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Computational representation of unbounded stress: Tiers with structural features

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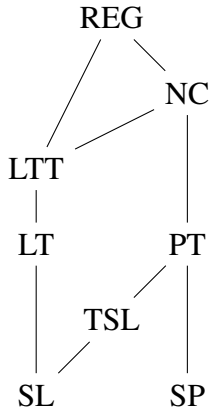
1 Introduction

Defining computational representations for phonological patterns reveals what formal classes they belong to. Studies within the framework of formal language theory have provided clear evidence that phonology is *regular* (Johnson 1972; Kaplan & Kay 1994). Being computationally regular means that the amount of information that has to be remembered by a speaker or a computational device to generate a certain pattern is bounded. More recent studies have argued that most phonological patterns are *subregular* and fit into a smaller domain than the region of regular languages. The Subregular Hierarchy shown in Figure 1 (Heinz 2018) divides the regular region into smaller regions in an hierarchical order based on their complexity. Heinz (2018) and related works have provided evidence that most phonotactics attested in natural languages fit into the classes of *Stictly Local* (SL), *Strictly Piecewise* (SP), or *Tier-based Strictly Local* (TSL) (Heinz 2018; Heinz *et al.* 2011).



Names of the classes of stringsets	
REG	Regular
NC	Non-Counting
LTT	Locally Threshold Testable
LT	Locally Testable
PT	Piecewise Testable
TSL	Tier-based Strictly Local
SL	Strictly Local
SP	Strictly Piecewise

Figure 1: The Subregular Hierarchy (Heinz 2018).

However, some patterns still remain which ostensibly display higher complexity than SL, SP, or TSL. One example is culminative quantity-sensitive stress rules, which assign one primary lexical stress per word on the basis of syllable weight (Hayes 1995). These stress patterns are *unbounded* in that stress can be an arbitrary number of syllables away from the left/right edge of a word. Previous studies have shown that unbounded stress requires higher complexity than SL, SP, or TSL. This paper re-analyzes these unbounded stress patterns and argues that once the grammar has access to metrical information, i.e., structural information of syllables, then they

are TSL after all. The hypothesis that phonological dependencies are TSL-like thus can be maintained.

This paper is organized as follows. Section 2 begins by introducing a case of unbounded stress rule and presents two computational analysis of the pattern. Section 2.1 shows how the pattern can be represented as SP, and section 2.2 show how it cannot be represented as TSL. Then, section 3 proposes an extension of TSL that accomodates the unbounded stress pattern. Section 4 introduces a more complex unbounded stress pattern and shows how the extended formal class can also represent this pattern. Section 6 discusses further questions and concludes.

2 Rightmost heavy, otherwise leftmost

In Chuvash, a Turkic langauge spoken in central Russia, reduced vowels /ă, ĕ/ form a light syllable, and all other vowels form a heavy syllable. Coda does not contribute to syllable weight. Given the weights of syllables, a Chuvash word has one primary stress that falls on the rightmost heavy syllable (1a-b). When there is no heavy syllable in the word, stress falls on the leftmost syllable (1c).

(1) Chuvash word stress (Chuvash Org. 2007)

a.	kama'**ka**	*stove*	HHH́
b.	jĕ'**ner**chĕk	*saddle*	LH́L
c.	'**ĕş**lĕpĕr	*we shall work*	ĹLL

Hayes (1995) provides a typology of such unbounded stress patterns. He calls the pattern found in Chuvash *Rightmost Heavy, Otherwise Leftmost* (RHOL), along with similar patterns such as LHOR, RHOR, and LHOL as analogous acronyms.[1] Table 1 shows examples of well-formed and ill-formed strings according to the RHOL pattern.

well-formed	ill-formed
LHH́	*ĹHH́
LH́L	*LH́H
ĹLL	*LLĹ

Table 1: Well-formed and ill-formed RHOL strings.

The stress assingment pattern of RHOL is independent from the number of syllables, and stress can be an arbitrary number of syllables away from the left/right edge of a word. This unboundedness of RHOL triggers interesting questions with regard to the formal language classes it fits into. Given the hypothesis that phonological dependencies are SL, SP, or TSL, these three classes are possible answers

[1] Each of these four patterns is attested in more than one natural languages. Examples from Hayes (1995) include RHOL in Chuvash and Eastern Cheremis, LHOR in Komi and Kwakw'ala, RHOR in Aguacatec and Western Cheremis, and LHOL in Amele and Au. Since all these patterns display similar stress assignment rules, the analyses of RHOL in this paper are applicable to the other three patterns as well.

to the question. The class of SL is not suitable, however, because it is only capable of looking at adjacent symbols and thus cannot capture long-distance dependencies. The following two subsections will present analysis of RHOL as SP and TSL grammars, respectively.

2.1 SP analysis of RHOL

The RHOL pattern consists of two requirements or generalizations. First, a word must have exactly one primary stress. This generalization is called *culminativity* (Hayes 1995). Second, primary stress falls on the rightmost heavy, otherwise leftmost syllable. In his analysis of unbounded stress patterns, Heinz (2014) factors out culminativy and shows that the remaining generalization of stress assigment in Hayes (1995)'s unbounded stress typology (RHOL, RHOR, LHOR, and LOHL) is *Strictly 2-Piecewise* (SP_2). Thus, the unbounded stress patterns with culminativity will be the intersection of SP_2 and another formal class. The rest of this section reviews Heinz (2014)'s analysis with culminativity factored out. Section 2.2 will come back to the issue of culminativity.

An SP_2 grammar evaluates a string based on its *subsequences* consisting of two symbols, or pairs of symbols based on their precedence order within the string (Heinz 2010b). For a string *abca*, for instance, the set of its subsequences is {*ab, ac, aa, bc, ba, ca*}. An SP_2 grammar compares subsequences of a given string with a conjunction of forbidden subsequences specified in the grammar. A string is *accepted* or *generated* if none of its subsequences matches with the list. If it contains one or more forbidden subsequences, the string is *rejected* or *blocked*. Since an SP grammar is able to look at some arbitrary non-adjacent symbols in a string, it captures long-distance dependencies such as consonant agreement (Rose & Walker 2004). Heinz (2010a) provides a simple example of an SP_2 phonological pattern, sibilant harmony of Samala, based on data from Applegate (1976). In Samala, sibilants [s, ʃ] in a word must agree in anteriority. Since [s] and [ʃ] cannot co-occur within a word, the SP_2 grammar of sibilant harmony is a conjunction of forbidden subsequences, $S = \{{}^{*}\text{sʃ}, {}^{*}\text{ʃs}\}$. Thus, a grammatical string *sasas* is accepted because it contains no forbidden subsequence. In contrast, an ungrammatical string **sasaʃ* is rejected because the string contains a subsequence **sʃ*, which is forbidden by the grammar. By breaking down strings into their subsequences, SP grammars capture locally unbounded dependencies between arbitrary segments.

Heinz (2014)'s analysis of unbounded stress also uses the notion of subsequence. By listing forbidden subsequences as *ḦH, *ĹH, *HĹ, and *LĹ as shown in (2), the grammar can correctly rule out stress on non-rightmost H (2a), stressed L followed or preceded by H (2b-c), and stress on non-initial L (2d). Heinz's analysis of RHOL as an SP_2 grammar shows that by factoring out culminativity, unbounded stress patterns can fit into the formal class of SP, supporting the hypothesis that phonological dependencies belong to the classes of SL, SP, or TSL.

(2) SP grammar for sibilant harmony

$S = \{{}^{*}\acute{H}H, {}^{*}\acute{L}H, {}^{*}H\acute{L}, {}^{*}L\acute{L}\}$

	well-formed	ill-formed	
a.	LHL$\acute{H}$	${}^{*}\acute{H}$LH	(${}^{*}\acute{H}$H)
b.	L$\acute{H}$LL	${}^{*}\acute{L}$HLL	(${}^{*}\acute{L}$H)
c.	L$\acute{H}$LL	*LHL$\acute{L}$	(${}^{*}H\acute{L}$)
d.	$\acute{L}$LL	*LL$\acute{L}$	(${}^{*}L\acute{L}$)

2.2 TSL analysis of RHOL

Another formal class is *Tier-based Strictly Local* (TSL) (Heinz *et al.* 2011). With a TSL_2 grammar, a subset of symbols in a string are projected onto a tier. The projected string is then evaluated by a conjunction of forbidden *substrings*, or pairs of adjacent symbols. The case of sibilant harmony in Samala can also be formalized as a TSL_2 grammar by creating a tier consisting of sibilant segments only. In the grammar given in (3), the T component specifies that the symbols *s* and *ʃ* must be projected onto the tier. Consequently, the string *sss* is projected from *sasas* as in (3a), and *ssʃ* from *sasaʃ* as in (3b). The projected strings are then evaluated on the basis of the forbidden substrings listed in the S component of the grammar. The string *sasas* in (3a) is accepted because the projected string *sss* does not contain any forbidden substring. The string **sasaʃ* in (3b), on the other hand, is rejected because its projected string contains a forbidden substring **sʃ*.

(3) TSL grammar for sibilant harmony

$G = \langle T = \{\text{s}, \text{ʃ}\}, \quad S = \{{}^{*}\text{sʃ}, {}^{*}\text{ʃs}\}\rangle$

a.

Tier		s		s		s
	ok	s	a	s	a	s

b.

Tier		s		s		ʃ
	*	s	a	s	a	ʃ

With the mechanism of tier projection, a TSL grammar represents non-local dependencies as local dependencies on tiers. The notion of dependencies on tiers has been acknowledged in existing phonological theories, including the autosegmental treatment of long-distance dependencies (Goldsmith 1976).

As a TSL grammar can represent unbounded harmony patterns, it is reasonable to expect that unbounded stress patterns can also be represented as a TSL grammar. First, a TSL grammar can easily enforce culminativity by looking at stressed syllables but ignoring unstressed ones. The grammar shown in (4) is able to do that by projecting left and right word boundaries and stressed syllables onto the tier. Then, the forbidden substrings rule out strings with no stress (4a) and strings with more than one stress (4b). Since the tier excludes unstressed syllables no matter how many, the unbounded property of culminativity becomes local on the tier.

(4) TSL grammar for culminativity

$G = \langle T = \{\rtimes, \ltimes, \acute{\text{H}}, \acute{\text{L}}\}, \quad S = \{^{*}\rtimes\ltimes, {}^{*}\acute{\text{H}}\acute{\text{H}}, {}^{*}\acute{\text{H}}\acute{\text{L}}, {}^{*}\acute{\text{L}}\acute{\text{H}}, {}^{*}\acute{\text{L}}\acute{\text{L}}\}\rangle$

a. * ⋊ L L H H ⋉ b. * ⋊ Ĺ L H Ĥ ⋉

In addition, a TSL grammar for RHOL must also be able to enforce the correct stress assignment pattern. In order to do so, the grammar has to project all four possible symbols and have four forbidden substrings as shown in (5). Each of the forbidden substrings is necessary to correctly rule out the ungrammatical stress patterns: stress on non-rightmost H (5a), stress on L when followed or preceded by H (5b-c), and stress on non-leftmost L (5d). On the other hand, the same grammar cannot correctly reject the ungrammatical strings in (5e-f). These strings have more than one H syllables separated by one or more L syllables, and they are ungrammatical because stress is on a non-rightmost H syllable. Since the evaluation on the tier is based on substrings, the grammar has no way to look at the initial Ĥ and the final H at the same time. Therefore, the RHOL pattern is not TSL.

— stressed non-rightmost H, stressed L followed or preceded by H, and stressed non-initial L — while accepting all the other patterns

(5) TSL grammar for RHOL

$G = \langle T = \{\acute{\text{H}}, \text{H}, \acute{\text{L}}, \text{L}\}, \quad S = \{^{*}\acute{\text{H}}\text{H}, {}^{*}\text{L}\acute{\text{L}}, {}^{*}\acute{\text{L}}\text{H}, {}^{*}\text{H}\acute{\text{L}}\}\rangle$

a. * Ĥ H b. * L Ĺ c. * Ĺ H d. * H Ĺ

e. * Ĥ L H f. * Ĥ L L L H

On the one hand, as a TSL grammar can look at some arbitrary symbols on the tier while ignoring others, it can succcessfully enforce exactly one primary stress per word, i.e., culminativity. On the other hand, however, since it still represents strictly local dependencies on the tier, it cannot look at non-adjacent symbols to represent unbounded stress patterns.

2.3 Interim summary

Thus far, we examined two possible formal classes that unbouded stress could belong to. It can be represented as an SP_2 grammar, which relies on the notion of subsequence. However, a TSL grammar cannot represent unbounded stress patterns, because the strictly local property of TSL is not compatible with the non-local

property of unbounded stress. The diagram in Figure 2 illustrates the relationship between the two formal classes and indicates where RHOL lies within the classes.

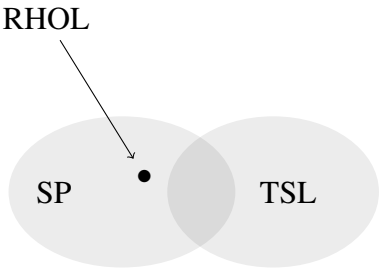


Figure 2: SP and TSL classes and RHOL with culminativiey factored out.

Heinz has provided linguistic motivation from typology and learnability for the SP class in his earlier works (Heinz 2010a; Heinz 2010b). Nevertheless, SP introduces the notion of subsequence as a new representation, while TSL is more grounded upon the existing ideas of phonological tiers and local dependencies. Thus, the following sections attempt a possible extension of the class of TSL by incorporating another linguistically natural component, *features*. In later sections it is shown that the extended class of TSL accomodates not only the RHOL pattern but also more complex unbounded stress patterns. For a similar approach that adds features to SP grammars, readers are referred to Strother-Garcia *et al.* (2016).

3 TSL with structural features

This section proposes an extended version of TSL, which allows the grammar to have access to structural information of syllables. It first proposes that prosodic elements, or syllables, are composed of features containing their structural information. Prosodic structural features include those that are already familiar in literature on prosodic phonology (e.g., syllable weight, stress) as well as those that are less so, such as syllable location and word boundary. For example, a grammatical RHOL string *LLHH́* is not a sequence of symbols but a sequence of feature bundles as illustrated in (6). The left and right word boundaries have [+boundary] feature. Each syllable is either [+light] or [+heavy] and either [+stress] or [-stress]. The word-initial syllable is [+initial], the word-final syllable is [+final], and all the other syllables are [-initial, -final]. This proposal is analogous to the main idea of the frameworks of SPE (Chomsky & Halle 1968) and Feature Geometry (Clements & Hume 1995) that phonological segments are composed of a number of features, the idea that is still evident in more recent phonological theories as well.

(6) Structural features of *LLHH́*

⋊	L	L	H	H́	⋉
+boundary	+light	+light	+heavy	+heavy	+boundary
	-stress	-stress	-stress	+stress	
	+initial	-initial	-initial	-initial	
	-final	-final	-final	+final	

In a *TSL grammar with Structural Features* (TSL-SF grammar), these features rather than symbols trigger tier projection. A component T specifies feature matrices such that a feature bundle (composing a syllable) is projected onto the tier iff it is compatible with one or more of the matrices. Feature bundles projected on the tier keep their feature values including positional ones (e.g., [initial], [final]) they had in the original string. The other component S specifies forbidden substrings that must not be present in strings projected on the tier.

With the addition of structural features to the grammar, the RHOL pattern can now be represented as TSL-SF. (7) shows the TSL-SF grammar representing RHOL. T lists features such that any feature bundle in a string (shown as symbols here to save space) containing one or more of them must be projected onto the tier. In other words, the grammar projects all H and H́, Ĺ, as well as word-initial and word-final L. After tier proejction, the projected string is evaluated by the list of forbidden substrings as specified in S. For example, out of the string *HH́H* in (7a), both syllables are projected, and the string is rejected because it contains a forbidden substring matching *[+heavy,+stress][+heavy]. From the string *ĹLH* in (7b), the initial stressed syllable and the final heavy syllable are projected, and this string is also rejected because of the substring matching *[+light,+stress][+heavy]. From the string *LĹLL* in (7c), the initial and final syllables as well as the stressed syllable are projected, and its substring matching *[+light,+stress,-initial] rules out the string.

(7) TSL-SF grammar for RHOL

$$G = \left\langle T = \left\{ \begin{matrix} \text{[+heavy]}, \\ \text{[+stress]}, \\ \text{[+initial]}, \\ \text{[+final]} \end{matrix} \right\}, \quad S = \left\{ \begin{matrix} *\text{[+heavy,+stress][+heavy]}, \\ *\text{[+light,+stress][+heavy]}, \\ *\text{[+light,+stress,-initial]} \end{matrix} \right\} \right\rangle$$

a. [+heavy] [+stress] [+heavy] [+initial] [+final]
H́ H
* H́ H

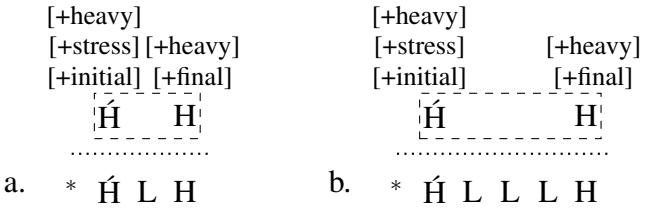
b. [+stress] [+heavy] [+initial] [+final]
Ĺ H
* Ĺ L H

c. [+initial][+stress][+final]
L Ĺ L
* L Ĺ L L

Since unstressed word-medial L syllables have no feature that would trigger tier projection, these irrelavant syllables are not visible on the tier anymore. This al-

lows the grammar to forbid the sequence of Ĥ followed by H, no matter how many intervening L syllables they have, as illustrated in (8). In both (8a-b), the intervening L syllables are not projected, and thus the two strings project the same string *ĤH* onto the tier, which matches *[+heavy,+stress][+heavy].

(8) TSL-SF grammar for RHOL: *Ĥ ... H



The current proposal posits a closed set of features, Σ = {[±boundary], [±light], [±heavy], [±stress], [±initial], [±final]}. Adding more to the representation can potentially make every regular language SL and hence TSL. In other words, if one can freely add any features, including not only segmental features but also other prosodic ones such as *n-th syllable in word*, this class of TSL becomes too expressive and thus able to generate patterns that are unattested in natural languages. The closed set of features proposed here makes the class of TSL-SF more constrained with regard to the expressivity of its grammar.

In this proposal, the representation of a syllable as a bundle of structural features has richer information than it did in previous analyses, where a syllable is represented as a symbol, or an alphabet. It reduces the number of segments that must be projected on the tier, and thus the distance between dependent segments also gets reduced. Consequently, the unbounded RHOL pattern that does not belong to the existing TSL class can be represented as a TSL-SF grammar. This is not the only advantage of the TSL class extension, as there are more unbounded stress patterns that are TSL-SF but not TSL. One example of such patterns is introduced in the following section.

4 Non-final rightmost heavy, otherwise leftmost

Stress assignment of Classical Arabic is similar to RHOL with a small but crucial difference. In Classical Arabic, a long vowel or coda makes a syllable heavy (McCarthy 1979). Putting aside irrelevant details[2], Classical Arabic words have one primary stress on the rightmost heavy syllable that is not word-final (9a). If there is no non-final heavy syllable, stress falls on the leftmost syllable (9b).

[2]When the final syllable is superheavy, stress falls on the final syllalble. Since superheavy syllables can only occur word-finally, words with the superheavy final syllable always have final stress, thus not interferring with the non-final RHOL pattern discussed here. The current analysis does not refer to the extrametricality account on the Arabic stress pattern (Hayes 1995; Kiparsky 2003).

(9) Classical Arabic word stress (McCarthy 1979)

a.	ki'**taa**bun	*book (nom. sig.)*	LH́H
b.	'**ka**taba	*he wrote*	ĹLL

The crucial difference between the RHOL pattern and the Classical Arabic pattern is that in Classical Arabic, a word-final heavy syllable never gets stress, as illustrated in the examples in Table 2. I refer to this pattern as *Non-final Rightmost Heavy, Otherwise Leftmost* (non-final RHOL).

well-formed	ill-formed
LHH́H	*LHHH́
LHH́L	*LHH́L
ĹLLH	*LLLH́
ĹLLL	*LLĹL

Table 2: Well-formed and ill-formed non-final RHOL strings.

A grammar for non-final RHOL must to be able to rule out word-final stress as in **LLH́*, while accepting non-final rightmost H stress as in *LLH́L*. When it comes to subsequences, the set of subsequences of **LLH́*, {LL, LH́} is a proper subset of the set of subsequences of *LLH́L*, {LL, LH́, H́L}. Therefore, no SP grammar can block the former without blocking the latter. Unlike the RHOL pattern, non-final RHOL does not belong to the class of SP. Moreover, non-final RHOL is not TSL, either, due to the same problem as RHOL (see (5)). As far as the grammar cannot know whether a heavy syllable is word-final or not, neither SP nor TSL can successfully represent the non-final RHOL stress pattern.

In TSL-SF, the grammar is given access to structural information of syllables, and thus tier pojection and substring evaluation are now sensitive to this information. This enables the non-final RHOL pattern to be represented as a TSL-SF grammar, as shown in (10). This grammar has the same list of feature values in T as that of the TSL-SF grammar for RHOL, projecting all H and H́, Ĺ, as well as word-initial and word-final L. The difference is captured in the list of forbidden substrings in S, which rules out word-final H́ (10a), non-initial Ĺ (10b), and H́ or Ĺ followed by non-final H (10c-d).

(10) TSL-SF grammar for non-final RHOL

$$G = \left\langle T = \left\{ \begin{matrix} [\text{+heavy}], \\ [\text{+stress}], \\ [\text{+initial}], \\ [\text{+final}] \end{matrix} \right\}, \quad S = \left\{ \begin{matrix} {}^{*}[\text{+heavy,+stress,-initial,+final}], \\ {}^{*}[\text{+light,+stress,-initial}], \\ {}^{*}[\text{+heavy,+stress][+heavy,-stress,-final}], \\ {}^{*}[\text{+light,+stress][+heavy,-stress,-final}] \end{matrix} \right\} \right\rangle$$

a.

	[+heavy]	
[+heavy]	[+stress]	
[+initial]	[+final]	
H	Ĥ	

* H L Ĥ

b.

	[+stress]
[+initial]	[+final]
L	Ĺ

* L L Ĺ

c.

[+heavy]			
[+stress]			[+heavy]
[+initial]		[+heavy]	[+final]
Ĥ		H	H

* Ĥ L H H

d.

[+stress]		[+heavy]
[+initial]	[+heavy]	[+final]
Ĺ	H	H

* Ĺ L H H

The evaluation of the two strings that were problematic for SP, **LLĤ* and *LLĤL*, is illustrated in (11a-b). Out of the ungrammatical string **LLĤ* in (11a), the initial syllable and the final stressed heavy syllable are projected onto the tier. This string is ruled out by the forbidden substring matching *[+heavy,+stress,-initial,+final]. This forbidden substring crucially blocks stress on word-final heavy syllable. On the other hand, the string projected from *LLĤL* in (11b) does not contain this forbidden substring, because the stressed heavy syllable does not have [+final] feature. With structural features, unbounded stress patterns including not only RHOL but also non-final RHOL can be represented as a TSL-SF grammar.

(11) TSL-SF grammar for non-final RHOL: final vs. non-final Ĥ

a.

	[+heavy]	
	[+stress]	
[+initial]	[+final]	
L	Ĥ	

* L L Ĥ

b.

	[+stress]	
[+initial]	[+heavy]	[+final]
L	Ĥ	L

ok L L Ĥ L

5 Discussion and conclusion

TSL-SF makes structural features of syllables available in tier projection and substring evaluation, motivated by existing theories of phonological tiers and features. This expands the expressivity of TSL and accommodates unbounded stress patterns, not only RHOL but also more complex patterns such as non-final RHOL. The reanalysis of unbounded stress patterns as TSL-SF supports the recent hypothesis that

phonological dependencies have the formal property of being either TSL or a TSL-based extension at most. Figure 3 shows a schematic diagram of relevant formal classes and the positions of unbounded stress patterns within them.

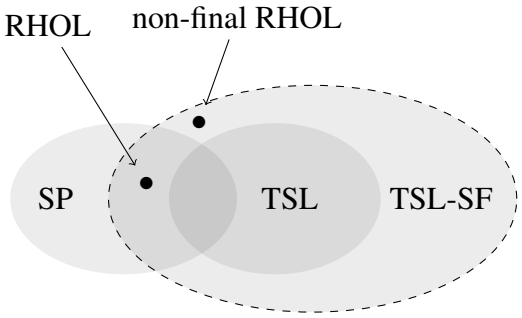


Figure 3: Subregular classes and unbounded stress patterns with culminativity factored out.

The step from TSL to TSL-SF for suprasegmental phonology is in line with the claim of Jardine (2016) that suprasegmental phonology is more powerful than segmental phonology. TSL-SF should not be extended to segmental phonology, where it would allow for various unattested patterns (e.g. First-Last harmony; Heinz 2018). Within the current analysis, the computational gap is derived from the limited availability of structure features. That is, in prosodic phonology, the grammar can refer to structural features of syllables, but not in segmental phonology. This mirrors existing phonological theories where prosodic features such as *stress* play roles only at a later stage of derivation (Hayes 1976).

In the current proposal of TSL-SF, the set of structural features are defined as Σ = {[±boundary], [±light], [±heavy], [±stress], [±initial], [±final]}. Limiting the syllable location features to [±initial] and [±final] has the consequence of maintaining the locality size of the grammar as 2. That is, the combination of these two features only shows whether a syllable is adjacent to left/right word boundary or not, but not how far it is from word boundaries or from another syllable. The feature set posited in the present paper is sufficiently expressive and restrictive enough to describe the unbounded stress patterns discussed here. In this sense, TSL-SF is a subtype of an independently motivated TSL extension studied by De Santo (2018). In his Structure-Sensitive TSL, the grammar looks at two symbols at a time in the process of tier projection so that a syllable is projected on the tier if it follows or precedes a word boundary, for instance.

This study suggests that once the grammar is given access to structural information of syllables, unbounded stress patterns can be formally characterized as TSL-like languages. It opens up several questions to be investigated in future research. First of all, it remains unanswered whether additional features such as [±penultimate], for example, are necessary to describe a wider range of attested prosodic patterns. Including such features will immediately have the effect of increasing the locality size of the grammar and thus extending the region of TSL-SF. While structural features are currently posited to be binary, the nature of structural features has to be further explored in future studies, as it will have direct impact

on the expressivity of TSL-SF grammars. Moreover, the analysis and discussion of the present study factored out the culminative property of stress patterns. A full description of culminative unbounded stress therefore requires some intersection between different formal classes, which is another significant question to be answered in future research.

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