Computing the gradient mind: from muscular coordination to phonological typology

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This study investigates how phonology utilizes gradient representations of speech sounds in computation. I propose gradient activations in the underlying representations for high vowels and the output representations for coronals depending on the vocalic contexts based on muscular interactions and demonstrate how phonology handles the gradience in computation using Harmonic Grammar (HG) framework (Smolensky & Legendre 2006). In the current approach, gradient faithfulness violations predict the attested typological patterns of coronal palatalization without stipulating a markedness constraint for a specific phonological phenomenon.

Cross-linguistically, high vowels tend to trigger coronal palatalization. The targets of palatalization triggered by non-front high vowels (/U/) are coronals only (Bhat 1978; Bateman 2007) and U triggers coronal palatalization only if front high vowels (/I/) also do in the same language (Bateman 2007). This implies that /I/ is a stronger trigger for coronal palatalization than is /U/. Considering /I/ and /U/ as triggers of coronal palatalization, there are six types of languages.

(1) L1. No coronal palatalization: Dakota, Luganda, Somali, …
L2. Secondary coronal palatalization before /I/: Hungarian, Tiwa, Watjarri, …
L3. Secondary coronal palatalization before /I, U/: Sentani
L4. Full coronal palatalization before /I/ and secondary before /U/: Coatzospan Mixtec
L5. Full coronal palatalization before /I/: Hausa, Japanese, Polish, …
L6. Full coronal palatalization before /I, U/: Maori, Tohono O'Odham

The typological asymmetry is predicted by neither the traditional featural nor the gestural approaches. The general approach to coronal palatalization is the spreading of the feature [-anterior] (Keating 1991; Clements & Hume 1995) or [+high] (Lahiri & Evers 1991; Lahiri & Reetz 2010) from a trigger vowel to a target coronal consonant. In the [-anterior] spreading approach, /U/ as a non-front vowel cannot trigger coronal palatalization. In the [+high] spreading approach, /I/ and /U/ are predicted to have the same strength as triggers of coronal palatalization. In the gestural approach that assumes the Tongue gesture (Bateman 2007), /U/ with posterior constriction location and narrow constriction degree are predicted to be the strongest trigger of coronal palatalization.

Through articulatory simulations that manipulate activations of individual tongue muscles, Jang (2018, 2019) shows that the muscular coordination of the tongue is a source of the typological asymmetry. Due to the activations of distinct tongue muscles, the tongue tip contributes more actively to the articulation of /I/ than to that of /U/. Since the major articulator of coronal consonants is the tongue tip, /I/ causes more perturbation, in particular, lowering of the tongue tip in the articulation of an adjacent coronal than /u/ does.

In the current study, based on the simulation results I propose that gradient activation values in the featural representations. Unlike the Gradient Symbolic Representation (GSR; Smolensky & Goldrick 2016) and the subfeatural representation (Lionnet 2016) that use gradient values from 0 to 1, I assume a range of gradient values for features between -1 and 1 as articulatory instructions activating muscle groups to move articulators into particular configurations and states (Halle 1983). Since the tongue tip is lowered and retracted in the articulation of /I/ in a more active manner compared to in that of /U/, in the underlying representation the activations of $[\text{distributed}]_V$ and $[\text{anterior}]_V$ for /i/ is set much higher (.9 and -.9 respectively as shown in the following tableau) than those for /u/ (.5 and -.5). Those features have zero activity for the low back vowel /a/ because there is no lowering and retraction of the tongue tip in its articulation.

Input	Output candidate	Constraints		
		FULL	IDENT-C	IDENT-V
i. /d/ [dist$_{-1}$ ant$_{1}$]$_{C}$	a. d[dist$_{-1}$ ant$_{1}$]$_{CV}$ i			3.8
+/i/ [high$_{1}$ low$_{-1}$ back$_{-1}$ dist$_{.9}$ ant$_{-.9}$]$_{V}$	b. d^{j}[dist$_{-.1}$ ant$_{.1}$]$_{CV}$ i	1	1.8	2
	c. dʒ[dist$_{1}$ ant$_{-1}$]$_{CV}$ i		4	0.2
ii. /d/ [dist$_{-1}$ ant$_{1}$]$_{C}$	a. d[dist$_{-1}$ ant$_{1}$]$_{CV}$ u			3
+/u/ [high$_{1}$ low$_{-1}$ back$_{1}$ dist$_{.5}$ ant$_{-.5}$]$_{V}$	b. d^{j}[dist$_{-.5}$ ant$_{.5}$]$_{CV}$ u	1	1	2
	c. dʒ[dist$_{1}$ ant$_{-1}$]$_{CV}$ u		4	1
iii. /d/ [dist$_{-1}$ ant$_{1}$]$_{C}$	a. d[dist$_{-1}$ ant$_{1}$]$_{C}$ a			
+ /a/ [high$_{-1}$ low$_{1}$ back$_{1}$ dist$_{0}$ ant$_{0}$]$_{V}$	b. dʒ[dist$_{1}$ ant$_{-1}$]$_{C}$ a		4	

The proposed gradient activations of features in the underlying representations allow gradient faithfulness violations as in GSR. The IDENT-C and -V constraints penalize a candidate in proportion to the degree to which the candidate changes activities for any consonantal/vocalic feature from the input to the output. For example, IDENT-C penalizes the candidate (ib) -1.8 because [distributed]$_{C}$ changes from -1 to -.1 (|-1+.1|=.9) and [anterior]$_{C}$ changes from 1 to .1 (|1-.1|=.9).

The co-articulatory effects of vocalic contexts on coronals are represented in the output representations. Similar to the concept of gestural blending in Articulatory Phonology (Browman & Goldstein 1992), this study assumes that the featural activations are blended only when there is a polarity contrast between positive vs. negative values of the same features that are co-activated. Depending on the relative blending strength of the competing features, results of blending could be different. If one of the competitors is stronger in blending, the blended feature will have the activity of the stronger feature, as in (ia, iia) in the tableau where consonantal [distributed, anterior] are stronger than vocalic ones. If competitors have the same blending strength, the activity of the blended feature will be the sum of activities of them, as in (ib, iib). The output candidates (ic, iic) shows the stronger blending strength of vocalic [distributed, anterior] than consonantal ones, but the output featural activities become full (1 and -1) due to the discrete markedness constraint FULL that assigns a violation for each feature with non-integer activation in outputs.

Gradient activation of coronal features for high vowels and co-articulatory effects between adjacent coronals and high vowels are universal, but phonological outputs can differ across languages because language-specific grammars regulate the presence, degree, and trigger of coronal palatalization in their computation. In HG, different constraint weights can derive the attested typological patterns of coronal palatalization in (1) as below:

Type of language	Constraint weights		
	FULL	IDENT-C	IDENT-V
L1. No CorPal	1	1.15	1
L2. 2nd/_I	3.5	22.5	25
L3. 2nd/_I, U	1	14	16
L4. Full/_I; 2nd/_U	1	2	4
L5. Full/_I	1.389	1	1.389
L6. Full/_I, U	1.5	1	2.5

References **Bateman, N. 2007**. A crosslinguistic investigation of palatalization. PhD thesis, UCSD. **Bhat, D.N.S. 1978**. A general study of palatalization. *Universals of Human Language*, 47-92. **Browman, C.P. and Goldstein, L. 1992**. Articulatory phonology: An overview. *Phonetica* 49, 155-180. **Halle, M. 1983**. On distinctive features and their articulatory implementation. *Natural Language & Linguistic Theory* 1(1), 91–105. **Jang, H. 2018**. Tongue tip as a synergy component in vowel articulations. Oral presentation at ICPM 7. **Jang, H. 2019**. Emergent phonological subfeatures from articulatory synergies: simulations of coronal palatalization. Oral presentation at LSA 2019. **Lionnet, F. 2016**. Subphonemic Teamwork: A Typology and Theory of Cumulative Coarticulatory Effects in Phonology. PhD thesis. UC Berkeley. **Smolensky, P. and G. Legendre. 2006**. *The Harmonic Mind: From Neural Computation to Optimality-Theoretic Grammar*. Cambridge. **Smolensky, P. and M. Goldrick. 2016**. Gradient symbolic representation in grammar: The case of French liason. *ROA 1286*.