Limits to the learnability of abstract underlying representations in Maga Rukai

Abstract. Standard morphophonological analysis allows for **composite** Underlying Representations (URs), which combine information from multiple allomorphs and are abstract in that they do not correspond to any single allomorph. This paper probes at the learnability of composite URs by looking at diachronic restructuring in the Maga dialect of Rukai. In Maga, rhythmic vowel deletion makes it so that no single allomorph has all the underlying vowels, and URs are composite (e.g. [tm**u**$_2$su]~[ik-t**i**$_1$msu:] → /t**i**$_1$m**u**$_2$su/). Drawing on corpus and comparative data, I find that paradigms have i) undergone substantial leveling, and ii) extended a vowel-matching alternation. Both changes make surface forms predictable form each other, removing the need for abstraction. To substantiate these results, I implement a maximum entropy model of Maga vowel alternations, and show that a model with concrete URs (that correspond to surface allomorphs) outperforms an abstract-UR model at predicting the patterns of restructuring found in Maga.

1 Introduction

In morphophonemic analyses, alternations are explained by positing abstract underlying representations (URs), with rules or constraints that derive the surface forms. Once we allow URs to deviate from surface forms, we must also ask how abstract URs can be. In other words, how much can URs diverge from their surface representations? This paper argues that abstract URs are dispreferred by learners, drawing on empirical evidence from Maga Rukai, which has undergone restructuring in a way that turned an abstract-amenable analysis into a more concrete one.

Early work in generative phonology, centered around SPE (Chomsky & Halle, 1968), allowed for high degrees of abstractness in underlying forms. Since then, various scholars have questioned how abstract URs can be (e.g. Kiparsky, 1968; Derwing, 1974; Tranel, 1981); this line of work argues that speakers cannot learn overly abstract URs, and morphophonological patterns which require positing highly abstract URs will either be unproductive or restructured by learners into more concrete patterns. Kiparsky's (1968; 1973; 1982) work was particularly influential in highlighting possible limits on abstractness, drawing on data from language change.

Maga Rukai (henceforth Maga) is an Austronesian language spoken in Southern-Central Taiwan (Li, 1977a). Maga is particularly suitable for addressing issues around representational abstractness, because it exhibits morphophonemic alternations that require positing relatively abstract URs. The pattern of interest is rhythmic vowel deletion (syncope), where every odd medial vowel counting from the left is deleted. Representative examples are given in (1), using the unaffixed and negative forms. In these examples, the deleted vowel is indicated with an underscore. The negative prefix /i-/ shifts which vowels get deleted, resulting in ∅~V alternations between the stem and negative allomorphs.

(1) *Examples of ∅∼V alternations in Maga*

	UR	STEM	NEGATIVE	GLOSS
a.	/kupɨcɨ/	k_pɨ́cɨ	i-kup_cɨ́:	'sting'
b.	/limilimacɨ/	l_mil_macɨ	i-lim_lim_cɨ:	'shine'

As a consequence of rhythmic syncope, many words require positing **composite URs**, which are abstract in the sense that the UR is not identical to any one surface allomorph, but must instead combine information from multiple allomorphs. For example, 'sting' (1a) would typically be analyzed as having the UR /kupɨcɨ/, which takes its initial vowel from the negative form and its second vowel from the stem form. If the Maga syncope pattern is stable over time, or if it is restructured in a way that maintains composite URs, this would suggest that speakers are able to learn composite URs. On the other hand, if speakers mis-learn paradigms in such a way that results in more concrete URs, this would suggest that composite URs are dispreferred.

In this paper, I track how the Maga syncope pattern has been restructured over time, by comparing Proto-Rukai and modern Maga data from Hsin (2000). To preview the results, I find that a large proportion of 'composite UR' paradigms in Maga have been restructured to result in more concrete URs. Two patterns of restructuring are observed: first, some paradigms have undergone so-called **vowel-matching** changes, which maintain the rhythmic syncope pattern but make paradigms less abstract. Other forms have been **leveled**, resulting in a loss of ∅∼V alternations. To explain these changes, I propose that rather than learning a rhythmic syncope pattern, speakers have instead learned a system of morphologically-conditioned vowel alternations.

The rest of this paper is organized as follows: Section 2 describes the Maga rhythmic syncope pattern, then Section 3 formalizes UR abstractness along a hierarchy and places Maga in this hierarchy. In Section 4, I show that two main types of paradigm restructuring have occurred: paradigm leveling (4.1) and vowel matching (Section 4.3-4.5). In Section 5, I implement a concrete analysis of Maga vowel alternations, and show that this model is better at predicting the Maga restructuring patterns than an abstract UR model. Finally, Sections 6-7 end with a discussion of the broader implications of these results for our understanding of abstractness.

2 Rhythmic syncope in Maga Rukai

Maga is the dialect of Rukai spoken in Maolin township (Li, 1977b). The population of the township is around 866 (Kaohsiung City Government Civil Affairs Bureau, 2023), but the number of fluent speakers is much less than that. The name Maga comes from the historic name of Maolin Township. The local community identify themselves and the dialect by the name *tḓilka*, but I use the term Maga to be consistent with prior literature.

Earlier descriptive work on the Maga dialect includes Li (1975) and Saillard (1995). More recently, Zeitoun (1995, 2024) provides cross-dialectal overviews of Rukai phonology and morphosyntax. Hsin (2000, 2003) provides a thorough description and analysis of Maga phonology and morphophonemic alternations; subsequent work by Chen (2008) focuses on the rhythmic syncope patterns. Additionally, Li (1977a) has done extensive work on the internal subgrouping of the Rukai dialects. Li (1977a) also reconstructs the phonological system of Proto-Rukai and provides a list of around 500 cognates from dialects of Rukai.

In the rest of this paper, examples are taken from Hsin (2000), supplemented with data from Li (1975). The resulting corpus has 1049 stems; of these, a subset of 790 words are given in both their stem and prefixed forms, allowing us to observe the syncope pattern.[1]

2.1 Basics of Maga phonology

Maga has seven vowels, /i e u o ɨ ə a/, as well as the consonants in Table 1. The two central vowels /ɨ/ and /ə/ are marginally contrastive; while there are minimal pairs between the two vowels (e.g. [bɨkɨ] 'pig' vs. [bəkɨ] 'nose running'), [ə] is sometimes an allophone of /ɨ/, and the perceptual distinction between them is unclear, even for native speakers (Hsin, 2000, p. 37).

	Labial	Dental	Alveolar	Retroflex	Dorsal
Stop	p b		t d	ɖ	k g
Affricate			c [t͡s]		
Fricative	v	θ (ð)	s (z)		
Nasal	m	n		ŋ	
Lateral			l		
Trill			r∼ɾ		

Table 1: Consonant inventory of Maga Rukai

Stress in Maga is argued to be predictable, falling on either the penultimate syllable (e.g. [ábu] 'ash') or on final heavy (C)V: syllables (e.g. [adóː] 'mud'). Maga syllables have a (C)(C)V(C) structure with some additional restrictions; no final consonants are observed, and both initial and medial consonant clusters are restricted to two segments.

2.2 Basic syncope pattern

In Maga, odd medial vowels counting from the left are deleted. This type of rhythmic syncope, or the deletion of vowels in metrically weak positions, has been observed in languages like Macushi (Hawkins, 1950; Kager, 1997), Nishnaabemwin (Valentine, 2001; Bowers, 2012), and Southern Pomo (Kaplan, 2022).

In the case of Maga, affixation can shift the position of the deleted vowel, resulting in ∅∼V alternations between forms of the same paradigm. This is demonstrated in (2) for the stem and negative allomorphs of 'shrimp'; negation is marked with both the prefix /i-/ and lengthening of the final syllable. Nouns and stative verbs take an additional stative prefix /k-/. More examples of alternations between the stem and negative forms are given in (3). For underlyingly disyllabic stems like (3a-b), syncope is accompanied by lengthening of the remaining surface vowel

[1]Note that are some inconsistencies between Li (1975, 1997) and Hsin (2000) in the transcription of stop voicing. For consistency, I use the transcription provided in Hsin (2000).

(e.g. [smáː], cf. *[smá]). Lengthening can be attributed to a typologically well-attested word-minimality restriction, requiring that content words be minimally bimoraic (Hayes, 1995).

(2) *Derivation for 'shrimp'*

UR	/ta$_1$ ka$_2$ su$_3$ lu$_4$ ɖu$_5$/	/i$_1$-k- ta$_2$ ka$_3$ su$_4$ lu$_5$ ɖu$_6$-V/
Syncope	t_kas_luɖu	ik-tak_sul_ɖuː
Stress	tkaslúɖu	iktaksulɖúː
SR	[tkaslúɖu]	[iktaksulɖúː]

(3) *Examples of rhythmic syncope in Maga*

	UR	STEM	NEGATIVE	GLOSS
a.	/rana/	rnáː	i-k-ranáː	'creek'
b.	/ɖamarɨ/	ɖmárɨ	i-k-ɖamrɨ́ː	'moon, month'
c.	/timusu/	tmúsu	i-k-timśuː	'salt'
d.	/giŋigiŋi/	gŋígŋi	i-k-giŋgiŋíː	'longan'
e.	/takasuluɖu/	tkaslúɖu	i-k-taksulɖúː	'shrimp'

In this paper, I focus on comparisons between the unaffixed stem and negative forms, because these forms are the most well-attested and found across all lexical categories. The stem and negative forms also represent the range of possible syncope patterns within a paradigm. However, not all affixes in Maga trigger syncope alternations, as summarized in Table (4). Hsin (2000) lists three affixes that trigger syncope: /i-/ 'negation', /l-/ 'plural', and /-a/ 'imperative'. Maga also has a set of verb-marking prefixes which obligatorily appear in the stem form but are not in the domain for syncope; these include /ma-/ 'stative verb marker' and /u-/ 'dynamic verb marker', and a few other less productive verbalizing prefixes.

(4) *Examples of prefixes that do and don't trigger syncope alternations*

Alternates	Affix	Gloss	Example	Unattested form
no	ma-	stative vb.	ma-rkɨ́mɨ	*ma-rɨkmɨ
	u-	dynamic vb.	u-θlibi	*u-θilbi
	si-	to put on	si-kpiŋi	*s-kipŋi
yes	i- -V	negative	i-pilŋɨː	*i-pliŋɨː
	-aː	imperative	sukl-aː	*skul-aː
	l-	plural	vlakɨ	l-valkɨ

Maga rhythmic syncope alternations are likely to have developed from severe phonetic reduction of unstressed vowels. Similar pathways of diachronic change have been reported from languages like Nishnaabemwin (Valentine, 2001; Bowers, 2012). The picture that emerges is that at a point earlier in history, Maga Rukai had paradigms with no $\varnothing \sim$V alternations, and therefore did not require positing abstract URs. The subsequent loss of metrically weak vowels then resulted in a synchronic pattern which requires composite URs. The (in)stability of the syncope pattern over time can then give us insight into how well abstract representations are learned and tolerated.

2.3 Blocking of syncope

There are several regular (phonologically-motivated) exceptions to syncope. First, syncope is blocked (near-exceptionlessly) in onsetless syllables. Examples of this are given in (5) for both word-initial vowels (5a), and medial vowels (5b). The vowel that otherwise would have been deleted (i.e. is underlyingly in an odd-numbered syllable) is underlined. Following Chen (2008), this can be characterized as the effects of a positional faithfulness constraint MAX-V/$[_\sigma$. Relatedly, vowels in hiatus also do not delete; examples are given in ()6); note that blocking of syncope in hiatus conditions has not been described in prior work.

(5) *Onsetless vowels do not delete (157/161; 97%)*

a. *Initial vowels (N = 120/124; 97%)*

SR	UR	GLOSS
ábu (cf. *bú)	/abu/	'ash'
uvácɨ (cf. *vácɨ)	/uvacɨ/	'vein'

b. *Medial onsetless syllables (N = 37/37; 100%)*

SR	UR	GLOSS
lθi**e**kɨ (cf. *lθikɨ)	/liθiekɨ/	'waterfall'
i-k-nu**ə**ŋɨ́ː (cf. *i-k-nuŋɨ́ː)	/nuəŋɨ/	'cattle, cow'

(6) *High vowels in hiatus that do not delete or become glides (60/62; 97%)*

a. *Hiatus in stem forms (N = 43/45, 96%)*

STEM	UR	GLOSS
n**u**ə́ŋɨ (cf. *nə́ŋɨ)	/nuəŋɨ/	'cattle, cow'
ŋ**í**u (cf. *ŋú)	/ŋiu/	'owl'

b. *Hiatus in negative forms (N = 17/17, 100%)*

STEM	UR	GLOSS
i-kul**u**əŋə́ː (cf. *i-kuləŋə́ː)	/kuluəŋə/	'sparrow'
i-tam**a**íː (cf. *i-tamíː)	/tamai/	'same'

Additionally, there is an effect of antigemination (McCarthy, 1986), where syncope is blocked if it would result in a geminate consonant; examples of this are given in (7). There is also a contrast between initial and medial geminates; syncope is always blocked if it would result in an initial geminate (7a), but only variably blocked in the case of medial geminates (7bb). The difference in initial and medial geminates can be attributed to a typologically common and phonetically-motivated dispreference for initial geminate consonants (Muller, 2001).

(7) *Deletion is blocked by geminates*

a. *Initial geminates (N=25/25; 100%)*

SR	UR	GLOSS
t**u**túku (*ttúku)	/tutuku/	‘rabbit’
r**a**rámɨ (cf. *rrámɨ)	/raramɨ/	‘bird’

b. *Medial geminates in stems (N=61/83; 73%)*

SR	UR	GLOSS
θlev**á**va (cf. *θlévva)	/θelevava/	‘rainbow’
vlir**ú**ru (cf. *vlírru)	/valiruru/	‘glutinous rice’

2.4 Other phonological alternations

There are two morphophonemic alternations that interact with rhythmic syncope, but are not of direct interest to the current paper. First, high vowels in hiatus (and in a deleting position) become glides rather than delete. Examples of glide formation are given in (8). Although Hsin describes glide formation as a productive process, her data contains many forms transcribed with high vowels where glides are expected. Examples include: [ciuwa] ‘bamboo shoot’, [u-piárcɨ] ‘shout’, and [buə́sə] ‘rice’. It is unclear if these are a result of transcription inconsistencies, or other more systematic factors.

(8) *Glide formation in VV sequences*

STEM	UR	GLOSS
kmus**y**áː	/kamusiaː/	‘sugar’
ma-l**y**ácɨ	/liacɨ/	‘blind’
arib**w**áː	/aribuaː/	‘sweat’
u-k**w**áŋɨ	/kuaŋɨ/	‘shoot (with firearm)’

The second process involves lowering of the high vowels /i, u, ɨ/ to mid vowels [e, o, ə]. Examples of vowel lowering are given in (9). Following Hsin’s (2003) description, all occurrences of /i, u, ɨ/ following an /a/ are lowered to [e, o, ə] respectively, but *only* if the /a/ is deleted. In words like (9a-b), this causes lowering of /i/ in the stem form, while in words like (9c), lowering happens in the negative form. Words like [amici] (*[amece]) ‘tree root’ and [pagu] (*[pago]) ‘gallbladder’ demonstrate that lowering does not happen if the preceding /a/ is not deleted.

(9) *Vowel lowering (alternating vowels are underlined)*

	UR	STEM	NEGATIVE	GLOSS
a.	/damili/	dm<u>**e**</u>l<u>**e**</u>	i-k-daml<u>**i:**</u>	‘hemp’
b.	/caki/	ck<u>**e:**</u>	i-k-cak<u>**i:**</u>	‘excrement’
c.	/alapi/	alap<u>**i**</u>	i-k-alp<u>**e:**</u>	‘slate’
d.	/valu/	vl<u>**o:**</u>	i-k-val<u>**u:**</u>	‘bee’
e.	/taluɖu/	tl<u>**o**</u>ɖ<u>**o**</u>	i-k-talɖ<u>**u:**</u>	‘bridge’

3 Formalizing degrees of UR abstraction in Maga

To formalize degrees of abstraction, I adopt Kenstowicz and Kisseberth’s (1977, ch. 1) taxonomy of UR abstractness, which defines levels of abstractness in terms of how divergent a UR is from its associated SRs; following Wang & Hayes (2025), I refer to this hierarchy as the KK-hierarchy. The KK-hierarchy not only allows for a finer-grained evaluation of how abstract URs can be in Maga, but also allows for comparison with recent work by Wang & Hayes (2025), who propose a model of UR learning that is situated in the same hierarchy. In this section, I give an overview of the KK-hierarchy, then and discuss possible outcomes of restructuring for Maga under each level of this hierarchy.

3.1 The KK-hierarchy

KK-A: only invariant properties of allomorphs

Under KK-A, the UR of a morpheme “consists of all and only the invariant phonetic properties of that morpheme’s various SRs” (Kenstowicz & Kisseberth, 1977, p. 8). This is highly restrictive, disallowing even standard phonemicization. For example, English “pan” [pæ̃n], where the vowel is predictably nasalized, would have the UR /pæ̃n/. KK-A’, a less restrictive version of KK-A, allows predictable allophony to be treated as unspecified.

Both KK-A and KK-A’, when applied to Maga Rukai, would not allow any of the alternating vowels to be present in the UR. A root like ‘moon’, given again in (10), would have the UR /ɖmrɨ/, whose only vowel is the non-alternating stem-final vowel. Under a KK-A approach to UR learning, URs should be reanalyzed in a way that removes all contrastive information about the alternating vowels. This could result in a hypothetical grammar like (11), where the vowel that surfaces is always some predictable ‘least-marked vowel’ like [ɨ].

(10) *Maga URs under KK-A*

stem	negative	gloss	UR-A
ɖmarɨ	i-k-ɖamrɨː	‘moon’	/ɖmrɨ/
tmusu	i-k-timsuː	‘salt’	/tmsu/

(11) Grammar A: only retain non-alternating parts of the paradigm.

UR		STEM	NEGATIVE
/ɖmrɨ/	→	[ɖmrɨ]	[i-k-ɖmrɨː]
/tmsu/	→	[tmsu]	[i-k-tmsuː]

KK-B: single allomorph

Broadly, KK-B requires that URs be based on the same surface allomorph (i.e. the same slot in a paradigm). Under the basic version of KK-B, the UR must be based on the isolation stem, or as close to the isolation stem as the language permits (Kenstowicz & Kisseberth, 1977, p. 11). The less restrictive KK-B' states that the learner should base the UR on the allomorph that appears in the most contexts, while KK-B", which has be extensively explored in work by Albright (2002a,b, 2010, et seq.), restricts URs to be based on the most informative slot in a paradigm.

The subtypes of KK-B, when applied to Maga, predict grammars like (12a), where paradigms have leveled towards the stem form, or (12b), where paradigms have leveled towards the negative allomorph.[2] Note that while grammars B1 and B2 have leveled out vowel alternations, this is not a requirement of KK-B. KK-B also allows for grammars like (12C), where ∅∼V alternations remain, but are completely predictable from one surface allomorph; in Grammar B3, the UR is based on the stem allomorph, and the vowel that surfaces in the negative form is a copy of the stem vowel.

(12) a. Grammar B1: leveling towards the stem allomorph.

UR		STEM	NEGATIVE
/ɖmarɨ/	→	[ɖmarɨ]	[i-k-ɖmarɨ]
/tmusu/	→	[tmusu]	[i-k-tmusuː]

b. Grammar B2: leveling towards negative allomorph.

UR		STEM	NEGATIVE
/ɖamrɨ/	→	[ɖamrɨ]	[i-k-ɖ**ɨ**mrɨː]
/timsu/	→	[timsu]	[i-k-t**ɨ**msuː]

c. Grammar B3: ∅∼V alternations are predictable from the stem allomorph

UR		STEM	NEGATIVE
/ɖmarɨ/	→	[ɖm**a**rɨ]	[i-k-ɖ**a**mrɨ]
/tmusu/	→	[tm**u**su]	[i-k-t**u**msuː]

KK-C: choosing among allomorphs

In the KK-C level of the hierarchy, the UR of a morpheme is always based on some surface allomorph, but this allomorph does not need to come from the same paradigm slot for every mor-

[2] Both allomorphs also surface in other morphological contexts

pheme. For Maga, this allows for grammars like (13), where some words have leveled towards the stem allomorph while others have leveled towards the negative allomorph.

(13) Grammar C: leveling towards either the stem or negative allomorph.

UR		STEM	NEGATIVE	
/ɖmarɨ/	→	[ɖmarɨ]	[i-k-ɖmarɨ]	(base = stem)
/timsu/	→	[timsu]	[i-k-timsuː]	(base = negative)

KK-D: segmentally composite URs

At KK-D, URs must be composed of segments that surface in some allomorph, but not necessarily the same one. This is the level required for a traditional analysis of the Maga syncope pattern. As schematized in (14), for words like 'salt', no single surface allomorph has information about all the underlying vowels. As a result, the UR must take V1 from the negative allomorph, and V2 from the stem allomorph. If the KK-D level of the hierarchy is learnable, then we would predict Maga syncope to be stable over time.

(14) *Composite UR of 'salt'*

UR - - - - - - - - - - - - / t **i** m **u** su /

SR - - - - - - - [ikt **i** msuː] [tm **u** su]

KK-E/F: featurally composite URs

Under KK-E/F of the abstractness hierarchy, underlying forms can have abstract phonemes which never occur in the surface allomorphs. This level of the hierarchy does not directly concern the current paper, since the Maga pattern does not require a higher level of abstraction than KK-D.

Multiple listed URs (KK-C')

The KK hierarchy assumes that learners have just one UR corresponding to each morpheme. However, it is also possible that learners list multiple underlying representations for a given morpheme, each corresponding to a surface allomorph (e.g. Zuraw, 2000, 2010; Moore-Cantwell & Pater, 2016; Kuo, 2023). For example, the paradigm [ɖm**a̲**rɨ]∼[i-k-ɖ**a̲**mrɨː] may be associated with two listed allomorphs, /ɖmarɨ/ and /ɖamrɨ/. In terms of learning difficulty, a listed allomorph approach would be similar to (or potentially easier than) a single-allomorph approach (i.e. KK-B), since learners can simply list any allomorph they encounter, without considering other alternatives. However, this approach would predict restructuring that is more similar to the changes predicted under KK-C. That is, we may expect to see leveling towards both the stem and negative allomorphs, since both allomorphs are listed in the grammar.

3.2 Degree of abstraction required in the Maga lexicon

Notably, although many paradigms in Maga require positing segmentally composite URs (KK-E), some paradigms are still predictable from one or both surface allomorphs. Table (15) provides examples of paradigms that vary in their degree of abstractness.

First, roots that are underlyingly /V1 CV2/ can be accounted for using KK-A URs. As shown in (15a), these paradigms have no vowel alternations; V1 in the stem does not delete because it's onsetless, while in the negative form, neither vowels are in positions for syncope. Roots of the shape /CV1 CV2/ (15b) never undergo syncope in the negative allomorph, so are fully predictable from this allomorph. Roots of the shape /V1 CV2 CV3/ (15c) are fully predictable from the stem allomorph; V1 does not delete because it is onsetless, and the other vowels are not in deleting positions. Blocking of syncope from vowel hiatus and/or antigemination can also result in surface allomorphs that contain information about all the underlying vowels.

(15) *Summary of UR types required in the lexicon (assuming regular application of syncope)*

	Predictable allomorph	**KK level**	**UR**	**stem**	**negative**	**gloss**	**N**	**P**
a.	both	A	/abu/	ábu	i-abúː	'ash'	84	0.08
b.	negative	B/C	/tupe/	cmíː	i-k-cimíː	'cheek'	96	0.09
c.	stem	B/C	/amici/	amíci	i-k-amcíː	'root'	230	0.22
d.	neither	D	/dukacɨ/	dkácɨ	i-k-dukcɨ́ː	'mud'	639	0.61

Table (15) additionally summarizes the degree of abstractness required in the Maga corpus, *if* syncope applies regularly (i.e. no restructuring has occurred). If Hsin's corpus is taken to reflect the general distributions of the Maga lexicon, then the majority of the lexicon requires positing abstract URs of some kind. Only 8% of the corpus can be accounted for under KK-A. In contrast, over 60% of words can only be accounted for under KK-D of the hierarchy.

4 Restructuring of rhythmic syncope alternations

Assuming regular application of syncope, over half of the Maga lexicon would require composite URs. However, it turns out that for the subset of forms where both the stem and negative allomorphs are known, about 24% (190/790) of stem forms and 23% (185/790) of negative forms fail to undergo the regular syncope pattern. Overall, 40% (314/790) of paradigms have at least one member that does not undergo syncope regularly. This irregularity suggests that substantial restructuring has occurred. In fact, these numbers do not reflect the full extent of restructuring in Maga, as some paradigms have also maintained what looks on the surface to be a regular rhythmic syncope alternation, but undergone changes in vowel-quality.

In this section, I describe several types of restructuring observed in Maga, and argue they all result in paradigms which require less abstract URs. First, as discussed in Section 4.1, some paradigms have leveled towards either the stem or negative allomorph, removing ∅∼V alternations. Additionally, in Section 4.3-4.5, I show that speakers have extended a ‘vowel-matching’ alternation which makes paradigms more concrete.

The data I use is the same corpus of 1049 words above; note that for some of these words, the negative allomorph is not available. In total, a subset of 790 words are listed with the stem/negative paradigm; for these, we can infer the direction of restructuring. Additionally, throughout this section, I use ‘UR’ to refer to the hypothetical composite UR that would be posited under a traditional morphophonemic analysis. The actual representation that speakers learn, as inferred by directions of restructuring, may not exactly match these URs.

4.1 Paradigm leveling

As previewed above, many paradigms have leveled towards either the stem or negative allomorph, removing ∅∼V alternations. Direction of leveling is inferred from the syncope pattern found in modern Maga. For example, given the word /simitu/ ‘lips’, there are three potential syncope patterns (not leveled, leveled to stem, leveled to negative) given in (16); where leveling has occurred, the leveled-out form is shaded in grey. In (16a), the negative allomorph does not show the regular syncope pattern, and instead has the same syncope pattern as the stem allomorph, implying that leveling towards the stem has occurred. Importantly, leveling always results in a more concrete paradigm, as it removes all vowel alternations.

(16) *Types of leveling for ‘lips’ /simitu/*

	Pattern	Paradigm	new UR
a.	Not leveled (regular syncope)	[smítu] ∼ [i-k-simtuː]	–
b.	Leveled to stem	[smitu] ∼ [i-k-s∅mi̲tuː]	/smitu/
c.	Leveled to negative	[si̲m∅tu] ∼ [i-k-simtuː]	/simtu/

In some composite-UR forms (i.e. paradigms where neither allomorph is an informative base), the syncope pattern is irregular, but alternations have not been fully leveled out. Examples of this are given in (17), where exceptional vowels (that fail to delete, or irregularly delete) are underlined. These examples are described in Section 4.2.

(17) *Forms where syncope exceptionally fails to apply*

	Paradigm	**Expected pattern**	**Gloss**
(a)	ma-ɖrɨmɨ́∼ik-ɖɨrɨ̲mɨ́ː	ma-ɖrɨmɨ́∼ik-ɖɨrmɨ́ː	‘cloudy’
(b)	ma-rmarmoː∼i-k-rama̲r_moː	ma-rmarmóː∼i-k-ramramoː	‘smooth’

Table (18) summarizes the proportion of forms that have been leveled, with examples; the row titled ‘other’ shows cases like (17), which have irregular syncope but not paradigm leveling. Where leveling has occurred, vowels that should have deleted are underlined, and irregularly deleted vowels are marked as ‘∅’. Paradigms are organized by their UR type (i.e. which allomorph the paradigm is predictable from). The UR listed in each example is the hypothetical UR that we would expect, if the syncope pattern were regular. For example, (18b) represents a case where the underlying vowels are predictable from the stem allomorph, and leveling towards the stem has occurred. The ‘regular’ negative form should be [i-udlɨ́ː], but instead, it has leveled towards the stem and is now [i-ud**a̲**lɨ́ː]. On the other hand, /ɨɖɨpɨ/ ‘quench’ is also predictable from the stem, but has leveled towards the negative allomorph, such that the isolation stem is [ɨ́ɖpɨ], with the syncope pattern of the negative form.

Looking at Table (18), as expected, non-alternating forms have not undergone any changes. Negative-base paradigms (i.e. ones predictable from the negative allomorph) almost always leveled towards the negative allomorph, if they were leveled (18f). Similarly, stem-base paradigms almost always leveled towards the stem (18b). For the composite UR forms, there has generally been less leveling (N = 63, 14%).[3] Where leveling has occurred, it has happened towards both allomorphs, with a bias towards the stem allomorphs.

(18) *Patterns of leveling*

	UR type	Leveled...	N	P	Example	
a.	non-alternating	not leveled	61	1	ábu∼i-abúː	‘ash’
b.	stem-base	towards stem	33	0.39	událɨ∼i-ud**a̲**lɨ́ː	‘rain’
c.		towards negative	1	0.01	ɨ́ɖ∅pɨ∼i-ɨɖpɨ́ː	‘quench’
d.		not leveled	51	0.60	amíci∼i-k-amcíː	‘tree root’
e.	negative-base	towards stem	1	0.01	u-kcyáː∼i-k∅cyáː	‘scissor’
f.		towards negative	70	0.43	t**é̲**θo∼i-k-teθóː	‘turnip’
g.		not leveled	93	0.56	tpeː∼i-k-tupéː	‘gourd dipper’
h.	composite	towards stem	36	0.08	blávnɨ∼i-k-b∅l**a̲**vnɨː	‘silver’
i.		towards negative	27	0.06	u-θ**í̲**l∅bi∼i-θilbíː	‘fly’
j.		other	96	0.20	ma-ɖrɨmɨ∼i-k-ɖɨr**ɨ̲**mɨː	‘mouth harp’
k.		not leveled	319	0.67	ɖmarɨ∼i-k-ɖamrɨː	‘moon’

Overall, there has been extensive leveling in Hsin’s corpus, which in turn makes paradigms more concrete. Leveling is generally in the direction of the predictable base. For example, paradigms that are predictable from the stem allomorph level towards the stem allomorph (N = 33/34 leveled items), with only one exception in the current data. For the composite UR forms that are predictable from neither allomorph, there is a slight preference for leveling towards the stem. These results are compatible with either a KK-C (choosing among allomorphs) or listed allomorphs view of UR selection.

One potential explanation for the observed directions of leveling is that paradigms level towards the most informative allomorph; similar informativity-driven leveling has been found by Albright (2002b, 2010, et seq.).[4] Alternatively, results could be driven by markedness restrictions

[3]Note that this is also the subset of forms that underwent vowel-matching restructuring.

[4]Note however that Albright finds leveling to be towards a single paradigm slot, not multiple slots as is found here.

that “override” a default tendency to level towards a single base. Put another way, paradigms may coincidentally appear to be leveling towards the most informative base, but are actually leveling in a way that results in more well-formed paradigms; this is the analysis put forth in Section 5.

Interestingly, composite UR forms have leveled less than other forms. If restructuring is driven by abstractness-avoidance, we should expect exactly these forms to be restructured the most. In Sections 4.3-4.5, I propose that composite UR paradigms have been restructured in other ways, which preserve the surface vowel alternation patterns but still result in a more concrete analysis.

4.2 Partial leveling

As previewed above, some paradigms in Hsin’s corpus have irregular syncope, but do not appear to have leveled towards either allomorph. Most of these cases look like ‘partial leveling’, where the paradigm has preserved vowel alternations at the left edge of the root, while leveling out alternations elsewhere. Representative examples are given in(19); in these examples, the stem is regularly alternating, while the negative allomorph differs from the stem only in that a vowel is inserted between the first two consonants. I characterize these paradigms as undergoing **copying** if the inserted vowel matches the first vowel of the stem, and **epenthesis** otherwise. Note that in the latter paaradigms, the epenthesized vowel is not completely predictable from the stem.

(19) *Examples of partial leveling*

		Negative allomorph		
Pattern	Stem	Observed	Not leveled	Unattested
copying	ma-θlímdi	i-k-θ<u>**i**</u>limdiː	i-k-θ<u>**i**</u>lm<u>**i**</u>diː	i-k-θlim<u>**i**</u>diː
	ma-rmarmo	i-k-r<u>**a**</u>marmoː	ik-r<u>**a**</u>mr<u>**a**</u>moː	ik-rmar<u>**a**</u>moː
	u-grɨgrɨ	i-g<u>**ɨ**</u>rɨgrɨː	i-g<u>**ɨ**</u>rg<u>**ɨ**</u>rɨː	i-grɨg<u>**ɨ**</u>rɨː
epenthesis	spégsi	i-k-s<u>**a**</u>pegsíː	i-k-s<u>**a**</u>pg<u>**i**</u>síː	i-k-speg<u>**i**</u>siː
	θtɨ́θpɨ	i-k-θ<u>**a**</u>tɨθpɨ́ː	i-k-θ<u>**a**</u>tθ<u>**ɨ**</u>pɨ́ː	i-k-θtθ<u>**ɨ**</u>pɨ

Table (19) also shows, for each partially leveled paradigm, the attested negative form, the regular/expected negative form, and an example of an unattested outcome of restructuring. Vowels that wre not in the stem allomorphv are underlined. In general, where there is partial leveling, paradigms have maintained alternation of vowels at the left edge of the root. Hypothetical forms like [i-grɨg<u>**ɨ**</u>rɨː], which maintain alternations at the right edge of the root but level out other alternations, are unattested. This provides additional support for the idea that speakers have learned a left-edge alternation, rather than a general rhythmic syncope alternation.

Notably, the majority (∼70%) of Maga stems are 2-3 syllables long; for these paradigms, rhythmic syncope looks exactly the same as a left-edge alternation (e.g. [ɖmarɨ∼[i-k-ɖamrɨː]]). In other words, a large chunk of the lexicon was already compatible with a left-edge alternation analysis. Maga also independently has paradigms that, on the surface, are compatible with a copying or epenthesis analysis; speakers may have picked up on and extended these patterns. Examples are given in (20).

	Pattern	UR	stem	negative	gloss
(20)	copying	/rigi/	rgiː	ik-r**i**gii	‘horse’
	epenthesis	/cɨpa/	mu-cpáa	i-c**ɨ**paː	‘landslide’

4.3 Vowel-matching and surface predictability from the stem form

For a subset of paradigms, the surface alternation pattern is compatible with alternate analyses that remove the need for proposing composite URs. In addition to the leveling described in the previous section, speakers also appear to have extended these alternate concrete analyses. Note that in the following descriptions, I assume that the base of derivations is the stem allomorph, meaning that these alternate analyses make alternations *predictable from the stem*. In principle, similar concrete sub-patterns can be found if the negative allomorph is assumed to be the base of derivation, but I focus on stem-based analyses for two reasons: i) results from the previous section suggest that there is a slight preference for leveling towards the stem allomorph, and ii) as will be described in Section 4.4, the direction of restructuring for these alternate analyses is overwhelmingly towards the stem allomorph.

First, for paradigms that are predictable from the stem allomorph, the surface pattern resembles deletion; given a word like /abakɨ/ [ab**a**kɨ∼i-k-ab∅kɨː], the negative form can be derived from the stem by simply deleting the second vowel. Another notable pattern in the Maga lexicon is that vowels in alternating positions tend to match each other; examples of this are given in (21), where the alternating vowels are underlined. In Hsin’s corpus, 388/723 paradigms with vowel alternations are vowel-matching. This tendency is also particularly strong for paradigms that require a composite UR (60%, n = 244/400). Crucially, if vowel-matching is a strong enough tendency, it would actually render a subset of paradigms predictable from just the surface allomorphs, removing the need for abstract URs.

(21) *Vowel matching examples*

	PARADIGM TYPE	UR	STEM	NEGATIVE	GLOSS
a.	composite	/sim**i**tu/	sm**i**tu	i-k-simtuː	‘lips’
b.	negative-base	/r**a**n**a**/	rn**a**ː	i-k-r**a**n**a**ː	‘creek’

First, in negative-base paradigms that are vowel-matching, the surface pattern can be described as vowel-copying; in (21b), the stem [rnáː] can be used to derive the negative form by copying the first vowel, giving us [i-k-ránaː]. These paradigms are already predictable from the negative allomorph, but vowel-matching makes them additionally predictable from the stem allomorph. Next, for the paradigms that should require a composite UR, vowel-matching causes the surface pattern to look like metathesis. In (21a), for example, the negative form can be derived from the stem through metathesis of [i] and [m]. If vowel-matching is predictable, than these paradigms become predictable from just the surface allomorphs, removing the need for abstract URs.

Table (22) summarizes the concrete sub-patterns found in Maga; counts are taken from Hsin's corpus, *assuming regular application of syncope*. Over half of the lexicon (63%) is predictable from these concrete sub-patterns. Slightly under half of the paradigms (N = 307, 43%) can be analyzed as undergoing metathesis, while deletion and copying explain a smaller proportion of the data.

(22) *Alternate analyses of Maga paradigms. Counts reflect the number of forms in Hsins' corpus that fit each analysis, if syncope is assumed to apply regularly*

	Base	Surface pattern	N	P	Example
a.	Stem	Deletion	84	0.10	ab**a**kɨ∼i-k-ab∅kɨː
b.	Negative	Copying	70	0.12	rn**aː**∼i-k-r**a**naː
c.	Neither	Metathesis	301	0.41	r**nɨ́**gɨ ∼ i-k-r**ɨn**gɨː
d.	(non-matching)	None	271	0.37	tbusu∼i-k-tibsuː sroː∼i-k-suroː

If speakers do in fact prefer to learn concrete URs, even if this results in an imperfect grammar with exceptions, then we might expect these concrete analyses to be extended throughout the lexicon. To preview the results of Section 4.4-4.5, restructuring has in fact caused the two patterns that rely on vowel-matching, metathesis and copying, to be extended.

4.4 Direction of vowel-matching changes

This section compares Proto-Rukai forms with their Maga Rukai reflexes, to first confirm that vowel-related restructuring has generally resulted in more vowel-matching. Additionally, I show that the direction of vowel-matching changes is overwhelmingly towards the stem allomorph, suggesting a bias for learning stem-based URs.

4.4.1 Data

To infer the direction of vowel changes over time, I compare Proto-Rukai forms with their known Maga reflexes. Mismatches in the vowels of a protoform and its reflex indicate that vowel-related restructuring has occurred. Importantly, no other dialect of Rukai has developed vowel syncope alternations. Tona, the dialect most closely related to Maga, has undergone no vowel-related changes. As a result, Proto-Rukai forms can be reliably used to infer what Maga vowels looked like prior to any restructuring that came after the development of rhythmic syncope.

As with the above sections, the Maga data comes from Hsin (2000). Data on Proto-Rukai comes from Li's (1977a) list of 532 protoforms, reconstructed from five of the six Rukai dialects[5]. Table (23) lists Proto-Rukai vowels and their regular reflexes in Maga; in the rest of the paper,

[5]The Labuan dialect is not included in Li's wordlist

for comparability with the Maga data, Proto-Rukai vowels are presented and organized by their reflexes in Maga, as summarized in (23).

(23) *Vowel correspondences, Proto-Rukai and Maga*

PROTO-RUKAI	MAGA	EXAMPLE
*a	a	*kav**a** > kv**a**ː 'hoe'
*i	i	*rig**i** > rg**i**ː 'horse'
*o, oa	u	*tim**o**s**o** > tm**ú**s**u** 'salt'; ***oa**lopo > **u**lúpu 'hunt'
*ə	ɨ	*pəl**ə**ŋ**ə** > pl**ɨ́**ŋ**ɨ** 'ghost'
*(a...)i	e	*caki > ck**é**ː 'excrement'
*(a...)o	o	*val**o** > vl**ú** 'bee'
*(a...)ə	ə	*bal**ə**bal**ə** > bl**ə́**bl**ə** 'bamboo'
*ay, *ai	e, eː	*acil**ay** > acíl**e** 'water'; *pag**ay** > pg**éː** 'rice plant'
*aw, *ao	o, oː	*maram**aw** > marám**o** 'same'; *ko**aw** > ku**oː** 'eagle'

In general, there is a straightforward correspondence between Proto-Rukai and Maga, with the exception that mid vowels *o and *ə have raised to Maga [u] and [ɨ]. Proto-Rukai diphthongs like *aw and *ay are reflected as monophthongs in Maga, variably as short or long vowels. The one wrinkle is that *i, *o, *ə are reflected as mid vowels [e], [o], and [ə] if they follow a *deleted* low vowel (*a). This lowering process generally does not apply if [a] has not been deleted (e.g. *aŋat**o** > aŋat**u** 'tree'), though there are a few exceptions where vowels adjacent to *a exceptionally lower (e.g. *aθ**o** > aθ**ó**ː 'dog'). The result is that in Maga, we observe vowel-lowering alternations that interact with syncope (see Section 2.4 for more details).

4.4.2 Results

Comparison of Proto-Rukai forms and their Maga reflexes first confirms that where vowel-related restructuring has occurred, it has primarily resulted in more vowel-matching, as opposed to some other type of change. The examples in (24) show the types of changes we are interested in, where the Maga paradigm does not show the expected vowel alternation, given the Proto-Rukai form. In these examples, the changed vowel is underlined.

(24) *Examples: vowel changes from Proto-Rukai to Maga*

Proto-Rukai	**expected UR**	**actual UR**	**paradigm**	**gloss**
*samito	/s<u>a</u>mitu/	/s<u>i</u>mitu/	smítu∼i-k-s<u>i</u>mtúː	'lips'
*sinaw	/sin<u>o</u>sino/	/sin<u>i</u>sino/	u-sn<u>i</u>snóː∼i-sinsinóː	'wash (clothes)'
*bicoka	/b<u>i</u>cuka/	/b<u>u</u>cuka/	bcúka∼i-k-b<u>u</u>ckáː	'stomach'

In total, there were 55 forms where Proto-Rukai and Maga Rukai vowels mismatched. Table (25) summarizes the types and frequencies of observed changes. The majority of changes (∼70%) resulted in more vowel-matching, consistent with the predictions of the previous section. Of the remaining changes, most neither increase nor decrease the rate of vowel-matching; for example, Proto-Rukai **ma-riday* should correspond to Maga [ma-rdé:]∼[i-k-r**i**dé:], but the observed paradigm is instead [ma-rdé:]∼[i-k-r**u**dé:].

(25) *Summary of vowel changes*

Change results in…	N	P	Example
MORE vowel-matching	38	0.70	*s**a**mito → /s**i**mitu/ 'lips'
LESS vowel-matching	5	0.09	*v**i**li → /v**u**li/ 'leech'
Neither	12	0.21	*ma-r**i**day → /r**u**de:/ 'fast'

For a few words (N = 5), vowel-matching forms were changed to be *non*-matching. Of these, two can plausibly be explained as the result of speakers extending a vowel-lowering alternation where high vowels lower to [e, o] following a deleted /a/ (see Section 2.4). For example, Proto-Rukai **ma-pilay* 'tired' should correspond to Maga [ma-plé:]∼[i-k-pilé:] (UR = /pile/), but instead we observe [ma-plé:]∼[i-k-p**alí:**] (UR = /pali/). This could be because speakers, when given the stem [ma-ple:], interpreted the final [e] as the result of /i/-lowering after a deleted /a/.

Vowel-related restructuring can be either towards the stem or negative allomorphs. Table (26) below summarizes the observed directions of vowel changes, with representative examples for each direction. For example, (26a) represents a case of restructuring based on the stem allomorph, as speakers are extending the vowel that is present in the stem allomorph to the negative allomorph. The opposite scenario, where speakers extend the vowel present in the negative allomorph to the stem allomorph, would result in [smatu]∼[ik-samtu:]. For a few paradigms, the direction of restructuring is unclear because both V1 and V2 have changed. When these are excluded, restructuring has overwhelmingly been based on the stem allomorph (48/50, P = 96%). In contrast, just two vowel-related changes were based on the negative allomorph. Both of these cases, shown in (27), turn out to be potentially problematic.

(26) *Directions of vowel-matching reanalysis*

	Base	N (P)	Proto-Rukai	Expected SRs	Actual SRs
a.	Stem	48 (0.87)	*s**a**mito	smitu∼i-k-samtu:	smitu∼ik-s**i**mtu:
b.	Negative	2 (0.04)	*sin**aw**	u-snosno∼i-sinsino:	u-sn**i**sno∼i-sinsino:
c.	Unclear	5 (0.09)	*t**o**l**a**rə	tlarɨ∼i-k-tulrɨ	tl**ura**∼i-k-t**a**lr**a:**

The source for 'borrow' is based on just one cognate from Tona, and potentially unreliable. Second, the word for 'wash' may have been influenced by a process of CiCo-reduplication that is found in other dialects of Rukai, where CiCo sequences are reduplicated as CiCi-CiCo Zeitoun (2007, 2024). The Maga word for 'wash' fits the phonological profile for CiCo-copying, so the shift of *o to [i] may have been due to influence from dialects that have CiCo-copying.

(27)

	Proto-Rukai	Change	gloss
	kyas**o**damə [Tona]	ks**u**dmɨ∼i-kesdami → ks**e**dmɨ∼i-kesdami:	'borrow'
	*(RED-)sin**aw**	u-sn**o**sno∼i-sinsino: → u-sn**i**sno∼i-sinsino:	'wash'

4.5 Vowel-matching as abstractness-avoidance

There are two reasons why we might observe vowel-matching changes. The first is that there is some kind of general vowel-harmony restriction on Maga vowels, which may have been present already in an earlier stage of Rukai. The second possibility is that speakers are extending vowel-matching specifically to remove abstract URs; in this case, we should only expect to see an increase in vowel-matching when it would increase a paradigm's predictability from a surface allomorph. Based on the direction of vowel-matching changes in Section 4.4, changes should specifically increase a paradigm's predictability from the stem allomorph.

These two hypotheses make different predictions, as vowel-matching improves a paradigm's predictability from the stem in only a subset of paradigms. As summarized in Table (28), in composite UR paradigms, vowel-matching allows the negative form to be derived from the stem form via metathesis. In negative-base paradigms, vowel-matching makes the negative form predictable from the stem via vowel-copying. In contrast, stem-base and non-alternating paradigms are already predictable from the stem, regardless of whether vowel-matching is present. If speakers are extending vowel-matching to remove abstract URs, rather than due to general vowel harmony pressures, vowel-matching should only increase in composite-UR and negative-base paradigms.

(28) *The effect of vowel-matching on a paradigm's predictability from the stem allomorph*

	Type	Surface Pattern	Example
a.	Composite UR	Metathesis	r**nɨ́**gɨ ∼ i-k-r**ɨn**gɨ:
b.	Negative-base	Copying	rn**a**:∼i-k-r**a**na:
c.	Stem-base	n.a.	**u**b**u**lu∼i-k-**u**blu:
d.	Non-alternating	n.a.	**á**b**a**∼i-k-**a**b**á**:

To test this prediction, I compare the distribution of vowel-matching forms in Proto-Rukai and Maga. In my comparison, I focus on just underlying V1 and V2 (e.g. /u/ and /a/ in /dukacɨ/ 'mud'). This data, though slightly pared down, should still be a good reflection of vowel-matching patterns across Maga, since most stems have 2-3 underlying vowels (70%, N = 735/1049), and for these words, only V1 and V2 are alternating. Additionally, the last two vowels have a tendency to match due to a process of echo epenthesis that is not the focus of the current study (Li, 1977a).

Going into the results, Fig. 1 compares vowel-matching rates in Proto-Rukai vs. Maga Rukai, by the type of UR that each paradigm has. We see that there has for the composite-UR and negative-base paradigms, there has been an increase in the proportion of vowel-matching forms. In particular this increase is the largest for the composite UR forms. On the other hand, stem-base

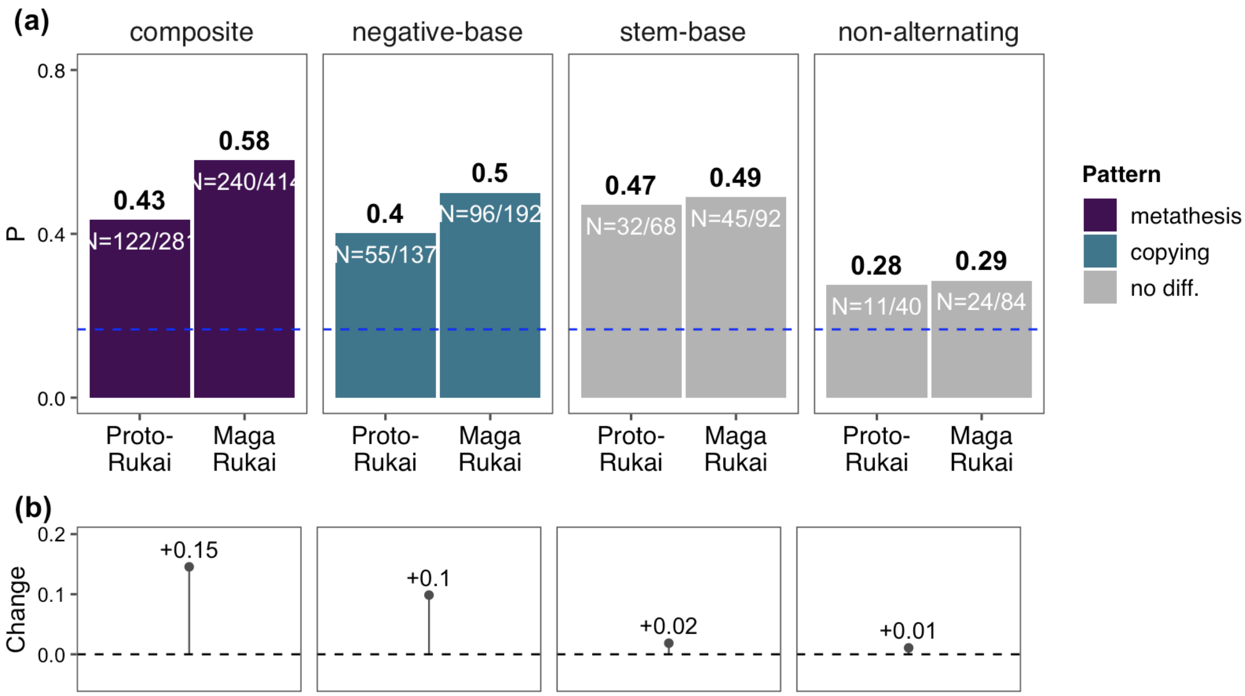

Figure 1: Vowel-matching in Proto-Rukai vs. Maga-Rukai (between V1 and V2). (a) shows the proportions of vowel-matching, while (b) shows the change in proportion of vowel-matching between Proto-Rukai and Maga ($P_{Maga} - P_{PrRu}$). Dashed line indicates the chance-level rate of vowel-matching alternations.

and non-alternating paradigms have seen a near-zero increase in vowel-matching. These results support the view that restructuring of UR vowels has occurred specifically to remove abstract URs, and in such a way that makes paradigms predictable from the stem allomorph.

It should also be noted that vowel-matching appears to already have been present as a weaker tendency in Proto-Rukai. Maga has 6-7 phonemic vowels (depending on whether /ə/ is treated as phonemic), meaning that if vowel-matching occurred at chance, it should occur about 16.7% (1/6) of the time; this value is shown for reference in Fig. 1. Even in Proto-Rukai, vowel-matching happened at well above this rate. This suggests that when faced with resolving the ambiguity caused by syncope, speakers utilized a tendency that was already present in the lexicon, causing it to become stronger over time.

4.6 Alternative accounts to abstractness-avoidance

So far, I have argued that patterns of vowel-matching and leveling both serve to remove abstract URs. In this section, I consider several alternative explanations for the observed patterns, and show that they do not provide a satisfactory account of the data.

4.6.1 Syncope as the innovative variant

Chen (2008) puts forth the idea that syncope is a innovative and recent development, and that paradigms which fail to undergo syncope actually reflect an earlier stage of Maga. Under this account, a paradigm like [udalɨ]∼[i-udalɨː] (cf. expected negative form [i-udlɨː]) has not leveled towards the stem. Instead, the negative allomorph has simply failed to undergo syncope, and reflects a more conservative stage of the language. If we adopt this idea, then around 75% of the leveling cases in Section 4.1 Table (18) can be re-interpreted as forms that reflect a conservative stage of Maga, and have not yet undergone syncope.

This account is less satisfactory for several reasons. First, it does not explain leveling in composite-UR paradigms (e.g. [blavnɨː]∼[i-k-blavnɨː]). For these, the leveled form has already undergone syncope, and cannot reflect an earlier pre-syncope stage of Maga. Additionally, in Section 4.1, leveling was shown to happen asymmetrically, happening at much higher levels for stem-base and negative-base paradigms than for composite-UR paradigms. If non-syncope is argued to reflect a more conservative stage of Maga, these asymmetries cannot be explained.

4.6.2 Historical explanations for failure to undergo syncope

Vowels that were historically long in Proto-Rukai have resisted syncope in Maga. As a result, apparent exceptions to the syncope pattern may actually be an artifact of historic long vowels, rather than the result of base-driven leveling. Proto-Rukai had diphthongs which monophthongized in Maga (e.g. *ɭikol**<u>aw</u>** → rkúl<u>**o**</u>); more examples are given above in Section 4.4.1. In addition, Proto-Rukai *ʔ was uniformly deleted in Maga, and as a result *VʔV sequences became either a short monophthong V or bimoraic Vː (e.g. *aboŋ**<u>oʔo</u>** → abúŋ<u>**u**</u> 'ant'). Both diphthongs and *VʔV sequences resisted syncope, as shown by the representative examples in (29).

Of the Maga Rukai words where syncope failed to apply *and* we have available protoforms, historic long vowels blocked syncope in just 39/109 stems and 4/6 negative forms (N = 43/115, P = 0.37).[6] In other words, most cases of exceptional non-syncope *cannot* be traced back to historic long vowels. The majority of non-syncope cases look like (30), where the non-deleted vowel corresponds to a historic short vowel.

(29) *Maga reflexes of Proto-Rukai diphthongs and *VʔV*

Proto-Rukai	Maga	gloss
*d**<u>aʔa</u>**nə	d<u>a</u>nɨ (cf. *dnɨː)	'house'
*p**<u>ay</u>**so	p<u>e</u>su (cf. *psuː)	'money'
*b**<u>əʔə</u>**kə	b<u>ɨ</u>kɨ (cf. *bkɨː)	'pig'

(30) *Examples of Proto-Rukai short vowels that fail to undergo regular syncope*

[6] This count does not include Proto-Rukai forms where the long vowel is not in a syncope position, e.g. *capəʔə→cpɨ́ː.

Proto-Rukai	Maga	Expected Maga	Gloss
*d**o**koʔo	d**u**ku	d∅kuː	‘grow (plant)’
*p**ə**kə	p**ɨ**kɨ	p∅kɨː	‘house lizard’
*ma-r**i**moro	ma-r**i**múru	ma-r∅muru	‘forget’

4.7 Picture so far

Examination of Maga paradigms (and comparison of these paradigms with Proto-Rukai) suggests that several types of restructuring have occurred, collectively moving the language away from a rhythmic syncope analysis, and towards a more concrete grammar.

Looking first at the Hsin corpus (without yet considering comparison with Proto-Rukai), I find that many paradigms have been leveled or partially leveled. Patterns of change are summarized in Fig. 2a, which groups paradigms by their ‘base type’; non-alternating paradigms are omitted since they have not undergone restructuring. Negative-base paradigms have generally leveled towards the negative allomorph, while stem-base paradigms have leveled towards the stem. Composite-UR forms have leveled in both directions (with a preference for leveling towards the stem). Some paradigms also have also been partially leveled, with speakers applying vowel copying or epenthesis. These partially leveled forms suggest that speakers are learning a pattern of ‘left-edge alternation’, rather than a general syncope pattern.

Paradigms can also be characterized by their predictability from the surface stem. In particular, as a result of vowel-matching tendencies, many composite-UR forms can be analyzed as undergoing metathesis, while many negative-base forms can be analyzed as undergoing vowel-copying. Fig. 2b organizes the data by the type of stem-based analysis each paradigm has (metathesis, copying, deletion, or unpredictable from the stem). When the data is organized this way, it is evident that the metathesis-type paradigms have resisted leveling much more than other paradigms.

Comparison of Proto-Rukai and Maga Rukai suggests that speakers have extended metathesis and (to a lesser extent) vowel-copying, increasing paradigms’ predictability from the stem. It is difficult to directly compare the patterns of leveling with these vowel-matching changes, as the former is based on patterns of syncope in the modern Maga lexicon, while the latter relies on comparison of Proto-Rukai and Maga Rukai. Nevertheless, we can approximate the proportion of paradigms that were restructured to result in metathesis or copying. Based on Section 4.5 (Fig. 1), around 17% of composite-UR forms were changed to be vowel-matching. Working backwards, this means that in Hsin’s corpus, around 17% of the metathesis-compatible paradigms were originally unpredictable from stem, but have been restructured to be analyzable as metathesis. Similarly, around 9% of the copying-type paradigms were originally unpredictable from the stem. Fig. 3 summarizes the patterns of restructuring in Maga after accounting for vowel-matching changes.

Overall, patterns of restructuring in Maga support the view that learners are biased against learning abstract URs. Leveling out alternations removes the need for abstract URs. Similarly, vowel-matching renders paradigms predictable from both surface allomorphs, removing the need

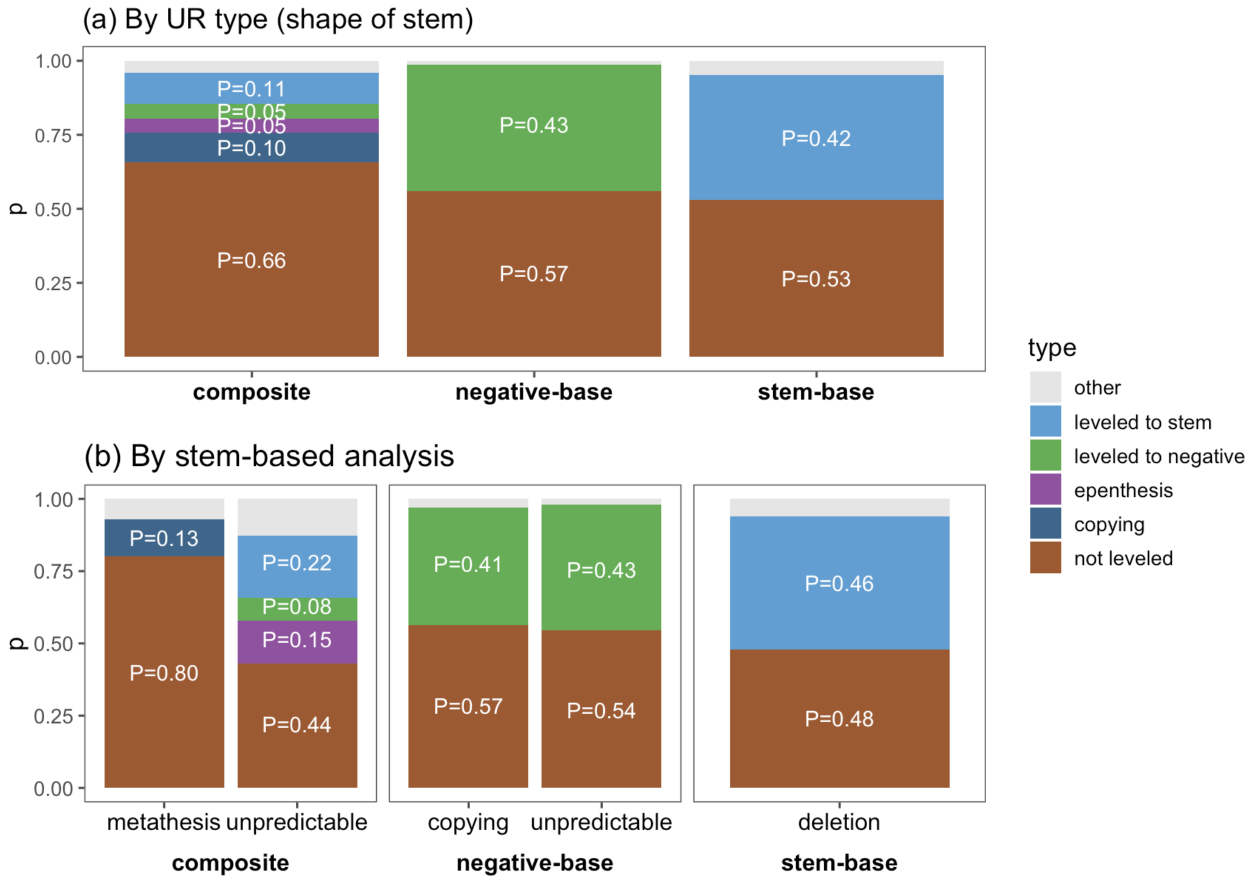

Figure 2: Summary of paradigms in Hsin's corpus by (a) type of UR and type of restructuring, and (b) type of stem-based analysis

for abstract URs. More generally, there is a tendency for restructuring to be based on the stem allomorph, but speakers must also have access to both the stem and negative allomorph, as leveling happens in both directions. This is in line with the KK-C (choosing from allomorphs) and KK-C' (listed-allomorphs) levels of UR learning.

5 A surface-oriented model of Maga vowel alternations

In this section, I propose a formal analysis of Maga alternations which assumes non-composite URs. This analysis explains the observed directions of restructuring and correctly predicts that some paradigms tend to level, while others tend to extend either metathesis or vowel-copying. I also compare several models that differ in their permitted level of UR-abstractness, on how well they predict patterns of restructuring in Maga.

The model is implemented in Maximum Entropy Harmonic Grammar (MaxEnt; Goldwater & Johnson, 2003), a probabilistic variant of Optimality Theory which uses weighted (instead of ranked) constraints and generates a probability distribution over the set of candidate outputs. The probabilistic nature of MaxEnt allows for better comparison of model results with the Maga

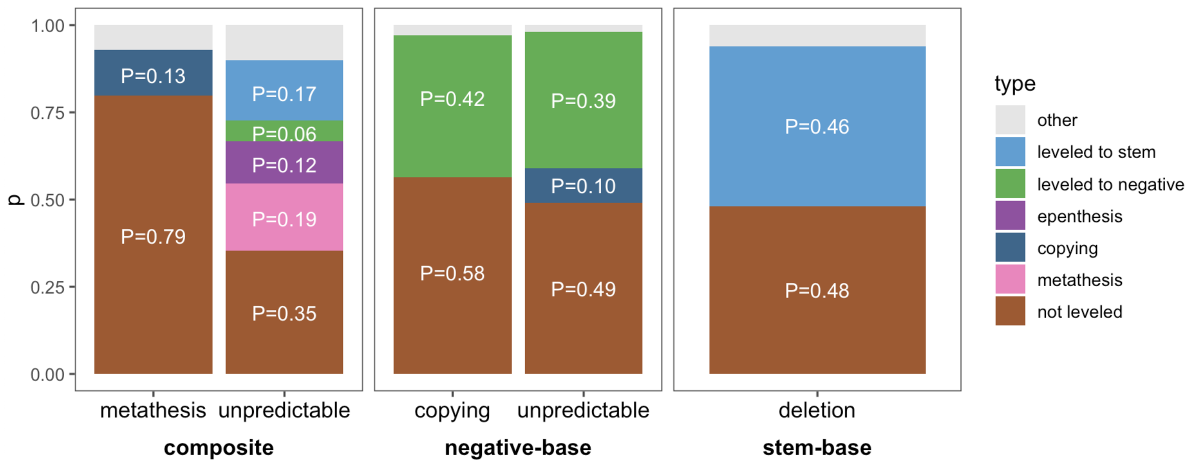

Figure 3: Summary of paradigms by type of base and type of restructuring (including an approximation of the vowel-matching changes)

lexicon, where patterns of restructuring are variable. Additionally, a bias is implemented as a Gaussian prior following Wilson's (2006) methodology. As will be discussed below, this prior can be used to enforce a bias towards stem-based restructuring.

There are two issues that must be addressed in a concrete analysis of Maga vowel alternations. First, there must be some mechanism that motivates alternations; this is not straightforward, as there are no language-general phonological constraints that can motivate vowel alternations. To deal with this problem, I propose that learners extract phonotactic generalizations about the shape of the root, and that these can be indexed to different morphosyntactic categories.

Next, findings so far suggest that learners have access to both the stem and negative allomorphs. At the same time, there is a bias for stem-based restructuring. There are two ways to account for this: under KK-C, each paradigm is associated with a single UR that corresponds to one of the surface allomorphs. Alternatively, each paradigm could be associated with multiple listed allomorphs. In this paper, I show that both approaches outperform the more abstract composite UR approach in predicting the directions of restructuring found in Maga Rukai.

In the rest of this section, I first outline the basic components of my analysis, then describe the MaxEnt model implementation and results. Constraints will be explicated using classical OT for ease of interpretation, although the actual models will use weighted constraints. Additionally, in illustrating constraint interaction, I (temporarily) assume that the UR corresponds to the stem allomorph; for example, given a paradigm [cŋɨlɨ]∼[i-ciŋlɨː], the stem UR is /cŋɨlɨ/. I also assume that final lengthening is either allophonic or a morphological exponent of negation, and never part of a root's underlying representation.

5.1 Motivating vowel alternations

Rhythmic syncope is often motivated by metrical constraints on syllable weight (e.g. Weight-to-Stress, Stress-to-Weight; Prince, 1990), alignment of feet to a word edge (Gouskova, 2003;

Kager, 1997), or penalizing unstressed vowels (McCarthy, 2008). For Maga, alternation in the negative form usually creates a root-initial heavy syllable, but stress never falls on this syllable. Consequently, alternation is not easily motivated by metrical constraints. Consider for example the negative form /i-cŋili/ → [i-ciŋlíː]; alternation causes the pretonic syllable [ciŋ] to be heavy, resulting in a violation of WEIGHT-TO-STRESS.

Additionally, the data in Section 4.2 suggests that speakers may have learned some kind of generalization about alternations at the left edge of root, rather than a rhythmic syncope alternation. The constraint(s) used to motivate alternation should ideally capture this observation.

Another challenge with motivating vowel alternations in Maga is that not all affixes trigger metathesis, and the ones that do are not phonologically uniform. Table (31), repeated from Table 4, lists the affixes that do/don't trigger alternations. Hsin reports three alternation-triggering affixes; of these, the negative and imperative affixes are highly productive, while /l-/ is restricted to kinship terms. There has been no detailed morphosyntactic analysis of Maga, but the alternation-triggering affixes may broadly be characterized as inflectional, while the non-triggering affixes are derivational. Importantly, affixes may resemble each other phonologically (e.g. /u-/ vs. /i-/), but still diverge in whether or not they trigger alternations on the root. Consequently, there is no general phonological environment that predicts metathesis.

(31) *Prefixes that do/don't trigger vowel alternations*

Alternates	Affix	Gloss	Example	Unattested form
no	ma-	stative vb.	ma-rkími	*ma-rikmi
	u-	dynamic vb.	u-θlibi	*u-θilbi
	si-	to put on	si-kpiŋi	*s-kipŋi
yes	i- -V	negative	i-pilŋiː	*i-pliŋiː
	-aː	imperative	sukl-aː	*skul-aː
	l-	plural	vlaki	l-valki

I account for this morpheme-specific behavior by adopting indexed constraints (Pater, 2008). Under this approach, any constraint in a language's grammar may be indexed to specific morphemes or sets of morphemes, capturing the idea that some alternations are exceptionally triggered by morphemes, rather than motivated by general phonology. Building on the observation that speakers may have learned a left-edge alternation, we can introduce a constraint like ALIGN-PREF$_I$-CV, which requires that a prefix indexed I (for inflectional) be followed by a CV; this constraint is defined in (32).[7] Tableau (33) shows how this constraint can motivate metathesis in consonant-initial stems. First, given an input like /u-pliŋi/, the faithful candidate (a) does not incur violations of ALIGN-PREF$_I$-CV because /u-/ is not indexed to I. When the prefix is indexed to I,

[7] Alternatively, forms like [cŋili] can be treated as having an initial non-moraic syllable with a representation [c^{V}ŋili] (cf. minor syllables, Shaw 1993; non-moraic vowels, Shih 2018). In this case the relevant constraint might be something that aligns affixes to a 'full', non-deficient syllable.

as with the input /$\mathrm{i_I}$-plɨŋɨ-V/, the faithful candidate (c) violates ALIGN-PREF$_\mathrm{I}$-CV and is eliminated. Candidate (d), which resolves the markedness violation through metathesis, is the winner.

(32) ALIGN(Prefix$_\mathrm{I}$, R, CV, L) (Align-Pref$_\mathrm{I}$-CV): The right edge of a prefix specified as I coincides with the left edge of a CV.

(33) *Constraints indexed to prefixes*

/u-plɨŋɨ/	ALIGN-PREF$_\mathrm{I}$-CV	LINEARITY
a. u-plɨŋɨ		
b. u-pɨlŋɨ		*!
/i$_I$-plɨŋɨ-V/		
c. i$_I$-plɨŋɨː	*!	
d. i$_I$-pɨlŋɨː		*

The analysis at this point still runs into some issues. First, it does not explain alternations in vowel-initial stems (e.g. [abuŋu]∼[ik-abŋuː]), though these could be accounted for using another indexed constraint. Another more serious issue is that there is non-locality in how Maga affixes interact with vowel alternations. The proposed constraint is triggered by a prefix aligned with the left edge of the root. However, the stative marker /k-/ may intervene between the negative prefix /i-/ and the root (e.g. ɖmárɨ∼i-k-ɖámrɨː). Additionally, the imperative /-aː/ productively triggers alternations, but is a suffix and therefore non-adjacent to the alternating root-initial segment. Indexed constraints as defined in Pater (2007) cannot account for this non-locality, because they require that the constraint's locus of violation be in the indexed morpheme.

This non-locality cannot be resolved even if we analyze Maga alternations as triggered by suffixes. The imperative /-aː/ is a suffix, and negation involves final lengthening that can be treated as a /-V/ suffix (i.e. empty vowel slot). The first issue with this idea is that speakers seem to have learned a left-edge alternation, while suffixes are expected to trigger alternations at the right edge of the root. Second, the right edges of roots do not have unifying phonological properties; in the negative form, for example, the final long vowel may be preceded by either a heavy syllable (e.g. [i-k-**ɖam**.rɨː]) or a light CV syllable (e.g. i-k-**ra**.naː]).

In summary, Maga vowel alternations are morpheme-specific, and complicated by the fact that the locus of alternations is not always local to the morpheme that is triggering alternations. As a solution, I propose that learners extract phonotactic generalizations about the shape of the root, and that these can be indexed to different morphosyntactic categories. Following Albright (2004), I refer to these as **root structure constraints (RSCs)**. There is some support for the idea that speakers can learn constraints on roots; roots come early in acquisition (Massar & Gerken, 1998), root-affix asymmetries are typologically common (for a review, see Gouskova, 2023), and models of phonological learning often perform better when a root/affix distinction is made (Gouskova & Gallagher, 2020).

When RSCs are indexed to (sets of) morphemes, they can drive morphophonological alternations. Section 5.3 outlines a method for inducing RSCs directly from the lexicon; here, I give an intuitive overview of how they can derive metathesis, copying, and deletion. First, as demonstrated in (34), the root phonotactics of stem and negative forms are in some ways complementary; in the unaffixed stem, roots can be CC-initial or VCV-initial, but they never begin with a CV or VCC sequence. Negative (and imperative) forms are the exact opposite; roots can start with a CV or VCC, but are never CC- or VCV-initial. Based on these observations, we can propose the RSCs $*\sqrt{}CV_{STEM}$,$*\sqrt{}VCC_{STEM}$, $*\sqrt{}CC_{I}$, and $*\sqrt{}VCV_{I}$. Finally, for the RSC analysis to work, assumptions about the locality of indexed constraints still have to be relaxed. I assume here that if a word takes an affix indexed to I, then the entire word also belongs to the class I; see Jurgec & Bjorkman (2018) for a similar approach.

(34) *Root phonotactics in stem vs. inflected forms*

stem	root-edge	Negative (inflected)	root-edge
rnaː	$\sqrt{}$CC	i-k-ranaː	$\sqrt{}$CV
cŋɨlɨ	$\sqrt{}$CC	i-cɨŋlɨː	$\sqrt{}$CV
ubulu	$\sqrt{}$VCV	i-ubluː	$\sqrt{}$VCC

Tableau (35) demonstrates how $*\sqrt{}CC_{I}$ can be used to motivate metathesis, using the example [cŋɨlɨ]∼[i-cɨŋlɨː]. Again, I assume that if a root takes an affix that is indexed to I, the entire word is also indexed to I. For ease of reading, copied vowels are highlighted. Given the input /cŋɨlɨ/, the faithful candidate (a) does not violate any RSCs, and therefore straightforwardly wins. In contrast, given the input /i_I-cɨŋɨlɨ-V/, the faithful candidate (d) incurs a fatal violation of $*\sqrt{}CC_{I}$. Candidate (e), which undergoes copying to resolve this violation, is ruled out by ranking INTEGRITY (which penalizes copying) above LINEARITY. Other competing faithfulness constraints would similarly be ranked above LINEARITY, allowing candidate (e) to win.

(35) *Tableau: metathesis motivated by RSCs*

/cŋɨlɨ/	$*$ CV_{STEM}	$*\sqrt{}CC_{I}$	INTEGRITY	LINEARITY
→ a. cŋɨlɨ				
b. cɨŋlɨ	*!			*
c. cɨŋɨlɨ	*!		*	
/i_I- cŋɨlɨ - V/				
d. $[$i-cŋɨlɨː$]_I$		*!		
→ e. $[$i-cɨŋlɨː$]_I$				*
f. $[$i-cɨŋɨlɨː$]_I$			*!	

Copying, which is found in the negative-base paradigms, works in much the same way, as demonstrated in tableau (36) for [kvaː]∼[i-kavaː]. Given the input /kva/, metathesis in candidate (b) results in a final consonant; final consonants are never found in the Maga lexicon, so (b) can be ruled out by a general, highly ranked constraint against final consonants, NoFinalC.[8] As a result, candidate (c), which undergoes vowel-copying, emerges as the winner.

(36) *Tableau: vowel-copying*

/i$_{I}$-kva-V/	*√CC$_{I}$	NoFinalC	Integrity	Linearity
a. [i-kvaː]$_{I}$	*!			
b. [i-kav]$_{I}$		*!		*
→ c. [i-kavaː]$_{I}$			*	

In vowel-initial stems, the negative allomorph undergoes deletion (e.g. [abakɨ]∼[i-k-abkɨː]); this cannot be motivated by *√CC$_{I}$, since the input /abakɨ/ is not CC-initial in the first place. Instead, we need to draw on a second RSC *√VCV$_{I}$. In tableau (37), this RSC penalizes the faithful candidate (a). Candidate (b), which undergoes metathesis, can be ruled out by ranking Linearity above Max-V.

(37) *Tableau: vowel-deletion*

/i$_{I}$-k-abakɨ-V/	*√VCV$_{I}$	Linearity	Max-V
a. [i-k-abakɨ]$_{I}$	*!		
b. [i-k-abkaɨː]$_{I}$		*!	
c. [i-k-abkɨː]$_{I}$			*

The analysis so far crucially relies on the assumption that paradigms are vowel-matching. Exceptions to this, such as [tmusu]∼[i-k-timsuː] cannot be accounted for if we assume a non-composite UR like /tmusu/. This is demonstrated in tableau (38), where the observed candidate (c) must undergo both metathesis and a change in vowel quality (violating Ident[front]). Candidate (c) is harmonically bounded by (b), which undergoes just metathesis, and therefore (b) will always be the winning candidate. This outcome is desirable, because it predicts paradigms to be mislearned in a way that results in vowel-matching, exactly as observed in the comparative data.

(38) *Tableau: predictions for non-matching paradigms*

/i$_{I}$-k-tmusu-V/	*√CC$_{I}$	Linearity	Ident[front]
a. [i-k-tmusuː]$_{I}$	*!		
💣 b. [i-k-tumsuː]$_{I}$		*	
c. [i-k-timsuː]$_{I}$		*	*!

Though not described in detail here, regular non-application of syncope pattern can be accounted for using general markedness constraints such as *Geminate and *CCC, which hold true across the lexicon. For example, in the paradigm [tlaléː]∼[i-k-talaleː] 'chief', the negative form

[8] alternatively, candidate (b) could be ruled out by a morpheme exponence constraint which requires the negative form to end in a final Vː.

does not undergo metathesis (cf. *[i-k-talleː]). In this example, metathesis is ruled out by a highly ranked *GEMINATE constraint.

Finally, for longer words, vowel alternations at the left edge of the root are motivated by RSCs, but other alternations happen simply to resolve violations of general markedness restrictions. This is shown in tableau (39) for [tkasludu]∼[i-k-taksulɖuː] 'shrimp'. Candidate (b), which undergoes one metathesis to resolve violations of $*\sqrt{}\mathrm{CC_I}$, ends up with a triconsonantal cluster. CCC clusters are generally prohibited in Maga, and observed only across morpheme boundaries in paradigms that have leveled towards the stem (e.g. [blavnɨ]∼[i-**k-bl**avnɨː]). Therefore, candidate (b) can be ruled out by a high-ranked *CCC constraint. As a result, candidate (c) is the winner.

(39) *Tableau: two metatheses in longer words*

Type	/i-k-tkasluɖu-V/	$*\sqrt{}\mathrm{CC_I}$	*CCC	LINEARITY
faithful	a. i-k-tkasluɖuː	*!	*	
1x metathesis	b. i-k-taksluɖuː		*!	*
2x metathesis	→ c. i-k-taksulɖuː			**

For some longer words that undergo metathesis, the grammar will predict vowel-copying to occur instead. This is demonstrated in (40) for /klubŋu/ [klubŋu]∼[i-kulbuŋuː]. In the negative form, the metathesis-undergoing candidates (b-c) result in an ill-formed output. Candidate (d), the observed output, undergoes both metathesis and copying to avoid violations of *CCC and NO-FINALC. Candidate (e), however, is more optimal in that it resolves all markedness violations with just one violation of INTEGRITY; the grammar, as is, will incorrectly predict (e) to be the winner. This actually matches the patterns of partial leveling described in Section 4.2 (e.g. [rmarmoː]∼[i-k-ramarmoː]), where syncope is relearned as vowel-copying at the left edge of the root.

(40) *Tableau: metathesis and copying in longer words*

Type	/i-klubŋu-V/	$*\sqrt{}\mathrm{CC_I}$	*CCC	NOFINALC	INTEGRITY	LINEARITY
faithful	a.i-klubŋuː	*!				
1x metathesis	b. i-kulbŋuː		*!			*
2x metathesis	c. i-kulbuŋ			*!		**
metathesis + copying	d. i-kulbuŋuː				*	*!
1x copying	💣 e. i-kulubŋuː				*	

5.2 The space of possible URs

The analysis above explains the basic patterns of vowel alternations, but also assumes that the UR always corresponds to the stem allomorph. However,speakers are likely to also have access to the negative allomorph in UR-learning, given that paradigms level towards the negative form. There are two ways of accounting for this, and I test both in the model comparisons below.

One is that learners only learn one UR for each paradigm, but this UR can correspond to either the stem or negative forms, in line with a KK-C level of abstractness. To implement KK-C URs, I make the simplifying assumption that the learned UR will correspond to the surface form that preserves the most vowel contrasts, and otherwise default to the stem form. For example, for [rdée]∼[i-k-rudeː], the UR would be /rude/, corresponding to the negative allomorph. For [smitu]∼[i-k-simtuː], both allomorphs are equally informative, so the UR is /smitu/. Future work should consider models of UR learning that simultaneously learn the UR and constraint weights (for a review, see Wang & Hayes, 2025).

Alternatively, learners could list multiple URs for each paradigm, each corresponding to a surface allomorph. I implement this using a base competition model (Breiss, 2021, 2024), in which outputs are faithful to multiple listed allomorphs (i.e. bases). Following Breiss (2021, 2024), this model has two sets of faithfulness constraints, each enforcing faithfulness to their respective base. Additionally, as described in Section 5.5.3, stem-faithfulness constraints are biased to have a higher weight, explaining why learners generally restructure paradigms towards the stem allomorph. Another more nuanced approach, explored in Breiss (2024), would be to scale faithfulness to each base by their resting activation levels.

Tableau (41) shows a tableau [cŋɨlɨ]∼[i-cɨŋlɨː], revised to reflect a listed allomorphs grammar. Crucially, there are now two versions of each faithfulness constraint, in this case LINEARITY, respectively enforcing faithfulness to the stem and negative allomorphs. RSCs like $*\sqrt{}\text{CV}_{\text{STEM}}$, which are indexed to the stem, prevent paradigms from leveling towards the negative form.

(41) *Listed allomorphs grammar*

/cŋɨlɨ/, /cɨŋlɨ/	$*\text{CV}_{\text{STEM}}$	$*\sqrt{}\text{CC}_{\text{I}}$	$\text{LINEARITY}_{\text{STEM}}$	$\text{LINEARITY}_{\text{I}}$
→ a. cŋɨlɨ				*
b. cɨŋlɨ	*!		*	
/i_{I}-cŋɨlɨ-V/, /i_{I}-cɨŋlɨ-V/				
c. $[\text{i-cŋɨlɨː}]_{\text{I}}$		*!		*
→ d. $[\text{i-cɨŋlɨː}]_{\text{I}}$			*	

5.3 Learning RSCs

Under the proposed analysis, speakers should have some way to induce RSCs that are indexed to morphosyntactic categories. I propose here that learners compare subsets of the lexicon (that are associated with particular morphemes) to learn general vs. specific phonotactics. For Maga, learners may have a general phonotactic grammar, a grammar for roots in the uninflected stem, and a grammar for roots in the negative form. Constraints that are active across all these sub-grammars are general markedness constraints, while ones that are active in just one sub-grammar are indexed to that morphosyntactic environment. A similar approach is taken by Becker & Gouskova (2016), who find evidence that learners use morphophonology to partition the lexicon into sublexicons, each with their own phonotactic grammar.

To implement this approach, I use the UCLA Phonotactic Learner (henceforth UCLAPL; Hayes & Wilson, 2008), which is a phonotactic grammar based in MaxEnt. The UCLAPL takes as input a feature set and a list of words; from this, it induces a weighted constraint grammar. I trained three sub-grammars with three different sets of training data: 1) a GENERAL grammar, where the input was both stem and affixed forms with no morpheme boundaries; 2) a STEM grammar, which includes only roots of unaffixed forms, and 3) an INFLECTED grammar, which only includes roots of inflected forms.

In all three models, the input was based on paradigms from Hsin (2000), but modified to assume that syncope regularly applies. For example, the paradigm [blávnɨ]∼[i-k-blavnɨ́ː] (which has leveled towards the stem) is modified to reflect the 'historical' negative form [i-k-bulvanɨ́ː]. Because the UCLAPL expects at least 3,000 words for training, the wordlist was multiplied by four, resulting in 3160 items. To encourage the UCLAPL to induce constraints specifically concerning the shape of the stem, models were trained on a simplified set of just three features, [word_boundary], [syllabic], and [long], where both vowels and consonants can be specified for length. For the subgrammars that were trained on bare roots, [+word_boundary] refers to the root boundary. For each grammar, the UCLAPL learned 20 constraints that were maximally 4-grams long. The resulting constraints were tested for significance using the Likelihood Ratio Test, with data fit to the original training set. Constraints were kept if they tested as significant ($p < 0.05$).

This process of model comparison resulted in the 12 constraints given in (42). Four of these constraints, shown in parentheses, are not violated by any candidates in the current model, and are therefore omitted from the rest of the analysis, resulting in 8 constraints. Each constraint has a shorthand name, which I will use for ease of interpretation. If a constraint with [+word_boundary] ([+wb]) is shared across all sub-grammars, this is assumed to be a word boundary (e.g. *[-syll][+wb] = NOFINALC); if the constraint is found in just the root-only subgrammars, it is a root boundary. Of the constraints, two are indexed to the stem sublexicon, and two are indexed to the inflected sublexicon. $*\sqrt{}\text{V,CV}_{\text{STEM}}$ is similar to the constraint $*\sqrt{}\text{CV}_{\text{STEM}}$ proposed above, but applies to a broader set of forms. $*\sqrt{}\text{CC}_{\text{I}}$ is the same constraint proposed above to motivate metathesis and copying, as shown in tableaux (35) and (36).

(42) *Phonotactic constraints (general vs. sublexicons); # indicates a word boundary, while $\sqrt{}$ indicates a root boundary.*

Type	Constraint	Shorthand
General	*[-syll, +long]	*GEMINATE
	*[-syll][+wb]	NOFINALC
	*[-syll][-syll][-syll]	*CCC
	*[+long]	*V:
	(*[+syll][+syll][+syll]	*VVV)
	(*[+wb][+syll][+syll]	*#VV)
	(*[+wb][+syll]	*#V)
	(*[+syll][+long]	*VV:)
Stem	*[+wb][-wb][+syll]	$*\sqrt{}$V,CV$_{\text{STEM}}$
	*[+wb][+syll][-syll][-syll]	$*\sqrt{}$VCC$_{\text{STEM}}$
Inflected	*[+wb][-syll][-syll]	$*\sqrt{}$CC$_{\text{I}}$
	*[+syll][-wb][+syll]	*VC,VV$_{\text{I}}$

For deletion-type paradigms like [ubulu]∼[ik-ublu:], $*\sqrt{}$VCV$_{\text{I}}$ is needed to enforce alternation. The UCLAPL did not learn this constraint, and instead learned a more general trigram constraint *VC,VV$_{\text{I}}$. While this RSC can motivate deletion, it has more exceptions, as many attested negative forms have a VCV sequence (e.g. ik-rana:, i-kuoto, ik-vantuku). As a result, *VCV$_{\text{I}}$ is likely to be weaker (i.e. assigned a lower weight in the MaxEnt grammars). There are two reasons why the UCLAPL may have failed to learn the necessary RSC: first, vowel-initial stems (which undergo deletion) are less frequent in the Maga lexicon, taking up around 10% (N = 80/790) of the model inputs. Second, the UCLAPL employs a set of search heuristics for constraint induction, one of which is a preference for shorter constraints. An RSC like $*\sqrt{}$VCV$_{\text{I}}$, which has four feature matrices, is less likely to be learned than a shorter trigam constraint like *VCV$_{\text{I}}$. This length heuristic is principled and based off of observations from typology and experiments that shorter constraints are preferred over longer/non-local ones (e.g. Santelmann & Jusczyk, 1998; Newport & Aslin, 2004; Belth, 2023).

5.4 Constraints that drive paradigm leveling

Recall that stem-base paradigms tend to level towards the stem form, while negative-base paradigms tend to level towards the negative form. The constraints introduced so far are actually enough to motivate both types of leveling.

Stem-base paradigms are typically vowel-initial. For these forms, the UCLAPL failed to learn the relevant RSC $*\sqrt{}$VCV$_{\text{I}}$, and instead learned *VCV$_{\text{I}}$. This RSC is likely to be assigned a low weight (or be ranked low in illustrative tableaux) because VCV sequences are generally attested in inflected forms. The low ranking of $*\sqrt{}$VCV$_{\text{I}}$, combined with high-ranked stem-faithfulness, will predict leveling towards the stem form. This is demonstrated in tableau (43). Suppose the input to the grammar is a regularly alternating vowel-initial paradigm (e.g. [abakɨ]∼[i-k-abkɨː]). In the unaffixed form, high ranked #VCC$_{\text{STEM}}$ and Max$_{\text{STEM}}$ causes candidate (a) to win. In negative-formation, however, candidate (c) wins because Max$_{\text{STEM}}$ outranks the relevant RSC *VCV$_{\text{I}}$.

(43) *Tableau: leveling towards the stem*

/abakɨ/ ∼/abkɨ/	*$\sqrt{}$VCC$_{\text{STEM}}$	Max$_{\text{STEM}}$	Max$_{\text{I}}$	*VCV$_{\text{I}}$
→ a. abakɨ			*	
b. abkɨ	*!	*		
/i-k-abakɨ-V/ ∼/i-k-abkɨ-V/				
→ c. i-k-abakɨ			*	*
d. i-k-abkɨː		*!		

For the negative-base paradigms (e.g. [bkɨ́ː]∼[i-k-bɨkɨ́ː]), leveling is motivated by a general markedness constraint *Vː. Long vowels may appear as an exponent of the negative and imperative forms, but are relatively rare in the uninflected stem forms, making them marked. In negative-base paradigms, however, the final vowel of the stem is lengthened to due to a word-minimality restriction; one way to avoid lengthening is to level the paradigm towards the negative allomorph. This is demonstrated in tableau (44). If *Vː outranks both *$\sqrt{}$CV$_{\text{STEM}}$ and INTEGRITY$_{\text{STEM}}$, candidate (a) will be ruled out. Candidate (c), which is completely faithful to the input, would presumably be ruled out by a word-minimality constraint (here WORDMIN).[9]. As a result, the leveled candidate (b) emerges as the winner. In the negative and imperative forms (e.g. [i-k-ranaː]), the long final vowel is presumably preserved by some morpheme exponence requirement.

(44) *Tableau: leveling towards the negative*

/bkɨ/ ∼/bɨkɨ/	WordMin	*Vː	*$\sqrt{}$CV$_{\text{STEM}}$	Integrity$_{\text{STEM}}$	Max$_{\text{I}}$
a. bkɨː		*!			*
→ b. bɨkɨ			*	*	
c. bkɨ	*!				*

5.5 MaxEnt model implementation

In this section, I introduce a MaxEnt implementation of the analysis described above. I compare four models which differ primarily in their UR type, and are otherwise nearly identical. The models are a STEM-BASE (KK-B) model where URs always correspond to the stem form, a MIXED-BASE (KK-C) model where URs correspond to either the stem or negative allomorph, a LISTED ALLOMORPHS (KK-C') model where both the stem and negative allomorphs are inputs, and a

[9]Constraints on foot binarity also work to enforce word-minimality requirements

COMPOSITE UR model which assumes the URs required by a traditional morphophonemic analysis of Maga.

In all models, constraint weights were learned using the R package maxent.ot (Mayer et al., 2024). In this package, constraint optimization is done using the OPTIM function from the Rcore statistics library and restricted to finite, non-negative values.

5.5.1 Inputs

The input to the model is the set of 790 stems from the Hsin corpus, modified to reflect a stage of Rukai prior to significant restructuring. First, paradigms were modified to have the expected alternation pattern, had syncope applied regularly. The rate of vowel-matching in the input was also changed to be roughly the same across all stem shapes, and be at around 45%, which was the rate seen in Proto-Rukai. To simplify the training data, forms were pooled by their syllable structure, alternating vowel qualities, and type of prefix (/i-/ vs /i-k-/); for example, [ɖmarɨ]∼[i-k-ɖamrɨː] and [rɖamɨ]∼[i-k-raɖmɨː] are both represented as [CCaCɨ]∼[i-k-CaCCɨː].

Example candidates for the model are shown in (45). For both the unaffixed and negative-prefixed inputs, I include the following candidates: the stem allomorph, negative allomorph, and outputs that resolve the relevant RSC using (where possible) metathesis, copying, vowel deletion, and vowel epenthesis. Candidates that undergo consonant epenthesis/deletion are not considered, and assumed to be ruled out by highly weighted faithfulness constraints DEP-C and MAX-C. For the epenthesis candidate, the epenthesized vowel is the vowel that surfaces in the stem form for a paradigm that's non-matching, or one of i, u (the two most frequent vowels) for paradigms that are vowel-matching. For longer words, I also include candidates that undergo a multiple metathesis or copying to resolve violations of general markedness (e.g. *CCC), as shown for /i-k-tkasluɖu/ here.

(45) *Example Input-candidate pairs*

Inputs	/i-k-tmusuː/		/i-k-tkasluɖu-V/	
Candidates:	i-k-tmusuː	(faithful)	[i-k-tkasluɖuː]	(faithful)
	i-k-tumsuː	(metathesis)	[i-k-taksluɖuː]	(1 x metathesis)
	i-k-tumusuː	(copying)	[i-k-taksulɖuː]	(2 x metathesis)
	i-k-timsuː	(epenthesis)	[i-k-takasluɖuː]	(copying)
			[i-k-tukasluɖuː]	(epenthesis)

5.5.2 Constraint set

The constraint set includes the 8 markedness constraints described in Section 5.3, all induced from the UCLAPL. In addition to these, I include faithfulness constraints that penalize metathesis, copying, epenthesis, and deletion. Any case of vowel insertion where the vowel quality matches an adjacent vowel is treated as copying, otherwise it is treated as epenthesis.

5.5.3 Incorporating a soft markedness bias

In the MaxEnt models, a 'prior' term is implemented as a Gaussian distribution over each constraint weight. During constraint optimization, the model learns constraints in a way that both maximizes log-likelihood (i.e. fit to the training data) and minimize the prior. The prior, calculated as in (46), is defined in terms of a mean (μ) and standard deviation (σ). For each constraint, *w* is its learned weight, and μ can be thought of as the 'preferred' weight. The numerator of the prior term reflects how much the actual weight deviates from the preferred weight of each constraint, and the penalty resulting from the bias term increases as constraint weights diverge from μ. Note that size of this penalty will increase with the square of the weight. The value of σ^2 determines how much effect the preferred weight (μ) has; lower values of σ^2 result in a smaller denominator, and therefore greater penalty for weights that deviate from their μ.

(46) $\sum_{i=1}^{m} \frac{(w_i - \mu_i)^2}{2\sigma^2}$

In the STEM-BASE, MIXED-BASE, and COMPOSITE UR conditions, $\mu = 0$ for all constraints while $\sigma^2 = 100$; this gives the models a small penalty for non-zero weights on any constraints, which ameliorates the tendency for models to overfit (Martin et al., 1999). In the LISTED ALLOMORPHS condition, μ is still zero for all constraints, but σ^2 is manipulated so that the model prioritizes faithfulness to the unaffixed stem over faithfulness to the negative allomorph (Wilson, 2006). Specifically, all FAITH$_I$ constraints have $\sigma^2 = 0.8$[10] (resulting in a strong pressure towards low weights), while all other constraints have $\sigma^2 = 10$.

5.6 Model results and comparisons

All three models with more concrete URs outperformed the COMPOSITE-UR model at predicting the modern Maga patterns. This is seen in Table (47), which shows the log likelihood ($\hat{L}$) for each model when fit to the modern Maga data (i.e. the Hsin corpus). The LISTED ALLOMORPHS model performed the best, followed by the MIXED-BASE and STEM-BASE models.

(47) *Table: Log likelihood ($\hat{L}$) of model predictions fit to modern Maga*

Model	KK-level	$\hat{L}$
STEM-BASE	KK-B	-1323.08
MIXED-BASE	KK-C	-1265.94
LISTED ALLOMORPHS	KK-C'	-1177.93
COMPOSITE	KK-D	-1455.35

A more detailed examination of model predictions shows that the LISTED ALLOMORPHS model in particular makes predictions which qualitatively match the observed patterns of restructuring

[10] This value was determined by testing σ^2 values ranging from 0.4-5 in increments of 0.2 and selecting the best-fitting model.

(see Fig. 3). In contrast, the COMPOSITE UR model predicts very little restructuring. Consider Fig. 4, which shows the predicted probabilities of the COMPOSITE UR and LISTED ALLOMORPHS models, organized by type of paradigm and type of restructuring. Table (48) below gives examples for each type of restucturing. The MIXED-BASE and STEM-BASE models made similar predictions to the LISTED ALLOMORPHS model, so are omitted here in the interest of space.

Looking at Fig.4a, the COMPOSITE UR model under-predicts the amount of restructuring. Additionally, it does not predict paradigms to undergo metathesis or leveling to the stem, though these were the two most common types of restructuring found in Section 4. In contrast, looking at Fig.4b, the LISTED ALLOMORPHS model predicts exactly the main patterns of restructuring found in Maga: composite-UR paradigms are restructured to show a metathesis pattern, while negative-base and stem-base paradigms level towards their respective bases. In the negative-base paradigms, the model also predicts some vowel-copying changes, which is compatible with the descriptive results. The main shortcoming of the LISTED ALLOMORPHS model is that it predicts little to no leveling in the composite-UR paradigms, even though around 20% of these paradigms have been leveled in the corpus data.

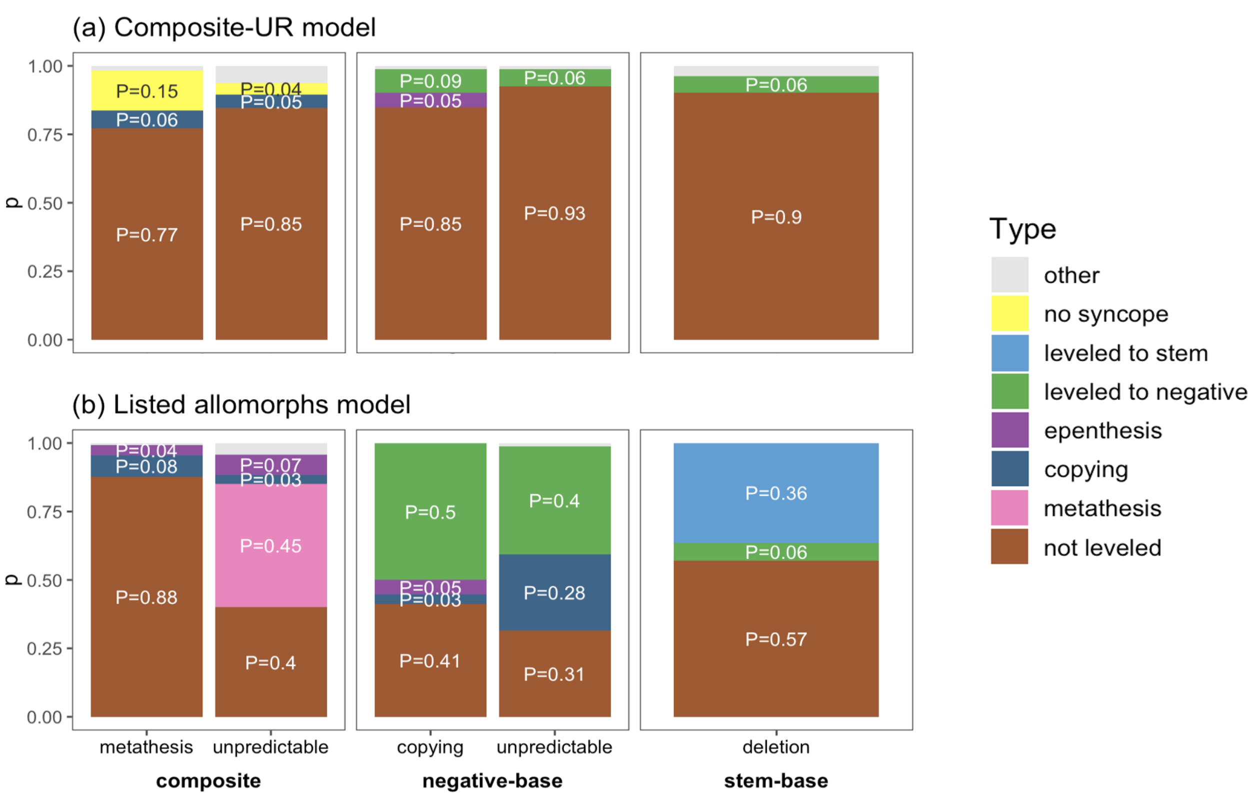

Figure 4: Predictions of the COMPOSITE UR and LISTED ALLOMORPHS models, by shape of input paradigm and type of restructuring

(48) *Examples of model predicted results*

Predicted change	Example
no syncope	[pliŋi∼ik-pilŋiː] → [piliŋi∼ik-piliŋiː]
level to stem	[cŋili∼i-cilŋiː] → [cŋili∼i-cŋiliː]
level to negative	[rnaː∼ik-ranaː] → [rana∼ik-ranaː]
epenthesis	[u-trági∼i-turgiː] → [u-trági∼i-turagiː]
copying	[ɖrimi∼ik-ɖirmiː] → [ɖrimi∼ik-ɖirimiː]
metathesis	[tmusu∼ik-timsuː] → [tmusu∼ik-tumsuː]

Table 49 shows the constraint weights learned by the LISTED ALLOMORPHS model. As seen here, the model learned relatively low weights for LINEARITY, allowing the metathesis-undergoing candidates to be assigned high probability. Most of the RSCs have relatively high weight, but $*VCV_{I}$ has a very low weight; the low weight of $*VCV_{I}$ relative to $*\sqrt{}VCC_{STEM}$ and competing faithfulness constraints is exactly what drives leveling in the stem-base paradigms. Additionally, the model learned high weights on all the general markedness constraints; the high weight of *Vː is what drives leveling in the negative-base paradigms.

(49) *Constraint weights learned by the LISTED ALLOMORPHS model*

FAITH_{STEM}	**w**	**FAITH_{I}**	**w**
Linearity_{STEM}	0.05	Linearity_{I}	0.36
Integrity_{STEM}	2.76	Integrity_{I}	0.00
DEP-V_{STEM}	3.19	Dep-V_{I}	1.12
MAX-V_{STEM}	0.33	MAX-V_{I}	0.18
General markedness	**w**	**RSCs**	**w**
NOFINALC	16.03	$*\sqrt{}CV_{STEM}$	6.30
*CCC	14.42	$*\sqrt{}VCC_{STEM}$	9.77
*GEMINATE	5.13	$*VCV_{I}$	0.04
*Vː	8.97	$*\sqrt{}CC_{I}$	7.45

In sum, the COMPOSITE UR model performed worse than all other models at predicting the patterns of change found in modern Maga Rukai. In fact, even the most restrictive STEM-BASE model has a better fit to modern Maga (as measured by log-likelihood).

6 Discussion

6.1 Abstractness vs. generality in learning

In this paper, comparison of Proto-Rukai and Maga Rukai suggests that an abstract-amenable rhythmic syncope alternation was relearned as a more concrete system. In this new grammar, which was substantiated by MaxEnt modeling results, I analyze alternations as motivated by RSCs that target the left edge of the root, rather than metrically-driven syncope. The new grammar maintains the surface alternations to some degree, but imperfectly accounts for the data, and as a result predicts substantial restructuring.

The results from Maga suggest that learners would rather learn more concrete representations, even at the cost of generality in the resulting grammar. This supports a growing body of work which finds that across languages, learners often acquire more concrete representations, even if doing so adds exceptionality and complexity to the phonological grammar. For example, Gouskova (2012) shows that Russian yer alternations, which were traditionally analyzed using abstract representational accounts, are better characterized with morpheme-specific constraints; in Polish, a similar set of jer alternations have evolved into a concrete system that is partially predictable from sonority sequencing (Czaykowska-Higgins, 1988; Jarosz, 2008; Rysling, 2016). In Yidiɲ, metrically-driven vowel alternations resulted in an abstract-requiring analysis, which was subsequently restructured into surface-predictable alternations that are productive, but not motivated by language-general phonology (Hayes, 1999).

6.2 Restructuring as the result of language attrition

Much of the work on restructuring in rhythmic syncope languages has focused on speakers in the context of shift and attrition. Examples include Yidiɲ (Hayes, 1999), Nishnaabemwin (Valentine, 2001), and Southern Pomo (Kaplan, 2022). Likewise, Maga Rukai is spoken only by elderly members of the community who experience significant language contact with Japanese (the language of primary education in their youth) and Mandarin (the societal dominant language). This raises the issue that restructuring of rhythmic syncope may only arise in attrition contexts.

Even if this is the case, patterns of restructuring can still tell us about general biases in phonological learning. The instability of rhythmic syncope in attrition contexts suggests that even if abstract URs are learnable, they are only learned with extensive linguistic exposure that overrides a 'default' preference for concrete analyses. In addition, similar cases of restructuring have been found in commonly spoken languages that are not experiencing attrition. For example, Slavic yers involve a similar case of abstractness resulting from diachronic vowel deletion, which in many languages was then mislearned into a more concrete pattern.

Finally, languages described as having robust rhythmic syncope patterns have often not been scrutinized in detail. Macushi Carib and Southeastern Tepehuan are two languages described as having stable rhythmic syncope (Kager, 1997). However, the Tepehuan pattern is potentially restricted to specific morphological contexts (Willett, 1982, 1989), and is based on a limited set of forms that has not been compared against more recent dictionary data (Willett & Willett, 2015). For Macushi, the original report of rhythmic syncope came from Hawkins (1950), when the pattern had very recently developed. An examination of how the pattern has developed over time would be informative for understanding the stability of rhythmic syncope alternations.

6.3 Placing Maga into the typology of metathesis and vowel-copying

Metathesis and vowel-copying in Maga are unusual because they do not follow typical cross-linguistic tendencies. Metathesis tends to be sporadic, phonetically incomplete, segmentally restricted to sonorants, and better characterized as gestural overlap than true segment transposition (Hall, 2006; Mooney, 2023). In contrast, metathesis in Maga applies across a range of consonants with no apparent restrictions. This is seen in Fig. 5a, which shows, for the subset of metathesis-undergoing paradigms, the proportion of alternating forms. As seen here, the rate of alternation remains high regardless of the manner of the metathesizing consonant. Similarly, copying tends to involve segmental restrictions, either of the vowels that can copy, or of the consonants that are transparent to copying (Mooney, 2023). In contrast, as shown in Fig. 5b-c, vowel copying is attested for most vowels, and across all manners of intervening consonants.

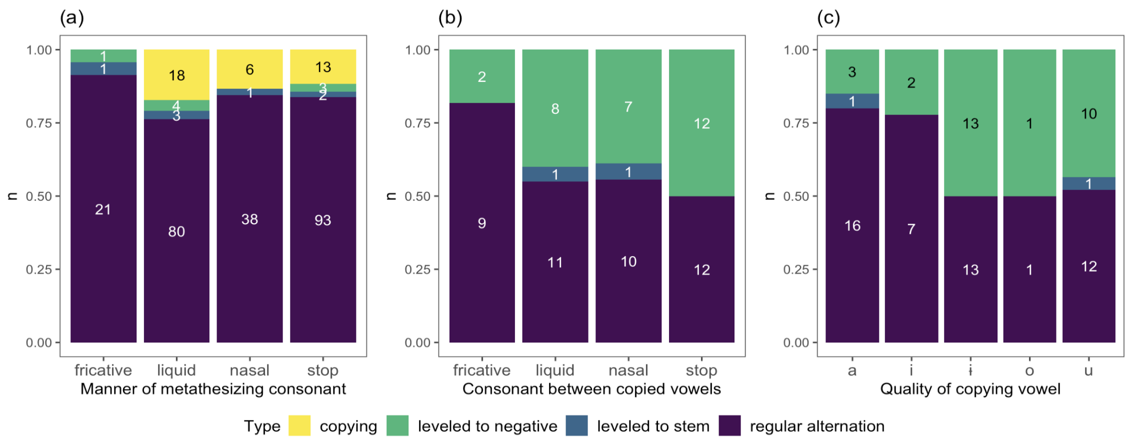

Figure 5: Rate of regularly alternating forms in paradigms that undergo (a) metathesis, by manner of metathesizing consonant; (b) copying, by manner of intervening consonant; (c) copying, by quality of copied vowel

When metathesis and copying do occur with little to no phonological restrictions, they tend to be morphologically restricted (Mooney, 2023). The Maga patterns fit into this characterization; they are non-phonologically optimizing and happen only with certain affixal triggers. In fact, the vowel alternations in Maga are in many ways similar to non-concatenative morphology, where morpheme exponents require roots to have a certain phonological form (McCarthy & Prince, 2017)

7 Conclusion

In Maga Rukai, a historical process of vowel deletion in prosodically weak positions resulted in a synchronic rhythmic syncope pattern, which can only be accounted for by positing abstract composite URs. In this paper, I propose that rather than maintaining rhythmic syncope, Maga paradigms were restructured in two ways. First, some paradigms preserved vowel alternations, but extended a vowel-matching pattern which made surface forms predictable form each other.

Other paradigms leveled out all vowel alternations, where leveling was towards both the stem and negative allomorphs. Crucially, both types of restructuring make paradigms more concrete, removing the need for composite URs.

These results support a concrete view of UR learning, but it remains to be seen if abstract URs are always unlearnable, or if learners are simply biased against them. Notably, there are documented cases where abstract URs seem to be robustly learned. For example, Paramore & Bennett (2025) describe a nasal vowel alternation in Western Panjabi that appear productive, but requires positing abstract phonemes. It could be that UR-learning is 'concrete by default'. That is, learners will assume that URs are concrete, and stop here if a concrete analysis accounts for some proportion of the data. It's only when a concrete analysis falls below this 'threshold accuracy' that learners will consider more abstract URs. Future work should test this hypothesis, by comparing cases like Western Panjabi to Maga Rukai, with a focus on how well concrete alternative analyses account for the observed data.

In Maga, speakers leveled towards both the stem and negative allomorphs, which is compatible with either a KK-C (choosing from allomorphs) or KK-C' (listed allomorphs) approach to UR-learning. Model comparisons (Section 5) suggest that of these two, the LISTED ALLOMORPH approach best accounts for the Maga patterns of restructuring. However, in the current study, UR-selection for the KK-C model was highly simplified (where the UR is whichever allomorph preserves the most vowel contrasts); future work should test the performance of a model that uses a more rigorous approach to UR learning.

References

Albright, Adam (2002). A restricted model of ur discovery: Evidence from Lakhota. Paper given at the GLOW Phonology Workshop, Utrecht.

Albright, Adam (2004). The emergence of the marked: Root-domain markedness in Lakhota.

Albright, Adam (2010). Base-driven leveling in Yiddish verb paradigms. *NLLT* **28:3**. 475–537. doi:10.1007/s11049-010-9107-z.

Albright, Adam C. (2002). *The identification of bases in morphological paradigms*. PhD dissertation, University of California, Los Angeles.

Becker, Michael & Maria Gouskova (2016). Source-Oriented Generalizations as Grammar Inference in Russian Vowel Deletion. *LI* **47:3**. 391–425. doi:10.1162/LING_a_00217.

Belth, Caleb (2023). A learning-based account of local phonological processes. *Phonology* **40:1-2**. 1–33.

Bowers, Dustin (2012). *Phonological restructuring in odawa*. MA thesis University of California, Los Angeles.

Breiss, Canaan (2021). *Lexical conservatism in phonology: theory, experiments, and computational modeling*. PhD dissertation, University of California, Los Angeles.

Breiss, Canaan (2024). When bases compete: A voting model of lexical conservatism. *Language* **100:2**. 308–358.

Chen, Yin-Ling Christina (2008). On the Rhythmic Vowel Deletion in Maga Rukai. *Concentric: Studies in Linguistics* **34**. 47–84.

Chomsky, Noam & Morris Halle (1968). *The sound pattern of English*. Harper & Row.

Czaykowska-Higgins, Ewa (1988). *Investigations into polish morphology and phonology*. PhD dissertation, Massachusetts Institute of Technology.

Derwing, Bruce L. (1974). *Transformational grammar as a theory of language acquisition* (Cambridge studies in linguistics 10). Cambridge, MA: CUP.

Goldwater, Sharon & Mark Johnson (2003). Learning OT constraint rankings using a maximum entropy model. In *Proceedings of the stockholm workshop on variation within optimality theory*, 111–120.

Gouskova, Maria (2003). *Deriving economy: syncope in optimality theory*. PhD dissertation, University of Massachusetts Amherst.

Gouskova, Maria (2012). Unexceptional segments. *Natural Language & Linguistic Theory* **30:1**. 79–133. doi:10.1007/s11049-011-9142-4. `http://link.springer.com/10.1007/s11049-011-9142-4`.

Gouskova, Maria (2023). Phonological Asymmetries between Roots and Affixes. In Peter Ackema, Sabrina Bendjaballah, Eulàlia Bonet & Antonio Fábregas (eds.), *The Wiley Blackwell Companion to Morphology*, 1–44. Wiley. doi:10.1002/9781119693604.morphcom007.

Gouskova, Maria & Gillian Gallagher (2020). Inducing nonlocal constraints from baseline phonotactics. *Natural Language & Linguistic Theory* **38:1**. 77–116. doi:10.1007/s11049-019-09446-x.

Hall, Nancy (2006). Cross-linguistic patterns of vowel intrusion. *Phonology* **23:3**. 387–429.

Hawkins, W Neil (1950). Patterns of vowel loss in macushi (carib). *International Journal of American Linguistics* **16:2**. 87–90.

Hayes, Bruce (1995). *Metrical stress theory: principles and case studies*. University of Chicago Press.

Hayes, Bruce (1999). Phonological Restructuring in Yidin and its Theoretical Consequences. In Ben Hermans & Marc van Oostendorp (eds.), *The derivational residue in phonological optimality theory*, 175–205. John Benjamins Publishing Company. doi:10.1075/la.28.09hay.

Hayes, Bruce & Colin Wilson (2008). A maximum entropy model of phonotactics and phonotactic learning. *LI* **39:3**. 379–440.

Hsin, Tien-Hsin (2000). *Aspects of Maga Rukai Phonology*. PhD Thesis University of Connecticut.

Hsin, Tien-Hsin (2003). The mid vowels of Maga Rukai and their implications. *Journal of East Asian Linguistics* **12:1**. 59–82. Publisher: Springer.

Jarosz, Gaja (2008). Partial Ranking and Alternating Vowels in Polish. In Rodney Edwards, Patrick Midtlyng, Coliin Sprague & Kjersti Stensrud (eds.), *Proceedings of the Chicago Linguistic Society 41*, vol. 1, 193–206. Chicago: CLS.

Jurgec, Peter & Bronwyn M Bjorkman (2018). Indexation to stems and words. *Phonology* **35:4**. 577–615.

Kager, René (1997). Rhythmic vowel deletion in optimality theory. In Iggy Roca (ed.), *Derivations and constraints in phonology*, 463–500. Oxford University Press.

Kaohsiung City Government Civil Affairs Bureau (2023). Population census. `https://cabu.kcg.gov.tw/web/HRStatReports.aspx?appname=HRStatReports`.

Kaplan, Max J. (2022). Stratal overgeneration is necessary: metrically incoherent syncope in Southern Pomo. *Phonology* **39:4**. 597–639. doi:10.1017/S0952675723000234.

Kenstowicz, Michael J. & Charles W. Kisseberth (1977). *Topics in phonological theory*. New York: Academic Press.

Kiparsky, Paul (1968). Linguistic universals and linguistic change. In Emmon W. Bach & Robert Thomas Harms (eds.), *Universals in linguistic theory*, 170–202. Holt, Rinehart, and Winston.

Kiparsky, Paul (1973). Abstractness, opacity, and global rules. In Osamu Fujimura (ed.), *Three dimensions in linguistic theory* Publications, 57–86. Tokyo: TEC. `https://books.google.com/books?id=YMaSOwAACAAJ`.

Kiparsky, Paul (1982). Lexical morphology and phonology. In I.-S. Yang (ed.), *Linguistics in the morning calm*, 3–91. Hansin.

Kuo, Jennifer (2023). *Phonological markedness effects in reanalysis*. PhD dissertation, University of California, Los Angeles.

Li, Paul Jen-Kuei (1975). Maga phonology: A preliminary report. *Bulletin of the Department of Archaeology and Anthropology, National Taiwan University* **37-38**. 16–28.

Li, Paul Jen-kuei (1977). The internal relationships of Rukai. *Bulletin of the Institute of History and Philology* **48:1**. 1–92.

Li, Paul Jen-kuei (1977). Morphophonemic alternations in Formosan languages. *Bulletin of the Institute of History and Philology, Academia Sinica* **48:3**. 375–413.

Li, Paul Jen-kuei (1997). Maga dialect. In Paul Jen-kuei Li (ed.), *The formosan languages in kaohsiung county*, 8–118. Kaohsiung: Kaohsiung Prefecture Government.

Martin, Sven C, Hermann Ney & Jörg Zaplo (1999). Smoothing methods in maximum entropy language modeling. In *1999 ieee international conference on acoustics, speech, and signal processing. proceedings. icassp99 (cat. no. 99ch36258)*, vol. 1, 545–548. IEEE.

Massar, Andrea & LouAnn Gerken (1998). Abstract output: an optimality-theoretic analysis of children's omissions from prosodically complex structures. In *Proceedings of NELS 28*, .

Mayer, Connor, Adeline Tan & Kie Zuraw (2024). *maxent.ot: A package for doing Maximum Entropy Optimality Theory in R (Version 1.0.0)*. `https://doi.org/10.5281/zenodo.7246367`.

McCarthy, John J (1986). Ocp effects: Gemination and antigemination. *LI* **17:2**. 207–263.

McCarthy, John J (2008). The serial interaction of stress and syncope. *Natural Language & Linguistic Theory* **26**. 499–546.

McCarthy, John J. & Alan S. Prince (2017). Prosodic Morphology. In Andrew Spencer & Arnold M. Zwicky (eds.), *The Handbook of Morphology*, 281–305. Wiley 1st edn. doi:10.1002/9781405166348.ch14.

Mooney, Kate (2023). *The theory and typology of phonological reordering*. PhD dissertation, New York University.

Moore-Cantwell, Claire & Joe Pater (2016). Gradient exceptionality in Maximum Entropy Grammar with lexically specific constraints. *Catalan Journal of Linguistics* **15**. 53–66.

Muller, Jennifer Suzanne (2001). *The phonology and phonetics of word-initial geminates*. PhD dissertation, The Ohio State University.

Newport, Elissa L & Richard N Aslin (2004). Learning at a distance i. statistical learning of non-adjacent dependencies. *Cognitive psychology* **48:2**. 127–162. doi:10.1016/S0010-0285(03)00128-2.

Paramore, Jonathan C. & Ryan Bennett (2025). Covert urs: evidence from nasalization in western panjabi. *lingbuzz/009318* .

Pater, Joe (2007). The locus of exceptionality: Morpheme-specific phonology as constraint indexation. In Leah Bateman, Michael O'Keefe, Ehren Reilly & Adam Werle (eds.), *University of Massachusetts Occasional Papers 32: Papers in Optimality Theory III*, 259–296. Amherst: GLSA.

Pater, Joe (2008). Morpheme-specific phonology: Constraint indexation and inconsistency resolution. In Steve Parker (ed.), *Phonological Argumentation: Essays on Evidence and Motivation*, 123–154. Equinox.

Prince, Alan (1990). Quantitative consequences of rhythmic organization. *CLS* **26:2**. 355–398.

Rysling, Amanda (2016). Polish yers revisited. *Catalan journal of linguistics* **15**. 121–143.

Saillard, Claire (1995). Is Maga accusative or ergative? evidence from case marking. In Feng-fu Tsao & Mei-hui Tsai (eds.), *Proceedings of the first international symposium on languages in taiwan*, The Crane.

Santelmann, Lynn M & Peter W Jusczyk (1998). Sensitivity to discontinuous dependencies in language learners: evidence for limitations in processing space. *Cognition* **69:2**. 105–134. doi: https://doi.org/10.1016/S0010-0277(98)00060-2.

Shaw, Patricia A (1993). The prosodic constituency of minor syllables. In *Wccfl 12*, 117–132.

Shih, Shu-hao (2018). *Non-moraic schwa: Phonology and phonetics*. PhD dissertation, Rutgers University.

Tranel, Bernard (1981). *Concreteness in generative phonology: evidence from French*. Berkeley Los Angeles London: University of California press.

Valentine, Randy (2001). *Nishnaabemwin reference grammar*. University of Toronto Press.

Wang, Yang & Bruce Hayes (2025). Learning phonological underlying representations: The role of abstractness. *LI* 1–44. doi:10.1162/ling_a_00553.

Willett, Elizabeth (1982). Reduplication and accent in southeastern tepehuan. *International Journal of American Linguistics* **48:2**. 168–184.

Willett, Elizabeth R & Thomas L Willett (2015). *Diccionario tepehuano de Santa María Ocotán, Durango*. D.F. México: Instituto Lingüístico de Verano, A.C.

Willett, Thomas L (1989). *A reference grammar of southeastern tepehuan.* University of Texas at Arlington.

Wilson, Colin (2006). Learning phonology with substantive bias: An experimental and computational study of velar palatalization. *Cognitive science* **30:5**. 945–982.

Zeitoun, Elizabeth (1995). *Issues on Formosan linguistics (problèmes de linguistique dans les langues aborigènes de taiwan)*. PhD Thesis University Paris 7.

Zeitoun, Elizabeth (2007). *A grammar of Mantauran (Rukai)*. Institute of Linguistics, Academia Sinica Taipei.

Zeitoun, Elizabeth (2024). Rukai. In Paul Jen-kuei Li, Elizabeth Zeitoun & Rik De Busser (eds.), *Handbook of Formosan Languages (part 3): The Indigenous Languages of Taiwan*, 396–445. Leiden, The Netherlands: Brill.

Zuraw, Kie (2010). A model of lexical variation and the grammar with application to tagalog nasal substitution. *NLLT* **28:2**. 417–472. doi:10.1007/s11049-010-9095-z.

Zuraw, Kie Ross (2000). *Patterned exceptions in phonology*. PhD dissertation, University of California, Los Angeles.