Productive phrasal opacity in Gua: a challenge to Stratal Optimality Theory*

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October 4, 2023

Abstract

We present new evidence for a special opaque interaction between phonological processes in Gua, a nearly endangered Guang (Niger-Congo) language spoken in eastern Ghana. This interaction, which was first observed by Obiri-Yeboah (2021), is between ATR vowel harmony and hiatus-resolution processes that render harmony opaque. A few properties of this interaction make it special. First, ATR harmony and hiatus resolution interact productively across arbitrary combinations of words. We show this using grammatical-yet-nonsensical Gua sentences akin to Chomsky's (1957) "colorless green ideas sleep furiously", which could not have been memorized by speakers. This makes the interaction a clear case of opacity acquired by speakers. Second, the interaction involves multiple types of opacity in different derivations – specifically, counterbleeding, (self-)counterfeeding, and the recently labeled "countershifting" (Rasin 2022) – which pose a challenge to non-serial phonological theories like Parallel Optimality Theory (OT; Prince & Smolensky 1993/2004). Stratal Optimality Theory (Bermúdez-Otero 1999, Kiparsky 2000, 2015) is a serial version of OT that attempts to account for opacity by assigning opaquely interacting processes to different serially ordered strata. A central prediction of Stratal OT is that opacity should correlate with morphosyntactic structure, because strata are limited to morphological or syntactic domains (Jaker and Kiparsky 2020). Building on Obiri-Yeboah and Rose (2022), we provide new evidence that ATR harmony and hiatus resolution in Gua apply only once to the entire utterance and thus cannot be attributed to different morphosyntactic domains, suggesting that Stratal OT's limited serialism is insufficient for solving the opacity problem for OT, and that a purely phonological mechanism for deriving opacity is needed.

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1 Introduction

An opaque phonological process, as defined by Kiparsky (1971), is a process that does not receive support on the surface, either because the process has applied and its conditioning environment is not present on the surface, or because the conditioning environment is present on the surface but the process has not applied (see also Baković 2007, 2011). In Bedouin Hijazi Arabic, for example, a process that palatalizes an underlying /k/ before /i/ applies even when the following /i/ ends up getting deleted, so the environment for palatalization is not surface-apparent, as demonstrated in (1) (Al-Mozainy 1981; see also McCarthy 2007, pp. 24–25).

(1) Opacity in Bedouin Hijazi Arabic
/ħaːkim-iːn/ → [ħaːk^{j}m-iːn] 'ruling-M.PL'

This and other kinds of opacity receive a straightforward account under rule-based phonology (Chomsky and Halle 1968), where they are analyzed using serial rule ordering. In the Bedouin Hijazi Arabic example, ordering palatalization before i-deletion would explain why palatalization applies even when its environment is missing on the surface. This is illustrated in the derivation in (2), where the rule that deletes /i/, here applying to non-final open syllables, removes the conditioning environment for palatalization only after the latter has already applied.

(2) A rule-based derivation of [ħaːk^{j}m-iːn]

UR	/ħaːkim-in/
$k \rightarrow k^j$ / __ i	ħaːk^{j}im-iːn
$i \rightarrow \emptyset$ / __ CV	ħaːk^{j}m-iːn
SR	[ħaːk^{j}m-iːn]

Opacity is known to pose an outstanding challenge for the basic parallel version of Optimality Theory (Parallel OT; Prince and Smolensky 1993/2004), which relies on surface-oriented markedness constraints and applies all phonological processes simultaneously. As shown by McCarthy (2007, pp. 24–25), a simple Parallel-OT attempt to account for the behavior of palatalization in Bedouin Hijazi Arabic could use markedness constraints that trigger palatalization and i-deletion (here, *ki and *iCV respectively) and rank them over the corresponding faithfulness constraints that militate against palatalization and deletion (here, IDENT[back] and MAX respectively). However, as tableau (3) shows, the correct output candidate (d) loses regardless of the ranking of the constraints, because it is harmonically bounded by the incorrect candidate (c). The problem is not specific to this set of constraints: as long as the constraints are limited to basic markedness and faithfulness constraints, no alternative set of constraints would work either (Buccola 2013).

(3) A failed Parallel-OT attempt to derive [ħaːk^{j}m-iːn]

		/ħaːkim-iːn/	*ki	*iCV	Ident[back]	Max
a.		ħaːkimiːn	*!	*		
b.		ħaːkʲimiːn		*!	*	
c.	☞	ħaːkmiːn				*
d.	☹	ħaːkʲmiːn			*!	*

There have been different kinds of responses to the opacity challenge within OT. One line of response denies that opacity is acquired by speakers (e.g., Sanders 2003). On this view, opaque surface forms might be stored faithfully in the lexicon or the opaque rule is not induced by language learners at all. Applying this view to Bedouin Hijazi Arabic, this could mean that words like [ħaːkʲm-iːn] are memorized by speakers and are stored in the lexicon with the relevant consonants already palatalized (e.g., /ħaːkʲm-iːn/, or with the deleted vowel: /ħaːkʲim-iːn/). If the palatalization process does not apply to such representations, it would no longer be opaque, and the problem for OT is eliminated. A memorization analysis is a viable option in many cases where the justification for an opaque phonological process relies on generalizations made over the surface forms of a language without additional evidence suggesting that speakers internalize the opaque process and can apply it productively in novel opaque contexts. And while some have argued that the productivity of opacity is empirically supported (see McCarthy 2007), the evidence so far has been scarce. After all, the original motivation for the introduction of the term opacity by Kiparsky has been the observation that opaque processes tend to disappear as languages change over time, so it would not be surprising if speakers have difficulties acquiring them.

The first of our two goals in this paper is to present new evidence for the productivity of opacity from Gua, a nearly endangered Guang language spoken in eastern Ghana. Gua exhibits a particularly clear case of opacity that can be shown to be acquired by speakers and cannot be accounted for by memorization. The evidence for the productivity of opacity in Gua is that the opaque process and the second process that makes it opaque both apply across word boundaries, including in nonsensical word combinations. To preview our argument, consider two Gua processes: regressive ATR vowel harmony, which spreads a [+ATR] feature to a preceding [-ATR] vowel (possibly across intervening consonants), and vowel assimilation, which fully assimilates a non-high vowel to an immediately following non-high vowel. An interaction of the two processes, first observed by Obiri-Yeboah (2021), is exemplified in (4).

(4) An opaque interaction across words
[àɲẽ́ kwɛ̀ ɛ̀dɛ̀]
/àɲɛ̃́ kwè ɛ̀dɛ̀/
man grind.HAB something
'A man grinds something'

In the three-word sentence in (4), the underlying [+ATR] vowel /e/ of the verb triggers harmony on the final vowel of the subject, changing it from the underlying [-ATR] vowel /ɛ/ to the [+ATR] vowel [e]. In addition, the triggering /e/ undergoes complete assimilation and changes its ATR value to match the following [-ATR] vowel /ɛ/. The result is that regressive ATR vowel harmony applies even though its [+ATR] trigger is not present on the surface. In other words, Gua ATR vowel harmony is opaque.

The fact that opaque harmony applies across word boundaries in (4) is already indicative of its productivity. But it is possible in principle that the sentence in (4) is stored with the relevant ATR features along the lines of the memorization analysis of palatalization discussed above. To conclusively rule out the possibility of such excessive storage in the case of Gua and provide strong evidence for the productivity of harmony, we will show that harmony applies opaquely across word boundaries in grammatical-yet-nonsensical Gua sentences akin to Chomsky's (1957) famous example "colorless green ideas sleep furiously", which could not have been memorized by speakers. An example is the nonsensical sentence in (5), which means "knowledge slaughtered a table".

(5) An opaque interaction across words in a nonsensical sentence
[àhḗ tɔ̀ ɔ̀kpʊ̀kɔ́]
/àhɛ̄́ tè ɔ̀kpʊ̀kɔ́/
knowledge slaughter.PST table
'Knowledge slaughtered a table'

This sentence exhibits the same opaque application of ATR vowel harmony as in (4), but each of its two-word subsequences would have zero or near zero occurrences in a typical Gua corpus, because knowledge cannot commit slaughters and tables do not get slaughtered. On the basis of a range of sentences along the lines of (5), we will conclude that harmony is acquired by Gua speakers as an opaque process that poses a real opacity challenge to Parallel OT.

A second line of response to the opacity problem within OT accepts that opacity is acquired by speakers and tries to amend OT with mechanisms that enable it to generate opaque interactions. Within this line of response, some theories maintain full parallelism and try to deal with opacity by enriching the representations or the constraint set. Examples include Turbidity (Goldrick 2000), Sympathy Theory (McCarthy 2003b), and Comparative Markedness (McCarthy 2003a). Other theories add serial power to OT directly, allowing it – at least in some cases – to provide serial analyses of opacity that recapitulate the corresponding rule-based analyses, as in Stratal OT (Bermúdez-Otero 1999, Kiparsky 2000), Harmonic Serialism (McCarthy 2000, 2016), OT with Candidate Chains (McCarthy 2007), and Serial Markedness Reduction (Jarosz 2014).

Our focus in this paper is on Stratal OT, a serial version of OT in which the grammar consists of multiple strata that interact serially, as developed in Kiparsky 2000, 2015, Bermúdez-Otero 1999, 2011, 2018, and Jaker and Kiparsky 2020. Each stratum in the Stratal-OT architecture corresponds to a morphological or a syntactic domain, such as the stem, the word, or the phrase, and it consists of a Parallel-OT grammar with its own constraint ranking. Phonological computation proceeds inside out in a cyclic fashion, starting from the most deeply embedded domain. In each cycle a Parallel-OT grammar applies. This means that on this architecture of grammar, serial interactions between phonological processes are only possible across strata – i.e., across different morphological or syntactic domains – and not within strata, where phonology applies in parallel. We refer to this property as MORPHOSYNTACTICALLY-CONFINED SERIALISM:

(6) MORPHOSYNTACTICALLY-CONFINED SERIALISM
Serial interactions are only possible between distinct morphological or syntactic domains.

A central prediction of Stratal OT's MORPHOSYNTACTICALLY-CONFINED SERIALISM is that opacity can only result from different morphosyntactic domains interacting serially (at least as long as the underlying Parallel-OT architecture of each stratum is not enriched with special opacity mechanisms as in the fully parallel attempts to generate opacity). This means that opacity must strongly correlate with morphosyntactic structure (Jaker and Kiparsky 2020): whenever a phonological process becomes opaque as a result of the application of another process, it should be possible to identify two distinct morphological or syntactic domains such that the opaque process applies in the first domain and the other process applies later in the second, larger domain.

Our second goal in this paper is to argue that the opacity of ATR vowel harmony in Gua poses a strong counterexample to the central prediction of MORPHOSYNTACTICALLY-CONFINED SERIALISM. The argument holds even if additional strata are added to the basic tri-stratal model of Stratal OT where there is one stem, one word, and one phrase stratum. The argument builds on Obiri-Yeboah and Rose's (2022) observation that the number of words in the Gua utterance determines if and when ATR vowel harmony can apply, often disrespecting the syntactic structure of the utterance. We use this observation to claim that harmony necessarily applies only once to the entire utterance. We provide new evidence showing that if harmony is assumed to also apply in any morphological or syntactic domain below the utterance level (such as the DP, VP, CP, and so on), wrong predictions would be made regarding its application. On the assumption that the largest domain of an utterance is the utterance itself, there is no distinct domain larger than the utterance that can trigger the processes that make harmony opaque. The implication of this argument is that Stratal OT's limited serialism is insufficient for solving the opacity problem for OT. In contrast to Stratal OT, theories that employ a purely phonological serial mechanism for deriving opacity provide a simple and straightforward account of the Gua pattern. We will illustrate this using rule-based phonology, though constraint-based theories could in principle work as well, as long as they reject MORPHOSYNTACTICALLY-CONFINED SERIALISM and have the ability to deal with the types of opacity observed in Gua.

Our arguments will be developed in several steps. In Section 2, we will provide some background on the phonology of Gua, with an emphasis on ATR harmony and a range of hiatus-resolution alternations that make harmony opaque. In Section 3, we will provide new data from Gua indicating that the opaque interaction between ATR harmony and hiatus resolution is productive. We will point out that serial rule-based phonology can provide a simple ordering analysis of the interaction given that its serialism is not a by-product of the interfaces. In Section 4, we provide new data indicating that ATR harmony applies only once to the entire utterance. We will discuss the theoretical consequences of the data, arguing that they pose a challenge to Stratal OT, and specifically to the assumption that serialism in phonology is only possible between distinct morphological or syntactic domains.

2 Background on Gua phonology

2.1 General background

Gua is an under-documented and understudied Guang language spoken in the eastern region of Ghana. Being a minority language in Ghana, Gua is under a threat of endangerment and possible extinction because Akan has taken over as a primary language of use both at home and in the community (Obiri-Yeboah 2021). Gua has two dialects, Anum and Boso. Much of the previous work on the language has focused on the Anum dialect (Painter 1967, Obeng 1995, Ofori 2014, Kügler 2022), but recent work has started describing and analyzing the phonological system of the Boso dialect (Obiri-Yeboah 2013, 2020, 2021, Obiri-Yeboah and Rose 2022). The present paper draws on data from the Boso dialect, and the data and generalizations in this background section are taken from Obiri-Yeboah (2021) and Obiri-Yeboah and Rose (2022).

2.2 ATR harmony

Gua has nine underlying oral vowels that can be grouped into two sets based on their tongue-root features – Advanced Tongue Root (+ATR) vowels and non-Advanced Tongue Root (-ATR) vowels – as shown in (7). A tenth [+ATR] vowel, [ɜ], is a surface variant of /a/ that results from ATR harmony (as discussed below).

(7) Oral vowel system

-ATR	+ATR
ɪ ʊ	i u
ɛ ɔ	e o
a	[ɜ]

Within words, all vowels can occur in word initial, medial, or final positions except for /u/ and /ʊ/, which never occur word-initially. There are seven underlying nasal vowels (ĩ, ɪ̃, ũ, ʊ̃, ɛ̃, ɔ̃, ã) and three surface nasalized vowels that are derived through nasalization and ATR vowel harmony (ẽ, ɔ̃, ɜ̃). They can occur with high or low tone (see Obiri-Yeboah 2021 for further discussion).

The near-minimal pairs in (8) are representative of the unpredictable distribution of ATR in monosyllabic words, suggesting that the [±ATR] distinction in Gua is represented underlyingly.

(8) Near-minimal pairs

	[-ATR]		[+ATR]	
a.	fɪ̀	'sell!'	fì	'swallow (soup)!'
b.	lɛ̀	'choke/hang!'	lé	'a song'
c.	tʊ́	'a gourd/calabash'	tù	'throw!'

Within multisyllabic roots and words, Gua shows regressive [+ATR] vowel harmony. First, the examples in (9) illustrate that in bisyllabic mono-morphemic words, the two vowels either have the same ATR value, or the ATR configuration is [+ATR][-ATR]. The ATR configuration [-ATR][+ATR] is not found with mono-morphemic words. So far, this is consistent either with regressive [+ATR] harmony or with progressive [-ATR] harmony. A first indication that ATR harmony is regressive is that the low [+ATR] vowel [ɜ] is only found before [+ATR] vowels. The examples in (10) further show that when a prefix combines with a root, the ATR value of the prefix is determined by the ATR value of the root, another indication that ATR harmony is regressive. Each line in (10) shows a prefix combining once with a [-ATR] root (left) and once with a [+ATR] root (right).

(9) ATR harmony within roots

a.	kpìtɛ́	‘separate!’	kpìté	‘clean!’
b.	sɔ̀kwí	‘collect/cease!’	sòbí	‘pull!’
c.	àdɛ́	‘a cutlass’	ɜ̀bú	‘a house’
d.	súnɔ̀	‘seven’	súmà	‘a god’

(10) Regressive ATR harmony across morphemes

a.	ɔ̀-kpítì	‘plucking’	ò-kpítè	‘cleansing/cleaning’
b.	á-nɛ̀	‘grandchild’	ɜ́-nì	‘mother’
c.	ɛ̀ɛ́-bɔ̀tɛ̀	‘is removing’	èé-sòbì	‘is pulling’
d.	bɛ́-fítɛ̀	‘will dry’	bè-bólì	‘will break’

Regressive ATR harmony also applies across words. Here, a clear asymmetry emerges between [+ATR] and [-ATR]: whenever a word begins with a [+ATR] vowel (underlyingly), the last vowel of the preceding word surfaces as [+ATR], suggesting that [+ATR] spreads leftwards across words. The feature [-ATR] does not seem to spread at all. Each of the examples in (11) has two sentences with the same initial [-ATR] word (i.e., the word would be realized with [-ATR] vowels in isolation). The final vowel of the first word remains [-ATR] when followed by a word that begins with a [-ATR] vowel (left) but changes into [+ATR] when followed by a [+ATR] vowel (right).

(11) Regressive [+ATR] harmony applies across words (Obiri-Yeboah and Rose 2022)

a.	tʊ́ wátɕì calabash break.PST ‘A calabash broke’	tú hè calabash fall.PST ‘A calabash fell’
b.	kpʊ́tɔ̀ fíńtɪ̃̀ frog jump.PST ‘A frog jumped’	kpʊ́tò sũ̀ frog cry.PST ‘A frog cried’
c.	ɛ̀ní sɔ́tɛ̀ ìfí we catch.PST rope ‘We caught a (falling) rope’	ɛ̀ní sóbì àkpákʊ̀ we pull.PST a male.goat ‘We pulled a male goat’
d.	ɛ̀mʊ́ bɛ̀ dá 3PL come.PRES/HAB there ‘They come there’	ɛ̀mú bùrùfè ɛ́hʊ̀tɔ́ɔ̀ 3PL urinate.PRES/HAB blood ‘They suffer from bilharzia’
e.	àkpákʊ̀ bɛ̀ dá male.goat come.PRES/HAB there ‘A male goat comes there’	àkpákù bùrùfè ɛ́hʊ̀tɔ́ɔ̀ male.goat urinate.PRES/HAB blood ‘A male goat suffers from bilharzia’

The examples in (12) illustrate the generalization that when a [+ATR] word is combined with a following [-ATR] word, no harmony takes place. This suggests both that [+ATR] harmony is not progressive and that there is no regressive spreading of [-ATR].

(12) No ATR harmony in the configuration [+ATR][-ATR]
  a. kòfí sóbȉ mí
  Kofi pull.PST 1SG
  'Kofi pulled me'
  b. ǹsóbȉ tʊ́
  1SG pull.PST calabash
  'I pulled a calabash
  c. kòfí sóbȉ ɛ̀mʊ́
  kofi pull.PST 3PL
  'Kofi pulled them'
  c. dʒɔ́ù sóbȉ àkpákʊ̀
  gyau pull.PST male.goat
  'Gyau pulled a male goat'

Although ATR harmony within roots and words spreads across the entire root or word constituent, the process across words affects just one vowel. We have already seen the examples in (11), where regressive cross-word harmony targeted only the final vowel of a multisyllabic word (e.g.,. /kpʊ́tɔ̀ sȕ/ → [kpʊ́tò sȕ], *[kpútò sȕ]). The example in (13) further shows that ATR harmony spreads only once even onto a preceding monosyllabic word and does not extend beyond that word onto the first word of the sentence. This suggests that ATR harmony applies non-iteratively: it fails to reapply when it creates a new input to itself.

(13) Non-iterative ATR harmony across words (Obiri-Yeboah and Rose 2022)
  [áfwɛ̀ sò kúrȉ] *áfwè sò kúrȉ
  /áfwɛ̀ sɔ̀ kúrȉ/
  stranger buy.PST pig
  'A stranger bought a pig'

Anecdotally, a [-ATR] vowel that undergoes cross-word harmony and surfaces as [+ATR] is indistinguishable from an underlying [+ATR] vowel that has surfaced unchanged, supporting the non-iterativity of ATR harmony. As reported in table (14) for one recording, the F1 formant frequencies (the primary phonetic correlate of ATR) of the vowels of [fȉ] 'swallow' and [fɪ] 'sell' are distinct (236Hz and 346Hz respectively) when the words occur in isolation, but become nearly identical (272Hz and 260Hz respectively) before the [+ATR] word [té] 'oath', which creates a context for cross-word ATR harmony.

(14) F1 measurements comparing underlying /i/ and /ɪ/ in isolation and in a harmony context

	UR: /i/	F1	UR: /ɪ/	F1
Isolation	fȉ	236Hz	fɪ	346Hz
ATR Harmony	fȉ té	272Hz	fȉ té	260Hz

In what follows, we will focus on ATR harmony across words. The facts regarding cross-word ATR harmony in examples (11)–(13) can be captured using the SPE-style rule in (15), which says that [+ATR] harmony spreads leftwards onto the final vowel of the preceding word, applying non-iteratively.

(15) An SPE-style rule for cross-word ATR harmony
$V \rightarrow [+ATR]\ /\ \_\_\ C_0\ \#\ C_0\ [+ATR]$ (non-iterative)

The sentences in (11)–(13) each contained two or three words. Cross-word harmony applied freely in those sentences between subjects, verbs, and objects. In four-word sentences, the situation is different. ATR harmony applies freely between the first and the second word and between the third and the fourth word, but it is blocked between the second and the third word. This is illustrated in the examples in (16), where some syntactic categories are labeled (S = subject, V = verb, O = object, N = noun, A = adjective, D = determiner, POSS = possessive). In (16a), harmony successfully applies between word one and word two (as indicated by the leftward arrow ←) and in (16b) it applies between words three and four. In (16c), harmony is blocked between words two and three (as indicated by the crossed leftward arrow ↚).

(16) Cross-word harmony in four-word sentences is position-dependent
   a. S[POSS ← N] V O
      mí sìsí sɔ̀ átɕɔ̀
      1POSS sister buy.PST hoe
      'My sister bought a hoe'
   b. S[N A] V ← O
      àɲɛ́ kɔ́ɔ̀ kítè bókìtì
      man red hold.PST bucket
      'A fair man held a bucket'
   c. S[N D] ↚ V O
      àɲɛ́ à kúbì téì
      man DET cut.PST food
      'The man cut/fetched food'

The additional examples in (17) suggest that blocking is indeed due to the position in the sentence rather than due to syntactic structure. While harmony was blocked in (16c) from applying between the verb (word three) and the subject (words one and two), in (17a) it has no problem applying from the verb (word two) onto the subject (word one). The blocking of harmony in (16c) is also not due to an inability of the final-subject definite determiner to be a target for harmony. In the three-word sentence in (17b), harmony applies between the verb and the definite subject, changing the definite determiner to be [+ATR]. Similarly, the object-verb word sequence /kítɛ̀ bókìtì/ undergoes cross-word harmony in (16b), when the two words are in position three and four in the sentence, but not in (17c) or (17d), when the same words are in position two and three. See Obiri-Yeboah and Rose (2022) for further justification and discussion of the behavior of ATR harmony in longer sentences.

(17) The application of cross-word harmony is independent of syntactic structure

a. S ← V O[N D]
àɲé kúbì ɜ́dʒè à
man cut.PST fire/firewood DET
'A man cut the firewood.'

b. S[N D] ← V
àɲɛ́ ɜ̀ sóbì
man DET pull.PST
'The man pulled'

c. S V ↚ O[N A]
àɲɛ́ kɪ́tɛ̀ bókìtì kɔ́ɔ̀
man hold.PST bucket red
'A man held a red bucket'

d. S V ↚ O Adv
àɲɛ́ kɪ́tɛ̀ bókìtì ǹdí
A man hold.PST bucket today
'A man held a bucket today'

Obiri-Yeboah and Rose (2022) analyze the difference between the free application of harmony in three-word sentences and its limited application in four-word sentences by assuming that the words in the Gua sentence are grouped into phonological phrases. Four-word sentences can be exhaustively parsed into binary (two-word) phrases, but three-word sentences contain one three-word phrase. This analysis is schematized in (18). Given these groupings, Obiri-Yeboah and Rose explain the behavior of ATR harmony by assuming that it can apply only within a phonological phrase but never across phrases.

(18) Word groupings in three- and four-word sentences

- (ww)(ww)
- (www)

In the next section we turn to discuss hiatus-resolution processes, which we will later show can make ATR harmony opaque.

2.3 Hiatus resolution

A vowel hiatus is generally permitted within words in Gua but not across words. When two consecutive vowels arise as a result of word concatenation, one of three phonological processes applies: assimilation, deletion, or glide formation. We will refer to such processes collectively as hiatus-resolution processes. The choice of the hiatus-resolution process that applies depends on vowel height. The generalizations are the following:

(19) Hiatus-resolution processes and their environments of application

1. *Two non-high vowels: assimilation.* A sequence of two non-high vowels V_1V_2 is resolved by the complete assimilation of V_1 to V_2, which creates a long vowel with the features of V_2.

2. *Two high vowels: deletion*. A sequence of two high vowels V_1V_2 is resolved by the deletion of V_2.
3. *High vowel + non-high vowel: glide formation*. A sequence of a high vowel and a non-high vowel (in any order) is resolved by turning the high vowel into a glide.

We will provide representative examples of each process before presenting a comprehensive table with all the possible vowel combinations.

(20) Assimilation

a. kwɛ̀lɛ́ téì → [kwɛ̀lé téì] (baseline; no assimilation)
fry.IMP food
'Fry food!'

b. kwɛ̀lɛ́ ònı́ → [kwɛ̀lòònı́]
fry.IMP fish/meat
'Fry fish/meat!'

(21) Deletion

b. ísɛ̀ → [ísɛ̀] (baseline; no deletion)
grass
'Grass.'

b. wʊ̀sʊ́ ísɛ̀ → [wʊ̀sʊ́sɛ̀]
shake grass
'Shake grass.'

(22) Glide formation

a. ɛ̀ní bɛ̀ → [ɛ̀ní bɛ̀] (baseline; no glide formation)
3PL come.PROG
'We are coming.'

b. ɛ̀ní àkpákʊ̀ → [ɛ̀nj àkpákʊ̀]
3PL male.goat
'Our male goat.'

c. ɛ̀ní ɔ̀kpʊ̀nɔ́ → [ɛ̀nj ɔ̀kpʊ̀kɔ́]
3PL table
'Our table.'

The tables in (23)–(24) exemplify the application of hiatus resolution for each possible sequence of two vowels that match in their ATR feature values underlyingly.[1] Since the ATR values match, ATR harmony does not play a role here, so the application of hiatus resolution can be observed independently of harmony.

(23) Hiatus resolution with [-ATR][-ATR] vowel combinations (Obiri-Yeboah 2021, p. 194)

[1] Recall that the high back vowels /u/ and /ʊ/ cannot occur word-initially. This is why they are missing from the columns in the tables, which represent the second vowel in a cross-word hiatus.

V1/V2	ɪ	ɛ	ɔ	a
ɪ	bòlí ísɛ̀ [í] python grass	bòlí ɛ́dɛ̀ [jɛ́] python thing	fìǹtí ɔ̀kpʊ̀nɔ́ [jɔ̀] jump table	bòlí àdɛ́ [jà] python’s cutlass
ʊ	wʊ̀sʊ́ ísɛ̀ [ʊ́] shake grass	wʊ̀sʊ́ ɛ́bì [wɛ́] shake palm tree	wʊ̀sʊ́ ɔ̀kpʊ̀nɔ́ [wɔ̀] shake table	wʊ̀sʊ́ àkpàkʊ́ [wà] shake male.goat
ɛ	bɔ̀tɛ́ ífì [ɛ́j] roll rope	bɔ̀tɛ́ ɛ̀dídɛ̀ [ɛ́ɛ̀] roll mat	bɔ̀tɛ́ ɔ̀wɛ́ [ɔ́ɔ̀] roll snake	sɔ̀tɛ́ àkpàkʊ́ [àà] catch whistle
ɔ	sɔ̀ ífì [ɔ́j] buy rope	kpʊ̀tɔ́ ɛ́bì [ɛ́ɛ́] frog’s palm tree	kpɔ̀tɔ́ ɔ̀kɔ́tɔ̀ [ɔ́ɔ̀] grind crab	sɔ̀ àbɛ́lì [àà] buy male.goat
a	bʊ̀á ífì [áj] prepare rope	tʊ̀á ɛ́sɛ̀ [ɛ́ɛ́] chase people	kpʊ̀sá ɔ̀wɛ́ [ɔ́ɔ̀] swish snake	kpʊ̀sá ásɛ̀ [áá] swish someone

(24) Hiatus resolution with [+ATR][+ATR] vowel combinations (Obiri-Yeboah 2021, p. 195)

V1/V2	i	e	o	ɜ
i	kùbí ìdʒójì [í] cut stalk (yam)	kùbí ékpù [jé] cut garden eggs	bòlí òsé [jò] break pottery	kùbí ɜ̀tèbí [jɜ̀] cut an animal
u	bùtú ìbíèsʊ̀ [ú] squat at a market	bùtú èbísè [wè] cover fibre	bùtú òní [wò] cover fish/meat	bùtú ɜ̀bòbí [wɜ̀] cover bird
e	kpè ísì [èj] weed anthill	bìsé ésè [éé] ask issue	wùlé òbíè [óò] finish bathing	kpìté ɜ́bùdè [ɜ́ɜ̀] clean indoors
o	kpò ìbíè [òj] stop market(ing)	kpò èsímì [èè] close work	kpò òní [òò] close fish	kpò ɜ̀tèbí [ɜ̀ɜ̀] close animal

The table in (25) shows the application of hiatus resolution in [-ATR][+ATR] vowel combinations. Here, ATR harmony also plays a role. For example, the output of /fìtɛ́ íkù/ ‘dry group’ is [fìtéjkù], where both hiatus resolution (/i/ → [j]) and ATR harmony (/ɛ/ → [e]) apply (we discuss the interaction between the two processes in the following section).

(25) Hiatus resolution with [-ATR][+ATR] vowel combinations (Obiri-Yeboah 2021, p. 196)

V1/V2	i	e	o	ɜ
ɪ	bɔ̀lí ìbíè [í] python market	bɔ̀lí ésè [jé] python matter	bɔ̀lí òsé [jò] python pottery	bɔ̀lí ɜ́dʒè [jɜ́] python wood
ʊ	wʊ̀sʊ́ ìdʒójì [ú] shake stalk	wʊ̀sʊ́ ébí [wé] shake palm kernel	wʊ̀sʊ́ ókítì [wó] shake lizard	wʊ̀sʊ́ ɜ́dʒè [wɜ́] shake wood
ɛ	fìtɛ́ íkù [éj] dry group	kwɛ̀lɛ́ ébì [éé] fry palm kernel	kwɛ̀lɛ́ òní [óò] fry fish/meat	sɔ̀tɛ́ ɜ́tɕì [ɜ́ɜ́] catch a knife
ɔ	sɔ̀ ìbíè [òj] buy market	sɔ̀ ébì [èé] buy palm kernel	kpɔ̀tɔ́ òní [óò] grind fish/meat	sɔ́ ɜ́dʒè [ɜ̀ɜ́] buy wood
a	kpʊ̀sá íkù [ɜ́j] swish a group	kpʊ̀sá ébì [éé] swish palm kernel	kpʊ̀sá òní [óò] swish fish/meat	kpʊ̀sá ɜ́bì [ɜ́ɜ́] swish snail

The generalizations regarding hiatus resolution presented in this section can be captured by the following SPE-style rules:

(26) SPE-style rules for hiatus resolution[2]

1. $V_{\text{[+high]}} \rightarrow \emptyset$ / $V_{\text{[+high]}}$ # __
2. $V_{\text{[+high]}} \rightarrow$ [-vocalic] / __ # $V_{\text{[-high]}}$
3. $V_{\text{[+high]}} \rightarrow$ [-vocalic] / $V_{\text{[-high]}}$# __
4. $V_{\text{[-high]}} \rightarrow V_i$ / __ # $V_{i\text{[-high]}}$

In the next section, we will present new data from Gua showing that ATR harmony and hiatus resolution can interact opaquely in a variety of ways, and that their interaction is productive.

3 The opaque interaction

ATR harmony and hiatus resolution can interact opaquely, as can be seen in the following example from Obiri-Yeboah (2021) (repeated from (4)):

(27) An opaque interaction
[àɲẽ́ kwɛ̀ ɛ̀dɛ̀]
/àɲɛ̃́ kwè ɛ̀dɛ̀/
man grind.HAB something
'A man grinds something'

Here, the final vowel of the first word has undergone ATR harmony even though the trigger of harmony is not present on the surface. In a serial rule-based theory, this output can be generated straightforwardly by ordering ATR harmony before hiatus resolution, as in (28). If hiatus resolution had applied first, as in (29), it would have destroyed the environment of ATR harmony, preventing harmony from applying. This is a bleeding interaction, and the correct derivation in (28) is therefore an instance of counterbleeding, which involves overapplication opacity (as we will see below, the range of interactions between ATR harmony and hiatus resolution in Gua goes beyond counterbleeding).

(28) ATR harmony precedes hiatus resolution (correct)

UR	/àɲɛ̃́ kwè ɛ̀dɛ̀/
ATR harmony	àɲẽ́ kwè ɛ̀dɛ̀
Hiatus resolution	àɲẽ́ kwɛ̀ ɛ̀dɛ̀
SR	[àɲẽ́ kwɛ̀ ɛ̀dɛ̀]

(29) Hiatus resolution precedes ATR harmony (incorrect)

UR	/àɲɛ̃́ kwè ɛ̀dɛ̀/
Hiatus resolution	àɲɛ̃́ kwɛ̀ ɛ̀dɛ̀
ATR harmony	-
SR	*[àɲɛ̃́ kwɛ̀ ɛ̀dɛ̀]

[2] If the rules apply in the given order, they could be simplified by removing a few [high] specifications.

Having established that ATR harmony and hiatus resolution can interact opaquely, our goal in this section is to provide new data from Gua showing that speakers apply the interaction between the processes in unseen contexts. To verify that the contexts have a zero or near-zero chance to have been encountered by speakers, we use grammatical-yet-nonsensical Gua sentences akin to Chomsky's (1957) "colorless green ideas sleep furiously", in which each two-word subsequence in nonsensical. Nevertheless, speakers can produce such sentences and apply the phonology of the language to them. To collect the data, we first created the desired sentences in English. One of the authors, who is a native speaker of Gua, translated the sentences from English into Gua. A representative subset of the sentences was checked with two additional speakers, a 52-year-old female and a 28-year-old male, who were presented with the Gua words in isolation and were asked to pronounce them as a sentence. There were no differences between the speakers in terms of whether ATR harmony and hiatus resolution have applied. We will first present the data with the application of ATR harmony independently of hiatus resolution, and then turn to contexts with the interaction. As we will see, the processes apply as expected, making opacity in Gua a clear case of opacity that is acquired by speakers.

Consider first the examples in (30), which show the application of ATR harmony with a range of [+ATR] triggers and [-ATR] targets. In these examples, harmony takes place between the second and the third word of the sentence. Semantically, the sentences and each of their two-word subsequences make no sense. For example, the sentence in (30a) means *A cheek caught an oath (falling)* (the verb for 'catch' is specific to falling objects), but cheeks cannot catch falling objects and oaths cannot be caught while falling, so this sentence is unlikely to have been encountered by speakers and memorized with its surface ATR values, suggesting that the speakers who produced it derived it by applying ATR harmony.

(30) ATR harmony in nonsensical sentences

a. Target: ɛ, Trigger: e
[ɔ̀tsʊ́ sɔ́tè té]
/ɔ̀tsʊ́ sɔ́tɛ̀ té/
cheek catch-falling.PST oath
'A cheek caught an oath (falling)'

b. Target: ɛ, Trigger: o
[àdɛ́dì kwɛ̀lé sóbì]
/àdɛ́dì kwɛ̀lɛ́ sóbì/
dream fry.PST cooking stove
'A dream fried a cooking stove'

c. Target: ɔ, Trigger: i
[àdɛ́ sò sìsí]
/àdɛ́ sɔ̀ sìsí/
cutlass buy.PST sister
'A cutlass bought a sister'

d. Target: ɪ, Trigger: u
[ɔ̀tsʊ́ kpítì sùmá]

/ɔ̀tsʊ́ kpítì sùmá/
cheek tear/pluck.PST god
'A cheek tore a god'

e. Target: ɪ, Trigger: u
[àdɛ́ lì sùmá]
/àdɛ́ lɪ̀ sùmá/
cutlass scoop/fetch.PST god
'A cutlass fetched/scooped a god'

f. Target: ɛ, Trigger: ɜ
[àhɛ́ lù bɜ́bì]
/àhɛ́ lʊ̀ bɜ́bì/
wisdom/knowledge weave.PST finger
'Wisdom/knowledge wove a finger'

g. Target: a, Trigger: i
[bɔ̀lí tʃɜ̀ sìká]
/bɔ̀lí tʃà sìká/
python dance.PST money
'A python danced money'

h. Target: ɛ, Trigger: o
[àdɛ́dì lé sóbì]
/àdɛ́dì lɛ́ sóbì/
dream hang.PST cooking stove
'A dream hanged a cooking stove'

Additional examples are provided in (31), this time with harmony applying between the first and the second word of each sentence:

(31) a. Target: ɛ, Trigger: e
[àhẽ́ tè téì]
/àhɛ̃́ tè téì/
knowledge slaughter.PST food
'Knowledge slaughtered food'

b. Target: ɪ, Trigger: o
[àdɛ́dì bólì lʊ́]
/àdɛ́dɪ̀ bólì lʊ́/
dream break.PST hernia
'Dream broke a hernia'

c. Target: ɔ, Trigger: i
[átɕò sítè búì]
/átɕɔ̀ sítè búì/
hoe set.PST stone
'A hoe set a stone'

We now turn to show that the opaque interaction between ATR harmony and hiatus resolution is also productive. To test its productivity, we first considered four scenarios with hiatus resolution – assimilation, deletion, glide formation applying to V_1 in the hiatus, and glide formation applying to V_2. We then considered two ATR configurations of three [-ATR] and [+ATR] word sequences: [-ATR][+ATR][-ATR] and [-ATR][-ATR][+ATR], where the second word is monosyllabic. We then matched each of the four hiatus-resolution scenarios with each of the two ATR configurations. From this total of $4 \times 2 = 8$ possibilities, we identified six configurations in which opacity is expected if the concatenation of the second and third word results in a vowel hiatus. We created a nonsensical sentence for each configuration. Hiatus resolution and ATR harmony applied as expected in all cases, as we show in what follows.

The examples in (32) are the two configurations where ATR harmony interacts with assimilation (which applies to non-high vowels).

(32) Opacity in nonsensical sentences: assimilation

a. Assimilation, ATR configuration: /- + -/ (counterbleeding)
[àhé tɔ̀ɔ̀kpʊ̀kɔ́]
/àhɛ́ tè ɔ̀kpʊ̀kɔ́/
knowledge/wisdom slaughter.PST table
'Knowledge slaughtered a table.'

b. Assimilation, ATR configuration: /- - +/ (countershifting)
[áfi sòòhílì]
/áfi sɛ̀ òhílì/
an axe fetch.PST game
'An axe fetched a game.'

The ATR configuration in (32a) is /- + -/. ATR harmony applies, changing the first [-] into [+], but assimilation changes the underlying [+] into [-]. The outcome is [+ - -], which is the same counterbleeding interaction as in (27) above. The ATR configuration in (32b) is /- - +/. Here, the [-ATR] vowel /ɛ/ assimilates to the following [+ATR] vowel /o/. The result is that the [-ATR] vowel /ɪ/ of the first word is followed by a [+ATR] vowel on the surface – the environment for ATR harmony – but ATR harmony has not applied to it. This is the expected outcome if harmony applies before assimilation, as shown in (33). In this example, harmony would have applied regardless of its relative ordering with respect to assimilation, but if assimilation had applied first, harmony would have applied in a different way: it would have incorrectly changed the first [-] into [+]. The outcome of this alternative ordering is shown in (34).

(33) ATR harmony precedes hiatus resolution (correct; countershifting)

UR	/áfi sɛ̀ òhílì/
ATR harmony	áfi sè òhílì
Hiatus resolution	áfi sò òhílì
SR	[áfi sò òhílì]

(34) Hiatus resolution precedes ATR harmony (incorrect; shifting)

UR	/áfi sɛ̀ òhílì/
Hiatus resolution	áfi sò òhílì
ATR harmony	áfì sò òhílì
SR	*[áfì sò òhílì]

Formally, the interaction in (34) is neither feeding or bleeding, because harmony applies regardless of the application of hiatus resolution. Effects of this kind have recently been labeled *shifting* (Rasin 2022, previously *transfusion* in Zwicky 1987), because the first process can be thought of as shifting the second process (i.e., making it apply in a different way). The opposite ordering, as in (33), has been accordingly labeled *countershifting*, the opaque counterfactual inverse of shifting. The opacity resulting from countershifting sometimes shares properties with underapplication opacity (e.g., in (33), the environment of ATR harmony is met on the surface) and sometimes with overapplication opacity, but it is different from both (see Kiparsky 2015, Rasin 2022, and Baković and Blumenfeld 2022 for examples and discussion).

In the examples in (35), ATR harmony interacts with glide formation (which applies to a sequence of a high vowel and a non-high vowel in any order).

(35) Opacity in nonsensical sentences: glide formation

a. V_1 gliding, ATR configuration: /- - +/ (countershifting)[3]
[àhɛ́ fjósù]
/àhɛ́ fɪ̀ ósù/
knowledge crack.PST crying
'Knowledge cracked a cry.'

b. V_1 gliding, ATR configuration: /- + -/ (counterbleeding)
[ɔ̀tʃú bjɛ́sɛ̀]
/ɔ̀tʃʊ́ bɪ̀ ɛ́sɛ̀/
cheek pluck.PST people
'A cheek plucked people.'

c. V_2 gliding, ATR configuration: /- - +/ (self-counterfeeding)
[ɔ̀tʃʊ́ sèjbɪ́è]
/ɔ̀tʃʊ́ sɛ̀ ɪ́bɪ́è/
cheek fetch.PST market
'A cheek fetched a market.'

In the ATR configuration /- - +/ in (35a), glide formation applies but ATR harmony does not, even though its environment is met on the surface. This again can be explained by ordering ATR harmony before glide formation. ATR harmony first changes the [-ATR] vowel /ɪ/ in /àhɛ́ fɪ̀ ósù/ into the [+ATR] vowel /i/. Then, glide formation changes this /i/ into [j] on the surface. As before, this is a countershifting interaction, because ATR harmony can apply non-vacuously either before or after glide formation. If glide formation had applied first, it would have caused harmony to apply in a different way: instead of harmony applying to /ɪ...o/, as is the case when it applies first, it would have applied to /ɛ...o/ following glide formation, changing /ɛ/ into [e]. In (35b), the ATR configuration is /- + +/. Here, both ATR harmony and glide formation apply even though the harmony trigger is not present on the surface – a counterbleeding interaction. The interaction in (35c), where the high vowel is the second vowel

[3] The underapplication of ATR harmony with glide formation cannot be attributed to an inability of harmony to cross a glide, as shown by the example /àtɕí jélɪ̀/ → [àtɕɪ́ jélɪ̀] 'a woman stood (up)'.

in the hiatus, is more difficult to classify. Here, both ATR harmony and glide formation apply. The /i/ that triggered harmony on /ɛ/ is not present on the surface, but the following [+ATR] vowel [i] surfaces without change, so there is an environment for the ATR change /ɛ/ → [e] on the surface (this is an accident of the third word being polysyllabic). Technically, since each of the two orderings would have resulted in the same surface form, this counts as a non-interaction. In addition, there is a context for ATR harmony on the surface, since the [-ATR] vowel [ʊ] of the first word is followed by the [+ATR] vowel [e]. This lack of application is the result of the non-iterativity of ATR harmony: ATR harmony applied and created an additional input for itself, but has not applied again. We will therefore label this case *self-counterfeeding*, a type of opacity exhibited by ATR harmony independently of hiatus resolution. Finally, V_2-gliding cannot interact with ATR harmony in the configuration /- + -/, because the elimination of the final /-/ does not affect and is not affected by changing the first /-/ into /+/. This is why (35) includes only three scenarios where harmony and glide formation interact.

The remaining interaction is between ATR harmony and vowel deletion (which omits the second vowel among two consecutive high vowels). It is abstractly similar to the interaction between harmony and V_2-gliding in (35c), because deleting the second vowel has the same effect as changing it into a consonant with respect to harmony. The interaction is illustrated in (36) and is labeled self-counterfeeding following the same reasoning as before.

(36) Opacity in nonsensical sentences: deletion

a. Deletion, ATR configuration: /- - +/ (self-counterfeeding)
[átɕɔ̀ sì̀kù]
/átɕɔ̀ sì íkù/
hole.digger barbered.PST group
'A hole digger barbered a group.'

This concludes our discussion of the range of opaque interactions involving ATR harmony and hiatus resolution. In different derivations we find either counterbleeding, countershifting, or self-counterfeeding, depending on the input. Those interactions occur in novel word sequences that speakers are likely to have never encountered, suggesting that the two processes and their interaction are internalized by speakers, and therefore should be accounted for by theories of phonology. In the next section we turn to discuss the theoretical implications of our findings for Stratal OT.

4 Theoretical implications

The opaque interactions between ATR harmony and hiatus resolution can be straightforwardly analyzed in rule-based phonology, by applying the ATR harmony rule before the application of the set of rules responsible for hiatus resolution. This is shown in (37), where each column illustrates a different type of interaction.

(37) Three types of interactions between ATR harmony and hiatus resolution

UR	/àhɛ́ tè ɔ̀kpʊ̀kɔ́/	/àhɛ́ fì ósù/	/ɔ̀tʃʊ́ sɛ̀ ɪ́bɪ́è/
ATR harmony	àhé tè ɔ̀kpʊ̀kɔ́	àhɛ́ fì ósù	ɔ̀tʃʊ́ sè ɪ́bɪ́è
Hiatus resolution	àhé tɔ̀ɔ̀kpʊ̀kɔ́	àhɛ́ fjósù	ɔ̀tʃʊ́ sèjbɪ́è
SR	[àhé tɔ̀ɔ̀kpʊ̀kɔ́]	[àhɛ́ fjósù]	[ɔ̀tʃʊ́ sèjbɪ́è]
Interaction	Counterbleeding	Countershifting	Self-counterfeeding
Gloss	‘Knowledge slaughtered a table’	‘Knowledge cracked a cry’	‘A cheek fetched a market’

These interactions cannot be generated by a Parallel-OT grammar using basic markedness and faithfulness constraints. To illustrate the problem, we will use the following simplified constraints: the markedness constraint *[-ATR]#[+ATR], which penalizes a [-ATR][+ATR] vowel sequence (potentially separated by consonants) across words, the faithfulness constraint Ident[+ATR], which ensures that the markedness constraint is repaired by regressive [+ATR] spreading, the markedness constraint AgreeV$_{\text{[-high]}}$, which requires adjacent non-high vowel to be identical, the positional faithfulness constraint Ident[V]/ #__, which protects a word-initial vowel from undergoing any change, and Ident[-ATR], which penalizes a change in ATR from an underlying [-ATR] to surface [+ATR].

The tableau in (38) shows that a ranking of these constraints fails to derive the correct output form in the Gua counterbleeding case.

(38) A failed Parallel-OT attempt to derive counterbleeding

		/àhɛ́ tè ɔ̀kpʊ̀kɔ́/	*[-ATR]#[+ATR]	AgreeV$_{\text{[-high]}}$	Id[V]/ #__	Id[+ATR]	Id[-ATR]
a.		àhɛ́ tè ɔ̀kpʊ̀kɔ́	*!	*			
b.		àhé tè ɔ̀kpʊ̀kɔ́		*!			*
c.	☞	àhɛ́ tɔ̀ ɔ̀kpʊ̀kɔ́				*	
d.	☹	àhé tɔ̀ ɔ̀kpʊ̀kɔ́				*	*!
e.		àhé tè èkpʊ̀kɔ́			*!		**

The reason for the failure follows the same logic of the discussion of the failure of Parallel OT in the case of Bedouin Hijazi Arabic in (3): applying only the second process – in this case, hiatus resolution, as in candidate (38c) – is sufficient for satisfying both markedness constraints, the markedness constraint *[-ATR]#[+ATR] that triggers ATR harmony, and the markedness constraint AgreeV$_{\text{[-high]}}$ that triggers hiatus resolution. Applying ATR harmony in addition to hiatus resolution, as in the correct candidate (38d), incurs an additional faithfulness violation that does not help satisfy additional markedness constraints. Therefore, candidate (38d) is harmonically bounded by candidate (38c) and cannot win under any ranking of these constraints. Buccola’s 2013 proof confirms that no other choice of basic markedness and faithfulness constraints would work either.[4] The countershifting and self-counterfeeding interactions in (37) pose an additional problem for Parallel OT with basic constraints.

[4] We leave aside another problem for Parallel OT that arises in (38): the problem of generating the surface ATR mismatch between the vowels of the first word. This is another instance of opacity, resulting from the interaction between word-level ATR harmony and phrasal ATR harmony, but we do not discuss it in this paper because our focus is on evaluating Stratal OT, and this instance of opacity is not problematic for it.

As mentioned in the introduction, there have been proposals for extending the possible representations or constraints to generate opacity within Parallel OT. Our focus here is on Stratal OT, which aims to solve the opacity problem by introducing serialism into the theory directly.

The fundamental property of Stratal OT is that the phonological grammar includes multiple constraint rankings. Each ranking is called a Stratum, and it operates like a regular Parallel-OT grammar. The strata interact serially, such that the output of one stratum serves as the input to the next stratum. Before turning to other properties of the theory, we will show why two serially ordered strata are sufficient, in principle, for a successful analysis of the counterbleeding interaction between ATR harmony and hiatus resolution in (37). The analysis relies on the possibility of reranking the constraints between strata. In the first stratum, the constraints are ranked such that ATR harmony but not hiatus resolution is active; *[-ATR]#[+ATR], which triggers harmony, is ranked highest, but AGREEV$_{\text{[-high]}}$, which triggers assimilation, is ranked below the faithfulness constraints that prevent assimilation. As a result of this ranking, the candidate in which only harmony applied wins in the first stratum, as shown in (39).

(39) Stratum I in a bi-stratal analysis of counterbleeding

		/àhɛ́ tè ɔ̀kpʊ̀kɔ́/	*[-ATR]#[+ATR]	ID[+ATR]	ID[V]/ #__	AGREEV$_{\text{[-high]}}$	ID[-ATR]
a.		àhɛ́ tè ɔ̀kpʊ̀kɔ́	*!			*	
b.	☞	àhé tè ɔ̀kpʊ̀kɔ́				*	*
c.		àhɛ́ tɛ̀ ɔ̀kpʊ̀kɔ́		*!			
d.		àhé tɛ̀ ɔ̀kpʊ̀kɔ́		*!			*!
e.		àhé tè òkpʊ̀kɔ́			*!		**

The candidate with ATR harmony serves as the input to the second stratum, in which the ranking of the constraints has changed. In the second stratum, the markedness constraint AGREEV$_{\text{[-high]}}$ has been promoted so as to trigger the assimilation of the [+ATR] vowel /e/ into the [-ATR] vowel /ɛ/. Since ATR harmony has already applied in the first stratum, this assimilation does not prevent harmony from taking place. The correct output candidate then wins, as shown in (40).

(40) Stratum II in a bi-stratal analysis of counterbleeding

		/àhé tè ɔ̀kpʊ̀kɔ́/	*[-ATR]#[+ATR]	AGREEV$_{\text{[-high]}}$	ID[V]/ #__	ID[+ATR]	ID[-ATR]
a.		àhé tè ɔ̀kpʊ̀kɔ́		*!			
b.	☞	àhé tɛ̀ ɔ̀kpʊ̀kɔ́				*	
c.		àhé tè òkpʊ̀kɔ́			*!		*

The success of the bi-stratal analysis means that Stratal OT could have succeeded on the opaque interaction in Gua if it had unlimited derivational power and strata could be posited arbitrarily. In practice, however, a central tenet of Stratal OT has been that strata are limited by the morphology-phonology interface, and we will see that the limitations that have been proposed make Stratal OT incapable of generating the Gua pattern.

The central limitation that Stratal OT places on the number of strata is what we refer to as MORPHOSYNTACTICALLY-CONFINED SERIALISM, as mentioned in the introduction and repeated below in (41).

(41) MORPHOSYNTACTICALLY-CONFINED SERIALISM
Serial interactions are only possible between distinct morphological or syntactic domains.

According to this property, each stratum is associated with a distinct morphological or syntactic domain. In the classical version of the theory (Bermúdez-Otero 1999, Kiparsky 2000, 2015), there are three such domains and accordingly only three strata: the stem stratum, the word stratum, and the phrase stratum (sometimes called the postlexical stratum):

(42) Three strata in the classical Stratal OT model

1. Stem stratum
2. Word stratum
3. Phrase stratum

Phonological evaluation proceeds inside out, starting from the stem and applying the constraint ranking of the stem stratum. Then, once a word has been built, the ranking of the word stratum takes effect, applying the word-level phonology of the language. Finally, after words have been combined, the phrase stratum comes into play, applying the phonological processes of the language that can apply across words. Since each stratum in this theory is a Parallel-OT grammar, opaque interactions between two processes can only be generated across strata, if the first process applies in one stratum and the second process applies in a later stratum.

The Gua interaction poses a challenge to the classical model of Stratal OT because both ATR harmony and hiatus resolution apply across word boundaries. In the classical model, the phrase stratum is the only stratum that can apply processes across words, so both processes necessarily belong to the phrase stratum. And since the phrase stratum is a Parallel-OT grammar, it runs into the problem for Parallel OT in (38) and cannot correctly generate the opaque interaction. Other cases of intra-stratal opacity that seem to pose a problem for the classical model have been discussed by McHugh (1990), Kavitskaya and Staroverov (2010), Jones (2014), Gjersøe (2016), and Bermúdez-Otero (2019).

In response to the problem of intra-stratal opacity, Jaker and Kiparsky (2020) have proposed a weaker version of Stratal OT (also alluded to in Kiparsky 2015) that allows for more than three strata but still respects MORPHOSYNTACTICALLY-CONFINED SERIALISM. On the weaker version of Stratal OT, individual languages can make use of more than three strata as long as each stratum is associated with a distinct morphological or syntactic domain. This means that, differently from the classical model, there can be more than one phrase-level stratum. For example, there can be one phrase-level stratum associated with a nominal phrase (NP), another with a clause (CP), and another with the entire utterance. A version with a CP stratum is schematized in (43). On this version, each CP functions as a cyclic node that triggers an application of the phonology of the CP stratum.

(43) Example: possible strata in a weak Stratal OT model

1. Stem stratum

2. Word stratum
3. CP stratum
4. Utterance stratum

The weak stratal model can successfully deal with the Gua data presented in this paper so far concerning the interaction of ATR harmony and hiatus resolution, because the data all contained single-clause utterances. The model can assign ATR harmony to the CP stratum and hiatus resolution to the Utterance stratum, replicating the bistratal analysis in (39)–(40). Even though there is no independent evidence for the association of the processes to strata in this way, the association is consistent with the model because it obeys MORPHOSYNTACTICALLY-CONFINED SERIALISM: the CP stratum and the Utterance stratum correspond to distinct syntactic domains (the CP and the utterance respectively), and these happen to coincide in single-clause utterances.

However, once multi-clausal utterances are considered, even the weak Stratal OT model breaks down. Recall from Section 2.2 that ATR harmony counts the number of words in the utterance. If the utterance contains three words, harmony can apply between any two adjacent words. But if the utterance contains four words, harmony is blocked between words two and three. Multi-clausal utterances allow teasing apart the CP stratum from the Utterance stratum, and they provide evidence that ATR harmony necessarily applies first to the entire utterance and cannot apply at the CP level. Consider the new data in (44)-(45).

(44) ATR harmony cannot apply at the CP level (adverbial construction)

a. [átɕi̇̀ wúrè ǹté]
/átɕì wúrè ǹté/
sponge finish.PST quickly
'A sponge finished quickly.'

b. [ǹjɛ́ɛ̀ átɕi̇̀ wúrè]
/ǹjɛ́ɛ̀ átɕì wúrè/
1SG.say.PST sponge finish.PST
'I said that a sponge finished.'

c. [ǹjɛ́ɛ̀ átɕì wúrè ǹté]
/ǹjɛ́ɛ̀ átɕì wúrè ǹté/
1SG.say.PST sponge finish.PST quickly
'I said that a sponge finished quickly.'

(45) ATR harmony cannot apply at the CP level (direct object construction)

a. [ɔ̀tsú séli̇̀ dzenmwɛ̃́]
/ɔ̀tsʊ́ séli̇̀ dzenmwɛ̃́/
cheek peel.PST history
'A cheek peeled history.'

b. [ǹjɛ́ɛ̀ ɔ̀tsú séli̇̀]
/ǹjɛ́ɛ̀ ɔ̀tsʊ́ séli̇̀/
1SG.say.PST cheek finish.PST
'I said that a cheek peeled.'

c. [ǹjɛ́ɛ̀ ɔ̀tsʊ́ séli̇̀ dzenmwɛ̃́]
/ǹjɛ́ɛ̀ ɔ̀tsʊ́ séli̇̀ dzenmwɛ̃́/
1SG.say.PST cheek peel.PST history
'I said that a cheek peeled history.'

Example (44a) is a simple three-word clause with a subject, a verb, and an adverb. ATR harmony applies between the subject denoting "sponge" (more specifically, a washing sponge) and the verb "finished", changing the [-ATR] vowel /ɪ/ of the word for sponge into [i]. The same subject and verb appear again in example (44b), where the adverb has been replaced with the embedding inflected verb "I said", which occurs at the beginning of the sentence. Here, the subject and the verb "the sponge finished" are in an embedded clause, and ATR harmony applies within that clause as expected, changing the final vowel of the subject to the [+ATR] vowel [i]. The sentence in (44c) combines both the embedding verb and the now-embedded adverb with the subject and verb "sponge finished". Now the subject and the verb occupy positions two and three in the utterance. This time, ATR harmony is blocked, and the final vowel of the subject remains [-ATR] on the surface, even though it is followed by the [+ATR] vowel of the verb.

The blocking of ATR harmony in (44c) is expected if harmony applies once to the entire utterance, but it is unexpected if harmony applies at the smaller, CP stratum. If harmony applies once to the entire utterance, it would count the number of words in (44c) as four and correctly underapply because the [-ATR][+ATR] sequence crosses words two and three. Alternatively, if harmony had applied at the CP stratum, it would have first applied to the embedded clause /átɕì wúrè ǹté/ meaning "a sponge finished quickly". But then, as (44a) shows, harmony would have changed the final [-ATR] vowel of the subject into [+ATR], yielding an incorrect output for (44c). This failed derivation is schematized in (46).

(46) A failed derivation of (44c) under the weak stratal model:

- Structure: [$_{\text{CP}}$ǹjɛ́ɛ̀ [$_{\text{CP}}$ átɕì wúrè ǹté $_{\text{CP}}$]$_{\text{CP}}$]
- 1st CP cycle: ATR harmony applies
  /átɕì wúrè ǹté/ → [átɕi̇̀ wúrè ǹté]
- 2nd CP cycle: ATR harmony applies (vacuously)
  /ǹjɛ́ɛ̀ átɕi̇̀ wúrè ǹté/ → *[ǹjɛ́ɛ̀ átɕi̇̀ wúrè ǹté]

We can conclude from (44) that harmony applies first to the entire utterance. The paradigm in (45) leads to the same conclusion using a different embedded construction (involving a direct object instead of an adverb). On the assumption that the utterance itself is the largest domain in an utterance, there is no stratum larger than the utterance to which hiatus resolution can be associated. The upshot is that both processes seem to apply at the utterance level. This is a direct counterexample to MORPHOSYNTACTICALLY-CONFINED SERIALISM, because two processes that interact opaquely cannot be assumed to apply in distinct morphological or syntactic domains.

5 Conclusion

The interaction between ATR harmony and hiatus resolution in Gua poses a challenge to serial versions of OT that restrict serialism to be a by-product of the serial or cyclic relationship between morphological or syntactic domains. This includes not just Stratal OT, which is the version of OT we focused on here, but also other versions of OT that obey MORPHOSYNTACTICALLY-CONFINED SERIALISM implicitly or explicitly, such as Cophonology Theory (Orgun 1996, Anttila 2002, Inkelas and Zoll 2007, Sande et al. 2020, a.o.), which is similar to Stratal OT in that it contains multiple different OT rankings that can interact serially and does not incorporate serialism as a purely phonological mechanism. Theories that incorporate such a mechanism can account for the interaction in a simple way by ordering harmony before hiatus resolution, as we illustrated using rule-based phonology. Overall, our findings suggest that phonological opacity exists as a productive phenomenon, and in so far as serialism is the correct way to derive it, it must be a phonological mechanism that exists independently of the phonological interface with the morphosyntax.

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