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Learning hidden structure in paradigms*

- I present results from wug-testing Turkish speakers, arguing for a theory of lexicon organization that uses UG to filter lexical generalizations. I argue that regular and irregular morpho-phonology should be derived from the same set of universal constraints, CON.
- I show that the traditional generative analysis, which attributes hidden structure to the UR's of roots, under-predicts the statistical knowledge that speakers have. I propose a learning model that attributes hidden properties to constraint rankings, and if necessary, also to the UR's of affixes. Attributing hidden structure to roots is done only as a last resort, via suppletion.
- My "inside-out" model (Hayes 1995, 1999) makes OT-based work, which benefits from UG effects, compatible with the single surface base hypothesis (Albright 2002, 2008a).

1 Turkish (Becker, Ketrez & Nevins 2008)

Famously, Turkish final stops are predominantly voiceless. When a vowel-initial affix is added, some words keep the stop faithfully voiceless, while others alternate (Lees 1961, Zimmer & Abbott 1978, Kaisse 1986, Inkelas & Orgun 1995, Inkelas et al. 1997, Avery 1996, Kallestinova 2004, Petrova et al. 2006, among others).

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(1)

bare stem	possessive	
sop	sop-u	'clan'
ʤop	ʤob-u	'nightstick'

1.1 The lexicon and speakers' knowledge of it

We searched TELL (Inkelas et al. 2000), and found that final stops in mono-syllabes mostly don't alternate, but in poly-syllables they mostly do.

(2)

Size	n	% alternating
Monosyllabic, simplex coda	137	12%
Monosyllabic, complex coda	164	26%
Polysyllabic	2701	59%

Most final t's don't alternate, other stops mostly do.

(3)

Place	n	% alternating
Labial (p)	294	84%
Coronal (t)	1255	17%
Palatal (ʧ)	191	61%
Dorsal (k)	1262	85%

Two other factors that partially predict altenation: The height and backness of the final vowel of the stem.

(4)

Height of stem's final vowel	n	% alternating
−high	1690	42%
+high	1312	72%

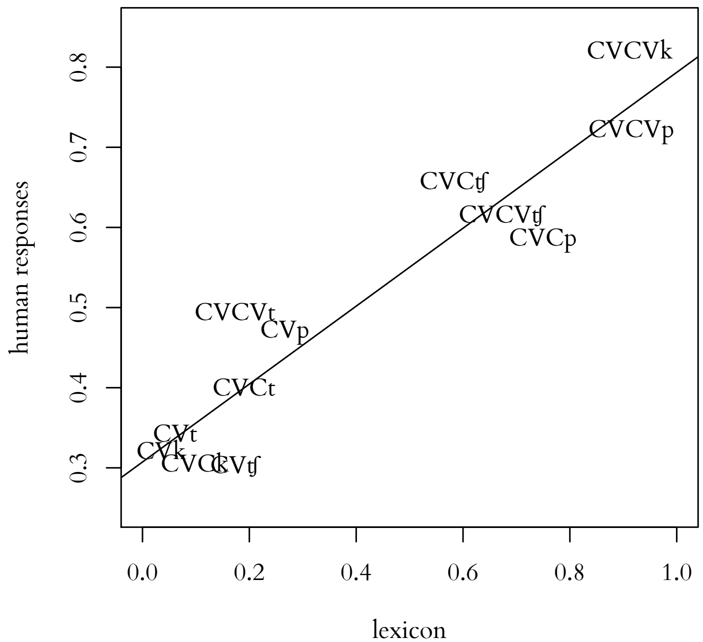
(5)

Backness of stem's final vowel	n	% alternating
−back	1495	50%
+back	1507	60%

We gave 24 Turkish speakers a novel noun task (Berko 1958) with 72 novel nouns of four places (p, t, ʧ, k), three sizes (CVC, CVCC, CVCVC), and eight vowels (a, ɨ, e, i, o, u, ø, y).

The speakers replicated the size and place effects from the lexicon, as in (6), but not the vowel quality effects (not shown, see stats and more detail in paper).

(6)



(7) It's natural to treat alternations in mono-syllabic stems separately from poly-syllabic stems via initial syllable faithfulness.

(8) It's natural to treat the propensity of different stops to voice differently.

(9) However, no language is known to change the voicing of a consonant based on the height or backness of a neighboring vowel.

In other words, Turkish speakers only learned the natural (=typologically supported) aspects of their lexicon, and ignored the unnatural ones. UG acts as a filter on the kinds of generalizations that speakers learn (for a more nuanced view, and a review of the literature, see Hayes et al. to appear).

1.2 Grammar-based analysis

Our analysis: Work "inside out" (Hayes 1995, 1999), so the alternations are considered to be irregular intervocalic voicing.

(10) The UR's of [sop] and [ʤop] are /sop/ and /ʤop/

(11) The UR of the possessive is /u/ (actually just a high vowel)

(12) /sop + u/ → [sopu] requires Ident(voice) ≫ *VpV
/ʤop + u/ → [ʤobu] requires *VpV ≫ Ident(voice)

We use constraint cloning (Pater 2006, 2008, Coetzee 2008, Becker 2009), which relies on the Recursive Constraint Demotion algorithm (RCD, Tesar & Smolensky 1998, 2000, Tesar 1998, Prince 2002), to detect inconsistent rankings.

(13) $\text{Ident(voice)}_{\text{sop}} \gg \text{*VpV} \gg \text{Ident(voice)}_{\text{ʤop}}$

From this point on, every word that is sensitive to the ranking of Ident(voice) relative to *VpV will be listed:

(14)

/top + u/	Ident(voice)	*VpV
a. ☞ top-u		*
b. tob-u	*!	

(15)

/ot + u/	Ident(voice)	*VpV
a. ☞ ot-u		
b. od-u	*	

(16) $\text{Ident(voice)}_{\{\text{sop, top, alp, ...}\}} \gg \text{*VpV} \gg \text{Ident(voice)}_{\{\text{ʤop, harp, ...}\}}$

Until the speaker gets:

(17) $\text{Ident(voice)}_{\{22 \text{ items}\}} \gg \text{*VpV} \gg \text{Ident(voice)}_{\{8 \text{ items}\}}$

Novel p-final mono-syllables will have a 8/30 (=27%) chance of alternating with [b]. The result: the lexical statistics are built into the grammar.

1.3 What's wrong with a UR-based analysis?

The classic generative analysis of Turkish (Lees 1961, Inkelas & Orgun 1995, Inkelas et al. 1997, Petrova et al. 2006, among others):

(18) The UR's of [sop] and [ʤop] are /sop/ and /ʤoB/

(19) The UR of the possessive is /u/ (actually just a high vowel)

(20) /sop + u/ → [sopu] requires IDENT(voice) ≫ *VpV

sop + u	IDENT(voice)	*VpV
a. ☞ sopu		*
b. sobu	*!	

(21) /ʤoB + u/ → [ʤobu] is consistent with IDENT(voice) ≫ *VpV

ʤoB + u	IDENT(voice)	*VpV
a. ʤopu	(*)	*!
b. ☞ ʤobu	(*)	

The grammar is consistent: IDENT(voice) ≫ *VpV

The problem: The learner has no way to encode the relative numbers of /p/'s and /B/'s in the grammar. Going directly to the lexicon to find them there, unhindered by UG, will find the vowel quality generalizations that speakers don't have.

Slightly better alternative that gets a consistent grammar: Attribute hidden structure to the affix.

(22) The UR's of [sop] and [ʤop] are /sop/ and /ʤop/

(23) The possessive has two allomorphs: /u/ and /[+voice] u/

(24) /sop + u/ → [sopu]
/ʤop + [+voice] u/→ [ʤobu]

The floating [+voice] is protected by MAX(float), as in Wolf (2007), and we get a consistent grammar:

(25) MAX(float) ≫ IDENT(voice)

Each allomorph of the possessive lists the roots it takes:

(26) /u/ takes {sop, tup, alp, ...}
/[+voice] u/ takes {ʤop, harp, ...}

The prediction: Speakers will know the relative frequency of voicing alternations for the language as a whole, but not for specific stops or sizes, since the allomorphs of the possessive say nothing about the shape of the nouns they take.

Conclusion: Assume the bases as UR's, assume that affixes only have segments in them, and try to get everything else by ranking constraints. Clone constraints as necessary.

2 Fallback: When the grammar is not enough

Korean (Albright 2008b):

(27)

Unmarked	Accusative		
nat̚	natʰɨl	'piece'	113
nat̚	naʧʰɨl	'face'	160
nat̚	nadɨl	'grain'	1
nat̚	naʤɨl	'daytime'	17
nat̚	nasɨl	'sickle'	375

Assuming /nat̚/ for the roots and /ɨl/ for the accusative can do some work:

(28)

/nat̚ + ɨl/	*VtV	Ident(voice)	Ident(asp)
a. natɨl	*!		
b. nadɨl		*!	
c. ☞ natʰɨl			*

(29) /nat̚ + ɨl/ → [natʰɨl], [naʧʰɨl]
requires *VtV $\gg$ Ident(voice) $\gg$ Ident(asp)

(30) /nat̚ + ɨl/ → [nadɨl], [naʤɨl]
requires *VtV $\gg$ Ident(asp) $\gg$ Ident(voice)

(31) Ident(voice)$_{\{113+160 \text{ items}\}}$ $\gg$ Ident(asp) $\gg$ Ident(voice)$_{\{1+17 \text{ items}\}}$

The prediction for a novel form, [pat̚]:

(32) 94% chance of [tʰ], [ʧʰ], 6% chance of [d], [ʤ]

*TI, which wants assibilation before a high vowel (Kim 2001), takes care of [s]:

(33) /nat̚ + ɨl/ → [nasɨl]
requires *TI $\gg$ Ident(cont)

(34) /nat̚ + ɨl/ → [natʰɨl], [naʧʰɨl], [nadɨl], [naʤɨl]
requires Ident(cont) $\gg$ *TI

(35) Ident(cont)$_{\{113+160+1+17 \text{ items}\}}$ $\gg$ *TI $\gg$ Ident(cont)$_{\{375 \text{ items}\}}$

The prediction for a novel form, [pat̚]:

(36) 56% chance of [s], 44% chance of [tʰ], [ʧʰ], [d], [ʤ]

But are there plausible constraints that will map /nat̚ + ɨl/ to [naʤɨl] or [naʧʰɨl]? It seems awfully hard to palatalize without a front vowel around.

With [naʧʰɨl] as the intended winner, [natʰɨl] is most faithful to it, but still incurs an Ident(ant) violation → add the missing feature as floating in the UR of the accusative affix: /[−ant] ɨl/.

(37) /nat̚ + [−ant] ɨl/ → [naʧʰɨl], [naʤɨl]
requires Max(float) $\gg$ Ident(ant)

(38) /nat̚ + [−ant] ɨl/ → [natʰɨl], [nadɨl]
requires Ident(ant) $\gg$ Max(float)

(39) /nat̚ + [−ant] ɨl/ → [nasɨl]
requires *ʃ $\gg$ Ident(ant), Max(float)

(40) *ʃ $\gg$ Ident(ant)$_{\{113+1 \text{ items}\}}$ $\gg$ Max(float) $\gg$ Ident(ant)$_{\{160+17 \text{ items}\}}$

The prediction for a novel form, [pat̚]:

(41) 61% chance of [ʧʰ],[ʤ], 39% chance of [tʰ], [d]

Summary of the predictions:

(42)

	Ident(cont) vs. *TI	Ident(voice) vs. Ident(asp)	Ident(ant) vs. Max(float)	
[s]	56%			= 56%
[ʧʰ]	44%	94%	61%	= 25%
[tʰ]			39%	= 16%
[ʤ]		6%	61%	= 2%
[d]			39%	= 1%

The high probability of [s] and [$ʧ^h$] conforms with the report in Albright (2008b) about the treatment of novel forms, loanwords, and many native items.

My analysis expresses the language-specific frequencies of mappings in terms of rankings of universal constraints.

3 Last resort: Suppletion and diacritics

It's certainly not the case that every paradigmatic relation can be derived with phonological mechanisms, e.g. English go ∼ went.

English ɔt-takers: teach, catch, think, bring, seek, fight, buy — how many of those can map to their past tense using phonological mechanisms?

The rhymes of [brɪŋ] and [baɪ] don't share any features with [ɔt] beyond [consonantal]. If we assume a floating pair of segments, /ɔt/, they can dock correctly and replace the root segments.

(43)

baɪ + {d, ɔt}	Max(float)	Max(root)
a. ☞ bɔt		**
b. bat	*	*
c. baɪ	**	
d. baɪd		

Cloning Max(float) or Max(root) will give a small probability to ɔt-taking, but will say nothing about the possible shapes of ɔt-takers.

The fact that the regular [baɪd] harmonically bounds the intended winner is also a hint that something non-phonological is going on, prompting the speaker to assume suppletion or some phonology-free diacritic.

Either cloning Max(float) or using diacritics is equally bad for finding out what kind of roots are ɔt-takers, and indeed speakers have no clue about ɔt-taking.

4 Summary: Learning morpho-phonology

The traditional search for the UR's of bases (à la chapter 6 of Kenstowicz & Kisseberth 1979) is replaced with a search for the UR's of affixes:

- Assume the bases as UR's, i.e. work "inside-out" (Hayes 1995, 1999)
- Assume that affixes only have segments in them (=Turkish)
- If necessary, attribute floating features to affixes (=Korean)
- If the grammar fails you, learn whole forms (=English bring∼brought)

A fully general mechanism for finding abstract underlying representations for roots is yet to be proposed, although significant headway was made by Tesar (2006), Tesar & Prince (2006), Merchant (2008), and in parallel lines of work, by Boersma (2001) and Apoussidou (2007), and by Jarosz (2006).

Example from Tesar & Prince (2006):

(44)
- Given language data sop ∼ sop-u and ʤop ∼ ʤob-u,
- Fix invariant aspects of morphemes in their UR's: /sop/, /ʤoB/, /u/,
- Generate candidates for incompletely specified UR's: /ʤop/, /ʤob/,
- Choose the UR's that are compatible with a consistent grammar.

Problems:

(45)
- Lexical trends are encoded in the UR's of individual roots, and thus become inaccessible to the grammar (as in §1.3).
- Multiple forms of roots need to be considered, so the search space grows with the number of known lexical items.

Since affixes are smaller in size and number than roots, the learning space in my "inside-out" approach is probably smaller — but a formal proof about the relative sizes of the search spaces is a matter for further research.

5 Beyond paradigms: Lexical stratification

A single language can entertain multiple grammars (Itô & Mester 1995, 1999, 2003, Féry 2003, Rice 2006, Jurgec 2010, and many others).
Can we understand stratification as an establishment of arbitrary links between lexically-specific rankings of Universal constraints?

Hebrew (Becker 2003):

(46) Mobile (final) stress, maximally disyllabic, no complex codas

	Singular	Plural	
Nouns:	dód	dod-ím	'uncle'
	ʃvíl	ʃvil-ím	'path'
	dikdúk	dikduk-ím	'grammar'
Adjectives:	tóv	tov-ím	'good'
	umlál	umlal-ím	'miserable'
	dikduk-í	dikduk-i-ím	'grammatical'
Verbs:	ʃamár	ʃamr-ú	'keep'
	bizbéz	bizbez-ú	'spend'

Mostly native items + some di-syllabic loanwords (salát 'salad', balón 'balloon', kartón 'carton')

(47) Fixed stress, no size restriction, complex codas allowed

	Singular	Plural	
Nouns:	ptór	ptór-im	'dispensation'
	párk	párk-im	'park'
	fonológ	fonológ-im	'phonologist'
	kóledʒ	kóledʒ-im	'college'
	ámbulans	ámbulans-im	'ambulance'
	kópirayter	kópirayter-im	'copywriter'
Adjectives:	róm-i	róm-i-im	'Roman'
	malyán	malyán-im	'rich'
	fonológ-i	fonológ-i-im	'phonological'

Mostly loanwords + some mono-syllabic and oversized native nouns (tút 'strawberry', itstadyón 'stadium', afarsemón 'persimmon')

Constraint rankings can easily regulate stress:

(48)

dikdúk + im	FinalStress	Ident(stress)
a. ☞ dikduk-ím		*
b. dikdúk-im	*!	

(49)

fonológ + im	Ident(stress)	FinalStress
a. ☞ fonológ-im		*
b. fonolog-ím	*!	

But how can we prevent all tri-syllables from getting final stress? We must make sure that bases that require Max-V ≫ Align-σ (Itô et al. 1996, Ussishkin 2000) always select Ident(stress) ≫ FinalStress.

(50) [Max-V ≫ Align-σ]$_{base}$ ⟶ [Ident(stress) ≫ FinalStress]$_{plural}$

Similarly, bases that allow complex codas must require fixed stress:

(51) [Max-C ≫ *ComplexCoda]$_{base}$ ⟶ [Ident(stress) ≫ FinalStress]$_{plural}$

Two required ingredients for this analysis to work:

(52) The phonological properties of bases need to be accessible in terms of lexically-specific rankings, as proposed by Coetzee (2008). In this theory, faithfulness constraints are always lexically-specific.

(53) Speakers must identify and extend regular implications between ranking arguments.

Finally, we need to do more experimental work to know which arbitrary relations speakers make.
See Gelbart (2005), Jurgec (2008), and references therein for work on speakers' ability to spot loanwords in Japanese, English, Latvian, and Slovenian.
See chapter 3 of Becker (2009) about the non-arbitrary connection between lexical stratum and plural allomorph selection in Hebrew, via stress.

6 Conclusions

Speakers learn statistical trends in their lexicon, and they do so in terms of UG. Now we have two ways of studying UG: Study regular phenomena typologically, and study lexical trends in individual languages.

To make sure that the grammar gets to see lexical statistics, don't bury them in the lexicon, and work "inside-out":

- Assume the paradigm's base as the UR, derive the other forms from it.
- Assume that affixes only have segments in them, and try to get the rest from constraint interactions. Clone constraints as necessary.
- If no grammar can be found, assume that missing structure is floating in the UR's of affixes, and try to get the rest from the grammar.
- If everything else fails, assume suppletion and/or diacritics.

This approach learns lexical trends and projects them onto novel words without extra-grammatical mechanisms, and thus without giving up the strengths of Optimality Theory.

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