Learnability of Derivationally Opaque Patterns in the Gestural Harmony Model

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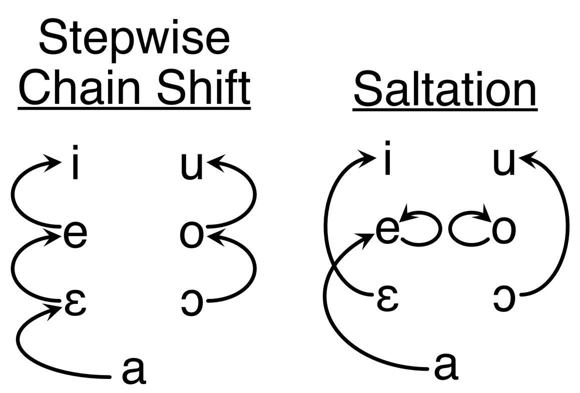
with support from Microsoft Research

Introduction



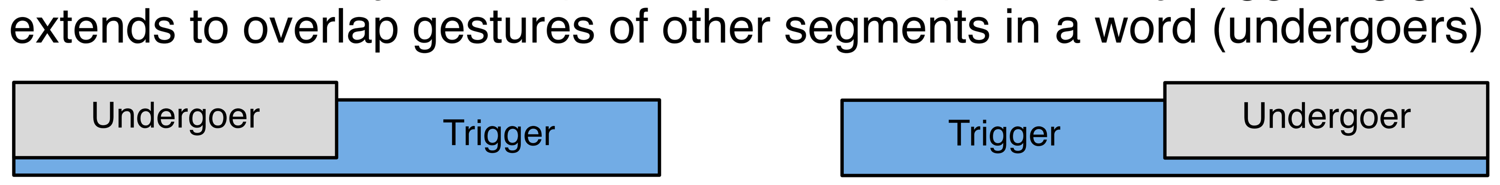
- Attested stepwise (chain-shifting) vowel raising: nonhigh vowels raise one step along height scale in presence of high vowel trigger
- Unattested saltatory (derived-environment) vowel raising:
  - Step in vowel height scale is 'skipped over'
  - Vowels at 'skipped' height do not raise
- Chain shifts and saltations are both examples of underapplication derivational opacity
- Saltations are rare among phonological processes and likely unattested in height harmony
- For a pattern to be robustly attested, it must be derivable within a phonological framework, but also easily learnable within that framework

Proposals

- Partial height harmony via blending in the Gestural Harmony Model (Smith 2016, 2018) generates attested stepwise raising and unattested saltatory raising
- Aspects of learnability of saltatory height harmony explain its lack of attestation

A Gestural Model of Height Harmony

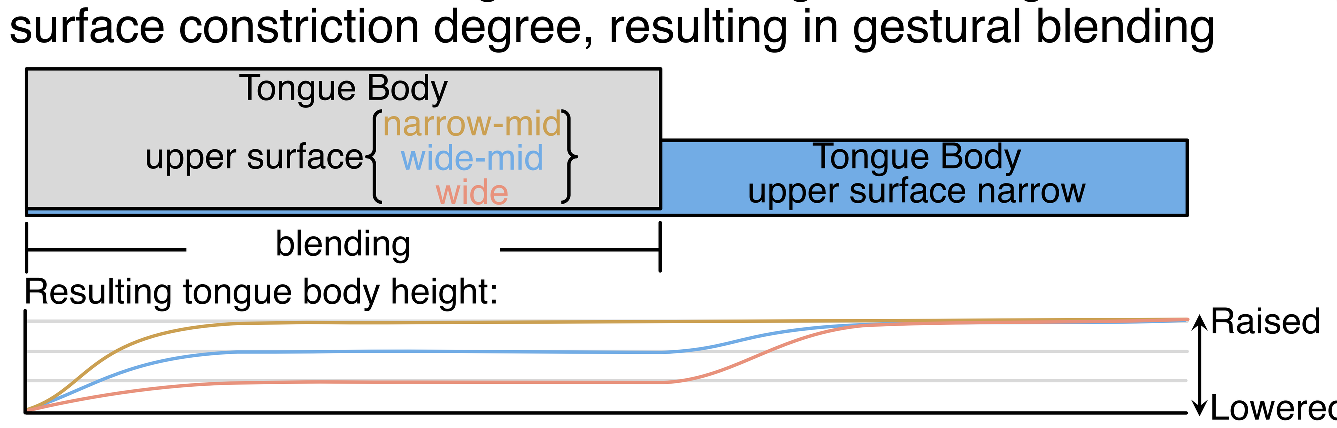
- Gestures (Browman & Goldstein 1986, 1989): dynamically-defined, goal-based units of phonological representation
- Gestural Harmony Model (Smith 2016, 2018): Harmony-triggering gesture extends to overlap gestures of other segments in a word (undergoers)

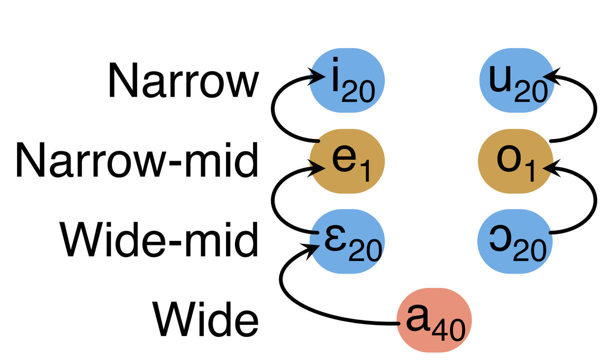


- Antagonistic gestures: gestures with conflicting target articulatory states
- Antagonism resolved by blending target articulatory states of concurrently active gestures according to Task Dynamic Model of speech production (Saltzman & Munhall 1989; Fowler & Saltzman 1993)

$$\frac{\text{Target}_1 * \text{Strength}_1 + \text{Target}_2 * \text{Strength}_2}{\text{Strength}_1 + \text{Strength}_2} = \text{Blended Target}$$

- Stepwise height harmony in Nzebi (Guthrie 1968; Smith to appear):
  - Vowel raising harmony due to overlap by anticipatory upper surface narrow gesture of suffix high vowel /i/
  - Vowels of different heights have antagonistic target states for upper surface constriction degree, resulting in gestural blending





- Narrow-mid vowels /e/ and /o/ fully undergo harmony, with relative gestural blending strengths favoring target constriction degree (narrow) of high vowels
- Overlap between gestures of wide-mid vowels /ɛ/ and /ɔ/ and narrow /i/ produces narrow-mid [e] and [o], with intermediate blended articulatory state due to equal gestural strengths
- Overlap between gestures of wide /a/ and narrow /i/ produces wide-mid vowel [ɛ], with blending strengths slightly favoring target of wide vowel

The Gestural Gradual Learning Algorithm

- With correct gestural strength settings, Gestural Harmony Model can generate both stepwise and saltatory height harmonies

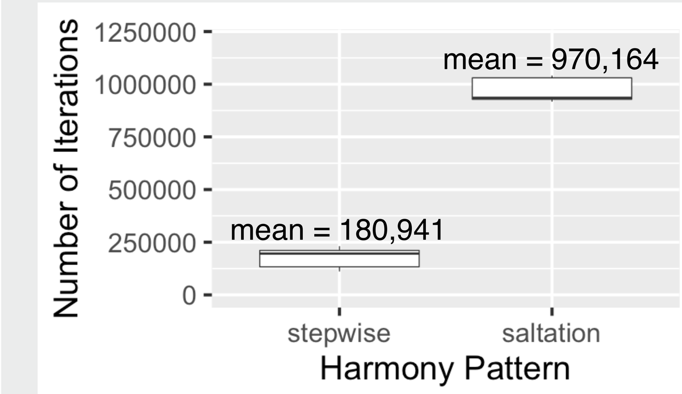
Are stepwise and saltatory height harmonies equally learnable?

- Task: set constriction degree targets and blending strengths for vowel and dorsal consonant gestures such that learner reproduces teacher's vowel raising pattern
- Patterns tested:
  - Four-height stepwise raising before high vowel trigger (Nzebi-like)
  - Four-height saltatory raising before high vowel trigger (unattested)
- Ran 100 models of each type until convergence

Learning Algorithm

1. Initialize target constriction degree of 16 mm (i.e., all vowels start as [a]) and random strength (between 1 and 20)
2. On each iteration randomly generate (V)CV sequence
3. If V_2 is a trigger of harmony, it overlaps V_1, resulting in blending
4. If C is dorsal /g/, following V overlaps it, resulting in blending
5. If learner produces error (segment with target farther than 0.2 mm from teacher's production):
   a. Update constriction degree target of learner's tongue body gesture to produce a constriction degree that better matches teacher's output
   b. In cases of blending: update strength of learner's tongue body gesture to produce a constriction degree that better matches teacher's output

In the Gestural Harmony Model, the stepwise vowel raising pattern is faster/easier to learn than the saltatory vowel raising pattern



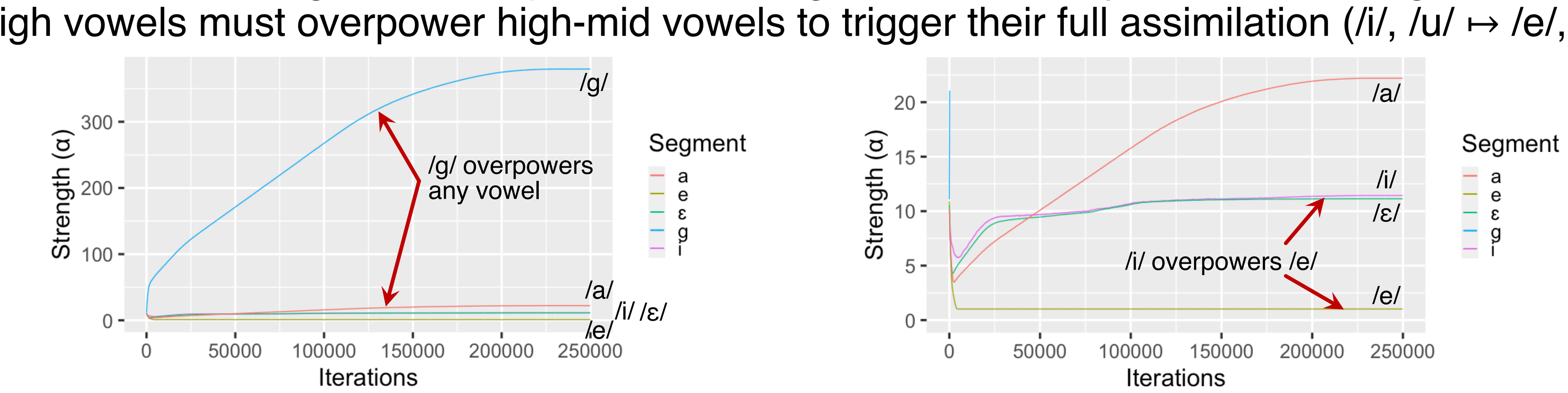
Overall Results

- Stepwise raising is substantially easier/faster to learn than saltation raising
- Saltation takes ~5.3 times as many iterations to learn
- Hard-to-learn saltatory patterns are more likely to be mis-learned across generations and become less frequent

- For assimilation of X to Y, Y's gestural strength must be exponentially higher than that of X
- For X to resist assimilation to Y, X's gestural strength must be exponentially higher than that of Y
- More **overpowering** relationships in a pattern → more extreme strengths necessary → more strength updates necessary during model training

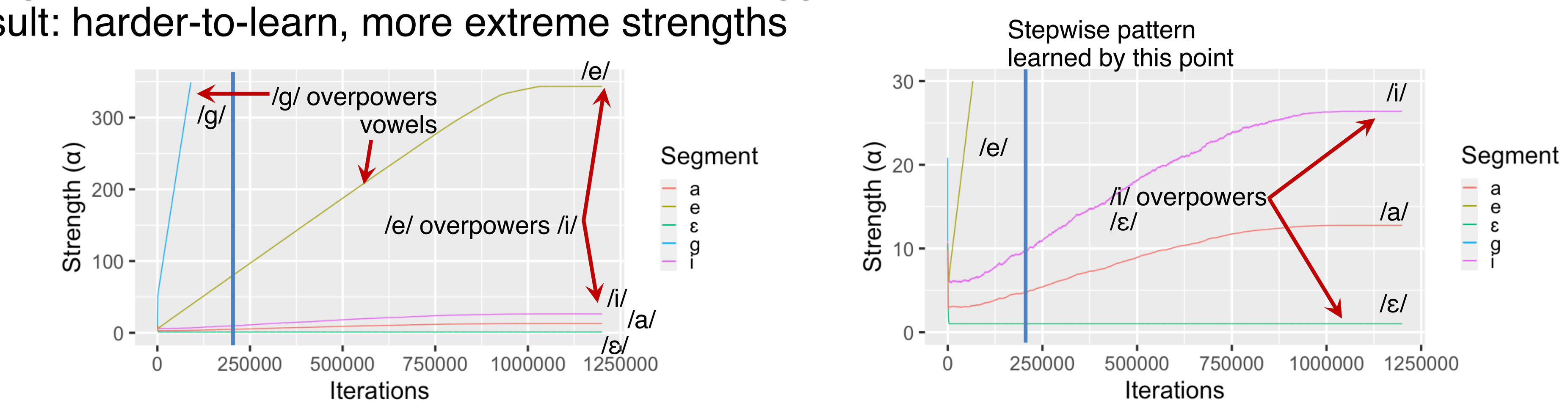
Stepwise Height Harmony

- Only two overpowering relationships in stepwise harmony:
  1. Dorsal consonant /g/ must overpower the strongest vowel to fully resist lenition (/g/ ↦ /a/)
  2. High vowels must overpower high-mid vowels to trigger their full assimilation (/i/, /u/ ↦ /e/, /o/)



Saltatory Height Harmony

- Saltation requires three overpowering relationships:
  1. Dorsal /g/ must overpower the strongest vowel to fully resist lenition (/g/ ↦ /e/, /o/)
  2. High-mid vowels overpower high vowels to fully resist raising (/e/, /o/ ↦ /i/, /u/)
  3. High vowels overpower low-mid vowels to trigger their full assimilation (/i/, /u/ ↦ /ɛ/, /ɔ/)
- Result: harder-to-learn, more extreme strengths



Alternatives

- Assuming standard feature theory and markedness/faithfulness constraints, neither chain shifts nor saltation are derivable in Harmonic Grammar (Albright, Magri, & Michaels 2008; Farris-Trimble 2008)
- Assuming non-standard features and/or constraint definitions, both opaque patterns are derivable in Harmonic Grammar
- Necessary conditions for each type of pattern:
  - Chain shifts: There exists a constraint **C** such that **C**(/ɛ/→[i]) > **C**(/ɛ/→[e]) + **C**(/e/→[i])
  - Saltation: There exists a constraint **D** such that **D**(/ɛ/→[i]) < **D**(/ɛ/→[e]) + **D**(/e/→[i])
- Two possible types of constraint **D** in approaches to generating saltatory patterns: overlapping and non-overlapping faithfulness

- Overlapping faithfulness: any change on a scale violates the same faithfulness constraint
- With scalar IDENT[height] (Gnanadesikan 1997) as constraint **D**:

D(/ɛ/→[i]) < **D**(/ɛ/→[e]) + **D**(/e/→[i])
1 < 1 + 1

- Non-overlapping faithfulness: all mappings violate distinct faithfulness constraints, i.e. *MAP constraints (Zuraw 2007; White 2013; Hayes & White 2015)
- With *MAP(e,i) as constraint **D**:

D(/ɛ/→[i]) < **D**(/ɛ/→[e]) + **D**(/e/→[i])
0 < 0 + 1

- MaxEnt Generational Stability Model (O'Hara 2020, in prep):
  - Maximum Entropy Harmonic Grammar learner with each trained model used as teacher to train next generation of learner
  - Hard-to-learn patterns are less stable across generations
  - Stability: Proportion of 100 models in which a pattern remains the same for 10 generations
  - Stability of stepwise and saltation harmonies:

	Stepwise	Saltation
Overlapping Faith	0%	34%
Non-Overlapping Faith	28%	100%

Featural frameworks that derive both stepwise and saltation height harmonies predict saltation harmonies to be more stable/better attested, contra the typological facts