Two Tools for Learning Gestural Parameters and Constraint Based Grammars

Computational Approaches to Phonology
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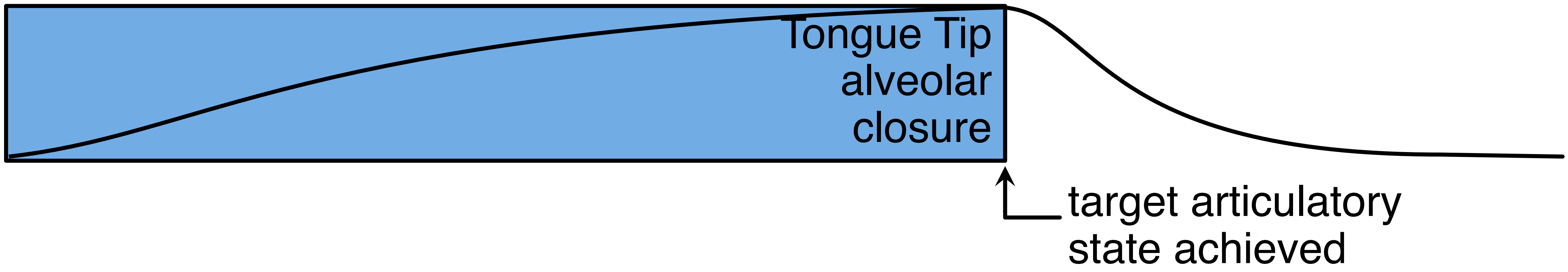
Gestures in Articulatory Phonology
(Browman & Goldstein 1986, 1989 et seq.)

- Gestures: dynamically-defined, goal-based units of phonological representation in Articulatory Phonology

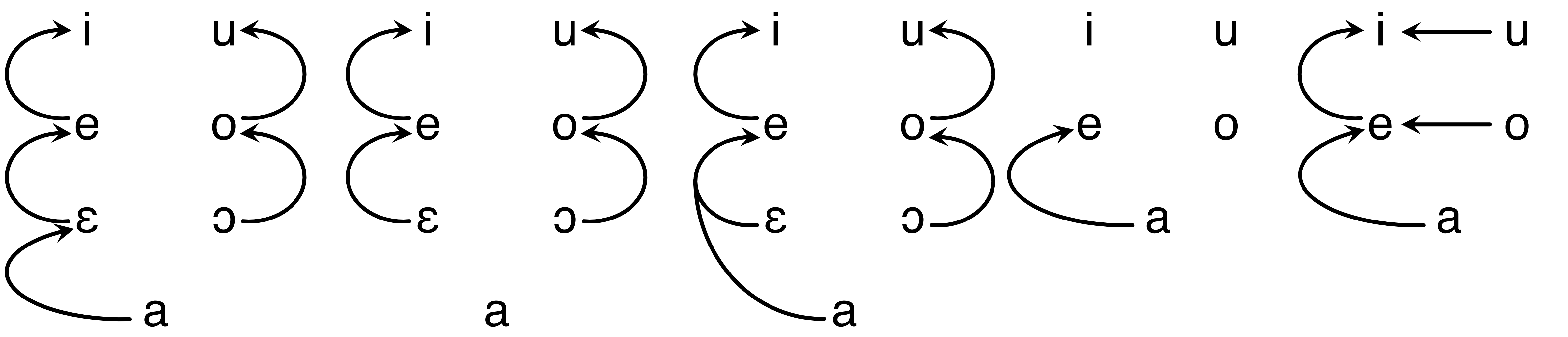


- Ample work on computational modeling of speech production with gestural representations, e.g. TADA (Task Dynamic Application; Nam et al. 2004)
- Less work on computational modeling of learning of gestural parameters from observed articulations

Chain-Shifting Height Harmony

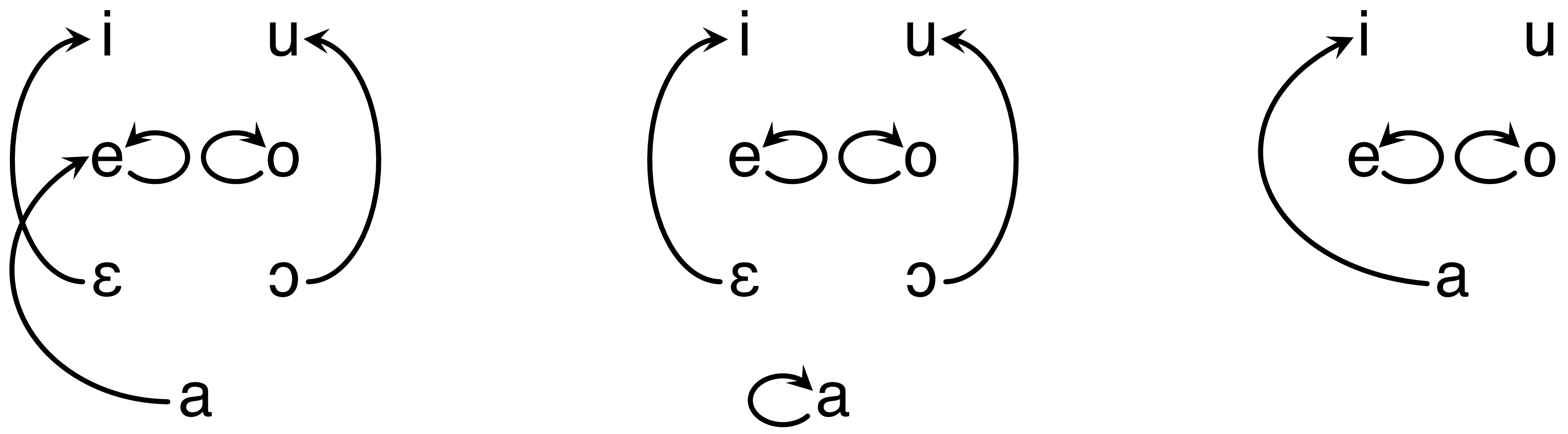
Chain-shifting vowel raising patterns in which vowels raise single step along height scale are well attested:

Nzebi	Servigliano Italian	Basaa	Basque	Fyem
Guthrie (1968)	(Nibert 1998)	(Schmidt 1996)	(Hualde 1988)	(Nettle 1998)



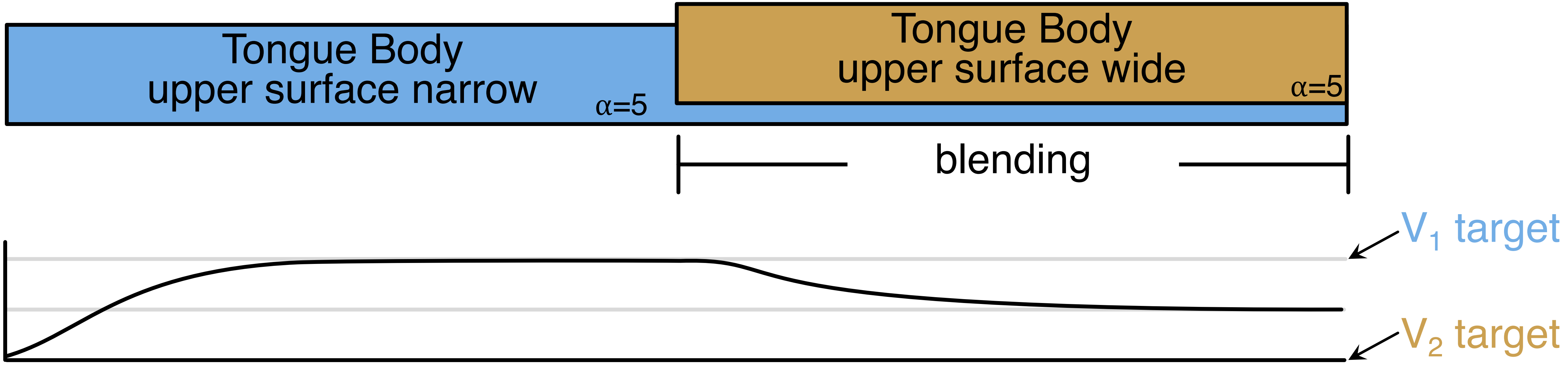
Unattested Saltatory Height Harmony

Two-step vowel raising patterns that ‘skip over’ a step in the height scale (i.e., saltation) are unattested (Parkinson 1996):



Gestural Overlap, Blending, and Strength

- Gestural Harmony Model (Smith 2016, 2018, et seq.): harmony is extension of trigger gesture to **overlap** surrounding gestures
- Partial height harmony is result of **blending** between vowel gestures with different target articulatory states (heights)



Gestural Overlap, Blending, and Strength

- Conflicting gestural targets resolved by blending targets of overlapped gestures according to Task Dynamic Model of speech production (Saltzman & Munhall 1989, Fowler & Saltzman 1993)

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

- Different height harmony patterns results from different gestural parameter settings for vowels' target heights and blending strengths

Gestural Gradual Learning Algorithm (GGLA)

(Smith & O’Hara 2021)

- Learns gestural parameters necessary to correctly produce target partial height harmony pattern (chain shift or saltation) when trigger/undergoer overlap occurs
- Agent-based: learner agent trying to learn harmony pattern produced by teacher agent
- Online and error-driven: For each incorrect vowel production, perform parameter updates to any vowel gestures involved in that production

Error-Driven Online Learning

- During a learning trial, randomly generated two-syllable input is produced according to teacher's and learner's individual gestural parameter settings
- Check learner and teacher productions for a match (i.e. both learner vowels produced within specified window around both teacher vowels)
- In event of production error, perform necessary updates to learner's constraint weights and/or gestural parameter settings (constriction degree, blending strength)

Gestural Gradual Learning Algorithm (GGLA)

(Smith & O'Hara 2021)

- Constriction degree update for blended and unblended vowel productions:

sgn(teacher prod. – learner prod.) × LR

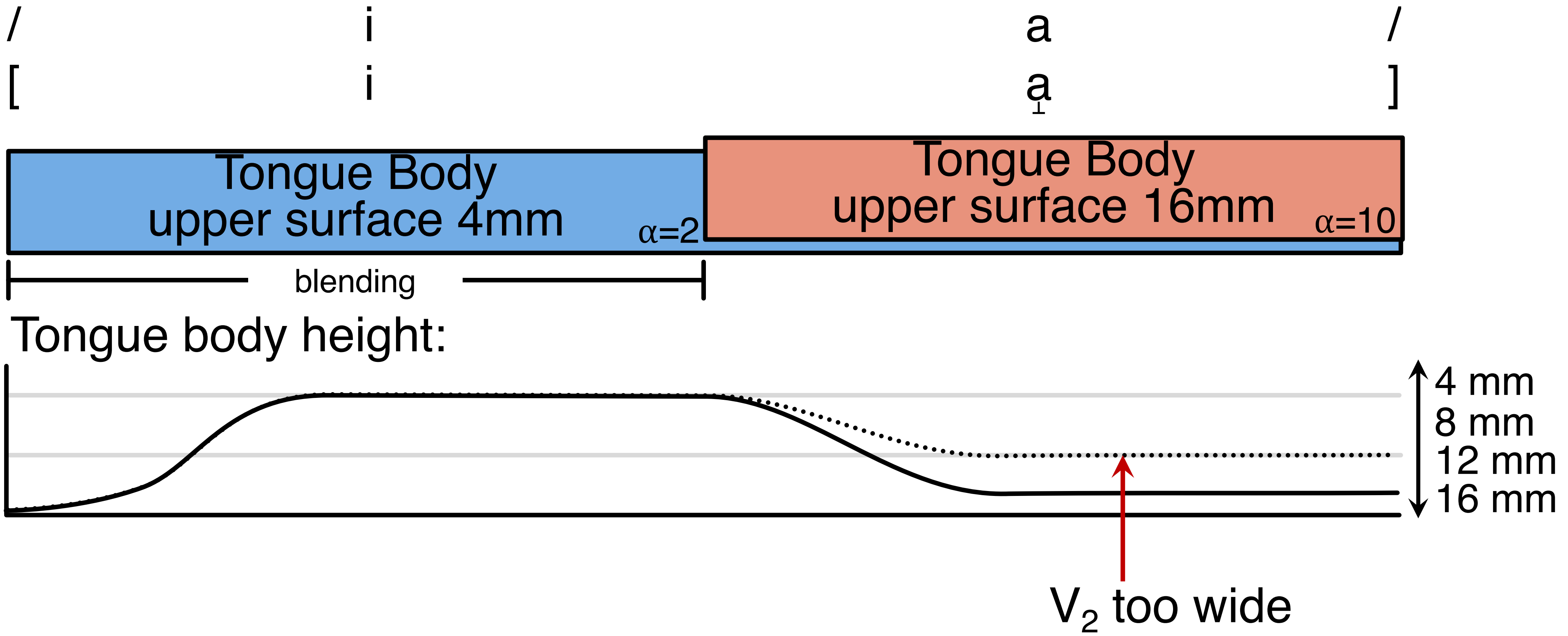
- Blending strength updates for blended vowel gestures V_1 and V_2:

V_1: sgn(learner V_1 CD – learner V_2 CD) × sgn(teacher prod. – learner prod.) × LR

V_2: sgn(learner V_2 CD – learner V_1 CD) × sgn(teacher prod. – learner prod.) × LR

CD = constriction degree, LR = learning rate

Sample Training Iteration



/i/ updates: 3.9mm↓
2.1α↑

/a/ updates: 15.9mm↓
9.9α↓

GGLA on Google Colab

Visit the Google Colab for the GGLA:

tinyurl.com/ampggla

Extending the GGLA

- GGLA-based learning simulations assume:
  - Learner already knows which vowels are harmony triggers
  - All vowels are undergoers of harmony
- GGLA-based learning simulations do not assume:
  - Any kind of phonological grammar
  - Any kind of input-output mapping

Grammar + Gesture Gradual Learning Algorithm (GGGLA) (Smith 2022)

- Compares articulatory productions of gestural scores from teacher and learner agents during training
- Learns phonological grammar necessary to correctly cast vowels as triggers, undergoers, and blockers of harmony
- Learns gestural parameters necessary to correctly produce a given height harmony pattern (chain shift or saltation) when trigger/undergoer overlap occurs via GGLA

Constraint Weight Learning in Maximum Entropy Harmonic Grammar

- Constraint-based grammars implemented in Maximum Entropy Harmonic Grammar (MaxEnt; Goldwater & Johnson 2003; Jäger 2007): weighted constraints and variable outputs

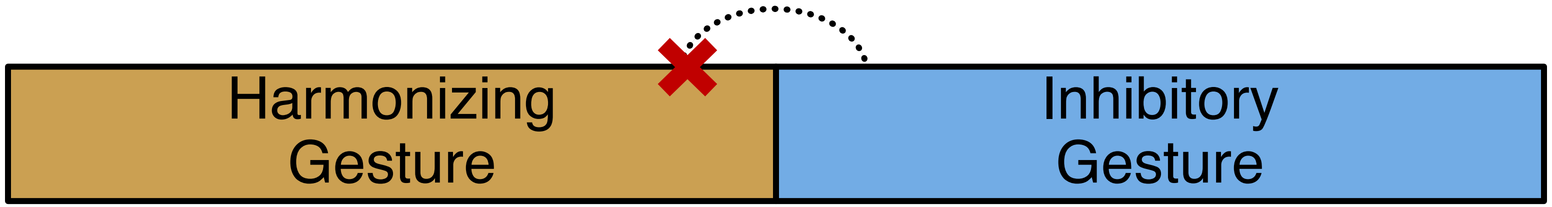
- Learning of constraint weights based on Gradual Learning Algorithm for Harmonic Grammar (GLA; Boersma & Pater 2016), based on earlier Perceptron Algorithm (Rosenblatt 1958)

Error-Driven Online Learning (Again)

- During a learning trial, randomly generated two-syllable input is evaluated by teacher's and learner's individual phonological grammars and winning output candidate gestural score is produced according to their individual gestural parameter settings
- Check learner and teacher productions for a match (i.e. both learner vowels produced within specified window around both teacher vowels)
- In event of error, perform necessary updates to learner's constraint weights and/or gestural parameter settings (constriction degree, blending strength)

Blocking as Gestural Inhibition

- Blocking: inhibition (deactivation) of harmonizing gesture by incompatible gesture, preventing gestural overlap (Smith 2016, 2018)

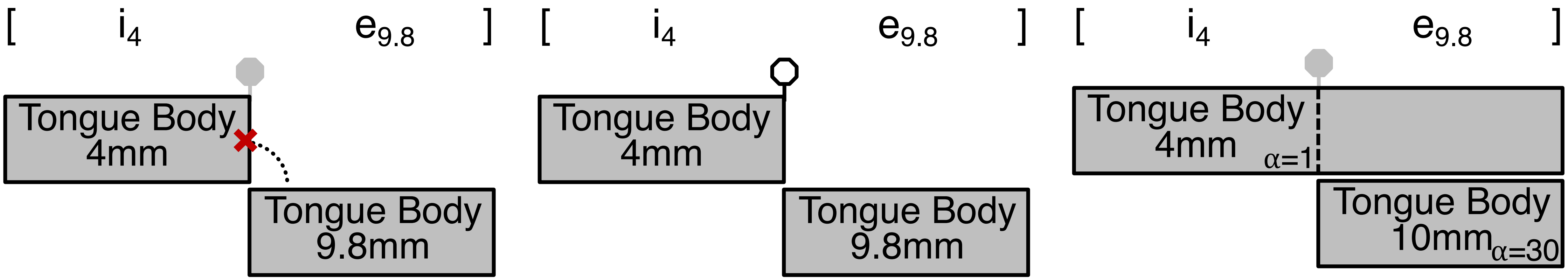


- Inhibited gesture cannot reactivate itself, so harmony ceases
- Combined effects of blending and blocking result in productions whose gestural underpinnings are ambiguous

Articulatory Productions and Hidden Structure

- To perform constraint weight updates, learner must compare violations incurred by its and teacher's chosen winner candidates

- Teacher's output candidate gestural score is often unknown to learner based solely on teacher's production:



Hidden Structure Learning

- Robust Interpretive Parsing (RIP; Tesar & Smolensky 1998, Boersma 2003): determine teacher candidate's hidden structure (e.g. metrical structure) from its surface form

- Robust Interpretive Production Parsing (RIPP): determining teacher candidate's hidden phonological surface form (i.e. gestural score) from its articulatory production

GGGLA on Google Colab

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https://tinyurl.com/ampgggla

Conclusions

- Results of learning simulations:
  - With GGLA, extreme strengths necessary to generate saltatory height harmony are substantially slower/harder to learn
  - With GGGLA, extreme strengths and/or grammars favoring blocking (no gestural overlap) necessary to generate saltatory height harmony are substantially slower/harder to learn

- Learning simulations correctly indicate a typological bias favoring attested chain-shifting harmony and against saltatory harmony

Works In Progress / Coming Soon

- Learning of additional gestural parameters (e.g. constriction location, persistence)
- Learning of additional phonological phenomena (e.g. consonant lenition)
- Support for multi-gestural segments to learn settings of multiple parameters for multiple phenomena concurrently
- Noisy productions of output gestural representations
- Running GGLA and GGGLA with graphical user interfaces