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Vowel Harmony in the Optimality Theory-Candidate Chains and the Optimal Interleaving Models: A Case Study in Kalhori Kurdish

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ABSTRACT

Two of the models in the Serial Optimality Theory in which derivational paths compete and are evaluated by PREC(A, B) family of constraints are Optimality Theory- Candidate Chains (OT-CC) and Optimal Interleaving (OI). The former operates exclusively at the level of phonology, while the latter postulates the interplay between morphology and phonology. This article presents a case study of vowel harmony in Kalhori Kurdish that necessitates a level where phonological and morphological processes alternate to account for both the application and lack of application of a phonological process. In Kalhori Kurdish, the features of [o] are spread regressively all the way to the leftmost edge of the verb; however, this is not the case when the coordinating conjunction clitic [=o] is added to the verb. The analysis of the data collected from 15 Kalhori Kurdish speakers revealed that OT-CC cannot simultaneously explain the root-prefix vowel harmony and the absence of this process between the clitic and the verbal ending, unless the morphological information is duplicated at this level. However, benefiting from the possibility of morphological processes alternating with the phonological ones, the OI model successfully explains both the presence and the absence of the vowel harmony.

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1. Introduction

Parallel Optimality Theory, where the Generator component is considered to have the power to exert an unrestricted number of changes on the input, proves to be inadequate when it comes to analyzing phenomena in which the steps of derivation and their order matter (McCarthy, 2007, pp. 99–105). In Serial OT, however, the gradual, stepwise evaluation allows for intermediate outputs to undergo multiple constraint applications, making it possible to account for opaque interactions. For example, through Harmonic Serialism, a form can meet a constraint at one stage and then subsequently undergo further changes that obscure this compliance in the final output, accurately modeling opacity as seen in cases of counterbleeding and counterfeeding (Kimper, 2011, pp. 995–997; McCarthy, 2000, p. 150; McCarthy, 2007, pp. 113–117). More recent studies have extended Serial OT's principles to address opacity in vowel harmony and long-distance assimilation, with findings that intermediate steps can represent gradual phonological shifts within words and phrases more effectively than parallel OT (Elfner, 2016, pp. 55–58; McCarthy, 2008, pp. 128–130). This sequential approach provides a natural framework for modeling complex phonological patterns, yielding valuable insights into opaque interactions across various languages.

However, some cases of phonological opacity are explicable only if the theory allows for morphology–phonology interaction, and it is precisely at this point that traditional OT comes up short. One successful attempt in this direction has been Optimal Interleaving (OI), which serially interleaves morphological and phonological constraints, thereby allowing morphological information to interleave with phonological steps across the derivation. This proposal, by Wolf (2008), suggests that morphologically triggered phonological changes take place at specific positions in the serial analysis, thus accounting for opacity by allowing phonological rules to apply as a function of both phonological and morphological information. For instance, morphologically driven vowel harmony processes that exhibit opacity can be captured using OI, since intermediate phonological stages are changed as morphological information becomes available (Pater, 2009, pp. 1013–1015; Wolf, 2008). To this, others have added the observation that such an interaction between morphology and phonology often is responsible for opaque rule ordering, especially because morphological triggers, such as affixation, can change the expected phonological result, particularly in languages with very complex morphophonological alternations (Kiparsky, 2000, pp. 347–349; McCarthy, 2007, pp. 88–90). By integrating morphology and phonology serially, OI and related models offer a more effectively explanation of such opaque phenomena than parallel OT, in which morphological factors cannot intervene at intermediate phonological stages. The details of Serial OT principles and those of OI in particular are elaborated on and demonstrated through the Kalhori Kurdish data analysis.

2. Method

This study analyzes a case of vowel harmony in the verbal structure in Kalhori Kurdish, both in the presence and in the absence of an added clitic. This variety of the Kurdish language is mainly spoken in Kermanshah and Ilam provinces in Iran. The relevant data were collected from a corpus obtained through recording interviews with 15 native speakers of Kalhori Kurdish from Eslamabad-e Gharb, the second largest city in Kermanshah Province. The recorded interviews were comprised of around 10 hours of data, which were then

transcribed and segmented. The relevant examples were subsequently extracted and used in this study.

3. Results

In Kalhori Kurdish, the subjunctive and imperative moods are formed by adding the same prefix to the beginning of the verbal stem. In the examples below, the prefix appears to the left of the verb root, while the personal ending follows the verb root. As in many other Iranian languages, in Kalhori Kurdish the subjunctive and imperative prefixes are identical in their phonetic form. Therefore, for the purpose of the examples given within this article, either one or both may be used and distinguishing between them is not a focus of this study. Following are examples of the various forms of the subjunctive/imperative prefix to illustrate its usage within context.

Table 1. Alternating Forms of Subjunctive/Imperative Prefix n Kalhori Kurdish

1.	**be′**.-	tʃe.r	-e:	2.	**be′**.-	ka.n	-em
	IMP	*call*	3S.clit.		SUBJ	*dig*	1S
	"Call him!"				"(if) I dig"		
3.	**bo′**.-	koʃ	-em	4.	**bo′**.-	koł	-e:
	SUBJ	*kill*	1S		SUBJ	*boil*	3S
	"(if) I kill"				"(if) it boils"		
5.	**bu′**.-	wɑ.ɾ	-e:d	6.	**bu′**.-	wa	-m
	SUBJ	*rain*	3S		SUBJ	*take*	1S
	"(if) it rains"				"(if) I take"		
7.	**b-**	ɑ′.ɾ	-im	8.	**b-**	y′.ʃ	-id
	SUBJ	*bring*	1P		SUBJ	*say*	2S
	"(if) we bring"				"(if) you say"		

As it can be seen from the above examples, in Kalhori Kurdish, the subjunctive/imperative prefix in this variety of Kurdish is made with the initial consonant /b/. However, this prefix has different phonetic forms in what follows this consonant: [be-] ~ [bo-] ~ [bu-] ~ [b-].

Since [be-] occurs in a wider range of environments than do the other three predictable forms, [bo-], [bu-], and [b-], Fattahi (2011) identifies the /be-/ as the underlying form in his generative phonological analysis of these examples. Thus, [bu-] can occur only in the limited context before the labial glide [w], while [b-] can occur only before a vowel. Finally, the form [bo-] is formed when the first vowel of the stem following the consonant is /o/. Thus, taking /be-/ as the underlying representation, we have three processes: elision, vowel assimilation with the glide, and vowel harmony.

The main concern of the present study is the forms which undergo vowel harmony. The vowel harmony in question involves right-to-left feature spreading, resulting in the vowel of

the prefix taking the shape of the vowel of the root. However, this process unexpectedly ceases to affect the verbal form if the clitic =o (a coordinating conjunction meaning "and") is added to verb. If the vowel harmony enforces spreading of the features from right to left, then an underlying form as /be-koʃ-em=o/ must be phonetically realized as *[bo.ko.ʃo.mo] since the final [o] has spread its features over the preceding vowels. Nevertheless, considering [bo.ko.ʃe.mo] as the only grammatical form, what actually happens in Kalhori Kurdish is that the vowel harmony applies only between the verbal root and the prefix, and not between the clitic and the verbal ending. With this in mind and considering the brief introduction regarding models of Optimality Theory, the present article seeks to answer the following questions:

1. How does Serial Optimality Theory explain vowel harmony in the structure of verbs in the subjunctive/imperative mood in Kalhori Kurdish?
2. If the clitic =o (the conjunction marker) is added to a verb form affected by vowel harmony, does Serial OT have sufficient explanatory power?
3. Can the Optimal Interleaving model explain vowel harmony between the verb vowel and the prefix, as well as the absence of this process between the clitic and the suffix?

4. Discussion

Vowel harmony results in a change in the mapping from input to output. Therefore, to account for this phenomenon, a markedness constraint must be assumed to dominate a faithfulness constraint. Whatever the markedness constraint may be, it enforces the sharing of the rounding feature, while the faithfulness constraint resists any change. This faithfulness constraint can be regarded as the general faithfulness constraint IDENT, while the vowel harmony-promoting constraint can be defined as a markedness constraint from the ALIGN-L(X, Y) family.

Constraint 1. IDENT: In the input-to-output mapping, one violation mark must be assigned to the candidate for each process that must be applied on the input for that to be produced.

Constraint 2. ALIGN-L([+round], Word)[1]: In the input-to-output mapping, one violation mark must be assigned to the candidate for each non-round element between a round vowel and the beginning of the word (the left edge of the word).

By assuming this markedness constraint to dominate the faithfulness constraint that prevents change (IDENT), the rounding of the prefix vowel, resulting from vowel harmony, can be explained. In the following tableau and the other tableaux in this article, lip rounding of the consonants is shown with the superscript ^{w} over the consonants. Showing this detail is necessary since Constraint 2 is sensitive to the presence and absence of lip rounding.

Tableau 1. ALIGN-L([+round], Word) >> IDENT

be-koʃ-em	ALIGN-L([+round], Wd)	IDENT
a. ☞b^{w}ok^{w}oʃem		*
b. bek^{w}oʃem	**W	L

1. The vowel-harmony promoting constraint may be postulated and entitled differently, e.g., AGREE [COLOR] in Mahmoodi and Modarresi Ghavami (2010), S-IDENT in Razinejad (2015), and AGREE [F] in Jam (2020). The Align-L constraint in this study has been adopted from McCarthy (2008); however, the main concern here is to study how vowel harmony is treated in OT-CC and OI, as two models of Serial OT.

The aforementioned hierarchy corresponds with the criteria for establishing a dominance relationship among constraints (McCarthy, 2008, pp. 41–42), permitting the markedness constraint that promotes vowel harmony in Kurdish to take precedence over the faithfulness constraint that inhibits alteration. In this tableau, candidate (a) presents a form where the lips remain rounded from the onset of the word to the second vowel [o], indicating that there is effectively no non-rounded element situated between this vowel and the left edge of the word. Conversely, candidate (b), despite the consonant [k] preceding the vowel [o] being rounded, receives two violation marks from the ALIGN-L constraint, as neither the vowel [e] nor the preceding consonant [b] is rounded.

Vowel harmony, in Kalhori Kurdish, is observed solely when the initial vowel of the verb stem is the round non-high vowel /o/. In instances where the first vowel is /u/, however, the prefix vowel does not exhibit harmony. The data below demonstrate vowel harmony with /o/ alongside the absence of this phenomenon with /u/. The example presented on the left side of the tables depicts vowel harmony involving /o/, whereas the one on the right side exemplifies the absence of harmony when the rounded vowel /u/ is present.

Table 2. Vowel Harmony Applicability With /o/ and its Inapplicability With /u/ in Kalhori Kurdish

9.	**boˈ**.-	ko.ɬ	-e:		10.	**beˈ**.-	ʃu.ɾ	-em
	SUBJ	*boil*	3S			SUBJ	*wash*	1S
"		(if) it boils"				"(if) I wash"		

Thus, it becomes clear that vowel harmony with a round vowel at the place of articulation is limited to non-high vowels. This means, for instance, that with the underlying form /be-ʃuɾ/, the form *[buʃuɾ] will not result. Therefore, to ensure that /be/ does not appear as [bu] adjacent to a syllable containing the vowel /u/, a constraint must be assumed to dominate the above assimilation constraint, disfavoring such a configuration. In the incorrect form *[bu.ʃuɾ], what has happened is that two adjacent syllables contain high vowels. A constraint rejecting this type of repetition can be posited as follows:

Constraint 3. OCP-HIGHSYLL: In the input-to-output mapping, one violation mark must be assigned to the candidate for each pair of adjacent syllables containing high vowels.

By allowing this constraint to dominate the vowel harmony-promoting constraint, the formation of incorrect generalizations can be prevented. The tableau below illustrates this dominance by presenting the candidates.

Tableau 2. OCP-HighSyll >> Align-L(+round, word)

be-ʃuɾ	OCP-HIGHSYLL	ALIGN-L(+round, Wd)
a. ☞beʃ^{w}uɾ		**
b. b^{w}uʃ^{w}uɾ	*W	L

The two constraints above are in a dominance relation; they fulfill all the conditions outlined in establishing such a relation (McCarthy, 2008, pp. 41–42). Here, the notation “W” over “L” shows that the two constraints are in conflict and which form wins. The only argument which might undermine this dominance relation is that in the example at hand, the faithfulness constraint IDENT could fulfill the same function in picking the winner as OCP-

HIGHSYLL, therefore undermining the “no-disjunction” requirement (McCarthy, 2008, pp. 41–42).

This issue does not pose a concern, however, because an examination of cases where vowel harmony is allowed shows that IDENT is dominated by the vowel harmony-promoting constraint. With OCP-HIGHSYLL dominating ALIGN-L(+round, Wd), through a transitive relation, OCP-HIGHSYLL can also be assumed to dominate IDENT. Thus, the dominance of OCP-HIGHSYLL over ALIGN-L(+round, Wd) also respects the "no-disjunction" condition.

Tableau 3. ALIGN-L(+round, Wd) >> IDENT

be-koʃ	OCP-HIGHSYLL	ALIGN-L(+round, Wd)	IDENT
a. ☞b^{w}ok^{w}oʃ			*
b. bek^{w}oʃ		**W	L

4.1 Opacity in Vowel Harmony

In Kalhori Kurdish, the clitic /=o/ may be added to the verbal or nominal structure. This clitic is a conjunction meaning "and"—it is considered a clitic owing to its lexical yet phonologically dependent nature. If this clitic is added to the verbal form /be-koʃ-em/ ("(if) I kill") at the level of morphology, and the result passes on to the phonological component, the latter has to interpret the phonetic form of this verbal structure by applying interactions among violable universal constraints. Now, as determined earlier, the constraint hierarchy is as follows: OCP-HIGHSYLL >> ALIGN-L(+round, Wd) >> IDENT. With this in mind, one can provide the verbal form with the clitic /=o/ as input to the Generator and Evaluator. Tableau 4 illustrates the first stage of derivation. It is worth mentioning again that in Serial OT, the candidates are produced by applying solely one process to the input.[1]

Tableau 4. The First Stage of Vowel Harmony Derivation With the Presence of the Clitic /=o/

be-koʃ-em=o	OCP-HIGHSYLL	ALIGN-L(+round, Wd)	ID
a. ☞b^{w}ok^{w}oʃem^{w}o		**	*
b. bek^{w}oʃem^{w}o		****W	L

Since, in Serial OT, the Generator is forced to apply only one change at a time, in the first stage of derivation, in order to increase the degree of harmony, the vowel of the subjunctive/imperative prefix assimilates to the rounded vowel of the verb root, with the consequence that this prefix surfaces as [bo-]. In Tableau 4, the first candidate has received two violation marks from the vowel-harmony promoting constraint because of the lack of lip rounding in the sequence [em]. In contrast, the second candidate does worse in this regard as the number of non-round consonants and vowels is twice as large: [be] and [em].

Now, in the second stage, we are expecting still another harmony to take place since in the first stage the vowel of the syllable preceding the clitic /=o/ did not undergo the process of vowel harmony. The asterisk for the winning form under the vowel harmony-promoting

1. Although the lip rounding of the consonants preceding round vowels can be a process itself—as this feature is not inherent to the phonological forms of these consonants—in this article this step is overlooked in order for the analysis to be simpler and more devoted to the topic of vowel harmony. The same can be said about syllabification as an independent process.

constraint indicates that more changes are required for the winner to be ideal. The second stage of derivation is shown in the following tableau, in which this other vowel undergoes vowel harmony, too. In this round, the input is the winner of the previous stage, which, again, the Generator component can only apply one process on.

Tableau 5. The Second Stage of Vowel Harmony Derivation With the Presence of the Clitic /=o/

bo-koʃ-em=o	OCP-HIGHSYLL	ALIGN-L(+round, Wd)	ID
a. ☞ bʷokʷoʃʷomʷo			*
b. bʷokʷoʃemʷo		**	

In the above tableau, the first candidate has done a perfect job regarding vowel harmony since lip rounding is maintained from the final round vowel all the way to the beginning of the word, encompassing all the consonants and vowels. However, despite its brilliant performance in vowel harmony, this candidate is, in fact, ill-formed in Kalhori Kurdish. In Kalhori Kurdish, the verbal ending is not subject to vowel harmony and the grammatical form is [bo.ko.ʃe.mo], which is flagged here as the loser. It would appear that, all things being equal, it is preferable to assume, at a higher rank, a faithfulness constraint which argues against functional morpheme change. Before assessing the relative success of this analysis, the grammatical morpheme change constraint can be posited as follows:

Constraint 4. $\text{IDENT}_{\text{FUNC}}$: In the input-to-output mapping, one violation mark must be assigned to the candidate for each instance of change in grammatical morphemes.

The issue is that by allowing this faithfulness constraint to dominate the vowel harmony-promoting constraint, although it prevents the inflection from changing before the clitic, it also prevents the subjunctive/imperative prefix vowel from undergoing harmony with the root vowel. Overall, this approach effectively disallows any grammatical morphemes—whether prefixes or suffixes—from participating in vowel harmony.

Tableau 6. The Inability of $\text{IDENT}_{\text{FUNC}}$ to Explain Vowel Harmony

be-koʃ-em=o	$\text{IDENT}_{\text{FUNC}}$	ALIGN-L(+round, Wd)	ID
a. ☞ bekʷoʃemʷo		****	
b. bʷokʷoʃemʷo	*	**	*

In the above tableau, due to the dominance of the $\text{IDENT}_{\text{FUNC}}$ constraint, none of the grammatical morphemes can undergo any change. Although this constraint effectively prevents alteration in the vowel of the inflection, it also blocks vowel harmony in the subjunctive/imperative prefix.

It seems that we are in a situation where general phonological constraints cannot resolve the issue. Although Optimality Theory at the level of phonology introduces constraints marked as LEX and FUNC, for lexical and grammatical morphemes respectively, there is no constraint in Optimality Theory that specifically targets only suffixes. Even if there were, it would not be desirable from a theoretical economy perspective since it would not be surprising, then, if constraints were proposed that exclusively target prefixes, clitics, or other lexical items. Such an approach would make phonology appear to replicate structures and

rules from the morphological level.

A linguistic theory operates economically when rules and structures from each level are confined to that level, rather than reapplying the rules of a prior level in subsequent analyses. This issue of theoretical economy is referred to as the "duplication problem" in analyses (Chomsky & Halle, 1968, p. 382). The most effective analysis occurs when phonology uses constraints that solve the issue within its own level without relying on morphology, unless we fundamentally reconsider our conception of language levels and systems, imagining phonological and morphological processes as occurring on a single level. This is the approach which is adopted by Optimal Interleaving. In the following section, we will examine the solution proposed by this model for the opacity problem in applying vowel harmony in Kalhori Kurdish.

4.2 The Optimal Interleaving Account of Vowel Harmony in Kurdish

According to the OI model, the morphological and phonological processes of language occur on one level, and it is conceivable that some phonological rules are ranked higher in their ordering than some morphological ones. With respect to vowel harmony in Kurdish through the lenses of OI, for a form like [b^{w}o.k^{w}o.ʃe.m^{w}o] to surface, all the morphological operations such as root insertion, prefix insertion, suffix insertion, and clitic insertion and phonological operations like vowel harmony may apply in any order, after which this phonetic form would result.

Assuming the sequential application of the morphological processes mentioned above, as well as the vowel harmony process that violates IDENT, we examine the possible derivational paths that lead to [b^{w}o.k^{w}o.ʃe.m^{w}o]. However, before getting started, we must also consider the hierarchical structure of the morphemes in this verbal form. Generally, in verbal forms with a clitic, clitics occupy the peripheral position, as these morphemes are essentially separate words that are phonologically dependent, attaching to a host (Spencer & Luis, 2012, p. 4)—in this case, the verb form with subjunctive prefix and inflection. The ordering of rules must respect this hierarchy as well. Thus, the insertion of each morpheme in this verb structure, regardless of the sequence, must place the clitic as the final insertion. Additionally, by a general principle, morpheme insertion begins with the innermost morpheme, namely the root, progressively followed by outer morphemes.

Just like Optimality Theory-Candidate Chains (OT-CC) (McCarthy, 2007), OI enjoys gradualness—meaning changes (unfaithful mappings of input to output) occur stage by stage, with only one change occurring at each stage. Furthermore, the chain of non-faithful mappings must enhance the level of harmony[1], and any change that reduces harmony is inherently rejected, as dominant constraints prevent it. Now, we will examine possible derivations that can, in various sequences, yield [b^{w}o.k^{w}o.ʃe.m^{w}o], and then we will present the non-faithful mappings associated with each derivation.

As mentioned, in OI, the innermost morphemes must be inserted earlier in the word. This morpheme, in the present example, is the verb root. In the first possible chain, after inserting the verb root /koʃ/, the subjunctive prefix /be-/ is inserted. Next, the verbal ending /-em/ is added. With the prefix and suffix now attached to the verb root, forming the intermediate structure *be-koʃ-em*, it is time for the vowel harmony process to apply, rounding the vowel in

1. This term is different from what we have in vowel harmony. Harmony in this new sense refers to the winner of each step violating constraints of lower ranks, which will ideally result in the last step violating no constraint, thereby having the highest level of harmony.

the subjunctive prefix in the vicinity of the vowel of the root; this results in the formation of [b^{w}o-]. At this stage, the clitic, which is made up of a round vowel /=o/, has not yet been inserted, so the vowel in the verbal ending cannot undergo harmony as there is no round vowel on the right side to trigger the vowel harmony. In the last step, the clitic /=o/ is finally added to the verb structure, resulting in the final form [b^{w}o.k^{w}o.ʃe.m^{w}o]. With the clitic insertion, although the phonetic context is suitable for verbal ending's vowel to undergo vowel harmony, this process can no longer apply since it occurred prior to the clitic's insertion. Below are the stages of the verb form at each step and the chain of non-faithful mappings based on this definition. Since the following derivation chain is the first one introduced in this article, it helps to know that the first two lines illustrate the gradual manifestation of each morpheme in the general morphological format of the word, and in the last line, LUMSeq, which is the abbreviated form for Localized Unfaithful Mapping Sequence, summarizes the operations, with the phonological operations being shown by mentioning the relevant faithful constraint that is violated.

Derivation Chain 1. [b^{w}o.k^{w}o.ʃe.m^{w}o]

<PREFIX-ROOT-SUFFIX=CLITIC, PREFIX-koʃ-SUFFIX=CLITIC, be-k^{w}oʃ-SUFFIX=CLITIC, be-k^{w}oʃ-em=CLITIC, b^{w}o-k^{w}oʃ-em=CLITIC, b^{w}o-k^{w}oʃ-em^{w}=o>

LUMSeq: <Insert-root, Insert-prefix, Insert-suffix, IDENT, Insert-clitic>

A sequence of non-faithful mappings that progresses step-by-step, increases harmony, and results in the form [b^{w}o.k^{w}o.ʃe.m^{w}o] can also take a different shape. Unlike the previous chain, after inserting the root /koʃ/, the suffix (inflection) /-em/ can be inserted, delaying the prefix insertion to the next stage. After the insertion of the prefix /be-/, vowel harmony occurs, forming [b^{w}o.k^{w}o.ʃem] at this stage in the chain. After the application of vowel harmony, the clitic /=o/ can then be added, resulting in the final form [b^{w}o.k^{w}o.ʃe.m^{w}o]. The only difference between this chain and Chain 1 is the order of inserting the prefix and the suffix (inflection). In any case, in this chain as well, vowel harmony occurs before the clitic insertion, which prevents the harmony of the inflectional vowel with the round clitic vowel. The new chain of forms and the chain of non-faithful mappings are shown below.

Derivation Chain 2. [b^{w}o.k^{w}o.ʃe.m^{w}o]

<PREFIX-ROOT-SUFFIX=CLITIC, PREFIX-k^{w}oʃ-SUFFIX=CLITIC, PREFIX-k^{w}oʃ-em=CLITIC, be-k^{w}oʃ-em=CLITIC, b^{w}o-k^{w}oʃ-em=CLITIC, b^{w}o-k^{w}oʃ-em^{w}=o>

LUMSeq: <Insert-root, Insert-suffix, Insert-prefix, IDENT, Insert-clitic>

There is a third possible chain, however, where the final form is again [b^{w}o.k^{w}o.ʃe.m^{w}o], except that this time, the sequence of changes is different from those of the two previous chains. In this new chain, after the root /koʃ/ is inserted, the insertion of the subjunctive prefix /be-/ follows, which creates the intermediate form [be-k^{w}oʃ]. This insertion prepares the grounds for the vowel harmony to apply at this stage. In the next step, before any other morpheme is inserted, the vowel of the prefix assimilates with the stem vowel, resulting in the form [b^{w}o.k^{w}oʃ]. Subsequently, the suffix /-em/ and the clitic /=o/ are inserted in turn, and the final verbal structure [b^{w}o.k^{w}o.ʃe.m^{w}o] will be the final form.

What this chain has in common with the two previous ones is that, here, the clitic is added only after the application of vowel harmony, and no further vowel harmony occurs following this. This chain is presented below.

Derivation Chain 3. [b^{w}o.k^{w}o.ʃe.m^{w}o]
<PREFIX-ROOT-SUFFIX=CLITIC, PREFIX-k^{w}oʃ-SUFFIX=CLITIC, be-k^{w}oʃ-SUFFIX=CLITIC, b^{w}o-k^{w}oʃ-SUFFIX=CLITIC, b^{w}o-k^{w}oʃ-em=CLITIC, b^{w}o-k^{w}oʃ-em^{w}=o>
LUMSeq: <Insert-root, Insert-prefix, IDENT, Insert-suffix, Insert-clitic>

In order for the form [b^{w}o.k^{w}o.ʃe.m^{w}o] to be produced, it appears that no other possible chain exists. In Chains 1 and 2, the difference lies in the order of prefix insertion versus suffix insertion. The difference between Chain 3 and Chains 1 and 2 is in the sequence of vowel harmony in relation to suffix insertion. What these three chains have in common is that, throughout their derivation, vowel harmony occurs only before the clitic is inserted, and it is not allowed to apply after the insertion of the clitic. Additionally, as briefly discussed earlier regarding the structural relationships among these morphemes, the clitic morpheme can only attach to its host (here the verb structure) only when the verb form has been created. The clitic in question here cannot be inserted while the verb's inflection has not yet been added, since the clitic can only be inserted when it can rely on the inflection for support.

In the OT-CC framework preserved within OI, once the possible chains are generated, all chains that reach the same final form, despite differences in their sequence, should undergo a process of merging. Only those sequential pairings which regularly appear in all chains are preserved in the chain of transformations resulting from such a merge. For example, in all of the three chains above, the root insertion comes before the prefix insertion. A combined chain must, therefore, contain the sequence <Insert-root, Insert-prefix> as one of its crucial orderings. We can remove non-crucial orderings and discover the crucial ones by noticing these persistent pairwise orderings. Chain 4 illustrates the merging of the three chains above. Each key pair in this chain is separated with a comma (,), whereas a semicolon (;) gives the boundary between different pairwise orderings. Moreover, there is only one case of vowel harmony throughout the chains—that of the subjunctive prefix vowel. This reflects the assumption that, in all chains, prefix insertion occurs prior to vowel harmony.

Derivation Chain 4. The reduced LUMSeq (rLUMSeq) for [b^{w}o.k^{w}o.ʃe.m^{w}o]
<Insert-root, Insert-prefix; Insert-root, Insert-suffix; Insert-root, IDENT; Insert-root, Insert-clitic; Insert-prefix, IDENT; Insert-prefix, Insert-clitic; Insert-suffix, Insert-clitic; IDENT, Insert-clitic>

After examining all the possible chains that can lead us to the optimal form [b^{w}o.k^{w}o.ʃe.m^{w}o] and identifying the crucial orderings among the processes, we intend to apply the same approach to the possible chains that ultimately produce the incorrect form *[b^{w}o.k^{w}o.ʃ^{w}o.m^{w}o]. We know this form is incorrect as the vowel of the verbal inflection /-em/ has been influenced by the rounding of the clitic /=o/. Although right-to-left vowel harmony is desirable for the prefix vowel, it should not affect that of the verbal ending. Now, we will trace the possible chains that lead to the incorrect form *[b^{w}o.k^{w}o.ʃ^{w}o.m^{w}o] and, in the end, subject them to the chain merger.

In the first possible scenario, after the insertion of the root /koʃ/, the chain continues with the attachment of the prefix /be-/. The next to attach would be the verbal inflection /-em/, with the intermediate form now being [be-k^{w}oʃ-em]. Another possible step at this stage that is morphological would be the insertion of the clitic /=o/. The result in that case would be the form [be.k^{w}o.ʃe.m^{w}o]. This form provides two possible contexts in which vowel harmony could apply to increase the harmony level of the derivation. One is a vowel harmony between the prefix vowel and the vowel of the immediately following syllable; the other affects the

inflectional vowel, making it agree with the roundness of the clitic vowel that follows. Since the former follows the latter in any event, if vowel harmony is to be the last process, it must apply twice: once to the prefix vowel, once to the vowel of the verbal ending. This process applied to these two vowels finally yields the wrong form *[b^{w}o.k^{w}o.ʃ^{w}o.m^{w}o]. The chains and their LUMSeqs are as follows:

Derivation Chain 5. *[b^{w}o.k^{w}o.ʃ^{w}o.m^{w}o]
<PREFIX-ROOT-SUFFIX=CLITIC, PREFIX-k^{w}oʃ-SUFFIX=CLITIC, be-k^{w}oʃ-SUFFIX=CLITIC, be-k^{w}oʃ-em=CLITIC, be-k^{w}oʃ-em^{w}=o, b^{w}o-k^{w}oʃ-em^{w}=o, b^{w}o-k^{w}oʃ^{w}-om^{w}=o>
LUMSeq: <Insert-root, Insert-prefix, Insert-suffix, Insert-clitic, IDENT (prefix vowel), IDENT (suffix vowel)>

As the above chain shows, vowel harmony occurs when conditions are favorable for the alteration of both the prefix and the inflectional vowels. However, this is not the only chain that ultimately leads to the incorrect form. If, after inserting the root /koʃ/, the verbal inflection /-em/ is added, and the prefix /be-/ is then attached, we again reach the verbal form [be.k^{w}o.ʃem]. With this form established, the structure is now ready to accept the clitic, so in the next step, adding the clitic results in the form [be.k^{w}o.ʃe.m^{w}o]. The only remaining process is the phonological process of vowel harmony. At this point, the process identifies two contexts for harmony: one involves the harmony between the prefix vowel (the initial vowel) and the root vowel, and the other involves harmony between the verbal ending vowel (suffix) and the clitic vowel. This is how the process of vowel harmony applies twice here too, ultimately producing the form [b^{w}o.k^{w}o.ʃ^{w}o.m^{w}o]. These steps are summarized below as a harmonically-improving chain and its LUMSeq.

Derivation Chain 6. *[b^{w}o.k^{w}o.ʃ^{w}o.m^{w}o]
<PREFIX-ROOT-SUFFIX=CLITIC, PREFIX-koʃ-SUFFIX=CLITIC, PREFIX-k^{w}oʃ-em=CLITIC, be-k^{w}oʃ-em=CLITIC, be-k^{w}oʃ-em^{w}=o, b^{w}o-k^{w}oʃ-em^{w}=o, b^{w}o-k^{w}oʃ^{w}-om^{w}=o>
LUMSeq: <Insert-root, Insert-suffix, Insert-prefix, Insert-clitic, IDENT (prefix vowel), IDENT (suffix vowel)>

By comparing the two chains above, it becomes clear that the difference between them lies solely in the order of prefix insertion versus suffix insertion. What they share, however, is that in both cases, the verb structure is first completed by adding the prefix and suffix, after which the clitic attaches to its prepared host. What causes both chains to result in the same form is that in both cases, vowel harmony only applies once the verb form with the clitic has been fully established at the morphological level. After the verb form with the clitic is complete, the vowel harmony process identifies two positions (the prefix vowel and the verbal ending vowel) where it can be applied and is implemented in both places, ultimately producing the form *[b^{w}o.k^{w}o.ʃ^{w}o.m^{w}o].

Another chain that can also result in the form *[b^{w}o.k^{w}o.ʃ^{w}o.m^{w}o] involves a different sequence. Instead of applying vowel harmony twice in quick succession as in the previous two chains, the first vowel harmony is applied immediately as soon as the initial vowel meets the conditions for it, and then morpheme insertion continues. In the subsequent steps, the second harmony process is applied to the verbal ending vowel. To illustrate: first, the root /koʃ/ is inserted, followed by the prefix /be-/, yielding the form [be.k^{w}oʃ], which is now ready for vowel harmony. This results in the form [b^{w}o.k^{w}oʃ]. In the next step, the verbal ending and the clitic are added in order, producing the form [b^{w}o.k^{w}o.ʃe.m^{w}o]. At this point, the

conditions for the second harmony are also met, and since the aim is for the form to undergo vowel harmony in both positions, this process is applied to the verbal ending vowel too, resulting in the final form *[bʷo.kʷo.ʃʷo.mʷo]. The harmonically-improving chain of this sequence and its LUMSeq are summarized below.

Derivation Chain 7. *[bʷo.kʷo.ʃʷo.mʷo]

<PREFIX-ROOT-SUFFIX=CLITIC, PREFIX-koʃ-SUFFIX=CLITIC, be-kʷoʃ-SUFFIX=CLITIC, bʷo-kʷoʃ-SUFFIX=CLITIC, bʷo-kʷoʃ-em=CLITIC, bʷo-kʷoʃ-emʷ=o, bʷo-kʷoʃʷ-omʷ=o>

LUMSeq: <Insert-root, Insert-prefix, IDENT (prefix vowel), Insert-suffix, Insert-clitic, IDENT (suffix vowel)>

It is possible to imagine yet another sequence of processes that would ultimately produce a form in which both the prefix vowel and the suffix vowel undergo vowel harmony. In this new sequence, unlike the previous chains, it is the suffix vowel that first undergoes vowel harmony. This sequence unfolds as follows: after inserting the root /koʃ/, the suffix (verbal ending) /-em/, and then the clitic /=o/ are added. This results in the form [kʷo.ʃe.mʷo]. This form suggests that the context is suitable for the suffix vowel to undergo vowel harmony, preparing the grounds for the creation of the form [kʷo.ʃʷo.mʷo]. In the next step, the prefix /be-/ is added. With the addition of this prefix, the conditions for vowel harmony with the verb root vowel are met, and with this adjustment, the final form [bʷo.kʷo.ʃʷo.mʷo] is obtained. Summarizing this new sequence, this new chain and its LUMSeq are as follows:

Derivation Chain 8. *[bʷo.kʷo.ʃʷo.mʷo]

<PREFIX-ROOT-SUFFIX=CLITIC, PREFIX-kʷoʃ-SUFFIX=CLITIC, PREFIX-kʷoʃ-em=CLITIC, PREFIX-kʷoʃ-emʷ=o, PREFIX-kʷoʃʷ-omʷ=o, be-kʷoʃʷ-omʷ=o, bʷo-kʷoʃʷ-omʷ=o>

LUMSeq:<Insert-root, Insert-suffix, Insert-clitic, IDENT (suffix vowel), Insert-prefix, IDENT (prefix vowel)>

It does not seem that there is any other possible chain besides these four, in which vowel harmony can access both contexts for application and result in the production of this form. Thus, since these chains end in the same form, they should undergo chain merger. The merged chain of these two is presented below.

Derivation Chain 9. The rLUMSeq for *[bʷo.kʷo.ʃʷo.mʷo]

<Insert-root, Insert-prefix; Insert-root, Insert-suffix; Insert-root, Insert-clitic; Insert-root, IDENT (prefix vowel); Insert-root, IDENT (suffix vowel); Insert-prefix, IDENT (prefix vowel); Insert-suffix, Insert-clitic; Insert-suffix, IDENT (suffix vowel); Insert-clitic, IDENT (suffix vowel)>

The above chain is a set of crucial binary orderings from the chains that ultimately lead to the formation of the form *[bʷo.kʷo.ʃʷo.mʷo]. One point that should not be overlooked here is that, in this merged chain, the change that occurs in each vowel is expressed according to its position (suffix or prefix). For example, in the case of the order between the insertion of the prefix and the vowel harmony process in the prefix vowel, the ordering is crucial. However, with respect to the insertion of the prefix and harmony in the suffix vowel, this certainty does not exist, and it is evident that it is not included in the merged chain.

Now, imagine a constraint that penalizes any occurrence of vowel harmony (regardless of the context of occurrence) if this process has not been preceded by prefix insertion. A critical question is whether the above chain comply with such a constraint. The answer is negative. It can only be claimed that the prefix is inserted before the vowel harmony process (violation of

IDENT) if the prefix is inserted before any occurrence of vowel harmony, whether in the prefix or suffix, and not just in one of these two positions. In the case of the order between the insertion of the root and vowel harmony, this claim can be made, because the root insertion occurs both before the violation of IDENT (prefix vowel) and before IDENT (suffix vowel). So, it can be confidently stated that the root insertion occurs before the vowel harmony process. However, in the case of the order between the insertion of the prefix and vowel harmony, such a claim cannot be made. As illustrated in the merged chain, the prefix insertion only occurs before one of the two occurrences of harmony and not both.

Therefore, if we are to disregard the distinction between the positions where vowel harmony is applied, and we want to introduce a crucial ordering between the morphological processes and the vowel harmony process, we must only consider those orderings in which the morphological process precedes both of the instances of vowel harmony. This only happens in the case of the ordering between the morphological process of root insertion and vowel harmony. Thus, the merged chain above can be summarized as Chain 10, where the goal is to establish crucial orderings between the morphological processes and the phonological process of vowel harmony in general, regardless of where it is applied.

Derivation Chain 10. The Final rLUMSeq for *[b^{w}o.k^{w}o.ʃ^{w}o.m^{w}o]
<Insert-root, Insert-prefix; Insert-root, Insert-suffix; Insert-root, Insert-clitic; Insert-root, IDENT; Insert-suffix, Insert-clitic>

With a close examination of the above chain, it becomes clear that, for instance, it is not possible to establish a crucial ordering between Insert-clitic and IDENT. This is because, in the merged chain, after Insert-clitic, only a violation of IDENT is observed in the suffix vowel, and this ordering is not crucial concerning Insert-clitic and IDENT in the prefix vowel. Therefore, it cannot be claimed that in the chains leading to the form *[b^{w}o.k^{w}o.ʃ^{w}o.m^{w}o], there is generally a crucial precedence relation of Insert-clitic over vowel harmony.

In the OT-CC, chains can only compete with one another in optimality tableaux if they have undergone chain merger, and we know that the merger only applies to chains that result in the same phonological form. We also know that the main purpose of the merger is to discover crucial orderings. Thus, when two merged chains are obtained from harmonically-improving stage-by-stage changes, they can compete within a single optimality tableau. This means that the final merged Chain 10—which leads to an ungrammatical form—can be seen as a competitor against the correct form chain [b^{w}o.k^{w}o.ʃe.m^{w}o].

These two chains compete in a context where the form [b^{w}o.k^{w}o.ʃe.m^{w}o]—in which vowel harmony occurs only in the prefix vowel—should win over the ungrammatical form *[b^{w}o.k^{w}o.ʃ^{w}o.m^{w}o]. In the crucial ordering chain of changes that produces the correct form [b^{w}o.k^{w}o.ʃe.m^{w}o], Insert-prefix crucially precedes vowel harmony, as only the prefix vowel change counts as vowel harmony in that chain. Therefore, if a constraint were defined to necessitate the precedence of Insert-prefix over IDENT, then the chain candidate [b^{w}o.k^{w}o.ʃe.m^{w}o] would win over the other candidate.

Based on this precedence constraint, vowel harmony can only be applied if Insert-prefix has crucially occurred beforehand. This is where one of the constraints from the PREC(A, B) family can enforce this precedence. Below, you will see this constraint along with its definition.

Constraint 5. PREC(Insert-Prefix, IDENT): In the input-output mapping, if vowel harmony has been applied in a candidate, assign a violation mark for each of the following cases:

1. Vowel harmony (violation of IDENT) has occurred without any prefix having been inserted beforehand.
2. Vowel harmony has occurred with a following insertion of a prefix.

Postulating the dominance of this constraint over the vowel harmony-supporting constraint, ALIGN([+round], Wd), the incorrect form *[b^{w}o.k^{w}o.ʃ^{w}o.m^{w}o] will not have any chance to be selected as the optimal candidate.

Tableau 7. PREC(Insert-Prefix, IDENT) >> ALIGN(+round, Word)

//PREFIX-ROOT-SUFFIX=CLITIC//	PREC(Insert-prefix, IDENT)	ALIGN-L(+round, Wd)
a. ☞[b^{w}o.k^{w}o.ʃe.m^{w}o] **rLUMSeq:** <Insert-root, Insert-prefix; Insert-root, Insert-suffix; Insert-root, IDENT; Insert-root, Insert-clitic; Insert-prefix, IDENT; Insert-prefix, Insert-clitic; Insert-suffix, Insert-clitic; IDENT, Insert-clitic>		**
b. [b^{w}o.k^{w}o.ʃ^{w}o.m^{w}o] **rLUMSeq:** <Insert-root, Insert-prefix; Insert-root, Insert-suffix; Insert-root, Insert-clitic; Insert-root, IDENT; Insert-suffix, Insert-clitic>	*W	L

The conflict between the two candidates, each of which is a chain of orderings of changes, is clear. In the rLUMSeq of candidate (a), one of the crucial orderings is "prefix insertion before the violation of IDENT," while in the final merged chain of changes in candidate (b), no such ordering exists. In the candidate chain (b), vowel harmony—i.e., a violation of IDENT—has occurred, but before that, what has been applied is the root insertion, not the prefix insertion. This causes the constraint PREC(Insert-prefix, IDENT) to penalize candidate (b) once. On the other hand, the ALIGN([+round], Word) constraint prefers the opposite candidate. According to ALIGN([+round], Word), any segment on the left side of the round vowel /o/ that has not been rounded must be penalized. This is exactly what happens in candidate (a). In this candidate, the consonant and vowel preceding the clitic /=o/ are not produced with lip rounding, and thus, this candidate is penalized twice. In contrast, in candidate (b), vowel harmony has applied and all the segments preceding the clitic are rounded all the way to the left edge of the word, and the vowel harmony-supporting constraint definitely prefers this candidate.

5. Conclusion

This article attempted to first present a case of vowel harmony and the unexpected absence of this process in a verbal form in Kalhori Kurdish, and second, to compare the explanatory power of two models in Serial Optimality Theory, namely Optimality Theory–Candidate Chains and Optimal Interleaving. As explained in the introduction of the article, the latter model is based upon the former with the only difference being the ability of the morphological operations to appear at the same level as the phonological ones. Three questions were raised earlier in this study, and now that the data have been fully analyzed, one can consider better responses to them. For convenience, the three questions are repeated here:

1. How does Serial Optimality Theory explain vowel harmony in the structure of verbs in the subjunctive/imperative mood in Kalhori Kurdish?
2. If the clitic =o (the conjunction marker) is added to a verb form affected by vowel harmony, does Serial OT have sufficient explanatory power?
3. Can the Optimal Interleaving model explain vowel harmony between the verb vowel and the prefix, as well as the absence of this process between the clitic and the suffix?

In response to the above questions, it is concluded that the vowel harmony process in the verbal form of Kalhori Kurdish spreads features from right to left, but even so, the verbal ending is not affected if the clitic =o is added to the rightmost side of the verb. The OT-CC model cannot fully explain this pattern unless the morphological information is duplicated at the phonological level. If this model chose to avoid this, the result would lead to an ungrammatical form. The Optimal Interleaving model, however, considers the phonological and morphological operations to apply at the same level. This framework offers more explanatory power as the PREC constraint, which is a powerful tool in both OT-CC and OI, can mandate the insertion of the verbal ending solely before vowel harmony. This is enough to prevent from winning the chain that accepts the rounding of the clitic =o.

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The author declares no conflicts of interest related to this research.

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