Bedouin Arabic multiple opacity with indexed constraints in Parallel OT

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1 Introduction

Phonological opacity (Kiparsky 1973) is a phenomenon that has sparked many debates in theoretical phonology, including the question of whether the phonological component of language uses extrinsic ordering of rules or processes (e.g., McCarthy 2007, Jarosz 2014). Here, I will consider the case of Bedouin Arabic multiple opacity (McCarthy 2007), which McCarthy argues to be a case in favor of serial computation and extrinsic ordering of processes. As will be reviewed in section 3.2, McCarthy argues that parallel representational analyses in terms of Turbidity (Goldrick 2001) or Colored Containment (Van Oostendorp 2008) are impossible, while intrinsic ordering of processes through morphology-phonology interaction in Stratal OT (Bermúdez-Otero 1999) is also argued to be an unsatisfactory explanation, which only leaves a derivational account with extrinsic ordering (see McCarthy 2007, Jarosz 2014).

In this paper, I will offer an account of Bedouin Arabic multiple opacity that, on the contrary, does not require any extrinsic ordering or serial computation in phonology (even if it is compatible with the notion). It is a representational account (analogous to Van Oostendorp 2008, Boersma 2007). that uses multi-level surface representations. However, the levels in this model are formed by various diacritics (indices, Pater 2000), assumed to be discovered by the learner in the course of acquisition. Such diacritics/indices are normally found in analyses of exceptionality (see section 4.1). However, following a proposal I have made in earlier work (Nazarov 2019; see section 4), they can be extended to other phenomena, including opacity. This will be the basis of a Parallel OT analysis of Bedouin Arabic, as will be presented in section 5: the three processes involved in the interaction will be presented as essentially non-interacting due to the activity of indices/diacritics (see also section 3.3). Crucially, the surface realization of segments with particular diacritics is regulated by the grammar, so that just those alternations that occur in the language are allowed by the grammar. This shows that extrinsic ordering is not necessary to account for this particular case.

The rest of this paper will be built up as follows. Section 2 will give an overview of the problem of opacity and its connection to exceptions. Section 3 will then discuss the Bedouin Arabic data and how they are claimed to necessitate extrinsic ordering; a short preview of the alternative analysis will also be given. In section 4, I will explain the mechanism needed to make the alternative analysis work in OT. The latter will then be presented in section 5. Finally, section 6 will discuss the consequences of this analysis for our understanding of opacity and phonological grammar, and will offer some concluding remarks.

2 Opacity and its connection to exceptionality

2.1 *Opacity and extrinsic ordering* Phonological opacity (Kiparsky 1973) is usually defined in reference to feeding and bleeding, or 'normal application'.[1] McCarthy (1999) gives a particularly insightful definition in terms of over- and underapplication of processes, as paraphrased in (1):

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[1] Baković (2011) does point out that definitions of this type are not always useful, as they do not always line up with an intuitive concept of 'opacity'.

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(1) *Definition of opacity following McCarthy (1999)*
A process *P* = A → B / C_D is opaque iff the application of some other process, *Q*, leads to:
a. instances of A → B outside of C_D (i.e. *P overapplies*), or
b. instances of CAD on the surface (i.e., *P underapplies*).

Patterns of the overapplication kind include Raising in Canadian English (Chomsky 1956, Chambers 1973), a process that changes diphthongs /aɪ,aʊ/ to [ʌɪ,ʌʊ] before voiceless consonants, as in (2a). Another process, Flapping, turns /t,d/ into a voiced flap, [ɾ], in certain intervocalic environments, as in (2b). Crucially, in instances of /aɪtV/ and /aʊtV/ (in relevant prosodic environments), Raising changes the diphthong to [ʌɪ/ʌʊ] before voiceless /t/, but Flapping changes /t/ to a voiced [ɾ], yielding instances of /aɪ/ → [ʌɪ] outside the proper environment: before a voiced instead of a voiceless consonant. This, by clause (1a), is a form of overapplication opacity. (See Nazarov 2019 for an account of Canadian Raising in the same framework as pursued here.)

(2) *Canadian Raising: overapplication*

a. *Raising*	b. *Flapping*	c. *Interaction: Raising overapplies*
/raɪt/ → [rʌɪt] 'write'	/kʌt-ɚ/ → [kʌɾɚ] 'cutter'	/raɪt-ɚ/ → [rʌɪɾɚ] 'writer'
/raɪd/ → [raɪd] 'ride'	/kʌt/ → [kʌt] 'cut'	/raɪd-ɚ/ → [raɪɾɚ] 'rider'

Underapplication is exemplified by both interactions in Bedouin Arabic that will be discussed here (see section 3.1 for a fuller description). Briefly, Raising in Bedouin Arabic changes /a/ to a high vowel ([i] or [u] – see McCarthy 2007:189-190 for the exact conditioning) when it occurs before a CV sequence, see (3a). In addition, final obstruent-sonorant sequences are broken up by an epenthetic vowel, as in (3b). Finally, there is a Syncope process, which deletes high vowels before a CV sequence, as in (3b). However, as can be seen in (3ab), the surface configuration that should trigger Syncope, [iCV], is, in fact, attested in surface forms when Raising or Epenthesis applies, which is an instance of underapplication by clause (1a). In addition, Raising also underapplies when Epenthesis is applied: the surface configuration [aCV] is created by Epenthesis when the configuration /CaCR#/ (R = sonorant) occurs – but Raising does not apply in these cases, as shown in (3d). Thus, there is a nested underapplication interaction here: Syncope underapplies because of Raising, while Raising itself underapplies due to Epenthesis.

(3) *Raising in Bedouin Arabic: underapplication*

a. *Raising*	b. *Epenthesis*	c. *Syncope (underapplies in a.,b.)*
/samiʕt/ → [simiʕt] 'I heard'	/libn/ → [libin] 'clay'	/kitib/ → ktib 'it$_M$ was written'
d. *Raising underapplies*		
/gabl/ → [gabil] 'before'		

As shown by Idsardi (2000) and others, over- and underapplication patterns of this kind generally cannot be accounted for in Parallel OT (although see Baković 2011 for particular kinds of opacity that can be analyzed in Parallel OT). The problem is that, in overapplication patterns, there is no Markedness constraint that can motivate the overapplication just when another process applies, while in underapplication patterns, there is no Faithfulness constraint that can stop the opaque process from applying whenever another process applies. One solution to this problem is introducing *extrinsic ordering* of stepwise optimization steps in serial forms of OT (OT-CC, McCarthy 2007; Harmonic Serialism with Serial Markedness Reduction, Jarosz 2014).

Extrinsic ordering of phonological processes was central in SPE (Chomsky & Halle 1968) and has been applied in generative analyses of opaque interactions since at least Chomsky (1954). It may be defined as follows:

(4) Extrinsic ordering is a language-specific, obligatory ordering of two processes in a derivation that is unpredictable from anything else in that derivation (forms, rules, interactions with morphology…).

Rule ordering (Chomsky & Halle 1968) is a clear example of this, but in the modern OT literature, extrinsic ordering is represented by OT with Candidate Chains (OT-CC, McCarthy 2007) and Serial Markedness

Reduction (SMR, Jarosz 2014). In both of these approaches, the derivation between underlying and surface form is subdivided into steps that constitute a single Faithfulness constraint violation (McCarthy 2007), and the order of these steps is remembered for every possible candidate. Extrinsic ordering is achieved by language-specific ranking of constraints that penalize candidates with certain orders of steps – McCarthy (2007) does this with reference to Faithfulness, while Jarosz's (2014) approach refers to Markedness.

Both Canadian English and Bedouin Arabic can be easily accounted for in terms of extrinsic ordering. For Canadian English, overapplication can be accounted for by extrinsically ordering the Raising process before the Flapping process. In this way, Raising will always have access to the distinction between /t/ and /d/ before the voicing of these segments can be neutralized by Flapping, so that /raɪt-ɚ/ → rʌɪtɚ → [rʌɪɾɚ] 'writer'.

For Bedouin Arabic, the ordering Syncope < Raising < Epenthesis yields the desired result. Syncope does not have access to the output of Raising or Epenthesis, so that it cannot apply to a configuration [iCV] that arises from the result of these processes. In the same way, Raising does not have access to the output of Epenthesis, so that [aCV] configurations made by Epenthesis do not undergo Raising. Both ordering effects are briefly demonstrated in table (5).

(5) *Ordering of processes for Canadian English and Bedouin Arabic*

Canadian English	/raɪt-ɚ/	/raɪd-ɚ/	**Bedouin Arabic**	/samiʕt/	/libn/	/kitib/	/gabl/
1. Raising	rʌɪtɚ	———	1. Syncope	———	——	[ktib]	——
2. Flapping	[rʌɪɾɚ]	[raɪɾɚ]	2. Raising	[simiʕt]	——	——	——
			3. Epenthesis	———	[libin]	——	[gabil]

While extrinsic ordering is a very effective way of accounting for opacity, it is an open question whether its power is truly needed in phonological grammars is a hotly debated topic. McCarthy (2007) provides arguments in favor of this necessity on the basis of the Bedouin Arabic data that will be re-examined in this paper – see section 3.2 for a summary of McCarthy's arguments. While other arguments for extrinsic ordering exist, I will focus on Bedouin Arabic only, and show that an account without extrinsic ordering is possible.

2.2 *Connection between opacity and exceptionality* As could be seen in (1) above, taken from McCarthy (1999), opacity may be defined in terms of over- and underapplication. However, over- and underapplication also applies to exceptionality: a process with exceptions either applies outside its usual context, or fails to apply when the right context is present. In fact, if the interacting process *Q* in (1) is replaced by "lexical items", we obtain a definition of exceptions:[2]

(6) *Definition of exceptions*

A process *P* = A → B / C_D is opaque iff there are lexical items that exhibit:

a. instances of A → B outside of C_D (i.e. *P overapplies*), or

b. instances of CAD on the surface (i.e., *P underapplies*).

This parallel – that both opacity and exceptions are both types of over- or underapplication – is the basis of the type of account pursued here. According to the parallel definitions in (1) and (6), opacity is a type of exceptionality where one process, *Q*, creates exceptions to another process, *P* – as opposed to the lexicon creating exceptions to the process. This link is further strengthened by work that views opacity either as being always exceptional (e.g., Sanders 2003), or sees opacity as arising from language-specific, non-universal constraints (Pater 2014).

The major theories of exceptionality in OT are indexed constraints (Kraska-Szlenk 1995, Pater 2000) and cophonology theory (Inkelas & Zoll 2007). Here, indexed constraints (see section 4.1) will be extended to accommodate opaque mappings. The intuition is that, while an exceptionful process is conditioned by indices/diacritics that have a phonologically arbitrary distribution (i.e., any morpheme may be marked as exceptionally (not) undergoing a process), an opaque process is conditioned by indices that have a phonologically systematic distribution (e.g., only morphemes that have an underlying (low) vowel in a

[2] See also Nazarov (2019) for further parallels between exceptionality and opacity.

particular position may be marked as undergoing the process). As will be explained in section 4, this is done by extending indices to be binary features on specific segments. The exact way in which this helps in accounting for Bedouin Arabic will be explained in section 5.

3 Bedouin Arabic: data and previous analyses

3.1 *Bedouin Arabic data* The data discussed here are taken from McCarthy (2007:Chapter 4.3), whose description is based on Al-Mozainy (1981) along with additional data points. In the multiple opaque interaction that I will focus on, three processes are important: *Syncope*, *Raising*, and *Epenthesis*. I omit interactions with stress, height harmony, consonant place, and metathesis. Syncope, (7a), deletes short high vowels in a non-final open syllable (in Bedouin Arabic, this is equivalent to 'before CV'). However, Raising, (7b), turns short low vowels into short high vowels in the same environment (before CV). Finally, Epenthesis, (7c), inserts [i] to break up a word-final and sonorant-final consonant cluster.

(7) *Individual processes involved in opaque interaction*

a. *Syncope*	$[+high]_{\mu} \rightarrow \varnothing$ / __ CV	/kitib-at/ → kitbat	'it_F was written'
		/kitib/ → ktib	'it_M was written'
b. *Raising*	a → [+high] / __ CV	/katab/ → kitab	'he wrote'
		/samiʕt/ → simiʕt	'I heard'
c. *Epenthesis*	$\varnothing \rightarrow$ i / _$CC_{[+son]}$#	/gabl/ → gabil	'before'
		/libn/ → libin	'clay'

As previewed in section 2, both Syncope and Raising underapply in this complex interaction. Underapplication of Syncope is caused by both Raising and Epenthesis, as shown in (8a) and (8b), respectively. Raising creates novel instances of short high vowels before CV, which is the environment in which Syncope deletes short high vowels – but Syncope does not apply here, as in (8a). Epenthesis creates novel instances of CV, before which short high vowels may occur – Syncope should apply to such vowels, but does not, as in (8b). Epenthesis also causes underapplication of Syncope, as shown in (8c), through the same mechanism as for Syncope: Epenthesis makes new open syllables, which may contain instances of short [a] that do not undergo Raising. Section 3.2 will summarize McCarthy's (2007) arguments that representational and Stratal OT accounts of these interactions are not possible; section 3.3 will then give a brief (pre-OT) preview of the mechanics of the analysis proposed in this paper.

(8) *Underapplication interactions among the three processes*

a. Syncope and Raising:	/katab/ → kitab, *ktab	(Syncope does not apply)
b. Syncope and Epenthesis:	/libn/ → libin, *lbin	(Syncope does not apply)
c. Raising and Epenthesis:	/gabl/ → gabil, *gibil	(Raising does not apply)

3.2 *Arguments for necessity of extrinsic ordering* McCarthy (2007) argues that this interaction of three processes cannot be handled by existing representational, non-ordering approaches (Goldrick 2001, van Oostendorp 2008) or by Stratal OT (Bermúdez-Otero 1999), which presupposes morphologically intrinsic ordering when dealing with opacity, and that an extrinsic ordering approach best captures opacity.

The argument in the case of representational approaches is that the number of levels needed to describe multiple opacity is not available in representational approaches like Goldrick's (2001) (and van Oostendorp's 2008): there is only one intermediate level, which leads to problems with multiple opacity problems, such as the Bedouin Arabic case; McCarthy considers various other non-ordering approaches, and finds them to have similar problems. Boersma's (2007) Bidirectional Phonetics and Phonology approach to opacity (contemporary to the pressing of McCarthy's book) can, indeed, handle multiple opacity, since it has more than one intermediate representation. However, it does require that the transparent process be driven entirely by phonetic constraints, since the 'shallowest' level of representation is the phonetic surface form. It is not entirely clear whether the Bedouin Arabic Epenthesis process, which has to be represented at the phonetic level, can be motivated by entirely phonetic considerations, since it is bounded by the word and does not take place or continuancy into account. However, this is an important area for future research.

In the case of Stratal OT (Bermúdez-Otero 1999), the argument is more subtle. In Stratal OT, opaque interactions arise because different morphosyntactic domains are associated with different OT grammars. Processes that apply at the stem level preceded processes that apply at the word level, which precede those that apply at the phrase level. This means that a word-level process could make a stem-level process opaque, while a phrase-level process should be able to make a stem-level process opaque: a case of intrinsic ordering of processes. McCarthy's (2007) objection to a Stratal OT analysis of Bedouin Arabic lies in the fact that the order of processes necessary for opaque interaction (Syncope < Raising < Epenthesis) does not correspond to their morphosyntactic domains. Specifically, McCarthy (2007:196–198) shows that Syncope has a greater morphosyntactic domain (it applies across words) than Raising (which does not apply across words), which predicts that Raising is at the word level, which Syncope is at the phrase level, and Raising applies before Syncope. This latter leads to the wrong prediction: /katab/ → kitab → *[ktab], leading McCarthy to conclude that ordering of processes cannot be entirely intrinsic.

3.3 *Preview of analysis* The analysis of the Bedouin Arabic data is based on the idea that every segment carries a value for two non-phonetic features (indices; see section 4): [±L] ("behaves like a low vowel") and [±V] ("behaves like a non-epenthetic vowel"). The assignment of these two features in the lexicon is arbitrary – the constraint ranking ensures that only the attested alternations emerge (see section 5.3). In addition, the phonological component is not allowed to manipulate these features (see section 4).

In the proposed analysis, Syncope only applies to [-L] vowels, while Raising only applies to [+L] vowels. Both processes take place before a single C followed by a [+V] vowel, as shown in (9ab) below. By convention (see section 4), all epenthetic vowels receive the unmarked (minus) value of any non-phonetic feature, as shown in (9c).

(9) *Sketch of extended indexation analysis of Bedouin Arabic*

a. Syncope: $[+\text{high}]_{[-L]} \rightarrow \varnothing$ / __C$V_{[+V]}$

b. Raising: $[+\text{low}]_{[+L]} \rightarrow [+\text{high}]$ / __C$V_{[+V]}$

c. Epenthesis: $\varnothing \rightarrow V_{([-L,\ -V])}$ / C__R# (R = sonorant)

The addition of these indices to each of these processes makes it so that they no longer interact. Syncope and Raising will never be able to apply to the same vowel: Syncope only applies to [-L] vowels, while Raising only applies to [+L] vowels, and the phonological component may not change a [-L] vowel into a [+L] vowel. This automatically entails that high vowels generated by Raising (which are [+L]) cannot undergo Syncope, leading to underapplication of Syncope. The fact that Raising and Syncope must apply before a [+V] vowel means that they can never apply before an epenthetic vowel, since the latter is always [-V]. This means that any ordering of the rules will yield the correct outcome, as shown in (10): the order Epenthesis < Raising < Syncope leads to the incorrect outcome for unindexed rules, but for the indexed rules in (9), it will still yield the correct outcome: [gabil].

(10) *Ordering is irrelevant for indexed processes*

Unindexed rules	/gabl/	**Indexed rules**	/ga$_{[+L]}$bl/
1. Epenthesis: ∅ → V / C__R#	gabil	1. Epenthesis: ∅ → $V_{([-L,\ -V])}$ / C__R#	[ga$_{[+L]}$bi$_{[-V]}$l]
2. Raising: [+lo] → [+hi] / __CV	gibil	2. Raising: $[+lo]_{[+L]}$ → [+hi] / __C$V_{[+V]}$	————
3. Syncope: [+hi] → ∅ / __CV	*[gbil]	3. Syncope: $[+hi]_{[-L]}$ → ∅ / __C$V_{[+V]}$	————

This non-interaction between the three processes is key to its being compatible with Parallel OT and a lack of extrinsic ordering. However, this non-interaction is dependent on the appropriate distribution of [±L] and [±V], which is not guaranteed, since indices are assumed to be randomly distributed throughout the lexicon (see also section 4). Having low, [-L] vowels in the lexicon would lead to exceptions to Raising: some words might have low vowels that do not undergo Raising despite being before CV. Similarly, having high, [+L] vowels in the lexicon would lead to exceptions to Syncope. Finally, having non-epenthetic vowels with [-V] would lead to exceptions to either process. These exceptions will be worked out in section 5.3.

To rule out the possibility of such exceptions, redundancy rules of the type in (11) can be employed: whenever the rules in (9) do not apply, [+L] vowels should surface as low, [-L] vowels should surface as high, and [-V] segments should surface as consonants. This can easily be formulated in Parallel OT (see section 5.3) and ensures that the analysis of opacity in terms of indexed constraints is restrictive. I will now turn to explaining the representational and constraint framework that allows for this type of analysis.

(11) *Redundancy rules for indices*
a. $V_{[+L]} \rightarrow$ [-high]
b. $V_{[-L]} \rightarrow$ [+high]
c. $X_{[-V]} \rightarrow$ [-syll]

4 Theoretical framework: Extended indexation of OT constraints

Indexed constraints (Kraska-Szlenk 1995, Pater 2000), originally intended to represent exceptionality effects, are copies or clones of existing universal constraints that are relativized to a set of words or morphemes:

(12) a. *ai: One violation for every instance of the sequence [ai].
b. $*ai_i$: One violation for every instance of [ai] that contains an exponent of one of the morphemes i = {/-i/, /-i/, /-ite/, …}. (after Pater 2010: 133)

While indexation to words/morphemes works well to account for exceptions, it is not fine-grained enough to account for opacity, as shown in Nazarov (2019). The core proposal for the current re-analysis of Bedouin Arabic opacity is *extended indexation* (see also Nazarov 2019): indices are binary features, for which every segment has a value, as shown in (13) below.

(13) *Traditional and extended indexation*
a. Traditional indexation: $/ite/_i$
b. Extended indexation: $/i_{[+i]}t_{[-i]}e_{[-i]}/$

This proposal is well-rooted in the literature. Firstly, SPE (Chomsky & Halle 1968) used a very similar device to represent exceptions: these were non-phonetic features of the type [-rule *n*] or of the type [+A] that were specified for an individual segment and could not be modified by phonological rules. Secondly, the representations used here are the union of two previous proposals for extending indexation in OT. Becker (2009) proposes to view indexation as binary: for every indexed constraint C_i, there is a constraint C_j, indexed to all the words/morphemes in the lexicon that are not in *i*. For instance, if we have $*ai_i$ indexed to /-i/, /-i/, and /-ite/, there is also $*ai_j$ indexed to all morphemes that are not /-i/, /-i/, and /-ite/. In addition, Temkin-Martínez (2010) and Round (2017) propose that indexation should be specified on individual segments, rather than attached to words/morphemes. If these proposals are combined, then, for every constraint that has indexed versions and for every segment in the lexicon, the segment is specified for which indexed version of the constraint it refers to. This is exactly the proposal of extended indexation.

Following the original indexation proposal, it is assumed that indices must remain constant between input and output: the phonological component may not change indexation. Whenever a constraint $*[+voice]_{[+i]}$ outranks Faithfulness, the grammar will change the underlying voicing of segments indexed [+i], because the indices cannot be changed. In addition, if a segment deletes, its index will be left behind in the same segmental position: $a_{[+i]} \rightarrow \varnothing_{[+i]}$. As will be shown in section 5.3, this is a crucial component in allowing restrictive accounts of phonological opacity.

5 Indexed constraint analysis

5.1 *Individual processes* The analysis of the Bedouin Arabic data (see section 3) in terms of indexed constraints is based on the introduction (during the acquisition stage) of two indices: [±L] and [±V]. While the names of these indices are arbitrary, I have chosen mnemonic names for expository purposes: [+L] stands for "behaves like a <u>low</u> vowel (undergoes Raising but not Syncope)" and [+V] stands for "behaves like a (non-epenthetic) <u>vowel</u>". This means that [-L] vowels behave like high vowels (undergo Syncope but not Raising), while [-V] vowels do not behave like non-epenthetic vowels (they are either consonants or epenthetic vowels). The table in (14a) summarizes how these indices are intended to map onto types of segments in the data (long vowels are excluded), and the examples in (14b) show this categorization on the data points shown in section 3.1 (+ values of indices are indicated with gray shading).

(14) *Illustration of indices in this analysis*

a. *Intended properties of indices (long vowels not included)*

	[+V]	**[–V]**
[+L]	non-epenthetic vowels subject to Raising before CV	(consonants)
[–L]	non-epenthetic vowels subject to Syncope before CV	(consonants or) epenthetic vowels

b. *Representation of vowels in data points in section 3*

Syncope only:	/ki$\begin{bmatrix}-L\\+V\end{bmatrix}ti\begin{bmatrix}-L\\+V\end{bmatrix}ba\begin{bmatrix}+L\\+V\end{bmatrix}$t/ →	ki$\begin{bmatrix}-L\\+V\end{bmatrix}$t∅$\begin{bmatrix}-L\\+V\end{bmatrix}ba\begin{bmatrix}+L\\+V\end{bmatrix}$t	'it$_F$ was written'
	/ki$\begin{bmatrix}-L\\+V\end{bmatrix}ti\begin{bmatrix}-L\\+V\end{bmatrix}$b/ →	k∅$\begin{bmatrix}-L\\+V\end{bmatrix}ti\begin{bmatrix}-L\\+V\end{bmatrix}$b	'it$_M$ was written'
Raising, Syncope underapplies:	/ka$\begin{bmatrix}+L\\+V\end{bmatrix}ta\begin{bmatrix}+L\\+V\end{bmatrix}$b/ →	ki$\begin{bmatrix}+L\\+V\end{bmatrix}ta\begin{bmatrix}+L\\+V\end{bmatrix}$b	'he wrote'
	/sa$\begin{bmatrix}+L\\+V\end{bmatrix}mi\begin{bmatrix}-L\\+V\end{bmatrix}$ʕt/ →	sa$\begin{bmatrix}+L\\+V\end{bmatrix}mi\begin{bmatrix}-L\\+V\end{bmatrix}$ʕt	'I heard'
Epenthesis, Syncope underapplies:	/li$\begin{bmatrix}-L\\+V\end{bmatrix}$bn/ →	li$\begin{bmatrix}-L\\+V\end{bmatrix}bi\begin{bmatrix}-L\\-V\end{bmatrix}$n	'clay'
Epenthesis, Raising underapplies:	/ga$\begin{bmatrix}+L\\+V\end{bmatrix}$bl/ →	ga$\begin{bmatrix}+L\\+V\end{bmatrix}bi\begin{bmatrix}-L\\-V\end{bmatrix}$l	'before'

Based on this representational world (which will be formalized further in section 5.3), we can formulate three Markedness constraints that will motivate the three processes involved: Syncope, Raising, and Epenthesis, while expressing their underapplication contexts, as shown in (15). The constraint in favor of Syncope, (15a), favors the deletion of a [-L] vowel before a consonant and a non-epenthetic vowel (with the appropriate Faithfulness interactions, see below). The constraint in favor of Raising, (15b), favors the raising of a low vowel in the same environment (also in cooperation with Faithfulness). Finally, the constraint in favor of Epenthesis, (15c), disfavors word-final consonant clusters that end in a sonorant.

(15) *Markedness constraints for the three crucial Bedouin Arabic processes*

a. *Pro-Syncope:* *$V_{[-L]}CV_{[+V]}$: One violation mark for every [-L] vowel followed by a consonant and a [+V] vowel.

b. *Pro-Raising:* *$a_{[+L]}CV_{[+V]}$: One violation mark for every low [+L] vowel followed by a consonant and a [+V] vowel.

c. *Pro-Epenthesis:* *$CC_{[+son]}$#: One violation mark for every consonant cluster at the end of a word that ends in a sonorant.

As can be seen, the constraint that motivates Syncope, the process that underapplies due to two processes, has two indexed segment positions: one to prevent feeding by Raising (only [+L] vowels undergo Raising), and one to prevent feeding by Epenthesis (only [-V] vowels can be epenthetic). The constraint that motivates Syncope has one indexed position to prevent feeding by Epenthesis (again, because only [-V] vowels can be epenthetic). Finally, the pro-Epenthesis constraint has no indexed positions, since Epenthesis applies transparently. Section 5.2 will show how this helps account for opacity.

For Syncope to be motivated by the constraint in (15a), the latter must dominate MAX(V) (1 violation mark for every deleted vowel). Vowels in closed syllables must be protected by MAX(V)/CLOSEDSYLL (1 violation mark for every deleted vowel in a closed syllable). Additionally, DEP must be above Max(V) to prevent insertion of an additional consonant to close the open syllable. This is shown in (16), where the winning candidate, b., has a Max(V) violation that weighs less strongly than the *$V_{[-L]}CV_{[+V]}$ violation of candidate a. In addition, candidate c., where deletion takes place in the final closed syllable, is harmonically bounded. Finally, candidate d., with an additional [t] to close the first syllable, can be ruled out by DEP.

(16) *Rankings necessary for Syncope*

/ki$\left[\begin{smallmatrix}-L\\+V\end{smallmatrix}\right]ti\left[\begin{smallmatrix}-L\\+V\end{smallmatrix}\right]$b/	*V$_{[-L]}$CV$_{[+V]}$	DEP	MAX(V)	MAX(V)/CLOSEDSYLL
a. ki$\left[\begin{smallmatrix}-L\\+V\end{smallmatrix}\right]ti\left[\begin{smallmatrix}-L\\+V\end{smallmatrix}\right]$b	*!			
b. ☞ k∅$\left[\begin{smallmatrix}-L\\+V\end{smallmatrix}\right]ti\left[\begin{smallmatrix}-L\\+V\end{smallmatrix}\right]$b			*	
c. ki$\left[\begin{smallmatrix}-L\\+V\end{smallmatrix}\right]$t∅$\left[\begin{smallmatrix}-L\\+V\end{smallmatrix}\right]$b			*	*!
d. ki$\left[\begin{smallmatrix}-L\\+V\end{smallmatrix}\right]$t . ti$\left[\begin{smallmatrix}-L\\+V\end{smallmatrix}\right]$b		*!		

For Raising to be motivated by *a$_{[+L]}$CV$_{[+V]}$, the latter constraint has to dominate IDENT(high) (1 violation for every underlyingly [+high] segment that is realized [-high], or *vice versa*). To prevent deletion as a response to *a$_{[+L]}$CV$_{[+V]}$, MAX(V) must be ranked above IDENT(high). This is shown in (17), where the winning candidate, b., in which the first /a/ has been raised, violates only IDENT(high), while losers a. (fully faithful) and c. and e. (deletion) violate only *a$_{[+L]}$CV$_{[+V]}$ or MAX(V). Raising the second vowel in /aCa/, as in candidate d., does not improve on *a$_{[+L]}$CV$_{[+V]}$, which leads to the harmonic bounding of this candidate.

(17) *Rankings necessary for Raising*

/ka$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]ta\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$b/	*a$_{[+L]}$CV$_{[+V]}$	MAX(V)	IDENT(high)
a. ka$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]ta\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$b	*!		
b. ☞ ki$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]ta\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$b			*
c. k∅$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]ta\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$b		*!	
d. ka$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]ti\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$b	*!		*
e. ka$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$t∅$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$b		*!	

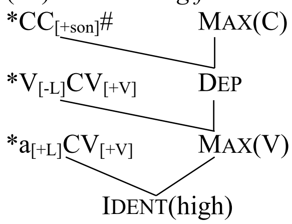
Finally, for Epenthesis to be motivated by *CC$_{[+son]}$#, this latter constraint has to be ranked above DEP to allow insertion of a vowel, while MAX(C) has to be ranked above DEP to prevent consonant deletion in CC$_{[+son]}$# clusters. This is shown in tableau (18), where the winning candidate, b., only has a violation of DEP, while losers a. (fully faithful) and c. (deletion) violate only *CC$_{[+son]}$# or MAX(C).

(18) *Rankings necessary for Epenthesis*

/ga$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$bl/	*CC$_{[+son]}$#	MAX(C)	DEP
a. ga$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$bl	*!		
b. ☞ ga$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]bi\left[\begin{smallmatrix}-L\\-V\end{smallmatrix}\right]$l			*
c. ga$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$b		*!	

I will now show how the opaque interaction of these processes falls out from combining the rankings established from these individual processes, as summarized in the Hasse diagram in (19).

(19) *Ranking for Bedouin Arabic*



5.2 *Interaction between processes* The interaction between Syncope and Raising is one of underapplication (or counterfeeding): the surface context for Syncope is present, but it does not apply. This behavior actually falls out from the already established ranking: as shown in (20) below, the presence of *V$_{[-L]}$CV$_{[+V]}$ above MAX(V) still does not lead to deletion of the first /a/ in /ka$_{[+L,+V]}$ta$_{[+L,+V]}$b/.[3] This is because this first /a/ is [+L] and does not yield a violation of *V$_{[-L]}$CV$_{[+V]}$. In this way, all candidates with deletion (c. – the candidate that would be preferred by a surface formulation of Syncope – and e.) are still ruled out by MAX(V), while lack of Raising (candidates a. and d.) are ruled out by *a$_{[+L]}$CV$_{[+V]}$. Insertion of an additional consonant to avoid Syncope or Raising, as in f., is ruled out by DEP.

(20) *Interaction between Syncope and Raising*

/ka$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]ta\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$b/	*CC$_{[+son]}$#	MAX(C)	*V$_{[-L]}$CV$_{[+V]}$	DEP	*a$_{[+L]}$CV$_{[+V]}$	MAX(V)	MAX(V) /CLSSYLL	IDENT(hi)
a. ka$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]ta\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$b					*!			
b. ☞ ki$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]ta\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$b								*
c. k∅$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]ta\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$b						*!		
d. ka$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]ti\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$b					*!			*
e. ka$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$t∅$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$b						*!	*	
f. ka$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$t . ta$\left[\begin{smallmatrix}+L\\+V\end{smallmatrix}\right]$b				*!				

Syncope also underapplies due to Epenthesis (Epenthesis counterfeeds Syncope): Epenthesis creates new [iCV] configurations, but the [i] in these configurations is still not deleted. This lack of deletion is achieved because epenthetic vowels must have the minus values of all indices, including [-V], while Syncope only happens before [+V] vowels. This is shown in tableau (21), where candidate a. (with final CC$_{[+son]}$ cluster) is ruled out by *CC$_{[+son]}$#, while deletion of one of the consonants, as in d., is ruled out by MAX(V). Crucially, deleting the high vowel in an open syllable, as in c., is not motivated by *V$_{[-L]}$CV$_{[+V]}$, since the second vowel is [-V]. Because of this, candidate c. (with Syncope) is harmonically bounded.

[3] The ranking *V$_{[-L]}$CV$_{[+V]}$ >> Non-Finality would account for another opaque interaction discussed by McCarthy (2007): Syncope applies even when it creates monosyllables, as in /kitib/ → [ktib], despite the preference for non-finality in the language. In addition, if deleting /i$_{[+V]}$/ leaves a 'trace' with the label [+V], this makes it easy to account for a lack of syllable-final a+guttural metathesis (/aG/ → [Ga]) before deleted /i/. In an example like /jiʃtaʁilin/ (McCarthy 2007:207), /i/ is deleted, leading to the expectation that syllable-final /ʁ/ will metathesize with /a/: *[jiʃtʁalin]; however, the actual form keeps syllable-final [ʁ]: [jiʃ.taʁ.lin]. This might be explained by the avoidance of a vowel followed directly by a [+V] segment (a type of 'abstract' hiatus avoidance): *[ji$_{[+V]}$ʃtʁa∅$_{[+V]}$lin]. Finally, the fact that metathesized vowels do not raise, /jaχdim/ → [jχadim] (McCarthy 2007:205), may follow from a similar principle: if metathesis is an insertion-and-deletion process, the surface [a] in [jχadim] may be inserted and, thus, [-L] and not eligible for Raising. However, these are but initial ideas, and are topics for future research.

(21) *Interaction between Syncope and Epenthesis*

/li$_{\begin{bmatrix}-L\\+V\end{bmatrix}}$bn/	*CC$_{[+son]}$#	MAX(C)	*V$_{[-L]}$CV$_{[+V]}$	DEP	*a$_{[+L]}$CV$_{[+V]}$	MAX(V)	MAX(V) /CLSSYLL	IDENT(hi)
a. li$_{\begin{bmatrix}-L\\+V\end{bmatrix}}$bn	*!							
b. ☞ li$_{\begin{bmatrix}-L\\+V\end{bmatrix}}bi_{\begin{bmatrix}-L\\-V\end{bmatrix}}$n				*				
c. l∅$_{\begin{bmatrix}-L\\+V\end{bmatrix}}bi_{\begin{bmatrix}-L\\-V\end{bmatrix}}$n				*		*!		
d. li$_{\begin{bmatrix}-L\\+V\end{bmatrix}}$b		*!						

Finally, the underapplication of Raising due to Epenthesis has the exact same explanation: Raising is conditioned by a following [+V] vowel, while epenthetic vowels are always [-V]. This can be seen in tableau (22), where candidate a. (with final cluster) is ruled out by *CC$_{[+son]}$#, while candidate d. (consonant deletion) is ruled out by MAX(C). Candidate c., which has apparent Raising, is harmonically bounded, since candidate b. does not violate *a$_{[+L]}$CV$_{[+V]}$.

(22) *Interaction between Raising and Epenthesis*

/ga$_{\begin{bmatrix}+L\\+V\end{bmatrix}}$bl/	*CC$_{[+son]}$#	MAX(C)	*V$_{[-L]}$CV$_{[+V]}$	DEP	*a$_{[+L]}$CV$_{[+V]}$	MAX(V)	MAX(V) /CLSSYLL	IDENT(hi)
a. ga$_{\begin{bmatrix}+L\\+V\end{bmatrix}}$bl	*!							
b. ☞ ga$_{\begin{bmatrix}+L\\+V\end{bmatrix}}bi_{\begin{bmatrix}-L\\-V\end{bmatrix}}$l				*				
c. gi$_{\begin{bmatrix}+L\\+V\end{bmatrix}}bi_{\begin{bmatrix}-L\\-V\end{bmatrix}}$l				*				*!
d. ga$_{\begin{bmatrix}+L\\+V\end{bmatrix}}$b		*!						

5.3 *Restrictiveness of the analysis: Richness of the Base* In the preceding discussion, an account of Bedouin Arabic multiple opacity was shown based on a particular assignment of indices to segments as summarized in (15). However, the Richness of the Base (ROTB) principle states that any conceivable input should yield a grammatical optimal candidate. Thus, underlyingly low vowels that are [-L], as well as underlyingly high vowels that are [+L], should also yield a grammatical outcome, as well as underlying vowels that are [-V] – otherwise, the opaque interactions described in section 3.2 are expected to have routine exceptions, which does not seem to be the case given McCarthy's description.

This ROTB problem may be solved by introducing context-free Markedness constraints that are indexed to particular segments. Specifically, [-L] vowels must be high, [+L] vowels must be low (unless specified otherwise by the pro-Raising constraint, *a$_{[+L]}$CV$_{[+V]}$), and [-V] segments must not be vowels:

(23) *Context-free Markedness constraints to maintain ROTB*
*[-high]$_{[-L]}$ *[+high]$_{[+L]}$ *[+syll]$_{[-V]}$ = *V$_{[-V]}$

Since the indices of a segment may not be changed, these constraints must change the underlying value of [±high] and [±syll], respectively, of the segments they apply to. This means that each of these constraints must dominate appropriate Faithfulness constraints. For *[-high]$_{[-L]}$ and *[+high]$_{[+L]}$, this is IDENT(high), while for *V$_{[-V]}$, this is MAX(V). In addition, *[+high]$_{[+L]}$ must itself be dominated by *a$_{[+L]}$CV$_{[+V]}$ to ensure that [+L] vowels appear as high vowels in the Raising context, and *V$_{[-V]}$ must be dominated by *CC$_{[+son]}$# (and MAX(C)) to ensure that epenthetic vowels (which must be [-V]) are allowed.

This is shown in the set of tableaux in (24). In (24abc), underlying /a/ with [-L] comes out as deleted (through Syncope) or else as a high vowel to avoid violations of *V$_{[-L]}$CV$_{[+V]}$ and *[-hi]$_{[-L]}$. In (24def), underlying /i/ with [+L] comes out as a high vowel (through Raising) or else as a low vowel to avoid violations of *a$_{[+L]}$CV$_{[+V]}$ and *[+hi]$_{[+L]}$. In (24gh), underlying /i/ with [-V] is deleted outside an epenthesis context (here: after VC). However, (24gh) shows that an epenthesis context may still call for a [-V] vowel.

(24) *ROTB tableaux for Bedouin Arabic*

/ba$_{\left[\substack{-L\\+V}\right]}ta_{\left[\substack{-L\\+V}\right]}$/	*CC$_{[+son]}$#	*V$_{[-V]}$	*V$_{[-L]}$CV$_{[+V]}$	MAX(V)	*a$_{[+L]}$CV$_{[+V]}$	*[-hi]$_{[-L]}$	*[+hi]$_{[+L]}$	IDENT(hi)
a. ba$_{\left[\substack{-L\\+V}\right]}ta_{\left[\substack{-L\\+V}\right]}$			*!			**		
b. b∅$_{\left[\substack{-L\\+V}\right]}ta_{\left[\substack{-L\\+V}\right]}$				*		*!		
c. ☞ b∅$_{\left[\substack{-L\\+V}\right]}ti_{\left[\substack{-L\\+V}\right]}$				*				*
/ti$_{\left[\substack{+L\\+V}\right]}ki_{\left[\substack{+L\\+V}\right]}$/								
d. ti$_{\left[\substack{+L\\+V}\right]}ki_{\left[\substack{+L\\+V}\right]}$							**!	
e. ta$_{\left[\substack{+L\\+V}\right]}ka_{\left[\substack{+L\\+V}\right]}$					*!			**
f. ☞ ti$_{\left[\substack{+L\\+V}\right]}ka_{\left[\substack{+L\\+V}\right]}$							*	*
/bi$_{\left[\substack{+L\\+V}\right]}ki_{\left[\substack{+L\\-V}\right]}$/								
g. bi$_{\left[\substack{+L\\+V}\right]}ki_{\left[\substack{+L\\-V}\right]}$		*!						
h. ☞ bi$_{\left[\substack{+L\\+V}\right]}$k∅$_{\left[\substack{+L\\-V}\right]}$				*				
/bn/								
i. bn	*!							
j. ☞ bi$_{\left[\substack{-L\\-V}\right]}$n		*						

With the adjustments made here, the account laid out in 5.2 becomes a truly general account of multiple opacity: any input given to the grammar, regardless of whether its indexation follows the pattern in (14), will yield an output that conforms to the multiple opaque interaction described in section 3.

6 Discussion and concluding remarks

As shown in section 5, an account of Bedouin Arabic multiple opacity without extrinsic ordering is, indeed, possible, as long as the grammar provides for the possibility of extended indexation (Nazarov 2019). This allows for an account that acknowledges opacity's connections to exceptionality (see section 2.2) while retaining a systematic, non-exceptional account of the opaque mapping described by McCarthy (2007).

One important implication of an extended indexation account of opacity is that indexed constraints are not present universally, but must be induction in the course of acquisition, since they refer to morphemes that are language-specific. Algorithms exist for inducing such constraints (e.g., Pater 2010, Becker 2009, Coetzee 2009). The necessity of such an induction step for finding indexed constraints, which inherently comes with a chance that this induction step might have gone wrong, lead to the prediction that any pattern that is impossible without indexed constraints will occur less often typologically. This prediction is made based on the idea that acquisition mistakes will accumulate over time, and it is less likely for once-innovated patterns that require indexed constraints to be robust over time (see also Staubs 2014). In addition, it is predicted that opaque processes will take longer to learn, since they require an additional step compared to similar transparent processes. The intuition that opaque interactions are rarer compared to transparent processes is still to be tested in rigorous typological work, and the learnability predictions are still to be tested in acquisition studies, but computational studies have yielded results that also predict this (Jarosz 2016).

Much additional work is still needed, both on the details of accounting for additional Bedouin Arabic data (see fn 3 in section 5.2) and on further testing of the extended indexation model of opacity. In addition, an account of Bedouin Arabic in terms of Boersma's (2007) framework should also be considered. Further implications of extended indexation for opacity should also be explored, including implemented learning simulations to test whether the indexation assumed in the current account of Bedouin Arabic can be plausibly discovered by a learner. Finally, the combination of extended indexation with Harmonic Serialism (McCarthy 2008) should be explored to allow for serial accounts of opacity without the necessity of extrinsic ordering.

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