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*The binary-to-ternary rhythmic continuum in stress typology: layered feet and non-intervention constraints**

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This article presents a novel OT analysis of ternary rhythm, using the restrictive format of McCarthy (2003)'s categorical alignment constraints, which we will refer to as 'non-intervention constraints', using the terminology of Ellison (1994), and argues for the rehabilitation of internally layered feet in metrical representations (i.e. feet with one layer of recursion). By means of a computer-generated factorial typology, we demonstrate that the constraint set proposed here generates the full typology of binary and ternary rhythm. The resulting typology suggests that there is no absolute boundary between binary and ternary systems; rather, a continuum emerges, such that binary and ternary feet may coexist in rhythmic stress systems.

1 Introduction

'Ternary rhythm' refers to patterns in which stress falls rhythmically on every third syllable or mora. A paradigm case is Cayuvava (Key 1961),

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where stress occurs on every third syllable counting backwards from the end of the word. According to Levin (1988: 105), the rightmost stress is primary, as in (1a), where *n* indicates the number of syllables. Another classical example is Chugach Alutiiq Yupik (Leer 1985a, b, c) in (1b). Stress falls on every second syllable and every third syllable thereafter. In 3*n*+1 forms (i.e. 4- and 7-syllable words) the final syllable is also stressed. Leer (1985a) describes all stresses as equally strong. A third example is Tripura Bangla (Das 2001) in (1c), where stress falls on every third syllable, except that final syllables are always unstressed. The leftmost stress is primary.

(1) a. *Cayuvava*

3*n*	ˌpo.po.he.ˈce.βa.ka	'inside of cow'
3*n*+1	ma.ˌra.ha.ha.ˈe.i.ki	'their blankets'
3*n*+2	i.ki.ˌta.pa.re.ˈre.pe.ha	'the water is clean'

b. *Chugach Alutiiq Yupik*

3*n*	a.ˈku.tar.tu.ˈnir.tuq	'he stopped eating akutaq'
3*n*+1	ma.ˈŋar.su.qu.ˈta.qu.ˈni	'if he (REFL) is going to hunt porpoise'
3*n*+2	ta.ˈqa.ma.lu.ˈni	'apparently getting done'

c. *Tripura Bangla*

3*n*	ˈo.nu.kɔ.ˌro.ni.jɔ	'imitable'
3*n*+1	ˈo.no.nu.ˌda.βo.ni.jɔ	'unintelligible'
3*n*+2	ˈʃɔ.ma.lɔ.ˌsɔ.na	'criticism'

Ternary stress has been reported for a handful of other languages: Estonian (Hint 1973), Sentani (Cowan 1965), Hocąk (Miner 1979) and possibly Finnish (Carlson 1978). The pitch-accent patterns of a few other systems, for example Gilbertese (Blevins & Harrison 1999) and Irabu Ryukyuan (Shimoji 2009), have also been claimed to display similar ternary groupings.[1]

The dominant analysis of ternary rhythm in metrical theory has traditionally involved binary feet and the non-parsing of a light syllable ('weak local parsing'; Hayes 1995). Weak local parsing as a parsing mechanism in rule-based metrical theories was well constrained and typologically successful. However, it has been shown that more recent weak local parsing analyses couched in Optimality Theory (OT) suffer from both undergeneration (i.e. they are not able to predict all the attested ternary systems) and pathological overgeneration (Eisner 1997, Kager 2001, McCarthy 2003). In an attempt to develop an alternative OT account of ternary rhythm, the main goal of this article is to present an analysis of binary and ternary quantity-insensitive stress patterns that overcomes the empirical limitations of previous constraint-based analyses.

[1] Hayes (1995) mentions three other languages where ternarity occurs more locally, co-occurring with binarity: Auca (Pike 1964), Mantjiltjara (Marsh 1969) and Bani-Hassan Arabic (Kenstowicz 1983).

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On the representational side, we will argue for the rehabilitation of internally layered ternary (ILT) feet in metrical representations (Prince 1980, Selkirk 1980). An ILT foot consists of a binary foot with a right- or left-adjoined syllable, i.e. $((\sigma\sigma)_{\mathrm{Ft}}\sigma)_{\mathrm{Ft}}$ or $(\sigma(\sigma\sigma)_{\mathrm{Ft}})_{\mathrm{Ft}}$. Contrary to the originally dominant belief that the unique *raison d'être* of ternary feet is their ability to model ternary rhythm, a number of recent works in metrical phonology have provided cross-linguistic segmental and tonal evidence in support of the incorporation of ILT feet in prosodic representations (Davis 1999, 2005, Jensen 2000, Davis & Cho 2003, Yu 2004, Bennett 2012, 2013, Martínez-Paricio 2012, 2013, Buckley 2014). Importantly, some of these studies have shown that ILT feet can also be active in languages with binary rhythm, hence an ILT foot should no longer be regarded as a ternary-specific ad hoc device exclusively required to account for ternary stress distributions. On this point, we will argue that the strict typological subdivision between BINARY and TERNARY rhythmic systems should be relaxed in favour of the introduction of the notion of a RHYTHMIC CONTINUUM. More specifically, we will propose that there is no absolute boundary between binary and ternary systems; rather, a typological rhythmic continuum emerges, in which systems differ in the number and type of binary and ternary feet they allow, as shown in Table I.

strictly binary non-exhaustive	binary and ternary exhaustive	ternary and binary exhaustive	ternary and binary non-exhaustive	strictly ternary non-exhaustive
(ó σ) σ	((ó σ) σ)			
(ó σ)(ó σ)			((ó σ) σ) σ	
(ó σ)(ó σ) σ	((ó σ) σ)(ó σ)			((ó σ) σ) σ σ
(ó σ)(ó σ)(ó σ)		((ó σ) σ)((ó σ) σ)		
(ó σ)(ó σ)(ó σ) σ	((ó σ) σ)(ó σ)(ó σ)		((ó σ) σ)((ó σ) σ) σ	
(ó σ)(ó σ)(ó σ)(ó σ)		((ó σ) σ)((ó σ) σ)(ó σ)		((ó σ) σ)((ó σ) σ) σ σ

binary ⟷ ternary

Table I

The binary-to-ternary rhythmic continuum.

At one end of this continuum, we find systems with strictly binary feet (Pintupi, Warao), and at the other end systems with only ternary feet (Cayuvava, Gilbertese). In between, we find MIXED systems, in which binary and ternary feet coexist in three different ways. In binary and ternary exhaustive systems (Garawa, Wargamay), feet are preferably

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binary, but a single ternary foot emerges to avoid underparsing. In ternary and binary exhaustive systems (Chugach, Estonian), feet are preferably ternary, while (one or two) binary feet emerge whenever needed to avoid underparsing. In ternary and binary non-exhaustive systems (Tripura Bangla, Hocąk), feet are preferably ternary, but one binary foot is allowed to avoid double underparsing. Note that in order to improve comparisons between systems, Table I exemplifies only ((σ́σ)σ) 'dactylic' systems with directionality oriented toward the left edge; however, systems with different types of ILT feet and different directionalities will also be shown to fall into the continuum.

Our OT analysis of quantity-insensitive binary and ternary stress will use only a small set of categorical alignment constraints of the 'non-intervention' format (McCarthy 2003). We will demonstrate that our constraint set generates the full typology of binary and ternary quantity-insensitive stress systems, while avoiding undergeneration and pathological overgeneration. We will do so by means of a computer-generated factorial typology calculated using OTSoft (Hayes *et al*. 2003). Interestingly, the resulting typology will include all systems occurring on the rhythmic continuum; our constraint set thus *predicts* the existence of the rhythmic continuum.

The article is organised as follows. First, we present the main ingredients of our theoretical proposal (§2). Second, we analyse the factorial typology of our constraint set, exploring the binary-to-ternary continuum (§3). Next, we discuss a number of residual theoretical issues in §4, and conclude in §5.

2 Theoretical proposal: representations and constraints

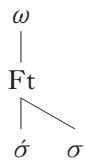
This section introduces the principal components of the analysis of binary and ternary rhythm, which will be typologically motivated in §3. We first present our working hypothesis and assumptions about metrical representations (§2.1), and then discuss the format of the non-intervention alignment constraints necessary to model the rhythmic patterns of stress (§2.2).

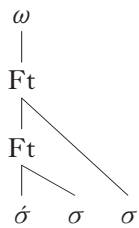
2.1 Representations: internally layered ternary feet

In line with standard metrical theories, we assume that stress is the manifestation of a foot head (Liberman & Prince 1977, Selkirk 1980, Halle & Vergnaud 1987, Hayes 1995).[2] However, rather than adopting the standard assumptions that metrical feet are maximally binary and universally dominated by the prosodic word (2a), we utilise ILT feet in metrical representations. As previously mentioned, ILT feet result from adjoining a weak syllable to a binary foot. More specifically, our working hypothesis will be that foot structure can be recursive (2b), but only minimally so: a single foot layer can be stacked on top of a 'minimal' foot by adjunction.

[2] This statement does not entail that all foot heads must be overtly realised with stress. For recent discussion on the existence of stressless feet see Buckley (2009) and Bennett (2012).

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(2) a. 

b. 

Foot recursion involves a departure from the traditional assumption that feet must be exclusively dominated by the prosodic word (*ω*). However, the idea that a metrical foot might undergo minimal recursion, giving rise to a layered trisyllabic foot (2b), is not new in phonological theory. It was originally proposed by Selkirk (1980) and Prince (1980) in their early work on English and Estonian foot structure. Additionally, ILT feet, or fairly similar structures, have been posited in other studies (e.g. Dresher & Lahiri 1991, Rice 1992, Kager 1994). Such proposals have not met with the same amount of approval as standard metrical theories, but ILT feet have recently experienced a modest revival: they have been invoked for a variety of languages, many of which do not display ternary rhythm (see the references in §1, as well as Caballero 2008 and Kager 2012). These studies have shown that minimally recursive feet are supported on empirical grounds that go well beyond the explanation of ternary stress. On the one hand, it has been demonstrated that some phonological processes need to differentiate between two types of foot heads: those that are dominated by one foot projection (cf. (2a)) and those that are dominated by two foot projections (cf. (2b)). This has been argued to be the case in Wargamay and Yidiɲ, two Australian languages with binary stress where only syllables with a double-head status undergo a vowel-lengthening process (see Martínez-Paricio 2012, 2013 for details). Similarly, it has been proposed that the layered foot provides an optimal framework for capturing reported differences among weak syllables. Note that the two unstressed syllables in an ILT foot have different structures: each weak syllable is immediately dominated by a different foot projection, and hence the phonology may exploit this structural difference in phonological processes. This has been reported to be the case in Chugach, where Low tonal accents only dock onto weak syllables that occupy the adjunct position of an ILT foot. Furthermore, in some ILT configurations, one of the two weak syllables is located at the left edge of the foot, whereas the other is placed in foot-final position, e.g. $((\sigma\acute{\sigma})_{\mathrm{Ft}}\sigma)_{\mathrm{Ft}}$, $(\sigma(\acute{\sigma}\sigma)_{\mathrm{Ft}})_{\mathrm{Ft}}$. Since the initial position of a foot is prominent (just like the initial position of other prosodic domains), this syllable, even if weak, may be the target of strengthening effects, and behave as phonologically stronger than the other weak syllable in an ILT foot (Bennett 2012, 2013). Such foot-initial strengthening in systems has been documented in English (Davis & Cho 2003, Davis 2005), Dutch (Kager & Martínez-Paricio 2014), Chugach (Leer 1985c, Rice 1992) and Huariapano (Bennett 2013), among other languages. In

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all these systems, only weak syllables that occur in a foot-initial position are targeted by a range of fortition phenomena, e.g. aspiration (English), glottal insertion (Huariapano), fortition of consonants (Chugach) and greater resistance to vowel reduction (Dutch).[3] Furthermore, beyond these subtle strength distinctions, the ILT foot has been argued to constitute a useful analytical device for restricting the typology of stress-window systems (Kager 2012, based on Caballero 2008, 2011).

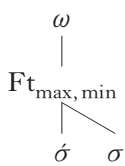
2.1.1 *Minimal and maximal foot projections*. We propose that, in languages whose metrical structure involves ILT feet, the phonology is able to distinguish between its different foot projections, but in a restrictive way. Borrowing the definitions of minimal and maximal prosodic categories of Ito & Mester's recursion-based subcategories model (2007, 2009, 2013), we claim that prosodic systems may exploit the structural contrast between MINIMAL and MAXIMAL feet, as well as their negative counterparts, NON-MINIMAL and NON-MAXIMAL feet, as in (3).

(3) *Metrical foot projections*

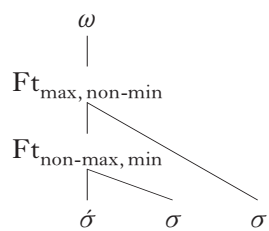
Maximal	(Ft_{max})	Ft not dominated by Ft (the largest Ft projection)
Minimal	(Ft_{min})	Ft not dominating Ft (the smallest Ft projection)
Non-maximal	($Ft_{non\text{-}max}$)	Ft dominated by Ft
Non-minimal	($Ft_{non\text{-}min}$)	Ft dominating Ft

These are illustrated in (4) (see Elfner 2012 for evidence for other non-minimal prosodic subcategories).

(4) a.



b.



As shown in (4), every foot layer can be characterised with a positive or negative value for the parameters 'minimal' and 'maximal'. A traditional (binary or unary) foot will be both 'minimal' and 'maximal' (4a): its single projection is 'maximal' by not being dominated by another foot, and 'minimal' by not dominating a foot. The top node in the recursive foot in (4b) is defined as 'maximal' in the same way as (4a), but since it directly dominates a foot, it is 'non-minimal' as well. The bottom node of the

[3] Importantly, this work has shown that alternative analyses of the dual behaviour of unstressed syllables in terms of a contrast between weak *footed* syllables and weak *unfooted* syllables prove inadequate for these particular cases.

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recursive foot in (4b), its innermost foot, is both 'minimal' by not dominating a foot and 'non-maximal' by being directly dominated by a foot. As pointed out by Itô & Mester, these terms (minimal/maximal and non-minimal/non-maximal) are not mere notational variants referring to new language-particular categories in the prosodic hierarchy. On the contrary, they are structural terms that can be fully and locally inferred from domination relations. When applied to the category foot, they capture information about its specific daughter (i.e. whether it immediately dominates another foot) and/or its mother node (i.e. whether it is immediately dominated by another foot). In this sense, these terms are local: the specific characterisation of a given foot layer is directly inferred from local relations. In §2.1 we saw that different metrically conditioned phenomena need to distinguish between different foot projections. This distinction will also turn out to be crucial for stress assignment, and the formulation of our metrical constraints will therefore involve reference to the different projections of a foot (§2.2).

2.1.2 *Restrictions on* GEN. Before discussing the main properties of the violable constraints used in our OT analysis of rhythmic stress, we outline in this section a few inviolable restrictions which we will tentatively assume to be enforced by GEN. These restrictions should not be taken as axioms, but merely as initial working hypotheses that will facilitate our typological investigation of the ILT foot in §3.

(5) GEN*: a working hypothesis*

a. Feet are maximally binary branching.

b. Recursion at the foot layer is minimal: feet display maximally one layer of recursion.

c. Recursive feet arise by adjunction of a syllable to a foot, i.e. a recursive foot may not branch into two feet: $((\sigma\sigma)_{\mathrm{Ft}}(\sigma)_{\mathrm{Ft}})_{\mathrm{Ft}}$ and $((\sigma\sigma)_{\mathrm{Ft}}(\sigma\sigma)_{\mathrm{Ft}})_{\mathrm{Ft}}$ are not possible recursive feet.

(5a) excludes flat ternary branching feet from GEN, in accordance with standard metrical theories of stress (Rice 2011 and references therein). As pointed out by Hayes (1995: 315), flat ternary feet are unable to capture typological predictions relating to the binary foot inventory. In particular, a theory with flat ternary feet cannot account for the similarities between ternary and binary feet within a language. Consider for instance a language with iambic lengthening and ternary rhythm, like Chugach, where lengthening occurs in both ternary feet, e.g. (*σσ́*:*σ*), and binary feet, e.g. (*σσ́*:) (Leer 1985a). A theory with flat ternary feet would fail to unify the structural context of lengthening, since lengthening occurs in different types of feet: amphibrachs and iambs. In contrast, in a theory where ternary feet arise by adjoining a syllable to a binary foot (in the case of Chugach, an iambic foot) it is evident why binary feet (*σσ́*:) and ternary feet ((*σσ́*:)*σ*) both display lengthening: both structures contain an

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iamb. Another reason to exclude flat ternary feet from GEN is their inability to capture the reported difference in phonological behaviour between the head of a binary foot and the head of a flat ternary foot, as well as the different behaviour of weak syllables within a ternary foot (see §2.1.1 for references and details). Note that the heads of binary and ternary flat feet have similar structures and, therefore, it is in principle predictable that they should display similar phonological behaviour. Likewise, a theory with flat ternary feet can only account for the dual behaviour of unstressed syllables by stipulating the position of the weak syllable within the foot (at an edge or not) that targets a particular process, and/or by referring to its adjacency (or lack of adjacency) to the foot head. This is not sufficient in the analyses of various fortition phenomena, which need to appeal to the structural difference between weak syllables in an ILT foot.

The other two restrictions in (5) limit prosodic recursion at the level of the foot in two respects. First, (5b) bans quaternary feet, (((*σσ*)*σ*)*σ*), and larger recursive feet from GEN. Second, (5c) disallows feet from dominating two feet, i.e. it prohibits BALANCED feet, and only allows UNBALANCED recursive feet in which a foot dominates another foot and a weak syllable. Note that these restrictions are specific to the foot: both balanced recursive prosodic structures in which a category X dominates two categories X and prosodic structures with more than one layer of recursion have been proposed for higher layers of the prosodic hierarchy (Ladd 1986, Ito & Mester 2007). In §4 we will clarify the specific arguments that lead us to posit these restrictions as absolute conditions within GEN rather than violable constraints in CON. For the moment, we observe that these arguments stem partially from the rhythmic nature of the foot and its relational inherent definition.

Assuming the three working hypotheses in (5), there are seven types of maximal feet that can be generated by GEN in our framework: four ILT feet (6a), two binary feet (6b) and one unary foot (6c).

(6) a. ((*σσ*)*σ*) b. (*σσ*) c. (*σ*)
((*σσ*)*σ*) (*σσ*)
(*σ*(*σσ*))
(*σ*(*σσ*))

To facilitate our typological research, we have also excluded from GEN candidates with internally layered feet in which a syllable is adjoined to a unary foot (e.g. ((*σ*)*σ*)). The goal of the present paper is to account for quantity-insensitive binary and ternary stress patterns. Whether a particular binary or ternary system is better analysed with this type of unary recursive foot or with a simple binary foot (*σσ*) is an open question. However, as the former merely introduces recursiveness without optimising parsing in any respect, and given the lack of compelling evidence for such type of foot (cf. Buckley 2014), we have omitted them from GEN. As pointed out by an anonymous reviewer, if future research proves that GEN must include such feet, the task of ruling them out in certain

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evaluations would be shifted to CON, presumably by markedness constraints specifically penalising unary feet and/or superfluous complex structure (e.g. *STRUCTURE; Gouskova 2003).

We now turn to the constraints that are responsible for the location of feet within the prosodic word, and for the size and type of feet.

2.2 Non-intervention alignment constraints

All constraints used in our analysis conform to McCarthy's (2003) alignment format: (i) they are CATEGORICAL (i.e. they maximally assign one violation mark per locus of violation), and (ii) they qualify as LOCAL, in the sense that they do not 'mention more than two distinct constituents and a relation between them, such as adjacency or shared membership in a superordinate constituent' (McCarthy 2003: 80). According to McCarthy's definition, constraints involving three categories can still be local, as long as one of them is a superordinate category that CONTAINS the other two. We will see this is relevant for the definition of our constraints. In addition, to avoid complex computational problems that arise when the locus of violation refers to more than one constituent (see §4 for discussion), we follow McCarthy's restriction on the locus of violation: every locus will be a SINGLE PHONOLOGICAL CONSTITUENT (2003: 77). Finally, to make the assignment of violation marks more explicit and as a means of achieving local foci, we also follow McCarthy's proposal of formulating categorical alignment constraints according to the non-intervention format presented in Ellison (1994) and Zoll (1998). This non-intervention schema, which will be implemented in our constraint set, is illustrated in (7), which is adapted from McCarthy (2003: 78).

(7) ALIGN-L/R(Cat_1, Cat_2, Cat_3)
For every prosodic category Cat_1, assign a violation mark if some prosodic category Cat_2 intervenes between Cat_1 and the left/right edge of Cat_3.

Note that Cat_1 corresponds to the locus of alignment (or violation), i.e. the designated category that is required to be aligned with the (left or right) edge of a particular domain or superordinate category, Cat_3. This locus of violation can be separated from the left/right edge of the superordinate category by a SEPARATOR category, Cat_2. In such a case, the constraint will assign only a single violation mark per locus of violation, no matter how many separators intervene between the locus of alignment and the relevant edge of the domain. To better illustrate the non-intervention format, consider the constraint in (8), which is a concrete example from our set.

(8) ALIGN-L($[Ft_{max}]_{\omega}$, Ft, ω) (ALIGN-L_{max})
For every maximal foot Ft_{max}, assign a violation mark if some foot intervenes between Ft_{max} and the left edge of its containing ω.

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This non-intervention constraint penalises maximal foot projections (Cat_1 = locus of violation) that are separated from the left edge of the ω (Cat_3 = domain, superordinate category) by some foot (Cat_2 = separator), independently of its minimal/maximal status. As shown in (9), it assigns fewer violations to candidate (b), with two ternary feet, than to (a), with three binary feet. However, the true function of this constraint is to promote candidates with a single foot, like (c).

(9)

σσσσσσ	ALIGN-L_{max}	*loci of violation*
a. $(\sigma\acute{\sigma})_i(\sigma\acute{\sigma})_j(\sigma\acute{\sigma})_k$	*!*	$(\sigma\acute{\sigma})_k$, $(\sigma\acute{\sigma})_j$
b. $((\sigma\acute{\sigma})\sigma)_i((\sigma\acute{\sigma})\sigma)_j$	*!	$((\sigma\acute{\sigma})\sigma)_j$
☞ c. $(\sigma\acute{\sigma})_i\sigma\sigma\sigma\sigma$		

Candidate (c) will be selected when constraints ensuring exhaustive parsing of syllables are low-ranked. We have indicated on the right of the tableau the exact loci that incur a violation. Note that the maximum number of violations which a constraint of this sort can assign is bounded: it equals the number of loci of violation present in a given domain. This boundedness property of our constraints will be argued to be warranted on computational grounds in §4. In the example above, where the locus of alignment is a maximal foot, the number of violation marks a particular candidate incurs will never exceed the number of maximal feet present in a prosodic word.

Note that the non-intervention relation between Cat_1 and Cat_3 in McCarthy's constraint format cannot always be characterised as 'local'. Since Cat_1 (e.g. an unparsed σ) and Cat_3 (e.g. the designated edge of ω) can be at an unbounded distance from one another, the non-intervention constraint must be able to 'look' an unbounded distance from the locus of violation (Cat_1) to test for the absence of an intervening Cat_2 (e.g. a Ft). Locality is considered to be a fundamental principle of grammar (Chomsky 1965), in the sense that it constrains the expressive formats of rules and constraints in syntax as much as in phonology. Nevertheless, we propose that the relation between Cat_1 and Cat_3 can be characterised as 'local' in a particular way. We assume (following Eisner 1997 and McCarthy 2003) that edges of Cat_3 are accessible to Cat_1 and Cat_2 by virtue of 'vertical' locality. In order to contribute to a more restrictive theory of CON and limit the size of the constraint set, we impose two vertical locality conditions on our non-intervention constraints. These conditions, stated in (10), restrict the types of prosodic elements that can occupy each of the three categories in the non-intervention format. In §3 we will demonstrate that these locality restrictions are typologically motivated.[4]

[4] As a reviewer points out, it might be the case that a set of other arbitrary constraints, not subject to our vertical locality conditions, can generate the full typology. However, since we have not been able to identify such a constraint set, we assume these locality arguments here, due to their predictive power.

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(10) *Vertical locality conditions*

a. *Daughterhood Condition*
The locus of alignment (Cat_1) and the separator category (Cat_2) must be immediately dominated by the domain constituent (Cat_3).

b. *Adjacency Condition*
The separator category (Cat_2) and the domain category (Cat_3) must be adjacent categories in the prosodic hierarchy.

Taken together, the conditions in (10) fully determine the values of the separator and the domain category for a given locus. First, the Daughterhood Condition establishes that the locus and separator must be immediate daughters of the superordinate category, thereby establishing the superordinate category and restricting the separator category. For instance, within the ω-domain, where the locus of alignment is the Ft, the separator category can only be a Ft_{max} or a σ, since only maximal feet and unfooted syllables are directly dominated by ω. Second, the Adjacency Condition requires the separator to be vertically adjacent in the prosodic hierarchy to the superordinate domain category. Hence, in cases where the domain category is ω, the separator will be Ft. In cases where the domain is Ft, the separator will be σ. These conditions greatly restrict the number of possible constraints in our model. For instance, a constraint such as ALIGN-L/R(Ft_{max}, $[\sigma]_{Ft}$, ω), in which the locus of alignment is a Ft_{max}, the separator category is a footed syllable and the domain or superordinate category is ω, is not possible in our framework, because it does not satisfy the locality conditions in (10). On the one hand, the Daughterhood Condition is violated because the maximal projection of the foot, Ft_{max}, is an immediate daughter of ω, but the footed syllable is not: it is immediately dominated by Ft, and hence is not a sister of Ft_{max}. On the other hand, this constraint is also defective according to the Adjacency Condition, because ω and σ are not vertically adjacent categories in the prosodic hierarchy: Ft intervenes between them.

We will assume that the locus category can be instantiated by different projections of a recursive foot, by feet with specific prominence and branchingness properties (head feet, non-branching feet) and by unfooted syllables or syllables with foot-head status. On the basis of this, we derive the sets of constraints in (11) and (18) below, all of which satisfy the two vertical locality conditions. The constraints are arranged in two classes, determined by the superordinate category, ω or Ft. In (11) we present the class that determines the location and number of feet, as well as the location of unfooted syllables within a prosodic word. Later, in (18), we present the class of constraints which regulates the location of foot heads and foot dependents. We use square brackets with a subindex to represent immediate domination in our constraint set. Since in (11) the superordinate category is the prosodic word, all loci are indicated with $[\ldots]_{\omega}$. In (11a) the indication that the maximal foot is immediately dominated by the prosodic word ($[Ft_{max}]_{\omega}$) is redundant, but in other cases, like (11b), where the

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locus category is $[Ft_{min}]_{\omega}$, the $[\ldots]_{\omega}$ notation becomes crucial: it indicates that the constraint will only affect minimal feet that are immediately dominated by ω (i.e. non-recursive feet). This notation is equally crucial in (11f), where the locus is stated as $[\sigma]_{\omega}$, which means that the constraint only targets syllables that are immediately dominated by ω, i.e. unfooted syllables.

(11) *Non-intervention constraints regulating the location and number of foot projections and unfooted syllables within a ω*

a. ALIGN-L/R($[Ft_{max}]_{\omega}$, Ft, ω) (ALIGN-L/R_{max})
For every maximal foot Ft_{max}, assign a violation mark if some foot intervenes between Ft_{max} and the left/right edge of its containing ω.

b. ALIGN-L/R($[Ft_{min}]_{\omega}$, Ft, ω) (ALIGN-L/R_{min})
For every foot that is minimal and maximal ($[Ft_{min}]_{\omega}$), assign a violation mark if some foot intervenes between $[Ft_{min}]_{\omega}$ and the left/right edge of its containing ω.

c. ALIGN-L/R($[Ft_{non\text{-}min}]_{\omega}$, Ft, ω) (ALIGN-L/$R_{non\text{-}min}$)
For every non-minimal foot $Ft_{non\text{-}min}$, assign a violation mark if some foot intervenes between $Ft_{non\text{-}min}$ and the left/right edge of its containing ω.

d. ALIGN-L/R($[Ft_{unary}]_{\omega}$, Ft, ω) (ALIGN-L/R_{unary})
For every unary foot Ft_{unary}, assign a violation mark if some foot intervenes between Ft_{unary} and the left/right edge of its containing ω.

e. ALIGN-L/R($[Ft_{main}]_{\omega}$, Ft, ω) (ALIGN-L/R_{main})
For every head foot of a ω (Ft_{main}), assign a violation mark if some foot intervenes between Ft_{main} and the left/right edge of its containing ω (based on ENDRULE-L/R; Prince 1983, McCarthy 2003).

f. ALIGN-L/R($[\sigma]_{\omega}$, Ft, ω) (CHAIN-L/R)
For every unfooted syllable $(\sigma)_{\omega}$, assign a violation mark if some foot intervenes between $(\sigma)_{\omega}$ and the left/right edge of its containing ω.

A complete factorial typology of these constraints will be presented in §3. Here we concentrate on illustrating the main functions of some of these constraints and their roles in predicting ternary and binary patterns. Since the first pair of constraints, ALIGN-L/Rt_{max}, was exemplified in (8) and (9), we turn to the effects of ALIGN-L/R_{min} in (11b). The locus of violation in this pair of constraints is a minimal foot that is simultaneously maximal, i.e. a non-recursive foot. The constraints have two functions. First, they draw non-recursive feet toward the left/right edge of their containing ω. Second, they share the economising function of the other alignment constraint: whereas ALIGN-L/R_{max} minimises the number of maximal feet in general, ALIGN-L/R_{min} minimises the number of maximal feet that are minimal, maximising the emergence of recursive

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feet. As such, they promote ternarity. The two functions are illustrated in the tableau in (12). Given a candidate with eight syllables, ALIGN-L/R_{min} favours the candidate with two ILT feet (a), rather than alternative parsings with four minimal binary feet (b) or two ILT feet and a binary foot (c), (d). (We abstract away from headedness parameters for the moment, so that the head of all candidates in (12) is in foot-initial position.)

(12)

σσσσσσσσ	ALIGN-L_{min}	ALIGN-R_{min}
☞ a. ((*σσ*)*σ*)((*σσ*)*σ*)*σσ*		
b. (*σσ*)(*σσ*)(*σσ*)(*σσ*)	*!**	*!**
c. ((*σσ*)*σ*)((*σσ*)*σ*)(*σσ*)	*!	
d. (*σσ*)((*σσ*)*σ*)((*σσ*)*σ*)		*!

These constraints alone cannot be responsible for selecting the ternary pattern in (13a). Note that candidates with a single recursive foot (b) or a single non-recursive foot (c) satisfy the two constraints equally well, as with ALIGN-L/R_{max} in (8).

(13)

σσσσσσσσ	ALIGN-L_{min}	ALIGN-R_{min}
☞ a. ((*σσ*)*σ*)((*σσ*)*σ*)*σσ*		
☞ b. ((*σσ*)*σ*)*σσσσσ*		
☞ c. (*σσ*)*σσσσσσ*		

To derive the ternary stress pattern in (12a) and (13a), ALIGN-L/R_{min} must crucially dominate the constraint that minimises the number of unparsed syllables and chains feet towards the left edge of the prosodic word. This is CHAIN-L, the left version of the constraint in (11f), which promotes exhaustivity while chaining any unfooted syllables to the left edge of *ω* and feet to the opposite edge. Hence, for a pattern like (12a), ALIGN-L/R_{min} and CHAIN-R must be undominated, so that all unfooted syllables are chained to the right edge of *ω*. When these three constraints dominate CHAIN-L, a system like Cayuvava, with *extreme* ternarity, emerges, as in (14).

(14)

σσσσσσσσ	CHAIN-R	ALIGN-L_{min}	ALIGN-R_{min}	CHAIN-L
☞ a. ((*σσ*)*σ*)((*σσ*)*σ*)*σσ*				**
b. ((*σσ*)*σ*)*σσσσσ*				***!**
c. (*σσ*)*σσσσσσ*				***!***
d. ((*σσ*)*σ*)((*σσ*)*σ*)(*σσ*)		*!		
e. (*σσ*)(*σσ*)(*σσ*)(*σσ*)		*!**	*!**	
f. *σσσσσ*((*σσ*)*σ*)	*!****			

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Candidate (f), with unfooted syllables chained at the right edge of the prosodic word, is eliminated because it violates CHAIN-R. Candidates (d) and (e) are also ruled out because they incur various violations of the ALIGN-L/R_{min} constraints. Finally, candidates (a)–(c) all respect high-ranked CHAIN-R and ALIGN-L/R_{min}, but violate CHAIN-L. Since (a) has only two unfooted syllables at the right edge of *ω*, it incurs fewer violations of CHAIN-L than (b) and (c), and is thus optimal. The ranking in (14) thus promotes ternarity, while allowing a small amount of underparsing, i.e. of two syllables. Observe that CHAIN-L and CHAIN-R together eliminate the need for PARSE-*σ*, by minimising the number of unparsed syllables. When CHAIN-L and CHAIN-R are both undominated, candidates with exhaustive parsing of syllables will surface as optimal, even if exhaustivity is achieved by means of a binary foot. This pattern is illustrated in (15a), and corresponds to languages like Estonian. These systems promote ternarity, but prefer building a binary foot to leaving two syllables unparsed.

(15)

σσσσσσσσ	CHAIN-L	CHAIN-R	ALIGN-R_{min}	ALIGN-L_{min}
☞ a. ((*σσ*)*σ*)((*σσ*)*σ*)(*σσ*)				*
b. ((*σσ*)*σ*)((*σσ*)*σ*)*σσ*	*!*			
c. ((*σσ*)*σ*)*σσσσσ*	*!****			
d. (*σσ*)(*σσ*)(*σσ*)(*σσ*)			*!**	***

To account for languages that also display exhaustive parsings of syllables, but invoke binary footing instead of achieving exhaustivity by means of building ternary feet, we need to introduce the constraint in (11c), which regulates the position of non-minimal feet, ALIGN-L/$R_{non\text{-}min}$. As can be seen in the tableaux in (16), the role of this constraint is to minimise ternary feet. When either the left or right edge version of this constraint is undominated, and ranked together with CHAIN-L/R above the ALIGN-L/Rt_{min} constraints, a system with binary feet in even-parity forms arises, as in (16a.i). However, in odd-parity forms, exhaustivity is ensured by the presence of one ternary foot, as in (16b.ii).

(16)

	σσσσσσσσ	CHAIN-L	CHAIN-R	ALIGN-$L_{non\text{-}min}$	ALIGN-$R_{non\text{-}min}$	ALIGN-L_{min}	ALIGN-R_{min}
a.	☞ i. (*σσ*)(*σσ*)(*σσ*)(*σσ*)					***	***
	ii. ((*σσ*)*σ*)((*σσ*)*σ*)(*σσ*)			*!	**	*	
	iii. ((*σσ*)*σ*)((*σσ*)*σ*)*σσ*	*!*		*!	*		
b.	*σσσσσσσ*						
	i. (*σσ*)(*σσ*)(*σσ*)*σ*	*!				**	**
	☞ ii. ((*σσ*)*σ*)(*σσ*)(*σσ*)				*	**	*
	iii. ((*σσ*)*σ*)((*σσ*)*σ*)*σ*	*!		*!	*		

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Tableaux (14)–(16) show that our constraint set predicts that there is no absolute boundary between binary and ternary systems, but that there is indeed a typological rhythmic continuum, as anticipated in §1. In §3, we will present evidence for the predicted continuum from language examples in the context of a full factorial typology. First, however, we discuss the two remaining pairs of constraints needed to account for the typology of rhythmic stress, ALIGN-L/R_{unary} (11d) and ALIGN-L/R_{main} (11e), which are necessary to minimise the number of unary feet in languages and select the primary stress in a word. Both constraints pull unary feet and main stress towards the edges of words.

The function of ALIGN-L/R_{main} corresponds to the old ENDRULE-L/R, and for this reason, there is no need for illustration. Tableau (17) shows the principal effects of ALIGN-L/R_{unary}: they minimise the number of unary feet in ω and, when present, they chain the unary feet to a particular ω-edge.

(17)

σσσσσσσ	ALIGN-R_{unary}	ALIGN-L_{unary}
☞ a. (*σ́σ*)(*σ́σ*)(*σ́σ*)(*σ́*)		*
b. (*σ́σ*)(*σ́*)(*σ́σ*)(*σ́σ*)	*!	*
c. (*σ́*)(*σ́σ*)(*σ́σ*)(*σ́σ*)	*!	
d. (*σ́*)*σ*(*σ́*)(*σ́σ*)(*σ́σ*)	*!*	*

The second class of constraints, given in (18), has the foot as the superordinate category.

(18) *Constraints regulating the location of foot heads and foot dependents within a* Ft

a. TROCHEE
For every foot head, assign a violation mark if it is not initial in its containing Ft.

b. IAMB
For every foot head, assign a violation mark if it is initial in its containing Ft.

c. ALIGN-L/R(Ft_{min}, σ, $Ft_{non\text{-}min}$) (TROCHEE$_{non\text{-}min}$/IAMB$_{non\text{-}min}$)
For every minimal foot Ft_{min}, assign a violation mark if some footed syllable intervenes between $Ft_{non\text{-}min}$ and the left/right edge of its containing Ft.

The first two constraints correspond to the traditional foot-type constraints: TROCHEE favours feet beginning with a strong syllable, and IAMB feet beginning with a weak syllable. The formulation of these constraints does not follow the non-intervention format in (7): they do not specify a separator category. Instead, these alignment constraints favour the presence of a head at the left edge of a foot (in the case of TROCHEE) or its absence (in the case of IAMB). This is for typological reasons, to

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avoid unary-only languages. Note that a unary foot (*σ́*) starts and ends with a strong syllable, while not containing any separators. Hence, if TROCHEE and IAMB were formulated as mirror-image non-intervention constraints, such that TROCHEE banned feet whose head was separated from the left edge of the foot by an intervening syllable, and IAMB banned feet whose head was separated from the right edge of the foot by an intervening syllable, a unary foot would simultaneously respect both constraints. This problem with mirror versions of the foot-form constraints is not specific to our framework, and has been noted by previous authors, who have solved it in a similar asymmetrical way, assuming all unary feet to incur a violation of IAMB (e.g. Tesar & Smolensky 2000). Finally, we propose the foot-form constraints in (18c) to determine the location of the adjunct in an ILT foot: the left version ($\text{TROCHEE}_{\text{non-min}}$) favours ILT feet with a right adjunct ((*σσ*)*σ*), whereas the right version ($\text{IAMB}_{\text{non-min}}$) prefers feet with a left adjunct (*σ*(*σσ*)).

The interaction of these constraints will be crucial in selecting the particular shape of any ILT foot. To illustrate the effects of the constraints in (18), in (19) we provide a list of the possible feet in our model and their respective violations of these constraints.

(19)

	$\text{IAMB}_{\text{non-min}}$	$\text{TROCHEE}_{\text{non-min}}$	TROCHEE	IAMB
((*σ́σ*)*σ*)	*			*
((*σσ́*)*σ*)	*		*	
(*σ*(*σ́σ*))		*		*
(*σ*(*σσ́*))		*	*	
(*σ́σ*)				*
(*σσ́*)			*	
(*σ́*)				*

3 Factorial typology

3.1 Method

The factorial typology of the constraint set was calculated using OTSoft (Hayes *et al*. 2003). Candidates and their violations were generated using a computer script. The constraint set consisted of the twelve *ω*-domain constraints in (11) and the four Ft-domain constraints in (18). With 16 constraints, the number of logically possible rankings equals 16! ($2{\cdot}1 \times 10^{13}$).

Candidates to be evaluated were all the logically possible metrifications of input strings ranging in length from two to eight syllables. GEN was limited to metrifications containing all logically possible combinations of the seven feet in (6) (ternary, binary and unary) plus unparsed syllables. We also excluded two types of candidates. First, candidates whose primary stress foot was in a non-leftmost or non-rightmost position were excluded. These candidates are harmonically bounded under the current

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constraint set. Second, all candidates satisfied culminativity: each contained one and only one primary stress foot. The total number of candidates equalled 10,612 (distributed over different word lengths).

3.2 Results

There were 316 different output patterns, all with distinct bracketings. This represents a huge reduction in the number of logically possible rankings, by a factor $1{\cdot}5 \times 10^{-11}$. For conciseness, we collapsed the 316 patterns by abstracting over the following properties: (a) primary/secondary stress; (b) left/right mirror image; (c) foot headedness. The collapsed forms for the three foot types are given in Table II.

foot forms	collapsed patterns	
unary (U)	(σ́)	(σ̀)
binary (B)	(σσ́), (σ́σ)	(σσ̀), (σ̀σ)
ternary (T)	((σ́σ)σ), ((σσ́)σ), (σ(σ́σ)), (σ(σσ́))	((σ̀σ)σ), ((σσ̀)σ), (σ(σ̀σ)), (σ(σσ̀))

Table II
Collapsed patterns.

We will refer to the collapsed patterns as BTU-PATTERNS. Abstracting in this way allows for a more condensed and insightful discussion of the factorial typology than presenting all the individual patterns, since headedness at the level of Ft_{min} and $\text{Ft}_{\text{non-min}}$ and differences between primary and secondary stresses never interact with foot distribution. For the BTU-patterns presented below as illustrations, we chose to have binary feet (σ́σ) and (σσ́) always agree in headedness with the heads of ILT feet that co-occur in the same pattern.[5]

The factorial typology contained a total of 22 BTU-patterns, classified into nine categories on a rhythmic continuum. None of the potentially optimal candidates in the tableaux submitted to OTSoft had tied violation profiles. This was checked by running the same input file in OTWorkplace (Prince *et al*. 2015). It was established that the total number of predicted languages was the same as the number generated in OTSoft. The factorial typology of 316 languages was also independently replicated from a newly generated input file. This replication was run in OTWorkplace on an automatically generated enlarged set of 27,526 candidates, rather than 10,612, which included all candidates with primary stress on a medial (non-peripheral) foot, all of which turned out to be harmonically bounded.

[5] We present all the individual patterns in the online supplementary materials, available at http://www.journals.cambridge.org/issue_Phonology/Vol32No03, where we indicate whether they are attested.

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We will now discuss the 22 BTU-patterns, subdivided into nine categories. For each BTU-pattern, we will present the ranking that is responsible for generating it, and an example showing data from a language that instantiates it, with the foot boundaries hypothesised. References for metrical systems will be taken mainly from Gordon (2002), and occasionally from other typological studies (Elenbaas & Kager 1999, Kager 2005, 2012).

3.3 The factorial typology

3.3.1 *Rhythmic category A: single-foot systems.* Category A contains two BTU-patterns: a single binary foot and a single ternary foot. Table III shows parsings for forms of two to eight syllables, with examples of attested languages.

B(σ*) (4 subpatterns)	T(σ*) (8 subpatterns)
($\sigma\sigma$) ($\sigma\sigma$)σ ($\sigma\sigma$)$\sigma\sigma$ ($\sigma\sigma$)$\sigma\sigma\sigma$ ($\sigma\sigma$)$\sigma\sigma\sigma\sigma$ ($\sigma\sigma$)$\sigma\sigma\sigma\sigma\sigma$ ($\sigma\sigma$)$\sigma\sigma\sigma\sigma\sigma\sigma$	($\sigma\sigma$) ($\sigma\sigma\sigma$)σ ($\sigma\sigma\sigma$)$\sigma\sigma$ ($\sigma\sigma\sigma$)$\sigma\sigma\sigma$ ($\sigma\sigma\sigma$)$\sigma\sigma\sigma\sigma$ ($\sigma\sigma\sigma$)$\sigma\sigma\sigma\sigma\sigma$ ($\sigma\sigma\sigma$)$\sigma\sigma\sigma\sigma\sigma\sigma$
Tunica, Mohawk, Lakota, Atayal	Macedonian, Choguita Rarámuri

Table III
BTU-patterns for rhythmic category A: single-foot systems.

The notation B(σ*) is used to represent a single binary foot followed by an optional sequence of unparsed syllables, and T(σ*) a single ternary foot followed by an optional sequence of unparsed syllables. The number of subpatterns for each BTU-pattern (4, 8 or 16) is determined by three factors: (a) the number of ILT feet (4 possibilities), (b) the position of the primary stress (2), which is irrelevant in single-foot parsings, and (c) the directionality of parsing (2). Since BTU-patterns abstract over left–right mirror images, the foot occurs either at the left edge (with stress falling on the initial syllable (Tunica), the second syllable (Lakota) or the third syllable (Choguita Rarámuri)) or at the right edge (with stress falling on the final syllable (Atayal), the penultimate (Mohawk) or the antepenultimate (Macedonian)). Note that the two subpatterns converge if the ILT foot in T(σ*) is left-branching at the left word edge or right-branching at the right word edge.

The first pattern, B(σ*), is exemplified in (20a) by initial stress in Tunica (Haas 1946); the other pattern, T(σ*), in (20b) by antepenultimate stress in Macedonian (Lunt 1952).

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(20) a. (ό*σ*)*σ* (ˈlu.pi).ran ‘chameleon’
(ό*σ*)*σσ* (ˈpah.pah).ka.na ‘pleated woodpecker’
b. *σ*((ό*σ*)*σ*) vo.((ˈde.ni).car) ‘miller’
σσ((ό*σ*)*σ*) vo.de.((ˈni.ca).ri) ‘millers’

These patterns are generated by the rankings in (21). Here and below, we suppress any constraints regulating primary/secondary stress. For foot-form constraints, we will assume trochee as a default at the Ft_{min} level, and left-headed ILT feet at the $Ft_{non\text{-}min}$ level.[6] In some cases, foot-form constraints play a crucial role in imposing size restrictions on feet, and hence are included in the rankings.

(21) a. *Ranking for* B(*σ**) (*Tunica*)
CHAIN-R, ALIGN-L/R_{max}, ALIGN-L/$R_{non\text{-}min}$, ALIGN-L/R_{min}, ALIGN-L/R_{unary}, TROCHEE, $TROCHEE_{non\text{-}min}$, $IAMB_{non\text{-}min}$ ≫ CHAIN-L, IAMB
b. *Ranking for* T(*σ**) (*Macedonian*)
CHAIN-L, ALIGN-L/R_{max}, ALIGN-L/$R_{non\text{-}min}$, ALIGN-L/R_{min}, ALIGN-L/R_{unary}, TROCHEE, $TROCHEE_{non\text{-}min}$ ≫ CHAIN-R, IAMB ≫ $IAMB_{non\text{-}min}$

3.3.2 *Rhythmic category B: strictly binary rhythmic systems.* Binary feet are combined with an unparsed syllable in odd-parity forms. There are two BTU-patterns: one attested and basic, another with trisyllabic forms parsed into a single ternary foot, predicting an unattested pattern in case the head of the ternary foot in trisyllabic forms is not in the same position as in forms with binary feet, as in Table IV.

B*(*σ*) (8 subpatterns)	B*(*σ*); T in $[3\sigma]_{\omega}$ (16 subpatterns)
(*σσ*) (*σσ*)*σ* (*σσ*)(*σσ*) (*σσ*)(*σσ*)*σ* (*σσ*)(*σσ*)(*σσ*) (*σσ*)(*σσ*)(*σσ*)*σ* (*σσ*)(*σσ*)(*σσ*)(*σσ*)	(*σσ*) (*σσσ*) (*σσ*)(*σσ*) (*σσ*)(*σσ*)*σ* (*σσ*)(*σσ*)(*σσ*) (*σσ*)(*σσ*)(*σσ*)*σ* (*σσ*)(*σσ*)(*σσ*)(*σσ*)
Pintupi, Warao, Araucanian, Creek	*unattested*

Table IV
BTU-patterns for rhythmic category B: strictly binary systems.

[6] A full typology, with all foot forms unpacked, can be found in the online supplementary materials.

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The first pattern, B*(σ), has iterative binary feet with an unparsed syllable at one edge. In the case of left-to-right trochees, primary stress can be leftmost or rightmost (Pintupi *vs*. Cairene), and similarly for right-to-left trochees (Wargamay *vs*. Warao). Left-to-right iambs occur in Araucanian (primary leftmost) and Creek (primary rightmost). The Pintupi subpattern (Hansen & Hansen 1969) is exemplified in (22).

(22) (σ́σ)(σ̀σ)(σ̀σ) (ˈtʲa.mu).(ˌlim.pa).(ˌtʲuŋ.ku) 'our relation'
(σ́σ)(σ̀σ)(σ̀σ)σ (ˈtʲi.ɭi).(ˌri.ŋu).(ˌlam.pa).tʲu 'the fire for our benefit flared up'

The second pattern, B*(σ); T in $[3\sigma]_{\omega}$, is equivalent to B*(σ), except that an ILT foot occurs in trisyllabic forms. This pattern is equivalent to B*(σ) if left-to-right languages have a left-branching foot in trisyllabic forms and right-to-left languages have a right-branching foot, but not if branchingness and directionality are not correlated in this way. For example, an inconsistency would be difficult to notice if the ternary foot were left-headed ((σσ)σ), since the difference between the adjunct of a $\text{Ft}_{\text{non-min}}$ (trisyllabic forms) and an unparsed syllable (longer odd-numbered forms) would not be audible. Still, inconsistency may arise with a ternary foot with a left adjunct. One example pattern, given in §2 of the online supplementary materials, has initial stress in all #(σ́σ) … forms, except for the unattested trisyllabic (σ(σ́σ)), which has second-syllable stress.

The two patterns are generated by the rankings in (23).

(23) a. *Ranking for* B(σ*) (*Pintupi*)
CHAIN-R, ALIGN-L/$\text{R}_{\text{non-min}}$, ALIGN-L/$\text{R}_{\text{unary}}$, TROCHEE, $\text{TROCHEE}_{\text{non-min}}$, $\text{IAMB}_{\text{non-min}}$ ≫
CHAIN-L ≫
ALIGN-L/R_{max}, ALIGN-L/R_{min}, IAMB
b. *Ranking for* B(σ*); T in $[3\sigma]_{\omega}$ (*unattested*)
CHAIN-R, ALIGN-L/$\text{R}_{\text{non-min}}$, ALIGN-L/$\text{R}_{\text{unary}}$, TROCHEE, $\text{IAMB}_{\text{non-min}}$ ≫
CHAIN-L ≫
ALIGN-L/R_{max}, ALIGN-L/R_{min}, IAMB, $\text{TROCHEE}_{\text{non-min}}$

3.3.3 *Rhythmic category C: mixed binary/unary systems*. Here, binary feet combine with a single unary foot. Again, there are two BTU-patterns: the first is common, while the second (with the unary foot suppressed in trisyllabic forms) is unattested, as shown in Table V.

The first pattern, B*(U), has iterative binary feet and a unary foot at the left or right edge in odd-parity forms. This results in a perfect grid, with left-to-right trochees (Maranungku) or right-to-left iambs (Weri). A stress clash occurs in the remaining cases (leftward trochees (Passamaquoddy); rightward iambs (Ojibwa)). Examples from Maranungku (Tryon 1970) are given in (24).

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B*(U) (8 subpatterns)	B*U; T in $[3\sigma]_{\omega}$ (16 subpatterns)
$(\sigma\sigma)$ $(\sigma\sigma)(\sigma)$ $(\sigma\sigma)(\sigma\sigma)$ $(\sigma\sigma)(\sigma\sigma)(\sigma)$ $(\sigma\sigma)(\sigma\sigma)(\sigma\sigma)$ $(\sigma\sigma)(\sigma\sigma)(\sigma\sigma)(\sigma)$ $(\sigma\sigma)(\sigma\sigma)(\sigma\sigma)(\sigma\sigma)$	$(\sigma\sigma)$ $(\sigma\sigma\sigma)$ $(\sigma\sigma)(\sigma\sigma)$ $(\sigma\sigma)(\sigma\sigma)(\sigma)$ $(\sigma\sigma)(\sigma\sigma)(\sigma\sigma)$ $(\sigma\sigma)(\sigma\sigma)(\sigma\sigma)(\sigma)$ $(\sigma\sigma)(\sigma\sigma)(\sigma\sigma)(\sigma\sigma)$
Maranungku, Weri	*unattested*

Table V
BTU-patterns for rhythmic category C: mixed binary/unary systems.

(24) (σ́σ)(σ̀σ) (ˈja.ŋar).(ˌma.ta) 'the Pleiades'
(σ́σ)(σ̀σ)(σ̀) (ˈŋal.ti).(ˌri.ti).(ˌri) 'tongue'

The second BTU-pattern, B*(U); T in $[3\sigma]_{\omega}$, which is unattested, is a minimal variation on the Maranungku pattern, such that trisyllabic words have no final secondary stress. The rankings for the two patterns are given in (25).

(25) a. *Ranking for* B*(U) (*Maranungku*)
CHAIN-L/R, ALIGN-L/$R_{non\text{-}min}$, ALIGN-R_{unary}, TROCHEE, TROCHEE$_{non\text{-}min}$, IAMB$_{non\text{-}min}$ ≫
ALIGN-L/R_{max}, ALIGN-L/R_{min}, ALIGN-L_{unary}, IAMB
b. *Ranking for* B*(U); T in $[3\sigma]_{\omega}$ (*unattested*)
CHAIN-L/R, ALIGN-L/$R_{non\text{-}min}$, ALIGN-R_{unary}, TROCHEE, TROCHEE$_{non\text{-}min}$, IAMB$_{non\text{-}min}$ ≫
ALIGN-L/R_{max}, ALIGN-L/R_{min}, ALIGN-L_{unary}, IAMB

3.3.4 *Rhythmic category D: mixed binary/ternary systems.* In this category binary feet combine with a ternary foot in odd-parity forms, as in Table VI.

The first BTU-pattern, B*(T), corresponds to BIDIRECTIONAL systems such as Garawa (initial primary stress, secondaries from right-to-left) and Piro (its mirror image), which are predicted to be exhaustively footed. This pattern also predicts an (alternative) exhaustive parsing of UNIDIRECTIONAL systems (in addition to category B). Importantly, although the stress pattern is ambiguous between two metrical bracketings (categories B and D) in such cases, non-stress evidence may be available to resolve this ambiguity. Whether the pattern is bidirectional or unidirectional depends on the location of the adjunct in the ILT foot. If it is left-branching in a left-to-right pattern (or right-branching in a right-to-left pattern), it is unidirectional; however when directionality and

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B*(T) (16 subpatterns)	B*(T)(B) (16 subpatterns)
(σσ) (σσσ) (σσ)(σσ) (σσ)(σσσ) (σσ)(σσ)(σσ) (σσ)(σσ)(σσσ) (σσ)(σσ)(σσ)(σσ)	(σσ) (σσσ) (σσ)(σσ) (σσ)(σσσ) (σσ)(σσ)(σσ) (σσ)(σσσ)(σσ) (σσ)(σσ)(σσ)(σσ)
Garawa, Piro, Pintupi, Araucanian	Indonesian

Table VI

BTU-patterns for rhythmic category D: mixed binary/ternary systems.

branchingness have the opposite relationship (a right-branching ILT foot in a left-to-right pattern or a left-branching ILT foot in a right-to-left pattern), it is bidirectional. The bidirectional pattern with right-to-left trochees and initial dactyl is exemplified in (26a) by Garawa (Furby 1974).

(26)	a.	(σ́σ)(σ̀σ)(σ̀σ)	(ˈja.ka).(ˌla.ka).(ˌlam.pa)	‘loose’
		((σ́σ)σ)(σ̀σ)(σ̀σ)	((ˈŋan.ki).ɽi).(ˌki.rim).(ˌpa.ji)	‘fought with boomerangs’
	b.	(σ(σ́σ))	(bi.(ˈca.ra))	‘speak’
		(σ̀σ)(σ́σ)	(ˌbi.jak).(ˈsa.na)	‘wise’
		(σ̀σ)(σ(σ́σ))	(ˌkon.ti).(nu.(ˈa.si))	‘continuation’
		(σ̀σ)(σ̀σ)(σ́σ)	(ˌe.ro).(ˌdi.na).(ˈmi.ka)	‘aerodynamics’
		(σ̀σ)(σ(σ̀σ))(σ́σ)	(ˌa.me).(ri.(ˌka.ni)).(ˈsa.si)	‘Americanisation’

The second BTU-pattern, B*(T)(B), has T in medial position. This is attested in a rather subtle way in Indonesian (Cohn 1989), as shown in (26b). Primary stress is penultimate, and an initial secondary stress occurs in forms of minimally four syllables, while in longer odd-parity words, secondary stresses go from right to left. Penultimate stress in trisyllabic forms indicates a right-headed $\text{Ft}_{\text{non-min}}$ ((σ(σ́σ))), while consistent initial secondary stress in longer forms shows that $\text{Ft}_{\text{non-min}}$ avoids initial position. This pattern is referred to as ‘complex bidirectional’ by Elenbaas & Kager (1999), as the secondary stress foot is at the opposite edge to the primary stress, while the other secondaries depart from the primary stress.[7] However, the terms

[7] An anonymous reviewer reminds us that ‘words of 9 syllables are needed to see directionality in such systems, e.g. (σσ)(σσ)(σσσ)(σσ) *vs*. (σσ)(σσσ)(σσ)(σσ), and it is in such cases that categorical alignment constraints have been known to fail in determining a unique optimum (e.g. McCarthy 2003: 79)’. The reviewer is correct that the current constraint set fails to differentiate these parsings. Yet non-intervention constraints are in principle able to succeed, staying fully within general assumptions on the non-intervention format. Specifically, what is needed is a constraint pair banning $\text{Ft}_{\text{non-min}}$ at the right/left edge, plus a pair of non-intervention constraints ‘No $\text{Ft}_{\text{non-min}}$ intervenes between Ft and the L/R edge of ω’.

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'bidirectional' and 'complex bidirectional' do not readily translate into our typology as B*(T) *vs*. B*(T)(B), which abstracts away from the primary–secondary distinction.

The rankings for Garawa and Indonesian are given in (27).

(27) a. *Ranking for* B*(T) (*Garawa*)
CHAIN-L/R, ALIGN-$L_{non\text{-}min}$, ALIGN-L/R_{unary}, TROCHEE, $TROCHEE_{non\text{-}min}$ ≫
ALIGN-L/R_{max}, ALIGN-$R_{non\text{-}min}$, ALIGN-L/R_{min}, IAMB, $IAMB_{non\text{-}min}$

b. *Ranking for* B*(T)(B) (*Indonesian*)
CHAIN-L/R, ALIGN-L/R_{unary}, TROCHEE, $IAMB_{non\text{-}min}$ ≫
$TROCHEE_{non\text{-}min}$ ≫
ALIGN-L/R_{max}, ALIGN-L_{min}, IAMB ≫
ALIGN-$L_{non\text{-}min}$, ALIGN-R_{min} ≫
ALIGN-$R_{non\text{-}min}$

3.3.5 *Rhythmic category E: mixed ternary/binary/unary systems*. This category combines ternary with binary and unary feet, as in Table VII.

T(B*)(U) (16 subpatterns)	T*(B/U)(B) (16 subpatterns)	T*(B/U) (16 subpatterns)	(B)T*(U) (16 subpatterns)
(σσ) (σσσ) (σσσ)(σ) (σσσ)(σσ) (σσσ)(σσ)(σ) (σσσ)(σσ)(σσ) (σσσ)(σσ)(σσ)(σ)	(σσ) (σσσ) (σσσ)(σ) (σσσ)(σσ) (σσσ)(σσσ) (σσσ)(σσ)(σσ) (σσσ)(σσσ)(σσ)	(σσ) (σσσ) (σσσ)(σ) (σσσ)(σσ) (σσσ)(σσσ) (σσσ)(σσσ)(σ) (σσσ)(σσσ)(σσ)	(σσ) (σσσ) (σσσ)(σ) (σ)(σσσ) (σσσ)(σσσ) (σσσ)(σσσ)(σ) (σσ)(σσσ)(σσσ)
Kashaya	*unattested*	*unattested*	*unattested*

Table VII
BTU-patterns for rhythmic category E: mixed ternary/binary/unary systems.

The first pattern, T(B*)(U), has a single ternary foot at one edge, with binary feet moving away from the ternary foot, and a unary foot at the opposite edge. The pattern seems to be attested in Kashaya (Buckley 2014) with third-syllable accent (an ILT anapest) and rightward iambic rhythm, as in (28).[8]

Such constraints, whose separator category equals a *specific* foot type, fully conform to the non-intervention format.

[8] Note that final unary feet (but not initial ternary feet) are assumed by Buckley (1997). However, Buckley (2014) adopts initial ternary feet, abandoning the final

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(28) (σ(σό))(σὸ) (ʃu.(ʈ'o.ˈji)).(ʧ'e.ˌdu) 'keep peeling'
(σ(σό))(σὸ)(ὸ) (bi.(mu.ˈʧi)).(du.ˌʧe).(ˌdu) 'used to eat'

The next two patterns, T*(B/U)(B) and T*(B/U), have iterative ternarity, resolving non-ternary sequences with various combinations of binary and unary feet. These patterns appear to be unattested. Note that both correspond to Chugach when the ILT foot is a left-branching amphibrach with an iambic head. However, the bracketings do not correspond to Chugach; (*σόσ*)(*ό*), for example, differs from (*σό*)(*σό*), as evidenced by consonant fortition and other foot-based processes (Rice 1992).

The fourth pattern, (B)T*(U), is 'non-directional', since it is inconsistent in the edge (left/right) towards which the pattern is oriented (Elenbaas & Kager 1999: 322). Ternary feet are assigned from left to right in forms of length 3*n*+1, but from right to left in forms of length 3*n*+2. Non-directionality may disrupt the consistency of stress placement at the left or right edge, depending on foot headedness. For example, if ILT feet are left-branching in the (B)T*(U) pattern, stress placement will be consistent at the left edge, but inconsistent at the right edge, and *vice versa*. Notice too that non-directionality may cause inconsistent placement of primary or secondary stress, depending on the edge at which the primary stress is situated.

The ranking for the four patterns is given in (29).

(29) a. *Ranking for* T(B*)(U) (*Kashaya*)
CHAIN-L/R, ALIGN-$L_{non\text{-}min}$, ALIGN-R_{unary}, IAMB, $IAMB_{non\text{-}min}$ ≫
ALIGN-L/R_{max}, ALIGN-L/R_{min}, TROCHEE ≫
ALIGN-$R_{non\text{-}min}$, ALIGN-L_{unary}, $TROCHEE_{non\text{-}min}$

b. *Ranking for* T*(B/U)(B) (*unattested*)
CHAIN-L/R, ALIGN-R_{unary}, TROCHEE, $TROCHEE_{non\text{-}min}$ ≫
ALIGN-L/R_{max}, IAMB ≫
ALIGN-$L_{non\text{-}min}$ ≫
ALIGN-L/R_{min} ≫
ALIGN-$R_{non\text{-}min}$, ALIGN-L_{unary}, $IAMB_{non\text{-}min}$

c. *Ranking for* T*(B/U) (*unattested*)
CHAIN-L/R, ALIGN-R_{min}, ALIGN-R_{unary}, TROCHEE, $TROCHEE_{non\text{-}min}$ ≫
ALIGN-L/R_{max}, ALIGN-$L/R_{non\text{-}min}$, ALIGN-L_{min}, ALIGN-L_{unary}, IAMB, $IAMB_{non\text{-}min}$

d. *Ranking for* (B)T*(U) (*unattested*)
CHAIN-L/R, ALIGN-R_{unary}, TROCHEE, $TROCHEE_{non\text{-}min}$ ≫
ALIGN-L/R_{max}, ALIGN-L_{min}, IAMB ≫
ALIGN-$L_{non\text{-}min}$, ALIGN-R_{min} ≫
ALIGN-$R_{non\text{-}min}$, ALIGN-L_{unary}, $IAMB_{non\text{-}min}$

unary foot. The status of the final unary foot in even-parity words is based on Buckley's (1997) analysis.

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3.3.6 *Rhythmic category F: ternary and binary exhaustive systems.* This rhythmic category combines basic ternarity with occasional binarity to achieve exhaustivity, as in Table VIII.

T*(B)(B) (16 subpatterns)	T*(B)(B/T) (16 subpatterns)	(B)T*(B) (16 subpatterns)
(σσ) (σσσ) (σσ)(σσ) (σσσ)(σσ) (σσσ)(σσσ) (σσσ)(σσ)(σσ) (σσσ)(σσσ)(σσ)	(σσ) (σσσ) (σσ)(σσ) (σσσ)(σσ) (σσσ)(σσσ) (σσσ)(σσ)(σσ) (σσσ)(σσ)(σσσ)	(σσ) (σσσ) (σσ)(σσ) (σσσ)(σσ) (σσσ)(σσσ) (σσ)(σσσ)(σσ) (σσσ)(σσσ)(σσ)
Estonian, Chugach	*unattested*	*unattested*

Table VIII

BTU-patterns for rhythmic category F: ternary and binary exhaustive systems.

The first pattern, T*(B)(B), is unidirectional, as all ternary feet are built starting from a single edge; binary feet occur in pairs or singles at the right edge, resolving non-ternary intervals of four and two syllables respectively. This pattern is attested in Estonian (dactyls) and Chugach (left-branching amphibrachs).

The other patterns, T*(B)(B/T) and (B)T*(B), are respectively bidirectional and non-directional variants of the first one. The patterns are generated by the rankings in (30).

(30) a. *Ranking for*(T*(B)(B) (*Chugach*)
CHAIN-L/R, ALIGN-L/R_{unary}, IAMB, $TROCHEE_{non\text{-}min}$ ≫
ALIGN-L/R_{max}, ALIGN-R_{min}, TROCHEE ≫
ALIGN-L/$R_{non\text{-}min}$, $IAMB_{non\text{-}min}$ ≫
ALIGN-L_{min}

b. *Ranking for* T*(B)(B/T) (*unattested*)
CHAIN-L/R, ALIGN-L/R_{unary}, TROCHEE, $TROCHEE_{non\text{-}min}$ ≫
ALIGN-L/R_{max}, IAMB ≫
ALIGN-$L_{non\text{-}min}$, $IAMB_{non\text{-}min}$ ≫
ALIGN-$R_{non\text{-}min}$, ALIGN-L_{min} ≫
ALIGN-R_{min}

c. *Ranking for* (B)T*(B) (*unattested*)
CHAIN-L/R, ALIGN-L/R_{unary}, TROCHEE, $TROCHEE_{non\text{-}min}$ ≫
ALIGN-L/R_{max}, ALIGN-R_{min}, IAMB ≫
ALIGN-$R_{non\text{-}min}$, ALIGN-L_{min}, $IAMB_{non\text{-}min}$ ≫
ALIGN-$L_{non\text{-}min}$

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3.3.7 *Rhythmic category G: ternary and binary non-exhaustive systems*. This category involves ternary systems that only opt for a binary foot in $3n+2$ forms, but have an unparsed syllable in $3n+1$ forms, as in Table IX.

T*(B/σ) (16 subpatterns)	(B)T*(σ) (16 subpatterns)
(σσ) (σσσ) (σσσ)σ (σσσ)(σσ) (σσσ)(σσσ) (σσσ)(σσσ)σ (σσσ)(σσσ)(σσ)	(σσ) (σσσ) (σσσ)σ (σσ)(σσσ) (σσσ)(σσσ) (σσσ)(σσσ)σ (σσ)(σσσ)(σσσ)
Tripura Bangla, Hocąk	*unattested*

Table IX
BTU-patterns for rhythmic category G:
ternary and binary non-exhaustive systems.

The first pattern, T*(B/σ), is unidirectional, as all ternary feet are built starting from a single edge; ternary feet are preferred, but a binary foot occurs to avoid a pair of unparsed syllables and a single syllable remains unparsed. This pattern is attested in light-syllable words in Tripura Bangla (dactyls), and in Hocąk (anapests).

The second pattern, (B)T*(σ), is a non-directional variant of the first, combining binary feet and unparsed syllables at *different* edges. As shown in §7 of the online supplementary materials, breaking down this pattern into left-branching *vs*. right-branching feet brings out two degrees of non-directionality: one pattern (with left-branching feet) is inconsistent at the right edge only, while the second pattern (with right-branching feet) is inconsistent at both edges. The rankings are given in (31).

(31) a. *Ranking for* T*(B/σ) (*Tripura Bangla*)
CHAIN-R, ALIGN-R_{min}, ALIGN-L/R_{unary}, TROCHEE, $\text{TROCHEE}_{non\text{-}min}$ ≫
CHAIN-L ≫
ALIGN-L/R_{max}, ALIGN-$L/R_{non\text{-}min}$, ALIGN-L_{min}, IAMB, $\text{IAMB}_{non\text{-}min}$

b. *Ranking for* (B)T*(σ) (*unattested*)
CHAIN-R, ALIGN-L_{min}, ALIGN-L/R_{unary}, TROCHEE, $\text{IAMB}_{non\text{-}min}$ ≫
CHAIN-L ≫
ALIGN-L/R_{max}, ALIGN-$L/R_{non\text{-}min}$, ALIGN-R_{min}, IAMB, $\text{TROCHEE}_{non\text{-}min}$

3.3.8 *Rhythmic category H: strictly ternary systems*. This category displays a single strictly ternary pattern, attested in Cayuvava (dactyls), Gilbertese (left-branching amphibrachs) and Sentani (right-branching amphibrachs), as in Table X.

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T*(σ)(σ) (16 subpatterns)
(σσ) (σσσ) (σσσ)σ (σσσ)σσ (σσσ)(σσσ) (σσσ)(σσσ)σ (σσσ)(σσσ)σσ
Cayuvava, Gilbertese, Sentani

Table X
BTU-patterns for rhythmic category H: strictly ternary systems.

Cayuvava data were presented in (1a). The ranking for Cayuvava is given in (32).

(32) *Ranking for* T*(σ)(σ) (*Cayuvava*)
CHAIN-R, ALIGN-L/R_{min}, ALIGN-L/R_{unary}, TROCHEE, $IAMB_{non\text{-}min}$ ≫
CHAIN-L ≫
ALIGN-L/R_{max}, ALIGN-L/$R_{non\text{-}min}$, IAMB, $TROCHEE_{non\text{-}min}$

3.3.9 *Rhythmic category I: mixed ternary/binary triple stray systems*. This category contains four BTU-patterns with 'chained dual-foot parsings', as in Table XI: each has a single ternary foot, which is chained with a single binary foot. Patterns differ in their parsing of four-syllable forms (which either have an unparsed syllable or a unary foot), as well as in whether the ternary or binary foot occurs in peripheral position. None of the patterns seem to be attested (but see below).

T(B)σ* (16 subpatterns)	T(B/U)(σ*) (16 subpatterns)	(B)T(σ*) (16 subpatterns)	(B/U)T(σ*) (16 subpatterns)
(σσ) (σσσ) (σσσ)σ (σσσ)(σσ) (σσσ)(σσ)σ (σσσ)(σσ)σσ (σσσ)(σσ)σσσ	(σσ) (σσσ) (σσσ)(σ) (σσσ)(σσ) (σσσ)(σσ)σ (σσσ)(σσ)σσ (σσσ)(σσ)σσσ	(σσ) (σσσ) (σσσ)σ (σσ)(σσσ) (σσ)(σσσ)σ (σσ)(σσσ)σσ (σσ)(σσσ)σσσ	(σσ) (σσσ) (σ)(σσσ) (σσ)(σσσ) (σσ)(σσσ)σ (σσ)(σσσ)σσ (σσ)(σσσ)σσσ
unattested	*unattested*	*unattested*	*unattested*

Table XI
BTU-patterns for rhythmic category I: mixed ternary/binary triple stray systems.

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The four patterns are generated by the rankings in (33).

(33) a. *Ranking for* T(B)(σ*) (*unattested*)
CHAIN-R, ALIGN-$L_{non\text{-}min}$, ALIGN-R_{min}, ALIGN-L/R_{unary}, TROCHEE, $\text{TROCHEE}_{non\text{-}min}$ ≫
CHAIN-L ≫
ALIGN-L/R_{max}, ALIGN-$R_{non\text{-}min}$, ALIGN-L_{min}, IAMB, $\text{IAMB}_{non\text{-}min}$

b. *Ranking for* T(B/U)(σ*) (*unattested*)
CHAIN-R, ALIGN-$L_{non\text{-}min}$, ALIGN-R_{min}, ALIGN-R_{unary}, TROCHEE, $\text{TROCHEE}_{non\text{-}min}$ ≫
CHAIN-L ≫
ALIGN-L/R_{max}, ALIGN-$R_{non\text{-}min}$, ALIGN-L_{min}, ALIGN-L_{unary}, IAMB, $\text{IAMB}_{non\text{-}min}$

c. *Ranking for* (B)T(σ*) (*unattested*)
CHAIN-R, ALIGN-$R_{non\text{-}min}$, ALIGN-L_{min}, ALIGN-L/R_{unary}, TROCHEE, $\text{TROCHEE}_{non\text{-}min}$ ≫
CHAIN-L ≫
ALIGN-L/R_{max}, ALIGN-$L_{non\text{-}min}$, ALIGN-R_{min}, IAMB, $\text{IAMB}_{non\text{-}min}$

d. *Ranking for* (B/U)T(σ*) (*unattested*)
CHAIN-R, ALIGN-$R_{non\text{-}min}$, ALIGN-L_{min}, ALIGN-L_{unary}, TROCHEE, $\text{TROCHEE}_{non\text{-}min}$ ≫
CHAIN-L ≫
ALIGN-L/R_{max}, ALIGN-$L_{non\text{-}min}$, ALIGN-R_{min}, ALIGN-R_{unary}, IAMB, $\text{IAMB}_{non\text{-}min}$

(34) gives a tableau for an eight-syllable form, which illustrates how 'chained dual-foot parsings' may arise.

(34)

σσσσσσσσ	ALIGN-$L_{non\text{-}min}$	ALIGN-R_{min}	CHAIN-L
☞ a. ((σσ)σ)(σσ)σσσ			***
b. ((σσ)σ)σσσσσ			****!*
c. ((σσ)σ)(σσ)(σσ)σ		*!	*
d. (σσ)(σσ)(σσ)(σσ)		*!**	
e. ((σσ)σ)((σσ)σ)σσ	*!		**

Maximally one ternary foot ($Ft_{non\text{-}min}$) occurs in leftmost position, and maximally one binary foot (Ft_{min}) occurs in rightmost position. So when two feet occur, these are necessarily of different sizes, with two opposite-edge non-intervention constraints targeting different feet. The pattern perhaps looks strange, but it may nevertheless be attested. For example, Ioway-Oto (Whitman 1947: 238) is reported to have free primary stress falling on the initial or second syllable (a disyllabic stress window), while secondary stress predictably falls on the third syllable after the one bearing the primary stress. No examples are given in the source, and for this reason we are hesitant to classify any of the patterns in category I as 'attested'.

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3.4 Discussion

The factorial typology contains 316 patterns, grouped into nine rhythmic categories, giving a total of 22 BTU-patterns. All nine rhythmic categories, except possibly one (category I), contain at least one attested stress pattern. Our discussion will focus on two criteria: undergeneration and overgeneration. We will then turn to the binary-to-ternary rhythmic continuum.

3.4.1 *Undergeneration*. We will compare our typology with Gordon's (2002) factorial typology of quantity-insensitive stress systems. As compared to Gordon's typology, two cases of undergeneration occur; for each case, we will discuss the possible need for additional constraints.

Our constraint set fails to generate 'dual stress systems' such as Sibutu Sama (Allison 1979), in which one foot is fixed at one edge and another at the opposite edge.[9] Such systems fall outside the current study, together with quantity-sensitive and lexical stress systems.

Another pattern that our typology fails to generate is a specific subtype of what Gordon (2002: 531) refers to as 'binary-plus-clash' systems. Our typology includes four of the five binary-plus-clash systems reported by Gordon: Central Alaskan Yup'ik, Southern Paiute, Gosiute Shoshone and Biangai, all generated in the class of mixed binary/unary systems (C). The only system the typology fails to generate has stresses on both the first and final syllables, with binary rhythmic stresses in between, as has been reported for Tauya (MacDonald 1990). In order to generate Tauya, the current constraint set needs to be enlarged by a categorical alignment constraint that anchors a unary foot at the right ω-edge. The consequences for the factorial typology are an extension of the current one from 316 to 616 patterns. However, since the evidence for initial secondary stress in Tauya is rather doubtful (Hyde 2014: 320), we are reluctant to adopt this constraint.

3.4.2 *Overgeneration*. Since twelve of the 22 BTU-patterns are unattested, we must ask whether any of these unattested patterns are in any sense 'pathological'. The term has been employed in different ways in the literature; here we use the following definition: 'any pattern in which the location of stresses in forms of different lengths is inconsistent, with respect to strings of syllables counted from both edges of the ω'. Possible types of inconsistencies are defined below.

This definition covers pathologies such as those in Table XII: (a) inconsistency in the position in which the primary stress occurs (i.e. the primary stress is sometimes aligned with one ω-edge and sometimes with the opposite edge; 'licensor attraction'); (b) inconsistent alignment of feet at the left or right edge, depending on syllable count ('odd-even alignment pathology'); (c) inconsistent distance of the primary stress when counted

[9] In order to generate dual stress systems, it is sufficient to extend the current constraint set with a categorical alignment constraint that anchors a foot at the left/right ω-edge.

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from both *ω*-edges ('midpoint pathology'); (d) inconsistent parsings – iterative *vs*. non-iterative – that depend on syllable count ('odd-even parsing pathology'); (e) inconsistent directionality of iterative footing ('non-directionality'); (f) inconsistent parsings of strings that cannot be parsed by a canonical foot ('three-syllable exceptionality').

(a)

Licensor attraction (primary stress)		
	left	right
(σ́σ)σ	1	3
(σ́σ)(σ̀σ)	1	4
(σ̀σ)(σ́σ)σ	3	3
(σ́σ)(σ̀σ)(σ̀σ)	1	6
(σ̀σ)(σ̀σ)(σ́σ)σ	5	3
(σ́σ)(σ̀σ)(σ̀σ)(σ̀σ)	1	8
(σ̀σ)(σ̀σ)(σ̀σ)(σ́σ)σ	7	3

(b)

Odd–even alignment pathology		
	left	right
(σ́σ)σ	1	3
σσ(σ́σ)	3	2
(σ́σ)σσσ	1	5
σσσσ(σ́σ)	5	2
(σ́σ)σσσσσ	1	7
σσσσσσ(σ́σ)	7	2
(σ́σ)σσσσσσσ	1	9

(c)

Midpoint pathology		
	left	right
σ(σ́σ)	2	2
σ(σ́σ)σ	2	3
σσ(σ́σ)σ	3	3
σσ(σ́σ)σσ	3	4
σσσ(σ́σ)σσ	4	4
σσσ(σ́σ)σσσ	4	5
σσσσ(σ́σ)σσσ	5	5

(d)

Odd–even parsing pathology		
	left	right
(σ́σ)σ	1	3
(σ́σ)(σ̀σ)	1 3	2 4
(σ́σ)σσσ	1	5
(σ́σ)(σ̀σ)(σ̀σ)	1 3 5	2 4 6
(σ́σ)σσσσσ	1	7
(σ́σ)(σ̀σ)(σ̀σ)(σ̀σ)	1 3 5 7	2 4 6 8
(σ́σ)σσσσσσσ	1	9

(e)

Non-directionality		
	left	right
((σ́σ)σ)	1	3
((σ́σ)σ)σ	1	4
(σ́σ)((σ̀σ)σ)	1 3	3 5
((σ́σ)σ)((σ̀σ)σ)	1 4	3 6
((σ́σ)σ)((σ̀σ)σ)σ	1 4	4 7
(σ́σ)((σ̀σ)σ)((σ̀σ)σ)	1 3 6	3 6 8
((σ́σ)σ)((σ̀σ)σ)((σ̀σ)σ)	1 4 7	3 6 9

(f)

Three-syllable exceptionality		
	left	right
((σ́σ)σ)	1	3
(σ́σ)(σ̀σ)	1 3	2 4
(σ́σ)(σ̀σ)(σ̀)	1 3 5	1 3 5
(σ́σ)(σ̀σ)(σ̀σ)	1 3 5	2 4 6
(σ́σ)(σ̀σ)(σ̀σ)(σ̀)	1 3 5 7	1 3 5 7
(σ́σ)(σ̀σ)(σ̀σ)(σ̀σ)	1 3 5 7	2 4 6 8
(σ́σ)(σ̀σ)(σ̀σ)(σ̀σ)(σ̀)	1 3 5 7 9	1 3 5 7 9

Table XII

Six pathologies covered by the revised definition; each is exemplified by strings of three to nine syllables; for (a), the position of primary stress is counted from the left and right edges; for (b)–(f), the positions of all stressed syllables are counted from the left and right edges.

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Our factorial typology turns out to have only a modest amount of stress pathology. Importantly, it excludes BTU-patterns exhibiting licensor attraction, odd-even alignment pathology, midpoint pathology and odd-even parsing pathology. However, it does include trisyllabic exceptionality and non-directionality.

Trisyllabic exceptionality occurs in several BTU-patterns in categories B and C, where deviations from binarity are resolved by underparsing or unary feet, except in trisyllabic forms, where ILT feet occur. We hypothesise that its non-attestation arises from perceptual factors. Hayes (1995: 100ff) argues that a stressed *vs*. unstressed contrast may be difficult to perceive in word-final syllables, due to their propensity to undergo final lengthening (see also Lunden 2014 for an account along the same lines, with experimental support). Final lengthening is known to depend on the length of a word; shorter words may show greater degrees of final lengthening, adding to the perceptual confusability of stressed *vs*. stressless, in particular in the final syllable of a trisyllabic word. This has implications both for the reliability of transcriptions of secondary stress in trisyllables and for the learnability of trisyllabic exceptionality.

Non-directionality occurs in three BTU-patterns (E, F and G), which always occur as a specific variant of some directional pattern. Elenbaas & Kager (1999) judge non-directionality to be sufficient grounds for rejecting a metrical constraint model, but in retrospect this assessment appears to be too harsh. First, instability in the position of primary stress as a function of word length is known to be a major factor in negatively impacting the learnability of a stress system (Staubs 2014). Typological underrepresentation may well be strongly related to reduced learnability. Second, the non-directional character of unattested BTU-patterns is usually only apparent in forms of considerable length, which again reduces the learnability of the non-directional pattern, given reasonable assumptions about the limited amount of relevant input to the learner in the form of long words (Stanton 2014). Consider, for example, the third BTU-pattern in category F, which is identical to the first and second ones for forms with fewer than six syllables.

We conclude that the factorial typology of ILT feet powered by non-intervention constraints contains little 'pathological' overgeneration. However, since so much is still uncertain regarding the impact of learnability on phonological typology, imposing an absolute boundary between 'pathological' and 'well-behaved' patterns may be premature.

3.4.3 *The binary-to-ternary rhythmic continuum*. As anticipated in §1 and §2, an interesting consequence of our factorial typology is that the rhythmic categories B–H form a binary-to-ternary rhythmic continuum. At one end of the continuum, binarity is a strict requirement, while at the other end ternarity is enforced. In between, binary and ternary feet occur in combination. Estonian and Chugach display mixed ternary/

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binary patterns, with the ternary foot being the preferred foot. However, mixed binary/ternary patterns, with the binary foot as the preferred foot, are also attested in languages such as Wargamay, Yidiɲ and Garawa (Kager 1994, Martínez-Paricio 2012, 2013). Distributional evidence for ternarity in such languages was offered in previous studies (see §1 and §2.1 for references). Among the predominantly ternary systems, increasing strictness is seen when going from Estonian and Chugach (category F) through Tripura Bangla and Hocąk (category G) to Cayuvava (category H). The relevant part of the rhythmic continuum (categories D, F, G and H) is given in Table XIII (cf. Table I above).

	Garawa Wargamay	Estonian Chugach	Tripura Bangla Hocąk	Cayuvava
3*n*	((ό*σ*)*σ*)			
3*n*+1	(ό*σ*)(ό*σ*)		((ό*σ*)*σ*)*σ*	
3*n*+2	((ό*σ*)*σ*)(ό*σ*)			((ό*σ*)*σ*)*σσ*
3*n*	(ό*σ*)(ό*σ*)(ό*σ*)	((ό*σ*)*σ*)((ό*σ*)*σ*)		
3*n*+1	((ό*σ*)*σ*)(ό*σ*)(ό*σ*)		((ό*σ*)*σ*)((ό*σ*)*σ*)*σ*	
3*n*+2	(ό*σ*)(ό*σ*)(ό*σ*)(ό*σ*)	((ό*σ*)*σ*)((ό*σ*)*σ*)(ό*σ*)		((ό*σ*)*σ*)((ό*σ*)*σ*)*σσ*
	(T)B*	T*(B)(B)	T*(B/*σ*)	T*(*σ*)(*σ*)

Table XIII
Patterns D, F, G and H on the binary-to-ternary continuum.

At the left end of the continuum (Garawa, Wargamay), ternary feet are used only as last-resort devices in odd-parity forms to ensure exhaustive parsing (Bennett 2012, Martínez-Paricio 2012). At the right end of the continuum (the Cayuvava mirror-image pattern), ternary feet occur rigorously, at the expense of exhaustivity (Kager 1994, Martínez-Paricio 2013). In the two rhythmic types lying between these extremes, ternary feet are preferred to binary feet; exhaustivity is either maintained (allowing multiple binary feet per form; Estonian, Chugach) or relaxed (allowing only one binary foot per form; Tripura Bangla, Hocąk).

The binary-to-ternary rhythmic continuum in Table XIII emerges from the relative ranking of three constraint pairs: CHAIN-L/R (which promote exhaustivity), ALIGN-L/R_{min} (which promote ternarity) and ALIGN-L/$R_{non\text{-}min}$ (which promote binarity).

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(35) *The continuum emerging from constraint rerankings*

a. *Garawa*
CHAIN-L/R, ALIGN-$L_{non\text{-}min}$ ≫ ALIGN-$R_{non\text{-}min}$, ALIGN-L/R_{min}

b. *Estonian*
CHAIN-L/R ≫ ALIGN-R_{min} ≫ ALIGN-$L/R_{non\text{-}min}$ ≫ ALIGN-L_{min}

c. *Tripura Bangla*
CHAIN-R, ALIGN-R_{min} ≫ CHAIN-L ≫ ALIGN-$L/R_{non\text{-}min}$, ALIGN-L_{min}

d. *Cayuvava*
CHAIN-R, ALIGN-L/R_{min} ≫ CHAIN-L ≫ ALIGN-$L/R_{non\text{-}min}$

As mentioned in §2.2, the core roles of CHAIN-L/R are to chain feet at an edge and to promote exhaustivity: an unparsed syllable incurs a violation of either the left-edge or right-edge version of the constraint. If both CHAIN-L and CHAIN-R are top-ranked, exhaustivity emerges (Garawa, Estonian). The role of ALIGN-L/R_{min} is to promote ternarity: if both are undominated, strict ternarity emerges (Cayuvava). Finally, ALIGN-$L/R_{non\text{-}min}$ functions to promote binarity; if both its members are top-ranked, ternary feet are excluded (e.g. category B, not shown in (35)). A preference for binarity over ternarity (Garawa, as compared to Estonian) emerges when either ALIGN-$L_{non\text{-}min}$ or ALIGN-$R_{non\text{-}min}$ dominates ALIGN-L/R_{min}. Finally, note that ALIGN-L/R_{max}, targeting feet in general, plays no crucial role in defining binary–ternary differences, as it is neutral with respect to foot size, and can only affect (minimise) the number of feet, not the distribution of differently sized feet.

The tableaux below highlight the three major boundaries on the rhythmic continuum in Table XIII, illustrating how pairs of languages differ minimally from each other with respect to rankings. We start with Garawa and Estonian, languages which both maintain strict exhaustivity. They have identical parsings for odd-parity words, as shown in (36).

(36) a. *Garawa*

σσσσσσσ	CHAIN-R	CHAIN-L	ALIGN-$L_{non\text{-}min}$	ALIGN-$R_{non\text{-}min}$	ALIGN-L_{min}	ALIGN-R_{min}
☞ i. ((*óσ*)*σ*)(*óσ*)(*óσ*)				*	*	*
ii. ((*óσ*)*σ*)((*óσ*)*σ*)*σ*		*!	*!	*		
iii. ((*óσ*)*σ*)*σσσσ*		*!***				

b. *Estonian*

σσσσσσσ	CHAIN-R	CHAIN-L	ALIGN-R_{min}	ALIGN-$L_{non\text{-}min}$	ALIGN-$R_{non\text{-}min}$	ALIGN-L_{min}
☞ i. ((*óσ*)*σ*)(*óσ*)(*óσ*)			*		*	*
ii. ((*óσ*)*σ*)((*óσ*)*σ*)*σ*		*!		*	*	
iii. ((*óσ*)*σ*)*σσσσ*		*!***				

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However, they differ in even-parity forms of six or more syllables, as in (37).

(37) a. *Garawa*

σσσσσσ	CHAIN-R	CHAIN-L	ALIGN-$L_{non\text{-}min}$	ALIGN-$R_{non\text{-}min}$	ALIGN-L_{min}	ALIGN-R_{min}
☞ i. (σσ)(σσ)(σσ)					**	**
ii. ((σσ)σ)((σσ)σ)			*!	*		
iii. ((σσ)σ)σσσ		*!**				

b. *Estonian*

σσσσσσ	CHAIN-R	CHAIN-L	ALIGN-R_{min}	ALIGN-$L_{non\text{-}min}$	ALIGN-$R_{non\text{-}min}$	ALIGN-L_{min}
i. (σσ)(σσ)(σσ)			*!*			**
☞ ii. ((σσ)σ)((σσ)σ)				*	*	
iii. ((σσ)σ)σσσ		*!**				

Both languages enforce exhaustive parsing. Garawa prefers binarity to ternarity; Estonian ternarity to binarity. The relative ranking of ALIGN-$L_{non\text{-}min}$ and ALIGN-R_{min} determines the rhythmic preference: with the former higher-ranked, the rhythm is binary (37a); the reverse ranking produces ternarity (37b). Garawa and Estonian also differ in even-parity words of eight or more syllables, as in (38).

(38) a. *Garawa*

σσσσσσσσ	CHAIN-R	CHAIN-L	ALIGN-$L_{non\text{-}min}$	ALIGN-$R_{non\text{-}min}$	ALIGN-L_{min}	ALIGN-R_{min}
i. ((σσ)σ)((σσ)σ)(σσ)			*!	**	*	
ii. ((σσ)σ)((σσ)σ)σσ		*!*	*!	*		
iii. ((σσ)σ)σσσσσ		*!****				
☞ iv. (σσ)(σσ)(σσ)(σσ)					***	***

b. *Estonian*

σσσσσσσσ	CHAIN-R	CHAIN-L	ALIGN-R_{min}	ALIGN-$L_{non\text{-}min}$	ALIGN-$R_{non\text{-}min}$	ALIGN-L_{min}
☞ i. ((σσ)σ)((σσ)σ)(σσ)				*	**	*
ii. ((σσ)σ)((σσ)σ)σσ		*!*		*	*	
iii. ((σσ)σ)σσσσσ		*!****				
iv. (σσ)(σσ)(σσ)(σσ)			*!**			***

Again, the relative ranking of ALIGN-$L_{non\text{-}min}$ and ALIGN-R_{min} determines rhythmic preference.

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The difference between Estonian and Tripura Bangla can be seen only in odd-parity forms, as in (39).

(39) a. *Estonian*

σσσσσσσ	Chain-R	Chain-L	Align-R_{min}	Align-$L_{non\text{-}min}$	Align-$R_{non\text{-}min}$	Align-L_{min}
☞ i. ((*óσ*)*σ*)(*óσ*)(*óσ*)			*		*	*
ii. ((*óσ*)*σ*)((*óσ*)*σ*)*σ*		*!		*	*	
iii. ((*óσ*)*σ*)*σσσσ*		*!***				

b. *Tripura Bangla*

σσσσσσσ	Chain-R	Align-R_{min}	Chain-L	Align-$L_{non\text{-}min}$	Align-$R_{non\text{-}min}$	Align-L_{min}
i. ((*óσ*)*σ*)(*óσ*)(*óσ*)		*!			*	*
☞ ii. ((*óσ*)*σ*)((*óσ*)*σ*)*σ*			*	*	*	
iii. ((*óσ*)*σ*)*σσσσ*			**!**			

Estonian values exhaustivity higher than ternarity, allowing multiple binary feet whenever needed; in the same-sized strings, Tripura Bangla attaches more importance to ternarity, leaving one syllable unparsed. This difference is due to the relative ranking of Chain-L and Align-R_{min}.

Finally, the difference between Tripura Bangla and Cayuvava can be observed in the even-parity forms in (40).

(40) a. *Tripura Bangla*

σσσσσσσσ	Chain-R	Align-R_{min}	Chain-L	Align-$L_{non\text{-}min}$	Align-$R_{non\text{-}min}$	Align-L_{min}
☞ i. ((*óσ*)*σ*)((*óσ*)*σ*)(*óσ*)				*	**	*
ii. ((*óσ*)*σ*)((*óσ*)*σ*)*σσ*			*!*	*	*	
iii. ((*óσ*)*σ*)*σσσσσ*			*!****			
iv. (*óσ*)(*óσ*)(*óσ*)(*óσ*)		*!**				***

b. *Cayuvava*

σσσσσσσσ	Chain-R	Align-R_{min}	Align-L_{min}	Chain-L	Align-$L_{non\text{-}min}$	Align-$R_{non\text{-}min}$
i. ((*óσ*)*σ*)((*óσ*)*σ*)(*óσ*)			*!		*	**
☞ ii. ((*óσ*)*σ*)((*óσ*)*σ*)*σσ*				**	*	*
iii. ((*óσ*)*σ*)*σσσσσ*				***!**		
iv. (*óσ*)(*óσ*)(*óσ*)(*óσ*)		*!**	*!**			

Tripura Bangla prefers binarity to non-exhaustive parsing; Cayuvava the reverse. The crucial constraints are Chain-L and Align-L_{min}.

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4 General discussion

4.1 Minimal recursion

After the presentation of the empirical force and typological coverage of our theory of ILT feet, there is a major conceptual issue that still needs to be addressed: why are recursive feet different from other recursive prosodic structures? In other words, why is recursion at the foot level *minimal*, if prosodic recursion at other layers of the prosodic hierarchy can in principle be unbounded (Wagner 2005, van der Hulst 2010)?

We believe that the answer to this question lies precisely in the different nature of supra-foot prosodic categories (e.g. the prosodic word, the phonological phrase, etc.) and lower prosodic categories such as the foot. As traditionally acknowledged in prosodic hierarchy theory (e.g. Selkirk 1980, 1981, Nespor & Vogel 1982, 1986), prosodic constituents above the foot are generally defined in relation to their corresponding morphosyntactic categories. That is, the prosodic word is defined in relation to the morphosyntactic word, the phonological phrase in relation to the syntactic phrase, etc. (Ito & Mester 2013: 21 and references therein). Since syntactic structure in principle displays unlimited layers of recursion, it is not unexpected that prosodic categories above the foot display *unlimited* layers of recursion too (e.g. Ladd 2008, Wagner 2010, Ito & Mester 2013). The foot is different in that it is not defined by its relation with morphosyntax, but according to phonological properties such as rhythm, sonority and relative prominence. A foot expresses a rhythmic relation between strong and weak nodes in the prosodic word. Consequently, foot recursion is in principle unmotivated, and has therefore often been completely banned from GEN (Ito & Mester 2007).

Given that there is recent non-stress evidence for ILT feet (see again §1 and §2 and references therein), as well as stress evidence (there are languages with ternary rhythm and mixed binary–ternary rhythm, but not with quaternary rhythm), this paper has investigated the possibility of minimally relaxing the ban on recursion at the foot level, exploring the typological consequences of a framework with minimally recursive feet. More specifically, in our model only $\mathrm{Ft}_{\mathrm{min}}$ can participate in the adjunction operation in GEN, giving rise to ILT feet.

A thorough investigation of the representational and typological predictions made by a theory allowing feet with more than one layer of recursion would require another full-length study. Although we have not found compelling linguistic evidence for multiple layers of recursion at the foot level (not even in languages with one stress per ω), and even though there is no apparent syntactic motivation for recursion at this level of the prosodic hierarchy, it still needs to be explored (i) whether it is desirable to allow multiple layers of foot recursion, and (ii) whether there is in fact any compelling distributional evidence for positing such structures. If there is evidence that GEN can produce such types of multiply recursive feet, our constraint set would need to be reconsidered, since our current

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non-intervention constraints would favour multiply recursive feet, e.g. $[(((\text{Ft})\sigma)\sigma)\sigma)\sigma)]_{\omega}$, over flatter multiply footed structures, e.g. [(Ft)(Ft)(Ft)]$_{\omega}$, and over structures with a single foot plus a sequence of unparsed syllables, e.g. $[(\text{Ft})\sigma\sigma\sigma\sigma]_{\omega}$, under certain circumstances. This is because our non-intervention constraints specifically target multiply footed structures and sequences of unparsed syllables, but not multiply recursive feet.

In an earlier stage of our research, we explored a version of GEN which also allowed $\text{Ft}_{\text{non-min}}$ to participate in the adjunction operation, i.e. we assumed that feet could display more than one layer of recursion. However, the factorial typologies in this approach (comparing our current constraint set with others containing no restrictions on the levels of recursion allowed by GEN) were unable to predict half of the attested systems. For these reasons, and given that it is uncertain which metrical systems could possibly benefit from being analysed with multiply recursive feet, we have followed the lead of authors like van der Hulst (2010) and Ito & Mester (2007, 2013), who suggest that the absolute upper limit on recursion in the foot reflects its intrinsic relation with rhythmic well-formedness, whereas supra-foot prosodic categories, which display a closer relation with syntax, may involve various layers of recursion.[10]

4.2 Unbalanced recursion

Prosodic recursion can take one of two forms: (i) BALANCED, where a higher node dominates two (full) categories of the same type (41a), and (ii) UNBALANCED, where a category of a lower level is adjoined to a higher-level category (41b) (van der Hulst 2010: 322, Vigário 2010: 491). This latter type of structure has been proposed for clitic adjunction in various languages, and matches the type of structure currently proposed for ILT feet, where a syllable is adjoined to a foot to form a superordinate foot, e.g. $((\text{Ft})\sigma)_{\text{Ft}}$.

(41) a. 

b. 

Given that balanced prosodic structures have been proposed for other prosodic categories (e.g. a prosodic word dominating two prosodic words (Ito & Mester 2009: 96a), or an intonational phrase dominating two intonational phrases (Myrberg 2013)), one might wonder whether it is appropriate to ban balanced feet (e.g. $((\sigma\sigma)_{\text{Ft}}(\sigma\sigma)_{\text{Ft}})_{\text{Ft}}$) from GEN. Some authors have posited balanced feet (referred to as 'cola') to account for the existence of tertiary stress in languages like Hungarian (Hammond 1987, Green 1997) and Passamaquoddy (Stowell 1979). However, later research has questioned the empirical status of tertiary

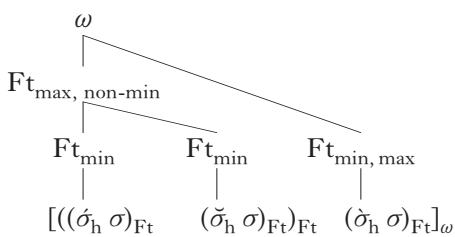
[10] There is yet another possibility: rhythmic systems with intervals of three weak beats between strong beats are difficult to learn (regardless of metrical structure, whether grid or feet); see Heinz (2009).

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stress in these languages, weakening the arguments for cola (e.g. LeSourd 1993, Siptár & Törkenczy 2000).

In our study, we have also banned balanced feet from GEN. That is, we have assumed that GEN does not generate any non-minimal feet such as those in (42) below. Once again, we believe that this difference between recursive feet and recursive supra-foot prosodic categories, which may be balanced, emerges from the close relation between foot-level prominence and rhythm. At higher levels of the prosodic hierarchy, where syntactic structure is mapped onto prosodic structure, prosodic categories are not defined by their phonetic properties, but by their particular relation with (morpho-)syntax. In syntax, a category can be self-embedded in a category of the same type, and hence a head can contain more than one head. In contrast, the rhythmic nature of the metrical foot strictly links up the notion of 'head/stress' and 'foot' in a one-to-one fashion: a foot can have at most one head. In the same way that binary feet with two heads (e.g. $(\sigma_h\sigma_h)$) have generally been excluded from GEN (cf. Bye 1996, Kager 1996), we assume that recursive feet that dominate two feet are also excluded. Note that a balanced foot implies that a non-minimal foot contains more than one foot head at the syllable level. One of the predictions of a language with balanced feet of this sort is that multiple levels of stress can arise, as illustrated in (42), where tertiary stress is represented as $\breve{\sigma}$.

(42)



The primary-stressed syllable is at the same time the head of a minimal foot, the head of a balanced foot and the head of ω. The secondary-stressed syllable is the head of a minimal foot, which is also maximal. Finally, the tertiary-stressed syllable is the head of a minimal foot, which is located in the dependent position of the balanced foot (or colon). It surfaces with stress, but this stress is weaker than the others, due to its dependent status. Self-embedding more than one foot in a recursive foot has various implications with respect to prominence, multiplying the levels of stress, but also the types of weak syllables. Since we do not know of any system or phonological phenomena that could benefit from these structures, and we believe that at lower levels of the prosodic hierarchy, headedness is a definitional property (i.e. the presence of one syllable head or one foot head entails the presence of exactly one syllable/foot), we have not incorporated balanced feet into our analysis.

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4.3 Categorical *vs.* gradient alignment

Our theory of non-intervention categorical alignment constraints offers a new way of accounting for rhythmic stress distributions, which have previously been analysed by means of gradient alignment. Here we focus on some formal properties of categorical and gradient alignment, and on some differences in typological predictions.

In a formal sense, categorical and gradient constraints differ in the maximal number of violation marks they assign to a locus of violation (McCarthy 2003: 79). Gradient alignment constraints are known to cause a non-linear 'quadratic' relationship between the number of elements in a domain evaluated by a constraint and the number of violation marks it assigns (Bíró 2003; similar arguments are put forward by Riggle 2004 and Heinz *et al*. 2005). In contrast, the maximum number of violation marks assigned by a non-intervention categorical alignment constraint is a linear function of the number of loci of violation per form.[11]

A potential concern about non-linearity is related to computational tractability. Several proposals have been made to implement OT grammars as finite state transducers (FSTs) (e.g. Ellison 1994, Frank & Satta 1998, Karttunen 1998, Gerdemann & van Noord 2000). Yet it is known that quadratic constraints cannot be implemented as FSTs (e.g. Eisner 1997, Frank & Satta 1998, Bíró 2003). However, as pointed out by an anonymous reviewer, 'interpretability by a finite state grammar is neither necessary nor always sufficient for computational tractability under all forms'. In sum, quadratic constraints have more computational power than linear ones, yet this only leads to formal concerns if we adopt assumptions on the implementation of OT grammars that are not universally accepted.

A second set of arguments raised against gradient alignment constraints concerns incorrect typological predictions, such as 'midpoint pathology' (Table XIIc; see Eisner 1997, Hyde 2012) and unattested distinctions in directionality among metrical systems (e.g. Kager 2001, McCarthy 2003). Yet, as we argued in §3, criteria for pathology and insights into effects on learnability are currently insufficiently developed to base a decisive argument on.

[11] Gradient assessment by itself does not cause quadratic effects, nor is gradient assessment its only possible cause. First, there is no quadratic function associated with gradient alignment constraints that target a single category per word, such as the primary stress foot; here, the maximum number of violations remains a linear function of the number of syllables per word (e.g. Ellison 1994, Bíró 2003). Second, the number of loci of violation may itself become a non-linear function. For example, Hyde (2012: 799) proposes a change in McCarthy's format of locus of violation that enables categorical alignment constraints to capture distance-sensitive effects. To that end, Hyde redefines the locus of violation (λ) as a triplet $\lambda = (\mathrm{Cat}_1, \mathrm{Cat}_2, \mathrm{Cat}_3)$, where each λ receives maximally one violation mark. Although this format satisfies categorical evaluation for each λ, it nevertheless causes non-linearity, as the number of loci of violation itself becomes a quadratic function of the numbers of Cat_1 and Cat_2, again amounting to a maximum value of $\mathrm{Cat}_1(\mathrm{Cat}_2 - 1)/2$.

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Empirically, it might be asked whether gradient alignment is crucially needed to model metrical patterns. Among the critical cases which have been examined (McCarthy 2003: 116ff, Hyde 2012: 809ff), one stands out. In languages such as Maithili, Hindi, Paumari and Banawá, the primary stress foot cannot be in word-final position, so that the primary stress is retracted to the penultimate foot. This $n-1$ pattern, described using foot extrametricality in rule-based theory (Hayes 1995: 77), can be analysed in gradient alignment theory by ranking NON-FINALITY(Ft_{main}) above RIGHTMOST(Ft_{main}), pulling the primary stress onto the penultimate foot. It may seem that categorical alignment has no account, yet this is not the case. The pattern is analysable by ranking NON-FINALITY(Ft_{main}) above a non-intervention constraint ALIGN-L($[Ft_{max}]_{\omega}$, $[Ft_{main}]_{\omega}$, ω): 'For every maximal foot $[Ft_{max}]_{\omega}$ assign a violation mark if some main foot stress $[Ft_{main}]_{\omega}$ intervenes between Ft_{max} and the left edge of its containing ω', as in (43).

(43)

σσσσσσ	NON-FIN(Ft_{main})	ALIGN-L($[Ft_{max}]_{\omega}$,$[Ft_{main}]_{\omega}$,ω)
☞ a. (*σ̀σ*)(*σ́σ*)(*σ̀σ*)		*
b. (*σ́σ*)(*σ̀σ*)(*σ̀σ*)		**!
c. (*σ̀σ*)(*σ̀σ*)(*σ́σ*)	*!	

Note that the current set only includes constraints whose separator category is an unspecified category, e.g. Ft. Separator-specific non-intervention constraints are not included, since we have not considered non-finality effects (see §4.4). Interestingly, (43) shows that a categorical non-intervention constraint may produce gradient effects while still being linear (not quadratic), as its locus of violation is Ft. In sum, there seems to be no compelling evidence that gradient alignment is crucially needed.

Our approach to circumventing gradient alignment is not the first on record. Previous attempts have been based on the 'rhythmic licensing' framework of Kager (2001, 2005). This framework sets up constraints to license rhythmic configurations such as (extended) lapses and clashes near specific landmarks, such as word edges and stress peaks. Typological and computational studies exploring this approach include McCarthy (2003), Heinz *et al*. (2005) and Houghton (2006, 2008). A full review of this framework is beyond the scope of this paper, but we note here some criticisms that have been raised against it, such as the problem of stressing sequences of light syllables occurring between heavy syllables (Alber 2005), pathological patterns such as 'lapse-licensing' (Heinz *et al*. 2005), the complex locus of violation of lapse-licensing constraints (Buckley 2009) and the inability to deal with distance-counting patterns (Hyde 2012). None of these problems carry over to the present framework, however.

Since no decisive formal or typological arguments can be made against gradient alignment that might favour categorical alignment, we conclude that the two theories seem to be equally able to account for gradient

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metrical distributions. As pointed out by Alan Prince (personal communication), having two full-fledged theories of alignment instead of only one allows us to better evaluate their insights and shortcomings.

4.4 Non-finality

This study has not considered effects of constraints that enforce non-finality in the factorial typology. In order to motivate this, we must separate out the three main types of non-finality effects. It will become clear that in two out of three cases our account is nearly identical to standard accounts, while in a third case, which we consider first, we have offered a reanalysis.

The first non-finality effect is syllable unparsability at edges, the device which leads to locating a foot one syllable away from the edge (Hayes 1982, Prince & Smolensky 1993). At the right edge this leads to parsings such as …(σ́σ)σ]$_{\omega}$, needed for antepenultimate stress in Macedonian, Latin, etc., and at the left edge to parsings such as $_{\omega}$[σ(σσ́)…, required for third-syllable stress in Kashaya, Azkoita Basque, etc. ILT feet generally alleviate the need for non-finality in such cases, reanalysing them as …((σ́σ)σ)]$_{\omega}$ and $_{\omega}$[(σ(σσ́))… respectively (see §4). (See Kager 2012 for discussion of the ILT foot typology in trisyllabic window systems at the left and right word edges.) In summary, in an ILT framework, syllable unparsability at edges is not needed, and is clearly undesirable, because ILT feet in combination with unparsability incorrectly predict stress on the fourth syllable from the edge. Residual cases of unparsability fall out from the interaction of syllable unstressability at edges with foot-form constraints.

The second type is foot extrametricality (Hayes 1995, McCarthy 2003, Hyde 2012), which leads to the desired effect of removing the primary stress of the final foot, and relocating it on the rightmost non-final foot. Such cases were discussed in §4.3, where it was shown that our theory accounts in principle for such effects by the interaction of NON-FINALITY (Ft_{main}) – the constraint also used in standard accounts – with the separator-specific non-intervention constraint ALIGN-L([Ft_{max}]$_{\omega}$, [Ft_{main}]$_{\omega}$, ω).

The third non-finality effect is syllable unstressability at edges, associated mainly with patterns with iterative binary iambs with a foot-prominence reversal (to a binary trochee) on the final foot, e.g. (σσ́)(σσ́)(σσ́)(σ́σ). The constraint responsible bans stress (but not foot structure) from final syllables (see Gordon 2002, for example). Such patterns occur in languages such as Hopi and Ashininca, and in 'restricted trisyllabic window' systems in which primary stress can be antepenultimate or penultimate, but not final. Our analysis is identical to the standard analysis (see Kager 2012 for discussion of window systems).

5 Conclusions

This paper has offered a novel OT analysis of binary and ternary rhythm, using a restrictive format of categorical alignment constraints of the

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non-intervention type (McCarthy 2003). A factorial typology of the constraint set does not undergenerate rhythmic stress systems, and mostly avoids pathological overgeneration. Our alignment constraints are computationally restricted in the sense of lacking quadratic power. Overall, the approach is based on principles that aspire toward locality.

On the representational side, we have argued for the rehabilitation of ILT ternary feet in metrical theory. Contrary to the traditional view that the unique *raison d'être* of ternary feet is their ability to model ternary stress, we have proposed that several foot-conditioned processes in languages with binary stress, as well as in languages with mixed stress patterns, also necessitate ILT feet. This is corroborated by the resulting typology, which suggests that the boundary between binary and ternary systems is not absolute; rather, a continuum emerges, such that binary and ternary feet may coexist in rhythmic stress systems.

At a conceptual level, our non-intervention constraints and the minimally recursive foot constitute an attempt to adhere to locality principles both from the point of view of the formulation of constraints and the possible representations allowed by particular grammars. Our model has thus extended locality from the 'horizontal' dimension (adjacency of heads and dependents; non-intervention format) to the 'vertical' dimension (minimal recursion; vertical locality conditions).

Since the main focus of the paper is quantity-insensitive stress, the factorial typology in §3 was exclusively based on forms with strings of light syllables. Our typology evidently needs extension to quantity-sensitive (rhythmic) stress systems. Another area of future study concerns the typological properties of non-intervention constraints from the viewpoint of parallel *vs*. serial OT, which may answer the question whether the 'residual non-directionality' is an artefact of parallel evaluation or is fundamentally rooted in the constraint set.

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