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OT-CC: A Minimal Approach to Shaoxing Trisyllabic Tone Sandhi

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1. Phonological Opacity in Shaoxing Trisyllabic Tone Sandhi

Shaoxing Chinese, one of the Wu dialects in China, has eight citation tones, divided into four high register tones and four low register tones. Their tone pitches and feature specifications are presented in (1):

(1)	Falling	Rising	Low level	High level
High Register	52 [H.hl]	35 [H.lh]	33 [H.l]	5 [H.h]
Low Register	31 [L.hl]	13 [L.lh]	22 [L.l]	3 [L.h]

In Table (1), 'H' specified high register, 'L' is low register, 'hl' represents a falling contour, 'lh' a rising contour, 'l' is a low level tone, and 'h' is a high level tone. Shaoxing Chinese, like many other Chinese dialects, has various complicated tone sandhi rules. Zhang (2006) presents an analysis of Shaoxing disyllabic tone sandhi in classic OT (Prince & Smolensky 1993/2004) and argues that the surface dissimilation of a sequence of tones is in fact caused by underlying tone feature assimilation, which is realized by tone feature spreading or/and delinking in the foot domain (which is right-prominent). The right-prominent metrical structure of Shaoxing and the phonological behavior of the tone features in Shaoxing tone sandhi can be accounted for by the following constraint hierarchy (Zhang 2006):

(2) *CROSSL>>*LH，*RL>> OCP>>MAX-F>>DEP-F>> IDENT-T.[1]

These constraints are defined as follows:

*CROSSL: Feature spreading does not create crossing association lines (tone features only spread to or from adjacent syllables; no feature insertion is possible);
*LH: The left-most syllable cannot have a higher tone value than (the) other(s);[2]
*RL: The right-most syllable cannot have a lower tone value than (the) other(s);
OCP: Two adjacent identical contour tones are not permitted in the foot domain;
MAX-F: No tone-feature deletion is allowed;
DEP-F: No insertion of tone-feature spreading from an adjacent syllable is allowed;
IDENT-T: The output tone should be identical to the input tone.

This constraint hierarchy explains the disyllabic tone sandhi rules in Shaoxing from the perspective of tone features. To show how classic OT handles phonological changes in Shaoxing disyllabic tone sandhi, we present some examples[3] in tableaux (3-5):

1 There are other constraints for disyllabic tone sandhi not listed in (2) because they are irrelevant to this study.
2 The "strength" of Shaoxing four tones ranks as [hl]>>[lh],[h]>>[l] (for details, see Zhang 2006: 234-43).
3 All the data of Shaoxing tone sandhi in this paper are extracted from Yang & Yang (2000).

(3) /lh.lh/ → [lh.hl], e.g. /dɑɒ^{lh}.ɕɑɒ^{lh}/ → [dɑɒ^{lh}.ɕɑɒ^{hl}] ‘straw’:

/lh.lh/	*CROSSL	*LH	*RL	OCP	MAX-F	DEP-F	IDENT-T
a. [lh.l]		*!	*		*		*
b.☞ [lh.hl]							*
c. [l.hl]					*!		**
d. [l.lh]					*!		*
e. [lh.lh]				*!			

(4) /hl.hl/ → [l.hl], e.g. /ɕiaŋ^{hl}.ʔiẽ^{hl}/ → [ɕiaŋ^{l}.ʔiẽ^{hl}] ‘cigarette’:

/hl.hl/	*CROSSL	*LH	*RL	OCP	MAX-F	DEP-F	IDENT-T
a. [hl.hl]				*!			
b.☞ [l.hl]					*		*
c. [hl.l]		*!	*		*		*
d. [l.l]					**!		**

(5) /lh.l/ → [lh.hl], e.g. /me^{lh}.li^{l}/ → [me^{lh}. li^{hl}] ‘beautiful’:

/lh.l/	*CROSSL	*LH	*RL	OCP	MAX-F	DEP-F	IDENT-T
a. [lh.l]		*!	*				
b.☞ [lh.hl]						*	*
c. [l.l]					*!		*
d. [l.hl]					*!	*	**
e. [lh.lh]				*!		*	*

The tableaux above show that the optimal candidates in the three examples all violate certain constraints in terms of tonal reversal (lh → hl) in (3), [h] feature deletion in (4), and [h] feature insertion in (5). Thus, a rule based-approach requires *three* separate rules. It is to the credit of OT that it can deal with all three processes by a single constraint hierarchy. This therefore presents an example of a “rule conspiracy”: several seemingly unrelated rules derive outputs that must conform to certain output conditions. In Shaoxing tone sandhi, the output conditions are captured by the constraint hierarchy in (2).

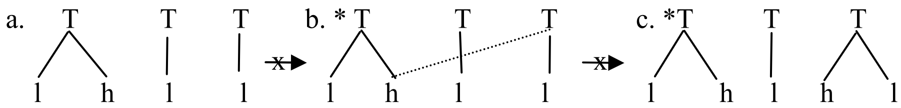
However, in disyllabic tone sandhi, the tone feature(s) spread(s) (if necessary) between the two adjacent syllables in foot domain without creating crossing association lines. Thus, the constraint *CROSSL is usually irrelevant (for a more detailed analysis of Shaoxing disyllabic tone sandhi, see Zhang 2006: 210-55). However, in trisyllabic tone sandhi, the tone feature would appear to spread directly from the left-most syllable to the right-most syllable, or vice versa. This would cross the association line of the tone of the middle syllable, leading to a violation of *CROSSL. According to the data available (Yang & Yang 2000), there are many such trisyllabic sandhi forms as /tu^{lh}.di^{l}.miɑɒ^{l}/ → [tu^{lh}.di^{l}.miɑɒ^{hl}] ‘Earth Temple’. In this case, the trisyllabic sandhi rule (/lh.l.l/ → [lh.l.hl]) cannot be explained by the classic OT constraint hierarchy in (2), which produces a wrong output, as shown in tableau (6):

(6) A wrong output by classic OT for /lh.l.l/ → [lh.l.hl]:

/lh.l.l/	*CROSSL	*LH	*RL	OCP	MAX-F	DEP-F	IDENT-T
a. [lh.l.l]		*!	*				
b. [lh.l.hl]	*!					*	*
c. ☞ *[l.l.l]					*		*
d. [l.lh.hl]					*	*!*	***
e. [l.lh.l]			*!		*	*	**
f. [l.l.hl]	*!				*	*	**

In tableau (6), the candidates (b) –the intended winner– and (f) are ruled out because they violate *CROSSL for a reason that in the output representation the [h] feature in the right-most tone cannot spread directly from the left-most tone across the association line of the middle tone, or be inserted; the candidates in (a) and (e) are ruled out by violating *LH and *RL respectively; candidate (d) is also ruled out by violating DEP-F; Thus, candidate (c) is the winner, but is in fact the wrong output. Without the constraint *CROSSL, candidate (b) would be more optimal than (c), but the right-most syllable in [lh.l.hl] has the feature [h] which spreads from the left-most syllable, creating a crossing-association line with the middle syllable, as presented in (7):

(7) Crossing association line from /lh.l.l/ to [lh.l.hl] in classic OT:



The prohibition against crossing association lines (Goldsmith 1976: 27) is a well-documented cross-linguistic principle which is also strictly observed in Shaoxing tone sandhi rules. In (7), we show that the [h] feature in the left-most tone crosses the association line of the middle syllable when spreading to the right-most syllable, which is not allowed. However, the feature spreading in /hl.l.l/ → [l.lh.hl] is transparent. It is easy to observe that the [h] feature in the middle syllable comes from the adjacent left-most syllable and spreads to the adjacent right-most syllable, and then the [h] feature is delinked from the left-most tone. In this way, it is legal to spread the [h] feature from the left-most syllable to the right-most one without creating a crossing association line. Sometimes in the Shaoxing trisyllabic tone sandhi, the feature spreading goes through several intermediate processes from the input to the output. These processes interact opaquely, as in the case of /lh.l.l/ → [lh.l.hl] where the [h] feature in the left-most syllable first spreads to the middle syllable, and then from the middle syllable to the right-most syllable to satisfy the Principle of Crossing Avoidance (McCarthy & Prince 1986). Then the [h] feature in the middle syllable is delinked because of the OCP. The intermediate steps from /lh.l.l/ to [lh.l.hl] can be presented as follows (where we use constraints to illustrate what the rules would derive):

(8) The derivational processes in /lh.l.l/→[lh.l.hl]:

Underlying:	/lh.l.l/
Feature spreading (satisfiying *LH):	[lh.hl.l]
Feature spreading (satisfiying *RL):	[lh.hl.hl]
Feature deletion (satisfiying OCP):	[lh.l.hl]
Surface:	[lh.l.hl]

Unlike disyllabic tone sandhi, trisyllabic tone sandhi always involves feeding, bleeding or counterbleeding order between the separate rules. There are more examples of trisyllabic sandhi forms which involve opaque interaction going from underlying to surface structure, as presented below (Yang & Yang 2000):

(9)	Citation tones	Sandhi forms	Gloss	Feature change
	a. /hu^{lh}.tsʼo^{hl}.lu^{l}/	[hu^{lh}.tsʼo^{l}.lu^{hl}]	‘railway’	/lh.hl.l/ → [lh.l.hl]
	b. /kəʔ^{h}.tɕʼi^{l}.ɦuo^{l}/	[kəʔ^{h}.tɕʼi^{lh}.ɦuo^{hl}]	‘polite words’	/h.l.l/ → [h.lh.hl]
	c. /ɦiɤ^{hl}.dɤ^{l}.ɦu^{l}/	[ɦiɤ^{l}.dɤ^{lh}.ɦu^{hl}]	‘fried bean curd’	/hl.l.l/ → [l.lh.hl]
	d. /kiẽ^{lh}.ɕi^{lh}.de^{l}/	[kiẽ^{lh}.ɕi^{l}.de^{hl}]	‘dare-to-die corps’	/lh.lh.l/ → [lh.l.hl]

In rule-based phonology (Chomsky & Halle 1968), different rule orderings make it possible to derive the feeding, bleeding or counterbleeding order of tone sandhi rules. The sandhi rule in (9e) is an example of counterbleeding opacity. Its derivation goes as follows:

(10) Counterbleeding opacity in /lh.lh.l/ → [lh.l.hl];

Underlying:	/lh.lh.l/
Feature spreading (satisfies *RL):	[lh.lh.hl]
Feature deletion (satisfies OCP):	[lh.l.hl]
Surface:	[lh.l.hl]

If feature deletion applies first ([lh.lh.l]→ [lh.l.l]), the right-most syllable cannot get the [h] feature from the adjacent syllable, creating a bleeding effect. But the sandhi rule in (9e) causes a counterbleeding order by applying feature deletion after feature spreading, which satisfies the *RL constraint, as presented in (10). In counterbleeding opacity, a phonological process occurs even though the conditioning environment is not present in surface structure (McCarthy 2007:24). Taking (9e) as an example, the right-most tone changes from [l] to [hl] even though the adjacent tone has no [h] feature in the surface form ([lh.l.hl]). So the /l/ → [hl] unfaithful mapping is a response to phonological conditions that are not visible in the output form, though they are visible in the input.

Another phonological opacity effect in Shaoxing trisyllabic tone sandhi is related to feeding order, through which the application of one rule makes the application of another rule possible, as is exemplified in (9c). The derivation is illustrated in (11):

(11) Feeding order in /h.l.l/ → [h.lh.hl]:

Underlying:	/h.l.l/
Feature spreading (satisfies *LH):	[h.hl.l]
Feature spreading (satisfies *RL):	[h.hl.hl]
Contour dissimilation (satisfies OCP):	[h.lh.hl]
Surface:	[h.lh.hl]

In (11), the first step (feature spreading from the left-most to the middle syllable) makes it possible to spread the [h] feature to the right-most syllable without creating crossing association lines. Thus, one application feeds another. Finally, contour dissimilation is applied because the OCP dominates MAX, DEP and IDENT in Shaoxing tone sandhi. In some cases, a sandhi form involves metathesis from input to output in terms of tone type. Phonologically, we cannot change the positions of two tones, as in (9a), without good reason. The surface metathesis in /lh.hl.l/ → [lh.l.hl] goes through a derivation as in (12):

(12) Metathesis in /lh.hl.l/ → [lh.l.hl]:

Underlying:	/lh.hl.l/
Feature spreading (satisfies *RL):	[lh.hl.hl]
Feature deletion (satisfies OCP):	[lh.l.hl]
Surface:	[lh.l.hl]

Processes involving counterbleeding order, feeding order and metathesis in Shaoxing trisyllabic tone sandhi cause opacity. These opaque interactions cannot be examined in classic OT, as was pointed out above.

As shown in (6), classic OT fails to select the optimal output of trisyllabic sandhi forms which involve opaque derivations because, as McCarthy (2007:20-21) puts it, classic OT denies the existence of rule ordering, and therefore abandons derivation. Classic OT recognizes just two levels of representation, underlying and surface, but nothing in between. To account for phonological opacity, McCarthy (2006, 2007) proposes a new and revolutionary theory: Optimality Theory with Candidate Chains (shorten as OT-CC). In the next section we will present an analysis of Shaoxing tone sandhi cast in this framework.

2. Analysis in OT-CC

2.1 Principle of OT-CC

McCarthy (2007:3-9) argues that any mapping from the underlying to the surface level of representation is a derivation. In OT-CC, he proposes a new version of OT that allows some derivation in OT and claims that a candidate in OT includes not just a surface form but also a series of intermediate forms, each of which is minimally different from the form that immediately precedes it. McCarthy (2007:67) points out the obvious resemblance between a candidate chain and the sequence of forms that appear in a phonological derivation: both involve intermediate representations that describe a path between the underlying and surface levels of representations.

In OT-CC, a candidate is a chain of forms rather than a single form; the number of constraints in $\mathcal{H}$ is finite; the number of candidates is also finite. The definition of a candidate chain in McCarthy (2007:71) specifies three requirements: the properties of the initial form in a chain, gradualness, and local optimization. These three requirements are the cornerstones of OT-CC, which can be briefly summarized as follows (McCarthy 2007:61):

- Faithful first member: The first member of every candidate chain based on the input must be a fully faithful parse of the input form;
- Gradualness: In every pair of immediately successive forms in a chain, $<\ldots, f_i, f_{i+1}\ldots>$, f_{i+1} has all of f_i's unfaithful mappings, plus one. i.e. after the faithful first member, every form in a chain is a localized unfaithful mapping (LUM).
- Local optimality: In every pair of immediately successive forms in a chain, $<\ldots, f_i, f_{i+1}\ldots>$, f_{i+1} is more harmonic than f_i according to EVAL$\mathcal{H}$.

Such a candidate chain as characterized with these three requirements fully embodies a phonological derivation between the underlying and the surface such as in the sandhi rules described in (8-12). Through an analysis in OT-CC, the phonological opacity in Shaoxing trisyllabic tone sandhi can be explicitly examined and interpreted.

2.2 Valid chains from input to output in Shaoxing tone sandhi derivation

Cross-linguistically speaking, *CROSSL is an undominated constraint in terms of feature spreading. Tightly connected to Shaoxing tone sandhi is metrical structure, which is characterized by right-prominence in the foot domain (Zhang 2006:229-240). To satisfy the right-prominent metrical structure, tone feature spreading and delinking are always invovled. But why is /lh.hl.l/ → [lh.l.hl] more harmonic than /lh.hl.l/ → [l.l.hl] or [l.lh.hl], even though both [l.l.hl] and [l.lh.hl] satisfy the right-prominent metrical structure? From the perspective of OT-CC, valid chains from the input to the output provide an insightful answer to this question. Take /lh.hl.l/ → [lh.l.hl] 'railway' as example:

(13) Valid chains from /lh.hl.l/ → [lh.l.hl]:

a. <lh.hl.l> Faithful parse

b. <lh.hl.l, lh.hl.hl> Harmonically improving because of *RL>>OCP.

c. <lh.hl.l, lh.hl.hl, lh.l.hl>✓ Harmonically improving because of OCP>>MAX.

In (13c), there are two LUMs after the faithful first member <…, lh.hl.hl, lh.l.hl>, of which f_{i+1} <lh.l.hl> has two f_i's unfaithful mappings by violating DEP and MAX, and f_{i+1} <lh.l.hl> is more harmonic than f_i by deleting the [h] feature from the middle tone to satisfy OCP. The derivation in (13c) is a minimal approach to the output of /lh.hl.l/. Any other possibility is either more expensive or less harmonic. For example, possible sandhi forms like /lh.hl.l/ → [l.l.hl] or [l.lh.hl] would have invalid chains, as presented below:

(14) *<lh.hl.l, l.hl.l, …> Not harmonically improving;

(15) *<…, lh.hl.hl, l.hl.hl> Not harmonically improving;

(16) *<…, lh.l.hl, l.l.hl> Not harmonically improving.

From (14) to (16), the f_{i+1} LUM is not at all more harmonic than the preceding f_i LUM, providing no local optimality. If we delete the [h] feature from the left-most tone in <lh.hl.l, l.hl.l>, or in <lh.hl.hl, l.hl.hl>, it does not make any harmonic improvement when the violation of *RL still remains as in (14), or when OCP is still violated as in (15); if we delete the [h] feature from the left-most tone in <lh.l.hl, l.l.hl>, it either does not make any harmonic improvement by violating the faithful MAX one more time. Thus, none of the chains from (14) to (16) is invalid. That's why /lh.hl.l/ → [lh.l.hl] is more harmonic than /lh.hl.l/ → [l.l.hl] or [l.lh.hl]. Candidate chains thus provide a minimal and economical approach to selecting the optimal output, especially because in OT-CC the number of candidates is finite. According to the valid chains in (13), the candidates from /lh.hl.l/ → [lh.l.hl] can be presented in LUMs as in (17):

(17) Candidates from (13):[4]

a. lh.hl.l, ∅, ∅

b. lh.hl.hl, {DEP@3}, ∅

c. lh.l.hl, {DEP@3, MAX@2}, {< DEP@3, MAX@2 >}✓

The intended winner is candidate (c) with output [lh.l.hl], though it violates DEP and MAX. Yet it satisfies the dominating *RL and OCP. The valid chains in (13) and the candidates in (17) explicitly explain the derivation processes from /lh.hl.l/ → [lh.l.hl]. As such, OT-CC is a minimal approach to phonological opacity. The same is true with another trisyllabic tone sandhi pattern like /hl.l.l/ → [l.lh.hl] 'fried bean curd', which has the following valid chains.

(18) Valid chains from /hl.l.l/ → [l.lh.hl]:

a. <hl.l.l>	Faithful parse
b. <hl.l.l, hl.hl.l>	Harmonically improving because of *LH>>OCP>> DEP.
c. <hl.l.l, hl.hl.l, l.hl.l>	Harmonically improving because of OCP>>MAX.
d. <hl.l.l, hl.hl.l, l.hl.l, l.hl.hl>	Harmonically improving because of *RL>>OCP>> DEP.
e. <hl.l.l, hl.hl.l, l.hl.l, l.hl.hl, l.lh.hl>✓	Harmonically improving because of OCP>>IDENT.
f. <hl.l.l, hl.hl.l, l.hl.l, l.hl.hl, l.l.hl>	Harmonically improving because of OCP>>MAX.
g. <hl.l.l, l.l.l>	Harmonically improving because of *LH>>MAX.

In (18), the intended winner is (e) with four LUMs, among which the immediately successive LUM is more harmonic than the preceding one. The ℒ-set of (18f) is also valid for the gradualness and local optimality. But [l.l.hl] is not the optimal output because MAX dominates IDENT in Shaoxing tone sandhi so that the violation of IDENT is less serious than that of MAX, making [l.lh.hl] preferred to [l.l.hl] as the sandhi form. Another way to satisfy *LH would simply be to delete the [h] feature from the left-most tone, as in (18g). But the candidate [l.l.l] has the potential disadvantage of being in a right-prominent foot domain, which always requires a high-value tone in the right-most syllable. Unless the input is /l.l.l/, the right-most tone always has an [h] value in trisyllabic sandhi forms. For this right-prominent metrical structure, I propose the R[h][5] constraint, which can be ranked low, e.g. dominated by MAX. In the ℒ-set of (18e), four different processes between the underlying and the surface interact opaquely as follows:

a. *Tone spreading*: The [hl] tone spreads to the adjacent middle syllable to replace its original [l] tone to satisfy *LH, resulting in [hl.hl.l].

b. *Feature deletion*: [h] is deleted from the left-most tone to satisfy the OCP, changing [hl.hl.l] into [l.hl.l].

c. *Tone spreading*: The [hl] tone of the middle syllable spreads to the adjacent right-most syllable to replace its original [l] tone, changing [l.hl.l] into [l.hl.hl], to satisfy *RL.

d. *Contour dissimilation*: The contour [hl] of the middle syllable changes into an [lh] contour to dissimilate the two contours, resulting in [l.lh.hl], to satisfy the OCP.

4 In feature representation of tones, the numbered position refers to the tone, rather than the feature.

5 R[h]: The right-most tone requires an [h] value, which is not listed in the OT-CC tableaux in this study because it is ranked low.

These processes interact opaquely one step after another. Without resorting to derivation, we could hardly see the intermediate processes between the underlying /hl.l.l/ and surface [l.lh.hl] which involves multiple cases of opacity. According to the valid chains in (18), necessary candidates from /hl.l.l/ → [l.lh.hl] include:

(19) Candidates from (18):

a. hl.l.l, ∅, ∅

b. hl.hl.l, {DEP@2}, ∅

c. l.hl.l, {DEP@2, MAX@1}

d. l.hl.hl, {DEP@2, MAX@1, DEP@3}

e. l.lh.hl, {DEP@2, MAX@1, DEP@3, IDENT@2},
{<DEP@2, MAX@1, DEP@3, IDENT@2>} ✓

In (19), the candidate chain (e) is the intended winner for its harmonic improvement through each LUM in the chain. The candidates in (19) also show that in OT-CC the number of candidates corresponding with the constraint hierarchy is finite and the candidates have to be properly ordered, while in classic OT the number of candidates are infinite and the candidates are free in order. Every candidate chain in OT-CC involves a process of derivation from the underlying to the surface. The phonological opacity during these processes of derivation is clearly illustrated by every LUM in the candidate chain, and the optimal candidate can be easily and correctly selected by an OT-CC tableau which includes a precedence constraint.

2.3 Effect of precedence constraints in Shaoxing trisyllabic tone sandhi

Another important point in OT-CC is the application of the precedence constraint. McCarthy (2007:98) formalizes precedence constraints in OT-CC as follows:

(20) PREC(A, B)(*cand*)

Let A' and B' stand for LUMs that violate the faithfulness constrains A and B, respectively.

Let *cand*=(*in*, *out*, $\mathcal{L}$, rL)[6]

(i) ∀B' ∈ $\mathcal{L}$, if ∄A' ∈ $\mathcal{L}$, where <A', B'>∈ rL, assign a violation mark.

(ii) ∀B' ∈ $\mathcal{L}$, if ∃A' ∈ $\mathcal{L}$, where <B', A'>∈ rL, assign a violation mark.

According to (20), PREC(A, B) demands that every B-violating LUM be preceded and not followed by an A-violating LUM in the rLUMSeq. This means the constraint PREC(A, B) is violated if a B-violating LUM is followed or not preceded by an A-violating LUM in the rLUMSeq and it violates PREC(A, B) twice if a B-violating LUM is followed and also not preceded by an A-violating LUM in the rLUMSeq.

Based on the constraint hierarchy in Shaoxing tone sandhi and the valid chains described in (13) and (18), the constraint PREC(A, B) in Shaoxing tone sandhi is PREC(DEP-F, MAX-F), which, by metaconstraint ranking (McCarthy 2007:99), never dominates the faithfulness constraint B. This means that PREC(DEP-F, MAX-F) is necessarily and universally ranked below MAX. Thus, we have a constraint hierarchy in OT-CC for Shaoxing trisyllabic tone sandhi, as is presented

6 In McCarthy (2007:97), *in* is a linguistic form, the input; *out* is a linguistic form, the output; $\mathcal{L}$ is a set of LUMs on *in* → *out*; rL (reduced LUM sequence) is a partial ordering on a subset of $\mathcal{L}$.

below:

(21) *CROSSL>>*LH, *RL>> OCP>>MAX-F>>PREC(DEP-F, MAX-F)>>DEP-F>>IDENT-T.

In the hierarchy of (21), PREC(DEP-F, MAX-F) plays a very important role in evaluating the candidates for Shaoxing trisyllabic tone sandhi which involves phonological opacity. From the tableau in (6), we have learnt that classic OT failed to derive the sandhi form /hl.l.l/ → [l.lh.hl] 'fried bean curd'. Bearing in mind the valid chains discussed previously and the hierarchy in (21), now let's see how OT-CC handles Shaoxing trisyllabic tone sandhi in a tableau, as presented below.[7]

(22) OT-CC analysis of /lh.l.l/ to [lh.l.hl]:

/lh.l.l/	*LH	*RL	OCP	MAX-F	PREC(DEP-F, MAX-F)	DEP-F
a. [lh.l.l] < >	*!	*				
b. [lh.hl.l] <DEP@2>		*!				*
c. [lh.hl.hl] < DEP@2, DEP@3>			*!			**
d. [lh.l.hl] ✓ < DEP@2, DEP@3, MAX@2 >				*		**
e. [l.l.l] < MAX@1 >				*	*!	

In (22), the rLUMSeq of (d) is more optimal than the rLUMSeq of (e) because the former has a B-violating LUM preceded but not followed by an A-violating LUM, satisfying PREC(DEP-F, MAX-F), while the latter violates PREC(DEP-F, MAX-F) for not having an A-violating LUM preceding the B-violating LUM, according to the definition of PREC(A, B) in (20). This result conforms to the right-prominent metrical structure.

However, the ℒ-set of (22d) looks problematic with both DEP@2 and MAX@2 in the same rLUMSeq; as McCarthy (2007:78) puts it: "a putative chain like **<pap, papə, pa.bə, pab> is invalid under the gradualness requirement because it adds and then withdraws a DEP-violating LUM, so its path of increasing unfaithfulness is nonmonotonic." But McCarthy immediately adds that "chains of this type can, at least in principle, be harmonically improving, so nothing else in the theory rules them out." It is true that the LUMs of DEP@2 and MAX@2 in the same rLUMSeq in (22d) are harmonically improving one after the other. The LUM of MAX@2 occurs in the quite different situation where the LUM of DEP@2 occurs. Thus, the chain of (22d) is valid for its gradualness and local optimality. The constraint PREC(DEP-F, MAX-F) has a clearer effect on the sandhi form of /lh.lh.l/ → [lh.l.hl], as is presented in tableau (23):

7 In the following tableaux, the constraints of *CrossL and IDENT are omitted since they are irrelevant to the data discussed in the evaluation.

(23) OT-CC analysis of /lh.lh.l/ → [lh.l.hl]:

/lh.lh.l/	*LH	*RL	Ocp	Max-F	Prec (Dep-F, Max-F)	Dep-F
a. [lh.lh.l] < >		*!	*			
b. [lh.lh.hl] < Dep@3 >			*!			*
c. [lh.l.hl] ✓ < Dep@3, Max@2 >				*		*
d. [l.lh.l] < Max@1 >		*!		*	*	
e. [l.lh.hl] < Max@1, Dep@3 >				*	*!*	*

In (23), the rLUMSeq of (c) is the winner because it does not violate the constraint Prec (A, B) while the rLUMSeq of (e) is ruled out by violating Prec (A, B) twice because its B-violating LUM is not preceded but followed by an A-violating LUM. The difference between (c) and (e) lies in the fact that in (c) the first LUM is made by Dep@3 to satisfy *RL because of *RL>>OCP>>Dep, while in (e) the first LUM is made by Max@1 to satisfy OCP because of OCP>>Max, leaving the violation of *RL unimproved. Thus (c) is more optimal than (e) because of *RL>>OCP and Max>>Dep. But this difference in ordering cannot be seen in the surface forms because the intermediate processes are opaque. However, OT-CC can effectively examine this phonological opacity. Other examples of Shaoxing trisyllabic tone sandhi can also be correctly and explicitly interpreted in OT-CC, even though the constraint Prec (A, B) may be irrelevant. See the following tableaux.

(24) OT-CC analysis of /lh.hl.l/ → [lh.l.hl]:

/lh.hl.l/	*LH	*RL	Ocp	Max -F	Prec (Dep-F, Max-F)	DEP-F
a. [lh.hl.l] < >		* !				
b. [lh.hl.hl] < Dep@3 >			* !			*
d. [lh.l.hl] ✓ < Dep@3, Max@2 >				*		*

In (24), the intended winner is (d). Even though Prec (A, B) is irrelevant, OT-CC derives the minimal necessary candidates according to the constraint hierarchy in (21), by which any other candidate chain from /lh.hl.l/ → [lh.l.hl] is invalid in OT-CC, as described in (14-16). The same is true with /hl.l.l/ → [l.lh.hl], as presented in (25):

(25) OT-CC analysis of /hl.l.l/ → [l.lh.hl]:

/hl.l.l/	*LH	*RL	OCP	MAX-F	PREC (DEP-F, MAX-F)	DEP-F
a. [hl.l.l] < >	* !	*				
b. [hl.hl.l] < DEP@2 >		*!	*			*
c. [l.hl.l] < DEP@2, MAX@1 >		*!		*		*
d. [l.hl.hl] < DEP@2, MAX@1, DEP@3 >			*!	*	*	**
e. [l.lh.hl] ✓ < DEP@2, MAX@1, DEP@3, IDENT@2 >				*	*	**
f. [l.l.hl] < DEP@2, MAX@1, DEP@3, MAX@2>				**!	*	**

The analysis in (25) shows that from /hl.l.l/ to [l.lh.hl] there are more intermediate processes which interact opaquely. However, the £-set in (e) is the winner because every LUM in it is harmonically improving, thus violating the constraint hierarchy least. Although the rLUMSeq in (f) is also a valid chain by applying MAX@2 in its last LUM to satisfy the OCP, yet the violation of MAX is more serious than that of IDENT because of MAX>>IDENT. Thus, (f) is ruled out because it violates MAX twice.

All the analyses of the examples of Shaoxing trisyllabic tone sandhi show that no matter how many candidate chains are listed in the tableaux, the number of candidates is finite and all candidates corresponding with the hierarchy have to be properly ordered for the gradualness and local optimality in OT-CC. With the constraint PREC (A, B), any phonological opacity of intermediate processes in Shaoxing tone sandhi can be explicitly accounted for.

3. Conclusion

Shaoxing trisyllabic tone sandhi involves phonological opacity between the underlying tones and the surface sandhi forms on the assumption that the different tone sandhi forms in Shaoxing are in fact caused by the spreading or/and delinking of the tone features. The prohibition against crossing association lines in feature spreading is a universal principle. Avoiding crossing association lines in trisyllabic tone sandhi is phonologically crucial. Tone sandhi involves intermediate processes interacting opaquely. Such phonological opacity is beyond the capability of classic OT, which abandons derivation between the input and output.

McCarthy (2006, 2007) applies derivations like those of rule-ordering to OT in terms of OT-CC, in which candidate chains have successive LUMs to bring out the opaque interactions between the underlying and the surface. This study shows that OT-CC provides an easy and minimal approach to the analysis of phonological opacity in the Shaoxing trisyllabic tone sandhi, casting insightful light on the interpretation of the complexity of phonological opacity in other aspects.

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