**Output-based computation and unbounded phonology**

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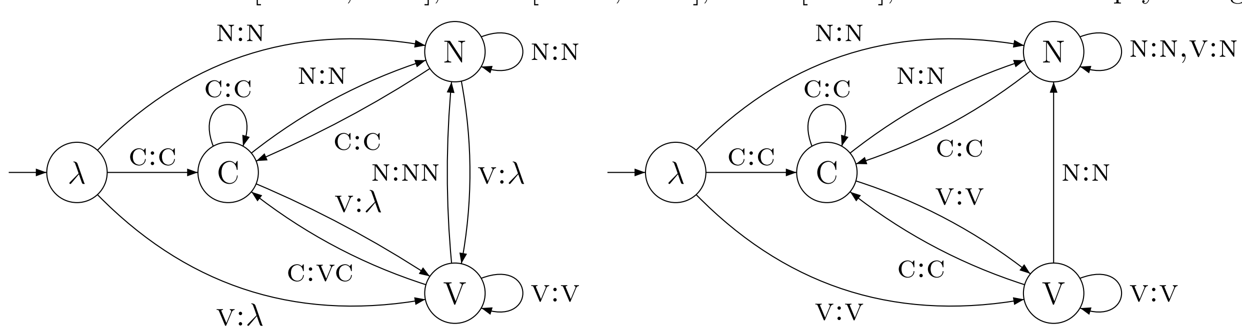
To address the inherent challenge posed by phonological processes that apply across *unbounded* distances, many theoretical frameworks have incorporated the notion of a phonological 'tier' (e.g., Goldsmith, 1990; Heinz et al., 2011). This paper explores the computational implications of tier-based representations from the perspective of modeling processes as *maps* or functions from input strings to output strings. While previous work in this vein (Chandlee, 2014) has shown that bounded maps require both input- and output-based computation, we argue that unbounded processes are necessarily output-oriented. This claim makes a number of typological predictions that are supported cross-linguistically and offers new insights into the computational nature of unbounded phonology.

Bounded segmental processes have previously been modeled with the Input Strictly Local (ISL) and Output Strictly Local (OSL) function classes, which are well-defined in terms of Finite State Transducers (FSTs). ISL functions enforce simultaneous 'rule application' whereas OSL enforces iterative application. While some phonological maps can be equally described with either type of function, others are necessarily ISL or OSL. For example, non-iterative regressive nasal assimilation in Auca (e.g., /wɑi-ŋɑ/ ↦ [wɑĩ-ŋɑ] 'good tooth'; Steriade, 1993) is only ISL, but progressive assimilation in Johore Malay is iterative (e.g., /pəŋawasan/ ↦ [pəŋãw̃ãsan] 'supervision'; Onn, 1980) and therefore must be OSL. The FSTs for these processes are shown in (1). FSTs represent maps as follows: starting in the $\lambda$ state, the input string is read one segment at a time and a transition is followed to a new state according to the left-hand side of its label $\boldsymbol{a}{:}x$ (e.g., for a string that starts with N the N:N transition is followed to state N). The right-hand side of the transition label ($a{:}\boldsymbol{x}$) is then appended to the output string. The difference between the ISL and OSL FSTs in (1) is that the transitions of the ISL FST always go to the state that matches the input ($\boldsymbol{a}{:}x$) while the transitions of the OSL FST always go to the state that matches the output ($a{:}\boldsymbol{x}$).

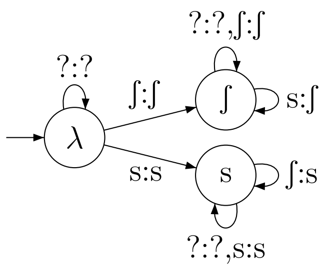
(1) FSTs for nasal assimilation in Auca (ISL, left) and Johore Malay (OSL, right). Note: 'C' denotes [+cons, –nas], 'V' is [–cons, –nas], 'N' is [+nas], and $\lambda$ is the empty string.



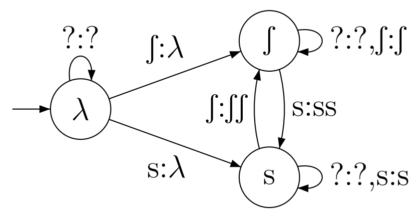

These examples demonstrate a further difference between input- and output-based computation. ISL FSTs can 'wait' to produce output (by outputting $\lambda$) and still proceed to a new state based on the current input. OSL FSTs cannot do this: since each transition must lead to the state for the recent output, they could not proceed to a new state when outputting $\lambda$. This means only ISL FSTs can model maps with two-sided contexts. OSL FSTs are limited to maps with one-sided contexts, because they cannot 'wait' to see what appears on the other side of the potential target. This is illustrated in the left FST of (1): the output for each vowel is delayed, as the next segment may or may not be a triggering nasal.

Since this 'waiting' can only be done a finite number of times, unbounded maps with arbitrarily long trigger-target distances are neither ISL nor OSL. In response, Chandlee et al. (2017) introduce the Tier-based Strictly Local (TSL) functions. Formally, I-TSL/O-TSL functions differ minimally from ISL/OSL in that the states keep track of the recent input and output only with respect to a designated subset of segments, or tier. For example, the O-TSL FST in (2) models progressive unbounded sibilant harmony in Aari, in which the suffix /-s/ surfaces as [-ʃ] when the stem contains a [−ant] sibilant (e.g., /ʃed-er-s-it/ ↦ [ʃederʃit] 'I was seen'; Hayward, 1990; assumed to be symmetric). The current state of the O-TSL FST always corresponds to the most recent output, but only for tier segments/sibilants, as non-tier segments (represented with '?') are not given states. While bounded phenomena require both the ISL and OSL function classes, we argue that *O-TSL alone* is the right characterization of unbounded phenomena, as I-TSL functions make incorrect typological predictions.

(2) O-TSL FST for progressive sibilant harmony




(3) I-TSL FST for regressive sibilant harmony (unsuccessful)




First, the ability of I-TSL FSTs (like ISL ones) to delay output predicts a striking pathology with unbounded regressive harmony like in Samala (e.g., /ha-s-xintila-waʃ/ ↦ [haʃxintilawaʃ] 'his former gentile name'; Applegate, 1972). As shown with the FST in (3), when non-tier segments intervene between the trigger and target, the result is a type of long-distance 'displacement' (e.g., /ha-s̲-xintila-waʃ/ ↦ *[haxintilawaʃ̲ʃ]) that, to our knowledge, is unattested synchronically. Second, the use of O-TSL FSTs amounts to the prediction that unbounded processes are necessarily iterative. As with the ISL FST in (1), the I-TSL FST in (2) only allows for one instance of harmony per triggering sibilant. This prediction of iterativity bears out in Samala (cf. /s-lu-sisin-waʃ/ ↦ [ʃluʃiʃiniwaʃ] 'it is all grown awry'), as well as in the typology of consonant harmony more generally (Hansson, 2010). Finally, attested non-iterative processes, such as tone spreading and vowel harmony, necessitate instead input-based computation. Such patterns, which are difficult to model in Optimality Theory, have been argued to be emergent phenomena (Kaplan, 2008). From the computational perspective advocated here, they need not be ruled out entirely, but instead are predicted to be restricted in several interesting ways (e.g., locally bounded, no derived triggers, etc.).


**Select references**: • Chandlee, J. (2014). *Strictly Local phonological processes.* PhD thesis, UD. • Goldsmith, J. A. (1990). *Autosegmental and metrical phonology.* Blackwell, Oxford. • Hansson, G. Ó. (2010). *Consonant harmony: long-distance interaction in phonology.* University of California Press, Berkeley, CA. • Kaplan, A. (2008). *Noniterativity is an*

*Emergent Property of Grammar*. PhD thesis, UCSC.