Revisiting Leti metathesis: a use case for boolean monadic recursive schemes

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Abstract

This paper demonstrates how Boolean monadic recursive schemes (BMRS), a computational method of modeling phonological processes (as proposed in Chandlee & Jardine 2021, characterized in Bhaskar et al. 2020), can model metathesis in Leti, a Timoric language spoken primarily on the island of Leti in the Maluku archipelago. In this language, metathesis—when two segments switch linear position—is morphologically productive and phonologically conditioned. Using data and analyses by Hume (1998) as a starting point, I build on the idea that metathesis is a process that simultaneously deletes a segment and inserts it in a new place, modeling this process using BMRS. In the case of Leti, in certain environments, a word-edge consonant deletes and inserts itself right before its preceding vowel. In contrast with Hume's optimality and correspondence theory-based analysis, however, BMRS can intuitively account for the environments and opaque phonological interactions driving Leti metathesis without having to appeal to linearity constraints and syllable-level representations, showing that Leti metathesis is a local process that applies to segments.

1 Introduction

In addressing the need for reconciling computational models of language with longstanding conventions and assumptions in phonology, Chandlee & Jardine (2021) proposed the use of Boolean Monadic Recursive Schemes (BMRS) for phonological analysis. The BMRS formalism makes use of simple `IF...THEN...ELSE` structures which define the output value of an element according to other input and output structures local to that element. BMRS are described in Bhaskar et al. 2020 as being a logical characterization of the subsequential functions as applied on strings. That is, they can represent processes that have a fixed memory and can be computed deterministically. This is hypothesized by Heinz & Lai (2023) to be the computational class that contains phonological processes. Chandlee & Jardine (2021) argue that BMRS addresses issues found with rule-based frameworks, which undergenerate, and constrained-based grammars like Optimality Theory, which overgenerate. Essentially, BMRS can capture multiple phonological generalizations in a purposefully computationally restrictive way while using representations familiar to phonologists.

In this paper, I will demonstrate how BMRS can model the process of metathesis in Leti, an Austronesian language spoken on the island of Leti in the Maluku archipelago of Indonesia. Metathesis, a process by which two segments apparently switch linear positions, is not only morphologically productive in this language but occurs systematically in a manner that can be explained within the realm of phonology. My analysis will build on the idea that metathesis is a process that simultaneously deletes a segment and inserts it in a new place; in the case of Leti, a consonant deletes and inserts itself right before the vowel that preceded it. I will show how BMRS blocking and licensing structures in two output copies can intuitively capture the phonology behind Leti metathesis. This contrasts with Hume's optimality theory-based analysis (1998) in that a BMRS account does not need to consider linearity and syllable-level constraints to predict the attested outputs.

This analysis is intended to serve as a demonstration for BMRS with a use case in an understudied endangered language with unique features. Not only does this paper present the fact that BMRS can capture phonological generalizations and opaque interactions through an intuitive yet computationally formal manner, but it also shows how computational methods in phonology can provide new insights for the study of typologically unusual languages.

2 Leti

Leti is an Austronesian language in the Timoric group of the Central-Eastern Malayo-Polynesian subfamily. It is spoken by around 7,700 people, primarily on the island of Leti in the Maluku archipelago (Eberhard et al. 2021). Most of the phonological work on Leti was made possible from data gathered by Aone van Engelenhoven, a linguist and native speaker of Leti. As such, data is primarily taken from the variety of Leti he speaks, Tutukeian.

Hume (1997, 1998) gives the segment inventory for Leti in Tables 1 and 2 for consonants and vowels, respectively.

	labial	dental	alveolar	velar
stop	p, pp	t, tt	d, dd	k, kk
continuant	β/v	s, ss	r, rr	
sonorant	m, mm	n, nn	l, ll	

Table 1: Leti consonant inventory (Hume 1998)

i		u
e		o
ɛ		ɔ
	a	

Table 2: Leti vowel inventory (Hume 1998)

There are no diphthongs in Leti. Two consecutive vowels in a string are part of their own respective syllables. Consonant clusters, including geminates, are not underlying; they are products of other morphophonological procesess (Hume et al. 1997, van der Hulst 1995).

Hume (1997, 1998, and in Hume et al. 1997) assumes that underlying forms in Leti can be either consonant- or vowel-final. This contrasts with van der Hulst and van Engelenhoven (1995) who assume only vowel-final forms. The analysis of metathesis in this paper will follow from Hume's work and assumes underlying forms that can be either consonant- or vowel-final. (It should be noted that a similar BMRS analysis should be workable with the interpretation in which there are only underlyingly vowel-final forms.) For consistency, all data within this paper is adapted from Hume 1997, Hume 1998, and Hume et al. 1997.

2.1 Conditions for metathesis

Hume (1997, 1998) notes that metathesis happens in two environments. It can occur phrase-final or phrase-medially. Other phonological processes can happen simultaneously with metathesis.

Hume's (1998) analysis hinges metathesis on Leti constraints on syllable well-formedness. My analysis is agnostic to syllable well-formedness. Instead, I summarize four ways phrase-medial metathesis can occur between two morphemes:

First, when the first morpheme ends in a consonant and the second morpheme begins with a consonant cluster, as in (1):

(1) a. /ukar + ppalu/ → ukrappalu
finger + bachelor = 'index finger'

b. /maun + ppuna/ → maːnuppuna
bird + nest

cf:

c. /ukar + lavna/ → ukarlavna
finger + big = thumb

d. /urun + moa/ → urunmoa
breadfruit + Moa island

Second, when the first morpheme ends in a consonant preceded by a high vowel and the second morpheme begins with a vowel as in (2):

(2) a. /maun + ori-ori/ → maːn^{w}or^{j}ori
bird + buffalo

b. /rain + iskɔla/ → raːniskɔla
blouse + school

c. /urun + ipar/ → urnipra
breadfruit + slice

Third, when the first morpheme ends in a consonant and the second morpheme begins with a consonant followed by a high vowel as in (3):

(3) a. /ukar + muani/ → ukramwani
finger + man = 'middle finger'

b. /puɔras + liɔra/ → p^{w}ɔrsaljɔra
door + seaside

Fourth, when the first morpheme ends in a high vowel and the second morpheme begins with a single consonant as in (4):

(4) a. /rai + lavan/ → ral^{j}avna
land + to be big

b. /kkani + tani/ → kkant^{j}ani
plate + soil = 'earthenware plate'

cf:

c. /rai + aan/ → rajaːna
finger + big = thumb

d. /mutu + vnua/ → mutuvnua
people + country

Elsewhere, phrase-medial metathesis does not occur.

Phrase-final metathesis occurs when an underlyingly consonant-final form occurs phrase-finally. In this case, the final consonant always switches places with the vowel preceding it, as in (5).

(5) a. urnu ‘breadfruit’
cf. urun moa ‘breadfruot + Moa Island’

b. bubru ‘porridge’
cf. bubur vetra ‘porridge + maize’

c. βuːra ‘mountain’
cf. βuar lavna ‘mountain + big’

Metathesis marks phrase boundedness in Leti, with metathesized and non-metathesized words receiving different interpretations. For instance, in (6a), with each word in its own phrase, one has a simple declarative sentence. Its counterpart in (6b) with more metathesized components, a new sense appears.

(6) /na vali vatu la eni/
‘3s + turn + stone + go + sand’

a. {nvali} {vatu} {la} {eni}
‘He turns the stone to the beach.’

b. {nvalv^{y}atl^{w}a} {eni}
‘He somehow turns a stone to the beach.’

2.2 Processes on vowels

Because Leti has phonological processes that occur when two vowels appear side by side, when metathesis affects or creates an environment where there are two consecutive vowels, these other rules may also apply. In particular, metathesis interacts with compensatory vowel lengthening and the various ways that high vowels reduce: deletion, secondary articulation, and glide formation (Hume 1997).

Compensatory vowel lengthening occurs when a morpheme with two consecutive vowels undergoes metathesis, and the second of those two vowels switches positions with the otherwise final consonant. The first of the two vowels is then lengthened in its original position. This can be seen in (1b), (2a), (2b), and (4c).

Whenever a high vowel is adjacent to another vowel, the following happens to the high vowel:

(i) it deletes if the second vowel is also high, as in (2b) after metathesis.

(ii) it surfaces as a secondary articulation on the previous consonant if it ends up on the right edge of a morpheme, as in (2a) and (4a); or after a phrase-initial consonant such as in (3b) and (4b).

(iii) it surfaces as a glide word-internally otherwise, as in the second morphemes in (3a) and (3b).

Given the previous data, we can now begin generating a model of the metathesis in Leti using BMRS.

3 BMRS

BMRS, Boolean Monadic Recursive Schemes, as adapted from computational theories of mathematics, logic, and automata, have been proposed as a method of modeling phonological processes (Chandlee & Jardine 2021, Bhaskar et al. 2020). BMRS are structures defined by logical predicates in an `IF...THEN...ELSE` syntax. Each predicate is monadic because they each take a single argument from the input; Boolean, because each returns a value of either true ($\top$) or false ($\bot$); and can be recursive in that they can refer to output predicates in their evaluation. The result of any group of phonological processes is thus described by a set of BMRS functions: the input is the string from underlying forms, and the output is the solution of equations for each index in the input string.

For a further discussion on the computational formalism of BMRS, see Bhaskar et al. 2020; for a fuller picture of adapting BMRS for phonological modeling, including more examples of BMRS in action, see Chandlee & Jardine 2021. Here I will simply present an overview of the BMRS tools needed for the task at hand.

BMRS, particularly as used for phonological modeling, are built off the following ingredients:

(i) Monadic predicates $P(t)$, each taking a single term t and returning $\top$ or $\bot$. BMRS represents both input feature predicates and output feature predicates.

(ii) Terms t, which represent segments and boundaries at a given index point.

(iii) Indices x, a number that represents the position of an element on a string.

(iv) Predecessor function: If t is a term, $p(t)$ is the segment in the preceding index point; $p(t)$ is itself a term.

(v) Successor function: If t is a term, $s(t)$ is the segment in the succeeding index point; $s(t)$ is itself a term.

(vi) Expressions:

(a) $\top$ and $\bot$ are expressions.
(b) Any predicate $P(t)$ is an expressions.
(c) If X, Y, and Z are expressions, then `IF` X `THEN` Y `ELSE` Z is an expression.
(d) Nothing else.

(vii) An expression of the form `IF` X `THEN` Y `ELSE` Z is evaluated as such:

(a) If X is true, the value of Y is returned.
(b) If X is false, the value of Z is returned.

(viii) In an expression of the form `IF` X `THEN` $\top$ `ELSE` Z, X is called a *licensing structure.*

(ix) In an expression of the form IF X THEN $\bot$ ELSE Z, X is called a *blocking structure*.

The output string can be longer than the input string when the predicates are relativized over a copy set. That is, while there is only one output per index, each index has an output for each element in the copy set $\mathcal{C} = \{1, ...m\}$. For a copy set $\mathcal{C} = \{1, 2\}$, for example, there will be two output functions per index. The output string is then composed at each index point by taking the output of the first copy, then the output of the second copy, before moving onto the next index point.

To model Leti metathesis, I propose two copies of each segment in the output to account for the insertion aspect of metathesis. I will also use the following symbols: # will mark morpheme boundaries, while $\rtimes$ and $\ltimes$ will mark the beginning and the end of a phrase, respectively. Output functions will be marked with apostrophes, such as C_1' and V_2'.

To simplify the BMRS expressions, I will also define the conjunction and disjunction operators as such:

- $F(x)$ AND $G(x)$ = IF $F(x)$ THEN $G(x)$ ELSE $\bot$
- $F(x)$ OR $G(x)$ = IF $F(x)$ THEN $\top$ G(x) $\bot$

The following input and output feature functions will be relevant to the following analysis:

- [±syllabic] - to distinguish between vowels and consonants.
- [±consonantal] - to distinguish between glides and other consonants.
- Place features, specified for vowels: [±round], [±high], [±low].

Consonant features do not affect metathesis, so each consonant will be expressed as a function $C(x)$. In the output, this will be taken to mean all the consonant features at index x. Likewise, as a shorthand, $V(x)$ in the output represents all the vowel features at index x. I use these abstract functions in the interest of space; a full implementation of BMRS would expand these to represent individual features.

Finally, comments for the BMRS code will be provided in the footnotes throughout to facilitate explanation.

4 BMRS for Leti metathesis

Modeling BMRS in metathesis hinges on the nesting of licensing and blocking structures. Licensing structures will reflect conditions in which a phonological process applies, while block structures reflect conditions in which they cannot apply. The final ELSE in each function reflects an elsewhere condition. The interaction between these expressions between the first and second output copies intuitively expresses the different conflicting pressures of Leti phonology.

4.1 Phrase-final metathesis

I will begin with phrase-final metathesis as this has the simplest condition for triggering: if the final segment of a phrase is a consonant, it switches positions with the vowel it follows.

First, I define the function $pf(x) = \ltimes(s(x))$ to show explicitly that the target of metathesis is the phrase final consonant. A monadic predicate like $\ltimes(x)$ simply returns $\top$ if the element at index x is the boundary symbol $\ltimes$. So, $pf(x)$ returns $\top$ if the element in $s(x)$, the index that follows x, is the phrase edge $\ltimes$.

Then, I define the output functions such that when the $phrasefinal(x)$ condition is met, the consonant is instead output in the previous index. Then, the preceding vowel is output to the second copy of its original index to ensure that it appears right after the inserted consonant. This is achieved by adding blocking structures to each of the output functions:

$$\begin{aligned}
C_1'(x) &= \texttt{IF } pf(x) \texttt{ THEN } \bot^{1} \texttt{ ELSE} \\
&\quad\; \texttt{IF } pf(s(x)) \texttt{ THEN } C(s(x))^{2} \texttt{ ELSE } C(x)^{3} \\
V_1'(x) &= \texttt{IF } pf(x) \texttt{ AND } C(s(x)) \texttt{ THEN } \bot^{4} \\
&\quad\; \texttt{ELSE } V(x)^{5} \\
C_2'(x) &= \bot^{6} \\
V_2'(x) &= \texttt{IF } V_1'(x) \texttt{ THEN } \bot^{7} \texttt{ ELSE } V(x)^{8}
\end{aligned}$$

Table 3 gives the outcome of using the above BMRS to model phrase-final metathesis on the underlying form /urun/. This graphically illustrates how each of the boolean monadic functions works. For instance $C(x)$ returns $\top$ for index 2, because r is a consonant; $\rtimes(x)$ returns $\top$ for index 5 because this marks the phrase boundary; $pf(x)$ returns $\top$ for index 4 because it is the index at the end of the phrase before the phrase boundary.

Also, highlighted on that table are the cells for the output functions to illustrate which segments

[1] The blocking structure here prevents any phrase-final consonants from surfacing phrase-finally.

[2] This outputs the consonant features from the input phrase-final consonant into the output pentultimate index instead.

[3] Elsewhere, this just outputs the consonant at its input position.

[4] This blocks the vowel before phrase-final consonants from surfacing before that consonant.

[5] This outputs the vowel features from x elsewhere.

[6] The second consonant copy is not needed yet.

[7] If a vowel is in the first copy output, this means it is not involved in metathesis. We won't need this second vowel copy.

[8] If a vowel *is* involved in metathesis, it gets output here.

surface in the output. Note that in index 3, both of the segments end up being output in the same index, but the metathesized consonant is output in the first copy C'_1, while the metathesized vowel is output in the second copy V'_2. As mentioned, first copies get linearized before second copies, which ensures the correct surface form.

Input:	u	r	u	n	⋊
x	1	2	3	4	5
$C(x)$	⊥	⊤	⊥	⊤	⊥
$V(x)$	⊤	⊥	⊤	⊥	⊥
⋊(x)	⊥	⊥	⊥	⊥	⊤
$pf(x)$	⊥	⊥	⊥	⊤	⊥
$C'_1(x)$	⊥	⊤	⊤	⊥	⊥
$V'_1(x)$	⊤	⊥	⊥	⊥	⊥
$C'_2(x)$	⊥	⊥	⊥	⊥	⊥
$V'_2(x)$	⊥	⊥	⊤	⊥	⊥
Output:	u	r	n u		

Table 3: /urun/ → urnu 'breadfruit'

4.2 Phrase-medial metathesis

We can extend the phrase-final BMRS to also account for phrase-medial metathesis. In the previous BMRS functions, $pf(x)$ was the only condition blocking the metathesized consonant from surfacing in its original index location. The next step would then be to add the conditions for phrase-medial metathesis. In cases (1) through (4) in Section 2.1, just like in the case for phrase-final metathesis, the metathesized consonant does not surface at its input index, but instead at the previous input index. Instead of $pf(x)$, we can thus define a function that takes all of the environments where metathesis occurs into consideration. To recap, phrase-medial metathesis occurs:

(7) a. when the first morpheme ends in a consonant and the second morpheme begins with a consonant cluster, as in (1): C#CC;

b. when the first morpheme ends in a consonant preceded by a high vowel and the second morpheme begins with a vowel as in (2): [+high]C#V;

c. when the first morpheme ends in a consonant and the second morpheme begins with a consonant followed by a high vowel as in (3): C#C[+high];

d. when the first morpheme ends in a high vowel and the second morpheme begins with a single consonant as in (4): [+high]#CV.

For the first three of these, the consonant involved in metathesis is the last consonant of the first morpheme in the pair. These first three conditions can be reflected in the following function:

$metC(x)$ = IF $C(x)$[9] THEN $pf(x)$[10]
OR ($\#(s(x))$ AND[11]
($C(s(s(x)))$ AND $C(s(s(s(x))))$) OR[12]
$[+\text{high}](p(x))$ AND $V(s(s(x)))$ OR[13]
$C(s(s(x)))$ AND $[+\text{high}](s(s(s(x))))$[14])
ELSE ⊥

The case in (7d), however, involves metathesis across word boundaries. It will get its own shorthand function because there is a different environment for insertion, as this case will have to be called separately at that index:

$mwbC(x)$[15] $=((V(s(x))$ AND $\#(p(x)))$
AND $[+high](p(p(x))))$

Now that these two functions are defined, we can add them to the blocking structures in the output function $C'_1(x)$:

$C'_1(x)$ = IF $metC(x)$ OR $mwbC(x)$ THEN ⊥[16]
ELSE IF $metC(s(x))$ THEN $C(s(x))$[17]
ELSE IF $mwbC(s(s(x)))$ THEN $C(s(s(x)))$[18]
ELSE $C(x)$[19]

The vowel output functions will also have to take these cases into consideration; the vowels involved in metathesis must emerge in the second copy V_2 and not the first copy V_1 in order to take a linear position after the metathesized consonant.

$V'_1(x)$ = IF $metC(s(x))$ OR $mwbC(s(s(x)))$
THEN ⊥ ELSE $V(x)$
$V'_2(x)$ = IF $V'_1(x)$ THEN ⊥ ELSE $V(x)$

[9] Metathesize the consonant at x if...
[10] it is phrase final, OR...
[11] if it is word final AND...
[12] the second morpheme begins with a consonant cluster as in (7a) OR...
[13] it is preceded by a high vowel and the second morpheme begins with a vowel as in (7b) OR...
[14] the second morpheme begins with a consonant followed by a high vowel as in (7c).
[15] This stands for '**m**etathesize across **w**ord **b**oundaries'.
[16] If the consonant is involved in metathesis, block the consonant from surfacing at its original index. Otherwise...
[17] ...if we're in cases (6a), (6b), or (6c), that consonant surfaces in the preceding index.
[18] Or if we're in case (6d), that consonant surfaces in the index that precedes the preceding index.
[19] Elsewhere, just output the consonant.

So far, the functions we have defined are sufficient to describe the cases where all the vowels are unchanged except for the fact that they are output after the metathesized consonant. This reflects case (1a), illustrated in Table 4.

Input:	u	k	a	r	#	p	p	a	l	u
x	1	2	3	4	5	6	7	8	9	10
$C(x)$	$\bot$	$\top$	$\bot$	$\top$	$\bot$	$\top$	$\top$	$\bot$	$\top$	$\bot$
$V(x)$	$\top$	$\bot$	$\top$	$\bot$	$\bot$	$\bot$	$\bot$	$\top$	$\bot$	$\top$
$\#(x)$	$\bot$	$\bot$	$\bot$	$\bot$	$\top$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$
$metC(x)$	$\bot$	$\bot$	$\bot$	$\top$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$
$C'_1(x)$	$\bot$	$\top$	$\top$	$\bot$	$\bot$	$\top$	$\top$	$\bot$	$\top$	$\bot$
$V'_1(x)$	$\top$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\top$	$\bot$	$\top$
$C'_2(x)$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$
$V'_2(x)$	$\bot$	$\bot$	$\top$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$
Output:	u	k	r a			p	p	a	l	u

Table 4: /ukar + ppalu/ → ukrappalu 'breadfruit'

The rest of the cases, however, involve various vowel processes that need to be accounted for in the BMRS.

4.3 Accounting for vowel processes

In Section 2.2, I outlined a number of various vowel processes that interact with metathesis. We can account for these in the BMRS with a few modifications.

First, to account for compensatory vowel lengthening, I observe that this only occurs phrase-medially after metathesis within a VVC#CC pattern and phrase-finally after metathesis within a VVC⋊ pattern. I propose that the first vowel in the pair gets output to both copies at its index; being output twice reflects lengthening. This environment can be translated into BMRS as follows:

$$lv(x) \;=\; metC(s(s(x)))\ \texttt{AND}\ V(s(x))$$

And we can insert this into the vowel output function as follows:

$$\begin{aligned} V'_2(x) \;=\; & \texttt{IF}\ lv(x)\ \texttt{THEN}\ V(x)^{20} \\ & \texttt{ELSE IF}\ V'_1(x)\ \texttt{THEN}\ \bot^{21} \\ & \texttt{ELSE}\ V(x)^{22} \end{aligned}$$

Table 5 shows how this applies to the case of (1b).

Next, we must account for environments like (2b) and (2c), where two high vowels would end up adjacent after metathesis. This environment can be generalized as one where metathesis has

[20] This licenses a second copy of the vowel and outputs those vowel features.

[21] Nothing is output in V_2 when there is no long vowel environment and the vowel is not involved in metathesis.

[22] The V_2 copy will only surface if it is involved in metathesis.

Input:	m	a	u	n	#	p	p	u	n	a
x	1	2	3	4	5	6	7	8	9	10
$C(x)$	$\bot$	$\bot$	$\bot$	$\top$	$\bot$	$\top$	$\top$	$\bot$	$\top$	$\bot$
$V(x)$	$\top$	$\top$	$\top$	$\bot$	$\bot$	$\bot$	$\bot$	$\top$	$\bot$	$\top$
$\#(x)$	$\bot$	$\bot$	$\bot$	$\bot$	$\top$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$
$metC(x)$	$\bot$	$\bot$	$\bot$	$\top$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$
$lv(x)$	$\bot$	$\top$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$
$C'_1(x)$	$\top$	$\bot$	$\top$	$\bot$	$\bot$	$\top$	$\top$	$\bot$	$\top$	$\bot$
$V'_1(x)$	$\bot$	$\top$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\top$	$\bot$	$\top$
$C'_2(x)$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$
$V'_2(x)$	$\bot$	$\top$	$\top$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$
Output:	m	a a	n u			p	p	u	n	a

Table 5: /maun + ppuna/ → maːnuppuna 'bird's nest'

occurred within a [+high]C#[+high] sequence. To make sure that the [+high] vowel before the metathesized consonant does not surface in either copy at that index, we will need to add a a blocking structure to V'_2.

$$\begin{aligned} V'_2(x) \;=\; & \texttt{IF}\ lv(x)\ \texttt{THEN}\ V(x) \\ & \texttt{ELSE IF}\ V'_1(x)\ \texttt{THEN}\ \bot \\ & \texttt{ELSE IF}\ metC(s(x)) \\ & \texttt{AND}\ [+high](x)\ \texttt{AND}\ [+high](s(s(s(x)))) \\ & \texttt{THEN}\ \bot^{23} \\ & \texttt{ELSE}\ V(x) \end{aligned}$$

Table 6 shows how this applies to (2c).

Input:	u	r	u	n	#	i	p	a	r	⋊
x	1	2	3	4	5	6	7	8	9	10
$C(x)$	$\bot$	$\top$	$\bot$	$\top$	$\bot$	$\bot$	$\top$	$\bot$	$\top$	$\bot$
$V(x)$	$\top$	$\bot$	$\top$	$\bot$	$\bot$	$\top$	$\bot$	$\top$	$\bot$	$\bot$
$\#(x)$	$\bot$	$\bot$	$\bot$	$\bot$	$\top$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$
$⋊(x)$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\top$
$metC(x)$	$\bot$	$\bot$	$\bot$	$\top$	$\bot$	$\bot$	$\bot$	$\bot$	$\top$	$\bot$
+high(x)	$\top$	$\bot$	$\top$	$\bot$	$\bot$	$\top$	$\bot$	$\bot$	$\bot$	$\bot$
$C'_1(x)$	$\bot$	$\top$	$\top$	$\bot$	$\bot$	$\bot$	$\top$	$\top$	$\bot$	$\bot$
$V'_1(x)$	$\top$	$\bot$	$\bot$	$\bot$	$\bot$	$\top$	$\bot$	$\bot$	$\bot$	$\bot$
$C'_2(x)$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$
$V'_2(x)$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\bot$	$\top$	$\bot$	$\bot$
Output:	u	r	n			i	p	r a		

Table 6: /urun + ipar/ → urnipra 'breadfruit slice'

In the interest of space, I will summarize what must be done to account for the last two vowel processes in the BMRS aside from the appropriate licensing and blocking structures for the environments in which they occur:

In the case of high vowels that surface as a secondary articulation on the previous consonant, such as in (2a) and (3b), I suggest that these vowels are output at the same index and the same copy as that previous consonant. So, both C'_1 and V'_1

[23] This blocks V'_2 from surfacing when it is the first [+high] vowel in a [+high]C#[+high] sequence.

will be true in the same index for these instances. This dual input at the same index in the same copy intuitively captures the idea of a secondary articulation.

As for underlying high vowels that surface as a glide, as in (3a) and (3c), I propose that these vowels are output as consonants. The appropriate blocking structures would appear in both V_1' and V_2', and C_1' would include a condition that allows for the output of the vowel features as a consonant.

To sum up this section, BMRS can describe metathesis and vowel processes in Leti using two output copies. The only time a consonant does not output in its original index position is if this consonant is involved in metathesis, instead surfacing in the previous index. As for vowels, the combination of blocking and licensing structures in the two vowel copies reflects when vowels are moved because of metathesis, surface as a glide or secondary articulation, or deleted entirely. The conditions for all of these processes are systematic and regular, and only involve analyses on the individual segments in each form in question. While seemingly complex in form because of the numerous phonological processes involved, the attested outputs are reached through a application of simple Boolean logic.

5 Advantages of BMRS

BMRS, through various applications of blocking and licensing structures, elegantly captures metathesis and the other phonological processes on vowels in Leti as simultaneous applications of processes of deletion and insertion on segments. This is more intuitive and less complex than Optimality Theory or Derivational/Rule-based accounts. BMRS also makes explicit that metathesis is a strictly local process (Chandlee 2014).

One advantage of this BMRS analysis is that it can easily account for other processes in terms of metathesis. For instance, Hume (1998) does not consider situations such as (2c) as involving metathesis, instead analyzing this as a consequence of two unrelated syllable-level processes: the avoidance of onsetless syllables, and a ban on phrase-medial open syllables containing the last vowel of a morpheme.

(2c)	/urun	+ ipar/	→ *ur.nip.ra*
	breadfruit	+ slice	

Simply concatenating both morphemes together would produce the unattested form **u.ru.nip.ra* that does not have any onsetless syllables. However, syllabification would leave the second /u/ in *urun*, the final vowel in that morpheme, in a now phrase medial open syllable. Thus, according to the analysis in Hume (1998), that /u/ deletes. By analyzing this as metathesis, however, these stipulations on syllable structure are unnecessary. Instead, it is readily apparent that what is happening in (2c) is a case of output-adjacent high vowels deleting.

Hume's (1998) analysis also hinges on other syllable-level processes. For example, in her account, compensatory vowel lengthening is explained as the insertion of a mora to accommodate the metathesized vowel's new position, but this metathesized vowel leaves a mora behind in its original place. This adds another layer of complexity that BMRS does away with. Because the segmental environments for metathesis and compensatory vowel lengthening are both completely regular and predictable with respect to the other processes in the language, BMRS only need to consider the properties of each segment to give the attested outputs. This does not discount, of course, the fact that phonological processes can apply on syllables; BMRS is also able to handle these where it is needed, but I leave a specific implementation to future work.

Additionally, the Hume (1997, 1998) analysis of metathesis and vowel reduction/preservation with Optimality Theory relies on the constraint LINEARITY, defined below in (8).

(8) LINEARITY: "No Metathesis" S_1 is consistent with the precedence structure of S_2 and vice versa. (McCarthy and Prince 1995)

However, LINEARITY adds complexity and the potential for an analysis that overgenerates (see Heinz 2005, Carpenter 2002). An OT account would have to considering gradience (e.g. Hume 1998, 2001) or resort to adaptations of OT like Harmonic Serialism (Takahashi 2018).

Solutions for this, as well as opaque interactions of processes, are known problems of classic OT, but they are all built into the inherently recursive system of BMRS: output functions can look at other output functions.

As an example of how LINEARITY overgenerates in the case of Leti, I present the tableau in Table 7, adapted from Hume 1998.

Each constraint proposed in this tableau in Hume (1998) rules out candidates (a) through (d): ONSET rules out the candidate provided for by simple concatenation; *COMPLEX eliminates candidates with syllables with consonant clusters such as in (b); MAX-V rules out deletion of the vowel in (c); *COMPSEG rules out the situation where the vowel becomes a secondary articulation on the consonant as in (d).

The CRISPEDGE constraint is motivated by cases where there is no metathesis, such as (9). As a consequence of syllabification, candidates with metathesis like (9b) will always violate

	ukar + muani	*Complex[24]	Max-V[25]	Onset[26]	*CompSeg[27]	CrispEdge[28]	Linearity
	a. u.kar.mu.a.ni			*!			
	b. u.kar.mwa.ni	*!					
	c. u.kar.ma.ni		*!				
	d. u.kar.m^{w}a.ni				*!		
☹	e. uk.ram.wa.ni					*	*
💣	f. u.kar.maw.ni						*
	g. uk.ra.maw.ni						**
	h. uk.ra.man.wi						***

Table 7: OT tableau for /ukar + muani/ → uk.ram.wa.ni 'index finger', adapted from Hume 1998. Candidates (a) through (e) are from Hume 1998. Candidate (e) is attested, but I present candidates (f), (g), and (h), which do not violate CrispEdge and are thus more optimal.

CrispEdge. The attested form in (9a), however, while it also violates CrispEdge, will not violate Linearity.

(9) a. /lopu + mderi/ → *lo.pum.de.ri*
dolphin + Mderi 'Mderian dolphin'

b. */lopu + mderi/ → *lop.mu.de.ri*

The problem in Table 7 is thus apparent: Candidate (f), in which metathesis occurs entirely within the second morpheme, does not violate CrispEdge at all, and should thus surface as optimal. I also present Candidates (g) and (h), which include even more instances of linear reorganization of segments fully contained within each morpheme: these are still more optimal than the attested candidate (e).

Hume's (1998) solution to this involves another constraint that is proposed as ranking higher than CrispEdge, O-Contiguity-V:

(10) O-Contiguity-V: A contiguous string in the input may not be separated by a vowel in the output. (Hume 1998, adapted from McCarthy and Prince 1995)

This is intended to rule out Candidate (f) in Table 7 as the /a/ in the second morpheme comes in between the /m/ and /w/. The claim is that the /a/ in Candidate (e) does not disrupt output-contiguity by being in between the morphemes. How contiguity applies in the space between two input morphemes is not specified in McCarthy and Prince (1995), and would thus have to be worked out before being implemented. BMRS, on the other hand, already takes word boundaries into account in the underlying representation and thus the conditions for metathesis.

To sum up, this section showed that other accounts of Leti metathesis may introduce more complexity than is necessary to explain the phenomenon, either through the introduction of stipulative syllable-level processes or overly-powerful constraints on linear order.

6 Conclusion

A carefully constructed set of BMRS, with the appropriate blocking and licensing structures, as well as two output copies, can intuitively account for the environments and processes that are involved in Leti metathesis. BMRS also captures the interaction of metathesis with other phonological processes, even ones that are opaque, because BMRS is inherently recursive. Essentially, all the processes involved can simply be reduced to something akin to deletion and insertion, all applied simultaneously. The analysis also shows how metathesis is regular, pervasive, and productive in Leti, which shows that it is a process that should be and can be captured solely within the confines of phonology. BMRS can elegantly resolve the problems and unnecessary complexities from OT and its implementations.

This analysis, however, hinges on those previously done for Leti in Hume 1997, Hume 1998, and Hume et al. 1998, where numerous assumptions are made in order for the data to specifically be workable within an OT framework. Most significant, perhaps, is the assumption that metathesis only occurs with words that are underlyingly consonant final. However, other analyses of Leti, such as van der Hulst and van Engelenhoven 1995, make a different assumption, instead positing that all Leti morphemes are underlyingly vowel final. Or, perhaps, there could be no restriction after all on which type of segments these underlying forms must end with. Testing these with BMRS could be enlightening; these assumptions may not be neces-

[24] *Complex: tautosyllabic consonant clusters are prohibited (Prince & Smolensky 1993 in Hume 1998).

[25] *Max-V: a vowel in the input has a correspondent in the output.

[26] Onset: a syllable has an onset.

[27] CompSeg: a segment may not have more than one place specification (Padgett 1995 in Hume 1998)

[28] CrispEdge: Morpheme and syllable boundaries are aligned (Itô & Mester 1994 in Hume 1998)

sary after all if BMRS can fully account for the environments and processes involved with metathesis in Leti without them.

Along the lines of Chandlee & Jardine (2021) showing BMRS case studies with length and stress interactions in Hixkaryana, Elsewhere Condition effects, and the typology of *NC̥ effects, one hope this author has with this paper is that it builds more interest in the application of BMRS to phonological analyses, particularly in languages with typologically rare features and opaque phonological interactions.

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