Evidence for the parallel architecture from the syntax-phonology interface

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Abstract

Two competing views exist on the origin of interface categories (prosodic words, phonological phrases, intonational phrases): rhythmic determinism, which holds that they originate in phonology, and syntactic determinism, which derives them from syntactic constituents. This paper presents empirical evidence from Japanese and Wenzhounese, showing that at least a subset of interface categories cannot be derived from syntax and therefore must be rhythmically determined. These rhythmically determined interface categories call for a generative phonological module, which is incompatible with the classic T-model's assumption that only syntax can generate hierarchical structure. Consequently, evidence for rhythmic determinism supports a parallel architecture, where phonology can be generative and is not secondary to syntax. In LFG's parallel architecture, adopting rhythmic determinism entails that a direct correspondence from c-structure to p-structure is empirically insufficient. I discuss two LFG approaches to the syntax-phonology interface, showing that they can capture the Japanese and Wenzhounese data, though some theoretical issues remain to be addressed.

1 Introduction

According to Ito & Mester (2012: 280–281), the prosodic hierarchy (1) comprises two groups of categories.[†] Syllables and feet are rhythmic categories, defined in purely phonological terms. Prosodic words, phonological phrases, and intonational phrases are interface categories, as they respectively correspond to lexical words, syntactic phrases, and syntactic clauses.

(1)
Intonational Phrase (ι)
|
Phonological Phrase (φ) } *interface categories*
|
Prosodic Word (ω)
|
Foot (Σ)
| } *rhythmic categories*
Syllable (σ)

There are two views regarding the genesis of the interface categories. *Rhythmic determinism* holds that the interface categories originate from phonology, while *syntactic determinism* assumes that they are derived from syntax (Lahiri & Plank 2010, 2022).[1] Works under the Minimalist tradition usually adopt a mixed approach (e.g., Kratzer & Selkirk 2020; Selkirk 2011), taking syntactic determinism as the default and rhythmic determinism as a fallback mechanism. Works under the LFG tradition may take a mixed approach (Bögel 2015; Butt & King 1998) or a purely rhythmic determinist approach (Dalrymple et al. 2019; Dalrymple & Mycock 2011).

I will argue in Section 2 that while both rhythmic determinism and a mixed approach can be accommodated in a parallel architecture of grammar, neither is compatible with

[†]I thank the two anonymous reviewers and the LFG25 audience (in particular, Ash Asudeh, Frances Dowle, Miriam Butt, and Tina Bögel) for their invaluable comments. All remaining errors are mine.

[1]Bögel (2015) refers to these as the parallel approach and the derivative approach, respectively.

Chomsky's (1995) T-model. The T-model presupposes syntactic determinism, which is empirically insufficient because at least a subset of interface categories must be rhythmically determined (Section 3). Consequently, the necessity of rhythmic determinism supports an architecture that acknowledges a generative phonology, i.e., the parallel architecture. Against this background, Section 4 discusses the consequences of adopting rhythmic determinism in the LFG setting and reviews two LFG approaches to the syntax-phonology interface.

2 The origin of interface categories

Rhythmic determinism and syntactic determinism diverge in whether the interface categories are defined independently of syntactic constituents, but neither prevents information from other modules from influencing prosodic phrasing. In this section, I first introduce these two views (for an overview, see Bögel 2015: §2.5 and Xie 2024: §3.3). Then I discuss how these views fit in different architectures of grammar (Section 2.3). It is commonly assumed that both syntactic determinism and rhythmic determinism are required at the syntax-phonology interface (Section 1), but I shall argue that this mixed approach, as well as pure rhythmic determinism, is untenable under the T-model.

2.1 Rhythmic determinism

Rhythmic determinism defines the interface categories in phonological terms. Arguments for rhythmic determinism mainly come from prosodic words because they may radically misalign with syntactic words. A classic example is *drinka pinta milka day* 'drink a pint of milk a day', where right-attaching syntactic words end up prosodically left-attaching (Lahiri & Plank 2010, 2022; Sweet 1885). According to Lahiri & Plank (2022: 140), the prosodic word (ω) in Germanic languages and beyond "begins with a stressed syllable and ends with the syllable that precedes the next main stress." This definition of ω is based on the foot (Σ) rather than a matching syntactic word, indicating that ω is not fundamentally distinct from the rhythmic categories in (1).

Radical mismatches are common at the word level but less common at the phrase and clause level. This leads Lahiri & Plank (2022: 162) to conjecture that "presumably it's syntax and ultimately semantics and pragmatics" that governs the grouping of φ and ι. However, not all work subscribing to rhythmic determinism adopts this mixed approach (e.g., Dalrymple & Mycock 2011; Xie 2023). For example, Dalrymple et al. (2019: 399) assume that all prosodic constituents are "defined independently of units at any other level such as c-structure." Xie (2024: 65) explicates that a higher degree of isomorphism at the phrase and clause level does not necessitate syntactic determinism or a mixed approach. This is because p(rosodic)-structure is headed, meaning that any non-recursive C_n (prosodic category of level n) must immediately dominate a C_{n-1}. Due to this headedness, once ω is rhythmically determined, all higher categories can be licensed without referring to c-structure.

The p-structure rules in (2) define these higher categories.[2] To begin with, (2a) cap-

[2]These rules should be interpreted as node admissibility conditions à la McCawley (1968). They are not rewriting rules, but are a characterisation of the daughters that a p-structure node can dominate (see Dalrymple et al. 2019: 140).

tures Lahiri & Plank's (2022) proposal that ω is based on Σ. It states that a prosodic word immediately dominates one or more feet (one of which would be the head) and zero or more unparsed syllable(s). Higher-level categories φ and ι are licensed by (2b), which requires that a C_n should dominate at least one C_{n-1} and optionally dominate some category lower than C_{n-1}. Finally, (2c) permits recursive p-structures in which a C_n dominates a C_n and other units, but it prohibits vacuous recursion of the form $[_{C_n}$ [... $[_{C_n} C_n]]]$.

(2) a. $\omega \rightarrow \Sigma^{+}, \sigma^{*}$
b. $C_n \rightarrow C_{n-1}^{+}, C_{n-m}^{*}(1 < m < n)$
c. $C_n \rightarrow C_n, C_{n-m}^{+}(0 \leq m < n)$

In sum, p-structure — like c-structure with phrase structure rules — can be licensed by purely phonological conditions such as those in (2). Thus, prosodic categories up to the ι-level are consistently rhythmically determined, regardless of whether they align with their c-structure counterparts. Importantly, these p-structure rules may be too permissive for a given language (e.g., ω in a language may be binary branching but (2a) licenses n-ary branching ωs). This overgeneration is not problematic, since rules like (2) are meant to work in consort with other types of constraints, including interface constraints, to ultimately determine the p-structure shape (Sections 3.1, 4.1). Therefore, the independence of p-structure does not imply that c- and p-structure cannot be mutually constraining.

2.2 Syntactic determinism and mixed approaches

Syntactic determinism assumes that the interface categories are derived from their syntactic counterparts via mapping algorithms (Nespor & Vogel 1986) or Optimality-Theoretic constraints (Selkirk 2011; Truckenbrodt 1999). Selkirk (2009: 40) makes it explicit that the interface categories are "syntactically grounded, in the sense that they *owe their existence* to constraints on the syntax-phonology interface" (emphasis mine).

The two most widely adopted constraint families are ALIGN and MATCH, which serve to convert syntactic constituents into prosodic constituents (see Scheer 2012: 69 for a critical review of this interpretation). ALIGN constraints (e.g., (3a)) require alignment at either the left or right edge, while MATCH constraints mandate that both edges should coincide (3b).

(3) XP-φ correspondence under Optimality Theory (OT)

a. ALIGN-R(XP, φ) (cf. McCarthy & Prince 1993: 80)
For every XP, there is a φ such that the right edge of XP and the right edge of φ coincides.

b. MATCH(XP, φ) (adapted from Elfner 2015: 1178)
For every XP that exhaustively dominates a set of one or more terminal nodes α, there must be a φ that exhaustively dominates all and only the phonological exponents of the terminal nodes in α.

These interface constraints predict that syntax-phonology isomorphism is the default, but they can be interspersed with other phonological markedness constraints, leading to mismatches (Selkirk 2011: §3).

Recent work by Selkirk and her colleagues argues for a division of labour between syntax-to-phonology mapping and phonological readjustment (Kratzer & Selkirk 2020; Lee & Selkirk 2022).

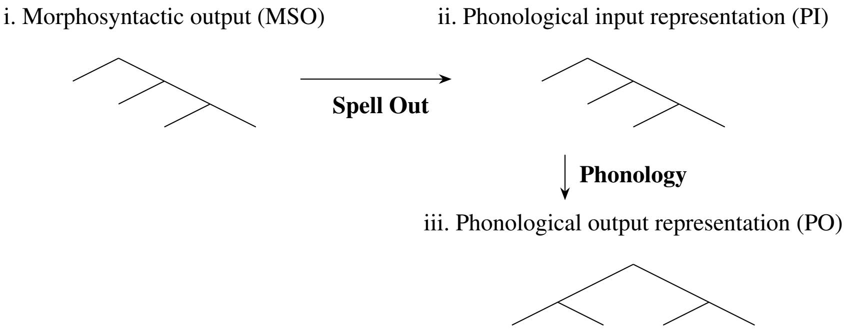


Figure 1: The MSO-PI-PO model (Kratzer & Selkirk 2020)

The model in Figure 1 is couched in a Minimalist framework. During the MSO-to-PI mapping, correspondence constraints like (3) convert surface morphosyntactic structure to hierarchical p-structure. The two structures are by and large isomorphic at this stage. Only during the PI-to-PO mapping do phonological constraints come into play; these constraints may readjust p-structures for rhythmic reasons (e.g., p-structure is optimally binary branching) and thus result in mismatches between the PO and the MSO.

The MSO-PI-PO model features a combination of syntactic determinism and rhythmic determinism. On the one hand, interface categories are derived from syntactic trees during Spell Out. On the other hand, the PI-to-PO mapping enables phonology to create prosodic constituents that lack syntactic correspondents, hence incorporating a certain degree of rhythmic determinism.

Although a mixed model usually has a derivational flavour (as exemplified in Figure 1), its non-derivational implementations can be found in, e.g., Butt & King's (1998) pioneering work that interfaces LFG with phonology. Butt & King (1998) posit a projection from c-structure to p-structure, the latter being described by annotated c-structure rules. As such, the definitions of interface categories are based on syntactic constituency, showing syntactic determinism (Dalrymple et al. 2019: 403).[3] However, as Butt & King (1998) observe, their mapping function cannot handle rebracketing, a type of mismatch where c-structure bracketing contradicts p-structure bracketing, as in (4). They propose to resolve rebracketing in the relationship between p-structure and phonology (similar to the PI-to-PO mapping above), thereby allowing phonology to create certain prosodic constituents as per rhythmic determinism.

While Kratzer & Selkirk (2020) and Butt & King (1998) permit the co-existence of rhythmic determinism and syntactic determinism, I have argued in Section 2.1 that

[3]Miriam Butt (p.c.) noted that they incorporated syntactic determinism not for conceptual reasons, but for ease of computational implementation at that time. More recent computational LFG grammars are able to take input p-structure to disambiguate syntactically ambiguous structures (Bögel & Zhao 2025), so p-structure need no longer be treated as secondary to c-structure in computational implementations.

a purely rhythmic determinist view is achievable. By contrast, a purely syntactic determinist view is untenable because not all interface categories have syntactic correspondents (noted in Butt & King 1998 and to be elaborated in Section 3). In other words, empirical evidence requires any modelling of the syntax-phonology interface to adopt some degree of rhythmic determinism. This poses a problem for the T-model, to which I now turn.

2.3 P-structure and the architecture of grammar

There are two major proposals for how linguistic modules should be organised with respect to each other. The most widely adopted one is the T-model of grammar (Chomsky 1965, 1988, 1995), which places syntax at the core of the grammatical architecture. Syntax is the only *generative* module, which can recursively build hierarchical structures out of primitive and/or derived linguistic objects (Scheer 2013, 2023). Phonology is *interpretive* but not generative, meaning that phonology does not build hierarchical structures but "freely accepts whatever syntax chooses to give it and forms a pronunciation" (Breiss & Hayes 2020: 338).

The other proposal is the parallel architecture, where linguistic structures exist in parallel and have proprietary well-formedness conditions (Bresnan 1998; Culicover & Jackendoff 2005; Jackendoff 1997; Kaplan & Bresnan 1982). Each structure is an independent generative system (Jackendoff 2011: 609), so both syntax and phonology can assemble or license their own hierarchical structures. Such independence does not rule out the possibility of mutual influence, as syntactic and phonological constituents can stand in correspondence via the interface (Kuhn 2007; Dalrymple et al. 2019).

Both the T-model and the parallel architecture can be considered *modular* in the sense that each linguistic structure is domain specific, having its own representations, rules, and/or constraints (Jackendoff 2000; Scheer 2020). However, the two architectures diverge in terms of the direction of information flow, which bears on how syntax should interface with phonology.

A parallel architecture of grammar does not impose an extrinsic ordering on linguistic modules, so information can flow between them freely (Kuhn 2007: 614). Therefore, the interface categories can in principle be either rhythmically determined or syntactically determined under a parallel architecture. In LFG, this means p-structure can be licensed by purely phonological rules like (2), which showcases rhythmic determinism. On the other hand, a non-derivational interpretation of syntactic determinism is that p-structure is described based on syntactic constituents (i.e., description by analysis; see Dalrymple et al. 2019: §7.4.1). To clarify, although pure syntactic determinism is theoretically compatible with LFG (and other parallel grammars), existing LFG works either assume pure rhythmic determinism or a mixed approach (Sections 2.1–2.2).

In the T-model, the information flow is uni-directional: syntax feeds its output as the input to phonology (cf. Reiss 2007). This, together with the assumption that only syntax is generative, entails pure syntactic determinism. Since no module other than syntax can generate hierarchical structure, any articulated structure in phonology must originate from syntax. In Minimalist terms, the syntactic operation Merge is the only way to combine smaller units into larger ones, so phonology cannot actively build hierarchical structures due to the lack of a Merge equivalent. This design feature of the

T-model requires every interface category to have a syntactic correspondent, for otherwise the relevant interface category would remain undefined. Therefore, the syntax-to-phonology mapping f can be conceived as a surjective partial function: every interface category p must be mapped to by at least one syntactic constituent s, i.e., $f^{-1}(p) \neq \emptyset$. In the MSO-PI-PO model (Figure 1), there should be an additional requirement that the PI-to-PO mapping be surjective, for otherwise phonology would be generative.

Section 3 will provide empirical evidence that not all interface categories have a syntactic correspondent, so the syntax-to-phonology mapping (or the PI-to-PO mapping) cannot be surjective. Thus, any adequate approach to the syntax-phonology interface must integrate some degree of rhythmic determinism, allowing phonology to generate a subset of prosodic categories. However, rhythmic determinism is precluded by the T-model, since phonology is assumed to be interpretive but not generative. As a result, grammars adopting the T-model face a dilemma. They must either consistently adhere to syntactic determinism and undergenerate the data, or acknowledge rhythmic determinism and deviate from one of the T-model's fundamental assumptions. The consequences of the latter option have not been addressed, as far as I am aware. In view of this, evidence for rhythmic determinism conflicts with the T-model, which leads to the conclusion that the parallel architecture more accurately reflects the nature of the syntax-phonology interface.

3 Supporting rhythmic determinism

This section presents data from Japanese (Section 3.1) and Wenzhounese (Section 3.2), showing that an interface category does not necessarily have a matching syntactic constituent. Such interface categories must be formed in phonology proper, hence invalidating pure syntactic determinism. In other words, any adequate modelling of the syntax-phonology interface must admit some degree of rhythmic determinism.

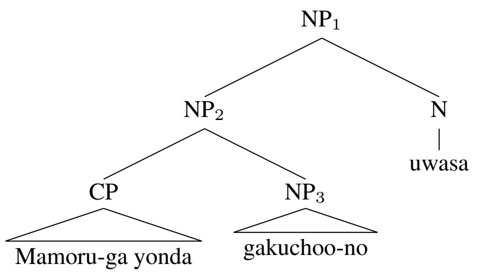
3.1 Rebracketing and category promotion in Japanese

Kubozono (1989) observes that, in Tokyo Japanese, a uniformly left-branching syntactic tree may be parsed as a symmetrically branching prosodic tree.

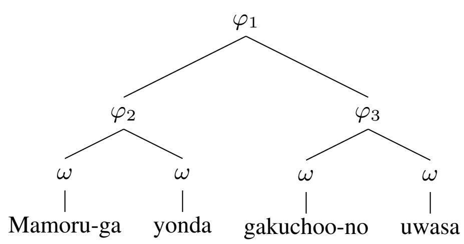
(4) Left-branching phrase with unaccented words (Kalivoda 2018: 95)

a. Mamoru-ga yonda gakuchoo-no uwasa
Mamoru-NOM invited college.president-GEN rumour
'the rumour of the college president that Mamoru invited'

b.



c.



The words in (4a) are all unaccented (accented words will be discussed shortly).[4] In (4b), *Mamoru-ga yonda* and *gakuchoo-no* form a constituent NP_2 to the exclusion of *uwasa*. In (4c), *gakuchoo-no* and *uwasa* form a constituent φ_3 to the exclusion of *Mamoru-ga yonda*, thus exhibiting a rebracketing mismatch. Crucially, φ_3 does not have a matching syntactic phrase.

Selkirk (2011: 469) attributes the mismatch in (4) to the markedness constraint BIN-MAX(φ, ω), which requires φ to contain no more than two ωs. In (5), "U" denotes unaccented words, square brackets mark syntactic phrases, and parentheses delimit phonological phrases.

(5)

$[[[[\mathrm{U}_1]\mathrm{U}_2]\mathrm{U}_3]\mathrm{U}_4]$	BINMAX(φ, ω)	MATCH(XP, φ)
⇒ a. $((\mathrm{U}_1\mathrm{U}_2)(\mathrm{U}_3\mathrm{U}_4))$	*	**
b. $((((\mathrm{U}_1)\mathrm{U}_2)\mathrm{U}_3)\mathrm{U}_4)$	**!	

The candidate (5a) violates BINMAX once because the maximal φ contains four ωs. It also incurs two violations of MATCH since $[\mathrm{U}_1]$ and $[[[\mathrm{U}_1]\mathrm{U}_2]\mathrm{U}_3]$ are not mapped to φ. The isomorphic candidate (5b) satisfies MATCH but violates BINMAX twice due to the oversized phonological phrases $(((\mathrm{U}_1)\mathrm{U}_2)\mathrm{U}_3)$ and $((((\mathrm{U}_1)\mathrm{U}_2)\mathrm{U}_3)\mathrm{U}_4)$. The ranking BINMAX $\gg$ MATCH selects (5a) as optimal.

Proposals distinct from (5) have been advanced by, *inter alia*, Bellik et al. (2022), Ishihara (2014), Ito & Mester (2013), and Kalivoda (2018), but they all concur that Japanese rebracketing is driven by some higher-ranking phonological markedness constraint.[5] However, one issue remains unaddressed: if prosodic phrasing violates interface constraints to satisfy a phonological markedness constraint, such phrasing must be motivated on phonological grounds. Particularly, no mapping algorithm can derive φ_3 in (4c) from a syntactic phrase, so φ_3 has to be formed in phonology as rhythmic determinism predicts.

The example in (4) contains unaccented words. Another challenge for syntactic determinism arises when we consider accented words, which are parsed as phonological phrases despite their syntactic wordhood (Ito & Mester 2013; Kubozono 1989). To il-

[4] It is usually assumed that Japanese accents are lexically specified (Kubozono 2008).

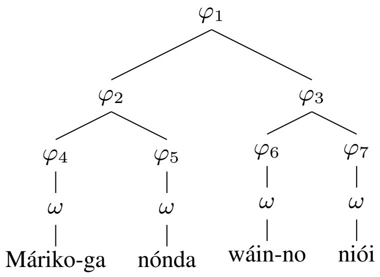
[5] An exception is Wagner (2010), who discusses the rebracketing in English relative clauses. According to Chomsky & Halle (1968: 372), a right-branching clause like *This is [the cat that caught [the rat that stole [the cheese]]]* is divided into three chunks in phonology: *This is the cat | that caught the cat | that stole the cheese*. Wagner (2010: 226) argues that the mismatch is only apparent, since the relative clause should be syntactically analysed as *[[This is the cat$_i$][~~cat~~$_i$ that t_i caught the rat$_j$][~~rat~~$_j$ that t_j stole the cheese]]*, which actually aligns with the prosodic phrasing. Applying this analysis to (4) would lead to *[[Mamoru-ga t_i yonda ~~gakuchoo~~$_i$][gakuchoo$_i$-no][uwasa]]*. Leaving aside the theoretical and empirical plausibility of this analysis, it notably fails to explain why *gakuchoo-no* and *uwasa* form a prosodic constituent, so mismatches persist.

lustrate, (6) has the same c-structure as (4), but their p-structures are different — each word in (6) projects a φ while those in (4c) only projects up to ω.

(6) Left-branching phrase with accented words (Kubozono 1989: 60)

a. Máriko-ga nónda wáin-no niói
Mariko-NOM drank wine-GEN smell
'the smell of the wine which Mariko drank'

b.



The X^0-to-ω-to-φ mapping in (6b) instantiates a *category promotion* mismatch, which occurs "when a syntactic constituent is mapped to a prosodic constituent that is too high in the [prosodic hierarchy] to satisfy MATCH" (Bellik et al. 2023: 10). Unlike rebracketing, category promotion does not create correspondentless prosodic constituents (e.g., φ_7 corresponds to the noun *nióí*); however, it shares with rebracketing the property of being phonologically motivated. In the case of (6), the X^0-to-ω-to-φ mapping involves a markedness constraint (7) that outranks interface constraints, suggesting that these φs are formed in phonology due to the presence of accents. This again deviates from syntactic determinism but aligns with rhythmic determinism.

(7) ACCENT-AS-HEAD (Ito & Mester 2013: 30)
Assign one violation for each accent that is not the head of a minimal phonological phrase φ.

As Section 2.3 shows, the syntax-to-phonology mapping should be a surjective function under the T-model. The mismatches in Japanese indicate that this is not the case. On the one hand, rebracketing creates prosodic constituents that lack syntactic correspondents (i.e., $\exists p,\ f^{-1}(p) = \emptyset$). On the other hand, category promotion leads to a one-to-many mapping, such that $\exists s, f(s) = \{p_1, p_2\}$ (e.g., the N^0 *nióí* maps to ω and φ_7). These mismatches can only be accounted for within a theory that adopts both rhythmic determinism and a parallel architecture.

3.2 Prosodic word expansion in Wenzhounese

Much work has demonstrated that the prosody of function words cannot be syntactically determined (e.g., Bögel 2021; Lahiri & Plank 2010; Tyler & Broadwell 2021). Using novel data from Wenzhounese, this section shows that even lexical words may display rhythmically determined mismatches. Wenzhounese is a Chinese Wu dialect with eight lexical tones (see, e.g., Rose 2004; Scholz 2012; Zhang & Mok 2020 for phonetic analyses of Wenzhounese tones). For ease of presentation, I use H(igh), M(id), and L(ow) to indicate tone heights, though nothing theoretical depends on this.

In connected speech, a syllable often surfaces with a tone distinct from its citation tone (i.e., underlying tone), depending on its position within a ω. As Figure 2 schematises, the last two syllables within a ω is governed by disyllabic tone sandhi (DTS). Synchronically, there seems to be little phonetic or phonological motivation for DTS, but as a generalisation, the final syllable typically retains its tonal contour while the penult undergoes tonal alternation. The antepenult is targeted by the polarity rule, which dissimilates its tone to H when followed by L and to L when followed by H (Chen 2000: 480). For the pre-antepenult and all the preceding syllables (if any), their tones are obligatorily neutralised, meaning that their tonal contrast is entirely lost.[6]

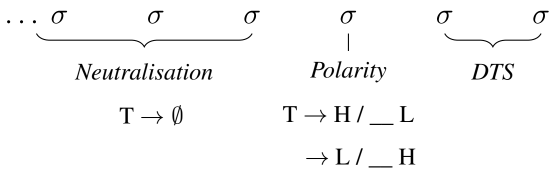


Figure 2: Lexical tone sandhi processes in Wenzhounese (fast speech rate)

The examples in (8) – (10) illustrate tone sandhi processes in polysyllabic words, where square brackets mark morphological constituency and parentheses demarcate tone sandhi domains. In the trisyllabic word in (8), the last two syllables do not form a morphological constituent but form a tone sandhi domain.

(8)

[[døy	søy]	[ky]]	‘library’
ML	M	MH	*Citation tones*
ML	(HM	MH)	*DTS*
(L	(HM	MH))	*Polarity*

The word in (9), compounded from [tso.sɤu] ‘renovation’ and [koŋ.sz̩] ‘company’, displays a balanced morphological structure. However, its tone sandhi domain is right-branching.

(9)

[[tso	sɤu]	[koŋ	sz̩]]	‘renovation company’
M	M	M	M	*Citation tones*
M	M	(L	L)	*DTS*
M	(H	(L	L))	*Polarity*
(∅	(H	(L	L)))	*Neutralisation*

In (10), [ɕi.mu.lɔ.ŋo] ‘Himalaya’ form a morphological constituent to the exclusion of [sɔ] ‘mountain’. In phonology, [sɔ] and [ŋo] group together as the domain for DTS.

[6]Speech rate also affects Wenzhounese tone sandhi, leading to variation in prosodic phrasing (Xie 2024: §5.2). This paper focuses on fast-tempo tone sandhi.

(10)

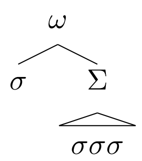
[[ɕi	mu	lɔ	ŋo]	[sɔ]]	‘The Himalayas’
MH	MH	MLM	MH	M	*Citation tones*
MH	MH	MLM	(HL	L)	*DTS*
MH	MH	(L	(HL	L))	*Polarity*
MH	(∅	(L	(HL	L)))	*Neutralisation*
(∅	(∅	(L	(HL	L))))	*Neutralisation*

From these data, we can make two generalisations. First, tone sandhi domain formation disregards morphological constituency and is uniformly right-branching, i.e., $(\ldots(\sigma(\sigma(\sigma\sigma))))_{\omega}$. Second, within such a prosodic domain, only the last three syllables license tonal contrast, while all the preceding syllables undergo tonal neutralisation.

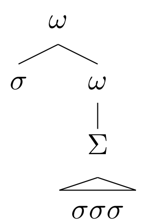
The second generalisation pertains to metrical foot. According to Duanmu (1999), Zhu (2023), and others, tonal contrast must be licensed within a foot. This suggests that the last three syllables of a Wenzhounese word form a foot, whereas all preceding syllables remain unfooted and consequently lose their tonal specifications (see Xie 2024: §5.1 for additional evidence for the foot in Wenzhounese). Grouping the final three syllables as a foot also explains why DTS and the polarity rule disregard morphological structure, since the foot is a rhythmic category that does not interface with morphosyntax (Section 1). However, I will demonstrate below that the unfooted syllables form an articulated prosodic word structure, hence bearing directly on the syntax-phonology interface.

For quadrisyllabic words like (9), there seems to be two plausible p-structures. (11a) is a weakly-layered structure (cf. Ito & Mester 2003), where ω immediately dominates Σ and σ. In (11b), σ is adjoined to ω, leading to a recursive structure.

(11) a.



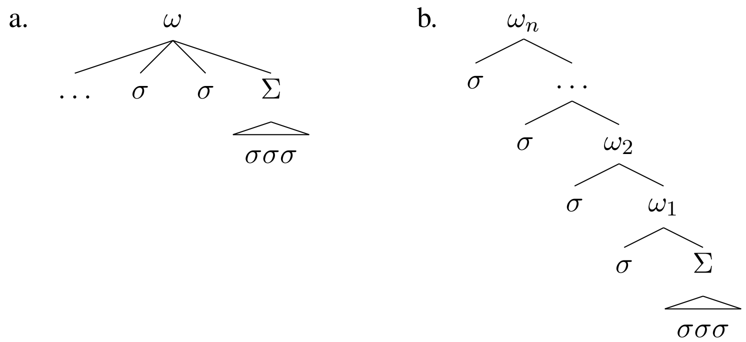
b.



In both structures, the pre-antepenult occurs outside of the foot, thus accounting for its tonelessness. In the absence of additional empirical evidence in favour of one or the other, I tentatively adopt the more economical (11a), which contains one fewer node than (11b). The conclusion regarding rhythmic determinism does not hinge on this choice.

For pentasyllabic and longer words, I present below two general arguments and one language-particular argument in favour of (12b), where all unfooted syllables but the pre-antepenult are recursively adjoined to ω.

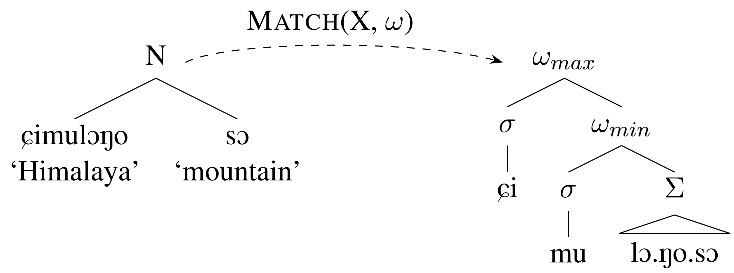
(12)



First, there is a cross-linguistic preference for prosodic representations to be binary branching (Mellesmoen & Urbanczyk 2021; Selkirk 2000). Since the ω in (12a) is n-ary branching whereas all the ωs in (12b) are binary branching, (12b) is more well-formed than (12a) with respect to binarity. Second, Bellik & Van Handel (2023: 435) observe that in analyses where structures like (12a) are possible candidates, they are never selected as optimal. This suggests that such structures are universally dispreferred. Finally, the language-particular evidence comes from constituency: (12a) fails to reflect that the last four, five, or more syllables may form a prosodic constituent corresponding to polysyllabic words such as (9) and (10). This constituency is encoded as prosodic word segments $\omega_1, \omega_2, \ldots, \omega_n$ in (12b). In other words, all the ωs in (12b) correspond to well-formed polysyllabic words in Wenzhounese, but such information is not available in (12a).

Adopting (12b) means that the p-structure for Wenzhounese polysyllabic words involve potentially unbounded ω-recursion. The corresponding c-structure, however, is a simple X^0, following the Lexical Integrity Principle (Bresnan & Mchombo 1995). This is illustrated in (13): while N^0 and the maximal ω are co-extensive, the minimal ω does not match with any morphosyntactic constituent (the internal structure of N^0 is not visible to syntax).

(13)



Recursive prosodic words as in (12b) and (13) instantiate what I term the *expansion* mismatch, which occurs when a c-structure with n-level recursion maps to a p-structure with more than n levels of recursion (Xie 2024: 174). Since each of these morphologically complex words occupies a single c-structure node, the non-maximal ωs in the p-structure have no syntactic correspondent. As such, these ωs cannot be derived via MATCH(X, ω) or be described by annotated c-structure rules. The potentially unbounded ω-recursion must be generated within phonology itself, in line with rhythmic determinism. Similar to rebracketing (Section 3.1), expansion involves correspondentless p-structures and so it invalidates the assumption that the syntax-to-phonology mapping is surjective.

4 Implications for LFG

The discussions in Sections 2 and 3 establish that an adequate model of the syntax-phonology interface must incorporate at least some degree of rhythmic determinism. This, in an LFG context, entails that p-structure cannot be fully captured by a direct c-to-p-structure projection (Section 2.2). Consequently, we are left with two options to analyse the syntax-phonology interface in LFG. The first is a purely rhythmic determinist view that rejects any c-to-p-structure projection and instead consistently defines interface categories in phonology proper (Section 4.1). The second option assumes the co-existence of rhythmic and syntactic determinism (Section 4.2). Specifically, it posits an indirect projection between c-structure and p-structure (as in Asudeh et al. 2023: 40), allowing an additional module to introduce syntax-phonology mismatches.[7] This section reviews existing LFG approaches that instantiate these views and discusses revisions necessary to accommodate the observations made in Sections 2 and 3.

4.1 A rhythmic determinist model

The double-tree model (Dalrymple & Mycock 2011; Dalrymple et al. 2019; Mycock & Lowe 2013; Mycock et al. 2021) assumes that p-structure is built independent of c-structure. It adopts the architecture in Figure 3, where there is no direct correspondence function between c-structure and p-structure.

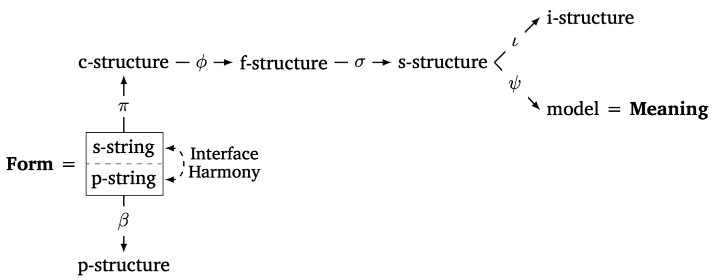


Figure 3: A projection architecture in LFG (Findlay 2023: 209)

Under this model, syntax and phonology is mediated via the lexicon and the string. The s-string stores labels that represent the left and right edges of syntactic constituents, which are obtained by applying a designated function to c-structure trees (Dalrymple et al. 2019: §11.4.2). The p-string likewise stores labels that represent the left and right edges of prosodic constituents. For example, the string information for $[_{\text{AdjP}}[_{\text{Adj}}$ *happy*$]]$ may look like (14).

(14) a. s-string: $\begin{bmatrix} \text{FM} & \text{happy} \\ \text{L} & \{\text{AdjP, Adj}\} \\ \text{R} & \{\text{AdjP, Adj}\} \end{bmatrix}$ b. p-string: $\begin{bmatrix} \text{FM} & \text{hæ} \\ \text{L} & \{\varphi, \omega\} \\ \text{R} & \{\} \end{bmatrix} \begin{bmatrix} \text{FM} & \text{pɪ} \\ \text{L} & \{\} \\ \text{R} & \{\varphi, \omega\} \end{bmatrix}$

[7] I thank Ash Asudeh for suggesting this to me.

Since p-structure is governed by purely phonological principles, syntax-phonology mismatches come as a default. The theory naturally predicts the rebracketing, category promotion, and expansion mismatches identified in Section 3, as these can be generated by p-structure rules such as (2).

The independence of p-structure does not rule out the possibility of isomorphism: a principle of Interface Harmony requires an s-string label to be matched with a corresponding p-string label and *vice versa*, hence enforcing the alignment of c-structure and p-structure boundaries (Dalrymple et al. 2019: 417). In (14), for example, the s-string label "AdjP" is associated with the p-string label "φ".

Importantly, Interface Harmony does not build p-structures from c-structures; instead, it evaluates independently generated p-structures and rules out those that fail to achieve correspondence with the relevant c-structure. Thus, although p-structure is built independently within phonology, information from syntax or other modules can still affect p-structure.

Given the ample cases of mismatches, Interface Harmony must be understood as a preference rather than an inviolable constraint, but the formal implementation of this preference is not fully explored, as Bögel (2023: 804–807) points out. Since preference implies constraint competition, I propose a formalisation under OT-LFG (e.g., Bresnan 2000; Mohanan & Mohanan 2003). The alignment between c-structure and p-structure can be readily captured by interface constraints like ALIGN and MATCH, defined in (3). Under rhythmic determinism, however, these interface constraints do not convert syntactic constituents to prosodic constituents. Instead, they function as *correspondence*, which "only establishes a connection between the pieces of its domain and range [...without deriving] the desired formal properties of the range" (Kaplan 1995: 15). This does not imply an implicit projection from c-structure to p-structure. For one thing, ALIGN and MATCH are relations rather than functions, because the mapping between syntax and phonology (from either direction) can be one-to-many. For another, ALIGN and MATCH establish correspondence between string labels (see (14)), not directly between c-structure and p-structure.

Against this background, Figure 4 illustrates an OT-LFG grammar for the syntax-phonology interface within the double-tree model, focusing on the mapping from syntax to phonology. SYN refers to the triple $\langle$c-structure, s-string, $\pi\rangle$ and PHON refers to $\langle$p-structure, p-string, $\beta\rangle$. For expository purposes, Figure 4 takes SYN as the input. One could equally well start from PHON; doing so does not imply any directionality between the two modules. This is because the mapping in OT-LFG is not inherently directional: given any two structures α and β, we can take α to be the input and $\alpha + \beta$ the output (Mohanan & Mohanan 2003: 313).

P-structure rules like (2) are GEN constraints, ensuring that GEN only generates phonological representations that conform to these rules — a design that reflects rhythmic determinism. In the candidate set, these generated PHONs are paired with the input SYN. These candidate pairs are then evaluated by interface constraints (which are a subset of Interface Harmony) and phonological markedness constraints. A language-particular constraint ranking decides which pair is the optimal candidate.

Admittedly, Interface Harmony cannot be reduced to interface constraints. This is because ALIGN/MATCH constraints only regulate the correspondence between constituents, but not all labels in the s/p-string concern constituents. For example, in their

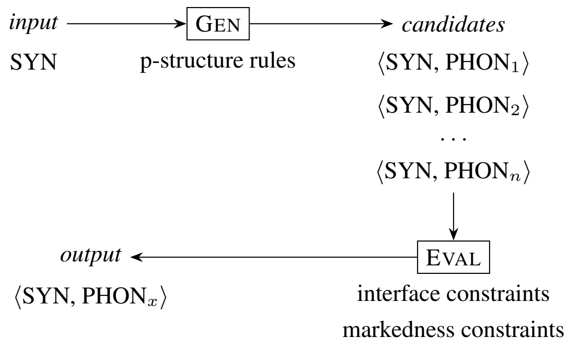


Figure 4: The input-output relation between syntax and phonology

analysis of declarative questions like *Anna was studying at the university?*, Dalrymple & Mycock (2011) contend that the right edge of the IP root node at c-structure is associated with the meaning constructor [**PolarInt**], which introduces the s-string label 'PolarIntSem'. Interface Harmony requires a corresponding label *PolarInt* to occur in the associated p-string unit, which is responsible for the interrogative intonation.

How the full range of Interface Harmony should be formalised in OT-LFG will be left for future research. However, the fact that non-constituent information may bear on the syntax-phonology interface is additional evidence for the parallel architecture, as various types of representations (trees, AVMs, etc.) can co-exist and be co-described. By contrast, a syntactocentric model might be forced to encode non-constituent information as functional categories in the tree, often without syntax-internal motivation. Along this line of reasoning, Ishihara (2022) examines the frequent lack of correspondence between syntactic clauses and intonational phrases, proposing that pragmatic information can directly affect ι-formation without the mediation of syntactic constituency.

4.2 A mixed model

Bögel's (2015) model combines rhythmic determinism and syntactic determinism. As Figure 5 shows, this model is bidirectional, incorporating the perspectives of production and comprehension. My discussion focuses on production, specifically the syntax-to-phonology mapping.[8]

According to Bögel (2015, 2021), prosodic word status is rhythmically determined and specified in a word's lexical entry. Therefore, the matching between syntactic and prosodic words (called the *transfer of vocabulary*) occurs in the lexicon. For example, (15) represents the lexical entry for the Swabian 1SgNom pronoun (Bögel 2021: 19). This pronoun may be parsed as a monosyllabic prosodic word $(\text{'}\sigma)_\omega$ or an enclitic $=\sigma$. The variable prosodification cannot be determined by the invariant s-form; rather, the prosodic status is governed by metrical stress and constrained by information structure

[8]In a production system, syntax is responsible for assembling words into sequences. However, this does not entail that syntactic constituency determines prosodic constituency. For example, Wheeldon & Lahiri (1997) find that prosodic words, rather than syntactic words, predict speech production latencies. Wynne et al. (2018) also observe that prosodic words are the primary planning unit in production. If prosodic words were derived from syntax, we would expect syntactic words to drive planning latencies, but this is not what these psycholinguistic experiments show.

— the unstressed /ə/ is only available when the pronoun is not focused.

(15)

s-form			**p-form**		
ich	D	NUM = SG	[iː]	SEGMENTS	/i/
		PERS = 1		METRICAL FRAME	$(\text{ˈ}\sigma)_\omega$
		CASE = NOM	[ə]	SEGMENTS	/ə/
		PRON = PERS		METRICAL FRAME	=σ
		...		$\neg(\uparrow_i$ FOCUS)	

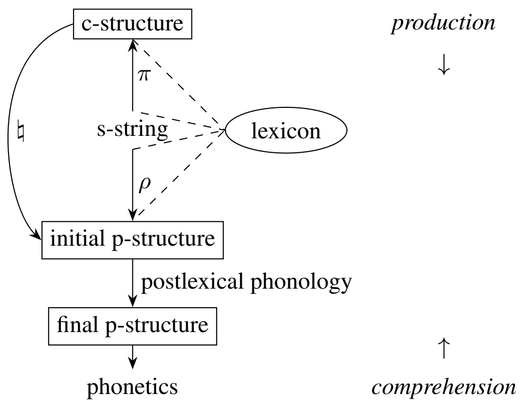


Figure 5: The syntax-phonology interface adapted from Bögel (2015: 223)

In contrast to prosodic words, higher-level prosodic constituents are assumed to be syntactically determined. A process called the *transfer of structure*, formalised as the composite function $\natural(*)$ $(\equiv \rho(\pi^{-1}(*)))$ in Figure 5, relates syntactic phrases to φs and syntactic clauses to ιs. For instance, the c-structure annotation in (16) assigns two ι boundaries in the p-structure, respectively aligning with left and right edges of the root node S (Bögel 2023: 810).

(16)

$$\text{S}$$
$$(\natural(T(*))\ S_{min}\ \text{PHRASING}) = {}_\iota($$
$$(\natural(T(*))\ S_{max}\ \text{PHRASING}) =)_\iota$$

Bögel's approach naturally captures the expansion mismatch in Wenzhounese (Section 3.2), since prosodic word structure is governed by rhythmic principles and stored in the lexicon. For example, the pentasyllabic word [ɕi.mu.lɔ.ŋo.sɔ] 'The Himalayas' would assume the lexical entry in (17). (See Xie 2024: §6.3 for an alternative analysis.)

(17)

s-form	**p-form**	
The Himalayas	SEGMENTS	/ɕ i m u l ɔ ŋ o s ɔ/
...	METRICAL STRUCTURE	$(\sigma(\sigma(\sigma\sigma\sigma)_\Sigma)_\omega)_\omega$
	TONE	...

Apart from the lexicon, postlexical phonology can also drive syntax-phonology mismatches. While the *transfer of structure* predicts a largely faithful c-to-p-structure mapping, prosodic boundaries can be rearranged for purely phonological reasons. As a result, the prosodic constituents in the final p-structure may misalign with their c-structure counterparts. Moreover, nothing in the parallel architecture prevents the final p-structure to contain correspondentless prosodic constituents, so this model can also account for rebracketing mismatches without undermining the grammatical architecture.

Notably, the postulation of two levels of p-structure appears to deviate from LFG's surface-true spirit. The other LFG modules each encode different aspects of a linguistic expression (e.g., c-structure for linear order and constituency, f-structure for GFs and grammatical features), but the two p-structures encode different stages (initial vs. final) of the same aspect (i.e., phonological information such as syllabification and prosodic boundaries). These p-structures must be extrinsically ordered, with only the final p-structure representing surface phonology.

Extrinsic ordering also characterises the p-to-p-structure mapping in Bögel (2015), who uses SPE-style rewrite rules for postlexical phonological processes. This raises the question of whether the mapping between the two p-structures in Figure 5 is monotonic. In Section 4.2.1, I show that the mapping is non-monotonic, and Section 4.2.2 discusses potential consequences of this non-monotonicity.

4.2.1 Non-monotonic mapping

Monotonicity, as defined in (18), is considered a fundamental computational constraint imposed on the design of LFG (Bresnan 1990: 637). In particular, the c-to-f-structure mapping is monotonic because adding new functional equations to the functional description yields increasingly specific f-structures (Bresnan et al. 2016: 73). The mapping from f-structure to s(emantic)-structure is also monotonic due to Glue Semantics' resource sensitivity: all and only the premises instantiated from the syntax are used in semantic composition (Asudeh 2022: 323).[9]

(18) Monotonicity (Graf 2019: 6)
Given two sets A and B, let $\leq_A \subseteq A \times A$ and $\leq_B \subseteq B \times B$. A function $f : A \to B$ is *monotonic* with respect to $\leq_A$ and $\leq_B$ iff it holds for all x and y in A that $x \leq_A y$ implies $f(x) \leq_B f(y)$.

Whether the syntax-to-phonology mapping, or the mapping between two levels of p-structure, should be monotonic in LFG remains an open question. However, in the general phonological literature, Bird & Klein (1994: 468) note that monotonic operations are "methodologically desirable," and Kálmán (1989: 134) proposes a principle of derivational monotonicity which is closely related to (18):

(19) A grammar is *derivationally monotonic* iff for any pair r_1, r_2 of representations such that r_2 can be derived from r_1 by some rule of the grammar, the information content of r_2 includes the information content of r_1.

Kálmán (1989: 134) emphasises that the formulation of (19) is independent of how rules are interpreted. That is, (19) can be applied to Figure 5 no matter if those postlexical phonological operations are construed as processes, relational rules, or constraints.

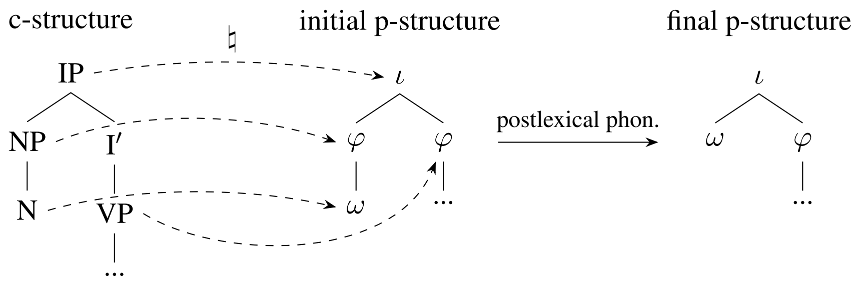
I provide two arguments showing that the mapping between the two p-structures in Figure 5 is not derivationally monotonic. First, Bögel (2015) employs extrinsic ordering for postlexical phonological rules, which is not available in a derivationally monotonic

[9]The term "monotonicity" may be used in different but related senses in the study of, for example, quantification (Geurts & van Der Slik 2005) and computational linguistics (Maxwell III & Kaplan 1993).

system (Kálmán 1989: 140). Second, even without rule ordering, the mapping deletes prosodic constituents in two types of syntax-phonology mismatches discussed below, so certain information is present in the initial p-structure but not in the final one.

The first type is *category demotion*, cases where a syntactic constituent (say, NP) is mapped to a prosodic constituent that is too low in the prosodic hierarchy to satisfy MATCH (e.g., ω) (Bellik et al. 2023: 10). A frequent motivation for category demotion is prosodic binarity, as illustrated in (20).

(20)



Suppose that φs in a given language must be minimally binary branching, but the NP subject is composed of a single word. The *transfer of structure* would first map the NP to a unary-branching φ, and postlexical phonological must then delete this φ. Consequently, the final p-structure has less information than the initial p-structure.

The second type is rebracketing (see Section 3.1 for Japanese examples). Consider (21), where a, b, c are prosodic words. The initial p-structure (21b) faithfully reflects (21a)'s constituency as per the *transfer of structure*. Rebracketing occurs postlexically during the mapping from (21b) to (21c).

(21) a. c-structure: [[a b $]_{XP_1}$ c $]_{XP_2}$
b. initial p-structure: ((a b $)_{\varphi_1}$ c $)_{\varphi_2}$
c. final p-structure: (a (b c $)_{\varphi_3})_{\varphi_4}$

It is clear that the prosodic boundaries in (21b) are placed differently from those in (21c). Here, I focus on whether there is correspondence relation between φ_1 in (21b) and φ_3 in (21c). If the two φs are not correspondents, it means postlexical phonology deletes φ_1 and creates a distinct φ_3, which is not derivationally monotonic.

While a p-structure-to-p-structure mapping is postulated in Bögel's model and also the MSO-PI-PO model (Section 2.2), the mechanism for establishing correspondence between p-structures is understudied. In Xie (2024), I propose that this relationship is anchored by prosodic heads. Specifically, prosodic structures P_1 and P_2 stand in correspondence, i.e., $\mathcal{R}(P_1, P_2)$, if their heads are in correspondence (Xie 2024: 224).

Let us assume that all the prosodic words in (21b) have a unique correspondent in (21c), i.e., $\mathcal{R}(a_{initial}, a_{final})$, $\mathcal{R}(b_{initial}, b_{final})$, and $\mathcal{R}(c_{initial}, c_{final})$. The head of φ is the most prominent ω it dominates, i.e., the locus of phrasal stress. Therefore, whether $\mathcal{R}(\varphi_1, \varphi_3)$ holds boils down to whether their head ωs stand in correspondence.

As Selkirk (2011: 470–471) observes, "the location of main stress within φ would be edgemost, on a language-particular basis — falling in the rightmost ω in some languages, the leftmost ω in others." In (21), if the most prominent ω aligns with the left edge of φ, then φ_1 is headed by a and φ_3 is headed by b. Since $\mathcal{R}(a_{initial}, b_{final})$ does not hold, φ_1 and φ_3 do not stand in correspondence. On the other hand, if phrasal stress is rightmost, then φ_1 is headed by b and φ_3 is headed by c. As b and c are distinct words without correspondence, the relation $\mathcal{R}(\varphi_1, \varphi_3)$ cannot be established. The absence of correspondence between φ_1 and φ_3 indicates that the mapping from (21b) to (21c) does not simply involve reordering prosodic boundaries. Rather, postlexical phonology deletes φ_1 and creates φ_3.

The discussion above shows that category demotion and rebracketing both involve the deletion of prosodic constituents. One may ask whether this deletion is analogous to information loss in the mappings between other LFG modules. In *it is raining*, for instance, the subject is syntactically required but has no semantic content. Put differently, the expletive is the f-structure SUBJ but is absent in s-structure. Such instances of information loss are not counterexamples to monotonicity but are a desirable consequence of LFG's modularity architecture, because information that is domain-specific to syntax need not be relevant to semantics. In the case of expletives, the dummy subject introduces no meaning constructor, so it is not constrained by resource sensitivity (cf. Findlay et al. 2023: 763). Consequently, we can treat expletives as outside the domain of the f-to-s-structure mapping.

Information loss occurs naturally when the two structures have distinct theory primitives (e.g., f-structure and s-structure). In the p-to-p-structure mapping, however, the two structures have the same theory primitives and are represented by the same p-diagram notation (Bögel 2015: §3.3). Hence, one cannot motivate constituent deletion by claiming that a prosodic constituent is domain-specific to the initial p-structure but not to the final one. In other words, it is not feasible to exclude the deleted prosodic constituent from the domain of the p-to-p-structure mapping in order to maintain monotonicity.

4.2.2 Consequences of (non-)monotonicity

As Section 4.2.1 demonstrates, the mapping from the initial p-structure to the final p-structure is not monotonic. Non-monotonicity is not without precedent in LFG analyses. To illustrate, Mahowald (2011) develops a non-monotonic account of word order freezing. In early LFG, relation changes like passivisation and intransitivisation were handled by lexical rules (Bresnan 1982) that are not information-preserving (Findlay et al. 2023: 711).

Given that monotonicity is imposed on LFG as a computational constraint to prune unnecessary computation (Maxwell III & Kaplan 1993), its violation tends to have computational rather than empirical consequences. Consider the restriction operator, which removes an f-structure attribute and is therefore non-monotonic (Kaplan & Wedekind 1993). The drawback for grammars using this operator is that the generation problem becomes undecidable (Forst 2011: 7). Nevertheless, the restriction operator may be required for analysing complex predicates (e.g., Butt et al. 2003). Likewise, in Bögel's (2015) model, a non-monotonic mapping helps capture empirical data such as those discussed in Section 3. These observations suggest that monotonicity is an area where theoretical LFG analyses and computational implementations of LFG diverge (see also Findlay et al. 2023: 711 for a discussion).

Though non-monotonic analyses have been motivated on empirical grounds, monotonic alternatives are worth pursuing to narrow the gap between LFG theories and computational implementations. For the p-to-p-structure mapping, one alternative would be to reformulate postlexical phonology in OT. Bögel (2015: 131) voices concern that OT grammars would considerably increase computational complexity, but non-monotonic mappings do so as well. Another possibility would be to posit a distinct module for phonetic implementation (as in Kálmán 1989) instead of two levels for phonology, so information loss could be modelled in a manner parallel to the expletive example discussed above. The development of such a module must, of course, be left to future work.

To summarise this section, Bögel (2015) treats prosodic words as rhythmically determined and higher categories as syntactically determined. Although p-structure is largely isomorphic to c-structure during the *transfer of structure*, a subsequent p-to-p-structure mapping allows postlexical phonology to reorganise p-structure and derive syntax-phonology mismatches. This mixed model is empirically adequate to analyse the mismatches observed in Section 3, but the mapping between p-structures is non-monotonic.

5 Conclusion

Rebracketing mismatches in Japanese (Section 3.1) and expansion mismatches in Wenzhounese (Section 3.2) confirm that a subset of interface categories have no syntactic correspondents. These interface categories must be generated in phonology, in accordance with rhythmic determinism. In other words, syntactic determinism alone is empirically inadequate.

This observation implies that in LFG, a direct projection from c-structure to p-structure would undergenerate the data, which leaves us with two options to analyse the syntax-phonology interface. We either reject any c-to-p-structure projection (as in the double-tree model) or assume the co-existence of rhythmic and syntactic determinism (as in Bögel 2015). Both approaches can adequately analyse the Japanese and Wenzhounese data, but there is space for development. The principle of Interface Harmony in the double-tree model awaits full formalisation, and in Section 4.1 I proposed to formalise a subset of Interface Harmony as Optimality-Theoretic interface constraints. Bögel's (2015) model posits two levels of p-structures, but Section 4.2 shows that the mapping is non-monotonic, which may be potentially problematic for computational implementations.

Acknowledging rhythmic determinism has far-reaching theoretical consequences beyond LFG. In Section 2.3, I argued that rhythmic determinism can be accommodated in a parallel architecture but is incompatible with the T-model. Therefore, these data that attest to rhythmic determinism provide new evidence that linguistic modules should be organised in parallel.

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