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Recursive Constraint Evaluation in Optimality Theory:
Evidence from Cyclic Compounds in Shanghai*

Abstract

An important assumption in Optimality Theory is parallelism, and a proper analysis of cyclic effects is crucial. I examine a typical case of cyclicity, namely, stress in Shanghai compounds, where the layers of embedding are in principle unlimited. I show that alignment constraints are inadequate. Instead, identity constraints are needed, in particular Stress-ID which requires that stress locations in the immediate constituents of a compound be the same as when the constituents occur alone. In addition, Stress-ID (and other constraints) must be checked recursively, namely, at every layer of syntactic bracketing. This analysis incorporates the essential properties of the cycle and can therefore handle all cyclic cases. Finally, I discuss the compatibility of recursive constraint evaluation with parallelism, and the remaining differences between a cyclic analysis and recursive constraint evaluation.

1. Introduction

Optimality Theory (Prince and Smolensky 1993, hereafter OT) has made important contributions to our understanding of some long-standing phonological problems. For example, it has been a puzzle as to why phonological rules sometimes conspire to achieve certain output goals. Similarly, although many phonological constraints recur in language after language, such as the requirement for a syllable to have an onset, it is nevertheless hard to find universal constraints that are not violated somewhere. The OT solution to the first problem is that surface forms are determined by output constraints, not by rules and derivations. The OT solution to the second problem is that constraints can be in conflict, in which case some will override others. In other words, when a constraint is violated, it is always because it is in conflict with another more important constraint that must be satisfied.

In a derivational model, such as that of Chomsky and Halle (1968), a set of ordered rules applies to the input. Each rule application (except the last) gives an intermediate level of representation. There can, therefore, be many intermediate levels before the final output is reached. With a shift from derivational rules to output constraints, intermediate levels are called into question. In particular, if ranked constraints do the same job as (or a better job than) a set of ordered rules, then just two levels are needed, the input level and the output level. OT has shown that a constraint-based analysis can often be superior (Prince and Smolensky 1993, and much subsequent OT literature). An emerging model, then, is the 'parallel' analysis, in which given an input, all possible output candidates are evaluated in one step.

Two challenges to the one-step analysis have been noted. First, as Booij (1995) points out, there are cases that are traditionally addressed in Lexical Phonology, whereby different sets of rules apply at different lexical levels. In Optimality Theory, this requires positing two or more levels of grammar, each with a different constraint ranking. This modification seems to have been accepted by some OT researchers. For example, McCarthy and Prince (1993b) suggest that the phonology of Axininca Campa may involve three levels, each having a different constraint ranking.

A second challenge to the one-step analysis is the traditional cycle, according to which phonological rules apply first to the smallest morphosyntactic units and then to larger and larger morphosyntactic units (Chomsky, Halle, and Lukoff 1956, Chomsky and Halle 1968). There are two well-known cyclic cases: cyclic affixation and cyclic compounding. In the former case,

several studies have suggested that parallelism can be maintained (e.g. Cohn and McCarthy 1994; Kenstowicz 1995; Benua 1995a,b; Buckley 1995; McCarthy and Prince 1995; for a different view, see Orgun 1994). Compared with affixation, compounding presents a greater challenge. This is because the number of cyclic affixes in a language is often limited. For example, in Indonesian, stress is sensitive to suffixes, but only two suffixes can be attached to a word (Cohn 1989). In contrast, in compounds the layers of embedding are in principle unlimited in number, and the kinds of branching are much richer. In this study, therefore, I will focus on cyclicity in compounds.

I use evidence from compound stress in Shanghai (also called Mainstream Shanghai by Xu et al. 1988), a Chinese dialect spoken by the majority of people in Shanghai City. In Section 2 I describe compounding, tone, and stress in Shanghai. In Section 3 I list the major patterns to be analyzed in this article. A cyclic analysis in traditional terms is given in Section 4. In Section 5 I discuss an OT analysis that uses alignment but not identity constraints and show that it is inadequate. In Section 6 I discuss an OT analysis that uses an identity constraint Stress-ID, which requires stress locations in the immediate constituents of a compound to be the same as when the constituents occur alone (see (56) for a precise definition); I show that in order to get the correct result, Stress-ID (and other constraints) must be checked recursively on every layer of syntactic bracketing. In Section 7 I make some concluding remarks, including the compatibility of recursive constraint evaluation with parallelism, and a comparison between a recursive constraint evaluation and the traditional cyclic analysis.

2. Compounds, tone, and stress in Shanghai

My Shanghai data come from Xu et al. (1988), Duanmu (1995), and the native speakers I consulted.¹ I discuss compounds, tone, and stress in turn.

2.1. Nominal compounds in Chinese

I restrict my discussion to nominal compounds, which constitute the majority of all compounds. Chinese has two nominal structures, [M N] and [M de N], shown in (1a) and (1b) respectively, where N is the head noun, M a modifier, and 'de' a particle.² Like other lexical items, the pronunciation of 'de' varies in dialects. Since the compound properties discussed in this section are true for all Chinese dialects, I transcribe the data in Pinyin (a spelling system that approximates the standard dialect Mandarin), with tones omitted. In addition, since Chinese does not mark number, all nouns are glossed in the singular.

- | | | | | |
|-----|----|-----------------|----|------------------|
| (1) | a. | [M N] | b. | [M de N] |
| | | gao shan | | gao de shan |
| | | tall mountain | | tall DE mountain |
| | | 'tall mountain' | | 'tall mountain' |

There is a consensus that [M de N] is not a compound. Standard Chinese grammar books, such as Chao (1968:285), consider [M de N] a phrase. Some researchers even consider (1b) to contain a relative clause, so that its correct English translation is not 'tall mountain' but 'mountain that is tall' (Sproat and Shih 1991). In contrast, the status of [M N] is more controversial (see Duanmu 1994 for a review). Some [M N] nominals, such as [you zui] 'glib talker' (lit. 'oil mouth') and [da yi] 'coat' (lit. 'big garment'), are semantically idiosyncratic and are clearly compounds. Opinions differ with regard to [M N] nominals like (1a), which are made of two free words and which are semantically compositional. Besides, nominals like (1a) and (1b) seem synonymous. Moreover, although stress can sometimes distinguish a compound from a phrase in English (cf.

'BLACKbird' vs. 'black BIRD'), the same is not obvious in Chinese. Thus, some Chinese linguists, such as Chao (1968: 185), consider both (1a) and (1b) phrases, with an optional use of the particle 'de'.

There is, however, good evidence that [M N] and [M de N] are syntactically different. In particular, [M N] is not a phrase (XP) but a compound (X^0). The point was made as early as Fan (1958) and reiterated recently by Lu (1990), Dai (1992), and Duanmu (1994). I will mention three properties in which [M N] and [M de N] differ: productivity, conjunction reduction, and adverbial modification. This is shown in (2).

(2)		[M N]	[M de N]
	Productivity	no	yes
	Conjunction Reduction	no	yes
	Adverbial Modification	no	yes

First, consider productivity. [M de N] is fully productive but [M N] is not, as shown in (3).

(3)	a.	*gao shu	b.	gao de shu
		tall tree		tall DE tree
		'tall tree'		'tall tree'

Although [gao] 'tall' can directly modify nouns like [shan] 'mountain', as seen in (1a), it cannot directly modify nouns like [shu] 'tree', as seen in (3a). Instead, the particle 'de' must be used, as seen in (3b). In general, [M N] is not fully productive but [M de N] is, in agreement with the fact that compounds are not fully productive but phrases are. Second, [M de N] allows conjunction reduction but [M N] does not, as noted by Zhu (1982) and Huang (1984). (4) is an example.

(4)	a.	da mao he gou	b.	da de mao he gou
		big cat and dog		big DE cat and dog
		'[big cat] and [dog]'		'[big cat] and [dog]'
		*'big [cat and dog]'		'big [cat and dog]'

There are two meanings in (4b). However, there is just one meaning in (4a), even though [da cat] 'big cat' and [da gou] 'big dog' are good expressions independently. The reason for the lack of the second meaning in (4a) is that the conjunction [he] 'and' usually joins two XPs but not two X^0 s. Since [mao he gou] is already an XP, it cannot take a modifier directly (only an X^0 can), but must do so through the particle 'de'. The same restriction accounts for the lack of reduction in English from '[New York] and [New Orleans]' to *'New [York and Orleans]'. Finally, consider adverbial modification. Whereas the M in [M de N] can be modified by an adverbial, the M in [M N] cannot. This is shown in (5).

(5)	a.	*[[Adv M] N]	b.	[[Adv M] de N]
		*hen/bijiao gao shan		hen/bijiao gao de shan
		very/fairly tall mountain		very/fairly tall DE mountain
		*'very/fairly tall mountain'		'very/fairly tall mountain'

If adverbials are XPs, the difference between (5a) and (5b) has an explanation. Since [M N] is an X^0 , it cannot contain an XP inside. In contrast, [M de N] is an XP, and therefore, can contain another XP. The translation of (5a) may seem good in English, but it is in fact parallel to

*'very/fairly blackbirds', which is also ill-formed (thanks to an NLLT reviewer for this point). For further arguments that [M N] and its recursive derivatives, such as [M [M N]] and [[M N] N], are compounds in Chinese, see Dai (1992) and Duanmu (1994).

With regard to tone and stress in Shanghai, there is always a domain break in [M de N] in normal careful speech, which occurs between the particle 'de' and N (M and N may each contain further domain breaks depending on their internal structures). In [M N], whether there is a domain break or not depends on the length of M and N and their internal structures, to be discussed below.

2.2. Tone in Shanghai

Shanghai is a tone language. There are five phonetic pitch patterns on isolated syllables. Jin (1986) calls them high-falling [HL], mid-rising [MH], low-rising [LH], short-high [MH], and short-low [LH]. These names should not be taken literally. For example, short-low is not a low level tone but a rising tone, which is why Jin uses LH, not L. The five patterns correlate with onset voicing and rime glottalization. [MH] occurs on syllables with a voiceless onset, and [LH] occurs on syllables with a voiced onset. The short tones occur on glottalized rimes only, and other tones occur on non-glottalized rimes only. It is possible, therefore, to posit just two underlying tone patterns, LH and HL (see, for example, Selkirk and Shen 1990, Zhang 1992, Duanmu 1995).³ This is shown in (6).⁴

(6) Shanghai tones

	Voiced Onset		Voiceless Onset	
	+ glottal rime	- glottal rime	+ glottal rime	- glottal rime
/LH/	short [LH]	[LH]	short [MH]	[MH]
/HL/				[HL]

In a polysyllabic domain (discussed below) the initial syllable determines the tonal pattern of the whole: when the initial syllable is LH, the domain pattern is [L H L...L], and when the initial syllable is HL, the domain pattern is [H L...L] (a third domain pattern will be discussed shortly). It can be seen that the surface tones of the first two syllables come from the underlying tones of the initial syllable; other syllables get default L (or perhaps remain toneless). (7) shows some examples (in phonetic transcription; underlying syllable tones are shown above surface tones).

(7)	HL LH LH	LH LH LH	HL HL LH	LH HL LH
	H L L	L H L	H L L	L H L
	çĩ ve ti	lo ve ti	çĩ kō ts ^h ã	lo kō ts ^h ã
	new meal store	old meal store	new work factory	old work factory
	'new restaurant'	'old restaurant'	'new factory'	'old factory'

2.3. Stress in Shanghai

Whether Shanghai has stress or not is a controversial issue. Yip (1980) and Wright (1983) propose that Shanghai compounds have left-headed stress, but Selkirk and Shen (1990:315) argue that native speakers do not have such an intuition. The speakers I have consulted share the view of Selkirk and Shen. In fact, some researchers believe that Chinese has no stress beyond the existence of a small number of unstressed and toneless syllables (Gao and Shi 1963). The lack of native judgment for stress may suggest a lack of phonetic stress (in terms of duration, intensity, and/or pitch range), but it does not exclude the possibility that stress is still present but is realized in other ways.⁵ In other words, to establish the presence of a metrical

system in Chinese, one must go beyond native intuition.⁶ Yip (1992, 1994) has shown that, despite the popular belief that Chinese lacks stress, several Chinese languages do have prosodic feet. Similarly, Shih (1986) and Chen (1993) argue that tone sandhi in Mandarin Chinese is determined by prosodic feet. With regard to Shanghai, Duanmu (1995) has argued that not only are there binary feet, but the feet are left-headed metrical constituents. Let us review some of the evidence. First, we have seen that the underlying tones of the initial syllable are preserved, and those of noninitial syllables are lost. Since it is common in Chinese languages for unstressed syllables to lose their underlying tones, the preservation of tones from the initial syllable supports left-headed stress in Shanghai.

Second, in normal speech, polysyllabic foreign words form disyllabic tonal domains (with a trisyllabic final domain if there is an odd final syllable), indicated by parentheses in (8), which suggest binary foot formation ([z] can be syllabic; hyphens indicate syllable boundaries in the same morpheme).⁷

- (8)
- | | |
|--|---------------------|
| LH LH HL LH LH LH | HL LH LH LH LH |
| (L H) (H L) (L H) | (H L) (L H L) |
| dʒe'-k ^h a'- sz- lu- va'- k ^h a' | ka- li- fo'- ɲi- ja |
| 'Czechoslovakia' | 'California' |

Third, there is an asymmetry between [1 2] and [2 1] compounds (digits indicate the number of syllables in a word). In normal speech, a [1 2] compound forms one domain, as in (9), but a [2 1] compound forms two, as in (10).

- (9)
- | | | |
|--------------|-------------|-----------|
| HL HL LH | *(HL) (H L) | *(H L H) |
| (H L L) | sã fe- ga | sã fe-ga |
| sã fe- ga | | |
| raw tomato | | |
| 'raw tomato' | | |

- (10)
- | |
|-------------------------|
| HL LH HL |
| (H L) (HL) |
| fe- ga t ^h ã |
| tomato soup |
| 'tomato soup' |

It is clear that the underlying tones of the second syllable [fe] in (9) are deleted; if not, either [fe] should surface with its own H, or its H should be shifted to the third syllable [ga], but neither is the case. The obligatory tone deletion in (9) and the lack of it in (10) is predicted if stress is left-headed, so that in [1 2] there is stress clash, which leads to the deletion of stress on the second word,⁸ but in [2 1] there is not, as shown in (11).

- (11)
- | | |
|---------------|---------------|
| x x | x x |
| (x) (x x) | (x x) (x) |
| [1 2] | [2 1] |

Having determined the locations of stress, we turn to the location of metrical boundaries. Since stress is left-headed, it is clear that the left boundary is before the initial syllable. But what about the right boundary? Consider the trisyllabic example in (9). For Halle and Idsardi (1995),

who assume that a metrical domain can be marked at just one end, the metrical domain of (9) is unambiguous, as shown in (12).

- (12) x
 (x x x)

In this structure the right end of the domain is interpreted as extending all the way to the end of the final syllable. In more traditional metrical systems (such as that of Halle and Vergnaud 1987), both ends of a domain are marked, and there are three possibilities for (9), shown in (13).

- (13) x x x
 (x)x x (x x) x (x x x)
 a b c

There are two reasons to reject (13a). First, it assumes a monosyllabic foot, which is generally disfavored (Kager 1989, Prince 1992, among others). Second, it raises the question of how the second syllable can get its surface tone from the first syllable across a foot boundary. The choice between (13b) and (13c) is less obvious.⁹ Since the third syllable does not get its tone from the initial syllable, it is not clear whether it is inside or outside the domain. One may suggest that, all things being equal, (13b) is better, since a left-headed ternary foot is ill-formed (cf. the Strict Binariness Hypothesis of Kager 1989). On the other hand, there is some evidence in favor of (13c). Besides the two tonal patterns discussed so far, there is a third, which applies only when the initial syllable is underlyingly LH, has a voiced onset, and has a glottalized vowel (shown by [']). In this case the first syllable keeps its L, but its H is associated to the last syllable, not to the second.¹⁰ The intermediate syllable(s) also get L, either as a default tone or spread from the initial syllable. Some examples are shown in (14).

- (14) a. LH HL LH b. LH HL HL c. LH LH LH
 (L L H) (L L H) (L L H)
 lo' fe- ga lo'- se- tçi [ba' [bi ɸa]]
 'green tomato' 'Los Angeles' '[white [leather shoe]]'
- d. LH HL LH LH LH LH
 (L L H) (L H L)
 ba' ka- li- fo'- ni- ja
 'White California'¹¹

How tonal domains are determined will be discussed below. The point of interest here is, in the special pattern, the H moves all the way to the end of the domain: it can land at the end of the current word, as in (14b), or in the middle of another word, as in (14d), or it can travel through one (or more) words, as in (14c). If we assume that tonal movement takes place within a metrical domain, then the special pattern suggests that a foot can be trisyllabic (or longer). In the rest of this article I will mark the right end of a domain as far as the H tone can potentially move, as in (13c) and (14). It should be borne in mind though that a strictly binary representation, such as (13b), is not necessarily excluded, although nothing consequential follows from it.¹²

3. The patterns

In this section I list the patterns to be analyzed in this article. I only give the regular patterns in normal careful speech. In hyper articulated speech every syllable can surface with its underlying tones; in the present analysis, this is because every syllable is fully stressed in this style of speech, enabling them to keep their tones. In casual or fast speech, all domains in a compound can merge into one; in the present analysis, this is because stress reduction occurs on all but the initial syllable, as a result of which all but the initial syllable lose their underlying tones. Neither hyper-articulated nor fast speech will be discussed in this article. Finally, some idiomatic or high frequency compounds behave like single words. For example, [[yã mo] se] 'wool sweater' (lit. '[[sheep hair] shirt]') normally forms one domain (yã mo se), instead of the expected two (yã mo)(se) (see below form domain formation). Such cases are not included here. In what follows I list single words and compounds separately. The reason is that foot formation in the former is quite simple, essentially left-to-right binary foot construction; in contrast, foot formation in compounds is sensitive both to the lengths of the component words and to the bracketing structure.

3.1. Single words

The patterns of single words, up to six syllables long, are given in (15), with examples in (16). Longer words are theoretically possible but practically rare.

(15)	Length	Domain	
	1	(S)	
	2	(SS)	
	3	(SSS)	
	4	(SS)(SS)	
	5	(SS)(SSS)	
	6	(SS)(SS)(SS)	
(16)	1	LH (LH)	
		mo	'horse'
	2	HL LH (H L)	
		pa- li	'Paris'
	3	LH HL HL (L L H)	
		lo'- se- tçi	'Los Angeles'
	4	HL LH HL LH (H L) (H L)	
		ja- lu- sa- lã	'Jerusalem'
	5	HL LH LH LH LH (H L) (L H L)	
		ka- li- fo'- pi- ja	'California'
	6	LH LH HL LH LH LH (L H) (H L) (L H)	
		dže'-k ^h a'- sz- lu- va'- k ^h a'	'Czechoslovakia'

In traditional terms Shanghai shows left-to-right construction of binary feet, which, as discussed

above, are left-headed. A monosyllable is not footed unless it is the only syllable of a word.

3.2. Compounds

Selected compound patterns are given in (17), with examples in (18). All the compounds listed below are made of free words. The digits indicate the number of syllables in a morpheme, and S indicates a syllable. When the gloss is transparent, only the translation is given. More patterns will be discussed later as relevant.

(17)	Structure	Input	Surface
a.	[1 1]	[S S]	(SS)
b.	[2 3]	[SS SSS]	(SS)(SSS)
c.	[3 2]	[SSS SS]	(SSS)(SS)
d.	[1 2]	[S SS]	(SSS)
e.	[2 1]	[SS S]	(SS)(S)
f.	[[1 1] [1 [1 1]]]	[[S S][S [S S]]]	(SS)(SSS)
g.	[[1 [1 1]] [1 1]]	[[S [S S]][S S]]	(SSS)(SS)
h.	[[1 1] 1]	[[S S] S]	(SS)(S)
i.	[1 [1 1]]	[S [S S]]	(SSS)
j.	[1 5]	[S SSSSS]	(SSS)(SSS)
k.	[1 [1 [1 1]]]	[S [S [S S]]]	(SSSS)

(18) a.	HL HL (H L) [çi ko] west melon 'watermelon'	* (HL) (HL) [çi ko]
b.	LH LH LH HL LH (L H) (L H L) [ze'- pẽ mu- se- k ^h a'] 'Japanese mosaic'	
c.	HL LH LH LH LH (H L L) (L H) [pa- na- ma lo- po'] 'Panama radish'	* (H L) (L H L) [pa-na- ma lo- po']
d.	LH LH HL (L H L) [nø zo- çi] 'South Korea'	
e.	LH LH LH (L H) (LH) [zã- he z] 'Shanghai City'	

- f. HL HL LH LH LH
 (H L) (L H L)
 [[çĩ çi] [da [ba' ts^he]]]
 new fresh big white vegetable
 'fresh [Chinese cabbage]'
- g. LH LH LH HL LH
 (L H L) (H L)
 [[da [ba' ts^he]] [sã ti]]
 big white vegetable trade store
 '[Chinese cabbage] store'
- h. LH LH LH
 (L H) (LH)
 [[bi fia] ts^hã]
 '[[leather shoe] factory]'
- i. LH LH LH
 (L H L) * (L H) (LH)
 [ha' [bi fia]] [ha' [bi fia]]
 '[black [leather shoe]]'
- j. LH LH LH LH HL LH
 (L H L) (L H L) * (L H) (L H) (H L)
 [nø yĩ - du- ni- çi- ja] [nø yĩ - du-ni- çi- ja]
 'Southern Indonesia'
- k. LH LH HL LH
 (L L L H) * (L H) (H L)
 [ba' [ja [t^hi ŋu]]]¹³ [ba' [ja [t^hi ŋu]]]
 white wild sky goose
 '[white [wild swan]]'

Three remarks are in order. First, a monosyllabic foot is not very stable; it stays in careful speech but tends to merge with the preceding foot in faster speech. For example, [2 1] forms two domains (SS)(S) in careful speech but one domain (SSS) in faster speech. In addition, colloquial and idiomatic expressions tend to form one domain even in careful speech. For example, [[ze' se] ti] 'crazy' (lit. 'thirteen o'clock') forms one domain only. The contrast between [1 2] and [2 1] (and similarly between [1 [1 1]] and [[1 1] 1], etc.), therefore, is observed only in careful speech of non-idiomatic expressions, which is the style I discuss here. Second, large compounds are not common in natural speech; when a compound becomes long, one tends to break it up by inserting the particle [ge'], the Shanghai pronunciation of the particle 'de'. This tendency is especially strong when monosyllables are added repeatedly on the left, which is the location of primary stress (Duanmu 1995). Nevertheless, long compounds can arise under appropriate circumstances. For example, if one sees (18k) as the name of a bird in a zoo, one would only use a single tone domain, as indicated. Third, in all the compounds listed in (18), every component word, and every sub-compound within a larger one, is a free expression. For example, every

- d. [S SS] underlying
- x x
(S) (SS) cycle 1
- x
(SSS) cycle 2: clash
- e. [SS S] underlying
- x x
(SS) (S) cycle 1
- (no more change) cycle 2
- f. [[S S] [S [S S]]] underlying
- x x x x x
(S) (S) (S) (S) (S) cycle 1
- x x x
(SS) (S) (SS) cycle 2: clash
- x x
(SS) (SSS) cycle 3: clash
- (no more change) cycle 4
- g. [[S [S S]][S S]] underlying
- x x x x x
(S) (S) (S) (S) (S) cycle 1
- x x x
(S) (SS) (SS) cycle 2: clash
- x x
(SSS) (SS) cycle 3: clash
- (no more change) cycle 4
- h. [[S S] S] underlying
- x x x
(S) (S) (S) cycle 1
- x x
(SS) (S) cycle 2: clash
- (no more change) cycle 3

i.	[S [S S]]	underlying
	x x x (S) (S) (S)	cycle 1
	x x (S) (SS)	cycle 2: clash
	x (SSS)	cycle 3: clash
j.	[S SSSSS]	underlying
	x x x (S) (SS) (SSS)	cycle 1
	x x (SSS) (SSS)	cycle 2: clash
k.	[S [S [S S]]]	underlying
	x x x x (S) (S) (S) (S)	cycle 1
	x x x (S) (S) (SS)	cycle 2: clash
	x x (S) (SSS)	cycle 3: clash
	x (SSSS)	cycle 4: clash

5. OT analysis with alignment

We have seen that Shanghai compounds can be analyzed in a traditional cyclic approach quite simply. Let us now consider how an OT approach handles the data. In this section I discuss an OT analysis that uses alignment constraints (McCarthy and Prince 1993a). It has been proposed that alignment constraints can do the work of the cycle in a one-step analysis (Cohn and McCarthy 1994); however, I will show that alignment is inadequate to account for compounds in Shanghai. In particular, in a cyclic analysis feet built on a previous cycle are maximally preserved, but alignment can achieve this effect only sometimes. In addition, in a compound with multiple layers, alignment in effect flattens the layers and loses certain critical information. The inadequacy of the alignment analysis will be compared with an OT analysis that uses identity constraints (McCarthy and Prince 1995), to be discussed in Section 6.

5.1. Single words

Before we look at compounds, let us first look at the analysis of single words, which do not pose a problem.¹⁴ Single words can be accounted for by the ranked constraints in (20),

following McCarthy and Prince (1993a), Kenstowicz (1995), and references cited therein.

- (20) Parse >> Bin >> Align-Ft-L
 Parse: All syllables should be metrified.
 Bin: A foot should contain exactly two syllables (or two moras).
 Align-Ft-L: Align the left edge of a foot with the left edge of the word containing it.¹⁵

The most important constraint is Parse, and the least important is Align-Ft-L. Besides these three constraints, an additional constraint, Left-headed or Trochee, is also needed, but it will be ignored here. Parse is a gradient constraint, which tallies each unparsed syllable. Align-Ft-L (which McCarthy and Prince 1993a attribute to Robert Kirchner) is also a gradient constraint, which tallies for each foot how many syllables away it is from the target word edge. The idea that a foot must be either two syllables or two moras was originally proposed by Prince (1980). Since Shanghai does not have heavy syllables (Duanmu 1995), we will not be concerned with bimoraic feet here. Following a suggestion by Kenstowicz (p.c.), I use Bin as a gradient constraint, which tallies every extra syllable a foot has beyond two; Bin also gives a tally for each monosyllabic foot lacking another syllable.¹⁶ Ranking Parse higher than Bin ensures that a monosyllabic word is metrified, as shown in (21), where S is a syllable, () are foot boundaries, ☞ is the best candidate, * is a violation, and ! is the point at which a candidate is rejected.

(21) Input: /S/

Candidates	Parse	Bin
☞ (S)		*
S	*!	

Ranking Parse and Bin above Align-Ft-L ensures that long words are parsed into multiple feet, rather than a single one, as shown in (22), where # indicates the left edge of a word (not a violation mark).

(22) Input: /#SSSSS/

Candidates	Parse	Bin	Align-Ft-L
a. #(SSSSS)		*!***	#
b. #(SSS)(SS)		*	#, #**!*
c. ☞ #(SS)(SSS)		*	#, #**
d. #(SS)SSS	*!***		#

In (22a) there is one foot, which is aligned with the left edge of the word; this is indicated by '#' under Align-Ft-L. (22b) has two feet; the first is aligned with the left edge of the word, indicated by the first '#', but the second is three syllables away from it, indicated by the second '#' followed by three violation symbols. (22c) also has two feet; the first is aligned with the left edge of the word, and the second is two syllables away from it. Thus, (22c) is better than (22b). Although (22a) incurs no violation of Align-Ft-L, it incurs more violations of Bin than the other two candidates. Thus, (22c) is the best output. If Align-Ft-L were ranked higher than Bin, (22a) would become the best candidate.

Having determined the ranking of the constraints, let us now consider the analysis of single words, as shown in (23)-(28). All the foot patterns are predicted correctly.¹⁷

(23) Input: /#S/

Candidates	Parse	Bin	Align-Ft-L
☞ # (S)		*	#
#S	*!		

(24) Input: /#SS/

Candidates	Parse	Bin	Align-Ft-L
☞ # (SS)			#
# (S)(S)		*!*	#, #*

(25) Input: /#SSS/

Candidates	Parse	Bin	Align-Ft-L
☞ # (SSS)		*	#
# (SS)(S)		*	#, #*!*
# (S)(SS)		*	#, #*!

(26) Input: /#SSSS/

Candidates	Parse	Bin	Align-Ft-L
# (SSSS)		*!*	#
☞ # (SS)(SS)			#, #**

(27) Input: /#SSSSS/

Candidates	Parse	Bin	Align-Ft-L
# (SSSSS)		**!*	#
# (SS)(SS)S	*!		#, #**
# (SSS)(SS)		*	#, #**!*
☞ # (SS)(SSS)		*	#, #**

(28) Input: /#SSSSSS/

Candidates	Parse	Bin	Align-Ft-L
☞ # (SS)(SS)(SS)			#, #**, #*****
# (SSS)(SSS)		*!*	#, #**

5.2. Compounds

Unlike single words, which do not pose a problem, an OT alignment analysis can handle some compounds but not others. In particular, [1 n] compounds and those that consist of three or more words are problematic. We begin with the easy cases. First, consider [2 3] and [3 2]. If compounds behave like single words, both [2 3] and [3 2] should form (SS)(SSS), as a 5-syllable word does. The fact that [3 2] forms (SSS)(SS) suggests that the internal word boundary plays a role. In the traditional analysis (see Section 4), the difference between [2 3] and [3 2] is achieved by the cycle. According to Cohn and McCarthy (1994:48-49), 'Alignment constraints do the work of the cycle and they encode the morphological dependence in the phonology'. In the present case, one can assume a constraint Align-Wd, stated in (29), with the analysis of [2 3] and [3 2] shown in (30) and (31). For the present purpose, I will assume that Align-Wd gives a binary decision on each word, i.e., whether it is aligned (no marking) or not aligned (marked with '*').

(29) Align-Wd: Align the left edge of a word (i.e. X^0) with the left edge of a foot.

(30) Input: /#SS#SSS/

Candidates	Align-Wd
\curvearrowright #(SS)#(SSS)	
#(SS#S)(SS)	*!

(31) Input: /#SSS#SS/

Candidates	Align-Wd
#(SS)(S#SS)	*!
\curvearrowright #(SSS)#(SS)	

Alternatively, the difference between [2 3] and [3 2] can be accounted for by Align-Ft-L, as shown in (32) and (33).

(32) Input: /#SS#SSS/

Candidates	Align-Ft-L
a. \curvearrowright #(SS)#(SSS)	#, #
b. #(SS#S)(SS)	#, #*!

(33) Input: /#SSS#SS/

Candidates	Align-Ft-L
a. #(SS)(S#SS)	#, #*!*
b. \curvearrowright #(SSS)#(SS)	#, #

In (32a), the first foot is aligned with the first word, and the second foot is aligned with the second word. In (32b), the first foot is aligned with the first word, but the second foot is one syllable away from the left edge of the second word (the first word edge on its left). Thus, (32a) is the chosen form. In (33b) both feet are well aligned. In (33a) the first foot is well-aligned, but the second foot is two syllables away from the left edge of the first word (the first word edge on its left). Thus, (33b) is a better form. To see whether Align-Wd is needed in addition to Align-Ft-L, consider [2 1], the analysis of which is shown in (34), where $*_{\curvearrowright}$ = a wrongly predicted output.

(34) Input: /#SS#S/

Candidates	Parse	Bin	Align-Ft-L
a. \curvearrowright #(SS)#(S)		*	#, #
b. $*_{\curvearrowright}$ #(SS#S)		*	#

Align-Ft-L predicts that (34a) and (34b) are equally good. However, although (34b) is a good pattern in fast speech, it is not as good as (34a) in careful speech; the mark $*_{\curvearrowright}$ on (34b) indicates that it is wrongly predicted to be as well-formed. The use of Align-Wd, whose ranking will be ignored for the moment, can make the necessary distinction, as shown in (35).

(35) Input: /#SS#S/

	Candidate s	Parse	Bin	Align-Ft- L	Align-Wd
a.	$\text{\textcircled{S}}$ #(SS)#(S)		*	#, #	
b.	#(SS#S)		*	#	*!

Let us now consider [1 2]. The analysis is shown in (36).

(36) Input: /#S#SS/

	Candidates	Parse	Bin	Align-Ft-L	Align-Wd
a.	* $\text{\textcircled{S}}$ #(S)#(SS)		*	#, #	
b.	#(S#SS)		*	#	*!

The predicted pattern is (36a), but in fact (36b) is the only good pattern. Why is (35a) good but (36a) bad, given that they both contain a monosyllabic foot and a disyllabic foot? The reason, as I suggested earlier, is stress clash. Given left-headed feet in Shanghai, there is stress clash in (36a) but not in (35a). I state the constraint Clash (Avoidance) in (37), which must be ranked above Align-Wd, and reanalyze (36) in (38). (Apostrophes indicate stressed syllables.)

(37) Clash (Avoidance): Avoid stresses on adjacent syllables.

(38) Input: /#S#SS/

	Candidates	Clash	Align-Wd
	#('S)#('SS)	*!	
$\text{\textcircled{S}}$	#('S#SS)		*

Recall that the difference between [2 3] and [3 2] and that between [1 2] and [2 1] were handled by the cycle in the traditional analysis (Section 4). So far alignment constraints have done the same job. Let us now consider cases where alignment fails to choose the correct output. First, consider [1 5], analyzed in (39), where the ranking among Parse, Clash and Bin is immaterial.

(39) Input: /#S#SSSSS/

	Candidates	Parse	Clash	Bin	Align-Wd
a.	#S#(SS)(SSS)	*!		*	
b.	#(S)#(SS)(SSS)		*!	**	
c.	* $\text{\textcircled{S}}$ #(S#S)(SS)(SS)				*
d.	#(S#SS)(SSS)			*!*	*

Because of Parse and Clash, the inner word boundary cannot be aligned with a foot. Under this circumstance (39c) is predicted to be the best output, which is wrong. The correct pattern is (39d) instead. It can be seen that similar problems occur with other [1 n] compounds.

Intuitively, [1 n] compounds suggest that each word is metrified independently first, and their foot structures are maximally preserved at the compound level. In [1 5], the second word is first metrified as #(SS)(SSS). When clash occurs at the compound level, only the first foot is affected, giving #(S#SS)(SSS). Similarly, the second word in [1 4] is first metrified as #(SS)(SS), and clash at the compound level will only affect the first foot, giving #(S#SS)(SS),

instead of #(S#S)(SSS) as would be expected of a five-syllable word. The OT analysis discussed so far assumes no intermediate level between input and output, thus it cannot reflect the preservation of previously constructed feet.¹⁸ The same problem can be seen in compounds where stress is removed iteratively on several cycles, such as in [1 [1 [1 1]]]. In a one-step analysis, shown in (40), the prediction is again incorrect.

(40) Input: /#S#S#S#S/

	Candidates	Bin	Align-Wd
a.	*☞ #S(S#S)#(S#S)		**
b.	#(S#S#S#S)	*!*	***

Since (40b) misses three intermediate word boundaries as well as violating Bin, and (40a) misses just two intermediate word boundaries while observing Bin, (40a) is predicted to be a better output. Unexpectedly, (40b) is the only correct output. A similar problem is seen in [1 [1 2]], shown in (41) and (42).

(41) LH LH LH LH
 (L H L L) * (L H) (L H)
 [çø [fĩð lo- bo']] [çø [fĩð lo- bo']]
 [small [red turnip]]
 'small carrot'

(42) Input: /#S#S#SS/

	Candidates	Bin	Align-Wd
a.	*☞ #S(S#S)#(SS)		*
b.	#(S#S#SS)	*!*	**

In the one-step analysis (42a) is expected to be the better output, since it observes Bin and incurs just one violation of Align-Wd. Yet (42b) is the only valid output, even though it incurs two violations of Bin and two violations of Align-Wd. Unlike the one-step analysis, the cyclic analysis handles [1 [1 2]] quite easily, as shown in (43).

(43) [S [S SS]] underlying
 x x x
 (S) (S) (SS) cycle 1
 x x
 (S) (SSS) cycle 2: clash
 x
 (SSSS) cycle 3: clash

Stress on the third syllable is removed on cycle 2, and stress on the second syllable is removed on cycle 3. Thus, (SSSS) is properly predicted to be the only output.

The problem posed by [1 n] compounds is noted by Kenstowicz (1995). He suggests that [1 n] compounds in Shanghai (as well as similar cases in Carib and Polish) require a two-step

analysis. In the first step, each word is analyzed separately. In the second step, the two words are analyzed together. In addition, there is a constraint Overwrite, which says that feet built on the first step must be preserved on the second step. Each lost foot will incur a violation mark under Overwrite. (44) shows the second step of [1 5] in this analysis, where Overwrite is ranked below Clash and above Bin, and where # indicates the between-word boundary.¹⁹

(44) Input: / (S), (SS)(SSS)/

	Candidates	Clash	Overwrite	Bin
a.	(S)#(SS)(SSS)	*!		**
b.	(S#SS)(SSS)		**	**
c.	(S#S)(SS)(SS)		***!	

In (44a) there is a fatal violation of Clash. In (44b) there are two violations of Overwrite, and two violations of Bin. In (44c) there are three violations of Overwrite and no violation of Bin. Thus, (44b) is predicted to be the best, correctly. It can be shown, however, that, in this analysis, more complicated structures will require more steps. For example, [2 [1 5]] forms (SS)#(S#SS)(SSS) instead of (SS)#(S#S)(SS)(SS), as the made-up compound in (45) shows.

(45) LH LH LH LH LH LH HL LH
 (L H) (L H L) (L H L)
 [ne'- ta [nø yĩ - du- ni- çi- ja]]
 tropical south Indonesia
 '[Tropical [South Indonesia]]'

* (L H) (L H) (L H) (H L)
 [ne'- ta [nø yĩ - du- ni- çi- ja]]

In order for the inner [1 5] to form (S#SS)(SSS), it has to be processed in two steps; thus the entire [2 [1 5]] requires three steps. The inadequacy of Kenstowicz (1995) is resolved in Kenstowicz (1996), which employs identity constraints, discussed in Section 6. I will return to alignment in Section 7.

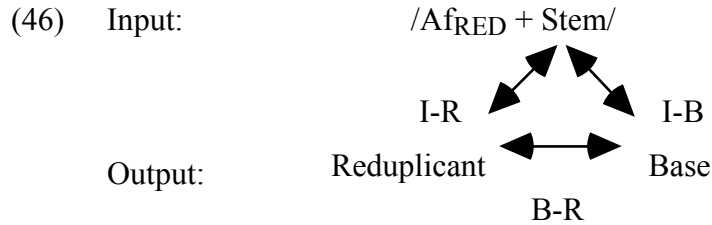
6. OT analysis with identity constraints

In this section I analyze Shanghai compounds using identity constraints and show that this approach can get the correct results, provided identity (and other) constraints are checked not just once but on every layer of a compound. In Section 6.1 I give some background on Correspondence Theory and identity constraints. In Section 6.2 I illustrate how the analysis with identity constraints works.

6.1. Correspondence and identity constraints

According to McCarthy and Prince (1995), there are 'three fundamental ideas of OT: parallelism of constraint satisfaction, ranking of constraints, and faithfulness between derivationally-related representations.' The idea of faithfulness is crucial; without it, all words in a language would be pronounced in a form that is phonologically most unmarked, perhaps [ba] (Chomsky 1994). McCarthy and Prince (1995) further developed the idea of faithfulness in Correspondence Theory, by which 'identity relations are imposed on pairs of related representations'.²⁰ For example, in their analysis of reduplication (triggered by the affix Af_{RED}),

McCarthy and Prince (1995) proposed the model in (46).



There are three identity relations (shown by double arrows). I-R (Input-Reduplicant) checks between the reduplicant (a surface form) and the stem being reduplicated (an input form). I-B (Input-Base) checks between the stem (an input form) and the base (a surface form). B-R (Base-Reduplicant) checks between the base (a surface form) and the reduplicant (also a surface form). Thus, I-R and I-B are cases of Input-Output relations, which check between a surface form and its input, and B-R is a case of Output-Output relations, which check between two surface forms. I-R requires the stem and the reduplicant to be identical, I-B requires the stem and the base to be identical, and B-R requires the base and the reduplicant to be identical.²¹

Like other constraints, an identity constraint can be overridden by another constraint. For example, consider a hypothetical language in which a nasal assimilates in place to a following stop. When a word [kam] is reduplicated, there are four possible results, [kamkam], [kamkaŋ], [kaŋkam], and [kaŋkaŋ]. For simplicity, let us ignore I-R. In addition, let us assume that the second part is the base and that I-B is ranked highest. By altering the ranking between B-R and the homorganic constraint, we get two results, shown in (47).

(47) a. Input: /kam/

Candidates	I-B	Homorganic	B-R
kamkaŋ	*!	*	*
kaŋkaŋ	*!		
☞ kaŋkam			*
kamkam		*!	

b. Input: /kam/

Candidates	I-B	B-R	Homorganic
kamkaŋ	*!	*	*
kaŋkaŋ	*!		
kaŋkam		*!	
☞ kamkam			*

In the output of (47a), there is nasal assimilation, but the reduplicant and the base are not identical. In the output of (47b) there is no nasal assimilation, and the reduplicant and the base are identical. Both possibilities can be found in real languages (see McCarthy and Prince 1995 for actual examples and sources).²²

While the constraint B-R in (46) compares two parts of a single surface word, it does not compare two different surface words directly. Extending the idea of correspondence, several subsequent works, notably Benua (1995a,b), Buckley (1995), Kenstowicz (1996), Kraska (1994),

and McCarthy (1995), and an independent proposal by Burzio (1994, 1995), suggest that identity constraints can hold between two different surface words. For example, in her analysis of morphological truncation, Benua proposed the model in (48).

(48)	IO-ID	OO-ID
Input	----->	Base
	----->	Truncated form

There are two correspondence relations. The Input-Output Identity (IO-ID) holds between the input of a word and its output (a surface full word, or base). The Output-Output Identity (OO-ID) holds between the base and the truncated surface word. (IO-ID and OO-ID each may represent a family of identity constraints; we will return to this point.) The motivation for OO-ID can be seen in the New York-Philadelphia English example in (49).

(49)	Base	Truncated
Massachusetts	[mæ.sə.tʃu.sɛts]	[mæs]
mass	[mɛs]	

The truncated form of 'Massachusetts' is [mæs] instead of [mɛs]. As Benua argues, this suggests a relation between the truncated word and the full surface word, or OO-ID. Had there been no OO-ID, the truncated word would relate to a truncated input and surface as [mɛs], as the word 'mass' does. A structure similar to (48) is proposed by McCarthy (1995) for phase relation in Rotuman. Adopting the idea of Output-Output Identity (or Surface-Surface Identity), one may propose (50) for the analysis of compounds.

(50)	IO-ID	OO-ID
/Word/	----->	[Word]
	----->	[Compound]

IO-ID compares the underlying form of a word with its surface form. OO-ID compares surface words with the surface compound they compose. IO-ID and OO-ID may have different functions. For example, if Shanghai words have no underlying stress, IO-ID will allow stress to be created on them, whereas OO-ID will preserve such stresses in compounding. I will say little about IO-ID here (except noting that it should allow left-headed binary feet to be created on surface words; see Section 5 for ranked constraints on single words). Instead, I will focus on OO-ID only.²³

6.2. Analysis with identity constraints

First, we look at an example of how identity constraints work. For illustration, we focus on one constraint, Stress-ID (similar to Head-Max proposed by McCarthy 1995), defined in (51).

- (51) Stress-ID (first approximation): The locations of stress between morphologically related expressions (words or compounds) must be identical.

The definition is to be understood as follows. If two words [W1] and [W2] make up a compound [W1 W2], then the stress locations in [W1] should be the same as those in the W1 part of the compound, and the stress locations in [W2] should be the same as those in the W2 part of the compound. Similarly, if a compound is made of [W1], [W2], and [W3], the stress locations in

[W1], [W2], and [W3] should be the same as those in the W1 part, W2 part, and W3 part of the compound, respectively. Stress-ID is a gradient constraint that tallies the number of syllables whose stress has changed. The ranking among Stress-ID, Clash, and Bin is as in (52), to be supported by the analysis in (53).

(52) Clash >> Stress-ID >> Bin

Now consider [1 3], analyzed in (53), where S = a stressed syllable, s = an unstressed syllable, and # = a word boundary.

(53) Input: [1 3] = /(S), (Sss)/

	Candidates	Clash	Stress-ID	Bin
a.	(S)#(Sss)	*!		**
b.	(S#sss)		*	**
c.	(S#s)(Ss)		**!	

For the moment, let us assume the analysis of (50), where the input to compounds is surface words (cf. the analysis of Kenstowicz 1996 below). In (53) the input consists of two surface words, (S) and (Sss). In (53a), there is no violation of Stress-ID. In (53b) there is one violation of Stress-ID: the first syllable of the second word had stress in the input but lost it in the output. In (53c) there are two violations of Stress-ID: the first syllable of the second word lost stress and the second syllable of the second word gained stress. As discussed earlier, the correct output of [1 3] is (S#sss). In order to obtain this result, one must assume the ranking in (52), which (53) does.

Let us now consider [1 [1 2]], which involves some complication. If we assume that compounds are directly related to surface forms of individual words that are their ultimate constituents, then [1 [1 2]] is directly related to three surface words, (S), (S), and (Ss), as shown in (54).

(54) Input: [1 [1 2]] = /(S), (S), (Ss)/

	Candidates	Clash	Stress-ID	Bin
a.	(S)#(S)#(Ss)	*!*		**
b.	(S#s)#(Ss)		*	
c.	(S#s#ss)		**!	**

This analysis predicts that the best form is (54b), which is incorrect. The correct form is (54c). In the cyclic analysis, the inner [1 2] is analyzed first, giving (Sss). On the final cycle, [1 [1 2]] is the same as [1 3], both giving (Ssss). Obviously, the failure of (54) results from the fact that it did not make use of enough bracketing information, in particular, [1 2] forms an inner constituent.

In view of problems like (54), Kenstowicz (1996) suggests that in compounds, identity constraints should not hold between individual surface words and the compound they compose, but between a compound and the surface forms of the compound's immediate constituents when they occur independently. This proposal is called Base-Identity and is given in (55).

(55) Base-Identity: Given an input structure [X Y], output candidates are evaluated for how well they match [X] and [Y] if the latter occur as independent words.

Since Stress-ID is an instance of Base-Identity, it should be evaluated in a manner consistent with the latter. In other words, a more accurate definition of Stress-ID should be (56), assuming that syntactic structures are strictly binary branching (Kayne 1984).

- (56) Stress-ID (final definition): Given a compound [X Y], where X and Y are its immediate constituents, the surface stress locations in the X part and the Y part of the compound should be identical to those in [X] and [Y] respectively, where [X] and [Y] are independent occurrences of X and Y respectively.

According to (56), Stress-ID does not hold between [1 [1 2]] and its three component words [1], [1], and [2], as shown in (54), but rather between [1 [1 2]] and its immediate constituents [1] and [1 2], as shown in (57).

- (57) Input: [1 [1 2]] = /(S), (S#ss)/

	Candidates	Clash	Stress-ID	Bin
a.	(S)#(S#ss)	*!		**
b.	(S#s#ss)		*	**
c.	(S#s)#(Ss)		**!	

Here the output is correctly predicted. But in order to evaluate [1 [1 2]], one needs to know the surface form of the inner unit [1 2], which itself must be evaluated separately against the surface forms of [1] and [2]. This is shown in (58).

- (58) Input: [1 2] = /(S), (Ss)/

	Candidates	Clash	Stress-ID	Bin
a.	(S)#(Ss)	*!		*
b.	(S#ss)		*	*

In summary, to analyze [1 [1 2]], Stress-ID, along with Clash and Bin, must be checked twice, once on the inner unit [1 2], and once on [1 [1 2]] as a whole. More generally, a structure [X Y] is evaluated with respect to its immediate constituents [X] and [Y] as stated in (55), and each of [X] and [Y] in turn is evaluated with respect to its own immediate constituents. I will call this kind of analysis RECURSIVE CONSTRAINT EVALUATION, in which constraint evaluation takes place at every layer of morphosyntactic embedding. The more complicated a compound is, the more evaluations are needed. For example, [1 [1 [1 1]]] has three layers of embedding, so it will need three evaluations of Stress-ID (along with other constraints). This is shown in (59).

- (59) a. [1], [1] --> [1 1]
 b. [1], [1 1] --> [1 [1 1]]
 c. [1], [1 [1 1]] --> [1 [1 [1 1]]]

The recursive constraint evaluation is reminiscent of the cycle; a comparison will be made in Section 7. In the rest of this section I show that, given recursive constraint evaluation, all the correct results are obtained. First, consider two-word compounds, shown in (60)-(64), where Stress-ID is checked just once.

(60) Input: [1 5] = /(S), (Ss)(Sss)/

	Candidates	Clash	Stress-ID	Bin
a.	(S)(Ss)(Sss)	*!		*
b.	(Ss)(Ss)(Ss)		*!***	
c.	\curvearrowright (Sss)(Sss)		*	**

(61) Input: [1 1] = /(S), (S)/

	Candidates	Clash	Stress-ID	Bin
a.	(S)(S)	*!		**
b.	\curvearrowright (Ss)		*	

(62) Input: [2 3] = /(Ss), (Sss)/

	Candidates	Clash	Stress-ID	Bin
a.	\curvearrowright (Ss)(Sss)			*
b.	(Sss)(Ss)		*!*	*

(63) Input: [3 2] = /(Sss), (Ss)²⁴

	Candidates	Clash	Stress-ID	Bin
a.	\curvearrowright (Sss)(Ss)			*
b.	(Ss)(Sss)		*!*	*

(64) Input: [2 1] = /(Ss), (S)/

	Candidates	Clash	Stress-ID	Bin
a.	(Sss)		*!	*
b.	\curvearrowright (Ss)(S)			*

All the results are correct. Next, we consider three-word compounds, [1 [1 1]] and [[1 1] 1], each of which involves two Stress-ID checkings, as shown in (65)-(66).

(65) [1 [1 1]]
 inner brackets: (S), (S) --> (Ss) same as [1 1]
 outer brackets: (S), (Ss) --> (Sss) same as [1 2]

(66) [[1 1] 1]
 inner brackets: (S), (S) --> (Ss) same as [1 1]
 outer brackets: (Ss), (S) --> (Ss)(S) same as [2 1]

Finally, consider [[1 1] [1 [1 1]]] and [[1 [1 1]] [1 1]], shown in (67)-(68).

(67) [[1 1] [1 [1 1]]]
 a. Inner brackets
 [1 1] --> (Ss)
 [1 [1 1]] --> (Sss) same as (65)
 b. Outer brackets
 (Ss), (Sss) --> (Ss)(Sss) same as [2 3] in (62)

- (68) [[1 [1 1]] [1 1]]
 a. Inner brackets
 [1 [1 1]] --> (Sss) same as (65)
 [1 1] --> (Ss)
 b. Outer brackets
 (Sss), (Ss) --> (Sss)(Ss) same as [3 2] in (63)

To summarize, I have shown, following Kenstowicz (1996), that in order to obtain correct results, Stress-ID (and other constraints) must be checked recursively between the surface form of a compound and the surface forms of its immediate constituents.

7. Concluding remarks

I have argued that alignment constraints cannot account for all cyclic data. Instead, cyclicity requires identity constraints, such as Stress-ID in (56). This conclusion agrees with recent works such as Benua (1995a,b), Buckley (1995), Burzio (1994, 1995), Kenstowicz (1995, 1996), Kraska (1994), and McCarthy (1995). In addition, in a compound [X Y], identity constraints should compare the immediate constituents X and Y in that compound against the independent occurrences of X and Y respectively, as suggested by Kenstowicz (1996). Finally, in a structure with multiple embedding, identity (and other) constraints should be checked recursively, i.e. at every layer of bracketing.

The recursive constraint evaluation raises two questions. First, what is its implication for parallelism? Second, what are the differences between recursive constraint evaluation and a traditional cyclic analysis? For the first question, it may appear that, if every layer of syntactic bracketing requires a separate constraint evaluation, there will be multiple steps, theoretically unlimited, in the analysis of a complex structure. However, unlike the traditional cyclic analysis, in which the multiple steps are sequentially ordered (from smaller units to larger units), in an OT analysis the multiple evaluations can be seen to take place all at once. For example, in the analysis of a four-word compound [[A B][C D]], seven evaluations are carried out in parallel on A, B, C, D, [A B], [B C], and [[A B][C D]].²⁵ On this view, there is no inherent incompatibility between parallelism and recursive constraint evaluation. As I will discuss below, there is no evidence that ordering is needed among evaluations at different levels of a cyclic compound, supporting the parallelist assumption.

Next, we compare recursive constraint evaluation with a traditional cyclic analysis. First, we note some similarities. In particular, cyclicity has three essential properties, given in (69).

- (69) a. having access to both bracket locations and bracket layering
 b. protecting structures built on previous cycles
 c. no information on earlier brackets is available to later cycles (bracket erasure)

These properties are all incorporated in the OT analysis discussed here. In particular, (69a) is captured by the recursiveness in constraint evaluation. (69b) is captured by identity constraints. (69c) is captured by the fact that an identity constraints refers to the immediate constituents only (see (55) and (56)).²⁶ Not surprisingly, recursive constraint evaluation handles cyclic compounds successfully. And since cyclic compounds represent a typical case of cyclicity, other cyclic cases are not expected to pose any problem.

We saw in Section 5 that alignment cannot handle cyclic compounds. It is worth asking why. It can be seen that alignment does not incorporate all the properties in (69). First, alignment

can access bracket locations, but it cannot access bracket layering in a natural way. Second, alignment does not offer a proper mechanism for preserving the integrity of the constituents (or in cyclic terms, for preserving structures built on previous cycles). Intuitively, the focus of alignment is on the edge of a constituent, instead of on the constituent itself. If the edge is aligned, the constituent is protected, but if the edge is not aligned, nothing is left to protect the constituent. In contrast, identity constraints focus on the constituent itself; even when some part of the constituent is altered, the rest is still under the protection of identity. Finally, alignment says nothing about (69c). Hence, alignment is inadequate for cyclic data such as that from the Shanghai compounds.

Although a recursive constraint evaluation shares some similarities with a traditional cyclic analysis, there remain important differences. First, in the traditional analysis, at every cycle, there can be many intermediate representations, one after each ordered rule. In the OT analysis, which does not use ordered rules, intermediate representations are not posited. Second, in an OT analysis with identity constraints, the influence of certain words can create a result that will appear irregular to a cyclic analysis. To see this, consider a case in Italian, discussed in Kenstowicz (1996). In northern varieties of Italian an intervocalic /s/ becomes voiced after prefixation, but some exceptions are found, such as (70a).

- (70) a. a-[s]ociale, *a-[z]ociale 'asocial'
 b. [s]ociale 'social'

Kenstowicz suggests that the failure of /s/-voicing in (70a) is due to two factors: (i) there is an independent word, shown in (70b), in which [s] is unvoiced, and (ii) there is an identity constraint (ranked above the constraint for intervocalic voicing) that requires the morpheme sociale to have the same phonetic form in different contexts. Examples like (70) suggest that OT is more general than a cyclic analysis. Not only can OT handle cyclic cases, but it can handle cases that appear irregular to a cyclic approach. For example, if the allomorph identity constraint in Italian is ranked below the /s/-voicing constraint, /s/ in (70a) will become voiced, and the irregular cases will disappear; this is what a cyclic analysis predicts. On the other hand, if the allomorph identity constraint is ranked above the /s/-voicing constraint, cases like (70a) will be found; this is what a cyclic analysis cannot account for. The existence of cases like (70), discussed in Burzio (1995), Kenstowicz (1996), and other works, suggest that the additional power of OT is a merit.

There are two further differences between an OT analysis and a cyclic analysis. First, a cyclic analysis assumes that smaller units are analyzed before larger units, but an OT analysis does not make this assumption. As far as the present data are concerned, the traditional assumption appears to be unnecessary. For example, in Shanghai, Clash cannot be violated; Stress-ID is violated only when a clash needs to be resolved by deleting a stress. In other words, in the analysis of a compound, if Stress-ID is violated at some level, it has to be violated at that level (to avoid clash), whether all levels are analyzed in parallel or in sequence. There is no evidence therefore that sequencing among levels of analyses needs to be assumed. Second, as an NLLT reviewer points out, according to Benua (1995a,b) and Kenstowicz (1996) the output of an identity constraint should always be a surface form, whereas in a cyclic analysis it does not have to be. For example, consider a hypothetical word [[Stem-Suffix1]-Suffix2], where both suffixes are cyclic and where [Stem-Suffix1] is not a possible surface word. In the cyclic analysis, the output of the inner cycle is [Stem-Suffix1]. But according to Benua and Kenstowicz [Stem-Suffix1] cannot be the output of an evaluation, since it is not a surface word; instead, [[Stem-Suffix1]-Suffix2] must be evaluated in one step, from [Stem] (plus the suffixes) directly

to [[Stem-Suffix1]-Suffix2]. Clearly, Benua and Kenstowicz's proposal puts a strong restriction on OT. However, since evidence that bears on this issue is rather subtle, I will leave it for further research.

Notes

* I thank Michael Kenstowicz, who provided continuous help in discussing many points in this paper, and four anonymous NLLT reviewers for several rounds of comments. This work is in effect a joint product between them and me. I also thank Benjamin Ao, Luigi Burzio, Prathima Christdas, Michel Degraff, Morris Halle, Jeff Heath, Peter Hook, Vasu Renganathan, Moira Yip, and audiences at NACCL7 and the Tilburg Conference on the Derivational Residue in Phonology for various comments.

¹ Thanks also to Shunde Jin and Zhongwei Shen for sharing their judgments.

² I have omitted two other nominal structures in Chinese which do not contain 'de'. The first is the classifier structure [numeral classifier noun], such as [yi ben shu] 'a book' (transcribed in Pinyin). The second is the [pronoun noun] structure, such as [ni baba] 'your dad'. Both of these nominals are clearly phrases.

³ The interaction between onset voicing and pitch height is well-known in Asian languages, although its phonetic basis is not fully understood (e.g. Haudricourt 1954, Halle and Stevens 1971, Matisoff 1973, Jun 1990, Duanmu 1992). Syllables with a voiced onset consonant tend to have lower tones, often accompanied by a murmured quality, and syllables with a voiceless onset consonant tend to have higher tones. Yip (1980) uses the feature [-upper register] for the former syllables and [+upper register] for the latter syllables, and the features H and L (or [+H] and [-H]) for the shape of the contour. (i) gives a more elaborate representation of the five Shanghai tones.

(i)		high-falling	mid-rising	low-rising	short-high	short-low
	register	+upper	+upper	-upper	+upper	-upper
	contour	HL	LH	LH	LH	LH

Both short-low and low-rising have a rising contour and both have a low initial pitch level. They differ in that the former is shorter than the latter. Because of their difference in length, these two tones are traditionally listed separately. However, when followed by another syllable, both short-low and low-rising become a low level tone, and the following syllable becomes a high tone, to be seen shortly. This suggests that both short-low and the low-rising are LH. By the same argument, both mid-rising and short-high are LH (in the upper register). The fact that a voiced consonant can lower the pitch height is observed in African tone languages as well (e.g. Laughren 1984).

⁴ It can be seen that the tone of a Shanghai syllable is not predictable from segmental features but must be marked lexically. In particular, a syllable with a voiceless onset and a nonglottal rime can be either /LH/ or /HL/, such as [se LH] 'umbrella' and [se HL] 'mountain'. In this regard, Shanghai differs from such languages as Chonnam Korean, in which tones are entirely predictable from the word initial segment (Jun 1990).

⁵ Zhu (1995), in an extensive phonetic study of Shanghai tone, has found that in disyllabic expressions the initial syllable is longer, in agreement with the present proposal that Shanghai has left-headed stress (see below). The only exception is when the initial syllable has a glottal rime, a low tone, and a murmured vowel, in which case it is shorter than the second syllable,

which has a high tone and a clear vowel. The exceptional case can be explained by the fact that some features (such as low tone, glottalization, and murmur) inherently lead to shorter durations (cf. the well-known fact that [i] is inherently shorter than [a]).

⁶ It should not be a surprise that many facts escape intuition. For example, no one feels that the earth is round. Similarly, it takes a theoretical breakthrough to realize that a contour tone is made of two or more level tones, a fact that few tone speakers have intuition for.

⁷ The underlying tones of a foreign word are those of the characters that are used to represent it. In hyper articulated speech, the underlying tones can surface on each syllable; I will return to this point. Thanks to an NLLT reviewer for raising this issue.

⁸ The reason to delete stress from the second word, rather than from the first, is that, first, feet in Shanghai are left-headed, and second, the first word of a compound has greater stress than the second, as explained in Duanmu (1995).

⁹ As we will see later, the choice between (13b) and (13c) is not crucial to our discussion, which focuses on stress locations and stress clash. However, since the choice between (13b) and (13c) generated considerable comments from three reviewers, I examine it in some detail here.

¹⁰ When the domain has four or more syllables, this pattern becomes optional, as shown in (i).

- (i) LH LH LH LH
 (L H) (L H) or (L L L H) or (L H L L)
 [vo'-de [da fi'o']]
 Fudan big school
 'Fudan University'

In slower speech, 'Fudan University' forms two domains. In faster speech, it forms one domain. Since the initial syllable is LH, with a voiced onset and a glottal vowel, (L L L H) can be used in the latter case. But since this domain is long, (L H L L) can also be used.

¹¹ This is a made-up compound modeled after 'White Russia'.

¹² Two NLLT reviewers suggest that instead of assuming that the H moves to the end of a foot in the special pattern, one can assume that it moves to the end of a (prosodic) word. I have two reservations. First, moving a tone to the end of a word may be fine in a language whose tonal domains are not metrically determined, but in Shanghai tonal domains are metrically determined; thus unless there is a reason it seems more natural assume that the domain of tonal movement is also metrically bound. Second, in the first domain of (14d), the third syllable is not word final, yet the H still spreads to it. One cannot call this domain either a word or a prosodic word. The third NLLT reviewer suggests that instead of moving H to the end of a foot, one can assume that it moves to the last toneless syllable. This is descriptively correct, but there is still the question of why the beginning of a tonal domain coincides with that of a foot but the end of it does not. It will be noted that admitting non binary feet occasionally while assuming a constraint for binary feet is no cause of concern in OT, which expects soft constraints.

¹³ In this compound the initial syllable has a voiced onset and a glottalized vowel, so its H moves all the way to the last syllable. If the initial syllable is [ha' LH] 'black', its H will only move to the second syllable, as in [ha' [ja [t^hi ɲu]]] 'black wild swan', whose tone pattern is [L H L L].

¹⁴ In an OT analysis, the first thing is to determine the constraints involved and their ranking. To examine a specific expression, an evaluation table, or tableau, is given. For example, suppose we have three constraints, C1, C2, and C3, where C1 ranks above C2, and C2 ranks above C3, or C1 >> C2 >> C3. Suppose now we have an expression /S/, which has two possible surface forms, or candidates, (S) and S. An evaluation of /S/ is given in (i).

(i) Input: /S/

Candidates	C1	C2	C3
☞ (S)		*	*
S	*!		

The top row shows the constraints, from the highest ranked (least violable) on the left to the lowest ranked on the right. The first column shows the candidates. Each cell to the right of a candidate shows its evaluation for the constraint in that column. An empty cell means that the constraint is satisfied. An * means a constraint is violated. An ! after an * means that the candidate is rejected at that point. The ☞ sign to the left of a candidate means that it is the best candidate, or the predicted output (actual surface form). In (i), (S) violates C2 and C3 but not C1, and S violates C1 but not C2 or C3. Since C1 is least violable, (S) is the predicted output. (Shaded cells indicate that these contests are irrelevant in the choosing of the output.)

¹⁵ This definition is suggested by an NLLT reviewer. In a previous version of this article, Align-Ft-L is defined as in (i), on a suggestion by another NLLT reviewer.

(i) Align-Ft-L: Align the left edge of a foot with the closest left edge of a word.

A third NLLT reviewer finds the notion closest objectionable. Besides, (i) can cause ambiguities. For example, consider (ii), where word edges are indicated by #.

(ii) #1 (SS)(SS) #2 (SS) #2

One would like to say that the first two feet aim to align to #1, and the third foot aims to align to #2. However, according to (i), it is unclear whether the second foot is aligned to #1 or #2, both of which are equally close. Similarly, consider (iii).

(iii) a. #1 (SS)(SS)S(SS) #2 (SS) #3
 b. #1 (SS)(SS)(SS)S #2 (SS) #3

For the third foot, the closest word edge is #2. According to (i) (and ignoring Parse), the result should be (iiia), but in the present definition, the result should be (iiib).

¹⁶ This use of Bin does not exclude the possibility that Bin can be decomposed into two independent constraints, one requiring a foot to have at least two elements and one requiring it to

have at most two elements (see, for example, Hewitt 1994, Green 1995, and Green and Kenstowicz 1995). I use Bin as a single constraint simply for ease of exposition.

¹⁷ Since my focus is on the treatment of the cycle, I have omitted constraints for deriving the tone patterns within each domain. One can think of several ways of doing so. Here I offer one possibility. I assume that the two underlying tone patterns are H and L (instead of HL and LH). In addition, there is a constraint Tone-Drop, which forbids an unstressed syllable from carrying a tone. Third, there is a constraint Tone-Polarity, which requires a tone to be followed by an opposite tone (similar to the case in Margi, discussed by Hoffmann 1963, Kenstowicz and Kisseberth 1979:43, and Pulleyblank 1986); thus, H will surface as HL and L will surface as LH. Finally, I assume that extra syllables in a trisyllabic or longer foot do not get L as default but remain toneless (which is phonetically a low pitch); thus, for example, [L H L L] is [L H ø ø] and [L L L H] is [L ø ø H], where ø = toneless. If we rank Tone-Polarity above Tone-Drop, we will force all unstressed syllables to drop their tones, yet the second syllable will have to take a tone opposite to that of the initial syllable. A further requirement, some version of Align-Tone-Left, will keep the polar tone on the second syllable. A stipulation has to be made for the special spreading case, so that the polar H is linked to the last syllable.

¹⁸ An NLLT reviewer suggests that a one-step analysis for [1 n] is possible if there is a constraint by which the initial syllable of a polysyllabic morpheme cannot lie at the end of a foot. The same point is made by Moira Yip (p.c.). However, this solution cannot apply to [1 [1 [1 1]]], discussed below.

¹⁹ (44) differs from Kenstowicz's (1995) analysis in some minor ways. In particular, in his analysis only the second word (but not the first) of [1 n] is analyzed on the first step. As a result, the best output of [1 5] (S#SS)(SSS) incurs only one violation of Overwrite (the loss of the first foot in the second word), instead of two violations as shown in (44). This difference is not consequential to the present discussion.

²⁰ An NLLT reviewer points out that identity relations are just one of many correspondence relations. However, the present discussion will only be concerned with identity relations.

²¹ McCarthy and Prince (1995) define correspondence as a relation from (the elements of) one representation to (the elements of) another representation. In this sense, each double-arrowed relation in (45) embodies two relations. For example, B-R can be seen as B->R and R->B. In principle, B->R and R->B need not be the same, in the sense that they can be ranked differently. However, we will not be concerned with such differences.

²² The OT analysis predicts a further case, which McCarthy and Prince (1995) call OVERAPPLICATION. In our hypothetical example, this happens when the constraint ranking is B-R >> Homorganic >> I-B, as illustrated in (i).

(i) Input: /kam/

Candidates	B-R	Homorganic	I-B
kamkaŋ	*!	*	*
☞ kaŋkaŋ			*
kaŋkam	*!		
kamkam		*!	

In the predicted output [kaŋkaŋ], [m]-->[ŋ] applies twice, once before [k], and once to the final [m]. The latter is an overapplication because the final nasal is not in a homorganic environment. According to McCarthy and Prince (1995), overapplication is due to the need to keep the base and the reduplicant identical, even though only one is in the proper environment for phonological change. However, I did not find examples like (i) in McCarthy and Prince (1995). Instead, they give examples like (ii).

(ii) Javanese:

Stem	Reduplicated
[dajɔh]	[dajɔ-dajɔ-e]
'guest'	

There is a rule in Javanese that deletes [h] between two vowels. However, in the reduplicated form the first [h] is not between two vowels but it is also missing, showing a case of overapplication. As McCarthy and Prince (1995:40) point out, examples like (ii) can be handled by rule ordering in a non-OT analysis, whereby reduplication happens after sound change (here [h] deletion). A stronger case for OT can be made if examples like (i) can be found, which cannot be accounted for by rule ordering. In particular, for /kam/, if [m]-->[ŋ] applies after reduplication, [kaŋkam] should be the result, which is the same as (47a), and if [m]-->[ŋ] applies before reduplication, [kamkam] should be the result, which is the same as (47b). Whether cases like (i) exist remains to be seen.

²³ In this regard, we note Burzio's (1995) proposal that there are no underlying forms; instead, all words are memorized as is in their surface forms. For Burzio, therefore, there is just OO-ID and no IO-ID. Obviously, some words will have two (or more) memorized forms, such as fast reading (fewer tone domains) and slow reading (more tone domains).

²⁴ As an NLLT reviewer points out, [3 2] shows that Stress-ID is ranked above Align-Ft-L. This follows from the fact that Stress-ID >> Bin, introduced in (52), and Bin >> Align-Ft-L, introduced in (20).

²⁵ This view was suggested in a talk I gave at the Tilburg Conference on the Derivational Residue in Phonology in 1995 and was independently suggested by an NLLT reviewer. However, an illustration of it, which I gave in an earlier version of this paper, involves some complications. On the recommendations of two NLLT reviewers, I have omitted it here.

²⁶ This point is made by an NLLT reviewer.

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