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Phonological opacity as local optimization in Gradient Symbolic Computation

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Phonological opacity as local optimization in Gradient Symbolic Computation

Introduction. Phonologically opaque counterbleeding patterns have presented difficulty for constraint-based models of phonology like classic Optimality Theory (OT; **[6]**) and Harmonic Grammar (HG; **[3]**) due to their global parallel evaluation of candidates **[4]**. In this paper, we present a novel connectionist approach for a classic counterbleeding pattern in Yowulmne Yokuts (Californian) using the Gradient Symbolic Computation (GSC) framework (**[1]**, **[7]**, **[8]**).

Counterbleeding in Yawelmani Yokuts. In the Yowulmne variety of Yokuts described in **[2]** (citing **[5]**), long vowels undergo lowering (1a,b) and context-specific shortening in closed syllables (1b, 2b). All other vowels surface faithfully in height and length (e.g., 2a).

(1) a. /**c'u:**.mal/ → [**c'o:**.mal] 'might destroy'
b. /**c'u:m**.hun/ → [**c'om**.hun] 'destroys'

(2) a. /**do:**.sol/ → [**do:**.sol] 'might report'
b. /**do:s**.hin/ → [**dos**.hin] 'reports'

In serial rule-based frameworks, a general lowering rule followed by a context-specific shortening rule describes this pattern. The opaque mapping (1b) arises from the counterbleeding relationship between these two rules: the later shortening rule eliminates potential inputs to the earlier lowering rule, yielding a surface form where lowering appears to have overapplied.

In OT, lowering is due to ⟦*LongHigh >> IdentHeight⟧ and shortening is due to ⟦*LongClosed >> IdentLength⟧. However, no ranking of these constraints can generate the opaque mapping when both processes are applicable (see tableau); the counterbleeding candidate (d) is harmonically bounded by the candidate which only undergoes shortening (c). Harmonic bounding of the opaque candidate also holds under any weighting of these constraints in HG.

/c'u:m.hun/	*Remark*	*LongHigh	*LongClosed	IdentHeight	IdentLength
a. c'u:m.hun	*faithful*	* !	* !		
b. c'o:m.hun	*lowering*		* !	*	
c. ☞ c'um.hun	*shortening*				*
d. c'om.hun	*opaque*			* !	*

Gradient Symbolic Computation. GSC is a dynamical systems model that gradually constructs discrete symbolic structures in a continuous representational space. For example, the height of a vowel can be specified within a 2-dimensional vector space, with one basis vector corresponding to [high] (e.g., [1, 0]) and a second basis vector corresponding to [low] ([0, 1]). Over the course of computation, the GSC system attempts to optimize two sets of constraints: a set specifying a Harmonic Grammar as well as a set of *quantization* constraints that prefer those points corresponding to discrete symbolic structures. The strength of quantization gradually increases over the course of this optimization process, such that at the end of computation the system is in a discrete symbolic state. At intermediate points of the computation, however, the GSC system will be in *blend* states where multiple symbolic candidates are simultaneously present in the representation. The numerical quantity *activation* specifies the degree to which each symbolic structure is present. For example, in the subspace specifying vowel height, the system might be in the state [0.1, 0.9], a blend of 0.1[high] and 0.9[low], at some point of the computation.

If quantization increases at the proper rate, the final state of the system will be the global optimum, the discrete symbolic state assigned the highest harmony by the Harmonic Grammar (see Fig. 1A). However, if quantization strength is not properly regulated, the lower harmony of intermediate blend states can trap the optimization process near less harmonic candidates (Fig. 1B), yielding locally optimal outputs that do not correspond to the global optimum of the Harmonic Grammar. We propose that this underlies counterbleeding patterns.

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GSC account of counterbleeding in Yokuts. We utilize GSC versions of the constraints in the tableau above. These assign numeric harmony penalties to discrete symbolic states as well as to intermediate blend states. For example, *LONGHIGH assigns harmony penalties proportional to the co-activation of [long] and [high]. This is strongest when these two features are maximally activated (violation for 1.0[long] 1.0[high] = 1.0 times weight of *LONGHIGH) but is non-zero for intermediate blend states (0.1[long] 0.9[high] = 0.09 times weight of *LONGHIGH). If this constraint is strongly weighted, the dispreference for such blend states will cause optimization processes to favor states that have 0 activation for both features — allowing the features of the counterbleeding candidate [low] [short] to become highly active. Critically, if quantization increases too quickly, the system will become trapped near this candidate, producing the opaque counterbleeding candidate. We tested this proposal in a simulation, using four units to realize [long] vs. [short] and [high] vs. [low] within a closed syllable. Optimization was initiated in the state corresponding to the fully faithful candidate (e.g., 1.0[long] 1.0[high] for a long high vowel). The figures below show how too-rapid quantization yields counterbleeding.

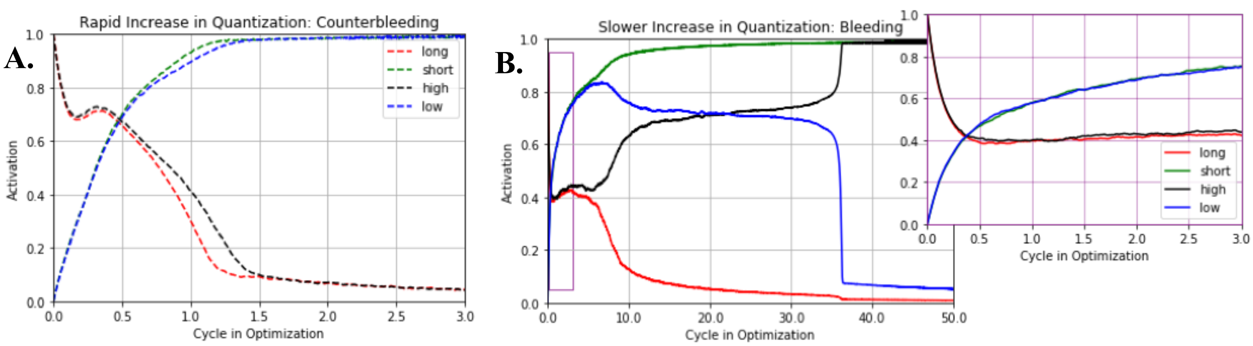

Fig. 1: Activations over course of optimization.

A: Counterbleeding. When quantization strength increases rapidly, activations are quickly driven towards extreme values. [high], suppressed by initially strong activation of [long], is therefore unable to increase its activation.

B: Bleeding. When quantization increases slowly, [high] is less suppressed during initial phases of optimization (see inset). As activation of [long] decreases, [high] is therefore able to increase its activation.

Conclusions and extensions. The markedness of intermediate blend states, combined with GSC dynamics, can lead to the local optimality of an opaque counterbleeding candidate rather than a globally optimal non-opaque candidate. Ongoing work scales up our analyses to more complex structures and examines this account's typological predictions.

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