

A Percolative Model of Phonology

L.H. Wee

Hong Kong Baptist University

lianhee@hkbu.edu.hk

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Abstract

This paper presents data from Tianjin tritonal sandhi patterns that challenge both traditional derivational approaches and standard Optimality Theoretic (OT) approaches to phonological alternation. If construed derivationally, Tianjin tritonal sandhi requires derivational reversals; but if construed within OT, involves combinations of opacity and transparency. The account proposed here appeals to a percolative model where phonological information from terminal nodes finds correspondences in higher nodes, such that the correspondences may be imperfect when triggered by markedness requirements. While this requires a total reconceptualization of phonological representations, this paper argues that it is well worth it because it predicts firstly, that directionality is a derivative from branching; secondly that the depth of derivational opacity is confined by structural depth; thirdly, that constituency, not adjacency, provides the environment for triggering alternation and alternation rules can therefore be blocked when marked collocations belong to different constituencies; and fourthly that underlying entities can have split surface correspondences. All these predictions are borne out.

Key words: *Percolation, Correspondence, Opacity, Directionality, Tone Sandhi, Hong Split Gemination*

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Hong Kong Baptist University

lianhee@hkbu.edu.hk

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Introduction

Derivational opacity in phonology has always received much attention from both skeptics and supporters of Optimality Theory (OT, Prince and Smolensky 1993/2004). The thing about opacity is that it seems so strictly derivational to be compatible with the output-based OT. This paper joins in the fun with data from Tianjin tone sandhi, which patterns seem just out-of-reach of a conceptually sensible account either in a derivational or an OT account. To the derivation-ist, Tianjin tone sandhi requires the undoing of derivations to arrive at the attested form; to the OT-ist, Tianjin tone sandhi involves a combination of transparency and opacity. The account proposed here is to marry the insights of both approaches, and to recognize the important roles that structures play in phonological alternations. This is done by assuming that in a structural representation, non-terminal nodes may carry information; the information having come from percolation/correspondence across each tier in the structure. Section 1 begins with an introduction to the peculiar patterns of Tianjin; section 2 outlines the key ideas for a solution; section 3 shows how the Tianjin patterns could fall out of the percolative model; and section 4 discusses implications and predictions. The paper ends with a conclusion.

1. Confused Traffic

Imagine a language with the following phonological alternation pattern:

- (1) a. AA → CA
- b. BB → AB
- c. AAA → CCA
- d. BBB → BAB

Such a language would be nightmarish for the phonologist because the order of application of the rudimentary rules seems erratic, even though the output of the tri-elemental string is clearly derivable from some kind of ordering of the rudimentary di-elemental string. This becomes clear when one considers their derivational histories and unattested possible alternatives. This is presented in (2) and (3) where the window of alternation is underlined and a vertical shaft “|” connects the target of alternation to the outcome below.

- (2) a. AAA
 |
 *CAA
 |
 CCA (cf. (1c))
- b. AAA
 |
 *ACA

[♦] This work grew out in part from Chapter Three of my PhD dissertation.

- (3) a. $\begin{array}{c} \underline{BBB} \\ | \\ * \underline{ABB} \\ | \\ * \underline{AAB} \\ | \\ * \underline{CAB} \end{array}$ b. $\begin{array}{c} \underline{BBB} \\ | \\ BAB \end{array}$

(Asterisk “*” indicates that the form is unattested for the given input.)

What is peculiar about this state of affairs is that the rudimentary di-elemental alternation rules apply rightwards for the case of AAA but leftwards for BBB. The simplistic solution to this confused traffic is to stipulate the directionality on the rules themselves, but that is clearly undesirable because firstly, both the AA and BB rules are regressive, providing no motivation for their individuality in directionality for longer strings; and secondly, the reason why BBB is leftwards might be attributed to the fact that a rightward application would produce either *AAB (which contains further alternation triggering environment) or *CAB (which involves very deep opacity on the occurrence of C). Given the way this example is constructed, the trigger for alternation and also the choice of the directionality of the application of alternation rules to longer strings is clearly the result of the Obligatory Contour Principle (OCP): it is the constraint against having adjacent identical elements that triggers alternation. (3a) is thus forbidden because it produces midway an OCP-violating form *AAB. This is the problem of “directionality” that this paper pursues.

A language such as that presented above does in fact exist. It has been the topic of study since Li and Liu (1985) reported the tone sandhi patterns of Tianjin. The problems have been discussed in Tan (1986, 1987), Zhang (1987), Shi (1988, 1990), Milliken et al (1997) and more recently in Chen (2000), Wee (2004) and Wee, Yan and Chen (2005). The key set of facts as presented in Chen’s (2000) is given in (4) and (5), where R is a rising tone, L a low tone and H a high tone.

- (4) a. $\begin{array}{c} \underline{RRR} \\ | \\ * \underline{HRR} \\ | \\ \underline{HHR} \text{ (cf. (2a))} \end{array}$ b. $\begin{array}{c} \underline{LLL} \\ | \\ \underline{LRL} \text{ (cf. (3b))} \end{array}$

An overview of Tianjin tones and its sandhi patterns are presented below:

- (5) a. Tones in Tianjin

	Pitch value		Description (Chen 2000 and Wang 2002a)
	Li and Liu (1985)	Shi (1990)	
First tone	[21]	[11]	L (Low)
Second tone	[45]	[55]	H (High)
Third tone	[213]	[24]	R (Rising)
Fourth tone	[53]	[53]	F (Falling)

b. OCP-triggered Ditonal Sandhi¹

- i. L → R / __ L
- ii. R → H / __ R
- iii. F → L / __ F

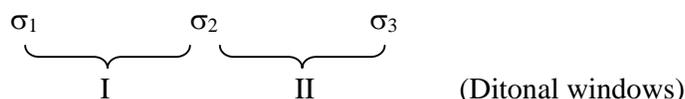
c. List of directional effect patterns²

Pattern	Input	Output	[x x] x	x [x x]	x x x
P1	<u>RRR</u>	HHR via HRR	[li.fa] suo 'barber shop'	mu [lao.hu] 'tigress'	ma.zu.ka 'marzuka'
P2	<u>LLL</u>	LRL	[tuo.la] ji 'tractor'	kai [fei.ji] 'fly a plane'	san.san.san 'three three three'
P3	<u>FFF</u>	HLF via FLF	[su.liao] bu 'plastic cloth'	ya [re.dai] 'subtropical'	yi.da.li 'Italy'
P4	<u>RLL</u>	HRL via RRL	[bao.wen] bei 'thermos cup'	Da [guan.qiang] 'speak in a bureaucratic tone'	ma.la.song 'marathon'
P5	<u>LFF</u>	RLF via LLF	[wen.du] ji 'thermometer'	tong[dian.hua] 'make a phone call'	san.si.si 'three four four'

(5c) presents only the 5 patterns that would be relevant for the discussion of directionality. With a tonal inventory of 4, tritonal combinations would come up to 64 (= 4³), many of which do not involve sandhi (such as /HHH/, /LHR/, etc) or contain only one sandhi site (such as /LLR/ → [RLR], /RRH/ → HRH, etc). Discounting these less interesting cases, only the 15 presented in (5c) would present any challenge.

Note that all the tritonal patterns can be derived from the rudimentary rules in (5b) not through ordering of each rule, but rather through ordering of the windows of tone sandhi:

(6) Windows of Tone Sandhi



For example, in P1 /RRR/ → HHR, the result is obtainable if sandhi applied rightwards starting from Window I, the reverse is true for P2 /LLL/ → LRL and P3 /FFF/ → FLF.³ Ordering the rules would not suffice because if cases like P2 and P4, it is simply the same rule applying iteratively to remove all OCP-violating environments. In short what one needs is a system that would derive the following effect:

- (7) a. Apply rules uniformly in a direction (in this case rightwards)
 b. If the outcome produces an OCP-triggering string, undo (7a), then apply rules uniformly leftwards.

Input	/RRR/	/LLL/
Step 1: Apply sandhi Rightward	HRR	RLL
Step 2: Check for OCP violations	HHR (pass)	RRL (fail)
Step 3: Undo Step 1	-	LLL
Step 4: Apply sandhi Leftward	-	LRL
Output	HHR	LRL

The account in (7) was first put forth in Chen (2000) which is very insightful in addressing the problem on how to traffic Tianjin tone sandhi. It is able to capture the fact that the difference in direction of tone sandhi traffic came from the OCP and not from stipulation, corroborated by cases such as P3 /FFF/ and even P4 /RLL/ → RRL → HRL and P5 /LFF/ → LLF → RLF (all leftward applications, because rightward application would produce OCP-violating cases).⁴

However, what kind of a theoretical framework would allow for such a flip in orientation? Standard OT models would be hard-pressed if one sticks to the “directionality” metaphor and the derivational stages as outlined in (7). For example, *RHR as an output of /RRR/ would incur fewer faithfulness violations while satisfying the OCP, which is an instance of the oft-cited challenge of opacity to classical OT models (Benua 1997; Kiparsky 2003, 2004, 2007; McCarthy 1998, 2000, 2002, 2003, 2006; Mohanan 2000; among others). Traditional derivation models (SPE or Lexical Phonology) would find it hard to include a device that would allow the undoing of earlier steps in the systematic way presented in (7). For computational purposes, it is quite simple to build-in a device that would include Step 3, but it would not have provided us with any deeper conceptual understanding of such a puzzling effect.

The reader might notice also that out of the 5 patterns in P1-5 in (5c), only P1 involves a rightward application of tone sandhi. It would seem that the implicit rightward default directionality in (7) is misconstrued. This is in fact not the case as can be seen in (8).

³ Which becomes [HLF] by virtue of F → H / __ L, one of the 3 rules that apply after all the OCP sandhi rules have applied, see footnote 1.

⁴ Longer strings are typically broken up into shorter ditonal or tritonal substrings where tone sandhi would apply as per (7b) and (7c), see Wee, Yan and Chen (2005) for details.

(8) Comparison of two hypotheses on default direction

Pattern	Input	Output	Direction	Hypothesis on default direction	
				Rightward	Leftward
P1	RRR	HHR	⇒	OK	Impossible
P2	LLL	LRL	⇐	(7b) Flip Condition	OK
P3	FFF	HLF	⇐		
P4	RLL	HRL	⇐		
P5	LFF	RLF	⇐		
Conclusion				OK	P2 contradict this.

As can be seen in (8), a rightward default traffic of tone sandhi is sustainable with the flip condition, but a leftward default is totally untenable.

(9) Flip condition (Chen 2000:111, cf. (7b))

By default rules apply from left to right (in Tianjin) – unless such a mode of application produces an ill-formed output (i.e. contains an environment where dissimilation rules can apply), in which case the direction of operation is reversed.

2. A Percolative Model of Phonology

2.1 Comparing Derivational Histories

The account in (7) is clearly undesirable, and Chen (2000) came up with an OT model that selects derivations, complete with entire derivational histories, (10):

(10) OCP

Do not allow adjacent identical tones in the final outcome.

*BACKTRACK

Do not apply sandhi to a window more than once.

TEMPORALITY

Apply sandhi from left to right.

FAITH

Input tones and output tones must be identical.

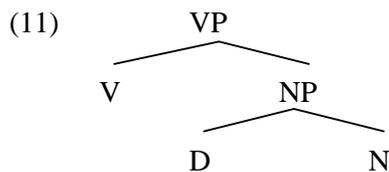
a.	/RRR/	OCP	*BACKTRACK	TEMPORALITY	FAITH
☞ i.	<u>RRR</u> <u>HRR</u> HHR				**
ii.	<u>RRR</u> RHR			*!	*

b.	/LLL/	OCP	*BACKTRACK	TEMPORALITY	FAITH
i.	<u>LLL</u> <u>RLL</u> RRL	*!			**
☞ ii.	<u>LLL</u> LRL			*	*
iii.	<u>LLL</u> <u>RLL</u> <u>RRL</u> HRL		*!		

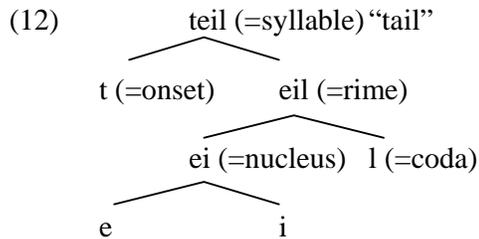
Chen (2000) appeals to constraints on derivations such as “backtracking” and required the candidates to be chains of derivations. This allowed for the selection of the attested candidate for both /RRR/ and /LLL/ cases, successfully accounting for the flip in directionality. However, it is a brute combination of OT parallel processing with derivations, and even Chen (p.c.) expressed some reservations over such an OT model. For one, it appears that the TEMPORALITY and the *BACKTRACK constraints are doing pretty much the same work. Also, if the rightward default directionality is motivated by TEMPORALITY, why is the ditonal sandhi regressive in the first place? Despite the problems, Chen is successful in capturing the choice in the direction of sandhi application, and therein lies an important insight: there is something about the derivation history that makes one candidate better than the other. The idea of comparing derivation histories can be captured in a percolative model of phonology, where derivational histories may be encoded in the constituencies of tree structures (Orgun 1996).

2.2. Towards a percolative model of phonology

Suppose one adopts a view of phonology where output representations are tree-like structures rather than linear strings, then any surface form such as HHR would be either a tree with a 2+1 constituency, a 1+2 constituency or a 1+1+1 constituency. This is nothing new, and is in fact how one represents morphological and prosodic structures. The novel idea here is to allow each higher node (i.e. non-terminal node) to contain content information that has percolated from the lower nodes, something akin to syntactic trees such as the following:



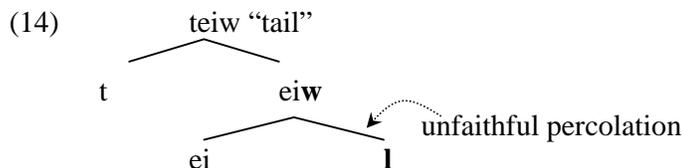
In (11), the root node (top) is a VP by virtue of the percolation of the verbal features of the daughter V, hence “pinch the elephant” is some kind of event about pinching and not some kind of animal/elephant. The same idea applies to the NP node. Whether or not one construes a representation such as (11) as the nominal and verbal features percolating upwards to form the phrase (i.e. upward projection of head features) or if it is the VP and NP that projects downwards to produce V and N heads is immaterial. Such a model of representation is endocentric, and is usually not extensively used in phonology until Orgun (1996) and Goldrick (2000). But suppose one accepts such a mode of representation in phonology, then a string such as [teil] “tail” would be represented as follows:



For the moment, (12) does not seem terribly interesting and would appear even cumbersome. This is because information across tiers is totally identical. However imagine now an L-vocalization rule that requires coda-L to vocalize as [w], a situation found in many varieties of English such as Australian (Borowsky and Horvarth 1997), Estuary (Alterndorf 2003), Hong Kong (Wee 2007a) and Singapore (Wee 2007b).



Thus for languages where a rule like (13) is active, /teil/ “tail” would surface as [teiw] but “tailing” would be [teiliŋ], since in “tailing”, the /l/ would be syllabified as the onset of /-iŋ/. In other words, it is the constituency that triggers the alternation. How can the effect of (13) be expressed in a representation like (12)? This is where the notion of percolation becomes useful, because there is now a need for a mismatch in the correspondence of information across tiers, such as (14).



In (14), the /l/ at the terminal node fails to percolate faithfully upwards, and instead becomes a [w] when it forms a constituent with [ei]. By default, one would normally have perfect correspondence across the dominating and subordinate tiers, but when triggered by requirements such as (13), then unfaithful percolation would result. The potential for a percolative model such as (12) and (14) to address the directionality issues of Tianjin tone sandhi is obvious. One can use these trees to encode the derivational paths of each input and then compare the trees in their entirety, which would give us an effect similar to Chen’s (2000) Derivation-selecting OT

model (more on this later). A percolative model would require the following assumptions:

- (15) a. **Carriage of information**
All nodes (terminal or non-terminal) are information-bearing.
- b. **Correspondence of information**
There is a correspondence of the information content between nodes that stand in immediate domination.
- c. **Violability of correspondence**
Correspondence of information between nodes is not necessarily perfect.

The assumptions in (15) are not new. Within phonology, Orgun (1996) and Goldrick (2000) have used them successfully to account for various opacity effects in phonological alternations. In syntax, such correspondence of information across tiers has been exploited since the advent of X-bar theory (Jackendoff 1977). However, when put as explicitly as in (15), some amount of careful conceptualization might be in order.

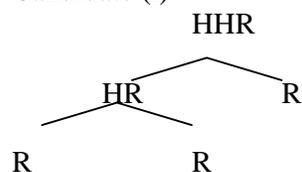
2.3. *Conceptualizing a percolative model of phonology*

Contrary to what the term “percolation” might imply, the model outlined in (15) does not involve any derivation, procedure or ordered steps. For there to be correspondence across tiers, there is no need for one particular tier to be more basic than the other: start from any tier and simply ensure that across each tier there is correspondence (faithful or otherwise). Thus, correspondence of information is in principle symmetrical. However, asymmetry sets in with an input.

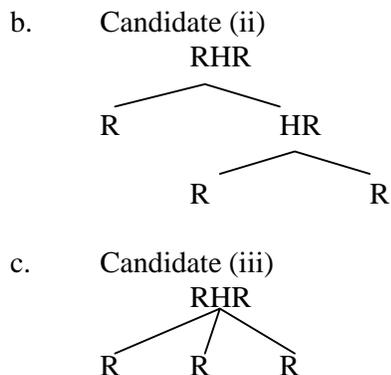
Inputs are fundamental strings of phonological entities. These entities are then organized into constituencies by whatever structure-building⁵ rules of the language, a situation one has seen in (12) where different syllable structures may be generated out of a morph such as “tail” depending on whether the string is /teil/ or /teiliŋ/. Because of this, terminal nodes (which would correspond to the input string) would appear to be the primary source of phonological content and correspondence of information across tiers would have to rely on the terminal nodes. This gives an upward percolation effect, which is exactly what is happening in (14).

Returning now to the case of /RRR/ in Tianjin, a derivational history can therefore be constructed/encoded in a (left-branching) tree representation, with each unfaithful correspondence motivated by an overarching OCP requirement against adjacent R tones.

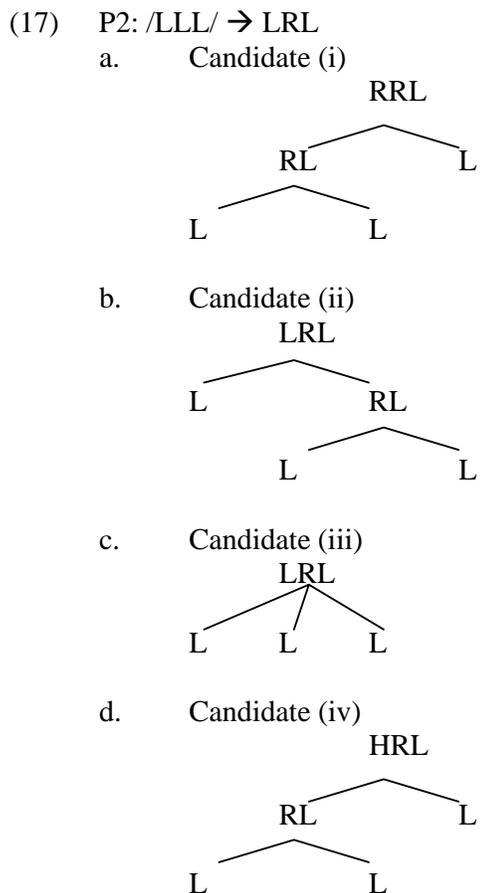
- (16) P1: /RRR/ → HHR
a. Candidate (i)



⁵ In OT, it would be a set of structure selection constraints since GEN would build all the logically possible structures there are.



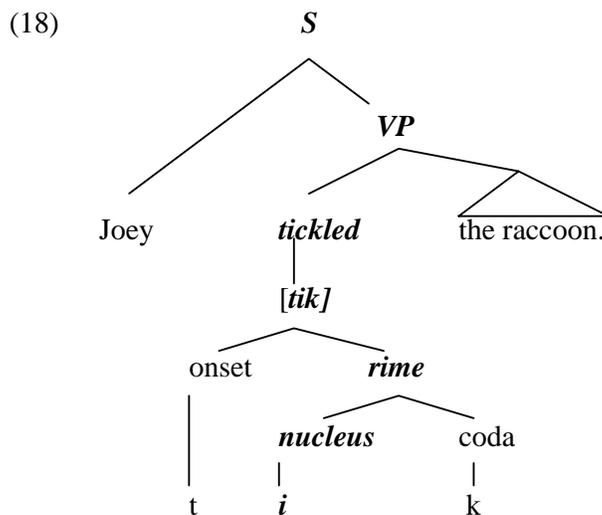
In (16), given an input string /RRR/, supposing the first pair of Rs forms a constituent, then the initial R would become H before moving up to a higher level where the medial R alternates, giving us the structural representational equivalent of /RRR/ → HRR → HHR, as shown in candidate (i). Alternatively, one can imagine configurations like candidate (ii) in (16b) or candidate (iii) in (16c), which are theoretically possible representations, but would not be the attested ones for the input /RRR/. This is precisely the state of affairs one hopes to achieve, because now there is no need for constraints like *BACKTRACK for us to choose between derivations. In an OT framework, GEN can produce all the candidate trees for EVAL to choose. The relevant candidate set for /LLL/ would be as shown in (17).



The set of possibilities that can be encoded in such Inter-tier Correspondence trees greatly outnumber the set of possible derivations because one can easily imagine other correspondences and a number of tree structures (calculable from the number of items in the input string). This would also include all the possible derivations. For the case of /LLL/, the total number of possible derivations is 3,⁶ but as can be seen from the set of trees in (17), there are at least 4 to contend with even though candidates (ii) and (iii) would both produce [LRL] in the end.

Armed now with these trees as the candidate set, what one needs is to ensure that a set of constraints select a left-branching tree as default (cf. Chen’s 2000 TEMP constraint in section 2.1), but a right-branching one when the default produces an OCP violation in the root node.

Before moving on to actually working out a detailed analysis, using these inter-tier correspondence trees, the reader would notice that these trees appear to have turned phonetic representations upside down so that the terminal nodes are identical to the underlying input string while the root node matches the output string. Uncomfortable as this might seem at first glance, it has really been implicit in many linguistic representations. In syntax, outputs are not mere strings of words but involve structural configurations complete with phrasal projections. In phonology, prosodic outputs are often construed as metrical trees where phonological entities like stress are noted at higher levels. Consider for example the interpretation of stress and focus in a sentence like “Joey **tickled** the raccoon” which gives a wide-scope focal interpretation. In this case, stress is manifested only on the vowel [i] in “tickled” which is interpreted eventually have scope over the entire event. The only way for this to be possible is to accept that focus must have percolated across the tiers in a tree, indicated by the italics in the tree in (18).

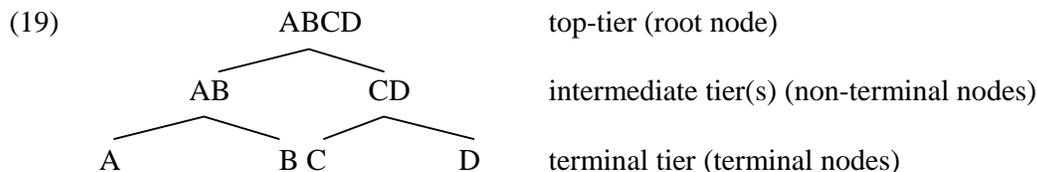


It is impossible to say in a representation in (18) whether it was focus percolating downwards from S and then manifesting itself as stress at [i], or if stress had percolated upwards from [i] to S. The direction of percolation is immaterial, what is key is the idea that there is correspondence of information across tiers, so that each

⁶ They are [LRL]; [RRL]; and [HRL].

non-terminal node actually carries content information (such as focus or stress) in addition to indicating constituency.

All that a percolative model of phonology is asking is that outputs are structural representations of given inputs where information across tiers is in (not necessarily perfect) correspondence, such as (19).

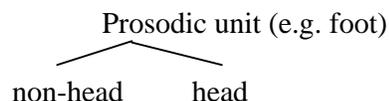


3. Deriving the Directionality of Tianjin Tone Sandhi

Within a percolative framework such as that outlined in section 2, two sets of constraints are necessary for a successful account of Tianjin tone sandhi. Firstly, there must be a set of constraints that would be responsible for the selection of the tree structures; secondly there has to be a set of constraints that would trigger/restrict the alternation of input entities.

Since the rudimentary ditonal sandhi in Tianjin is regressive, it is reasonable to assume that by virtue of the stability of the final tone, Tianjin prosody is right-headed.

(20) Right-headedness of Tianjin prosody



Since heads are stable, the assumption in (20) would predict that in longer strings, the final tone is always stable, which is correct as far as one can tell from the tone sandhi data (see P1-5 in (5c)).⁷ Together with the default rightward directionality of tone sandhi application, it would be necessary that the default optimal tree is left-branching, and binary, cf. (16a). This leaves us with the following constraints:

(21) Structure Related Constraints

BINARY

Non-terminal nodes are binary branching.

ALIGN LT

Align prosodic constituents left.

To trigger tone sandhi, a constraint to the effect of the OCP is needed. However, in Tianjin, only LL, RR and FF sequences trigger tone sandhi, not HH. As such, the family of OCP constraints must be split so that OCP [F, L, R] would outrank FAITH which would in turn dominate OCP [H]. However, because one is now working with structural candidates where nodes contain information, regular OT faithfulness

⁷ With the possible exception of neutral tones, which Wang (2002b) treats as non-moraic in the input rather than as reduction of fully specified tones. Wee (2004) treats the Chinese neutral tone as the result of suffixation of a tone-reducing morph.

constraints have to be adapted and modified as INTF and INTF HD for general faithfulness and faithfulness to head elements (see Beckman 1998 for discussion on positional faithfulness) respectively.

(22) Tone Sandhi Related Constraints

OCP [TONE]

Do not allow adjacent identical tones in a node.

INT(ertier)F**(aithfulness) **HD**(head)**

If node A immediately dominates node B and B is the head constituent, then B must have an identical correspondent in A.

INTF

If node A immediately dominates node B, then B must have an identical correspondent in A.

The constraints in (22) apply at every tier, so that candidates such as those below would receive the evaluations as listed on their right.

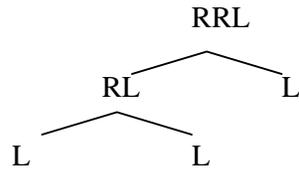
(23) P1: /RRR/ → HHR

		Violations:Count
a.	Candidate (i)	
		OCP[H]:2
		INTF:1
b.	Candidate (ii)	
		INTF:1
c.	Candidate (iii)	
		INTF:1

(24) P2: /LLL/ → LRL

Violations:Count

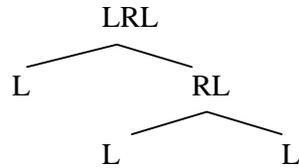
a. Candidate (i)



OCP[R]; INTF:2

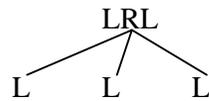
INTF:1

b. Candidate (ii)



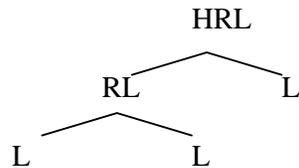
INTF:1

c. Candidate (iii)



INTF:1

d. Candidate (iv)



INTF:2

INTF:1

In all the above candidates, there were no cases of INTF HD violations because all the correspondences from the right branches had been perfect. At the terminal nodes, there are no OCP violations since there is no adjacency of identical tones at those points. The violation comes about only at higher nodes when the offending collocations belong to the same constituent. We are now ready to evaluate each of the above candidates in OT tableaux complete with the constraints BIN and ALIGN LT. To keep things concise, candidates in violation of INTF HD will not be considered.

(25) Getting /RRR/ → HHR (cf. (23))

/RRR/ \ candidate	BIN	OCP [L,F,R]	ALIGN LT	INTF
☞ i.				**
ii.			*!	*
iii.	*!			*

(26) Getting /LLL/ → LRL (cf. (24))

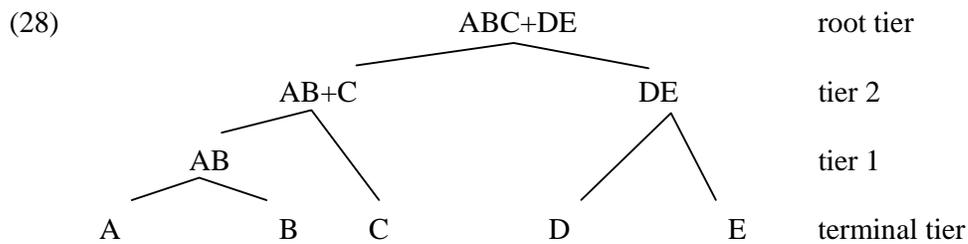
/LLL/ \ candidate	BIN	OCP [L,F,R]	ALIGN LT	INTF
i.		*!		**
☞ ii.			*	*
iii.	*!			*
☛ iv.				***

As may be seen in (25), the desired predictions can be made for the case of /RRR/ → HHR, but (26) is only partially successful. Given the ranking hierarchy, (26) correctly predicts that LRL would be more harmonious than RRL, which is the key idea behind the directionality flip. However, candidate (iv) HRL would be more harmonious than LRL because it violates none of the higher constraints.

In tree representations such as those in (24), candidate (iv) is not a case of “backtracking” (Chen 2000, cf. (10)).⁸ There is no backtracking here because there are no derivational steps, only correspondence. What is peculiar about candidate (iv) in (24d) is the non-locality of condition to change a derived R (from L) to H: the trigger came from the final L. Cashing in on this observation, suppose one posits a local condition to the following effect:

- (27) **CONTACT CONDITION**
 Across tiers, if a tone T does not share a boundary with another tone, T must have an identical correspondent.

To see the effects of CT COND, consider the following structure and correspondences.



In (28), at tier 1, AB and DE are collocations that will be evaluated such that if any of these four elements do not correspond with the terminal tier, there is no violation of the CT COND. Moving on to tier 2, any unfaithful correspondence in A between tier 1 and tier 2 would constitute a violation of the CT COND. This is because across tier 1 and tier 2, A does not share a boundary with another tone. It is B and C that share a boundary. The same logic applies to the root tier. Between tier 2 and the root tier, only C and D share a boundary, as such only unfaithful correspondences of C or D do not violate the CT COND.⁹ Unfaithful correspondences of A, B or E across tier 2 and the root tier would be violations of the CT COND.

With CT COND dominating ALIGN LT, the correct predictions could be made for /LLL/ → LRL, yielding the directionality patterns of Tianjin tone sandhi.

⁸ See also Chen et al (2004) for argument against *BACKTRACK as a general account for controlling the traffic of tone sandhi. Citing Changting Hakka which presents very similar tone sandhi directionality with Tianjin but with chain-shifts rules RM → HM; HM → FM, FM → RM, Chen et al argue that *BACKTRACK would not explain why an input RM would only surface as HM, never shifting ad infinitum. The general solution would be to appeal to a constraint that would allow each tone sandhi window to undergo sandhi application maximally once, which is the effect captured by the combination of structural percolation and the CT COND.

⁹ This would give the effect of the Bracket Erasure Convention of Lexical Phonology (Kiparsky 1982).

(26) Reprise: Getting /LLL/ → LRL (cf. (24))

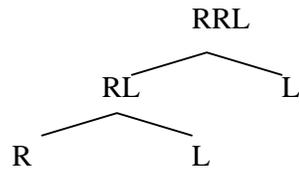
candidate \ /LLL/	BIN	OCP [L,F,R]	CT COND	ALIGN LT	INTF
i.		*!			**
☞ ii.				*	*
iii.	*!				*
iv.			*!		***

As may be seen in (26), candidate (iv) violates the CT COND because at the root node, the initial tone is not in a position of contact with the final tone.

The case with P3 /FFF/ is identical to (26). Likewise, patterns P4 and P5 are similar; only P4 is presented below:

(27) P4: /RLL/ → HRL

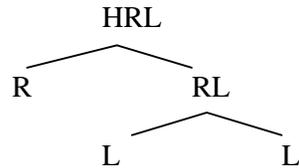
a. Candidate (i)



OCP[R]; INTF:1

INTF:1

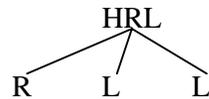
b. Candidate (ii)



ALIGN LT: 1; INTF:1

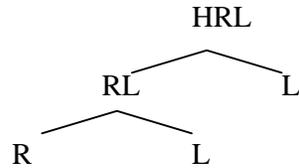
INTF:1

c. Candidate (iii)



BIN:1; INTF:2

d. Candidate (iv)



CTCOND:1; INTF:2

INTF:1

candidate \ /RLL/	BIN	OCP [L,F,R]	CT COND	ALIGN LT	INTF
i.		*!			**
☞ ii.				*	**
iii.	*!				**
iv.			*!		***

So, one has successfully derived the directionality patterns of Tianjin tone sandhi without appeal to “reverse” steps or derivational OT of the kind suggested in Chen (2000). In the account above, it appears that derivational histories are encoded in the structures through inter-tier correspondence of information, though in actuality, there is no need for the concept of “derivational history”. Derivation history is derivable from structural configuration which is implicit in the strata of lexical phonology and other cyclic phenomena (especially in the interface between morphology and phonology and in Chinese tone sandhi, often related to morphosyntax).

But, is this percolative model just a way of doing the same thing that Chen (2000) did? Is it a simple encoding of linear derivational procedures into a tree configuration? If so, there’s no value in the percolative model. As I have suggested in the above paragraph, the percolative model does capture insights not captured in derivation-centered accounts. In addition, the percolative model makes predictions about the depth of opacity, blocking of operations due to non-constituency, and the impact of constituency on direction “rule application”. These will be explored in the next section. For now, one has arrived at a ranking hierarchy for the constraints of Tianjin tone sandhi.

(28) BINARY; OCP[L,R,F] » CT COND » ALIGN LT » INTF

4. Predictions

4.1. Prosodic structure

One of the most striking features of Tianjin tritonal sandhi is its directionality. Directionality typically implies linearity in the sense that given an input string, one either applies the alternation rules from left to right, or vice versa, , regardless of morphosyntactic (or even prosodic) configuration. For the patterns P1-5 of Tianjin tone sandhi presented above, this appears to be true in that morphosyntactic configurations do not affect the result of tone sandhi. In contrast, the inter-tier correspondence model presented in section 3 would predict that there is some kind of hierarchical structure, since it is this structure that determines the outcome of tone sandhi. To check this prediction, I asked my informants¹⁰ to insert pauses in trisyllabic sequences that had a flat morphosyntactic configuration.¹¹ For example, with /LLL/ strings, examples would include number sequences like 3-3-3 or 7-3-8, since 3, 7 and 8 are syllables carrying the tone L.

(29) a. /HHH/ → [HH (pause) H]
 example:
 ling.ling.ling ‘zero zero zero’

¹⁰ Thanks to Lu Jilun a native of Tianjin for his help and patience as my main informant. His judgments are corroborated by Chi Defa, a secondary informant whom I interviewed 2-3 years later since the investigation first started.

¹¹ Because prosody is very subtle for these cases, each informant was interviewed separately. Solicitation of judgments for pause insertion for any given input string is deeply buried amidst unrelated tasks and often separated over extensive periods of time (at least a few hours). The results are verified at least twice to ensure consistency. The reason why I had to go through so much trouble was to prevent the informants making analogies from the judgment for one case, say /LLL/, to other cases, say /RRR/.

- b. /RRR/ → [HH (pause) R]
 example:
 wu.wu.wu ‘five five five’
 jiu.wu.jiu ‘nine five nine’
- c. /LLL/ → [L (pause) RL]
 example:
 san.san.san ‘three three three’
 san.qi.ba ‘three seven eight’

Because there is no influence from syntax in these cases, the location of pauses in (29) must have come only from prosodic structures. If the prosodic structure were flat, one would expect pauses intervening between the gaps of the initial, medial and final syllables without preference for either of the two gaps. However, as can be seen in (29), there is a preference for the location of the pause. In (29a, b), the pause is preferred between the medial and final syllables, but for (29c), the pause is preferred immediately after the initial syllable.

The data in (29) cannot be predicted by a linear model where the directionality of tone sandhi is construed as working either leftward or rightward. In an inter-tier correspondence model, directionality is the result of upward percolation combined with the directionality of branching. Thus with a left-branching structure,¹² one would witness rightward directionality, but leftward directionality with a right-branching structure. The inter-tier correspondence model predicts in (26), that /LLL/ → LRL because it has a rightward branching structure, which would also explain why a pause can be inserted between the initial and the medial syllables in (29c); similarly for /RRR/ → HHR, the prediction is that with a left-branching structure, the pause would come immediately before the final syllable of a trisyllabic string.

The ranking hierarchy in (28) predicts that the default prosodic structure would be left-branching, which is borne out in (29a), where the syllables do not involve any tone sandhi, and yet the insertion of pause is preferred before the final syllable. This prediction for default prosodic structure is corroborated by evidence from casual speech elision (Wee, Yan and Lu 2005; Wee and Yan 2006; Wee 2005) where given a trisyllabic input, elision (if applicable) applies almost always to the window between the initial and the medial syllable.

- (30) a. /tʰienF ʃʌF tʰeiL/ “television set”
 → [tʰieŋR tʰeiL]
 b. /tʰiauR tʰeiL kuanL/ “little west fort”
 → [tʰioiR kuanL]

In (30), I have used IPA notation for the Tianjin words so that the impact of casual speech elision on the segments and tones would be clear. The integrity of the final syllable is always kept, but material from the initial and medial syllables is often elided. This reflects the relative proximity of the initial and medial syllables,

¹² The structures that are alluded to here are of course prosodic, since the sequences in (28) do not involve any morphosyntactic constituency.

suggesting that the default 2+1 prosodic constituency as predicted by the ranking hierarchy (28) is correct

The reader may be perplexed by the complicated tone pattern of (30), and might even expect (30b), which is /RLL/, to have the elision window between the medial and final syllables (cf. P4 in (27)). Wee (2005) and Wee & Yan (2006) explains that when casual speech elision targets mora-bearing segments, corresponding tones are also removed. This creates new tone sequences which then undergoes tone sandhi, giving rise to all the tonal cases of (30), demonstrated in (31).

(31) a. /tien^F ʂŋ^F tɕiL / → [tiɛŋ^R tɕiL] “television set”

Derivation:

/tien^F ʂŋ^F tɕiL/

Deletion tiɛ^F ŋ^F

LL → RL tiɛL ŋ^F tɕiL

FL → HL¹³ tiɛL ŋ^H tɕiL = [tiɛŋ^R tɕiL]

b. /ɕau^R ɕiL kuanL/¹⁴ → [ɕɔi^R kuanL] “little west fort”

Derivation:

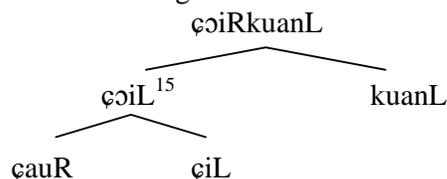
/ɕau^R ɕiL kuanL/

Deletion ɕɔiL kuanL

LL → RL ɕɔi^R kuanL

(31a) is fairly clear-cut, and would make the point about the prosodic proximity of the initial and medial syllables, making them the target of casual speech elision. The moot case is (31b). In Wee’s (2005) and Wee and Yan’s (2006) telling, [au] reduces to [ɔ] with a corresponding reduction in moraic count so that the residue of the initial and medial syllables merge to form ɕɔiL. Tone sandhi then applies to make [ɕɔi^R]. Since tone sandhi applies to outputs of elision, it is no surprise that even a /RLL/ sequence would exhibit the 2+1 prosodic structural default. To see this clearly, consider two inter-tier correspondence candidates for the input /RLL/ below:

(32) a. Left-branching candidate for /RLL/ with casual elision

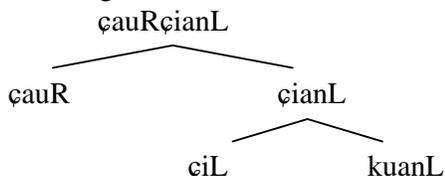


¹³ See footnote 1.

¹⁴ There is some controversy over the presence of a glide [i] for /ɕ(i)au^R/, but this shall not be taken up here.

¹⁵ We won’t consider ɕɔLiL because this would be two “incomplete” syllables. Tianjin syllables are generally bimoraic since the syllable is the minimal prosodic word. This effect can be easily achieved with appeal to universal constraints requiring bimoraicity on syllables, and is tangential to the focus here.

b. Right-branching candidate for /RLL/ with casual elision



candidate \ /RLL/	BIN	OCP [L,F,R]	CASELI	ALIGN LT
i.				
☞ ii.				*!

In (32), no candidate violating BIN or OCP is considered, and since the topic under discussion is on elision in casual speech, I have imagined a collection of constraints collapsed into the convenient CASELI and considered only candidates where elision has taken place. Since INTF is lowly ranked, it would not matter for us how to calculate the violation count for these candidates. What matters is that ALIGN LT would set in to choose the default left-branching structure (compare and contrast (27) with the same ranking hierarchy. This makes the inter-tier correspondence model particularly attractive because it allows us to predict that with /RLL/ inputs, but in cases where the tone sandhi is not (yet) applicable, the configuration of the input syllables would correspond to the default prosodic structure, otherwise, /RLL/ sequence would have a non-default right-branching prosodic structure. Similar predictions would be made for the patterns P2 /LLL/, P3 /FFF/ and P5 /LFF/. As far as I have been able to work out the data presented in Wee, Yan and Lu (2005), this appears to be true.

The feat of making predictions about the patterns of tone sandhi when interacted with elision in casual speech cannot be attained in a linear directionality account, and would argue in favor of the inter-tire correspondence model of phonology proposed in this paper.

4.2. *Constituencies and Depth of Opacity*

A percolative model of phonology outlined in section 2 makes an interesting prediction about the depth of derivational opacity. Opacity is the interesting case here because it is probably the strongest case one can construct for a derivational framework as against an output-based one such as OT (especially with Correspondence Theory, McCarthy and Prince 1995). Numerous attempts have been made at accommodating opacity into OT, with Sign-based Morphology (Orgun 1996), Sympathy Theory (McCarthy 1998, 2003), Transderivational Faithfulness Theory (Benua 1997), Turbidity (Goldrick 2000), Stratal OT (Kiparsky 2003, 2007 and to appear), Comparative Markedness (McCarthy 2002) and the more recent Candidate Chain Theory (McCarthy 2006a, b).

With perhaps the exception of the theories proposed by McCarthy, the linguists listed above have one idea in common: relating the depth of opacity with morphological embeddings. For example, Benua's Transderivational Faithfulness Theory allows for as many cycles as there are affixations. Benua's account confined derivational opacity to within morphological paradigms (words related to each other because they share the same root) and was able to capture the fact that with each cycle of affixation, deviation from the output of the last cycle is only motivated by

markedness requirements. However, such a framework cannot be extended to cover the kinds of opacity shown in Tianjin tone sandhi, where tone sandhi rules appear to cycle on prosodic structures and do not have any morphological identity to be described as being within the same “paradigm”. To force Benua’s theory by allowing for identity across paradigms would severely overgenerate.

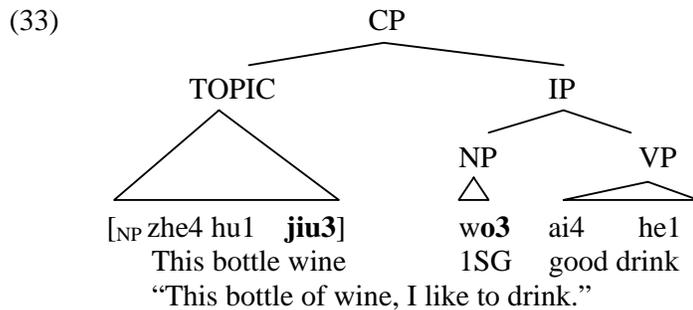
Kiparsky’s (2003, 2007 and to appear) re-creates the stratal ordering of Lexical Phonology by blending it into Stratal OT where an input undergoes as many layers of H-EVAL as there were strata in Lexical Phonology. In Stratal OT, each H-EVAL has the same set of universal constraints but with possibly different ranking hierarchies. However, this does not allow for opacity within the same stratum, though since the early days of Lexical Phonology there can cyclic rule applications in the same stratum (for roughly as many cycles of affixation of the same class of affixes, Mohanan 1986, 1995). Again, this makes Stratal OT powerless against the Tianjin tone sandhi problem where tone sandhi rules simply cycle up the prosodic tree structure (or to insist on a linear directionality account apply cyclically in a particular direction until the end of the string is reached), which if one looks at the examples in (5c) (or the entire corpus collected in Wee, Yan and Chen 2005) could either belong to the same stratum or cross strata.

Orgun’s (1996) relation with structural depth is even more explicit; his insight that non-terminal nodes carry information percolated from below is highly valuable, and is central to this model proposed here. One difference between Orgun’s model and that proposed here is that Orgun’s model required all information (phonological, syntactic and semantic) to percolate up the same tree. The model proposed here does not make that requirement, allowing for there to be different trees for the different dimensions of language, a necessary evil since structures of morphosyntax, semantics and phonology are often mismatched (recall the famous examples of “transformational grammarian”, “serial killer” or “optimality theoretic phonologist”).

In any case, these authors have implicitly or explicitly confined the depth of opacity to within the depth structural embeddings. Most interesting is that Benua’s insight and Kiparsky’s are complementary: opacity can stem from structures generated within a stratum and also from structures generated across strata. Clearly then, what one needs is a theory that simply allows opacity to fall out of structures, and this is supported by the facts in Tianjin tone sandhi. With the inter-tier correspondence model of phonology, the insights of these theorists can be captured quite straightforwardly. Because alternation is motivated by constituency through the percolation of information, the depth of opacity would be confined to within the number of structural embeddings.

An advantage of the inter-tier correspondence model is that it predicts that alternations cannot be triggered by adjacency alone. In SPE type phonology, triggering environments are often (mis-)represented as adjacencies, such as $A \rightarrow B / _ C$, though in fact this is very often not the case. For example, recall in (13) above on L-vocalization, which applies only when /l/ is parsed into the coda. In the inter-tier correspondence model, it is constituency that provides triggering environments, not adjacency, so one would predict that in Tianjin, OCP violations would be tolerated if the adjacent tones somehow do not form a prosodic constituency. This is certainly true: any rhythmic break would suffice to leave adjacent identical tones unalternated. But this result may seem trivial, since a rhythmic break could be construed as the presence of an intervening pause. Slightly more convincing evidence comes from Standard (or Beijing) Mandarin which is famous for its Third Tone sandhi (Cheng 1968, Zhang 1997; Duanmu 2000, and many others too numerous to list). It turns out

that for a number of speakers, third tone adjacency is tolerated (without any intervening pause) if syntactically, one belongs to the topic clause and the other to the comment clause, illustrated below in (33).



For the speakers of Standard Mandarin that have judgments like (33), the prosodic domain within which the third tone sandhi applies must be contained within the IP.

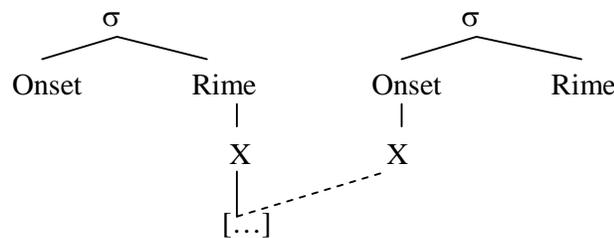
A model of phonology that works on inter-tier correspondence thus allows one to predict the depth of opacity through the structural embeddings as well as the blocking of alternation from non-constituency.

4.3. Split Correspondence

The inter-tier correspondence model also makes an interesting prediction that is otherwise awkward with earlier models: the possibility of split correspondence from spreading. This is best illustrated with the interaction between L-vocalization (cf. (13) and consonant gemination in Hong Kong English (Wee 2007a, for details).

In Hong Kong English (HKE), coda consonants geminate to serve as onsets of vowel initial suffixes, (34).

- (34) Root-final Consonant Geminates (HKE data)¹⁶
- a. i. [stɔp] “stop” ii. [stɔp.piŋ] “stopping”
 - b. i. [pin] “pin” ii. [pin.niŋ] “pinning”
 - c. i. [put] “put” ii. [put.tiŋ] “putting”



Further, HKE has L-vocalization such as the kind seen in (13), where coda /l/ surface as [w]. So, what would happen if a words ending with /l/, such as “kill” and “hell”, are

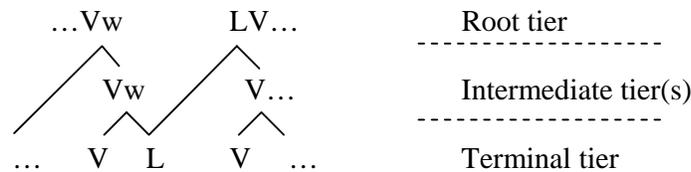
¹⁶ These are not true geminates in that the CC is ambisyllabic. Evidence for the geminates comes from the clear presence of both pre- and post-pausal Cs when informants are asked to insert pauses into multi-syllabic words. Thus, “stopping” is [stɔp^vpiŋ], where ^v=pause with two clear [p]s.

followed by vowel-initial suffixes? Would one get a heterosyllabic geminate [ww]? It turns out that one would get a [wl] sequence.

- (35) a. /kil + iŋ/ → kil.liŋ → [kiw.liŋ]
 b. /həl + iʃ/ → həl.liʃ → [hew.liʃ]

While it is easy to describe the process as an ordering of gemination then vocalization, a paradox would appear when one tries to reconcile the [w.l] sequence with the representation in (34). With two timing slots linked to one melody, they are either both [l] or [w], but not [w] and [l] at the same time unless one invokes a Schrödinger's Cat into HKE or one takes an inter-tier correspondence approach. The latter would look like (36).

- (36) Split Correspondence of L



In (36), the /l/ at the terminal node is doubly linked, firstly to the coda of the preceding syllable and also to the onset of the second. As a coda, it alternates to become [w], but not as the onset of the following syllable, which is naturally expressed in the inter-tier correspondence model.

This section explores the predictions and implications of a percolative/inter-tier correspondence model of phonology, and has demonstrated that the core idea of having non-terminal nodes bear information is a viable and desirable one. It predicts firstly that directionality is a derivate of branching; secondly that constituency is the necessary trigger for alternation hence the depth of opacity is confined to number of embeddings rather than to the number of strata or to within a stratum; and thirdly, that split correspondences are possible when a lower node is shared by two constituents. All these predictions are borne out.

5. Conclusion

In this paper, I have argued for a percolative model of phonology where opacity and other derivational effects are encapsulated through unfaithful percolation/correspondence of information across tiers in a structural representation. The key piece of evidence come from Tianjin tone sandhi which exhibits not only directionality of sandhi rule application, but a flip in the directionality depending on whether the outcome contains any violations of the OCP. The awkward state of affairs make a traditional derivational approach unviable, but the opacity involved in arriving at the attested outcome make it equally challenging for a classical OT approach.

The solution to the problems lies in the following assumptions, which make up the Inter-tier Correspondence Theory.

- (37) Inter-tier Correspondence Theory (repeated from (15))
- a. **Carriage of information**
All nodes (terminal or non-terminal) are information-bearing.
 - b. **Correspondence of information**
There is a correspondence of the information content between nodes that stand in immediate domination.
 - c. **Violability of correspondence**
Correspondence of information between nodes is not necessarily perfect.

Further evidence for this approach is to be found in the predictions it makes about the effect of structural branching on directionality; on the relevance of constituency and depth of opacity; as well as the possibility of split correspondences such as that found in Hong Kong English.

On grounds of the correctness of predictions made, this model shows promise as a general solution to understanding and capturing opacity in phonology, extending to cases where traditional derivations and classical OT have been unable to reach.

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