A Computational Account of Tone Sandhi Interaction

Jane Chandlee (Haverford College)

Tianjin Chinese has received a fair amount of attention (Chen, 2000; Lin, 2008; Wee, 2010, among others) due to an interesting interaction among three of its tone sandhi rules:

(1a) $F \rightarrow L\ /\ \_\_\ F$ (1b) $L \rightarrow R\ /\ \_\_\ L$ (1c) $R \rightarrow H\ /\ \_\_\ R$

The previous work has required stipulations on direction of rule application or added mechanisms to a constraint-based formalism. This paper presents a unified computational analysis of the rules and their interaction without relying on intermediate representations. What looks like a difference in the directionality of rule application is actually due to the processes being locally output-oriented in a particular computational sense.

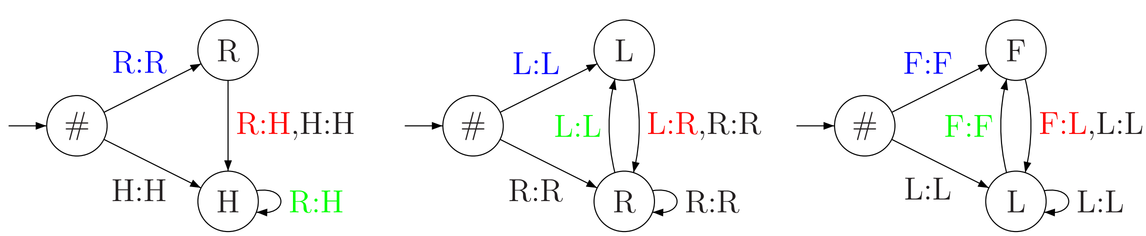
The example derivations below have lead to the interaction being called 'confused traffic', as (1a) and (1b) appear to apply right-to-left while (1c) applies left-to-right. (The SR of FFF is actually HLF due to another rule $F \rightarrow H\ /\ \_\_\ L$ that is irrelevant to this analysis.)

(2a) RRR ↦ HHR
(2b) LLL ↦ LRL
(2c) FFF ↦ FLF
(2d) RLL ↦ HRL
(2e) LFF ↦ RLF

UR:	**RRR**	**LLL**	**FFF**	**RLL**	**LFF**
(1a) right-to-left	–	–	FLF	–	LLF
(1b) right-to-left	–	LRL	–	RRL	RLF
(1c) left-to-right	HHR	–	–	HRL	–
SR:	**HHR**	**LRL**	**FLF**	**HRL**	**RLF**

Wee (2010) claims that rule ordering is not sufficient for this interaction and uses these patterns as motivation for an OT-based percolative model of phonology in which optimal derivational histories (represented with tree structures) are selected rather than candidates.

However, if direction of application is stipulated as a property of each rule, the ordering of the rules above attains the correct results. But granting that such a stipulation is undesirable and lacks insight (since as Wee notes all three rules are regressive), a computational account provides another option. If we characterize the rules as *maps* from an input string/UR to an output string/SR, they are revealed to be *output strictly local (OSL) functions* (Chandlee et al., 2015), a restrictive and formally learnable approach to modeling phonological maps. This means that at any given time the decision about what to add to the output string depends only on the current input segment and the most recently outputted segment. Using the finite state transducer (FST) characterization of OSL, the following diagrams illustrate.

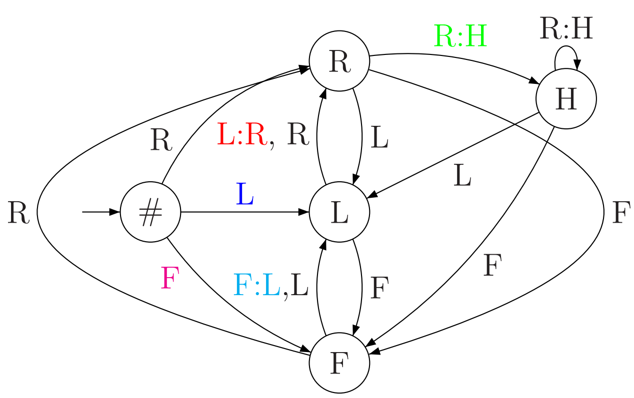


UR: # R R R # UR: # L L L # UR: # F F F #
SR: H H R SR: L R L SR: F L F

FSTs represent maps as follows. Starting in the # state, the input string is read one segment at a time to determine which transition/arrow to follow to the next state and which segment to add to the output string. The labels on the transitions represent input-segment: output-segment, such that the transition R:H means the current input is R and an H is appended to the output string at that point. Since these are all regressive phenomena, the input string is read from the right to the left and the output string is likewise built starting from the end.

The state labels are not arbitrary, but correspond exactly to the last segment contributed to the output string—visually one can confirm that all transitions in all three FSTs lead to the state that matches the output side of the transition label. This is not true of FSTs generally, only those that compute OSL functions. Likewise, not all string-to-string maps can be represented by FSTs that have this structure—only maps that are OSL functions can. Thus the fact that these three OSL FSTs can model the phenomena in question serve to classify them as OSL functions. OSL is one of several function classes argued to be desirable for their 1) efficient formal learnability and 2) broad typological coverage despite their restrictive computational complexity (Chandlee et al., 2014, 2015).

Furthermore, it is not in fact necessarily to model each sandhi map separately: the input-output map of all three functions combined is itself an OSL function, as evidenced by the single FST below (for readability single-segment transition labels are used for identity maps, e.g., F = F:F, and again the map proceeds from right to left as shown in the examples below). The interaction that at first seems to require rule ordering in derivations like RLL ↦ RRL ↦ HRL is accounted for because the L that surfaces as R (shown in red) leads to the same state as an underlying R, from which the next R is output as H (in green). Likewise, in the map of LFF ↦ LLF ↦ RLF, the middle F is output as L (in cyan), which takes the FST to state L from which the initial L can be output as R (again in red). In this way, the ability to track recent output means the map can be modeled without intermediate representations.



#	R	L	L	#
			L	

#	R	L	L	#
		R	L	

#	R	L	L	#
	H	R	L	

#	L	F	F	#
			F	

#	L	F	F	#
		L	F	

#	L	F	F	#
	R	L	F	

This paper thus demonstrates that the ‘confused traffic’ interaction in Tianjin tone sandhi can be straightforwardly accounted for without any theoretical augmentation by drawing on its computational nature. This co-occurrence of multiple, interacting tone sandhi phenomena can be modeled straightforwardly using the computational notion of output strict locality.

Select references: • Chandlee, J., Eyraud, R., and Heinz, J. (2015). Output strictly local functions. In *Proceedings of MOL 2015.* • Chandlee, J., Heinz, J., and Eyraud, R. (2014). Learning strictly local subsequential functions. *TACL*, 2:491–503. • Wee, L.-H. (2010). A percolative account of Tianjin tone sandhi. *Language and Linguistics*, 11(1):21–64.