Gradual Optionality in Noisy HG

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- Noisy Harmonic Grammar: probabilistic implementations of Harmonic Grammar (Jesney 2007; Hayes 2017; Flemming 2017; Zuraw & Hayes 2017).
- **Question 1:** How do its properties change when implemented serially?
- **Question 2:** Is it compatible with gradual approaches to deletion and feature change (McCarthy 2008)?

Introduction

- Only one version of NHG supports an analysis of optionality in Eastern Andalusian harmony in a parallel framework (Kaplan 2018a; Kaplan 2019).
  - The harmony-driving constraint in this analysis requires serialism.
- Harmony can be implemented gradually.
  - Does noise interfere with the necessary sequence of steps?

Introduction

Two test cases:

- **Eastern Andalusian harmony (Jiménez & Lloret 2007; Lloret & Jiménez 2009; Lloret 2018):** the same implementation of NHG that succeeds in parallel is also the only one that succeeds in serialism.
- **Hiatus resolution in Persian (Ariyaee & Jurgec 2020):** NHG successfully produces gradual vowel deletion; modeling output frequencies using serial NHG requires revisions to particular constraints.

Serial NHG closely resembles parallel NHG, but we may need to rethink our constraints.

Variable Harmony in Eastern Andalusian

- /s/-aspiration (= deletion) causes laxing of word final vowel, which triggers [–ATR] harmony on the stressed syllable:

tesis	ˈtɛsɪ	‘thesis’	*nenes*	ˈnɛnɛ	‘babies’
tienes	ˈtjɛnɛ	‘you have’	*pesos*	ˈpɛsɔ	‘weights’
monos	ˈmɔnɔ	‘monkeys’	*lejos*	ˈlɛhɔ	‘far’
bocas	ˈɔkæ̞	‘mouths’	*asas*	ˈa̞sæ̞	‘handles’

- Harmony on other vowels is optional. . .

Variable Harmony in Eastern Andalusian

- Nonfinal post-tonic vowels optionally harmonize in lockstep:

treboles	ˈtrɛβolɛ ∼ ˈtrɛβɔlɛ	'clovers'
cómetelos	ˈkɔmetelɔ ∼ ˈkɔmɛtɛlɔ	'eat them (for you)!'
	*ˈkɔmɛtelɔ, *ˈkɔmetɛlɔ	

- Likewise for pretonic vowels; post-tonic harmony is a prerequisite for pretonic harmony:

momentos	moˈmɛntɔ ∼ mɔˈmɛntɔ	'instants'
relojes	reˈlɔhɛ ∼ rɛˈlɔhɛ	'watches'
monederos	moneˈðɛɾɔ ∼ mɔnɛˈðɛɾɔ	'purses'
	*mɔneˈðɛɾɔ, *monɛˈðɛɾɔ	
recógelos	reˈkɔhelɔ ∼ reˈkɔhɛlɔ ∼ rɛˈkɔhɛlɔ	'pick them'
	*rɛˈkɔhelɔ	

Variable Harmony in Eastern Andalusian

- But high vowels do not undergo harmony:

crisis	ˈkɾisɪ	'crisis'
muchos	ˈmuʃɔ	'many'
ídolos	ˈiðolɔ ∼ ˈiðɔlɔ	'idols'
cojines	koˈhinɛ ∼ kɔˈhinɛ	'pillows'
cotillones	kotiˈʒɔnɛ ∼ kɔtiˈʒɔnɛ	'cotillions'

Core Constraints

- LICENSE([–ATR], $\acute{\sigma}$): assign $+1$ for each [–ATR] that coincides with $\acute{\sigma}$ and $+1$ for each additional syllable that [–ATR] appears in (Kaplan 2018b; Walker 2011).
  - Positive constraints require serialism (Kimper 2011).
- CRISPEDGE([–ATR], $\acute{\sigma}$, L): assign -1 for each syllable to the left of the stressed syllable with which it shares a [–ATR] feature (e.g. Ito & Mester 1999; Kaplan 2018c).
- *[–ATR]: assign -1 for each vowel bearing [–ATR].
- *[+hi, –ATR]: assign -1 for [ɪ, ʊ].

Add noise to the computation of harmony scores at various levels (Hayes 2017):

/rekóhelos/	LICENSE 11	CRISPEDGE 0.25	*[−ATR] 11	*H*
a. reˈkohelɔ			−1	−11
(☞) b. reˈkɔhelɔ	+2		−2	0
(☞) c. reˈkɔhɛlɔ	+3		−3	0
(☞) d. rɛˈkɔhɛlɔ	+4	−1	−4	−0.25
e. rɛˈkɔhelɔ	+3	−1	−3	−0.25

NHG: the Mechanics

Add noise to the computation of harmony scores at various levels (Hayes 2017): constraint ("classical NHG"),

/rekóhelos/	LICENSE 11 +.5	CRISPEDGE 0.25 −.2	*[−ATR] 11 +.3	*H*
a. reˈkohelɔ			−1	~~−11~~ → −11.3
(☞) b. reˈkɔhelɔ	+2		−2	~~0~~ → 0.4
(☞) c. reˈkɔhɛlɔ	+3		−3	~~0~~ → 0.6
(☞) d. rɛˈkɔhɛlɔ	+4	−1	−4	~~−0.25~~ → 0.75
e. rɛˈkɔhelɔ	+3	−1	−3	~~−0.25~~ → 0.55

Add noise to the computation of harmony scores at various levels (Hayes 2017): constraint ("classical NHG"), cell,

/rekóhelos/	LICENSE 11	CRISPEDGE 0.25	*[−ATR] 11	*H*	
a. reˈkohelɔ	+.9	−.8	−1 −.5	~~−11~~	→ −10.5
(☞) b. reˈkɔhelɔ	+2 +.5	−.7	−2 −.5	~~0~~	→ 2
(☞) c. reˈkɔhɛlɔ	+3 +0	+.6	−3 −.9	~~0~~	→ 2.7
(☞) d. rɛˈkɔhɛlɔ	+4 −.9	−1 +.7	−4 +.2	~~−0.25~~	→ −5.35
e. rɛˈkɔhelɔ	+3 +.2	−1 −.2	−3 +.6	~~−0.25~~	→ −1.25

NHG: the Mechanics

Add noise to the computation of harmony scores at various levels (Hayes 2017): constraint ("classical NHG"), cell, or candidate.

/rekóhelos/	LICENSE 11	CRISPEDGE 0.25	*[−ATR] 11	*H*	
a. re'kohelɔ			−1	~~−11~~ +.4	→ −10.6
(☞) b. re'kɔhelɔ	+2		−2	~~0~~ +.2	→ 0.2
(☞) c. re'kɔhɛlɔ	+3		−3	~~0~~ −.8	→ −0.8
(☞) d. rɛ'kɔhɛlɔ	+4	−1	−4	~~−0.25~~ −.3	→ −.55
e. rɛ'kɔhelɔ	+3	−1	−3	~~−0.25~~ .4	→ 0.65

Also MaxEnt (Goldwater & Johnson 2003)

Only classical NHG noise accounts for Eastern Andalusian in parallel NHG (Kaplan 2018a; Kaplan 2019); also in serial NHG...

Serial Versions of Constraint-Level Noise

1. Constant noise: weights are perturbed once at the outset, fixing their values for the whole derivation.

   Step 1: $w(C) + i$
   Step 2: $w(C) + i$

2. Variable Noise: weights are perturbed anew at each step in the derivation.

   Step 1: $w(C) + i$
   Step 2: $w(C) + j$

3. Cumulative variable noise: like variable noise, but the starting point for each step is the perturbed weights from the previous step.

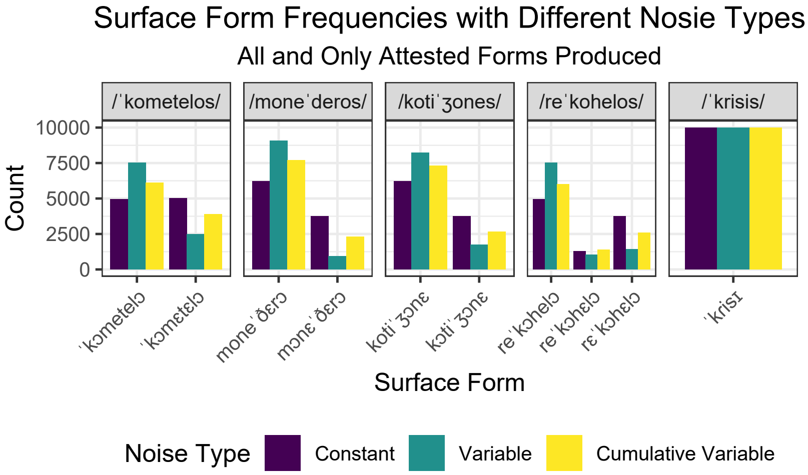
   Step 1: $w(C) + i$
   Step 2: $w(C) + i + j$

Simulations

- Existing software (OTsoft (Hayes, Tesar & Zuraw 2013), OT-Help (Staubs et al. 2010), e.g.) doesn't support serial NHG. (But OTSoft can help find constraint weights, as we'll see.)
- My own implementations, built in R (R Core Team 2020). Some details:
  - Noise was drawn from a normal distribution with mean of 0 and standard deviation of 1.
  - Negative weights were reverted to 0 (following Hayes (2017)).
  - In the event of tied winners, one is chosen at random.
  - Results from each implementation were aggregated over 10,000 iterations.
  - Weights supplied at the outset.

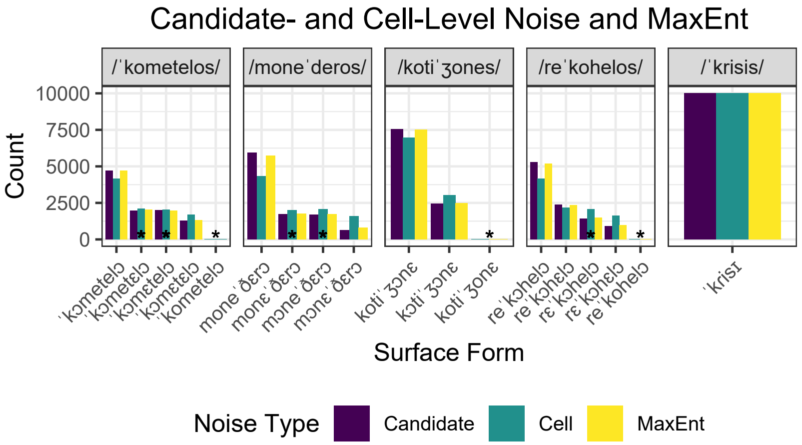
Simulations

- Fell-swoop harmony first.
- All three constraint-level noise simulations produce the licit outputs.
    - Different frequency predictions, but no way to assess them.
- Cell- and candidate-level noise and MaxEnt all overgenerate, unavoidably producing illicit candidates.



- Cumulative Variable: weights are doubled here to prevent accumulation of weights from subverting necessary dominance relationships.

Simulations



* = unattested; those with near-zero frequencies (8 tokens) all come from cell-level/MaxEnt.

A Gradual View of Harmony

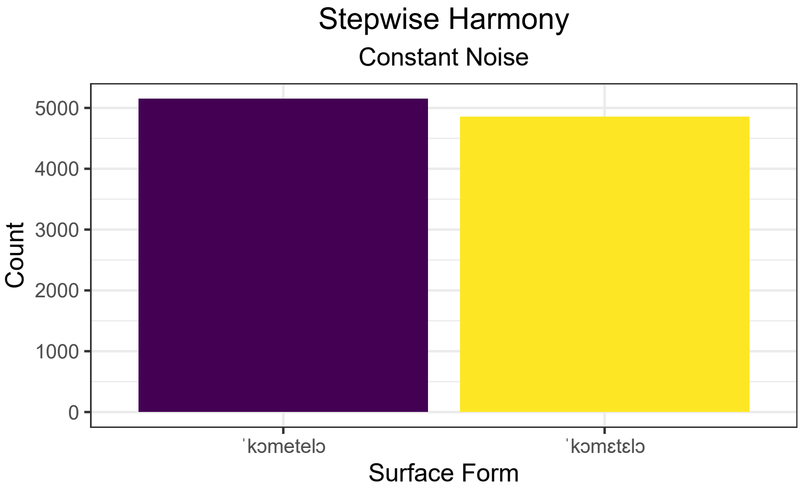
$$\text{re'kohelɔ} \xrightarrow{1} \text{re'kɔhelɔ} \xrightarrow{2} \text{re'kɔhɛlɔ} \xrightarrow{3} \text{rɛ'kɔhɛlɔ}$$

- How far down this path will we go?
- What if we treat feature changes, deletion, etc., as multi-step processes (e.g. McCarthy 2008)?

$$\text{re'kohelɔ} \xrightarrow{1} \text{re'kXhelɔ} \xrightarrow{2} \text{re'kɔhelɔ} \xrightarrow{3} \text{re'kɔhXlɔ} \xrightarrow{4} \text{re'kɔhɛlɔ} \xrightarrow{5} \text{rX'kɔhɛlɔ} \xrightarrow{6} \text{rɛ'kɔhɛlɔ}$$

- X = a V that's both [+ATR] and [–ATR]
- Now every other step is required. Can we ensure that Step 4 always happens if we choose to do Step 3, e.g.?
  - Yes: weight *DOUBLEASSOCIATION high enough that it will always trigger deletion of [+ATR], even after weights are perturbed.

A Stepwise View of Harmony



Summary: Eastern Andalusian

- Only constraint-level noise (all versions) provides a satisfactory analysis.
- The analysis succeeds with both fell-swoop and gradual harmony.
- Turning to Persian, focusing on constraint-level noise:
  - Test gradualism more fully
  - Match frequency data

Variable Hiatus Resolution in Persian

- Hiatus at morpheme boundaries is optionally resolved via epenthesis or deletion of the suffix-initial V (Ariyaee & Jurgec 2020):

/baba-emun/	→	[babaemun ∼ babamun ∼ babaʔemun]	'our dad'
/baba-eʃ	→	[babaeʃ ∼ babaʃ ∼ babaʔeʃ]	'his/her dad'
/baba-æm	→	[babaæm ∼ babam ∼ babaʔæm]	'my dad'

- If the suffix consists solely of the deleteable vowel, deletion is strongly disfavored (REALIZEMORPHEME (Kurisu 2001)):

/babae/ → [babae ∼ ???/*baba ∼ babaʔe] 'the dad'

- In the absence of hiatus Root + Suffix emerges unchanged:

/dæftær-emun/ → [dæftæremun] 'our office'

The Challenges

- Gradual deletion: can we ensure /babaemun/ → babaVmun → [babamun], not halting at *[babaVmun]?
- NoHiatus
  - Satisfied only by the final step in deletion, so it can't motivate the first step.
  - Let's assume NoHiatus penalizes consecutive *fully specified* vowels. Now [babaVmun] satisfies it.
- RealizeMorpheme
  - A standard view: as long as a morpheme has some phonological exponent, RealizeMorph is satisfied.
  - This will cause problems, and we'll revisit it later.

Constraints

- NoHiatus motivates epenthesis/deletion. (Penalizes [ae], not [aV].)
- RealizeMorpheme discourages deletion in /baba-e/.
- HavePlaceV penalizes placeless vowels, motivating V $\rightarrow \emptyset$.
- HavePlaceC penalizes [ʔ], hence penalizes epenthesis.
- Faithfulness:
  - MaxV (penalizes V $\rightarrow \emptyset$) & DepV (penalizes $\emptyset \rightarrow$ V)
  - MaxC & DepC
  - MaxVPlace (penalizes /e/ $\rightarrow$ V)
  - DepVPlace (penalizes V $\rightarrow$ [e])
- No MaxCPlace or DepCPlace: for simplicity, /ʔ/ $\rightarrow$ [t], e.g., not considered. Assume DepCPlace dominates everything.

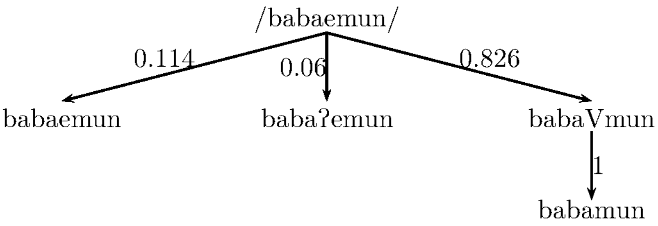
Variant Frequencies and Derivational Paths

Output variants inferred from graphs in Ariyaee & Jurgec (2020) using WebPlotDigitizer (Rohatgi 2020):

Surface Form	Target
/baba-e/	
babae	0.589
baba	0.080
babaʔe	0.331
/baba-emun/	
babaemun	0.114
babamun	0.826
babaʔemun	0.060
/dæftær-emun/	
dæftæremun	1.000

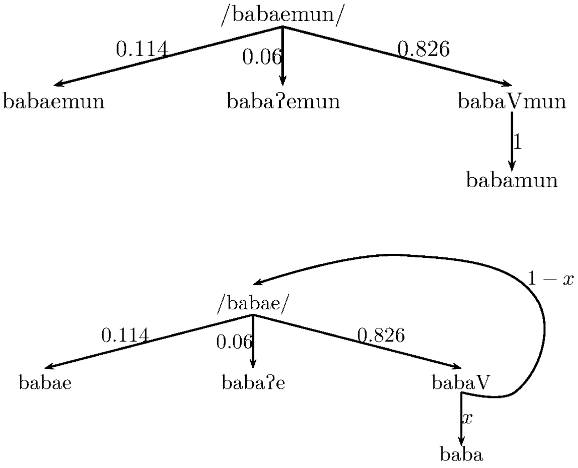
Variant Frequencies and Derivational Paths

- How do we get to these outputs? The simplest approach for /baba-emun/:



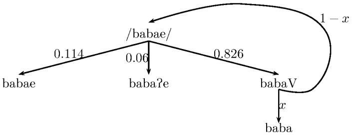
- /baba-e/: same paths, but different proportions due to REALIZEMORPH—the only constraint that distinguishes /baba-emun/'s derivations from /baba-e/'s.
- But REALIZEMORPH doesn't care about Step 1: it penalizes only /babaV/ $\rightarrow$ [baba], so the Step 1 proportions must match those for /baba-emun/.

Variant Frequencies and Derivational Paths



- What must the probability of /babaV/ → [baba] be to reduce the probability of deletion to .08?

Variant Frequencies and Derivational Paths



- Probability of convergence on [baba]:

$$0.826x + 0.826x(0.826(1-x)) + 0.826x(0.826(1-x))^2 + 0.826x(0.826(1-x))^3 + \ldots$$

- The infinite series $a + ar + ar^2 + ar^3 + \ldots = \frac{a}{1-r}$. Therefore:

$$\frac{0.826x}{1 - 0.826(1-x)} = .08$$

So $x \approx 0.018$

Deriving Weights

1. Create OTSoft file with each step in our derivations:

Input	Legal Outputs
/baba-e/	babae ∼ babaʔe ∼ babaV
babaʔe	babaʔe
babaV	baba ∼ babae
/baba-emun/	babaemun ∼ babaʔemun ∼ babaVmun
babaʔemun	babaʔemun
babaVmun	babamun
/dæftær-emun/	dæftæremun

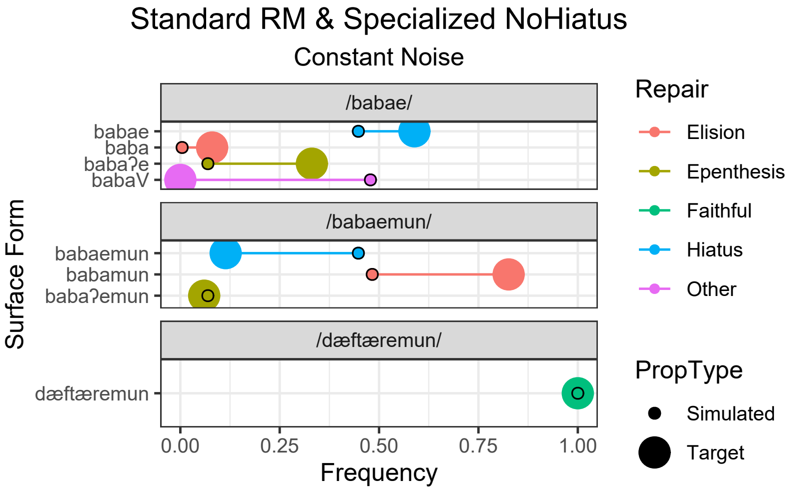
2. Probabilities for each candidate match what we saw before for /baba-e/ and /baba-emun/. For inputs with one possible output, that output's probability = 1. All other mappings = 0.

Deriving Weights

3. Submit file to OTSoft's NHG tool (premultiplicative constraint-level noise). The output:

Constraint	Weight	Remarks
NoHiatus	8.75	violated by [babaemun], not [babaVmun]
MaxVPlace	0.002	violated by /babaemun/ → [babaVmun]
DepC	6.78	violated by /babaemun/ → [babaʔemun]
MaxC	4	violated by /babaʔemun/ → [babaemun]
DepV	10	violated by /babamun/ → [babaVmun]
MaxV	1.15	violated by /babaVmun/ → [babamun]
HavePlaceV	8.31	violated by [babaVmun]
DepVPlace	0	violated by /babaVmun/ → [babaemun]
HavePlaceC	3.78	violated by [babaʔemun]
RealizeMorph	10.2	violated by [baba] but not [babV]

Results



Standard RM & Specialized NoHiatus
Constant Noise
/babae/
babae
baba
babaʔe
babaV
/babaemun/
babaemun
babamun
babaʔemun
/dæftæremun/
dæftæremun
Surface Form
0.00
0.25
0.50
0.75
1.00
Frequency
Repair
Elision
Epenthesis
Faithful
Hiatus
Other
PropType
Simulated
Target

Results

Target & Simulated Frequencies
Standard RM, Constant Noise

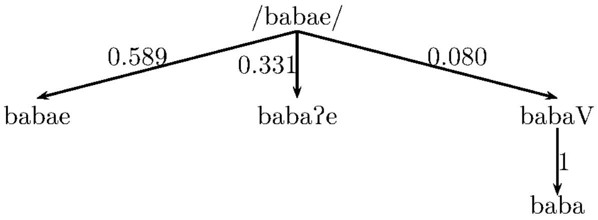
Surface Form	Target	Simulation
/baba-e/		
babae	0.589	0.4479
baba	0.080	0.0045
babaʔe	0.331	0.0693
babaV	0.000	0.4783
/baba-emun/		
babaemun	0.114	0.4479
babamun	0.826	0.4828
babaʔemun	0.060	0.0693
/dæftær-emun/		
dæftæremun	1.000	1.0000

Results

- Attempts to adjust weights to exclude [babaV] (e.g. by elevating HavePlaceV) also increased the likelihood of [baba], which quickly becomes the most common output for /babae/. (It should be the least common.)
- Perhaps there are weights that work, but I can't find them.

An Alterative RealizeMorph

- Alternative: match output frequencies at Step 1 as with /babaemun/:



- A new conception of RealizeMorph: in [babaV], the exponent of the suffix is a vowel lacking features. Maybe RM requires a *pronounceable* exponent for each morpheme.

An Alterative REALIZEMORPH

REALIZEMORPHEME: assign -1 for each morpheme that does not have a fully specified phonological exponent.

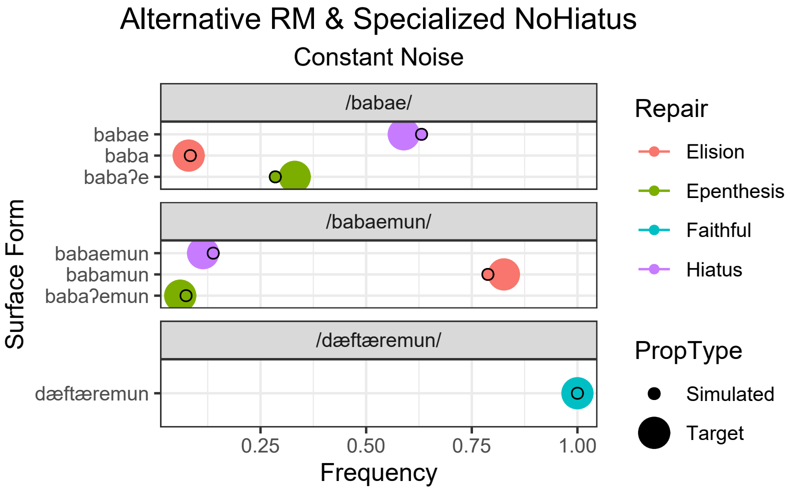
- What does "fully specified" mean? Not sure. . . let's assume that [V] doesn't cut it and worry about the details later.

An Alterative RealizeMorph

- Once again, using OTSoft to derive weights:

Constraint	New Weight	Old Weight
NoHiatus	11.2	8.75
MaxVPlace	2.74	0.002
DepC	7.03	6.78
MaxC	3	4
MaxV	0	1.15
HavePlaceV	6.74	8.31
DepVPlace	5	0
HavePlaceC	5.03	3.78
RealizeMorph	4.08	10.2

Results



Alternative RM & Specialized NoHiatus
Constant Noise
/babae/
babae
baba
babaʔe
/babaemun/
babaemun
babamun
babaʔemun
/dæftæremun/
dæftæremun
Surface Form
0.25
0.50
0.75
1.00
Frequency
Repair
Elision
Epenthesis
Faithful
Hiatus
PropType
Simulated
Target

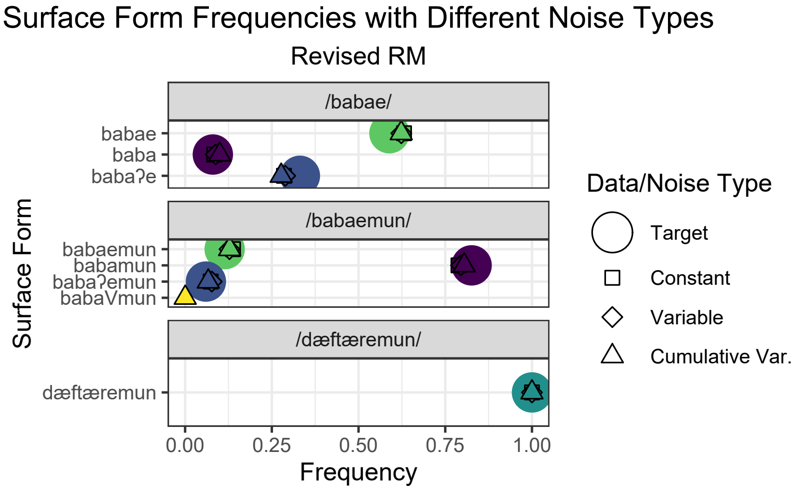
An Alterative RealizeMorph

Target & Simulated Frequencies
Alternative RM, Constant Noise

Surface Form	Target	Simulation	MaxEnt (A&J)
/baba-e/			
babae	0.589	0.6311	0.55
baba	0.080	0.0839	0.14
babaʔe	0.331	0.2850	0.31
/baba-emun/			
babaemun	0.114	0.1381	0.25
babamun	0.826	0.7881	0.61
babaʔemun	0.060	0.0738	0.14
/dæftær-emun/			
dæftæremun	1.000	1.0000	NA

Other Variants of Constraint-Level Noise

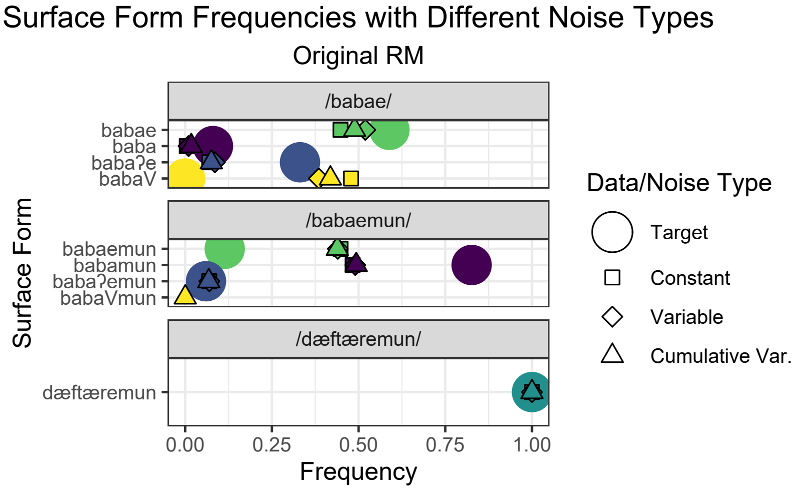
- The three versions of constraint-level noise are roughly similar:



- Cumulative Variable: doubling weights eliminates illicit outputs, but frequencies are less accurate.

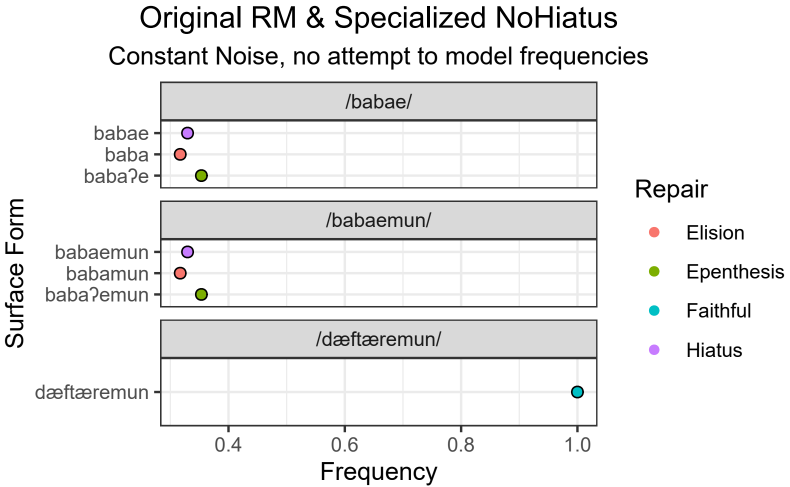
Other Variants of Constraint-Level Noise

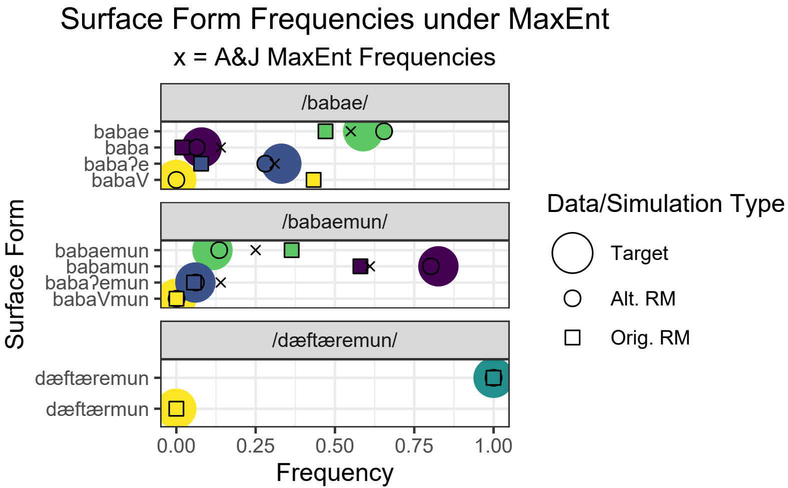
- And they all do poorly with the original REALIZEMORPH:



The Original REALIZEMORPH isn't all Bad

- Original RM can model outputs but not frequencies.
- Abandoning the frequency-matching effort (weights again derived via OTSoft):




Surface Form Frequencies under MaxEnt
x = A&J MaxEnt Frequencies
/babae/
babae
baba
babaʔe
babaV
/babaemun/
babaemun
babamun
babaʔemun
babaVmun
/dæftæremun/
dæftæremun
dæftærmun
Surface Form
0.00
0.25
0.50
0.75
1.00
Frequency
Data/Simulation Type
Target
Alt. RM
Orig. RM

Implications

- Modeling outputs is easy; matching frequencies is harder.
    - Frequencies require refinements to constraints.
- No frequencies are available for Eastern Andalusian—would the challenges presented by Persian reemerge in Eastern Andalusian if we had frequencies?
- Maybe, but there's an important difference between the two phenomena:
    - Persian: which path will we take? (Once that choice is made, the remainder of the derivation is deterministic.)
    - EA: how far down the path will we go? (Just the stressed syllable? Also post-tonic harmony? Also pretonic harmony?)

Implications

- Serial NHG is very similar to parallel NHG. 2 indications:
  - The version of parallel NHG that works for Eastern Andalusian is also the only version of serial NHG that works.
  - The weights that OTSoft provides when it thinks serial derivations are unrelated parallel evaluations hold up serially.

Remaining Issues

- Cell- and candidate-level noise?
- The simulations shown here use only premultiplicative noise: add noise to weight, then multiply by violations. What about post-multiplicative noise (for both Eastern Andalusian and Persian)?
- A better way to arrive at weights for Persian?

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