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Rhythmic Syncope in Subregular Phonology

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Abstract Rhythmic syncope describes the deletion of vowels in an alternating rhythmic pattern, so that every other underlying vowel deletes. We informally summarize a proof that rhythmic syncope cannot be represented by a strictly local function over segments. Rather, rhythmic syncope can only be generated by a strictly local function if input and output symbols are synchronized, so that locality can be computed over both the input and output value at a particular time step. This structural property may only be needed to describe rhythmic syncope, which means that before concluding that human phonology can compute such functions, it is essential to verify the extent to which rhythmic syncope is attested as a stable and productive synchronic pattern.

1 Introduction

Rhythmic syncope, sometimes called *metrically conditioned syncope*, describes the deletion of vowels in an alternating pattern reminiscent of metrical stress. While the program of subregular phonology has argued that phonological patterns can be unified by various formal notions of locality (Heinz 2018), in this paper we show that rhythmic syncope is not subsumed by the formal devices hitherto proposed in that literature. To that end, we provide phonologists with an informal summary of our proof, appearing in Hao and Bowers (2019), that rhythmic syncope falls outside the class of *tier-based input–output strictly local* functions, a restrictive subclass of the finite-state functions that has been proposed as a tight characterization of all segmental phonological processes as well as certain suprasegmental ones (Chandlee 2014, Chandlee et al. 2015, 2018a). To account for rhythmic syncope, we propose a new notion of locality that allows input and output segments to be *synchronized*, so that locality can be computed in terms of the individual segment-to-output mappings that comprise a phonological transformation. Ordinarily, the fact that synchronization allows rhythmic syncope to be generated in subregular phonology would be evidence that this formal machinery is part of phonological competence. However, Bowers (2019) has shown that rhythmic syncope may be acutely unstable, bringing into question the necessity for a descriptively adequate theory of phonology to account for this phenomenon. We conjecture that synchronization distinguishes rhythmic syncope from all other phonological processes, in which case rhythmic syncope may be prone to restructuring because synchronization is in fact *not* part of phonological competence.

Rhythmic syncope is a natural endpoint for unstressed vowel reduction in an iterative stress system.[1] Schematically, the progression is that unstressed vowels shorten until they are perceived to be absent, at which point a deletion grammar would presumably be induced by learners. For instance, a language might start with full vowels in weak positions, as [(ʌˈnɪ)(ʃɪˈnaː)(ˈbɛː)(mʊˈwɪn)] ‘Nishnaabemwin language’ (Baraga 1850 [1878], Valentine 1994). This could then progress to reduction as in [(əˈnɪ)(ʃəˈnaː)(ˈbɛː)(məˈwɪn)] (Sapir 1912, in Rhodes 2008), before attaining still stronger reduction as in [(ᵊˈnɪ)(ʃᵊˈnaː)(ˈbɛː)(mᵊˈwɪn)] (Bloomfield 1957), at which point the reduced vowels could be perceived as absent, as in [nɪʃnaːbɛːmwɪn]. Once reduced vowels are perceived as absent, the stage is set for learners to induce a rhythmic syncope grammar with a categorical deletion process. Whether or how often rhythmic syncope is actually acquired from this stage is a topic of ongoing research; see Bowers (2019).

Postponing the question of the stability of rhythmic syncope for now, rhythmic syncope crucially features an alternating deletion pattern, where underlying vowels alternate between being deleted and surfacing faithfully. In concert with appropriate morphology, this alternating pattern can make a tell-tale ‘ripple effect’ in paradigms, where the addition of an affix at the starting edge for stress assignment can cause refooting across the word, thus resulting in a radically different set of

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[1]Precisely which vowels delete depends on a variety of factors, corresponding to the different types of rhythmic stress (see Hayes 1995 for a typology of rhythmic stress).

vowels to be realized in different forms. For instance, consider the following alternations from the stage of Nishnaabemwin where reduction was perceived as absence.

(1)	‘If he rolls him’	‘I roll him’	
	/gʊtɪgʊmɪnʌgɪbɪn-aː-d/	/nɪ-gʊtɪgʊmɪnʌgɪbɪn-aː/	UR
	(gʊ.ˈtɪ)(gʊ.ˈmɪ)(nʌ.ˈgɪ)(bɪ.ˈnaːd)	(nɪ.ˈgʊ)(tɪ.ˈgʊ)(mɪ.ˈnʌ)(gɪ.ˈbɪ)(ˈnaː)	Iambic footing
	(gᵊ.ˈtɪ)(gᵊ.ˈmɪ)(nᵊ.ˈgɪ)(bᵊ.ˈnaːd)	(nᵊ.ˈgʊ)(tᵊ.ˈgʊ)(mᵊ.ˈnʌ)(gᵊ.ˈbɪ)(ˈnaː)	Severe Reduction
	[gtɪgmɪngɪbnaːd]	[ngʊtgʊmnʌgbɪnaː]	SR (Perceived)

Note that the term ‘rhythmic syncope’ does not cover all cases where unstressed vowels are lost. It is quite common for vowels in an individual weak prosodic environment to be dropped. For instance, Western Romance languages lost the post-tonic syllable from Latin (Latin *dominicus* *[do.ˈmi.ni.kus] > Spanish *domingo* [do.miŋ.go] ‘Sunday’, Latin *camera* *[ˈka.me.ɾa] > French *chambre* [ʃãmbʀə] ‘room’), and synchronically active syncope targeting (ante)-penultimate or (post)-peninitial syllables is reported (see McCarthy 2008:522–526 for an overview). These cases do not feature the simultaneous loss of vowels in an alternating pattern, and so do not require the synchronized strictly local functions described below.

1.1 Rhythmic Syncope in Phonological Theory

Rhythmic syncope differentiates Classical Optimality Theory (OT, Prince and Smolensky 2004 [1993]) from so-called serialist approaches to phonology, like *SPE*-style rules (Chomsky and Halle 1968) or Harmonic Serialism (McCarthy 2008). The serialist models of phonology are able to generate rhythmic syncope by setting up a grammar where unstressed vowel deletion is ordered after iterative stress (see subsection 2.3). Parallelist models of phonology have difficulty generating rhythmic syncope, and have resorted either to claiming that deleted vowels are unpronounced, but still present in the output (Kager 1997), or to relying on mechanisms such as those proposed by Blumenfeld (2006; see McCarthy 2008:527–536 for detailed remarks).

Our goal is to elucidate this theoretical dichotomy by identifying fundamental mathematical properties of the rhythmic syncope mapping. While clearly not a-theoretical, the approach here is independent of the mechanisms and proposals of any one particular phonological theory. Anticipating the main results, the intuitive rationales for the ability or failure to generate rhythmic syncope hold up fairly well. In the case of OT, changes from the input can only be compelled by constraints on outputs, so the theory lacks the ability to identify the necessary local configuration of input–output pairs (see subsection 2.1).[2]

In the case of serial theories of phonology, the ability to compute a synchronized strictly local mapping is a consequence of these theories making use of serialism, which is equivalent to the formal operation of function composition (see subsection 2.3). Strictly local maps are not closed under composition (Sakarovitch 2004, 2009:664; see also Chandlee 2014, Chandlee et al. 2018b, and Chandlee and Lindell in press), meaning that even if a process may be decomposed into several strictly local components, the overall transformation may not be strictly local. That is, if processes in a grammar are allowed to be ordered, the grammar as a whole may not respect the widely assumed restriction that mappings generally pay attention to local environments. In a serialist model of phonology, the non-strictly-local rhythmic syncope mapping emerges when an OSL function over segments (footing) is composed with a homomorphism (deletion).

It is important to note that although a serial derivation with decomposed intermediate processes superficially looks distinct from a direct input–output mapping, they are in fact the same formal objects. In terms of diagnosing the complexity of rhythmic syncope, it makes no sense to speak of synchronized strictly local maps as if they are an alternative to composition of footing and deletion. The mappings they produce are one and the same.

[2]Interestingly, OT does synchronize inputs and outputs while calculating faithfulness violations. The theory thus makes use of a computational device that ultimately does not appear in the phonological mappings it generates.

2 Formal Properties of Rhythmic Syncope

Since Johnson (1972) and Kaplan and Kay (1994), it has been accepted that phonological computation requires no more complexity than that afforded by finite-state machines. Finite-state machines are models of computation whose memory, or *state*, can only have finitely many possible configurations. For example, Figure 1 shows a finite-state transducer (FST) that implements rhythmic syncope. The FST reads an underlying representation (UR) one segment at a time, incrementally building the surface representation (SR). After seeing each segment of the UR, the FST may append an output symbol to the end of the SR before changing the state of its memory.

More recent work has pursued the subregular hypothesis (Heinz 2018), which states that phonology can be described with finite state machines obeying additional restrictions. The most restrictive of these models are the strictly k-local (k-SL) machines, which describe local phonotactic constraints. These machines belong to a family of models known as finite-state automata (FSAs). FSAs are similar to FSTs, except that they take an SR as input and simply decide whether the SR is phonotactically legal. During the computation of a k-SL FSA, each state represents the $k-1$ previous segments of the SR seen by the machine. In the case of non-local dependencies, tier-based strictly k-local (k-TSL, Heinz et al. 2011) FSAs enhance the k-SL ones by allowing a subset of the phonetic inventory—say, vowels—to be projected to a tier where consonants are excluded, so that vowels are local to each other on the tier, regardless of how many consonants intervene in the full string.[3]

Whereas SL and TSL FSAs describe local phonotactic constraints, possibly stated over tiers, analogous classes of FSTs have been proposed to capture UR–SR mappings. Strictly local FSTs are those whose states record the $k-1$ previous symbols encountered. Because strictly local FSTs are functions, at any point during the computation, the information in the window determines exactly one mapping for the current input symbol. Strictly local FSTs are divided according to whether they track only UR symbols (Chandlee 2014), SR symbols (Chandlee et al. 2015), or both UR and SR symbols (Chandlee et al. 2018a). These three classes are called input strictly k-local (k-ISL), output strictly k-local (k-OSL), and input–output strictly k-local (k-IOSL), respectively. As is the case with SL and TSL FSAs, a substantial amount of phonological processes can be modeled with ISL, OSL, and IOSL FSTs, and non-local dependencies can be captured using tier-based strictly local FSTs that are similarly sensitive to inputs, outputs, or both (see Heinz and Lai 2013, McCollum et al. 2018, Hao and Andersson 2019, and Hao and Bowers 2019). Because rhythmic processes are only sensitive to vowels or syllables, tier-based machines will allow us to bypass consonants when necessary. Notice that Figure 1 has such a bypass mechanism: reading a consonant does not cause the FST to change state.

In this section, we ask whether FSTs can generate rhythmic, alternating deletion while the states are constrained to represent only a fixed local window of input and output symbols at the end of the vowel tier. Section 2.1 shows that rhythmic syncope cannot be computed this way. Section 2.2 shows that if input and output segments are synchronized, so that the states record what an input segment was mapped to (i.e., an *action*), then rhythmic syncope can be generated by referring only to the most recent action. That is, rhythmic syncope is not tier-based strictly local, but it is tier-based *synchronized* strictly local. Section 2.3 shows how synchronization can result from the composition of non-synchronized strictly local functions.

2.1 Rhythmic Syncope is not TIOSL

Represented as a function mapping URs to SRs, rhythmic syncope does not adhere to the definition of locality used in standard strict locality. The action taken by a TIOSL FST at any particular point in computation is completely determined by the contents of the length-$(k-1)$ window at the end of all the input and output segments seen so far. Here, we informally show that when the length-$(k-1)$ window eventually fills up, a k-TIOSL FST must fail to determine whether or not to delete a vowel

[3] See Graf (2017), Baek (2018), Mayer and Major (2018), and Graf and Mayer (2018) for further extensions of TSL FSAs.

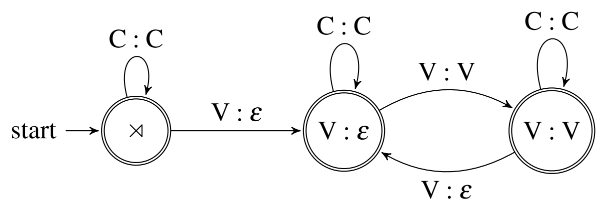

Figure 1: Rhythmic syncope as a finite-state transducer (FST). Each circle represents a possible state of the FST's memory. Arrows connect each state to a possible next state, and their labels represent what symbol is written to the output when an input symbol is encountered. Input and output symbols are on the left and right of colons, respectively. State labels correspond to the most recent input–output pair on the vowel tier. The empty string is represented by ε and the left word edge is represented by ⋊.

according to the alternating rhythmic syncope pattern. See Hao and Bowers (2019) for a formal proof.

Suppose that rhythmic syncope could be computed by a TIOSL FST. An FST that attempts to implement rhythmic syncope must read its input, delete some of the vowels of the UR, and copy all other segments to the SR. This can be carried out for a while, but a problem arises when the window of scanned segments fills up. At that point, if there are still vowels left to scan, the same combination of input and output symbols must condition different actions, thus violating the definition of a function and failing to reproduce the rhythmic syncope pattern.

This is illustrated for $k = 4$ in Table 1 with the input /badupilakone/. Each row of the table corresponds to a step of the derivation as the FST consumes the input and writes the output. The 'current action' column specifies whether a vowel must be deleted or preserved. The second and third columns track the $4-1=3$ most recent input and output symbols, which form the conditioning environments for actions. Note that because deletion involves not writing anything to the output, the output buffer accumulates nothing on the row after a deletion step. Up until the fourth row, each conditioning environment is associated with only one action, but in the last two rows, different actions must be triggered by the same conditioning environment. The alternating deletion pattern of rhythmic syncope is thus beyond what can be represented with a TIOSL FST.

Index	Recent Inputs	Recent Outputs	Current Action	/badupilakone/ → []
1	—	—	V : ε	b_
2	V	—	V : V	b_du
3	VV	V	V : ε	b_dup_
4	VVV	V	V : V	b_dup_la
5	VVV	VV	V : ε	?
6	VVV	VV	V : V	?

Table 1: An attempted rhythmic syncope derivation with a 4-TIOSL FST. Underscores mark omitted vowels for visual clarity but are not properly part of the output string.

Since we do not assume an upper bound on word length, there is always an overly long lexical item for which any strictly local mapping will fail to provide the correct alternating deletion pattern. One could object that human language lexicons are in fact finite, and that k could simply be increased to span the longest vocabulary item. While it is true that any set of linguistic observations can be captured with a sufficiently large list (or in our case, with a sufficiently large value of k), it is standard to assume that interesting linguistic phenomena are patterns that extend beyond a finite corpus. We assume that alternating deletion is such a potentially interesting pattern, and so we must be concerned with capturing deletion in a way that generalizes to indefinitely long strings.

A further objection to an attempted strictly local implementation of rhythmic syncope is that phonological theory maintains that there should be an underlying unity between the environments that condition a change, as well as a connection between the environments and the change itself. However, the varying configurations of input and output vowels in standard strictly local implementations do not satisfy this. There is no apparent reason why having scanned two input vowels and one output vowel should condition deletion, let alone why three input vowels and two output vowels should do so as well.

2.2 Strictly Local over Actions

The central problem for a standard strictly local representation of rhythmic syncope is that the deletion operation writes nothing to the output. Under the standard definition, a tier-based strictly local FST can only refer to what is present in the UR or the SR, and so with deletion writing nothing, there is no way to discern whether or not the FST performed a deletion at the previous time step. In this section, we enhance TIOSL FSTs to allow states to record length-$(k-1)$ windows of prior input–output *pairs*, thereby directly tracking actions taken by the FST. These pairs associate each of the $k-1$ most recently seen segments of the UR with their corresponding segments in the SR. We call such FSTs *tier-based synchronized strictly k-local functions* (k-TSSL), since they rely on aligning input–output pairs. Observe that Figure 1 is a 2-TSSL FST, since the states record the $2-1=1$ most recent action on the vowel tier (copying a vowel or deleting a vowel). A sample derivation is shown in Table 2.

Index	$k-1$ actions	Current action	/badupilakone/ → []
1	—	V : ε	b_
2	V : ε	V : V	b_du
3	V : V	V : ε	b_dup_
4	V : ε	V : V	b_dup_la
5	V : V	V : ε	b_dup_lak_
6	V : ε	V : V	b_dup_lak_ne

Table 2: A 2-TSSL derivation of rhythmic syncope. Underscores mark omitted vowels for visual clarity but are not properly part of the output string.

Most importantly, in a synchronized strictly local approach, the decision of whether to delete or keep a vowel is determined by consistent factors. That is, a vowel is kept when the previous action was to delete, and a vowel is deleted when the previous action was to preserve a vowel. This pattern can clearly continue indefinitely for strings of arbitrary length.

Furthermore, TSSL FSTs have a degree of linguistic naturalness. The performance of an action at any point is tied to the opposite value of that action, which is reminiscent of the alternating unstressed–stressed pattern of rhythmic stress. This is clearly superior to TIOSL FSTs, which, even if their failure to generate rhythmic syncope for any input could be overlooked, require conditioning deletion or preservation on arbitrary amalgamations of input and output segments.

However, the explicit ability of synchronized strictly local functions to condition processes on both the input and the output value of a segment obviously predicts likely unattested phonological processes. While synchronization may pre-theoretically be used as a shorthand for opaque or non-surface-true processes in informal discussions, theoretical phonology has generally confined itself solely to output markedness conditions in Optimality Theory (Prince and Smolensky 2004 [1993]), or in the case of *SPE*-style rewrite rules (Chomsky and Halle 1968), to configurations on a single level of representation. Whether synchronization is necessary for other phonological processes merits further attention.

2.3 Action Sensitivity via Ordering

While individual processes have been traditionally formalized without synchronizing inputs and outputs, if segmentally local processes are ordered, it is possible to generate rhythmic syncope and thus generate a synchronized strictly local mapping. In the standard phonological analysis of rhythmic syncope, the grammar first assigns iterative feet, and then the weak branches of those feet are deleted (McCarthy 2008). For example, Kaye (1973) proposed the derivation in (2) for Nishnaabemwin.

(2)	‘If he kicks him’	‘I kick him’	
	/dʌŋgɪʃkʌw-aː-d/	/nɪ-dʌŋgɪʃkʌw-aː/	UR
	(dʌŋgíʃ)(kʌwáːd)	(nɪdʌ́ŋ)(gɪʃkʌ́)(wáː)	Stress
	(d_ŋgíʃ)(k_wáːd)	(n_dʌ́ŋ)(g_ʃkʌ́)(wáː)	Syncope
	(d_ŋgíʃ)(k_wáːt)	—	Other rules
	[dŋgíʃkwáːt]	[ndʌ́ŋgʃkʌ́wáː]	SR

What crucially occurs here is that a TOSL map (stress) is ordered before a 1-ISL map (syncope) that both depends on and obliterates the intermediate structure. Iterative stress is TOSL because whether a vowel is stressed can be computed by attending to the previous output stress value, assigning stress if the previous vowel is unstressed, or *vice versa*.[4] When composed with a process that removes the alternating unstressed-stressed syllable pattern, the end result is a mapping that is not segmentally strictly local. Hao and Bowers (2019) show that in general, ordering a TOSL map before a 1-ISL map allows us to describe a large class of subregular functions, resulting in overgeneration.

3 Conclusion

Rhythmic syncope requires a novel class of formal device in subregular phonology: the tier-based synchronized strictly local functions. In more familiar phonological terms, the discussion of subsection 2.3 unveils a new structural implication of rule ordering. This is potentially important, since the necessity of process ordering has recently come under scrutiny. Specifically, Chandlee, Heinz and Jardine (2018b) show that opaque maps, which have traditionally provided the main arguments for process ordering, can be represented directly as ISL maps without resorting to composition of several distinct processes. Because it requires synchronization, which can be obtained by process ordering, rhythmic syncope provides a new potential justification for process ordering.

However, though the existence of true rhythmic syncope would conclusively establish the validity of action sensitivity and process ordering, language-learning children are apt to reject rhythmic syncope. Much like infant Hercules overcoming Hera’s snakes, learners have rapidly rejected incipient rhythmic syncope alternations in at least three cases (see Bowers 2019 and Rhodes 1985 on Nishnaabemwin; Thurneysen 1946:68–69, Armstrong 1976, and McCone 1985 on Old Irish; and Isačenko 1970 on Old Russian). In one of the more interesting cases of rhythmic syncope, Mojeño Trinitario (Rose 2019) has consistent alternating deletion in many forms, but about 45% of vowels that are predicted to delete fail to do so, which raises strong questions about the overall productivity of the pattern. These cases raise the possibility that tier-based synchronized strictly local mappings are too difficult or too complex for language-learning children to acquire. Until other potential cases of rhythmic syncope, such as Macushi (Hawkins 1950, Carson 1982, and Abbott 1991), Aguaruna (Payne 1990, Wipio Deicat 1996, and Overall 2007), Tonkawa (Hoijer 1933, 1946, 1949, Kisseberth 1970, Phelps 1975, and Gouskova 2003 *inter alia*), or South-East Tepehuan (Willett 1982, 1991 and Willett and Willett 2015) can be verified as synchronically real rhythmic syncope, it may be premature to conclude that human phonology can generate action sensitive maps.

[4] Iterative stress systems often assign a degenerate foot if there is not enough material at the end of a stress domain. Because of this, iterative stress algorithms also need input sensitivity to peek ahead and make sure that a degenerate foot is formed at the correct location. We abstract away from this detail. Note that sensitivity to both the input and the output does not entail that the input segments are synchronized with their output values.

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