts to the left at the top of the chart), but more inquiry is needed in this area. It is expected that these irregularities would smooth out with more learning trials.

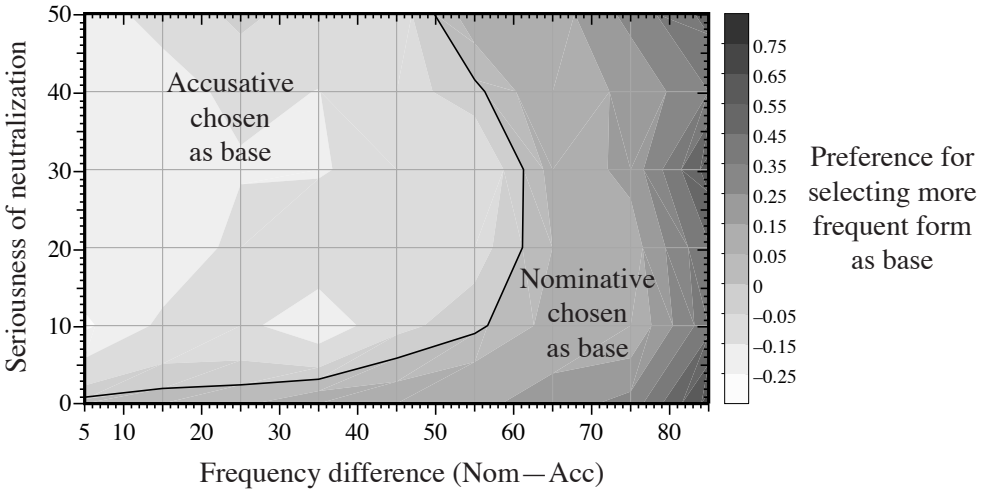

Figure 4: Trade-off between informativeness and frequency

negligible. All of the typologically "unusual" cases discussed at the end of section 3 appear to have these properties. In the case of Yiddish, the frequency imbalance between the 3sg and 1sg is most likely not as great as the difference between Unsuffixed and Nominative in Korean. Although I know of no statistical counts for Yiddish, equivalent counts for Spanish (Bybee 1985, p. 71, and references cited therein) and German (Baayen, Piepenbrock, and van Rijn 1993) indicate that the ratio of 1sg to 3sg tokens is typically about 25% to 45%, compared to the 20% to 75% difference in Korean nouns. Moreover, the neutralizations affecting the 3sg in Yiddish involve as much as 50% of the lexicon, placing it in the upper left region of the chart. Even less spoken frequency information is available to me about Lakhota or Latin, but these cases certainly involve more severe neutralizations than Korean, and seem to involve smaller frequency differences as well (see (Albright 2002a, §6.2.1) for discussion).

In sum, the model predicts that even when the most frequent paradigm member is less informative, it should be chosen as the base a modest majority of the time. Crucially, we must bear in mind that this graph shows only half of the logically possible languages (those in which the more informative form is less frequent); when the most informative form also happens to be the most frequent one, it is *always* selected as the base. Taken together, this means that the general tendency for analogical change to favor more frequent paradigm members is correctly predicted, even though the model has no built-in bias to do so. As discussed at the end of the preceding section, the result follows simply from the fact that the learner is reluctant to trust generalizations based on too few data, and thus a slightly more informative base form can actually be less reliable if it is too infrequent.

5 Conclusion

In this paper, I have argued that a synchronic model of paradigm acquisition can capture both language-particular *and* typological aspects of language change. On the one hand, the choice of base form, as well as the outcome of the eventual change (leveling vs. extension of alternations) can be seen to follow from structural properties of the language–in particular, the distribution

of contrasts and the seriousness of neutralizations. On the other hand, the overall typological preference for analogy to extend less marked, or more frequent forms is explained as a side effect of how learners evaluate the seriousness of neutralizations, and the predictive power of potential base forms.

These predictions follow from a synchronically-oriented model of language change, in which learners pay more attention to forms that are most helpful in predicting unknown forms, and analogical effects are rooted in this organization. The premise of this approach is that learners need to use limited information to learn how to produce and comprehend complete paradigms. In order to do this accurately and confidently, the learner must focus on those forms which permit the grammars with maximal confidence to be written for deriving the remainder of the paradigm. There are two sources of confidence under this model. First, rules are reliable when their inputs contain all of the necessary contrastive information to predict all of the surface forms; that is, when they do not suffer from neutralizations, forcing the grammar to probabilistically "guess" about outputs. Second, rules are reliable when they are general enough to have true predictive power. When rules are based on just a few examples, we cannot be confident that all future data will conform to the same generalizations that we have seen so far, whereas it is easy to trust a rule that are based on ample data, even if it suffers from a few exceptions. Since less frequent members of the paradigm are sparsely attested in the learning data, learners are unable to confidently assess their predictive power, and are less likely to select them as bases.

It should be emphasized that the base selection procedure that is proposed here is *deterministic*. Unlike a tendency-based approach, it is not based on statistical preferences or probabilities. This procedure is designed to generate a unique grammar for a given set of input data, and make predictions about likely changes.

An advantage to approaching analogical change in this way is that the model makes clearly testable predictions about both particular languages and the overall typology—so far, with promising results. Thus far, the focus has been on explaining typologically unusual cases of analogy, showing that they are sensible when viewed from the point of view of maintaining contrasts. An important result of this study, however, is the demonstration that predictability can be difficult to assess on the basis of schematic data, and that apparent neutralizations are often not as serious as they appear once one considers the number of words involved, correlations with other features, and so on. Furthermore, the Korean discussion highlights the fact that predictability can be influenced not only by the neutralizations involved, but also by the amount of data that is available to work with. The upshot is that the only true test of the model is one which takes all of these factors into account. If these results continue to hold with more detailed data and across a wider variety of cases, this approach has the potential to provide a more explanatory and predictive model of analogical change.

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