Sandhi, Bloody Sandhi

A Two-level Take on Tianjin Tone

1 An apparent paradox

Matthew Chen was the first linguist to draw attention to a phenomenon which in his words would "severely strain the descriptive and explanatory capability of current linguistic theory" and "call into question just about every assumption linguists have long held about the mode of application of phonological rules and their interaction with ... prosodic organization" (Chen 1986, 98, 111). "The paradox of Tianjin tone sandhi" – the title of his paper – arises when one tries to determine the rule ordering and/or modes of application of a set of seemingly very straightforward rules meant to describe the tonal alternations exhibited by the dialect of Mandarin spoken in and around the city of Tianjin, P. R. China.

The rules that Chen proposes look fairly innocent, yet in the course of his investigation it turns out that there is no principled – let alone uniform – way in which they could be applied to explain all the phenomena observed (see Chen 1986; Chen 1987 for more details). Subsequent researchers have taken up the Tianjin challenge, but it is not obvious in what respect the various anaemic bleeding/feeding theories that were sold as improvements on Chen's analysis (Hung 1987; Tan 1987; Zhang 1987; Hung 1989 [1987]) are in fact superior. Chen's (1995a, 1995b) recent attempts to account for the Tianjin facts using derivational optimality is yet another instance of failing to realize that the technical tools of rule-based phonology are ill-founded, inadequate for this problem, and improperly used by their proponents.

2 The facts

Approaching the status of a textbook example (cf. Kenstowicz 1994, 328 f.; Yip 1995, 491) the Tianjin tone sandhi have become the focus of quite a few recent studies (Chen 1986; Chen 1987; Tan 1987; Zhang 1987; Hung 1987; Hung 1989 [1987]; Davison 1991; Chen 1995a; Chen 1995b) since they were described in Li and Liu 1985.

Like many other Northern Mandarin dialects Tianjin has four tonal contrasts. In isolation, the four citation tones are: first, low falling [21]; second, high rising [45]; third, low falling-rising [213]; and fourth, high falling [53] (Chen 1986, 98).

Our data come mainly from Chen 1986, partly superseded by additional data from Tan 1987. The numbers after the glosses serve to locate the examples in Chen 1986, the glosses have been slightly changed. Immediately below the segmental material (in *Hànyǔ pīnyīn* for ease of exposition) are the tones lexically associated with each syllable, the surface tones appear below these.

2.1 First tone sandhi

The first tone sandhi changes underlying /21/ into a surface third tone [213] when it immediately precedes [21].

(1) gao shan — high mountain (C86–2.1)
21 21
213 21

That the triggering environment is a surface tone [21] is clear from (2), where the [21] sandhi tone of /53/ triggers the change of [21] to /213/.

(2) tong [dian huar] — connect phone-call (C86–4.1); cf. (C86–17), (C86–25)
21 53 53
213 21 53

That the triggering environment is not a lexical tone /21/ is evident from (3), in which the leftmost surface tone is identical to the underlying tone (also note that the sandhi is not sensitive to the morphological structure). When several lexical tones /21/ appear in a row as in (4), the surface form shows a characteristic alternation between [213] and [21] with the rightmost tone surfacing as [21].

(3)	kai	[fei	ji]	drive airplane (C86–3.1)
	[gao	ya]	guo	high pressure pot, ‘pressure cooker’ (C86–11)
	21	21	21	
	21	213	21	

(4)	kai	[[tuo	la]	ji]	drive push pull machine, ‘drive a tractor’ (C86–23)
	21	21	21	21	
	213	21	213	21	

2.2 Third tone sandhi

The third tone sandhi changes underlying /213/ into a surface second tone [45] when it immediately precedes ‘213’.

(5)	xi	lian	wash face (C86–2.2)
	213	213	
	45	213	

The third tone sandhi can either be triggered by a surface third tone [213] as in (6), where [213] is the sandhi tone of /21/, or by a lexical third tone /213/ as in (7). (This opaque interaction has been noted in passing by Chen (1986, 109), but was not pursued any further by him.) Multiple lexical third tones exhibit a surface pattern in which all tones but the last one surface as the sandhi tone [45].

(6)	ting	[guan	xin]	quite concerned (C86–4.2)
	[bao	wen]	bei	preserve warmth flask, ‘thermo flask’ (C86–8)
	213	21	21	
	45	213	21	

(7)	chang	[dang	wei]	factory party secretary (C86–13.1)
	[li	fa]	suo	hair-dressing place, ‘barbershop’ (C86–12)
	[ma	zu	ka]	mazurka (loan word) (C86–16.b)
	213	213	213	
	45	45	213	

2.3 Fourth tone sandhi

Space limitations do not permit us to discuss the fourth tone sandhi in much detail. Suffice it to say that two alternations take place, with more sources for interaction with the other tones: /53/ becomes [45] before [21], or else [21] before /53/. Our analysis below explains this as well as the data presented by Tan (1987, examples 7, 22, 26), which differ slightly from those discussed by Chen (1986).

(8)	zuo	[dian	che]	sit-on tram, ‘take the tram’ (C86–13.2)
	[dian	shi]	ji	television machine, ‘TV set’ (C86–16.c-2)
	53	53	21	
	21	45	21	

3 Paradox lost

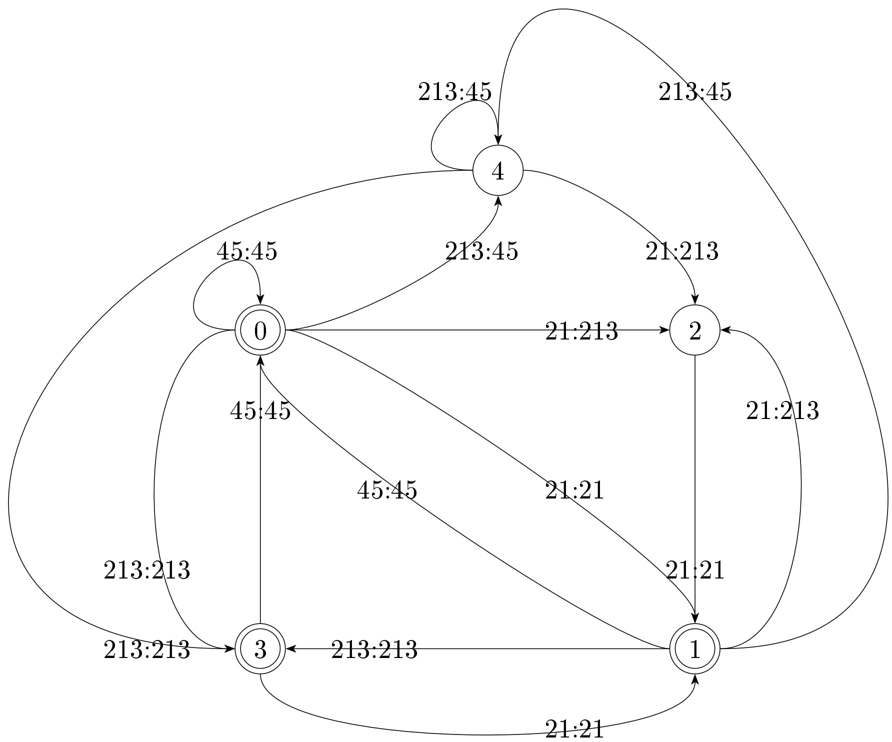
Not suprisingly, a change in the descriptive framework makes the apparent paradox of Chen 1987 disappear. The constraints on the correspondence between lexical and surface tones can be expressed very elegantly within the framework of Finite-State Morphology (Karttunen 1993 is an excellent overview). The observed tonal alternations are described as a rational function in the set $\{21, 213, 45, 53\}^*$, as defined by a finite-state transducer with a set of states $Q = \{0, 1, 2, 3, 4, 5, 6\}$, an input and output alphabet $\Sigma = \{21, 213, 45, 53\}$, an initial state $0 \in Q$, a set of final states $\{0, 1, 3, 5\} \subset Q$, and a partial transition function $Q \times \Sigma^2 \mapsto Q$ corresponding to the following transition table:

(9)

	21 : 21	21 : 213	45 : 45	213 : 213	213 : 45	53 : 53	53 : 45	53 : 21
0.	1	2	0	3	4	5	2	6
1.		2	0	3	4	5	2	
2 :	1							6
3.	1		0			5	2	6
4 :		2		3	4			
5.		2	0	3	4			
6 :						5	2	

States 1 and 2 of the transducer encode the first tone sandhi for the most part, states 3 and 4 the third tone sandhi, and 5 and 6 interact with 2 to derive the fourth tone sandhi. A subset of the transducer that leaves out the fourth tone is depicted below:

(10)



See what happens when the machine accepts the pairs 21:21 21:213 21:21 by switching its internal state from the start state 0 to 1, from 1 to 2, and from there to 1, one of the designated final states. When both the input and output are known, it behaves like a deterministic automaton. Note that although its underlying finite-state automaton is deterministic the transducer itself is inherently nondeterministic, i. e., it cannot be transformed into an equivalent deterministic (sequential) transducer (cf. Savitch 1982, 69 f.).

To see this, consider the behavior of the machine when it is operating as a transducer proper. For instance, it would map an input of /21 21 21/ to the unique output [21 213 21], or an input string /21 21/ to the corresponding output string [213 21]. Here the first token in the output string corresponding to the input with a length of 2 is '213', whereas it is '21' if the input string is 3 tokens long. This is true for all inputs of the form 21^* of even and odd length, respectively, as can be proved by induction on the input length. This incidentally also shows that the transducer is lacking the prefix property that is needed in order for it to be sequential (cf. Mohri 1997, 360).

If it is given an element of 21^* as an input, the nondeterminism becomes apparent immediately: in cases like this the transducer has to scan the whole input string before it can decide what the first output token should be. As a corollary, it follows that the transducer doesn't ever produce an output if given a suitable infinitely long input.

Now, humans hardly ever try to produce infinitely long outputs.[1] Still, the above insight is not totally meaningless if we assume that humans have limited memory resources and are not capable of massively parallel processing, for it would explain why no reasonably long strings of $(213\ 21)^n$ output corresponding to underlying 21^{2n} have been documented. Humans either make mistakes in this case, or break up the input into smaller, more easily processable parts by adding additional phrase boundaries across which the sandhi processes cannot operate.

A similar statement could be made about the fourth tone sandhi. But what is really important is the way in which both differ from the third tone sandhi. To decide whether an input of '213' comes out as '213' or '45', the transducer only has to wait for the next input token. If it is '213' again, the output corresponding to the previous token must be '45'. Ignoring the fact that the first and third tone sandhi interact, we can say that the former is not decidable with any fixed lookahead, while the latter one is decidable with a lookahead of 1. We can easily specify a sequential transducer that implements the third tone sandhi: take a set of states $Q = \{0, 1, 2\}$ with 0 and initial state and 2 a final state, and leave the alphabets implicit in the definition of the partial transition (and output) function $Q \times \Sigma \cup \{\$\} \mapsto Q \times \Sigma^*$ (where \$ signals the end of the input):

(11) ($\varepsilon \in \Sigma^*$ is the empty string)

	45	213	\$
0 :	$0, 45$	$1, \varepsilon$	$2, \varepsilon$
1 :	$0, 213\ 45$	$1, 45$	$2, 213$
2.			

A second important distinction between the third tone sandhi and its first tone and fourth tone counterparts is in the amount of ambiguity created. A surface string of the form 45^n 213 corresponds to $n + 1$ different underlying strings made up from tones /45/ and /213/, possibly involving the third tone sandhi. But where the two other sandhi processes might have applied, the number of underlying forms from which a surface string could have been generated is of a different order: for a surface string of the form $(213\ 21)^n$ there are 2^n underlying strings (due to the alternating pattern of the first tone sandhi), and a surface string $(45\ 21)^n$ 45 21 53 corresponds to $4 \cdot 3^n$ underlying strings.

4 Outlook

The formal properties of the Tianjin tone sandhi transducer raise a number of questions about how this grammatical system can be learned and used by both humans and machines. Since the transducer is not sequential, familiar techniques for inducing sequential transducers cannot be applied. How the above transducer can be learned efficiently (and ideally from positive examples only) is a question that we leave open. Machine processing of the transducer is largely unproblematic: for example, the time for generating a surface form from a lexical representation is linear in the length of the input; recognition is harder, but this is due to the inherent ambiguity of the surface forms noted above.

The first tone and fourth tone sandhi might however turn out to complicate generation for humans. Since in the worst case a lookahead equal to the total length of the input string is required, we would expect humans to break up large units that would trigger the problematic alternations into smaller parts, perhaps producing smaller phonological phrases. Since the central function of the tone sandhi is to indicate the presence of phrase boundaries, we are often able to see from a surface string (given its meaning) if a potentially larger phrase was split into several smaller ones. We then predict that this is to be encountered frequently with configurations triggering the first tone and fourth tone sandhi, but much less so with respect to the third tone sandhi, which is easy to process with a fixed amount of memory. We leave it for future research (hopefully in the near future) to design and run an experiment that would verify or falsify these predictions. If they are in fact borne out, we need an explanation for why this system is easy to learn, yet hard to use.

[1] With the possible exception of Marcel Proust.

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