

A Percolative Account of Tianjin Tone Sandhi^{*}

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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 that: (1) directionality is a derivate from branching; (2) the depth of derivational opacity is confined by structural depth; (3) constituency, not adjacency, provides the environment for triggering alternation so alternation rules can therefore be blocked when marked collocations belong to different constituencies; and (4) underlying entities can have split surface correspondences.

Key words: percolation, correspondence, opacity, directionality, tone sandhi, Tianjin

1. Introduction

Derivational opacity in phonology has always received much attention from both skeptics and supporters of Optimality Theory (OT, Prince & 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

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insights of both approaches, and to recognize the important roles that prosodic constituencies 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. To do so, constraints that allow us to derive prosodic constituencies (such as feet and phonological phrases, see Selkirk 1995 and Truckenbrodt 1995, 1999) will be needed. Relevant ones for this paper are listed as (1), below.

(1) Prosodic structural constraints

BINARY

Non-terminal nodes are binary branching.

ALIGN LT¹

Align the left edge of prosodic units² to the left edge of the matrix morpho-syntactic unit.

On the basis of structures established by (1), this paper argues that Tianjin tone sandhi can best be captured by a theory that allows for correspondence of information across nodes in a prosodic tree structure. The basic tenets of such a theory are as given in (2), and in (3), the corresponding constraint that demands faithful reconstruction of information across nodes.

(2) Inter-tier Correspondence Theory (from Wee 2004)

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 are directly linked to one another (i.e. inter-tier on a hierarchical structure).

c. **Violability of correspondence**

Correspondence of information between nodes is not necessarily perfect.

(3) Inter-tier Faithfulness (**INTF**)

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

¹ This effectively creates left-branching structures and favors embedding of prosodic units. If embedding is forbidden, gradable violations result. See McCarthy & Prince (1993) for discussion, see also Grimshaw (2008) for how such constraints work in tree structures.

² For the purposes of this paper, this refers to constituencies at or above the level of the foot. The distinction between foot and phonological phrase is not crucial for the data treated here.

Following earlier work on Tianjin tone sandhi (in particular Chen 2000:105-158, Wee 2004: Ch.3, Wee, Yan & Chen 2005, Lin 2008), tonal alternation is assumed to be triggered by OCP.³

Following this introduction, §2 introduces the peculiar tone sandhi patterns of Tianjin; §3 outlines the key ideas for a solution; §4 shows how the Tianjin tone sandhi patterns could fall out of a model of phonology that appeals to correspondence of information across nodes; and §5 presents corroborative evidence from Tianjin and beyond. Section 6 reviews related theoretical ideas on opacity and structure before the conclusion.

2. Confused traffic in Tianjin tone sandhi

To appreciate the subtleties of Tianjin tone sandhi, imagine a language with the following phonological alternation pattern:

- (4) 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 (5) and (6) where the window of alternation is underlined and a vertical shaft “|” connects the target of alternation to the outcome below.

- (5) a. AAA
 |
 *CAA
 |
 CCA (cf. (4c))
- b. AAA
 |
 *ACA

³ A reviewer rightly queried if Tianjin tone sandhi is indeed OCP-triggered, citing Ma & Jia’s (2006) claim that sequences with adjacent high tone feature like RH and RF do not trigger sandhi (contra Wee, Yan & Chen 2005:6). Further interviews with other native Tianjin informants matched Wee, Yan & Chen’s, not Ma & Jia’s. In any case, Ma & Jia’s research does not exclude OCP as triggers; it could be done with a prioritized set of OCP that militates against identical tone adjacency.

- (6) a. BBB
 |
 *ABB
 |
 *AAB
 |
 *CAB
- b. BBB
 |
 BAB

(An 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, first of all, both the AA and BB rules are regressive, providing no motivation for their individuality in directionality for longer strings; and, second, 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. (6a) is thus forbidden because it produces midway an OCP-violating form *AAB.

The confused traffic outlined above is, in fact, the distinguishing character of Tianjin tone sandhi. Since Li & Liu (1985) reported the tone sandhi patterns of Tianjin the challenges have been discussed in Tan (1986, 1987), Z. Zhang (1987), Shi (1988, 1990), Milliken et al. (1997) and more recently in Chen (2000:105-158), Wee (2004: Ch.3), Wee, Yan & Chen (2005) and Lin (2008). The key set of facts as presented in Chen (2000:107) is given in (7), where R is a rising tone, L a low tone and H a high tone; examples in (8c).

- (7) a. RRR
 |
 *HRR
 |
 HHR (cf. (5a))
- b. LLL
 |
 LRL (cf. (6b))

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

(8) a. Tones in Tianjin

	Pitch value		Description (Chen 2000 and Wang 2002a)
	Li & 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 Sandhi⁴

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

c. List of directional effect patterns⁵

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'

⁴ There are in fact three other rules (described in Chen 2000:106 as absorption): $F \rightarrow H / _ L$; $R \rightarrow L / _ H$; and $R \rightarrow L / _ F$ which apply consistently to the results of those rules in (8b). Except for $F \rightarrow H / _ L$, Ma & Jia (2006) do not recognize these absorption cases. This issue does not affect the main point of this study and will not be discussed in detail. Thus, the main challenge in this paper is to make sure one can derive the "correct" outputs of the rules in (8b) so that these three additional rules can apply correctly to produce the final output. Hence for example, given /FFF/, our concern is to derive FLF from the rules in (8b) rather than LLF. FLF then undergoes absorption $F \rightarrow H / _ L$ to produce [HLF].

⁵ Contrary to (8c)'s suggestion that Tianjin tone sandhi is oblivious to syntactic constituency, it is in fact always possible to apply tone sandhi starting from the minimum constituent, terminating tone sandhi at any constituent boundaries. In addition to the above, this table does not present various optional outputs of tritonal sandhi. This table is kept pristine so that directionality issues would not be obscured (see also §5.2).

(8c) presents only the five patterns most relevant for the discussion of directionality. With a tonal inventory of four, tritonal combinations would come up to 64 ($= 4^3$), many of which do not involve sandhi (such as /HHH/, /LHR/, etc.) or contain only one sandhi site (such as /LLR/ \rightarrow [RLR], /RRH/ \rightarrow HRH, etc.). Discounting these cases that do not involve directionality, P1-5 are the only ones of concern.

Note that all the tritonal patterns can be derived from the rudimentary rules in (8b), but not through ordering of each rule. Rather this has to be done through ordering of the windows of tone sandhi:

- (9) Windows of Tone Sandhi
- σ_1
 $\underbrace{\hspace{1.5cm}}$
 I

σ_2
 $\underbrace{\hspace{1.5cm}}$
 II

σ_3
 $\underbrace{\hspace{1.5cm}}$
 (Ditonal windows)

For example, in P1 /RRR/ produces [HHR], the result is obtainable if sandhi applied rightwards starting from Window I, the reverse is true for P2 where /LLL/ yields [LRL] and P3 /FFF/ produces [FLF].⁶ Ordering the rules would not suffice because in 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:

- (10) a. Apply rules uniformly in a direction (in this case rightwards).
 b. If the outcome produces an OCP-triggering string, undo (10a), 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

⁶ Which becomes [HLF] by virtue of $F \rightarrow H / __ L$, one of the three absorption rules that apply after all the OCP sandhi rules have applied, see footnote 3.

The account in (10) was first put forth in Chen (2000:111) 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 comes 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).⁷

The reader might notice also that out of the five patterns P1-5 in (8c), only P1 involves a rightward application of tone sandhi. It would seem that the implicit rightward default directionality in (10) is misconstrued, though (11) will demonstrate clearly that the rightward directionality default must be the correct one.

(11) 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	⇐	(10b) Flip Condition	OK
P3	FFF	HLF	⇐		
P4	RLL	HRL	⇐		
P5	LFF	RLF	⇐		
Conclusion				OK	P2 contradict this

As can be seen in (11), a rightward default traffic of tone sandhi is sustainable with the flip condition, but a leftward default is totally untenable.

(12) Flip condition (Chen 2000:111, cf. (10b))

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.

However, what kind of a theoretical framework would allow for such a flip as (12)? 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 (10). 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.

⁷ Longer strings are typically broken up into shorter ditonal or tritonal substrings where tone sandhi would apply as per (8b) and (8c), see Wee, Yan & Chen (2005) for details.

Standard OT models would be just as hard-pressed. For example, the unattested /RRR/ → *RHR would incur fewer faithfulness violations while satisfying the OCP, an instance of the oft-cited challenge of opacity to classical OT models (Benua 1997, Kiparsky 2003, 2009, McCarthy 1998, 2000, 2002, 2003, 2006, 2007, Mohanan 2000 among others).

The next section will attempt to build a slightly different model that would at once avoid both the problems of derivational models and classical OT ones.

3. Inter-tier correspondences: a percolative model of phonology

3.1 Derivational histories as static representations

An important stepping stone to finding a solution for the Tianjin tone sandhi patterns comes from Chen's (2000:105-158) idea to select optimal derivational histories rather than to arrive procedurally at surface candidates (derivational) or to select optimal candidates (classical OT). Such a conception is interesting in that what appears to be dynamic and diachronic can be taken in its entirety as a static and synchronic entity. Chen's approach is shown in (13).

(13) 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		*!		

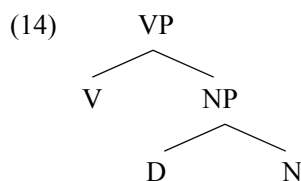
Chen (2000) appeals to constraints on derivations such as “backtracking” and requires the candidates to be chains of derivations (an idea later echoed in McCarthy 2006, 2007). This allows for the selection of the attested candidate for both /RRR/ and /LLL/ cases, successfully accounting for the flip in directionality. Though successful in picking out the desired candidate, this raises some questions. First, it appears that the TEMPORALITY and the *BACKTRACK constraints are doing pretty much the same work. Second, if the rightward default directionality is motivated by TEMPORALITY, why is the ditonal sandhi regressive in the first place?

The problems would be solved if “derivation histories” are static with all parts generated synchronically so that there will be no need to appeal to temporality. A percolative model of phonology, where derivational histories may be encoded in the constituencies of tree structures (Orgun 1996) by virtue of correspondences of information across nodes, would be what is exactly needed.

Percolation, widely used in syntax, is the flow of information across nodes in a tree. For example, saying that V projects V' and in turn VP, is saying that the [+v] feature percolates upwards. However, it is equally legitimate to say that percolation happened downwards from VP to V. In other words, though the idea of percolation began as a procedural transfer of information, it can also be interpreted as a correspondence of information across nodes. Thus, one has a static representation of [VP [V' [V]]] with no particular primacy on which came first. The ensuing section explores such a conception for phonology.

3.2 Towards a percolative model of phonology

Suppose one adopts a view of phonology where output representations are tree 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 morphophonological and prosodic structures.⁸ The novel idea here is to allow each higher node (i.e. non-terminal node) to contain content information that corresponds with the lower nodes, something akin to syntactic trees such as the following:

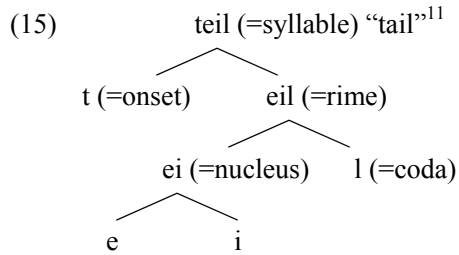


In (14), the root node (top) is a VP by virtue of the percolation of the verbal features of the daughter V, hence “pinch the elephant” is some kind of event about pinching and not some kind of animal/elephant. The same idea applies to the NP node. Whether or not one construes a representation such as (14) 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.⁹ Such a model of representation is endocentric, and is usually not extensively used in phonology until Orgun (1996) and Goldrick (2000).¹⁰ But suppose one accepts such a mode of representation in phonology, then a string such as [teil] “tail” would be represented as follows:

⁸ In the poetic prosody for example, couplets are broken in to lines, in turn to hemistiches, feet, and syllables. The same may be said of the prosody of regular speech, except that in regular speech, interface with syntactic constituencies would impact on prosodic structures (more in §6.2).

⁹ The uni-directionality of Phrase Structure rules (e.g. $VP \rightarrow V NP$) is encoded through the branching of trees like (14). This must not be construed as downward or upward percolation.

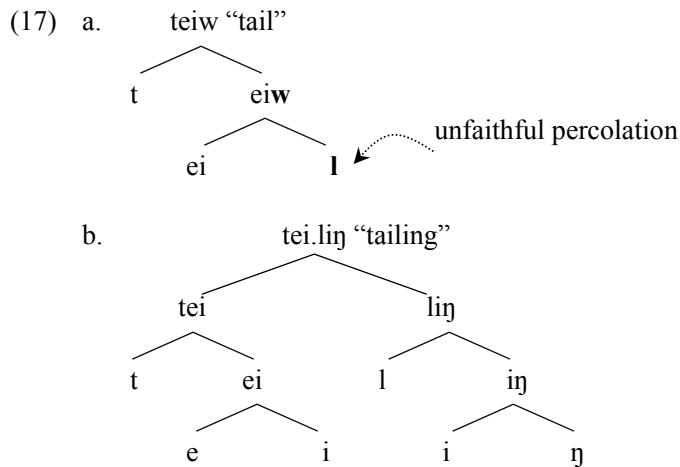
¹⁰ As pointed out by a reviewer, similar notions may be found in Autosegmental Phonology, where spreading/string of features would come close to the notion of percolation, for example Padgett (1995), though without explicit mention or representation of percolation or correspondence. A related, but different, notion is dependency. In correspondence of information across nodes, there is mutual dependency on information. In Padgett’s feature tree, there is dependency on dominating nodes for the existence of certain features. These are very different ideas.



For the moment, (15) does not seem terribly interesting and would even appear 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 & Horvath 1997), Estuary (Altendorf 2003), Hong Kong and Singapore (Wee 2008a, 2009a, 2009b).



Thus for languages where a rule like (16) is active, /teɪl/ "tail" would surface as [teɪw] but "tailing" would be [teɪlɪŋ], since in "tailing", the /l/ would be syllabified as the onset of /-ɪŋ/. In other words, it is the constituency that triggers the alternation. How can this insight be expressed in a representation like (15)? 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 depending on structural configurations, (17a-b).



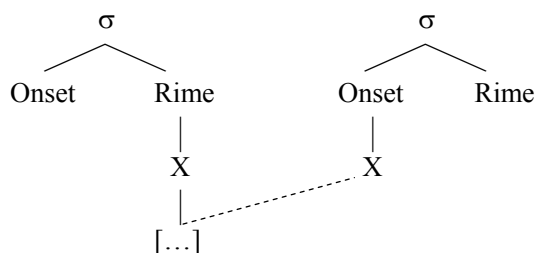
¹¹ The same may be made for a moraic representation of the syllable. Whether the syllable is best understood in the moraic model or an onset-rime model is tangential to this paper, but see Sloan (1991) and Yip (2003) for arguments.

In (17a), the /l/ at the terminal node fails to percolate faithfully upwards, and instead becomes a [w] when it forms a constituent with [ei]. In (17b), /l/ remains unvocalized precisely because it is not longer a constituent with [ei]. While it is possible to state rules to get the effect, such rules typically misses the point that it is the constituency that triggers the alternation. This crucial points fall out naturally from a model that works on the structural configuration of the entities involved, which underlines the need for the recognition of information correspondence across dominating/subordinating nodes in a tree.

Wee (2009b) further demonstrates that (17) would account for split gemination cases, as in Hong Kong English (HKE), where coda consonants geminate to serve as onsets of vowel initial suffixes, (18).

(18) Root-final Consonant Geminates (HKE data)¹²

a.	i.	[stɒp]	“stop”	ii.	[stɒp.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 (16). So, what would happen if words ending with /l/, such as “kill” and “hell”, are followed by vowel-initial suffixes? Would one get a heterosyllabic geminate [ww]? It turns out that one would get a [wl] sequence.

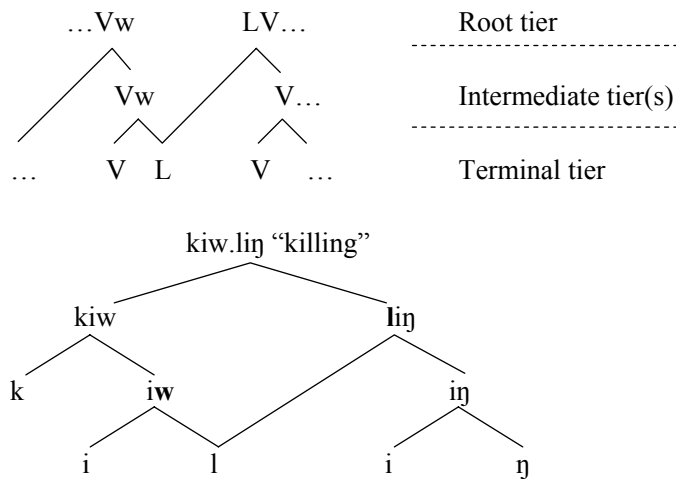
- (19) a. /kil + iŋ/ → kil.liŋ → [kiw.liŋ]
 b. /hel + iŋ/ → hel.liŋ → [hew.liŋ]

¹² 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 [stɒp^vpiŋ], where ^v=pause with two clear [p]s. Noteworthy also is that in (18), gemination does not happen when the rime of the syllable preceding the affix has three segments. This is why there is no gemination in (17b).

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 (18). The combination of (18) and (19) thus illustrates that firstly, data in (19) is a case of split gemination; secondly, a spreading and delinking procedure would not suffice; and thirdly, though a rule-ordering approach can generate the right results, it would not offer any explanation to the conspiracy of the patterns.

Since the existence of [w.l] sequence is motivated by the same environments that trigger heterosyllabic gemination, it would have the same autosegmental representation given in (18). However, 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, like (20).¹³

(20) Split Correspondence of L



In the percolative model, the default is to have perfect correspondence across the dominating and subordinate nodes, unless triggered by markedness requirements. The potential for such a percolative model 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 yield the effect that Chen's

¹³ A reviewer points out that one could conceive /l/ as being /+lateral, +velar/ (Sproat & Fujimura 1993) that undergoes fission to produce this effect, typical of autosegmental phonology. Such an approach would in principle be identical to that proposed here, except that the model here would also explicitly capture the fact that it is the syllabic constituency that is responsible for determining the alternation.

(2000:105-158) Derivation-selecting OT model seeks. The upside is that there would be no need for any derivation procedure in the percolative model because the entire ‘derivational history’ is really nothing more than correspondences across nodes in a tree. Underlying the model advocated by this paper are the following assumptions:

- (21) 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 are directly linked to one another.
- c. **Violability of correspondence**
Correspondence of information between nodes is not necessarily perfect.

The assumptions in (21) are not new. (21a-b) are necessary for any endocentric representational model. (21c) is novel only in the sense that it is typically not explicitly stated in rule-based frameworks, but is in fact perfectly natural in optimality theoretic ones.¹⁴ Within phonology, Orgun (1996) and Goldrick (2000) have used them successfully to account for various opacity effects in morpho-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 (21), some amount of careful conceptualization might be in order.

3.3 Percolation is inter-tier correspondence

It is important to note that contrary to what the term “percolation” might imply, the model outlined in (21) does not involve any derivation, procedure or ordered steps.¹⁵ In effect, percolation is really just a matter of 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-building¹⁶ rules of the language, a

¹⁴ In fact, even in (morpho-)syntax, (21c) must be active since higher projections do not necessarily belong to the same category as the projecting head, as in the case of V projecting gerunds that are nominal.

¹⁵ These terms remain useful as descriptive labels. However, it is unnecessary to assign them theoretical status under inter-tier correspondence.

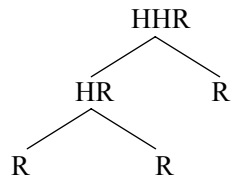
¹⁶ In OT, it would be a set of structure selection constraints since GEN would build all the

situation one has seen in (17) 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 (17).¹⁷

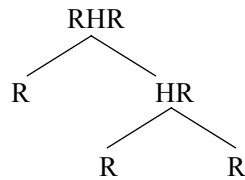
Returning now to the case of /RRR/ in Tianjin, a derivational history can therefore be constructed/encoded in a (left-branching) tree representation, with each unfaithful correspondence motivated by an overarching OCP requirement against adjacent R tones.

(22) P1: input: /RRR/; output: [HHR]

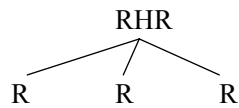
a. Candidate (i)



b. Candidate (ii)



c. Candidate (iii)



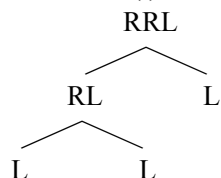
logically possible structures there are.

¹⁷ In generative phonology, rules of grammar manipulate features rather than segments. This assumption continues to be held in the model presented here though (20) may at first blush look like the segments are directly manipulated. The unfaithful correspondence is the result of a change in the [lateral] or [velar] feature specification of /l/. Likewise, in treating tone sandhi, it is the tonal features that are manipulated, i.e. when R percolates as H, it is really [lh] → [h], where the low tone feature is removed. Thanks to a reviewer for pointing this out.

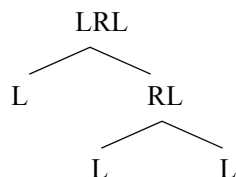
In (22), given an input string /RRR/, let us suppose the first pair of Rs forms a constituent. Then the initial R would become H before moving up to a higher level where the medial R alternates, giving us the structural representational equivalent of /RRR/ \rightarrow HRR \rightarrow HHR, as shown in candidate (i). Alternatively, one can imagine configurations like candidate (ii) in (22b) or candidate (iii) in (22c), which are theoretically possible representations, though not 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 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 (23).

(23) P2: input /LLL/; output [LRL]

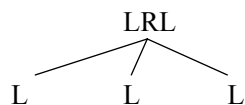
a. Candidate (i)



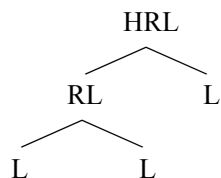
b. Candidate (ii)



c. Candidate (iii)



d. Candidate (iv)

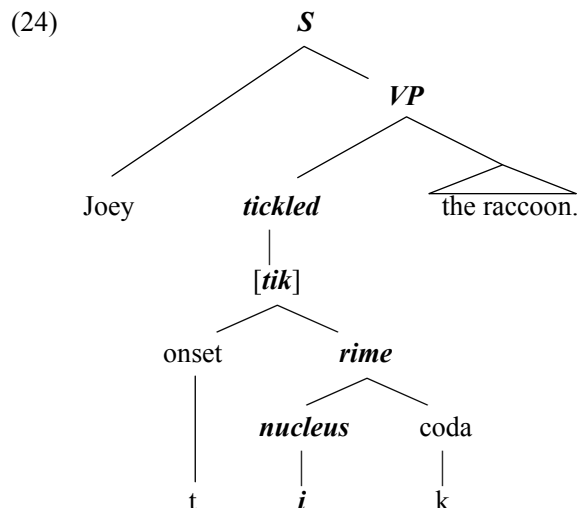


The set of possibilities that can be encoded in such Inter-tier Correspondence trees greatly outnumber the set of possible derivations because one can easily imagine other correspondences and a number of tree structures (calculable from the number of items in the input string). This would also include all the possible derivations. For the case of /LLL/, the total number of possible derivations is 3,¹⁸ but as can be seen from the set of trees in (17), there are at least four to contend with even though candidates (ii) and (iii) would both produce [LRL] at the root node. 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 2000:111 TEMP constraint), but a right-branching one when the default produces an OCP violation in the root node.

At this point, one is confronted with two issues. First, what evidence is there to claim that these tree structures actually exist for the cases at hand? Further, can similar evidence be found that for all cases of phonological alternation, tree structures (i.e. prosodic constituencies) are at what is responsible for providing the context? This will be taken up in §5. For the moment, suffice to say that prosodic structures can be independently motivated and it can be shown that prosodic boundaries such as pauses can block alternation.

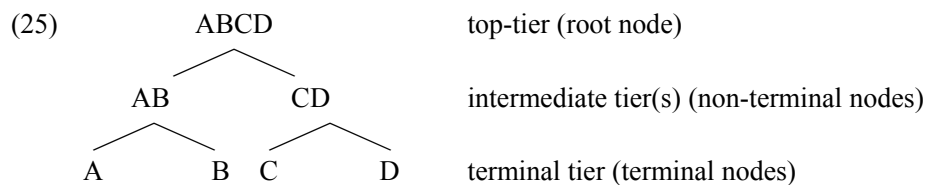
Second, the inter-tier correspondence trees appear to have turned phonetic representations upside down so that the terminal nodes are identical to the underlying input string while the root node matches the output string. Uncomfortable as this might seem at first glance, it has really been implicit in 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 a sentence like {Joey tickled the raccoon.}. Suppose the speaker of the sentence puts stress on it, presumably something like {I said *Joey tickled the raccoon*, not *Susan went to the zoo*.} in response to someone who misheard the utterance the first time. In such an utterance, the stress would fall on the first syllable of *tickled*. Likewise, a hearer of the sentence where stress falls on that syllable, the entire sentence is interpreted as being stressed. Phonetically, stress is manifested only on the vowel [i] in "tickled". The explanation for why this is so requires us to accept that focus must have percolated across the tiers in a tree, indicated by the italics in the tree in (24).

¹⁸ They are [LRL]; [RRL]; and [HRL].



It is impossible to say in a representation in (24) 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. Taking either side is a matter of whether one takes a speaker's perspective or a listener's. The direction of percolation is in fact immaterial, what is key is the idea that there is correspondence of information across tiers, so that each non-terminal node actually carries content information (such as focus or stress) in addition to indicating constituency.

Taking this cue, this paper suggests that outputs are structural representations of given inputs where information across tiers is in (not necessarily perfect) correspondence, such as (25).

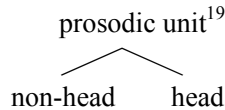


4. Directionality of Tianjin tone sandhi without derivation

Within an inter-tier correspondence framework such as that outlined in §3, two sets of constraints are necessary for a successful account of Tianjin tone sandhi. First, there must be a set of constraints determining prosodic constituency; and second 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 (see also Davidson 2004 for phonetic arguments).

(26) Right-headedness of Tianjin prosody



Since heads are stable, the assumption in (26) 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 (8c)).²⁰ 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. (22a). This leaves us with the following constraints:

(27) Structure Related Constraints

BINARY

Non-terminal nodes are binary branching.

ALIGN LT

Align the left edge of prosodic units to the left edge of the matrix morpho-syntactic unit.

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] outranks FAITH which would in turn outrank OCP [H].²¹ However, because one is now working with structural candidates where nodes contain information, regular OT faithfulness constraints have to be adapted and modified as INTF (Inter-tier faithfulness).²²

¹⁹ This would include all kinds of prosodic units from foot to intonational phrases (Selkirk 1995, Truckenbrodt 1995, 1999), and also include Shih (1986)'s superfoot and Chen's (2000) rhythmic units.

²⁰ 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: Ch.4) treats the Chinese neutral tone as the result of suffixation of a tone-reducing morph.

²¹ This issue is really a lot more complicated than this since RH and RF sequences do trigger sandhi. However, this is tangential to the concerns of this paper and hence will not be discussed here. The interested reader is referred to Wee (2008b). Also, see footnote 2.

²² One will of course require INTF HD for faithfulness to the head elements (see Beckman 1998

(28) Tone Sandhi Related Constraints

OCP [TONE]

Do not allow adjacent identical tones in a node.

INTF

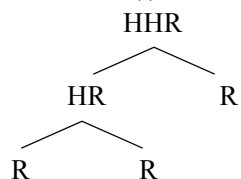
If node A immediately dominates node B, then B must have an identical correspondent in A.

The constraints in (28) apply at every tier, so that candidates such as those below would receive the evaluations as listed on their right.

(29) P1: input /RRR/; output [HHR]

Violations:Count

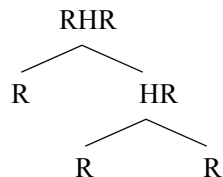
a. Candidate (i)



OCP[H]:1 INTF:1

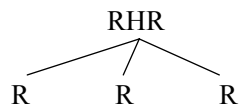
INTF:1

b. Candidate (ii)



INTF:1

c. Candidate (iii)



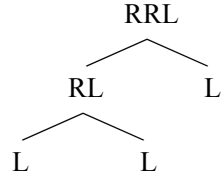
INTF:1

for discussion on positional faithfulness). Tianjin is prosodically right-headed, hence all items on the right branch would have to have faithful inter-tier correspondence. Thus, candidates considered in this paper would exclude those that violate INTF HD.

(30) P2: input /LLL/; output [LRL]

Violations:Count

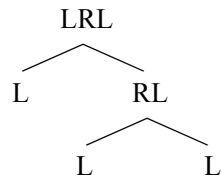
a. Candidate (i)



OCP[R]:1 ; INTF:1

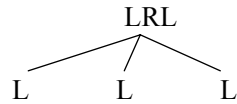
INTF:1

b. Candidate (ii)



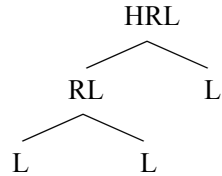
INTF:1

c. Candidate (iii)



INTF:1

d. Candidate (iv)



INTF:2

INTF:1

In all the above candidates, there are no OCP violations at the terminal nodes 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 considered do not include any that changed the tone of the final syllable.

(31) Getting (29)

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

(32) Getting (30)

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

Candidate (ii) in (31) and (32) are right-branching structures, which incur violations of ALIGN LT.²³ In (32), candidate (i), though with adjacent H, does not violate OCP [L,F, R], since as mentioned earlier, adjacent H is tolerated in Tianjin, presumably due to low ranking of OCP[H]. Otherwise, at every tier, any unfaithful correspondence would count for a violation of INTF, as illustrated in (29) and (30). As may be seen in (31), the desired predictions can be made for the case of /RRR/ → HHR, but (32) is only partially successful. Given the ranking hierarchy, (32) 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 (30), candidate (iv) is not a case of “backtracking” (cf. (10)).²⁴ There is no backtracking here because there are no derivational steps, only correspondence. What is peculiar about candidate (iv) in (30d) 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:

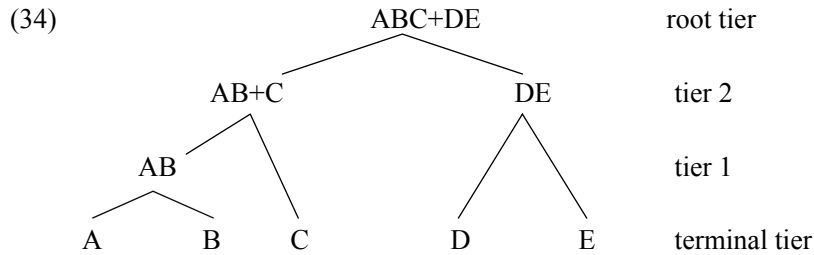
²³ The matrix morphosyntactic unit will inevitably correspond with the matrix prosodic unit, hence all right-branching structures such as (29b) and (30b) would incur violations of ALIGN LT.

²⁴ 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. (2004) demonstrates that *BACKTRACK be inadequate. The general solution would require a constraint that allows each tone sandhi window to undergo sandhi application maximally once. With structural percolation, the CT COND manages this.

(33) 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 (34), 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, AB is now a unit so that at tier 2, 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.²⁵ 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.

(35) Reprise: (30)

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

As may be seen in (35), 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.

²⁵ This would give the effect of the Bracket Erasure Convention of Lexical Phonology (Kiparsky 1982).

The case with P3 /FFF/ is identical to (35). Likewise, patterns P4 and P5 are similar; only P4 is presented below:

(36) P4: input /RLL/; output [HRL]

a. Candidate (i)

RRL

RL

L

R

L

Violations:Count

OCP[R]:1 ; INTF:1

INTF:1

b. Candidate (ii)

HRL

R

RL

L

L

ALIGN LT: 1; INTF:1

INTF:1

c. Candidate (iii)

HRL

R

L

L

BIN:1; INTF:2

d. Candidate (iv)

HRL

RL

L

R

L

CTCOND:1; INTF:2

INTF:1

<div><div></div><div>/RLL/</div></div>	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 comparison of derivation histories. In the account above, it appears that derivational histories are encoded in the structures through inter-tier correspondence of information, although there is actually no need for the concept of “derivational history” at all. 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 inter-tier correspondence model just a notational variant of Chen’s (2000:105-158) derivation history comparison? Is it a simple encoding of linear derivational procedures into a tree configuration? If so, there is no added value in this treatment. As I have suggested in the above paragraph, the inter-tier correspondence model captures insights not captured in derivation-centered accounts. In addition, the inter-tier correspondence model makes predictions about the depth of opacity, the 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.

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

5. Constituency as the basis of phonological alternations

The central idea in this paper is the relevance of structure to phonological alternation. This section explores that relevance by reviewing further evidence from Tianjin and beyond.

5.1 Pause insertion

The analysis of Tianjin tone sandhi relies heavily on the structural configuration of the tone sequences. In the case of Tianjin, since morphosyntactic configurations do not determine direction of sandhi application, the constituency must be prosodic. So, if the analysis is right, then one would predict that /LLL/ and /RRR/ sequences have different prosodic configurations. Further, the default prosodic configuration of Tianjin must be binary left-branching. Is there evidence for this? By extension, is there evidence for such an approach across languages? This section demonstrates to the affirmative.

First, it can be demonstrated that /LLL/ and /RRR/ do indeed have different prosodic constituencies. This can be done by checking pause-insertion possibilities of relevant tri-syllabic sequences. To check this, informants were asked to insert pauses in trisyllabic

sequences that had a flat morphosyntactic configuration.²⁶ 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.

- (38) a. /HHH/ → [HH (pause) H]
 example:
 ling.ling.ling ‘zero zero zero’
- 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 (38) 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 (38), there is a preference for the location of the pause. In (38a-b), the pause is preferred between the medial and final syllables, but for (38c), the pause is preferred immediately after the initial syllable. The situation in (38) is not only consistent with the inter-tier correspondence analysis, it is predicted by it when the model selected different configurations as optimal.

²⁶ 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/. The results in (38) are also supported by phonetic investigations on prosody by Davidson (2004), where she demonstrated that these sandhied tones from /L/ and /R/ produce intonational phrasal boundaries.

5.2 Syntactically licensed prosody

Another effect of prosody can be seen in the kinds of sandhi variation. According to the data collected in Wee, Yan & Chen (2005), depending on the syntactic configuration of a trisyllabic string, two forms are sometimes available: (i) sandhied output corresponds to the directionality effects given as P1-5 in (8c); and (ii) sandhied output mirrors syntactic configuration, (39) and (40) below.

- (39) a. input /RR+R/ e.g. [li.fà] suo ‘barber shop’
 i. [HHR]
 ii. *[RHR]²⁷
- b. input /R+RR/ e.g. mu [lao.hu] ‘tigress’
 i. [HHR]
 ii. [RHR]
- c. input /R+R+R/ e.g. 9-5-9
 i. [HHR]
 ii. *[RHR]
- (40) a. input /LL+L/ e.g. [tuo.là] ji ‘tractor’
 i. [RLL]
 ii. [LRL]
- b. input /L+LL/ e.g. kai [fei.ji] ‘fly a plane’
 i. *[RLL]
 ii. [LRL]
- c. input /L+L+L/ e.g. 3-8-3
 i. *[RLL]
 ii. [LRL]

Notice the unacceptability of (39aii, cii) and (40bi, ci). These are forms where the sandhied outputs are not licensed by the syntactic configuration when not in line with the directionality effects. The reason why syntactic configuration can allow such licenses is because it is always possible to force prosody to align perfectly with morphosyntax

²⁷ Wee, Yan & Chen (2005:67) report only two cases of [RHR] for a 2+1 syntactic configuration, which are judged by their informants as marginally acceptable.

(an effect of interface constraints like ALIGN and WRAP, Truckenbrodt 1999). Thus again, one sees that there is a structural element at work, that ultimately must be cast in terms of prosody.

5.3 Focal stress

Focal stress provides a third piece of evidence for the relevance of prosody. Any syllable in a given string that receives focal stress will retain its citation tone in Tianjin. Thus, in a trisyllabic string, if the second syllable is given focal stress, it will retain its tone, regardless of OCP-violating adjacencies with the third syllable.

- (41) Effect of focal stress
- a. /RRR/ → HRR, *HHR
 - b. /LLL/ → RLL, *LRL
 - c. /RRR/ → **R**HR, ***H**HR
 - d. /LLL/ → **L**RL

In (41), boldface indicates tone of syllable receiving focal stress. As can be seen, such syllables do not undergo sandhi, even if OCP-violating sequences would result. The effect of focal stress is that it creates a rhythmic break, effectively determining prosodic constituency, which may then block OCP requirements (41a-b) when potential triggers are outside the relevant prosodic domain.

5.4 Casual speech elision

A fourth piece of evidence comes from casual speech elision in Tianjin. Given the analysis proposed in §4, Tianjin trisyllabic sequences would have a default left-branching prosodic structure. Indeed, when presented with familiar trisyllabic sequences where truncation occurs, consonant segments between the initial and medial syllables get deleted (Wee, Yan & Lu 2005, Wee & Yan 2006, Wee 2008b).

- (42) Examples of casual speech elision in Tianjin²⁸
- a. /tien sɿ tɕi / “television set”
→ [tɿɿ tɕi]
 - b. /ɕiau ɕi kuan/ “little west fort”
→ [ɕioi kuan]

²⁸ Tones omitted to prevent confusion.

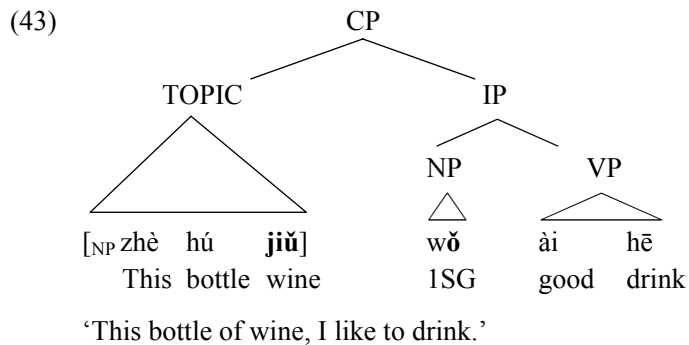
- c. /pin tɕian tau/ “Binjiang Road”
 → [pian tau]
 d. /təŋ ɕau p^{hiŋ}/ “Deng Xiaoping”
 → [təau p^{hiŋ}]

Casual speech elision data suggests that for trisyllabic sequences, the first two syllables are of closer proximity since it is at this window that elision occurs. This is in accord with the combination of ALIGN LT and BINARY (listed in (27)) as active constraints in the determination of Tianjin prosodic structure.

5.5 The centrality of structure

Thus one advantage the inter-tier correspondence model has over non-structure based theories is that inter-tier correspondence 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 (16) 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 have easily anticipated the patterns of pause insertion, syntactic mirroring, and focal stress as presented above.

The centrality of structure extends beyond Tianjin. Standard (or Beijing) Mandarin which is famous for its iron-clad ban against adjacency of the third tone (Third-tone sandhi, Cheng 1968, N. Zhang 1997, Duanmu 2000, and many others too numerous to list) tolerates sandhi-triggering sequences under similar circumstances. In (43) below, third-tone adjacency is tolerated when separated by a topic boundary.



For the speakers of Standard Mandarin that have judgments like (42), the prosodic domain within which the third tone sandhi applies must be contained within the IP.

Likewise, a different prosodic parse for a string of *jiǔ* ‘nine’ yields different sandhi patterns, such as those in (44).

- (44) a. nine-nine nine-nine nine-nine
 2-3 2-3 2-3
 b. nine-nine-nine nine-nine-nine
 2-2-3 2-2-3

In (44), hyphens indicate prosodic grouping and numerals below each line indicates the corresponding Standard Mandarin tone. Notice that the sandhi pattern mirrors the prosodic grouping.

Tone sandhi in other Chinese languages can be treated this way. Truckenbrodt (1999) demonstrated this for the Min sandhi patterns (citing Chen 1987) where the domain of sandhi is determined by a combination of WRAP, ALIGN and NON-RECURSIVITY constraints. Beyond the domain, sandhi is blocked. For cases like Shanghai and Suzhou, the domain would correspond to the level of the (prosodic) word. Outside of the Chinese languages, one sees similar domain/constituency sensitivity in Tohono-O’odham, Kimatumbi, Chichewa (all in Truckenbrodt 1999), among many others. It would be quite difficult to find a language where rule application does not respect domain boundaries. As such any account that merely states the position of a trigger without mention of domain would be inadequate.

Outside of tonal patterns, vowel reduction in unstressed positions offers a fine example of the impact of prosody on phonological alternation.

- (45) Vowel reduction in English
 a. i. demon [**di**:mən] ii. demonic [də**m**ənɪk]
 b. i. detriment [**de**trɪmənt] ii. detrimental [de**trɪ**mentəl]
 c. i. curious [**kj**uəriəs] ii. curiosity [kjuəriɪəsəti]

In (45), one can see that when unstressed, vowels get reduced to schwas. This demonstrates the relevance of prosody. In this case, it is a matter of how trochaic feet are parsed out of the sequences of syllables. That way, when two syllables combine into a trochee, the relevant markedness constraints on foot structure²⁹ would necessitate reduction.

²⁹ Presumably, WEIGHT-TO-STRESS (Prince 1990, Prince & Smolensky 1993/2004:56) and the demand that trochees have left-aligned stresses.

In the above paragraphs, one sees that constituency is important for any account of alternation. For phonological processes, the relevant kind of constituency would be prosodic, though domains may vary from the larger phrasal units (e.g. tone sandhi in Mandarin) to the smaller lexical units (e.g. Shanghai, Tohono O’odham), foot (e.g. vowel reduction in English), or even smaller units (e.g. l-vocalization in Hong Kong English).

6. Residue theoretical issues

The above sections have argued that any adequate phonological analysis of tone sandhi in Tianjin must take into account prosodic constituency. The argument is strengthened by facts beyond tone sandhi and beyond Tianjin in §5. This section explores some of the theoretical consequences.

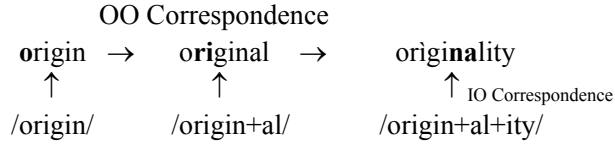
6.1 Depth of opacity and constituency

The inter-tier correspondence model entails a correlation between the depth of derivational opacity and structural embedding. This is in fact borne out both empirically, as demonstrated in preceding sections, and has been implicit in other theories of phonological opacity.

Opacity is particularly interesting because it is probably the strongest case one can construct for a derivational framework against an output-based one such as OT (especially with Correspondence Theory, McCarthy & 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, specific to Tianjin in Lin 2008), Turbidity (Goldrick 2000), Stratal OT (Kiparsky 2003, 2009), Comparative Markedness (McCarthy 2002), and the more recent Candidate Chain Theory (McCarthy 2006, 2007).

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. Thus in the cyclical stress shift of *origin*, *original*, and *originality*, locus of stress (in boldface) shifts one step with each suffix. Her analysis is reproduced below.

(46) Multiple Affixation



Recursion (A)

/origin/	NON FINAL	ALIGN HD RT	OO- IDENT	ALIGN HD LT	IO IDENT	»
a. o.(ri.gin)	*!			*		
b. (o.ri)gin		*				
c. (o.ri)gin		*				
d. \mathcal{F} (o.ri)gin		*				

Recursion (B)

»	/origin+al/	NON FINAL	ALIGN HD RT	OO- IDENT	ALIGN HD LT	IO IDENT	»
	a'. o(ri.gi)nal		**		*		
	b'. (o.ri)gi.nal		***!	*			
	c'. o(ri.gi)nal		**	*	*		
	d'. \mathcal{F} o(ri.gi)nal		**	*	*		

Recursion (C)

»	/origin+al+ity/	NON FINAL	ALIGN HD RT	OO- IDENT	ALIGN HD LT	IO IDENT
	a''. o(ri.gi)(na.li)ty		**		*	
	b''. (o.ri)gi(na.li)ty		**			
	c''. (o.ri)gi(na.li)ty		**	***!		
	d''. \mathcal{F} o(ri.gi)(na.li)ty		**	*	*	

Legend:

- . – syllable break; () – feet boundary
 NON-FINAL – Final syllable should not be footed.
 ALIGN HD LT/RT – Align feet to left/right.
 OO-IDENT – Have identical correspondences of this candidate to an immediately earlier output.
 IO IDENT – Have identical correspondences of this candidate with the input.

Benua’s account confines 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. This paradigmatic restriction is needed to ensure that outputs of other words do not exert effects. 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 (but see Lin 2008 who redefined the transderivational paradigms prosodically).³⁰

Kiparsky (2003, 2009) 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. This is illustrated in his treatment for Yokuts, where a number of phonological rules interact in the way shown in (47).

(47) /cu:m-hin/ → [comhun] “devour (aorist)”

Derivation:

/cu:m-hin/	
↓	Rounding Harmony
cu:mhun	
↓	Lowering
co:mhun	
↓	Shortening
[comhun]	

Kiparsky’s Stratal-OT treatment appeals to the set of constraint in (48), with the application in (49).

³⁰ Lin’s (2008) paradigm applies to tonal strings, which though fundamentally prosodic, cannot apply to accents as that would over-generate (as in the case for English stress). Though technically viable, the restriction would require further substantiation.

(48) **IDENT- σ_1 (ROUND)**

A segment in an initial syllable must have the same value for [round] as its I/O correspondent.

ID [RD]

A segment must have the same value for [round] as its I/O correspondent.

ID [HIGH]

A segment must have the same value for [high] as its I/O correspondent.

MAX- μ

Preserve input syllable weight in outputs.

 α HI/ β RD

Every path including [α high_i] includes [β round_j]. (Successive vowels of the same height have the same rounding).

***[+RD]**

No vowel is [+round].

***[HIVV]**

Do not have long high vowels.

***[$\mu\mu\mu$] σ**

Do not allow trimoraic syllables (*VVC)

(49) Stratal-OT on Yokuts

Stem level

/cu:m-hin/	MAX- μ	ID [HI]	ID- σ_1 (RD)	α HI/ β RD	*[+RD]	ID [RD]
i. co:mhun		*!			**	*
ii. co:mhin		*!			*	
iii.						

Postlexical level

/co:mhun/	*[μμμ] _σ	MAX-μ	ID [HI]	ID [RD]
i. ☞ comhun		*		
ii. cumhun		*	*!	
iii. co:mhin	*!		*	
iv. comhin		*		*!
v. cu:mhun	*!		*	
vi. co:mhun	*!			

Notice that in (49), inputs of subsequent levels come from the output of the preceding level.

Stratal-OT does not allow for opacity within the same stratum, though the predecessor Lexical Phonology allows for cyclic rule applications in the same stratum (for roughly as many cycles of affixation of the same class of affixes, Mohanan 1986, 1995). Evidently, Stratal OT is powerless against Tianjin tone sandhi problem where sandhi rules simply cycle up the same (lexical or postlexical) stratum or cross strata.

Orgun's (1996) sign-based morphology relates structural depth and opacity even more explicitly. In fact, his model and that proposed here are almost identical except for one crucial difference. Orgun's model requires all information (phonological, syntactic and semantic) to percolate up the same tree. This effectively disallows any form of mismatch between syntax, semantics and phonology. 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").

The preceding paragraphs show that theories of opacity have implicitly or explicitly confined the depth of opacity to within the depth structural embeddings. Interestingly, 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. 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 correspondence of information, the depth of opacity would be confined to within the number of structural embeddings.

6.2 Binary prosodic structures

In the treatment for tone sandhi, prosodic structures are binary. This is in part motivated by the fact that trisyllabic sequences exhibit clustering effects (cf. §5.1 and §5.4). There is, however, deeper motivation.

It is generally accepted today that prosodic structures are not flat. For example, syllables (or moras) are organized into feet, and feet into phonological phrases, etc. (since Selkirk 1972, and thereafter Liberman & Prince 1977, Hayes 1981, 1989, 1995, Selkirk 1995, Truckenbrodt 1995, 1999, among many others). Taking this as a starting point, two positions are open: (i) the weak hypothesis position where structures are flat unless constituency is motivated; or (ii) the strong hypothesis position where structures are maximally hierarchical (consequently binary branching) unless motivated. This section will demonstrate that there is evidence in favor of the strong position.³¹

First, binarity applies at the level of the foot, as has been accepted since Liberman & Prince (1977) and Hayes (1995). It can be demonstrated that the minimal prosodic word is a binary foot (bimoraic in English, for example).

(50) Minimal English prosodic word is a bimoraic foot

- | | | |
|-----------|----------|----------|
| a. [siti] | b. [sit] | c. *[si] |
| d. *[ti] | e. [si:] | f. [ti:] |

In (50), the only explanation for why (50c) and (50d) are unacceptable is that these do not constitute bimoraic feet.

Though in some cases, there may be degenerate feet that are uni-nary or ternary, such cases are avoided wherever possible. Default parses always aim to produce binary feet, as may be seen in expletive epenthesis cases like *Cali-fucking-fornia*, *abso-fucking-lutely*, etc. (McCawley 1978 and McCarthy 1982), where the expletive is located before the main stress such that preceding syllables must form a minimal foot. Now, if feet are binary, it would be natural that the binarity should not extend to higher prosodic domains.

Second, binarity can be observed at higher prosodic levels. This is most evident in verse where prosody provides the rhythmic template for the words so strongly that syncope is an oft used device to trim the number of syllables (e.g. *o'er*, *hast'ning*, *'tis*).

Consider the example in (51), the first stanza of a familiar song *Londonderry Air* also known as *Danny Boy*.

³¹ It is also noteworthy that scientific traditions prefer strong positions since these exhibit higher falsifiability, which if remaining unfalsified would provide a more stringent account.

(51) First stanza from *Londonderry Air*

Oh Danny ^G boy,	line 1
(σ σ) (σ σ)	
The pipes, the pipes are ^C calling	line 2
(σ σ) (σ σ) (σ σ) σ	
from glen to ^{G/B} glen and ^{A9} down the mountain ^{D7} side.	line 3
(σ σ) (σ σ) (σ σ) (σ σ) (σ σ)	
The summer's ^G gone	line 4
(σ σ) (σ σ)	
and all the flowers are ^C dying;	line 5
(σ σ) (σ σ) (σ σ) σ	
'tis you 'tis ^G you must ^{A9} go and ^{D7} I must ^G bide.	line 6
(σ σ) (σ σ) (σ σ) (σ σ) (σ σ)	

A careful parse at (51) reveals just how syncope (italicized, line 6) has applied to keep the metrical pattern intact. Each line is iambic with only the second and fifth lines having an extrametrical final syllable. Lines 1 and 4 correspond in terms of syllable count; lines 2 and 5 correspond perfectly and rhyme; lines 3 and 6 also correspond and rhyme.

Something else is afoot in (51); there is a sense that lines 1, 2 and 3 form a larger constituent echoed by lines 4, 5 and 6 as another larger unit of its own. This is reflected in the syntax of those lines and also from the progression of the music, which may be seen from the chords indicated in superscript. Notice that the chords cycle as G-C-G-A9-D7. So, here one sees that the stanza is bifurcated into two parts.

In each part, there are three lines, which are also divided into two. Lines 1 and 2 form a rhythmic constituent, as do lines 4 and 5. This is evidenced by the rhyming (lines 1 and 3 do not rhyme) and by the music (the first chords in lines 3 and 6 begin with G, as do the first chords of lines 1 and 4, but not lines 2 and 5), which gives the pattern Gx.Gyz.

The example cited here is not an isolated instance. Metrical verse across a large number of languages exhibits binary division extensively in the forms of couplets, hemistichs, and feet. In Chinese Tang poetry, for example, Chen (1979, and also 1984) demonstrates how the template for regulated verse can be derived by simple binary requirements starting from the stanza, to the couplet, the hemistich, and the foot.

As such, direct empirical support for binarity of prosodic structures come from (i) the need for binary constraints at the level of the foot anyway; and (ii) the rampant use of binary division of higher prosodic constituents in verse and lyric. Indirect support for such a position comes from binarity in syntax which tend to be aligned with prosody

(again Selkirk 1995, Truckenbrodt 1999 etc.), and also the relative simplicity of having a singular binary principle that applies across the board rather than an ad hoc set that has to be stipulated for the varied domains where binarity applies. Each of these arguments is in itself not very strong, but the convergence makes for a convincing case.

Finally, if it could indeed be demonstrated that binary requirements do not apply to prosodic structures, that is nonetheless not detrimental to the inter-tier correspondence account. Binarity of structure is not entailed per se in inter-tier correspondence. All that inter-tier correspondence requires is that there are hierarchical structures. If it could be demonstrated that hierarchical organization is illusory or irrelevant to phonology, then inter-tier correspondence would be falsified.

7. Conclusion

This paper argues for a model of phonology where information can be encoded in non-terminal nodes. Since structure is generated by principles, certain fundamental information would come from the terminal nodes, which percolates via correspondence across nodes that are connected. Not all information needs to come from terminal nodes though, since information like focal stress would more likely be assigned to a higher node before percolating downwards to the relevant vowel(s). By virtue of correspondence, percolation does not have to be construed as procedural.

Such a model captures opacity and other derivational effects through unfaithful percolation/correspondence of information across tiers in a structural representation. The case studied here comes 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. This awkward state of affairs makes 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.

(52) Inter-tier Correspondence Theory

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 are directly linked to one another.

c. **Violability of correspondence**

Correspondence of information between nodes is not necessarily perfect.

The theory derives phonological alternations, depth of opacity and blocking of alternation from structural configuration. This is appealing because it provides a unified account for a diverse range of phenomena across languages. Through looking at related phenomena in Tianjin and beyond, and also drawing upon studies by other scholars in the area of opacity and prosodic, the inter-tier correspondence model is argued to be a promising one.

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*ROA = Rutgers Optimality Archive, <http://roa.rutgers.edu>, retrieved 12 September 2009.

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以層級投射看天津方言的連讀變調

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天津方言中三連調的變化規律無論對優選論還是傳統的推演都構成很大的挑戰。若以推演的方式進行，則需要制定推演中途方向轉移的裝置；若以優選論進行解釋則會遇上透明與非透明現象相纏的死結。本文建議以層級投射的辦法來解決問題：結構樹中結點與結點之間所含信息必須有所對應，因而最低結點的音系訊息自然出現向上投射的效果。這個對應在一般情況下完全一致，但如果投射產生標記性，那麼對應可能會出現偏差。這個理論需要我們重新考慮語音的呈現形式，並且帶來四種預期效果：(1) 方向性可以從結構推衍出來；(2) 非透明性的深度與結構的層級有直接關係；(3) 音系規則的作用針對的是同屬一個音系單位的語音成分，不是相鄰的語音成分，所以出現變調組合時，如果兩個音節分屬不同單位經常可以維持不變調；(4) 深層的音段可分別以兩種形式同時在表層上出現。

關鍵詞：投射，對應，非透明，方向性，連讀變調，天津