A sublexicon approach to the Paradigm Cell Filling Problem*

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1 Introduction

The Hungarian possessive has allomorphs with and without [j]:

harmony	*without [j]*		*with [j]*	
back	gaːz-ɒ	'gas'	kɒpu-jɒ	'gate'
front	køɲː-ɛ	'tear'	bɛtyː-jɛ	'letter'

Table 1: Hungarian possessive allomorphy involving [j] (cuts across vowel harmony classes)

Learners must associate each noun with the possessive allomorph it selects for.[1]

How do they do this? They have some help!

- partial *phonological* predictability: the phonological form of a noun can determine (or at least give a clue to) its choice of possessive allomorph
- partial *morphological* predictability: a noun's plural form (for example) can determine (or at least give a clue to) its choice of possessive allomorph

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[1] A small number of nouns allow for both options.

Ackerman et al. (2009); Ackerman and Malouf (2013): the Paradigm Cell Filling Problem (how speakers can efficiently predict one inflected form of a word given others)

- architectural claim: this prediction can only be done efficiently through the use of a morphological module that includes paradigms as units of analysis
- . . . unlike theories like Distributed Morphology (Halle and Marantz, 1993) which do not establish formal relations between related words in the grammar

I propose an extension to the sublexicon model (Gouskova et al., 2015; Becker and Gouskova, 2016) that takes both *phonological* and *morphological* predictability into account in solving the Paradigm Cell Filling Problem

- integrates morphological and phonological predictability into the same model, allowing learners to use both sources of information at the same time
- does *not* require the grammatical module that handles morphology to include paradigms

Roadmap:

- show that lexically specific allomorphy in the Hungarian possessive is subject to both *phonological* and *morphological* predictability
- present the sublexicon model and its extension to capture morphological information, *SUBLEX constraints
- discuss the model in light of the Paradigm Cell Filling Problem

2 Case study: Hungarian possessives

2.1 Possessive allomorphy

Recall: the Hungarian possessive has allomorphs with and without [j]:

harmony	*without [j]*		*with [j]*	
back	gaːz-ɒ	‘gas’	kɒpu-jɒ	‘gate’
front	køɲː-ɛ	‘tear’	bɛtyː-jɛ	‘letter’

Table 1: Hungarian possessive allomorphy involving [j] (cuts across vowel harmony classes)

In some cases, a noun's phonology fully determines its choice of possessive:

stem shape	*possessive*	*example*	
V-final	-jɒ/jɛ	kɒpu-jɒ	'gate'
palatal-final	-ɒ/ɛ	laːɲ-ɒ	'girl'
sibilant-final	-ɒ/ɛ	gaːz-ɒ	'gas'

Table 2: Rácz and Rebrus (2012): Categorical generalizations about possessive allomorph selection

At other times, it merely provides a useful clue:[2]

final C manner	*possessive*	*count*	*proportion*	*example*	
alveolar	-ɒ/ɛ	216	21%	hɒd-ɒ	'army'
	-jɒ/jɛ	814	79%	pɒd-jɒ	'bench'
labial	-ɒ/ɛ	117	43%	laːb-ɒ	'leg'
	-jɒ/jɛ	156	57%	tʃaːb-jɒ	'lure'
velar	-ɒ/ɛ	126	36%	sɒg-ɒ	'scent'
	-jɒ/jɛ	224	64%	rɒg-jɒ	'suffix'

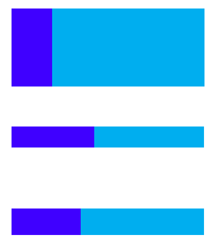


Table 3: Distribution of Hungarian possessive allomorphy by place of final consonant (excluding palatals and sibilants)

2.2 Lowering stems

Rácz and Rebrus (2012) also note: irregular noun classes usually take -ɒ. One example: *lowering stems* (see also Rebrus, 2013; Rebrus et al., 2017):[3]

stem class	*example*	*gloss*	*plural*	*possessive*
regular	paːr	'pair'	paːr-ok	paːr-jɒ
lowering	ɟaːr	'factory'	ɟaːr-ɒk	ɟaːr-ɒ

Table 4: Hungarian lowering stems

[2]My Hungarian source is Papp (1969), a morphological dictionary. I consider consonant-final, monomorphemic nouns that are not marked as variable in the possessive.

[3]By default, nouns are non-lowering stems, while all but a handful of adjectives are lowering stems, and some forms behave differently depending on the syntactic environment (Rebrus and Szigetvári, 2018). Setting aside these issues, I limit my inquiry to words that are listed as nouns.

In fact, there are very few lowering stems with possessive [j]:[4]

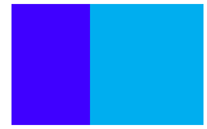
stem class	*possessive*	*count*	*proportion*	*example*	
regular	-ɒ/ɛ	656	41%	kaːr-ok, kaːr-ɒ ‘damage’	
	-jɒ/jɛ	943	59%	paːr-ok, paːr-jɒ ‘pair’	
lowering	-ɒ/ɛ	104	87%	ɟaːr-ɒk, ɟaːr-ɒ ‘factory’	
	-jɒ/jɛ	15	13%	ɲaːr-ɒk, ɲaːr-jɒ ‘poplar’	

Table 5: Distribution of Hungarian lowering stems and possessive allomorphy

Do lowering stems just look like typical -ɒ words? Not really:

stem class	*total*	*ending in palatal or sibilant*	*proportion*	
regular	1599	478	30%	
lowering	119	48	40%	

Table 6: Phonological distribution of Hungarian lowering and non-lowering stems

This alone doesn’t explain the effect—the morphological effect is independent of the phonological ones.

2.3 Phonological and morphological factors influencing possessive allomorphy

I fit two models for predicting a noun’s possessive allomorph—see Appendix A for the full models.[5]

[4]Not included in Table 5 are 23 nouns listed as having variable stem class.

[5]The models were fit using the `lrm` function in R’s `rms` package (R Core Team, 2020; Harrell Jr., 2020).

One includes phonological factors of the root, while the other has one additional factor, stem class:

variable	*values*
final C manner	plosive, fricative, sibilant, nasal, approximant
final C place	alveolar, labial, palatal, velar
vowel harmony	back, front, variable
final syllable V height	mid, high, low
final syllable V length	short, long
coda	singleton, geminate, cluster
syllables	monosyllabic, polysyllabic
stem class	non-lowering, lowering, undetermined,[6] variable

Table 7: Variables in the regression models for Hungarian possessive allomorphy

The models show both phonological and morphological predictability, independent of one another:

- adding stem class substantially and significantly improves the model
- the factors do not show substantial collinearity → not describing the same thing

So: seeing a noun's phonological form is helpful to the learner in figuring out its possessive—but seeing its plural to learn that it's a lowering stem is even more helpful.

3 Sublexicons with morphological dependencies

In this section: I present a theory for how speakers encode phonological and morphological trends in their grammar using *sublexicons* (Gouskova et al., 2015; Becker and Gouskova, 2016).

Assumptions:

- a *realizational* theory of morphology (Stump, 2001), in which the grammar produces exponents for abstract morphosyntactic properties (singular, nominative, possessive, etc.)
- these properties get spelled out into phonological material through *rules of exponence* ("the possessive is spelled out as -ɒ")
- rules of exponence can be *contextually specific*, only applying to certain lexical items that are marked in the lexicon ("the possessive is spelled out as -ɒ for stems such as [gaːz]")

Other architectural choices I make are for the purposes of illustration.

[6] The phonological distinction between low and mid vowels does not apply throughout the entire phonological system. In particular, back-harmonizing suffixes distinguish between low and mid vowels ([ɒ] vs. [o]), as do front suffixes harmonizing with a rounded vowel in the stem's last syllable ([ɛ] vs. [ø]). However, for front suffixes with unrounded harmony, the vowel is exclusively [ɛ]. Thus, the *undetermined* category is mostly the set of words with front harmony and unrounded vowels in the last syllable—a phonological category, not a morphological one.

Lexically specified allomorphs are associated with contextually specific rules of exponence marked with diacritics:

Grammar

POSS ↔ jɒ / [+j] ___ PL ↔ ɒk / [+lower] ___
POSS ↔ ɒ / [−j] ___ PL ↔ ok / [−lower] ___ …
… …

Lexicon

ɲaːr$_{[+j,\ +lower,\ \ldots]}$	'poplar'
paːr$_{[+j,\ -lower,\ \ldots]}$	'pair'
tʃaːb$_{[+j,\ -lower,\ \ldots]}$	'lure'
pɒd$_{[+j,\ -lower,\ \ldots]}$	'bench'
rɒg$_{[+j,\ -lower,\ \ldots]}$	'suffix'
kɒpu$_{[+j,\ \ldots]}$	'gate'
ɟaːr$_{[-j,\ +lower,\ \ldots]}$	'factory'
laːb$_{[-j,\ +lower,\ \ldots]}$	'leg'
hɒd$_{[-j,\ +lower,\ \ldots]}$	'army'
kaːr$_{[-j,\ -lower,\ \ldots]}$	'damage'
gaːz$_{[-j,\ -lower,\ \ldots]}$	'gas'
laːɲ$_{[-j,\ -lower,\ \ldots]}$	'girl'
sɒg$_{[-j,\ -lower,\ \ldots]}$	'scent'
…	

→

Surface forms

possessive	*plural*
ɲaːr-jɒ	ɲaːr-ɒk
paːr-jɒ	paːr-ok
tʃaːb-jɒ	tʃaːb-ok
pɒd-jɒ	pɒd-ok
rɒg-jɒ	rɒg-ok
kɒpu-jɒ	kɒpu-k
ɟaːr-ɒ	ɟaːr-ɒk
laːb-ɒ	laːb-ɒk
hɒd-ɒ	hɒd-ɒk
kaːr-ɒ	kaːr-ok
gaːz-ɒ	gaːz-ok
laːɲ-ɒ	laːɲ-ok
sɒg-ɒ	sɒg-ok
…	

Figure 1: Surface forms of possessive and plural allomorphs are inserted next to stems with particular lexical diacritics

Words sharing a diacritic are collected into *sublexicons*:

Sublexicons

[+j]	[−j]	[+lower]	[−lower]
ɲaːr$_{[+j,\ +lower,\ \ldots]}$	ɟaːr$_{[-j,\ +lower,\ \ldots]}$	ɲaːr$_{[+j,\ +lower,\ \ldots]}$	paːr$_{[+j,\ -lower,\ \ldots]}$
paːr$_{[+j,\ -lower,\ \ldots]}$	laːb$_{[-j,\ +lower,\ \ldots]}$	ɟaːr$_{[-j,\ +lower,\ \ldots]}$	tʃaːd$_{[+j,\ -lower,\ \ldots]}$
tʃaːb$_{[+j,\ -lower,\ \ldots]}$	hɒd$_{[-j,\ +lower,\ \ldots]}$	laːb$_{[-j,\ +lower,\ \ldots]}$	pɒd$_{[+j,\ -lower,\ \ldots]}$
pɒd$_{[+j,\ -lower,\ \ldots]}$	kaːr$_{[-j,\ -lower,\ \ldots]}$	hɒd$_{[-j,\ +lower,\ \ldots]}$	rɒg$_{[+j,\ -lower,\ \ldots]}$
rɒg$_{[+j,\ -lower,\ \ldots]}$	gaːz$_{[-j,\ -lower,\ \ldots]}$	…	kaːr$_{[-j,\ -lower,\ \ldots]}$
kɒpu$_{[+j,\ \ldots]}$	laːɲ$_{[-j,\ -lower,\ \ldots]}$		gaːz$_{[-j,\ -lower,\ \ldots]}$
…	sɒg$_{[-j,\ -lower,\ \ldots]}$		laːɲ$_{[-j,\ -lower,\ \ldots]}$
	…		sɒg$_{[-j,\ -lower,\ \ldots]}$
			…

…

Figure 2: Each diacritic is associated with a sublexicon containing lexical items with that diacritic

Each sublexicon is associated with a *sublexical grammar* that characterizes generalizations over its members in the form of *weighted constraints* (see Hayes and Wilson, 2008)

- phonological constraints: penalize sound sequences
- morphological constraints: penalize membership in other sublexicons

Sublexical grammars

[+j]		
constraint	*description*	*weight*
*[palatal]#	no word-final palatals	very strong
*[+sibilant]#	no word-final sibilants	very strong
*SUBLEX-[+lower]	no lowering stems	strong
	. . .	

[−j]		
constraint	*description*	*weight*
*[+syllabic]#	no word-final vowels	very strong
*[alveolar]#	no word-final alveolars	medium
	. . .	

. . .

Figure 3: Sublexical grammars for [+j] and [−j] diacritics

When the learner encounters a new word and wishes to form the possessive, they evaluate it on each sublexical grammar to see which is a better fit:

Known forms:	singular [ud]	plural [oːd-ɒk]
⇓	⇓	⇓
Lexical entry:	ud	$\text{oːd}_{[+\text{lower}]}$
Possessive:	[ud-jɒ] or [ud-ɒ]	[oːd-jɒ] or [oːd-ɒ]
⇓	⇓	⇓
Lexical entry:	$\text{ud}_{[+\text{j}]}$ or $\text{ud}_{[-\text{j}]}$	$\text{oːd}_{[+\text{j}, +\text{lower}]}$ or $\text{oːd}_{[-\text{j}, +\text{lower}]}$

Evaluation

(constraint weights made up for illustration purposes)

[+j]

constraint *weight*	*[palatal]# −10	*[+sibilant]# −10	*SUBLEX-[+lower] −7	. . .	total
ud	0	0	0	. . .	0
$\text{oːd}_{[+\text{lower}]}$	0	0	−7	. . .	−7

[−j]

constraint *weight*	*[+syllabic]# −10	*[alveolar]# −3	. . .	total
ud	0	−3	. . .	−3
$\text{oːd}_{[+\text{lower}]}$	0	−3	. . .	−3

Result:	ud → [+j] (0 < −3)	oːd → [−j] (−7 > −3)
⇓	⇓	⇓
Lexical entry:	$\text{ud}_{[+\text{j}]}$	$\text{oːd}_{[-\text{j}, +\text{lower}]}$
⇓	⇓	⇓
Rule of exponence:	POSS ↔ jɒ / [+j] ___	POSS ↔ ɒ / [−j] ___
⇓	⇓	⇓
Possessive:	[ud-jɒ]	[oːd-ɒ]

Figure 4: Evaluating a novel form on [+j] and [−j] sublexical grammars to determine its possessive

To summarize: The learner generates a novel word's possessive form by placing the word in one of the sublexicons associated with a rule of exponence for the possessive.

4 Discussion: sublexicons and paradigms

Ackerman and Malouf (2013) and others: implicational relationships like: "If a Hungarian noun has *-ɒk* in the plural, it (likely) has *-ɒ* in the possessive as well" require a morphological module in which the derivation of the possessive has access to the plural form

- this is an argument against theories like Distributed Morphology (Halle and Marantz, 1993) where words derived from the same root have no formal paradigmatic relation

In sublexicon terms, this relationship would be framed as: "If a Hungarian noun has [+lower] in its lexical entry, it (likely) has [−j] as well"

- this is a relationship between features of an item in the lexicon, not between exponents
- in this theory, the learning model can be sensitive to these implications *independent* of whether the morphological module encodes formal paradigmatic relations

The sublexicon theory does not resolve all architectural issues of morphology or fully settle the debate for or against paradigms, for example:

- metasyncretisms like "the accusative and genitive are identical for all plural nouns"
  - capturing this requires something more complicated than a 1-to-1 correspondence between exponents and rules of exponence
  - whatever the architectural account of these metasyncretisms *in the grammar*, the sublexicon learning model will operate on the diacritics the rules of exponence contain

5 Conclusion and predictions

The Hungarian possessive presents an interesting case for the learner:

- there are multiple allomorphs of the possessive
- speakers must learn to associate each noun with the allomorph it selects for
- in many cases, the choice of allomorph is (at least partially) predictable from the noun's *phonological form* and *morphological patterning*

The sublexicon model with *SUBLEX constraints provides a way of:

- encoding this (partial) phonological and morphological predictability in a formal grammar
- presenting a framework for acquisition and behavior

Predictions:

- acquisition
  - depending on which words children hear first/often, the implications between stem class and possessive allomorphy could be over- or underapplied at first
- behavior
  - phonological and morphological effects can compete: lowering stem [hold] 'moon' (plural [hold-ɒk]) has possessive [hold-jɒ], a good fit for its phonology
  - "morphological surprisal" on behavioral tasks, just like phonotactically atypical words elicit longer reaction times and neural responses on lexical decision tasks (Vitevich et al., 1997; Pylkkänen et al., 2002)

A Appendix: Full models

This appendix contains the full models calculated for predicting possessive allomorphs among monomorphemic Hungarian nouns without variable possessive forms, with data taken from Papp (1969). The models were calculated using the `lrm` function in R's `rms` package (R Core Team, 2020; Harrell Jr., 2020). The first model (Table 8) contains only phonological factors, while the second (Table 9) also includes the morphological factor of lowering stem class.

I assembled the models using stepwise comparison, where each additional factor significantly improved the model ($p < .0001$) according to the same package's `lrtest` function. For both cases, an ANOVA confirmed that each factor in the final models was significant ($p < .0001$). Furthermore, each addition to the models improved their Akaike Information Criterion (AIC), a metric that rewards model likelihood but penalizes model complexity—that is, the improvement in model fit brought by adding each factor outweighed the cost of having a more complex model. In particular, adding the morphological factor of stem class improved the model with $\chi^2 = 112.9$, reducing the AIC from 1276 to 1170.

The tables below also include the variance inflation factor (VIF) for the variables. For each coefficient $\hat{\beta}_j$ in the model, the VIF compares the amount of variance exhibited by $\hat{\beta}_j$ in the model to the amount of variance $\hat{\beta}_j$ would exhibit in a model with no other factors. The VIF measures collinearity among a model's factors, where a VIF of 1 indicates no collinearity and a VIF above either 5 or 10 for a given variable is problematic for the model (James et al., 2013). None of the factors reach either threshold; in particular, the VIF for lowering stems is very close to 1.

	β coef	*SE*	*Wald z*	*p*	*VIF*	*predicted rates*
Intercept	**3.02**	**.32**	**9.55**	**<.0001**		**bot-jɒ > bot-ɒ**
C Manner (default: plosive)						
fricative	**–1.44**	**.39**	**–3.73**	**.0002**	**1.54**	**raːf-jɒ < laːp-jɒ**
sibilant	**–10.69**	**.80**	**–13.36**	**<.0001**	**1.24**	**hɒs-jɒ < lɒt-jɒ**
nasal	**–1.95**	**.27**	**–7.16**	**<.0001**	**2.35**	**oːn-jɒ < toːt-jɒ**
approximant	**–4.08**	**.30**	**–13.47**	**<.0001**	**4.00**	**tʃɛr-jɛ < tsɛt-jɛ**
C Place (default: alveolar)						
labial	**–2.02**	**.26**	**–7.94**	**<.0001**	**2.22**	**tsiːm-jɛ < siːn-jɛ**
palatal	**–8.88**	**1.10**	**–8.06**	**<.0001**	**1.10**	**ryɟ-jɛ < tʃyd-jɛ**
velar	**–3.26**	**.29**	**–10.96**	**<.0001**	**3.32**	**gøːg-jɛ < tʃøːd-jɛ**
Harmony (default: back)						
front	**–2.03**	**.18**	**–10.96**	**<.0001**	**1.55**	**køb-jɛ < dob-jɑ**
variable	**2.26**	**.97**	**2.33**	**.0197**	**1.12**	**ɒnkeːt-jɒ/jɛ > klɒrineːt-jɒ**
V Height (default: mid)						
high	**1.73**	**.22**	**7.89**	**<.0001**	**1.21**	**cuːk-jɒ > tʃoːk-jɒ**
low	0.28	.19	1.50	.1342	1.53	kɒr-jɒ > kor-jɒ
V Length (default: short)						
long	**1.40**	**.17**	**7.98**	**<.0001**	**1.25**	**boːr-jɒ > bor-jɒ**
Coda (default: singleton)						
geminate	**2.47**	**.40**	**6.25**	**<.0001**	**1.15**	**ʃikː-jɛ > sik-jɛ**
cluster	0.04	.21	0.18	.8602	1.36	domb-jɒ > dob-jɒ
Syllables (default: monosyllabic)						
polysyllabic	**1.15**	**.17**	**6.67**	**<.0001**	**1.42**	**ɛlɛm-jɛ > sɛm-jɛ**

Table 8: Regression model with phonological predictors of possessive [j], with significant effects bolded

	β coef	*SE*	*Wald z*	*p*	*VIF*	*predicted rates*
Intercept	**3.53**	**.33**	**10.60**	**<.0001**		**bot-jɒ > bot-ɒ**
Stem class (default: non-lowering)						
lowering	**–3.71**	**.44**	**–8.44**	**<.0001**	**1.16**	**ɲaːr$_{[+\text{low}]}$-jɒ < paːr$_{[-\text{low}]}$-jɒ**
undetermined	–0.25	.25	–0.98	.3278	2.53	(no direct comparison)
variable	**–2.76**	**.69**	**–4.00**	**<.0001**	**1.05**	**taːr$_{[\pm\text{low}]}$-jɒ < tsaːr$_{[-\text{low}]}$-jɒ**
C Manner (default: plosive)						
fricative	**–1.03**	**.44**	**–2.37**	**.0179**	**1.40**	**raːf-jɒ < laːp-jɒ**
sibilant	**–11.07**	**.80**	**–13.86**	**<.0001**	**1.24**	**hɒs-jɒ < lɒt-jɒ**
nasal	**–2.07**	**.28**	**–7.39**	**<.0001**	**2.31**	**oːn-jɒ < toːt-jɒ**
approximant	**–4.06**	**.31**	**–13.10**	**<.0001**	**3.66**	**tʃɛr-jɛ < tsɛt-jɛ**
C Place (default: alveolar)						
labial	**–2.22**	**.27**	**–8.35**	**<.0001**	**2.12**	**tsiːm-jɛ < siːn-jɛ**
palatal	**–9.25**	**1.13**	**–8.22**	**<.0001**	**1.12**	**ryɟ-jɛ < tʃyd-jɛ**
velar	**–3.54**	**.31**	**–11.55**	**<.0001**	**3.26**	**gøːg-jɛ < tʃøːd-jɛ**
V Height (default: mid)						
high	**1.85**	**.23**	**8.09**	**<.0001**	**1.19**	**cuːk-jɒ > tʃoːk-jɒ**
low	**0.77**	**.21**	**3.66**	**.0003**	**1.50**	**kɒr-jɒ > kor-jɒ**
Harmony (default: back)						
front	**–1.98**	**.27**	**–7.41**	**<.0001**	**2.97**	**køb-jɛ < dob-jɑ**
variable	**2.25**	**1.04**	**2.17**	**.0297**	**1.10**	**ɒnkeːt-jɒ/jɛ > klɒrineːt-jɒ**
Coda (default: singleton)						
geminate	**2.43**	**.41**	**5.97**	**<.0001**	**1.15**	**ʃikː-jɛ > sik-jɛ**
cluster	–0.08	.22	–0.36	.7161	1.39	domb-jɒ < dob-jɒ
V Length (default: short)						
long	**1.30**	**.19**	**6.97**	**<.0001**	**1.24**	**boːr-jɒ > bor-jɒ**
Syllables (default: monosyllabic)						
polysyllabic	**0.79**	**.18**	**4.31**	**<.0001**	**1.46**	**ɛlɛm-jɛ > sɛm-jɛ**

Table 9: Regression model with phonological and morphological predictors of possessive [j], with significant effects bolded

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