A foot-based typology of tonal reassociation

Perspectives from synchrony and learnability

This dissertation is about the synchronic analysis, typology, and formal learnability of tonal reassociation. Tonal reassociation refers to a group of phonological phenomena where a lexical tone surfaces in positions that the tone did not occupy underlyingly, without an apparent phonological trigger for doing so. Linguistic theory must answer why tone reassociates, and how the surface targets for reassociation are determined. In addition, it must account for the attested crosslinguistic variation of such patterns.

To address this, the dissertation develops an analytical framework based on the interaction between tone and foot structure. Feet function as licensors for tone, driving and restraining tonal reassociation. Since many reassociation patterns involve ternary domains, the framework extends traditional binary feet theory by allowing layered, ternary feet. Grammar computation is modeled in Harmonic Serialism, which solves an opacity problem found for Optimality Theory.

The first half of the book motivates the framework through case studies of ternary spread-and-shift in Saghala, and quantity-sensitive ternary tone spread in Copperbelt Bemba. The framework accounts for both cases, and it is argued that layered feet are crucial to this success.

The third study investigates the typology predicted by the foot-based approach. By exploring factorial typologies, it is found that the approach accounts for much or all of the considered variation, but also shows several kinds of overgeneration. The fourth study accounts for the overgeneration by considering the learnability of foot-based analyses for various reassociation patterns in Optimality Theory. Attested patterns are learnable, and more easily so than unattested ones, under the condition that learners consider production and comprehension errors in tandem.

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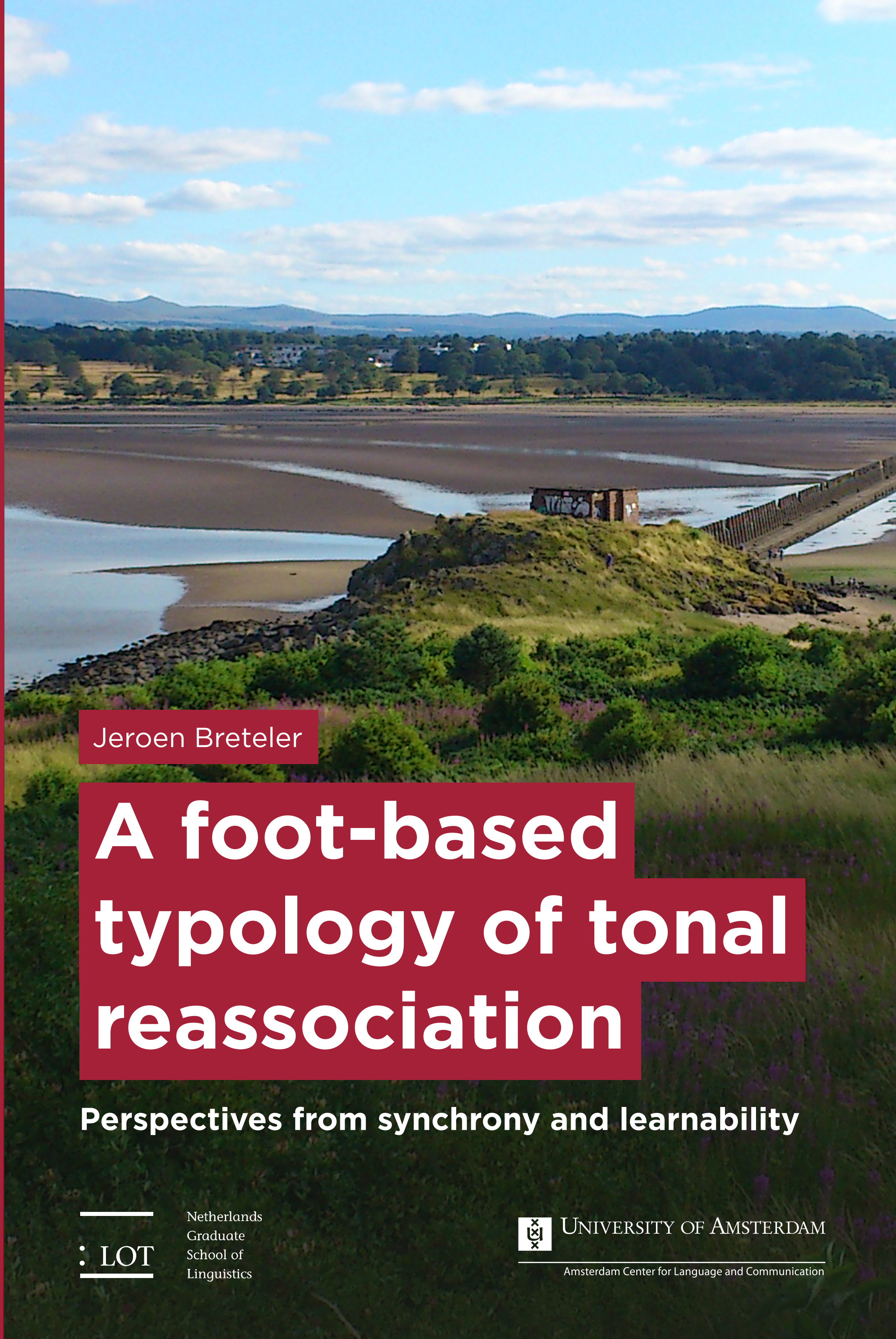

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LOT Netherlands Graduate School of Linguistics

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Author Contributions

Chapter 3, titled *"Layered feet and syllable-integrity violations in Copperbelt Bemba bounded tone spread"*, was coauthored by Jeroen Breteler (JB) and René Kager (RK). The chapter is in preparation for resubmission to the journal *Natural Language and Linguistic Theory.* JB identified the relevance of the Copperbelt Bemba data, developed a representational analysis with layered feet, and wrote the chapter. JB and RK jointly developed a constraint-based analysis. RK contributed to the contextualization of the chapter in the literature, and suggested improvements to the structure and formulation of all parts of the text, including several lines that were incorporated verbatim.

For all other chapters, Jeroen Breteler is the sole author.

Chapter 1

Introduction

The main objective of this dissertation is to give a formal account of the typology of *tonal reassociation* phenomena, where tone is realized on tone-bearing units that are different from the tone's lexical origin. I will do so by developing a framework to analyze the synchrony of various tonal reassociation patterns, all attested in Bantu languages, and by showing through simulations that attested tonal reassociation patterns are learnable in this analytical framework, to the exclusion of unattested patterns.

In this introductory chapter, I will first give a general motivation of the theory–typological enterprise, and by extension the methodology that I use, in section 1.1. In section 1.2 I introduce the data, giving examples and a general description of tonal reassociation patterns. Section 1.3 discusses previous literature on the topic, identifying outstanding problems. I will present a primer of my solutions to these problems, particularly the analytical framework of the dissertation, in section 1.4. Finally, I break down the contributions of the dissertation by chapter in section 1.5.

1.1 Theoretical typology

A major part of linguistic research is dedicated to the description of the languages of the world, and particularly of the linguistic generalizations that characterize a given language. By collecting and organizing language descriptions, one can construct a picture of the *variation* that occurs across languages. A common belief in linguistics research is that the picture that so emerges is not purely arbitrary. Rather, the attested crosslinguistic variation reflects the interactions among a range of processes and constraints involved in human language use. Consequently, the study of linguistic typology promises an insight into the factors that shape linguistic reality. Below, I identify the main factors that I will investigate in this dissertation.

For phonological typology, the most important ingredient for theory–typological work has been a theory of grammar. A theory of grammar defines limits to human linguistic capability; by extension, it predicts limits on the types of linguistic systems that people might come to employ in communication. Consequently, one method of accounting for a typology is to develop a grammar theory that includes only those grammars that relate to one of the attested languages, and that excludes all others. Indeed, in this dissertation I will strive to articulate a grammar framework that accomplishes this for tonal reassociation phenomena. However, in practice it is not feasible to achieve a perfect typological fit while maintaining a high degree of principledness of the account. As a consequence, grammar-based explanations of typology tend to *overgenerate*, meaning that they allow for the representation of linguistic phenomena that are not attested.

Overgeneration can be addressed by taking into consideration factors besides grammar theory. For this purpose, I will involve the *learnability* of languages in my theory–typological account of tonal reassociation. The rationale here is that even if a grammar theory states that a given grammar could be represented in human cognition, this doesn't yet guarantee the existence of a speaker that actually has that grammar, since speakers might fail to *acquire* that grammar. Consequently, a learnability investigation can enhance the typological predictions of a grammar theory if it is shown that languages that are part of the theory's overgeneration are the least likely to be acquired and, by extension, persist over multiple generations.

Many other factors, such as auditory and articulatory biases, considerations of diachrony, of sociolinguistics, etc., could contribute to an even more accurate set of typological predictions. Unfortunately, integration of these factors is beyond the scope of the present work. Here, I will develop a theory of grammar as it pertains to tonal reassociation, both from a broad-strokes point of view for a range of attested patterns, and through an in-depth look at the intricacies of tonal reassociation in two specific languages. I will determine the overgeneration of the resulting grammar theory, and assess the learnability of a variety of attested and unattested-but-generated patterns, with the aim of enhancing the theory–typological account.

Before making these proposals more specific further below, I will set the context by discussing tonal reassociation data.

1.2 Crosslinguistic variation in tonal reassociation

As stated, I use the term *tonal reassociation* for phonological patterns where tone is realized on syllables or moras that it is not associated to in the lexicon. This term encompasses tone spreading and tone shifting; the latter is also sometimes called tone displacement. An example is the alternation in (2), which shows data from Rimi (Olson 1964; Schadeberg 1978, 1979; Myers 1997).[1] In this and following examples, an accented vowel denotes high tone on the related mora or syllable. Underlining indicates the suggested lexical origin of a high tone, also termed its "sponsor", which I explain momentarily. Hyphens separate different morphemes.

(2) Bounded rightward shift in Rimi
  a. mo-nto 'person'
  b. <u>ɾa</u>-mó-nto 'of a person'

Here, the syllable [mo] is low-toned or toneless in isolation, as in (2a). However, when combined with the genitive prefix surfacing as [ɾa], the same syllable is realized as [mó], with a High tone, shown in (2b). Such alternations typically lead analysts to the conclusion that the *origin* of this tone must be the prefix /ɾá/, even though tone is realized on the syllable following the prefix.

A different kind of tonal reassociation is shown based on an alternation reported in Phuthi (Donnelly 2009a,b), shown in (3).[2] Here, the choice of the initial morpheme, [si] in (3a) versus [ɓá] in (3b), not only affects the presence or absence of High tone on the morpheme itself, but also on the five following syllables.

(3) Unbounded spreading in Phuthi
  a. si-ja-lima-lim-el-aː-na
    'we cultivate for each other now and then'
  b. <u>ɓá</u>-já-límá-lím-él-aːn-a
    'they cultivate for each other now and then'

The general pattern in Phuthi is that High tone will surface on all morphemes right of the sponsor, except for the final two syllables. In other words, the surface span for tone runs from the sponsor to the antepenultimate syllable. In (4), I list some further forms supporting this generalization.

(4) Unbounded spreading in Phuthi targets the antepenultimate
  a. <u>ɓá</u>-já-liːma 'they cultivate'
  b. <u>ɓá</u>-já-pátaːla 'they pay'
  c. <u>ɓá</u>-já-lím-él-aːn-a 'they cultivate for e.o. now and then'

The patterns in Rimi and Phuthi demonstrate various ways in which tonal reassociation patterns can differ. Rimi is an example of a "bounded" pattern, since the reassociation target is defined as being at a fixed distance from the

[1] I have used Olson (1964:1,12) to relate the transcriptions to IPA notation. Olson distinguishes four vowel heights; I write the second-highest level as [o]. Although Olson (1964) is the primary source, I follow Myers (1997) in adopting the alternation in (2) based on its presentation in Schadeberg (1978:204), where the tone-carrying form is included in the datum [ɾena ɾa-mónto] 'jemandes Name'.

[2] I have adapted Donnelly's transcriptions to IPA notation. For more detail, see my discussion of the Phuthi transcription in footnote 3 of Chapter 4.

location of the sponsor, meaning the distance across which a tone reassociates is bounded. On the other hand, the length of the surface tone span in Phuthi is a function of both the sponsor position and the position of the antepenultimate. There is no theoretical limit on the distance between the sponsor and the relevant word or phrase edge, so in theory, tone reassociation in Phuthi can take place across *unboundedly* long distances. Another difference between the Rimi and Phuthi patterns is that in Rimi, the High tone no longer shows up on its sponsor, whereas in Phuthi, tone surfaces both on the sponsor and on intermediate positions between the sponsor and the target. These two types of behavior are called "shifting" (or "displacement") and "spreading", respectively. Previous literature, primarily on Bantu languages, has identified a variety of bounded and unbounded patterns showing spreading or shifting — as well as some patterns that do not fall neatly into these categories. An additional regularity found across these various patterns is that, for bounded patterns, the reassociation typically occurs over a binary or ternary span counting from the sponsor to the target, and for unbounded patterns, the reassociation target typically falls within a ternary window from the edge of the relevant prosodic domain. For now, this concludes my cursory overview of the data; I will discuss the attested crosslinguistic variation in more detail in Chapters 2 and 4.

Tonal reassociation patterns include cases of phonological activity over spectacularly large distances (Kula and Bickmore 2015), and the patterns can be of a relatively complex nature (e.g. Chapters 2 and 3, Volk 2011). Moreover, tonal reassociation phenomena are "self-contained", in the sense that they apply without requiring a trigger in the form of other lexical phonological material (although such material might influence the outcome of reassociation, especially in the case of depressor consonants). This raises a challenge for a theory of tonal reassociation grammars; such a theory must address both why tonal reassociation is motivated in the first place, and how the targets of reassociation, which vary crosslinguistically as outlined above, are determined. Furthermore, as I explained in section 1.1, considerations from theoretical typology place further demands on a theory of tonal reassociation grammars; the theory should not only account for the workings of attested tonal reassociation patterns, but should also correctly predict the non-attestation of potential alternative patterns.

In the next section, I outline how previous literature has approached these issues, and I will identify some areas where this dissertation aims for improvement.

1.3 Previous work on tonal reassociation typology

In this section, I briefly discuss previous literature on the analysis of tonal reassociation patterns. Throughout the dissertation, I go into more detail on various matters; see especially section 4.1.

As I mentioned in the previous section, tonal reassociaton patterns typically have a default pattern whose targets are defined only in terms of their distance to the sponsor and/or the edge, and not by other phonological characteristics (additional complexity might be triggered by e.g. the presence of word boundaries (Chapter 2) or depressor consonants (e.g. Kisseberth 1984)). Most previous work does not take these targeting facts as primitives, but tries to relate reassociation targeting to more general concepts. For instance, analysts have appealed to the metrical strength of targeted positions (Goldsmith 1987; Sietsema 1989; Downing 1990), in combination with a traditional autosegmental interpretation of tone (Leben 1973; Goldsmith 1976). In the context of Optimality Theory (OT, Prince and Smolensky 1993), tonal reassociation was analyzed mostly through featural domains, namely in Optimal Domains Theory (Cole and Kisseberth 1994; Cassimjee and Kisseberth 1998; Volk 2011) and Headed Spans (McCarthy 2004; Key 2007; Key and Bickmore 2014). Under these approaches, a (tonal) feature is associated with a domain, i.e. a constituent of variable size containing some number of contiguous feature-bearing units. The actual realization of the feature on any part of the domain then depends on constraint evaluation. Despite a growing body of literature on foot–tone interactions in OT (Zec 1999; De Lacy 2002; Pearce 2006), *metrical* analyses of tonal reassociation are rare (but see Ham 1996; Kang 1997; Idsardi and Purnell 1997) and have received relatively little attention. In this dissertation, I will use foot structure to determine tonal reassociation targets, thus developing a theoretical framework using metrical and autosegmental representations that might offer alternative accounts for cases previously analyzed with featural domains. Moreover, in the course of presenting the foot-based analyses, I will identify several potential problems for featural domain analyses. In particular, I point to challenges for featural domain OT analyses of Saghala data in section 2.5.2, and of Bemba data in section 3.6.4.

In determining whether one analytical framework is preferable over another, it is helpful to take into consideration the frameworks' under- and overgeneration. However, almost all previous tonal reassociation literature has focused on case studies of one or several languages (cf. Bickmore 1996), without investigating the further typological predictions of the analytical framework that was used. In this dissertation, I take into account a larger number of patterns (including some that were only recently attested), and I calculate a factorial typology of the constraint set to investigate the framework's broader typological predictions.

As stated in section 1.1, I will also use computer simulations to examine the typological predictions through the lens of learnability, with the hope of finding that for some patterns, poor learnability can explain why the patterns are not attested despite being representable in the theoretical framework (Staubs 2014; Stanton 2016). To my knowledge, this is a first for tonal reassociation typology. Consequently, in addition to the learnability results, the dissertation will make methodological contributions about simulating the learning of tonal reassociation patterns. Since tonal reassociation involves tonal structure at both the lexical level and at the surface phonological level, learners will have the task of resolving ambiguity at both of these levels. This type of learning is called *hidden structure learning*, and has been a topic of ongoing research in Optimality Theoretic learning since Tesar and Smolensky (2000). While most hidden structure learning studies focus on the learning of hidden surface phonology, some studies have also successfully simulated simultaneous learning across both hidden lexical and surface phonological levels (Jarosz 2006, 2015; Apoussidou 2007; Akers 2012; Tesar 2014, 2017; Boersma and Van Leussen 2017). Nevertheless, within the context of error-driven learning, the challenge of learning tonal reassociation will raise new questions. In previous work, data sets and their associated learning tasks were typically of limited ambiguity in the sense that the learner would proceed by learning only from errors in *production* (cf. Hamann et al. 2009). In this dissertation, the tonal reassociation patterns that I will use for the learnability simulations are *bidirectionally* ambiguous. Consequently, the dissertation will investigate whether bidirectional error detection (i.e. learning from errors in both production and comprehension) is feasible and beneficial for learners, and if it yields a more typologically informative set of results.

The answers to all of the theoretical questions above rely on the assumptions I make regarding the analysis of tonal reassociation patterns. In the next section, I outline the ingredients of the dissertation's analytical framework.

1.4 A framework for foot–tone interactions

As I observed at the end of section 1.2, a commonality among the tonal reassociation patterns is that the target for bounded patterns stays close to the sponsor, and the target for unbounded patterns stays close to the edge. More specifically, there are at most three syllables or moras included in the range from sponsor to target, or from edge to target, respectively. In this dissertation, I build on the idea that both the bounded domain and the unbounded edge window can be captured with metrical feet. To negotiate the interactions between feet and tones, I develop a constraint set that uses licensing effects, and adopt the serially evaluating Harmonic Serialism as my grammar framework. In the remainder of this section, I give a brief introduction to these theoretical choices. As I will point out throughout this section, all these theoretical choices have precedents in the literature; no element was proposed purely for the application to tonal reassociation. Consequently, the analysis is supported by independent motivations for each of its ingredients.

1.4.1 Layered feet

Traditionally, (bounded) feet have been defined as maximally binary, meaning that they contain at most two constituents, which could be moras or syllables (McCarthy and Prince 1986; Hayes 1995). This reflects the binary distinction of weak and strong degrees of prominence in many languages, and the typically binarily alternating rhythm in languages with iterative stress. Nevertheless, there have been occasional investigations throughout the years into feet inventories that include some type of ternary parsing structure (Prince 1980; Selkirk 1980; Halle and Vergnaud 1987; Kager 1994; Rice 2007). Given the present dissertation's aim of providing a foot-based account of both binary and ternary tonal phenomena, as exemplified by Rimi and Phuthi in section 1.2, I will adopt a foot inventory that can parse ternary structures.

Specifically, I adopt a theory of representation with internally layered feet, as it has been proposed for stress typology and a variety of foot-conditioned phenomena in Bennett (2012); Martínez-Paricio (2013); Martínez-Paricio and Kager (2015). This theory retains the binary foot, but allows for a single application of prosodic recursion (Itô and Mester 2007; Itô and Mester 2013), so that a foot can be recursively parsed, along with some unparsed material, into a higher foot layer. For example, the string $\sigma\sigma\sigma$ can be footed as $((\sigma\sigma)\sigma)$.

1.4.2 Licensing constraints

Having established the types of feet that will interact with tones in the present theoretical framework, I here discuss what drives these interactions.

The principal driving force for foot–tone association is a set of *licensing* constraints (Zoll 1996; Kang 1997). For example, the licensing constraint License(H, Ft) punishes candidates where a tone is not associated to any footed position, as defined in (5).

(5) License(H, Ft)
For each H tone, assign one violation mark if it is not associated to a footed syllable

Such tone licensing constraints are a crucial engine for foot–tone interaction. To demonstrate, the tableau in Table 1.1 shows that License(H, Ft) can push the grammar to place a foot specifically in a position where tone is located, as in winning candidate 1.1b, even if foot placement is unwarranted elsewhere as in 1.1c.

$\acute{\sigma}\sigma\sigma$	License(H, Ft)
a. $\acute{\sigma}\sigma\sigma$	*!
b. ☞ $(\acute{\sigma}\sigma)\sigma$	
c. $\acute{\sigma}(\sigma\sigma)$	*!

Table 1.1: Licensing drives foot placement

Conversely, licensing constraints can cause tone to reassociate towards footed positions. I demonstrate this in Table 1.2, where the foot is fixed at the right edge because of a second constraint, namely high-ranked ALL-FT-RIGHT (McCarthy and Prince 1993a), defined in (6).

(6) ALL-FT-RIGHT
For every foot, assign one violation mark for every syllable between that foot and the right edge of the domain

Since ALL-FT-RIGHT punishes feet at any position other than the right edge, feet cannot be placed to license the tone on the initial syllable *in situ*, as demonstrated by candidate 6c. The optimal choice is the move the tone so that it can be licensed in a position where feet are allowed, namely at the right edge, as shown in 6b.

$\acute{\sigma}\sigma\sigma\sigma$	ALL-FT-RIGHT	LICENSE(H, FT)
a. $\acute{\sigma}\sigma\sigma\sigma$		*!
b. ☞ $\acute{\sigma}\acute{\sigma}(\acute{\sigma}\sigma)$		
c. $(\acute{\sigma}\sigma)\sigma\sigma$	**!	
d. $\acute{\sigma}\sigma(\sigma\sigma)$		*!

Table 1.2: Licensing drives tonal reassociation

Although not shown in the tableau, it is also possible in this situation — though not necessary — to delink the tone from the non-footed positions, so that the tone has in effect shifted from its underlying position to the penultimate position. In the following chapters, I will adopt further constraints relating to faithfulness, foot placement, and the avoidance of tone association to certain positions; among other things, these constraints will decide between spreading and shifting effects.

1.4.3 Harmonic Serialism

In Optimality Theory, all changes between the underlying and surface phonological forms are applied in parallel. This property, combined with several other common assumptions in OT work, makes it harder to account for *opaque* patterns, whose analysis requires more reference to the lexical form than OT analyses typically allow for (Prince and Smolensky 1993; Idsardi 1998). Among tone reassociation patterns, such a problem occurs for bounded shift patterns as exemplified by Rimi in (2) earlier; bounded shift patterns can never be optimal because of competition with the faithful, non-reassociating candidate on the one hand, and an unbounded shift candidate on the other. I treat this problem in detail in section 2.2.3, with the tableau in Table 2.3, and in footnote 8 in section 4.1. Because of this problem, for much of this dissertation I adopt a serial variant of Optimality Theory called Harmonic Serialism (HS, Prince and Smolensky 1993; McCarthy 2000, 2010a).

In HS, Gen is specified with a list of changes termed "operations", and Eval considers only the faithful candidate and candidates that have had a single operation applied to them. After the most optimal candidate is selected, the output of Eval is fed back into itself, until Eval converges to a state where input and output are identical.

I will demonstrate HS here with an example showing licensing-driven foot placement.[3] I define an operation Op:Place-Ft in (7). In addition, I will add a typical pair of markedness constraints used to effect iterative footing: All-Ft-Right, discussed above and defined in (6, and Parse-σ, defined in (8).

(7) Op:Place-Ft
Place a foot which parses two adjacent unfooted syllables.

(8) Parse-σ
Assign one violation mark for every unfooted syllable

(9) All-Ft-Right
For every foot, assign one violation mark for each syllable between that foot and the right edge of the domain

Given these constraints and operations, the multi-tableau in Table 1.3 shows how feet are placed with a sensitivity to tone licensing over the course of two steps, with the outcome being the mapping $/\sigma\sigma\acute{\sigma}\sigma\sigma/ \rightarrow \sigma\sigma(\acute{\sigma}\sigma)\sigma \rightarrow [(\sigma\sigma)(\acute{\sigma}\sigma)\sigma]$. Arrows denote the fact that the output of one step is fed as input into the next application of Eval.

$\sigma\sigma\acute{\sigma}\sigma\sigma$	License(H, Ft)	Parse-σ	All-Ft-Right
Step 1			
a. $\sigma\sigma\acute{\sigma}\sigma\sigma$	*!	*****	
b. $\sigma(\sigma\acute{\sigma})\sigma\sigma$		***	**!
c. ☞ $\sigma\sigma(\acute{\sigma}\sigma)\sigma$		***	*
d. $\sigma\sigma\acute{\sigma}(\sigma\sigma)$	*!	***	
Step 2			
e. $\sigma\sigma(\acute{\sigma}\sigma)\sigma$		**!*	*
f. ☞ $(\sigma\sigma)(\acute{\sigma}\sigma)\sigma$		*	****
Step 3 — convergence			
g. ☞ $(\sigma\sigma)(\acute{\sigma}\sigma)\sigma$		*	****

Table 1.3: Foot placement in HS, sensitive to tone licensing

Crucially, the first foot is not placed adjacent to the right edge, because the high rank of License(H, Ft) makes tone licensing a more immediate priority

[3]See Pruitt (2010, 2012) for an in-depth treatment of foot structure and stress in HS, and McCarthy et al. (2012) for an early treatment of tone in HS.

for the grammar. This is why the outcome of the HS process is different from OT. In OT, the optimal candidate does not have to decide which constraint to satisfy "first", because evaluation is parallel. Consequently, the optimal OT candidate can accomplish licensing and right-edge foot orientation in parallel, by selecting the candidate [$\sigma(\sigma\acute{\sigma})(\sigma\sigma)$]. I illustrate this with an OT tableau in Table 1.4.

$\sigma\sigma\acute{\sigma}\sigma\sigma$/	License(H, Ft)	Parse-σ	All-Ft-Right
a. $\sigma\sigma\acute{\sigma}\sigma\sigma$	*!	*****	
b. $\sigma(\sigma\acute{\sigma})\sigma\sigma$		**!*	**
c. $\sigma\sigma(\acute{\sigma}\sigma)\sigma$		**!*	*
d. $\sigma\sigma\acute{\sigma}(\sigma\sigma)$	*!	***	
e. $(\sigma\sigma)(\acute{\sigma}\sigma)\sigma$		*	***!*
f. $(\sigma\sigma)\acute{\sigma}(\sigma\sigma)$	*!	*	***
g. ☞ $\sigma(\sigma\acute{\sigma})(\sigma\sigma)$		*	**

Table 1.4: Simultaneous licensing and rightmost parsing in OT

1.5 Outline of the dissertation

The main objective in this dissertation is to give a formal account of the typology of tonal reassociation patterns. That is, I will develop a theoretical framework that models how attested tonal reassociation patterns are represented and generated, and that predicts that some patterns cannot be attested, because they fall outside the scope of human linguistic capacity. In addition, I will take into account the role of learnability, arguing that some patterns that are predicted by the theoretical framework are still unlikely to be attested because they are less learnable.

In the remainder of this section, I will discuss each of the chapters in some detail. Briefly, Chapter 2 will introduce the framework and demonstrate it with a case study of bounded spreading and shifting in Saghala (Patin 2009). Chapter 3 will present a case study of bounded, quantity-sensitive ternary spreading in Copperbelt Bemba, with a focus on layered feet representations. Chapter 4 will give an overview of the crosslinguistic variation of tonal reassociation and considers factorial typologies for two varieties of the theoretical framework. Lastly, Chapter 5 will report on learning simulations using the theoretical framework, enhancing the typological fit of the framework with arguments from learnability.

1.5.1 Chapter 2: Saghala case study

In Chapter 2, I will start from a typology of bounded reassociation patterns, focusing on the case of Saghala (Patin 2009). Saghala shows spreading and shifting over a ternary domain, as well as various deviant patterns triggered by the presence of word boundaries and adjacent tones. I will provide an analysis that covers all six subpatterns reported for the tonology of Saghala noun phrases. This chapter will also give the most thorough discussion in the dissertation of the theoretical framework. In analyzing the ternary tone pattern of Saghala, the study will demonstrate the need for a ternary parsing structure, motivating the adoption of layered feet. In particular, section 2.5.3 will point out some issues with alternative approaches using binary feet, as well as approaches with "flat" ternary feet that have no internal structure. The chapter will also discuss the implementation of licensing effects, with a brief consideration of alternatives in section 2.5.2. Finally, the study will show that parallel Optimality Theory runs into trouble in dealing with bounded tone shift, and will demonstrate that with a Harmonic Serialism approach, a general account of bounded tone reassociation patterns is possible that includes bounded tone shift.

1.5.2 Chapter 3: Copperbelt Bemba case study

Chapter 3 concerns the analysis of bounded ternary spreading in Copperbelt Bemba (Bickmore and Kula 2013; Kula and Bickmore 2015). The focus in this chapter will be on the representation of the spreading domain. It will be argued that foot structure offers the best way of describing the spreading domain, because the domain is sensitive to the sequencing of light and heavy syllables in the same way some feet are. The chapter will go on to argue that layered feet offer a superior account compared to traditional binary foot-based analyses (McCarthy and Prince 1986; Itô and Mester 1992; Hayes 1995), because layered feet are better suited for describing ternarity as found in bounded spreading patterns such as in Copperbelt Bemba. Hence, the chapter adds support for the overall decision of modeling tonal reassociation with foot structure, as well as the particular decision of adopting a representational theory with layered feet.

1.5.3 Chapter 4: Typology

Chapter 4 will expand the typological coverage of the dissertation first aimed at in Chapter 2, so that it also includes unbounded reassociation patterns. In this chapter, I will present a calculation of the first ever factorial typology for tonal reassociation patterns. These results will also frame the learning simulation study that is discussed in Chapter 5. As discussed above, the chapter will assume a framework based on foot–tone interactions, using licensing constraints, in Harmonic Serialism. In addition, the chapter will consider an alternative constraint set, where tone reassociation is "edgewise", i.e. where tone is drawn towards an edge of the relevant prosodic domain, and where foot structure constrains the freedom for tone to reassociate. Through comparing these different constraint sets, the chapter will aim to make more general claims about the typological predictions of foot–tone frameworks.

1.5.4 Chapter 5: Learning Simulations

Finally, in Chapter 5 I will present learning simulations based on the investigation of the factorial typology of the licensing framework from Chapter 4. I will approach the learning task as one of *hidden structure learning*, where the example data for the learner is not fully informative of the structure assigned by the teacher's grammar. Consequently, the learner will have to make their own interpretation of foot structure and tonal structure. In addition, the learner will have to decide on the correct underlying forms associated with the example data. The example data are pairs of *morpheme* forms, containing the morphological composition of the utterance, and *overt* forms, which are impoverished phonological forms that indicate only the number of syllables and the pitch contrasts carried on those syllables. Learning will be performed with an online, error-driven learning algorithm that uses Robust Interpretive Parsing (RIP, Tesar and Smolensky 2000) to handle structural ambiguity in the example data. Typically, RIP learners detect errors by testing the learner's hypothesized, *virtual* production, and seeing if it corresponds with the adult mapping between morpheme and overt form. In the present study, I will expand this approach so that the learner also tests their virtual *comprehension*, again checking if this accords with example adult behavior. The reason for the adoption of this bidirectional strategy is that the learning data contains bidirectional ambiguity; the adult's overt forms can correspond to multiple morpheme forms, and *vice versa*. While previous work has considered such bidirectionally ambiguous datasets before (e.g. Akers 2012; Tesar 2017), the study in Chapter 5 is to my knowledge the first study tackling such bidirectional ambiguity through bidirectional error detection.

With regards to the typological investigation, Chapter 5 will show that patterns that were predicted-but-not-attested in Chapter 4 are generally much harder for learners to correctly converge on. In this way, the study will tighten the typological fit of the licensing framework to be developed in this dissertation.

The dissertation offers a general conclusion in Chapter 6.

Chapter 2

Deriving bounded tone with layered feet in Harmonic Serialism: The case of Saghala

Abstract

This chapter proposes an approach to bounded tone shift and spread as found in Bantu languages. Its core intuition is that the bounding domain is delimited by foot structure. The approach uses layered foot representations to capture ternary phenomena, following Martínez-Paricio and Kager (2015). A set of licensing and structural constraints regulate tone–foot interactions. Harmonic Serialism is adopted as the grammatical framework, to allow for an account of opaque patterns (Prince and Smolensky 1993; McCarthy 2010a).

The present approach improves on previous accounts in two ways. Firstly, the size of the tonal bounding domain follows from independently motivated foot representations, rather than being stipulated in the constraint set. Secondly, the approach obviates the need for markedness constraints that refer to underlying structure, because all relevant lexical information is reflected in foot structures.

The approach is demonstrated on Saghala (Patin 2009). Saghala shows both shift and spread in a trisyllabic domain. There are six tone patterns, dependent on the contact or near-contact of tones, and the position of word boundaries. An analysis is presented that accounts for all patterns. The success of the analysis shows that the foot-based approach is equipped to deal with a variety of bounded tone phenomena.

2.1 Introduction

Some Bantu languages display tone shift or spread, but only over a short distance.[1] That is, the target tone-bearing unit (TBU) for the shift or spread is at most a few units away from the underlying position of the tone. The TBU hosting the tone in the underlying form is here termed the sponsor TBU. The unit span across which tonal activity takes place is termed the bounding domain. An overview of attested bounded tone patterns is shown in Table 2.1.[2]

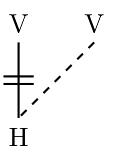
Pattern	*UF*	*SF*	*Example attestation*
Binary spreading	$..\acute{\mu}\mu..$	$..\acute{\mu}\acute{\mu}..$	Ekegusii
Ternary spreading	$..\acute{\sigma}\sigma\sigma..$	$..\acute{\sigma}\acute{\sigma}\acute{\sigma}..$	Copperbelt Bemba
Binary shift	$..\acute{\sigma}\sigma..$	$..\sigma\acute{\sigma}..$	Rimi
Ternary shift	$..\acute{\mu}\mu\mu..$	$..\mu\mu\acute{\mu}..$	Sukuma
Bin. shift + bin. spread	$..\acute{\sigma}\sigma\sigma..$	$..\sigma\acute{\sigma}\acute{\sigma}..$	Saghala

Table 2.1: A typology of attested bounded tone patterns

The crosslinguistic generalization from Table 2.1 is that the bounding domain is maximally three TBUs in size, counting from the sponsor TBU to the last TBU of the surface tonal span. That is, there are no attested cases of e.g. quaternary shift or spread.

In the autosegmental literature, most instances of bounded tone phenomena could straightforwardly be accounted for with locally defined rules. For example, (2) shows a typical definition of a tone shift rule, taken from Kenstowicz and Kisseberth (1990).

(2) Tone Shift



In Optimality Theory (OT, Prince and Smolensky 1993), demands on surface well-formedness and input-output correspondence are separated. Consequently, the direct formulation of the tone shift process as in (2) is unavailable. Despite this, constraint-based frameworks like OT are an appealing option for typological research, because they relate analytic choices to explicit typological predictions. Consequently, various OT approaches to the typology of Bantu bounded tone have since been proposed. Bickmore (1996) uses alignment constraints to derive a variety of bounded tone patterns. Two other approaches

[1] An earlier version of this chapter was published in the journal *Glossa* as Breteler (2017).

[2] References: Ekegusii (Bickmore 1996); Copperbelt Bemba (Bickmore and Kula 2013); Rimi (Olson 1964; Schadeberg 1978, 1979; Myers 1997); Sukuma (Sietsema 1989); Saghala (Patin 2009).

explore the merits of recasting tonal representations in featural domains: Optimal Domains Theory (Cassimjee and Kisseberth 1998), and Headed Spans (Key 2007). However, the above approaches suffer from two problems. As will be argued in section 2.5.2, all three approaches use well-formedness constraints that run counter to the OT tenet of output orientation. Furthermore, the representational approaches stipulate the size of the bounding domain.

This chapter presents a new constraint-based approach to bounded tone that avoids the above problems. Its core intuition is that the bounding domain is defined by foot structure. For example, a language with binary spreading would map $/\sigma\acute{\sigma}\sigma\sigma/$ to $[\sigma(\acute{\sigma}\acute{\sigma})\sigma]$, using a foot to determine the spreading domain.

The idea of relating metrical structure to tone is already present in the autosegmental literature (see Sietsema 1989; Bickmore 1995 for overviews). However, it was applied mainly to unbounded tone phenomena; tone was analysed as being attracted to metrically prominent positions near word or phrase edges. For bounded tone, an early foot-based approach was considered, and rejected, in an OT proposal by Bickmore (1996). In particular, Bickmore noted that the ternary nature of some bounded tone patterns posed a problem for binary feet.

Apart from Bickmore's study, the foot-based approach has remained underexplored.[3] This may have been due in part to the complexity of accounting for tonal shift. A foot-based approach to tone shift would need multiple steps: First a foot should be placed relative to a tone, and only then could the tone be shifted with reference to the foot. This is an opaque pattern, i.e. it requires intermediate forms. However, evaluation in OT is parallel, so it does not allow for intermediate forms. This problem will be demonstrated in detail in section 2.2.3.

Recent research provides answers to both the ternarity and opacity problems. Based on independent work on stress and foot representations, a layered, ternary foot was proposed by Kager (2012); Martínez-Paricio (2013); Martínez-Paricio and Kager (2015) *et seq.*, hereafter MPK. The ternary foot provides a natural way of defining the bounding domain for ternary tone phenomena.

The opacity problem is not unique to bounded tone, and research on accounting for opacity in OT has spawned a rich inventory of analytical tools. The present foot-based approach is couched in the Harmonic Serialism framework (HS, Prince and Smolensky 1993; McCarthy 2000, 2010a). HS is a variant of OT that employs derivations. HS's ability to account for opaque processes is limited; while it can accomodate the opacity of tone shift that is required here, it can only account for some types of counter-bleeding opacity

[3]One paper employing feet for an OT analysis of bounded tone is Kang (1997). The author thanks Clemens Poppe for pointing out this study. Kang combines foot structure and complex underlying tones (LH sequences) to derive tone shift in Sukuma. While there is some support for such tonal representations in Sukuma, this may not be the case for all bounded tone languages. Consequently, the present chapter aims to develop an account of bounded tone processes that does not rely on complex underlying tones.

and has no way of dealing with counter-feeding opacity (McCarthy 2007:36-8; Elfner 2016). It should be noted that HS is motivated not just by a need to deal with opacity; compared to OT, it can lead to different typological predictions that may exclude unattested patterns (McCarthy 2000, 2010b). It will be shown that HS lends itself particularly well to the present case, because the derivations are independent from morphological cycles.

It is beyond the scope of this chapter to account for the full typology of bounded tone. Rather, the foot-based analysis is demonstrated for Saghala, as described by Patin (2002, 2009). Saghala is a complex bounded tone system; it contains most of the phenomena seen in other bounded tone languages. In the default pattern, underlying /$\acute{\sigma}\sigma\sigma$/ maps to [$\sigma\acute{\sigma}\acute{\sigma}$]. This means Saghala shows both shift and spread characteristics, and covers a trisyllabic domain. Furthermore, as will be detailed below, the tonal pattern is sensitive to a number of factors. Specifically, one of five deviating patterns can arise, depending on tonal adjacency or near-adjacency and the position of word boundaries.

No previous constraint-based analysis of Saghala exists.[4] Consequently, the present goal is twofold. First, this chapter will present the first constraint-based account of Saghala tonology. Second, through giving this account, the chapter aims to demonstrate the general ability of the present proposal to deal with the complexities of trisyllabic domains, opaque patterns like tone shift, and interactions between metrically driven tone behavior and other tonal phenomena.

Section 2.2 outlines the foot-based Harmonic Serialism approach to bounded tone. Section 2.3 presents the data of Saghala, followed by an analysis in section 2.4. Section 2.5 discusses the proposal in the context of previous literature, after which the chapter wraps up with a conclusion.

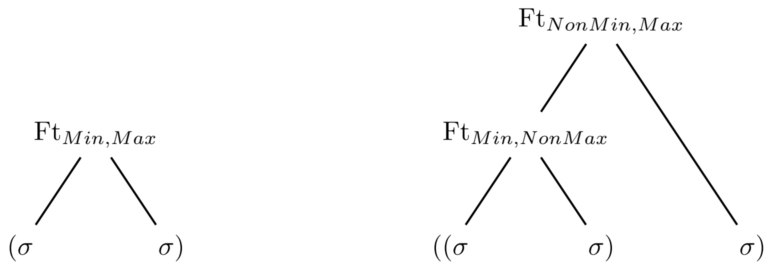
2.2 A foot-based approach in Harmonic Serialism

This section will outline a foot-based approach to Bantu bounded tone in a constraint-based context. First, section 2.2.1 discusses the layered foot representations assumed here. Then, section 2.2.2 details the constraint set used to relate tones and feet to each other. Section 2.2.3 shows why OT's parallel evaluation is problematic, and describes the Harmonic Serialism architecture adopted here. The representations, constraints, and grammatical framework are put together in section 2.2.4, which demonstrates the approach with a schematized example of binary rightward tone shift.

[4] Patin (2009) provides a descriptively adequate analysis that uses a rule-based theory. Since the present focus is on developing a constraint-based account of the typology of bounded tone, this chapter refrains from drawing a comparison to Patin's analysis.

2.2.1 Layered feet

Following MPK, who build on Selkirk (1980), Prince (1980), and Kager (1994), it is assumed that feet can be layered. That is, a flat, binary foot can be parsed together with an unfooted syllable to form a layered, trisyllabic foot.[5] Figure 2.1 shows examples of these foot structures.



(a) A flat, binary foot (b) A layered, ternary foot

Figure 2.1: Binary and ternary foot types in the MPK framework

The layered foot proposal mirrors the more generally formulated program of recursively deployed prosodic categories advanced by Itô and Mester (a.o. 2007); Itô and Mester (a.o. 2013). It also adopts their practice of distinguishing between structurally different constituents of the same prosodic category in terms of (non)minimality and maximality. A foot is maximal if it is not dominated by another foot. This holds for binary feet that are not part of a layered foot, such as in Figure 2.1a, and for the higher foot layer of ternary feet, as in Figure 2.1b. A foot is minimal if it does not dominate another foot. In the present chapter, all and only binary feet are instances of minimal feet. A foot is nonminimal or nonmaximal if it does not have the relevant property. This terminology can be used in constraint formulations, so that constraints can target specific types of feet. The necessity of referring to nonminimal constituents — specifically phonological phrases — has been argued for in Elfner (2013, 2015).

MPK assume that foot layering cannot be applied beyond the construction of ternary feet, making it different from the potentially infinitely recursed structures in Ito & Mester's work. Martínez-Paricio (2013:56*ff.*) cites the absence of any typological evidence to the contrary as a motivation for this assumption, and suggests that this fact may be related to the different *raison d'être* for foot structure compared to prosodic categories above the prosodic word.

[5]MPK's framework still includes unary feet as well. However, since unary feet will play no role in the present analysis, they are left out of consideration in the remainder of this chapter. This simplification can be represented formally with a top-ranked markedness constraint banning the presence of unary feet.

Adopting a layered foot is advantageous for the analysis of Bantu bounded tone. It allows for a straightforward definition of the bounding domain in ternary tonal patterns, such as ternary spread, ternary shift, and the Saghala mixed pattern of binary shift and binary spread.

In the present approach, there is no role for foot headedness or stress, so their implementation for layered feet is not discussed here. Section 2.5.4 of the discussion returns to the issue of foot headedness.

The next section will discuss the constraints that are needed to model tonal activity within the bounding domain.

2.2.2 Constraints

This section presents a constraint set to regulate the relationship between tone and feet. A major previous work on this topic is De Lacy (2002). Comparison between the present proposal and De Lacy's is taken up in section 2.5.4.

The relationship between tone and feet is an indirect one, as tone does not link directly to foot nodes, but rather to smaller tone-bearing units. This section takes the syllable as the TBU.[6] Consequently, the constraints presented here bear on the autosegmental links between tones and footed syllables.

It is proposed here that CON needs to allow for two effects; attraction, where the grammar promotes a tone–foot association; and repulsion, where the grammar militates against such an association. Examples of attraction are cases of tone-driven stress, where feet are ideally placed so that they overlap with a (high) tone (De Lacy 2002:2*ff.*). An example of repulsion is found in Lamba, where tone shifts away from its sponsor if the sponsor is in a rhythmically weak position (Bickmore 1995; De Lacy 2002:18–19). In general, repulsion is necessary to derive tone shift; attraction by itself does not drive the delinking of tone from its underlying position. In the following, constraint types for attraction and repulsion are discussed. First, the general format for the constraints is presented. Afterwards, it is discussed how they can be instantiated to target specific foot types and edges.

To drive the association between tones and feet, the present proposal adopts a set of licensing constraints (Zoll 1996, especially 147-152). Crucially, these constraints can take either the tone or the foot as the locus of violation. In other words, there are tone-licensing constraints and foot-licensing constraints. Both types are exemplified below by License(H, Ft) and License(Ft, H), respectively.[7] In general, License(X,Y) here means that an element of type X should be licensed by an element of type Y.

[6] This is not a claim about the universal nature of TBUs, but rather a choice made to simplify the presentation, as there are no moraic effects discussed in the present chapter.

[7] All references to tone in the constraint formulations are written with H for high tone, rather than T for any tone. This is only to reflect the privative tone system of Saghala and many other bounded tone languages, where syllables are underlyingly toneless or high-toned. Accounting for the typology of multi-level tone languages is beyond the scope of this chapter.

(3) License(H, Ft)
For each H tone, assign one violation mark if it is not associated to a footed syllable.

(4) License(Ft, H)
For each foot, assign one violation mark if none of its syllables are associated to a H tone.

For a given candidate, these two constraints may assign different numbers of violation marks. To demonstrate this, Table 2.2 shows the violation counts of various forms for License(H, Ft) and License(Ft, H).

	License(H, Ft)	License(Ft, H)
a. ($\sigma\,\sigma$) ($\sigma\,\sigma$) H H		
b. ($\sigma\,\sigma$) ($\sigma\,\sigma$) H H	**	**
c. ($\sigma\,\sigma$) ($\sigma\,\sigma$) H H		*
d. ($\sigma\,\sigma$) ($\sigma\,\sigma$) H	*	**

Table 2.2: Tone and foot licensing violations

Candidate 2.2a shows perfect one-to-one association between tones and feet, and candidate 2.2b shows complete nonassociation. For these candidates, the violation profiles are symmetrical. However, there are ways in which the violations assigned by the licensing constraints can differ. One example is in cases of multiple linking, as shown in 2.2c. Both tones have been licensed by a foot, satisfying License(H, Ft), but only the leftmost foot has been licensed by a tone, causing a violation of License(Ft, H). Moreover, candidate 2.2d shows that even in complete nonassociation, the violation counts can be different if the number of tones does not equal the number of feet. License(H, Ft) is violated once because there is one unlicensed tone, while License(Ft, H) is violated twice for two unlicensed feet.

The second tone–foot interaction that needs to be modeled is repulsion. It will be modeled using structural constraints.[8] These constraints militate against an association between a H tone and a foot. An example is *H/Ft:

[8] An obvious alternative are constraints with the opposite function of licensing, i.e. Non-License(H, Ft): "Assign one violation mark for each H that is associated to a footed syllable" and *vice versa* for Non-License(Ft, H). These constraints were rejected for the present

(5) *H/Ft
Assign one violation mark for each association between a H tone and a footed syllable.

In the case of structural constraints, the locus of violation is the association itself. Consequently, there is no distinction between a tone-version and a foot-version of the structural constraints.

The above definitions are the general forms of the proposed constraints. These general constraints coexist with more specific versions that target either the left or right edge of a specific foot type. For example, the following three constraints show instantiations of the constraint types for the right edges of minimal feet (MinFt):

(6) License(H, Min-R)
For each H, assign one violation mark if it is not associated to a syllable that is rightmost in a MinFt.

(7) License(Min-R, H)
For each MinFt, assign one violation mark if its rightmost syllable is not associated to a H tone.

(8) *H/Min-R
Assign one violation mark for each association between a H tone and a syllable that is rightmost in a MinFt.

With the use of these fine-grained constraints it is possible to model attraction and repulsion in specific contexts. Moreover, a grammar can now mix repulsion in one context with attraction in another. It is essential that the grammar has this flexibility, because this is exactly the type of situation that derives tone shift.

It is also possible to posit a constraint type that instantiates only to a specific edge, or only to a specific foot type. The analysis of Saghala does not motivate any such constraint, so these constraints will not be considered in the remainder of this chapter. Their desirability for the analysis of other languages is a topic for further research.

So far, this section has discussed constraints that handle the relationship between tone and feet. These constraints interact with constraints that pertain

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framework because of their potentially undesirable typological predictions, briefly outlined below, whose evaluation is beyond the scope of the present chapter.

Since an association link necessarily involves both a tone and a foot, any candidate that violates a tone-non-licensing constraint will also violate its commensurate foot-non-licensing constraint at least once. In effect, then, both a gradient and a categorical non-licensing constraint are part of the grammar. The categorical version allows for two potentially undesirable effects. Firstly, it can create a magnet effect, causing all tones to associate to one violating foot. Secondly, in derivational frameworks such as Harmonic Serialism it can cause a situation where repair strategies are only available to candidates with a minimal number of violating association links. For cases where a full repair would take multiple steps, e.g. multiple applications of delinking, no repair is started on, because a partial repair does not lead to a reduction in violation marks.

only to tone or only to feet. Of particular note are the constraints used to derive attraction of feet to one or the other edge of the footing domain. These constraints can put demands on foot placement that are orthogonal to those of the licensing constraints. As will be shown below, this is another ingredient required for an account of tone shift. In cases involving multiple feet, foot-to-edge attraction constraints also influence whether feet are built from right to left or the other way around. To derive these effects, the present chapter adopts the pair of constraints Chain-L(σ_ω) and Chain-R(σ_ω), proposed in Martínez-Paricio and Kager (2015), which are formulated in terms of non-intervention:

(9) Chain-L(σ_ω)
"For every unfooted syllable $(\sigma)_\omega$, assign a violation mark if some foot intervenes between $(\sigma)_\omega$ and the [left] edge of its containing ω [here: footing domain]." (Martínez-Paricio and Kager 2015:470)

Although MPK define the constraint for a prosodic word, the analysis of Saghala requires phrasal feet, as will be argued in section 2.4.1. Consequently, the definition of this constraint is amended here to refer to any footing domain that may be relevant in a language. Taken as such, Chain-L penalizes any unfooted syllable that is not in a chain, i.e. an unbroken sequence, of unparsed syllables starting from the left edge of the footing domain. Because it pushes unfooted syllables to the left, this constraint in effect pulls feet to the *right*. Similarly, its mirror image, Chain-R, has the effect of pulling feet to the left.

The constraint types discussed here will be relevant for the analysis of Saghala in section 2.4, but before that, their use will be demonstrated in the following sections, which discuss the adoption and practice of Harmonic Serialism.

2.2.3 Harmonic Serialism

In OT, foot-driven bounded tone shift is problematic, because it is opaque; a foot must be placed relative to the tone's underlying position, and only after this has been achieved is the tone free to shift across the foot. Table 2.3 demonstrates this in more detail. In this and following tableaux, some constraint names are shortened; in particular, the word License is denoted by $\mathcal{L}$. Various output candidates are listed for the input $/\sigma\acute{\sigma}\sigma\sigma/$, including the surface form corresponding to rightward foot-driven tone shift, which is $[\sigma(\sigma\acute{\sigma})\sigma]$. Only candidates with a single association link are considered, so that the example can abstract away from the matter of delinking from the sponsor position. The constraint set consists of the following elements needed for a foot-driven tone shift: License(H, Ft) to drive foot construction over the tone; Chain-L to pull the foot rightward; License(H, Min-R) to drive a tone to the right foot edge; and a catch-all faithfulness constraint Faith-Link inhibiting changes in tone association.

Candidates 2.3a-c show various legitimate outcomes given the constraint set, none of which shift the tone in any way. The desired candidate is 2.3e,

$\sigma\acute{\sigma}\sigma\sigma$	$\mathcal{L}$(H, FT)	CHAIN-L	$\mathcal{L}$(H, MIN-R)	FAITH-LINK
a. $\sigma\acute{\sigma}\sigma\sigma$	*!		*	
b. $\sigma(\acute{\sigma}\sigma)\sigma$		*	*	
c. $(\sigma\acute{\sigma})\sigma\sigma$		**		
d. $\sigma\sigma(\sigma\acute{\sigma})$				*
e. ϟ $\sigma(\sigma\acute{\sigma})\sigma$		*!		*

Table 2.3: Harmonically bounded, foot-driven bounded tone shift in OT

which positions the foot based on the underlying tone association and positions surface tone so it is at the right edge of the foot. However, it is harmonically bounded by candidate 2.3d, which shows that if tone can shift, it might as well shift all the way to the right edge so as to optimally accomodate rightward foot attraction. Consequently, there is no ranking under which local, bounded tone shift is preferred over a global, edgemost alternative.

To address this problem, the present framework adopts Harmonic Serialism, a variant of OT (HS, Prince and Smolensky 1993; McCarthy 2000, 2010a). Like OT, HS evaluates candidates through interaction of a ranked set of violable constraints. However, it deviates from OT in two ways. Firstly, GEN is limited to generating candidates that differ minimally from the input. Secondly, an evaluation happens serially: the output form of one tableau becomes the input form of another tableau. This repeats until the winning candidate is one that makes no change to the input. At that point, further evaluation would not yield any change, and so the winning form is the final result of the evaluation.

Candidates in HS can only differ from the input form by the application of one operation. The exact nature of the set of operations that a learner may acquire or carry innately is an open research question. This article will make use of the operations in (10):

(10)
1. Link a tone to a TBU.
2. Delink a tone from a TBU.
3. Merge two tones (tone fusion).
4. Build a foot.

The construction of a layered foot takes two steps: first, two syllables are parsed into a flat foot. Then, the flat foot and a third syllable are parsed into a layered foot. An application of the foot-building operation can correspond to either of these steps (Kager and Martínez-Paricio 2013). It is assumed that faithfulness to metrical structure is absolute, so that GEN can never delete, shift, or otherwise alter a foot (“Strict Inheritance”, Pruitt 2010:486).

The operations in (10) suffice for the arguments made in this chapter, but it is not claimed that these must be the only operations that can apply to tone and feet. For example, other grammars may make use of operations to delete, insert, or modify tones. The present operation set closely follows previous work on this topic. See Pruitt (2010, 2012) for an in-depth treatment of implementing metrical structure and stress in HS, and see McCarthy et al. (2012) for previous work on tone.[9] This chapter further follows previous work in assuming that a tone shift operation is not part of Gen (McCarthy et al. 2012:267ff, but see Gietz et al. 2015 for an opposing view). As will be shown in the remainder of the chapter, a shift operation is not necessary to derive tone shift effects, since they can also be derived from a combination of foot-driven spreading and delinking steps.

HS is particularly suitable for the present purposes because a foot-based analysis of bounded tone may involve several intermediate steps between underlying and surface levels. Specifically, foot placement needs to be relative to the position of tone, after which tone association must readjust itself to the presence of feet. Furthermore, nothing suggests that these steps are related to different morphological cycles, which could have provided another source of derivationality. Consequently, the amorphological derivationality provided by HS is ideally suitable for a foot-based analysis of bounded tone.[10]

The next section will demonstrate the foot-based HS approach to bounded tone on a schematized example.

2.2.4 Example: Binary tone shift using feet in Harmonic Serialism

This section will demonstrate the foot-based approach to bounded tone in HS using an abstract example of rightward binary tone shift, where a tone surfaces on the TBU to the right of its sponsor. This pattern is attested among others in Rimi (Olson 1964), Kikuyu (Clements 1984), and Zululand Zulu (Downing 1990). Concretely, this section will derive the mapping of $/\sigma\acute{\sigma}\sigma\sigma/$ to $[\sigma\sigma\acute{\sigma}\sigma]$. The example will serve both as an elaboration of the approach and as the foundation for the analysis of Saghala in section 2.4.

The constraints used in the OT example above are called upon once again. One additional constraint is needed: *H/MinFt-L. This constraint penalizes an association of H tone to the left edge of a minimal foot. This will be crucial to force tone to delink from its sponsor location, effecting a tone shift rather than only a spreading process.

[9] A major conclusion made by McCarthy et al. (2012) is that in HS, tone cannot be lexically linked in any language. This is at odds with the present approach, where lexical linking is assumed. Resolving this conflict is a matter for future research.

[10] Frameworks that are more tightly linked to morphology, such as Stratal OT (Bermúdez-Otero 1999; Kiparsky 2000) may still be able to accomodate a foot-based analysis of bounded tone. However, because Saghala tone operates postlexically (as argued in section 2.4.1), this will require the positing of multiple post-lexical levels. See Jones (2014) for a related proposal.

To save space, the tableaux below do not include candidates that are the result of a tone deletion or tone insertion operation. This choice is not problematic, because such operations can be ruled out by high-ranking MAX-T and DEP-T constraints. Candidates with gapped autosegmental structures or floating tones are also left out of consideration. These candidates can be ruled out with markedness constraints (see e.g. McCarthy et al. 2012).

The derivation is presented below, starting with Table 2.4. Adjacent High tones indicate spreading. That is, $\sigma\acute{\sigma}\acute{\sigma}\sigma$ denotes a form with one H tone, linked to two syllables. If adjacent syllables link to different tones, this will be indicated with subscript indices. For example, $\acute{\sigma}\acute{\sigma}_1\acute{\sigma}_2\acute{\sigma}$ denotes a form with two H tones each linked to two syllables. Since this chapter does not consider gapped autosegmental constructions, forms such as $\acute{\sigma}\sigma\acute{\sigma}$ necessarily contain two H tones, and do not need to be explicitly marked with indices.

$\sigma\acute{\sigma}\sigma\sigma$	$\mathcal{L}$(H, FT)	CHAIN-L	$\mathcal{L}$(H, MIN-R)	*H/MIN-L	FAITH-LINK
a. $\sigma\acute{\sigma}\sigma\sigma$	*!		*		
b. ☞ $\sigma(\acute{\sigma}\sigma)\sigma$		*	*	*	
c. $(\sigma\acute{\sigma})\sigma\sigma$		**!			
d. $\sigma\acute{\sigma}(\sigma\sigma)$	*!		*		
e. $\sigma\acute{\sigma}\acute{\sigma}\sigma$	*!		*		*

Table 2.4: Binary rightward shift in HS, step 1

Here, because LICENSE(H, FT) is top-ranked, the most urgent thing for the grammar to do is to license the H tone. This is achieved by placing a foot over the sponsor syllable. Both candidates 2.4b and 2.4c do so. However, the exact placement of the foot is left to CHAIN-L, which pulls unparsed syllables to the left, and hence feet to the right. This makes 2.4b the optimal candidate.

Candidate 2.4d has placed the foot so far to the right that it does not dominate the high-toned syllable. This favors rightward foot attraction, but under the present constraint ranking it is suboptimal. Candidate 2.4e demonstrates that tone spreading is in no way beneficial at this point in the derivation; there is no valid spreading target to satisfy LICENSE(H, MIN-R) yet.

Table 2.5 shows the next step in the derivation.

Now that the tone has been licensed, CHAIN-L(σ_ω) is the most important constraint to satisfy. This is done by reducing the number of unparsed syllables that are not in a sequence at the left edge of the domain. Candidate 2.5b shows

	$\sigma(\acute{\sigma}\sigma)\sigma$	$\mathcal{L}$(H, Ft)	Chain-L	$\mathcal{L}$(H, Min-R)	*H/Min-L	Faith-Link
a.	$\sigma(\acute{\sigma}\sigma)\sigma$		*!	*	*	
b. ☞	$\sigma((\acute{\sigma}\sigma)\sigma)$			*	*	
c.	$(\sigma(\acute{\sigma}\sigma))\sigma$		*!	*	*	
d.	$\sigma(\acute{\sigma}\acute{\sigma})\sigma$		*!		*	*
e.	$\acute{\sigma}(\acute{\sigma}\sigma)\sigma$		*!	*	*	*

Table 2.5: Binary rightward shift in HS, step 2

how: building a layered foot to incorporate the last unparsed syllable at the right.

Candidate 2.5c shows another way of expanding the binary foot into a ternary one, but in the wrong direction, yielding no reduction in violation marks. Candidate 2.5d shows an instance of premature spreading, ignoring the urgency of Chain-L(σ_ω).

Another spreading candidate is 2.5e. Although spreading outside the foot does not satisfy any constraint, it does not incur additional violations of any markedness constraint either. In particular, spreading outside the foot does not violate License(H, Ft). This is because the constraint is satisfied as soon as the H tone is licensed anywhere; it evaluates at the level of the tone, and not at the level of the syllable. Consequently, it does not require that every TBU carrying the H is in a licensed position, but just that one of them is.

As the final three steps are more straightforward, they are presented in Table 2.6, a multi-step tableau (Pruitt 2012). The semi-circle arrows to the left side of the tableau indicate which form at a given step is selected as the input form for the next step. Thus, for example, candidate 2.6b is optimal at step three, and becomes the input form for candidates 2.6c,d,e in step four.

In step three, footing is complete, and the grammar can attend to the position of tone within the foot. The winning move is to simply spread rightward, reaching the right edge of the minimal foot, as shown in candidate 2.6b. This takes away the violation of License(H, Min-R).

In step four, there are several linking and delinking options. The winning candidate, 2.6d, demonstrates the satisfaction of *H/Min-L through delinking of tone from the left foot edge. Candidate 2.6e shows a ternary high tone span covering the entire layered foot. Although it is not optimal with the given constraint ranking, it could be made optimal with some different rankings of tone–foot constraints. Specifically, a constraint License(H, NonMin-R)

$\sigma((\acute{\sigma}\sigma)\sigma)$	$\mathcal{L}$(H, Ft)	Chain-L	$\mathcal{L}$(H, Min-R)	*H/Min-L	Faith-Link
Step 3					
a. $\sigma((\acute{\sigma}\sigma)\sigma)$			*!	*	
b. ☞ $\sigma((\acute{\sigma}\acute{\sigma})\sigma)$				*	*
Step 4					
c. $\sigma((\acute{\sigma}\acute{\sigma})\sigma)$				*!	
d. ☞ $\sigma((\sigma\acute{\sigma})\sigma)$					*
e. $\sigma((\acute{\sigma}\acute{\sigma})\acute{\sigma})$				*!	*
Step 5 — convergence					
f. ☞ $\sigma((\sigma\acute{\sigma})\sigma)$					
g. $\sigma((\sigma\acute{\sigma})\acute{\sigma})$					*!

Table 2.6: Binary rightward shift in HS, steps 3-5

could induce spreading to the right edge of the non-minimal foot. This shows the framework is able to account for ternary spread patterns, as attested in Copperbelt Bemba (Bickmore and Kula 2013).

In step five, the faithful candidate, 2.6f, has no violation mark for any constraint. Since it is optimal to make no further changes, the evaluation converges here and the output form of the derivation is [$\sigma((\sigma\acute{\sigma})\sigma)$], which is equal to the desired [$\sigma\sigma\acute{\sigma}\sigma$], modulo foot structure. Candidate 2.6g shows that further spreading is unnecessary with the current constraint set. However, inclusion of License(H, NonMin-R) could again turn this into the optimal candidate, making the binary shift plus binary spread pattern derivable. This pattern is the default behavior of tone in Saghala, which is the topic of the next section.

2.3 Saghala tone

This and the following section provide an in-depth case study for the foot-based HS framework. The case at hand is the tonology of noun phrases in Saghala (Guthrie's E74b), spoken in southeastern Kenya. All data here are transcriptions taken from Patin (2002) and Patin (2009), which are based on Patin's fieldwork.[11] Glosses from Patin (2002) use adjectives as predicates, whereas similar phrases in Patin (2009) are glossed with the adjectives used attributively; I assume that this does not reflect a relevant difference between the two data sets. Glosses from Patin (2002) have been translated from French by the present author.

Saghala has several properties that make it a suitable test case. Firstly, it features both tone shift and tone spread. Secondly, this tonal activity takes place in a trisyllabic domain. Thirdly, there is no involvement of morphology in the tonal patterns. Finally, the tonal pattern is complex: There are six patterns, depending on the phonological context, specifically the proximity of tones to each other and to the position of word boundaries.

This section describes the data, while the next section takes up their formal analysis. The presentation essentially follows that of Patin (2009), although the patterns have been renamed and a sixth pattern has been added. Further following Patin, since there seems to be no role for low tone in the language, a privative analysis is pursued. That is, it is assumed that all syllables are phonologically either H-toned or toneless, and that toneless syllables receive a default low pitch only after the phonological derivation.

The nature of the Saghala lexicon precludes the attestation of certain data. Specifically, all words in Saghala carry at most one H. Furthermore, all words in the sample are either two or three syllables in length.[12] Lastly, only determiners can carry H on a word-final syllable. This means that there are no contexts which have three tones adjacent to each other. In addition, because there are no monomoraic words, it is impossible to create contexts with multiple word boundaries on sequential syllables.

Default context

The default pattern in Saghala is the following: The two syllables following a sponsor receive high tone, while the sponsor itself is low-toned at the surface. The term "default pattern" is defined as the tonal pattern displayed when there is no effect of tonal proximity or word boundaries.

The location of sponsors is an analytical claim. To support this claim, the data in (11) show alternation of a toneless word in isolated context with two contexts where it is preceded by another word. In this and the following examples, proposed sponsor syllables are indicated by underlining.

(11)	a.		nɟovu	'elephant(s)'
	b.	<u>i</u>zí	nɟóvu	'that elephant'
	c.	i<u>lya</u>	nɟóvú	'these elephants'

[11] Patin does not mention how his transcriptions relate to IPA; presumably, all symbols are IPA except for y, which represents IPA j.

[12] Patin (2002) contains one instance of a quadrisyllabic word, [nizamɲaŋge] 'white PL.'. In some attestations containing this word, the coda [m] is marked with surface H tone. Since the role of coda [m] here is not well understood, this word has been excluded from consideration.

The bare noun in (11a) is toneless, but tone can be contributed to it from the preceding words in (11b,c). This suggests that tone was specified on these words. Furthermore, these words differ in terms of onset of the tonal span and, relatedly, the degree to which the span crosses into the next word. This suggests that tone in Saghala is linked underlyingly, and can be linked to different places in a word.

The tone shifting nature of Saghala is apparent from (11c). Here, tone was contributed by the first word, yet surfaces exclusively on the second, suggesting a rightward shift. Another observation confirming the notion of rightward shift is that noun phrase-initial syllables never surface with high tone.[13]

Long Spreading

In a specific context, surface tone spans across three syllables, rather than the default two. This pattern is dubbed Long Spreading. Examples of Long Spreading and its non-application are shown in (12). The string *aa* denotes two syllables; length is not contrastive in Saghala.

(12)	a.	i.	ivilya vóŋgó víbwaa	'those heads are big'
		ii.	ilya mbúlá mbwáa	'that big nose'
		iii.	ilya mízí míbwaa	'those villages are big'
	b.	i.	ivilya vítánda vibwaa	'those big beds'
		ii.	i̲zí nɟóvu	'that elephant'

In the cases in (12a) the tonal span is extended to a third syllable. Crucially, this third syllable is word-initial. These forms also show that Saghala tone can cross more than one word boundary. There is no tone span extension if the third syllable is not word-initial. Examples of this are in (12b), where tone shows a binary spread, rather than a ternary spread or even a quaternary spread to reach a word-initial syllable.

The second example, (12bii), repeated from (11b), shows that the tonal span remains binary even if that causes it to end in a word-initial syllable. This means that the word-initial syllable high is a goal, not a means; it is not used as a stepping stone to form a ternary span, e.g. *i̲zí nɟóvú. Furthermore, as noted above, phrase-initial syllables are never high-toned at the surface, despite the present observation that word-initial syllables can warrant a larger tone spread. Moreover, Long Spreading will never motivate a tone to surface on its sponsor syllable. This suggests that the drive for tone shift in Saghala is stronger than that of associating H to word-initial syllables.

Summarizing so far, Saghala shows a ternary span following the sponsor if the third syllable following the sponsor is word-initial, and a binary span in other cases. The following discussion will delve into contexts containing more than one tone in close proximity.

[13] This refers to words that are initial in the noun phrase, which is what Patin (2009) reported on. It is not known how this relates to higher syntactic or prosodic structures.

Adjacent Sponsors

If a word with a word-final sponsor is followed by a word with a word-initial sponsor, this is termed an Adjacent Sponsors context. In such contexts, high tone surfaces only on the second sponsor. Strikingly, there is no tonal span of two or three syllables. Examples are shown in (13).

(13) a. ilya mbúzi 'that goat'
b. ilya ʃímba 'that lion'
c. uɣulya mwézi mbwaa 'that moon is big'

The adjacency of TBUs linked to different tones here leads to an outcome that is highly different from the patterns seen so far. In line with this, some of the following subpatterns display a strategy of avoiding adjacent tone spans.

Blocked Spreading

When sponsors are separated by a single syllable, one of two scenarios can occur. In the default case, both tones can shift, but the left H tone cannot spread, in effect keeping its one-syllable distance to the following tone. This is referred to as the Blocked Spreading context. Blocked Spreading is demonstrated in (14).

(14) a. ihí mbuzí 'this goat'
b. ihí mezí míbwaa 'these moons are big'
c. awá waná wálelé 'these tall children'

Examples (14a,c) also demonstrate the behavior of tone that is near the right edge of the domain. In these cases too, the tone will shift, despite the lack of opportunity for spreading. In addition, (14c) shows that Saghala allows two different tones to surface on the same word.

The Blocked Spreading context shows that the language may preserve some distance between tones. If the tones operated completely independently from another, then the first tone should be able to spread to the second sponsor syllable, resulting in a potential four-syllable tone span, e.g. *ihí mézí míbwaa.

Straddled Word-Initial Syllable

A different scenario applies when the syllable in between the two sponsors is word-initial. This context is called Straddled Word-Initial Syllable or SWIS. This is the second context that is dependent on a specific position of the word boundary, along with the Long Spreading context discussed above.

In SWIS contexts, the surface form looks as if the second tone was never there; tone surfaces on the two syllables to the right of the first sponsor, and there is no trace of tone from the second sponsor. This is shown in (15).

(15) a. ilya záwádi 'that gift'
b. ilyilya ízíso ibwaa 'that eye is big'
c. walye wálúme walelé 'those men are big'

If this context followed the Blocked Spreading pattern above, then the two tones should have shifted separately, e.g. showing *ilya záwadí. Instead, the surface span resulting from the two tones covers a smaller domain than expected, reminiscent of the Adjacent Sponsors context. Patin (2009) reports no indication that the surface tone span consists of two parts, which could for example be signalled by a downstepped second high syllable. Moreover, his analysis treats the surface tonal span as representing a single tone. Consequently, this chapter assumes that a single surface tone is an appropriate representation for the SWIS data.

Together, the Blocked Spreading and SWIS contexts cover all outcomes for sponsors that are one syllable apart. For contexts with a two-syllable distance between sponsors, there should generally be no expectation of tonal interaction, since both sponsors have enough room to shift and spread. However, there is one plausible exception. If the first tone is in a position to trigger Long Spreading, it is possible that the resulting three-syllable span causes tonal contact. The discussion of the sixth subpattern below tests this scenario.

Blocked Long Spreading

Although rare in the data sample, there is an instance of the context described above. It is shown in (16).

(16) izilya ŋgúkú nɟacé 'those little chickens'

If the Long Spreading pattern applied here, the first tone could cover a ternary span, because the third syllable after the sponsor is word-initial. Combined with the influence of the second tone, this could result in a quaternary surface span: *izilya ŋgúkú nɟácé. This is not the case, but the attested form does show the influence of both tones independently of each other. Consequently, this subpattern is most comparable to the Blocked Spreading pattern, rather than the contracted cases of Adjacent Sponsors and SWIS.

Overview

The six patterns are listed in Table 2.7 below. The context descriptions have been schematized. Word boundaries are only shown where relevant to the description of the context. All descriptions use enough syllables to show the end of the tone span, as indicated by a following low-toned syllable, but this final low syllable is not essential to the context; Saghala does not repel tones from the right phrase edge.

Context	*UF*	*SF*
Default: Surface high tone on the two syllables following the sponsor.	$..\acute{\sigma}\sigma\sigma\sigma..$	$..\sigma\acute{\sigma}\acute{\sigma}\sigma..$
Long Spreading: Surface high tone on the three syllables following the sponsor if the final syllable is word-initial, and not a sponsor syllable.	$..\acute{\sigma}\sigma\sigma\#\sigma\sigma..$	$..\sigma\acute{\sigma}\acute{\sigma}\#\acute{\sigma}\sigma..$
Adjacent Sponsors: A single surface high tone on the rightmost of two sponsor syllables.	$..\acute{\sigma}\#\acute{\sigma}\sigma..$	$..\sigma\#\acute{\sigma}\sigma..$
Blocked Spreading: Surface high tone only on the first syllable following the sponsor if the syllable after that is also a sponsor (tone from this second sponsor also shifts away).	$..\acute{\sigma}\sigma\#\acute{\sigma}\sigma\sigma\sigma..$	$..\sigma\acute{\sigma}\#\sigma\acute{\sigma}\acute{\sigma}\sigma..$
Straddled Word-Initial Syllable: Surface high tone on the two syllables following the leftmost of two sponsors, if those sponsors straddle a word-initial syllable.	$..\acute{\sigma}\#\sigma\acute{\sigma}\sigma..$	$..\sigma\#\acute{\sigma}\acute{\sigma}\sigma..$
Blocked Long Spreading: No Long Spreading if the third syllable of a potential ternary tone span is itself a sponsor.	$..\acute{\sigma}\sigma\sigma\#\acute{\sigma}\sigma\sigma\sigma..$	$..\sigma\acute{\sigma}\acute{\sigma}\#\sigma\acute{\sigma}\acute{\sigma}\sigma..$

Table 2.7: Six tonal patterns in Saghala

2.4 A foot-based HS analysis of Saghala tone

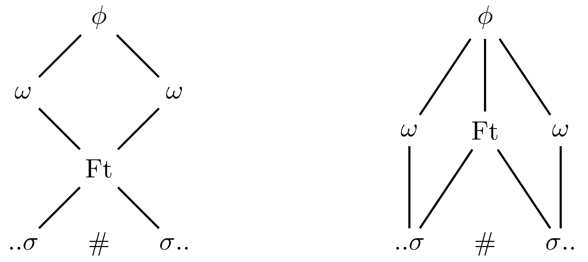
This section will account for all the Saghala subpatterns described in the previous section. First, the relationship between foot and word in Saghala is discussed below. Then, the constraint ranking for Saghala is presented. Finally, HS derivations are presented for all subpatterns.

2.4.1 The relationship between foot and word

In Saghala, tone spreading freely crosses word boundaries. If this process is to be analysed by feet, then feet need to be similarly free to straddle word boundaries. This is in fact the route taken here, with foot attraction being evaluated by CHAIN-L/R at the phrasal level. However, the process of Long Spreading shows that there is still a phonological role for the word to be played; word-initial syllables invite spreading from the previous word. This means that feet and prosodic word constituents must both be active, independently from each other.

The structures in Figure 2.2 show two ways of representing a foot straddling a word boundary.

In Figure 2.2a, a foot is dominated by both of the words whose syllables it parses. Syllable membership can then be calculated through orientation; in



(a) Two words dominating one foot

(b) A phrase directly dominating two words and a foot

Figure 2.2: Two representations of a foot straddling a word boundary

double-dominated feet, the left syllable belongs to the left dominating word, and the right syllable to the right dominating word. This approach violates the common assumption that every (non-root) node has exactly one dominating node ("Proper Bracketing", Itô and Mester 1992).

In Figure 2.2b, the phrase acts as the footing domain, directly dominating the foot as well as the word. While this goes against the original conception of the Prosodic Hierarchy by Nespor and Vogel (1986), it is in line with revisions by Inkelas (1989) and Downing (1998, 2006) who propose a split of the Prosodic Hierarchy into a prosodic and a metrical hierarchy (as summarized in Poppe 2015). Their arguments are based on distinctions between phonology and morphosyntax and the frequent absence of overlap between the two, rather than on the type of situation that obtains in Saghala, where feet need to straddle Prosodic Word boundaries. However, the Saghala case is not unique; Buckley (2014) reports a combination of word-straddling feet and word-level information being accessed at the phrase level for Kashaya.

For the analyses in the remainder of this section, the choice between the structures in (2.2) is not crucial; all that is needed is that footing can occur phrasally while syllables can still be checked for word-initiality.

2.4.2 Constraint ranking and definitions

The core of the constraint ranking is shown in (17), with the ranks numbered, 1 being the highest.

(17)
1. License(H, Ft)
   Assign one violation mark for each H that is not associated to a footed syllable.
2. Chain-L(σ_ω)
   For every unfooted syllable [σ_i], assign a violation mark if some foot intervenes between σ_i and the left edge of its containing prosodic word.

3. *H/Min-L
   Assign one violation mark for each association between a H and the leftmost syllable of a Min foot.
4. License(H, Min-R)
   Assign one violation mark for each H tone that is not associated to the rightmost syllable of a Min foot.
5. License(H, NonMin-R)
   Assign one violation mark for each H tone that is not associated to the rightmost syllable of a NonMin foot.
6. Dep-Link, Max-Link, Uniformity(H)

This constraint set is similar to the one presented for the binary rightward shift example in section 2.2.4. The main addition is another licensing constraint: License(H, NonMin-R). This constraint promotes association of H to the rightmost syllable of a layered foot. As a result, the grammar has cause to associate a H to two locations, which are the right edge of the minimal and of the nonminimal foot.

The schematized example mapped $/\sigma\acute{\sigma}\sigma\sigma/$ to $[\sigma((\sigma\acute{\sigma})\sigma)]$. With the inclusion of License(H, NonMin-R), the grammar will instead settle on $[\sigma((\sigma\acute{\sigma})\acute{\sigma})]$. This is exactly the result found in the Saghala default pattern, which will be derived below.

At the bottom of the ranking are faithfulness constraints against tone linking, tone delinking, and tone fusion. The bottom-ranked position of these constraints means that the related operations may be applied to satisfy any markedness constraint in the ranking.

Some further additions to the constraint set are needed to account for the other subpatterns. Firstly, it was apparent from the Long Spreading and SWIS contexts that word-initial syllables have a special status in Saghala. This is modeled in the grammar with License(PrWd-L, H):

(18) License(PrWd-L, H)
For each PrWd, assign one violation mark if its leftmost syllable is not associated to a H tone.

As will be discussed below, this constraint must be quite low-ranked. This is supported by the observation that not all word-initial syllables in the language are high-toned, and that tone can shift away even from word-initial sponsors.

A further addition to the grammar is the OCP (Myers 1997). The constraint is here defined as follows:

(19) OCP
For each pair of H tones, assign one violation mark if they are associated to the same or adjacent syllables.

Although surface forms in Saghala never violate OCP, it does not have a high rank. This is because, as will be shown below, tonal contact must be allowed during the derivation of the SWIS context, so OCP should not rule this out. Furthermore, most of the avoidance of tonal contact is already achieved by the tone shifting behavior.

A third addition is License(Ft, H). This constraint militates against tonally "empty" feet. In practice, this has two effects. Firstly, feet are not created in positions where there is no H-toned syllable. This runs counter to foot attraction constraints such as Chain-L, which promotes foot building if this helps to avoid unfooted syllables in certain positions. The second effect is that tone cannot delink from a syllable if that were to cause a toneless foot. In this sense, License(Ft, H) acts as a faithfulness constraint; licensed feet cannot lose their license. The definition of the constraint is as follows:

(20) License(Ft, H)
For each foot, assign one violation mark if none of its syllables are associated to a H tone.

The final addition to the constraint set involves several constraints meant to regulate the direction of foot expansion and its timing, i.e. the step in the derivation where foot expansion occurs. For the default pattern, the rightward expansion $((\sigma\sigma)\sigma)$ is correct and could be constructed right away. However, to account for some of the other subpatterns, the grammar must be able to delay foot expansion to a later step in the derivation, and even be able to expand leftward. Three constraints are adopted to achieve this extra flexibility. The first is Chain-R(σ_ω), which is the counterpart of previously seen Chain-L(σ_ω). It has the effect of pulling feet to the left, which means that it favors leftward foot expansion.

The other two constraints place demands on the presence or absence of tones with regards to layered feet:

(21) *H/NonMin-L
Assign one violation mark for each association between a H and the leftmost syllable of a NonMin foot.

(22) License(NonMax-R, H)
Assign one violation mark for each NonMax foot if its rightmost syllable is not associated to a H tone.

Crucially, these constraints only come into action in the context of layered feet, since flat binary feet are neither nonminimal nor nonmaximal. Consequently, the grammar is free to place flat binary feet, but must pass the criteria of the two constraints above before being allowed to expand. The criteria are demonstrated by means of Table 2.8.

The tableau has three parts. Candidates 2.8a,b show leftward and rightward expansion from $\sigma(\sigma\acute{\sigma})\sigma$, candidates 2.8c,d from $\sigma(\acute{\sigma}\sigma)\sigma$, and candidates 2.8e,f from $\sigma(\acute{\sigma}\acute{\sigma})\sigma$. The default pattern of rightward expansion is only optimal from a $\sigma(\sigma\acute{\sigma})\sigma$ starting point. In the case of candidates 2.8c,e, rightward expansion

	*H/NonMin-L	$\mathcal{L}$(NonMax-R, H)	Chain-L	Chain-R
a. ☞ $\sigma((\sigma\acute{\sigma})\sigma)$				*
b. $(\sigma(\sigma\acute{\sigma}))\sigma$			*!	
c. $\sigma((\acute{\sigma}\sigma)\sigma)$	*!	*		*
d. ☞ $(\sigma(\acute{\sigma}\sigma))\sigma$		*	*	
e. $\sigma((\acute{\sigma}\acute{\sigma})\sigma)$	*!			*
f. ☞ $(\sigma(\acute{\sigma}\acute{\sigma}))\sigma$			*	

Table 2.8: Violations of foot expansions

is blocked by *H/NonMin-L because it situates a H tone at the left edge of a nonminimal foot.

License(NonMax-R, H) does not favor either leftward or rightward expansion. However, it can serve as a deterrent from foot expansion in general; candidates 2.8c,d both incur violations from this constraint. This way, the constraint allows for a delay in foot expansion until a tone has reached the right edge of a prospective non-maximal foot.

The full ranking, shown in (23), consists of the core constraint set and the additions discussed above. Constraints listed within the same rank are not crucially ranked with respect to each other.

(23) 1. Max-T, Dep-T, NoFloat, NoGap,
*H/NonMin-L
Assign one violation mark for each association between a H and the leftmost syllable of a NonMin foot.
License(H, Ft) (abbreviated $\mathcal{L}$(H, Ft))
Assign one violation mark for each H that is not associated to a footed syllable.
License(Ft, H) (abbreviated $\mathcal{L}$(Ft, H))
For each foot, assign one violation mark if none of its syllables are associated to a H tone.
License(NonMax-R, H) (abbreviated $\mathcal{L}$(NonMax-R, H))
Assign one violation mark for each NonMax foot whose rightmost syllable is not associated to a H tone.

2. Chain-L(σ_ω) (abbreviated Chain-L)
For every unfooted syllable [σ_i], assign a violation mark if some

foot intervenes between σ_i and the left edge of the footing domain (in Saghala: phrase).

3. *H/MIN-L
   Assign one violation mark for each association between a H and the leftmost syllable of a Min foot.
4. CHAIN-R(σ_ω) (abbreviated CHAIN-R)
   For every unfooted syllable [σ_i], assign a violation mark if some foot intervenes between σ_i and the right edge of the footing domain (in Saghala: phrase).
5. LICENSE(H, MIN-R) (abbreviated $\mathcal{L}$(H, MIN-R))
   Assign one violation mark for each H tone that is not associated to the rightmost syllable of a Min foot.
6. LICENSE(H, NONMIN-R) (abbreviated $\mathcal{L}$(H, NONMIN-R))
   Assign one violation mark for each H tone that is not associated to the rightmost syllable of a NonMin foot.
7. LICENSE(PRWD-L, H) (abbreviated $\mathcal{L}$(ω-L, H))
   For each PrWd, assign one violation mark if its leftmost syllable is not associated to a H tone.
8. UNIFORMITY(H), MAX-LINK, DEP-LINK,
   OCP
   For each pair of H tones, assign one violation mark if they are associated to the same or adjacent syllables.

The composition of the above constraint set is principled, despite its size. About half of the constraints are instantiations of the constraint format put forth in section 2.4.2. The remaining constraints are taken from previous literature, and are established in mainstream OT literature. The only potential exception to this are the CHAIN constraints, which are an innovation of Martínez-Paricio and Kager (2015). However, the general concept of constraints deriving foot attraction is also an established part of OT literature, and nothing in the present proposal depends on the novel aspects of the CHAIN constraints as compared to e.g. ALL-FEET-LEFT/RIGHT (McCarthy and Prince 1993a, in Kager 1999).

2.4.3 Derivations

Default context

In the default context, tone surfaces on the two syllables following the sponsor. The relevant examples from section 2.3 are repeated below.

(11) b. i̲zí ɲɟóvu 'that elephant'
     c. ilya̲ ɲɟóvú 'these elephants'

The derivation of the Saghala default pattern will be shown for a five-syllable form with H tone linked to the second syllable underlyingly: $/\sigma\acute{\sigma}\sigma\sigma\sigma/$. From a five-syllable form it can be seen that the algorithm is not dependent on the adjacency of a tone to a word edge. The five-syllable string is an abstraction; all words in Patin (2002, 2009) are shorter, so any five-syllable string in Saghala will contain a word boundary. As will be argued in the discussion on Long Spreading below, the presence of word boundaries is inconsequential to the derivation of the default pattern, except when a word boundary precedes the third syllable following the sponsor. This is the Long Spreading context, and its derivation will be treated separately. Given the underlying form with second-syllable tone, the desired surface form has tone only on the third and fourth syllables: $[\sigma\sigma\acute{\sigma}\acute{\sigma}\sigma]$, which is indeed the output of the derivation, modulo foot structure. The steps followed by the derivation are shown in Table 2.9.

	Form	*Comment*
0.	$\sigma\acute{\sigma}\sigma\sigma\sigma$	Underlying form
1.	$\sigma(\acute{\sigma}\sigma)\sigma\sigma$	Foot placement
2.	$\sigma(\acute{\sigma}\acute{\sigma})\sigma\sigma$	Spreading to the right edge of MinFt
3.	$\sigma(\sigma\acute{\sigma})\sigma\sigma$	Delinking from the left edge of MinFt
4.	$\sigma((\sigma\acute{\sigma})\sigma)\sigma$	Rightward foot expansion
5.	$\sigma((\sigma\acute{\sigma})\acute{\sigma})\sigma$	Spreading to the right edge of NonMinFt
6.	$\sigma((\sigma\acute{\sigma})\acute{\sigma})\sigma$	Convergence of the HS algorithm; this is the output form

Table 2.9: Steps of the default derivation

The order of these steps follows from the constraint ranking, which is based on consideration of all patterns. Hence, although the order of some steps here is not crucial, the constraint rankings needed for the derivation of the other patterns forces the default derivation into this order. The following tableaux will show each of the steps in detail. The top-ranked and bottom-ranked faithfulness constraints are left out of the tableaux. Furthermore, License(PrWd-L, H) and OCP are irrelevant to the derivation of the default pattern and left out of the tableaux.

Firstly, Table 2.10 shows the first step taken from the underlying form. This step is similar to the first step of the schematized example in Table 2.4. Because of high-ranking License(H, Ft), it is optimal to construct a foot in such a way that it contains the high-toned syllable. The decision between having this syllable at the left or right edge of the foot is left to Chain-L, which prefers having feet pulled rightward. Consequently, candidate 2.10b is optimal, since it incurs less violations of Chain-L than 2.10c.

The derivation diverges from the schematized example in Table 2.11. Despite high-ranking Chain-L, it is not possible to expand the foot at this point. An attempt at foot expansion is shown in candidate 2.11c, but it runs into violations of the anti-expansion constraints *H/NonMin-L and License(NonMax-R, H). The leftward expansion attempted by candidate

$\sigma\acute{\sigma}\sigma\sigma\sigma$	*H/NonMin-L	$\mathcal{L}$(H, Ft)	$\mathcal{L}$(NonMax-R, H)	Chain-L	*H/Min-L	Chain-R	$\mathcal{L}$(H, Min-R)	$\mathcal{L}$(H, NonMin-R)
a. $\sigma\acute{\sigma}\sigma\sigma\sigma$		*!					*	*
b. ☞ $\sigma(\acute{\sigma}\sigma)\sigma\sigma$				**	*	*	*	*
c. $(\sigma\acute{\sigma})\sigma\sigma\sigma$				***!				*

Table 2.10: Default context, step 1

2.11d fails as well because it does not license the nonmaximal foot, i.e. the binary foot within the layered foot, with a H tone on its rightmost syllable. Consequently, the winning candidate 2.11b is optimal because it spreads tone to the right edge of the minimal foot, satisfying License(H, Min-R).

$\sigma(\acute{\sigma}\sigma)\sigma\sigma$	*H/NonMin-L	$\mathcal{L}$(H, Ft)	$\mathcal{L}$(NonMax-R, H)	Chain-L	*H/Min-L	Chain-R	$\mathcal{L}$(H, Min-R)	$\mathcal{L}$(H, NonMin-R)
a. $\sigma(\acute{\sigma}\sigma)\sigma\sigma$				**	*	*	*!	*
b. ☞ $\sigma(\acute{\sigma}\acute{\sigma})\sigma\sigma$				**	*	*		*
c. $\sigma((\acute{\sigma}\sigma)\sigma)\sigma$	*!		*	*	*	*	*	*
d. $(\sigma(\acute{\sigma}\sigma))\sigma\sigma$			*!	**	*		*	*

Table 2.11: Default context, step 2

An alternative candidate not shown in Table 2.11 is $\sigma(\acute{\sigma}\sigma)(\sigma\sigma)$. This candidate creates an extra foot, but the foot does not dominate any high-toned syllable. Consequently, it is ruled out by high-ranking License(Ft, H), which is not shown in the tableau. For the following tableaux, candidates with unlicensed feet are not considered.

Table 2.12 shows that after the spreading step, rightward expansion as in 2.12c is still blocked by *H/NonMin-L, but leftward expansion is possible. The higher permissibility of leftward expansion compared to rightward expansion will be crucial in deriving the Adjacent Sponsors pattern. For the present case, the left-expanding candidate, 2.12d, is suboptimal. Its expansion step satisfies CHAIN-R, but there is a more important constraint that can be satisfied: *H/MIN-L. This is achieved by the winning candidate 2.12b, by delinking from the left edge of the minimal foot.

$\sigma(\acute{\sigma}\acute{\sigma})\sigma\sigma$	*H/NONMIN-L	$\mathcal{L}$(H, FT)	$\mathcal{L}$(NONMAX-R, H)	CHAIN-L	*H/MIN-L	CHAIN-R	$\mathcal{L}$(H, MIN-R)	$\mathcal{L}$(H, NONMIN-R)
a. $\sigma(\acute{\sigma}\acute{\sigma})\sigma\sigma$				**	*!	*		*
b. ☞ $\sigma(\sigma\acute{\sigma})\sigma\sigma$				**		*		*
c. $\sigma((\acute{\sigma}\acute{\sigma})\sigma)\sigma$	*!			*	*	*		*
d. $(\sigma(\acute{\sigma}\acute{\sigma}))\sigma\sigma$				**	*!			

Table 2.12: Default context, step 3

Table 2.13 shows the remaining steps of the derivation. Firstly, step 4 shows that rightward expansion, in 2.13b, is now the optimal move. This is because tone has moved away from the left foot edge and positioned itself at the right edge, passing the criteria of both anti-expansion constraints. Candidate 2.13c shows leftward expansion. This is suboptimal because CHAIN-L outranks CHAIN-R, causing the grammar to value rightward over leftward expansion.

After foot expansion, the second spreading target has become available — the right edge of the nonminimal foot. Spreading is the winning strategy in step 5 by candidate 2.13e.

After reaching both its spreading targets and delinking from the sponsor, the derivation is complete. Step 6 shows the convergence of the algorithm as the faithful mapping is the optimal candidate. Candidate 2.13g shows that further delinking is unwarranted, as it causes tone to no longer be licensed by the rightmost syllable of a minimal foot. After step 6, the derivation is finished. The output is $\sigma((\sigma\acute{\sigma})\acute{\sigma})\sigma$, with surface tone at the two syllables following the sponsor, as desired.

$\sigma(\sigma\acute{\sigma})\sigma\sigma$	*H/NonMin-L	$\mathcal{L}$(H, Ft)	$\mathcal{L}$(NonMax-R, H)	Chain-L	*H/Min-L	Chain-R	$\mathcal{L}$(H, Min-R)	$\mathcal{L}$(H, NonMin-R)
Step 4								
a. $\sigma(\sigma\acute{\sigma})\sigma\sigma$				**!		*		*
b. ☞ $\sigma((\sigma\acute{\sigma})\sigma)\sigma$				*		*		*
c. $(\sigma(\sigma\acute{\sigma}))\sigma\sigma$				**!				
Step 5								
d. $\sigma((\sigma\acute{\sigma})\sigma)\sigma$				*		*		*!
e. ☞ $\sigma((\sigma\acute{\sigma})\acute{\sigma})\sigma$				*		*		
Step 6 — convergence								
f. ☞ $\sigma((\sigma\acute{\sigma})\acute{\sigma})\sigma$				*		*		
g. $\sigma((\sigma\sigma)\acute{\sigma})\sigma$				*		*	*!	

Table 2.13: Default context, steps 4–6

Long Spreading

In Long Spreading, there is a ternary surface span ending in a word-initial syllable. The relevant examples from section 2.3 are repeated below.

(12a) i. ivilya vóŋgó víbwaa 'those heads are big'
ii. ilya mbúlá mbwáa 'that big nose'
iii. ilya mízí míbwaa 'those villages are big'

The difference between the default pattern and Long Spreading is encoded solely in the constraint promoting word-initial H tone: License(PrWd-L, H). This constraint is ranked below all the other constraints shown in the default derivation. The default derivation has no ties for winning candidate, which means that at every step in the derivation, some constraint that is ranked higher than License(PrWd-L, H) was decisive. Consequently, there is no way in which License(PrWd-L, H) could influence the default derivation. Moreover, it means a derivation for Long Spreading will initially go through the same steps as the default context. However, instead of converging, the derivation will go through two extra steps.

For the Long Spreading derivation, the form used in the default context will be changed to include a word boundary between the second and third syllable after the tone sponsor. A sixth syllable is added at the end of the form, to show where tone spreading ends. The new underlying form is $/\sigma\acute{\sigma}\sigma\sigma\#\sigma\sigma/$. The derivation will pick up at the end of the default pattern, with the intermediate form $\sigma((\sigma\acute{\sigma})\acute{\sigma})\#\sigma\sigma$.

The steps of the Long Spreading derivation are shown in Table 2.14.

	Form	*Comment*
5.	$\sigma((\sigma\acute{\sigma})\acute{\sigma})\ \#\ \sigma\sigma$	(*previous steps collapsed*) Default pattern
6.	$\sigma((\sigma\acute{\sigma})\acute{\sigma})\ \#\ \acute{\sigma}\sigma$	Spreading to word-initial syllable
7.	$\sigma((\sigma\acute{\sigma})\acute{\sigma})\ \#\ (\acute{\sigma}\sigma)$	Footing
8.	$\sigma((\sigma\acute{\sigma})\acute{\sigma})\ \#\ (\acute{\sigma}\sigma)$	Convergence

Table 2.14: Steps of the Long Spreading derivation

The last three steps are shown in the multi-tableau in Table 2.15. Because the leftmost syllable can never be parsed, Chain-R is irrelevant here. There are also no opportunities for foot expansion in this form, so there is no role to play for the anti-expansion constraints. Consequently, these constraints have been taken out. License(PrWd-L, H) and Dep-Link are relevant here and have been added to the constraint set.

At step 6, faithful candidate 2.15a has two word-initial syllables without H tone. In comparison to winning candidate 2.15b, this is one too many; extending the tonal span to a third syllable is optimal. The repair of the two violations of Chain-L, which would give $\sigma((\sigma\acute{\sigma})\acute{\sigma})\#(\sigma\sigma)$, is suboptimal, because the extra foot would not be licensed by a tone.

In step 7, the foot placement has become a valid option since tone has spread, potentially licensing the foot in its new position. This development is leveraged by the winning candidate, 2.15d. The new footing does come at the cost of violating *H/Min-L, since there is now an association between a H tone and a syllable that is leftmost in a minimal foot.

Finally, the Long Spreading derivation converges in step 8. Candidate 2.15f shows that further spreading is suboptimal; it incurs a violation of Dep-Link because it introduces another association link, but this comes at no gain. None of the other constraints motivate additional spreading. This is because the grammar is centered on tone licensing. Since the tone is already licensed by the layered foot on the left, it does not need to seek further validation from the newly created foot on the right.

The output form is $[\sigma((\sigma\acute{\sigma})\acute{\sigma})\#(\acute{\sigma}\sigma)]$, showing a trisyllabic tonal span following the sponsor, with the third syllable from the sponsor being a word-initial syllable. This matches the description of the Long Spreading pattern.

$\sigma((\sigma\acute{\sigma})\acute{\sigma})\#\sigma\sigma$	$\mathcal{L}$(H, Ft)	Chain-L	*H/Min-L	$\mathcal{L}$(H, Min-R)	$\mathcal{L}$(H, NonMin-R)	$\mathcal{L}$(ω-L, H)	Dep-Link
Step 6							
a. $\sigma((\sigma\acute{\sigma})\acute{\sigma})\#\sigma\sigma$		**				**!	
b. ☞ $\sigma((\sigma\acute{\sigma})\acute{\sigma})\#\acute{\sigma}\sigma$		**				*	*
Step 7							
c. $\sigma((\sigma\acute{\sigma})\acute{\sigma})\#\acute{\sigma}\sigma$		*!*				*	
d. ☞ $\sigma((\sigma\acute{\sigma})\acute{\sigma})\#(\acute{\sigma}\sigma)$			*			*	
Step 8 — convergence							
e. ☞ $\sigma((\sigma\acute{\sigma})\acute{\sigma})\#(\acute{\sigma}\sigma)$			*			*	
f. $\sigma((\sigma\acute{\sigma})\acute{\sigma})\#(\acute{\sigma}\acute{\sigma})$			*			*	*!

Table 2.15: Long Spreading, steps 6–8 (following the default derivation)

Adjacent Sponsors

In the Adjacent Sponsors context, two adjacent syllables from different words are both sponsors. At the surface, this results in H tone only on the second sponsor. The examples from section 2.3 are repeated below:

(13)	a.	il<u>ya</u> <u>mbú</u>zi	'that goat'
	b.	il<u>ya</u> <u>ʃí</u>mba	'that lion'
	c.	uɣul<u>ya</u> <u>mwé</u>zi mbwaa	'that moon is big'

The derivation will account for the abstract case of $/\sigma\acute{\sigma}_1\#\acute{\sigma}_2\sigma/$ mapping to $[\sigma\sigma\#\acute{\sigma}\sigma]$. As before in section 2.2, here and in the following, subscripts indicate tone indices. That is, a string $\acute{\sigma}_1\acute{\sigma}_2$ denotes two different tones associated to adjacent syllables, while $\acute{\sigma}\acute{\sigma}$ denotes a single tone spread to two syllables. The steps of the derivation are shown in Table 2.16.

The adjacency of the two sponsors causes two crucial deviations from the default pattern. Firstly, the binary foot is placed over both tones, rather than more to the right. Secondly, foot expansion is leftward, rather than rightward. The differences in foot structure then lead to the singly-linked tone, rather than the default binary tone span.

	Form	*Comment*
0.	$\sigma\acute{\sigma}_1 \# \acute{\sigma}_2\sigma$	Underlying form
1.	$\sigma(\acute{\sigma}_1 \# \acute{\sigma}_2)\ \sigma$	Foot placement around both tones
2.	$(\sigma(\acute{\sigma}_1 \# \acute{\sigma}_2))\sigma$	Leftward foot expansion
3.	$(\sigma(\acute{\sigma} \# \acute{\sigma}))\sigma$	Tone fusion
4.	$(\sigma(\sigma \# \acute{\sigma}))\sigma$	Tone delinking
5.	$(\sigma(\sigma \# \acute{\sigma}))\sigma$	Convergence

Table 2.16: Steps of the Adjacent Sponsors derivation

Tables 2.17 through 2.19 will show how the constraint set motivates the steps in (2.16).

$\sigma\acute{\sigma}_1 \# \acute{\sigma}_2\sigma$	*H/NonMin-L	$\mathcal{L}$(H, Ft)	$\mathcal{L}$(NonMax-R, H)	Chain-L	*H/Min-L	Chain-R	$\mathcal{L}$(H, Min-R)	$\mathcal{L}$(H, NonMin-R)
a. $\sigma\acute{\sigma}_1 \# \acute{\sigma}_2\sigma$		*!*					**	**
b. ☞ $\sigma(\acute{\sigma}_1 \# \acute{\sigma}_2)\sigma$				*	*	*	*	**
c. $\sigma\acute{\sigma} \# \acute{\sigma}\sigma$		*!					*	*
d. $\sigma\acute{\sigma}_1 \# (\acute{\sigma}_2\sigma)$		*!			*	**	**	**

Table 2.17: Adjacent Sponsors, step 1

In Table 2.17, the optimal move is to place a foot over both sponsors, as shown in 2.17b. This is the only way to avoid both violations of License(H, Ft). An alternative is to first resolve the clash between the two tones through tone fusion, shown by 2.17c. This has several benefits: since there is only one tone now, all the tone licensing constraints are only violated once, instead of twice. Furthermore, although not shown, this also resolves the violation of low-ranked OCP. However, this candidate still incurs a critical violation of License(H, Ft), which makes it suboptimal.

The result of placing the foot more to the right is shown in 2.17d. With this rightmost foot, the first H tone is not licensed, and so the candidate incurs a violation of License(H, Ft). Consequently, the usual tendency of the language to pull feet rightward is not followed here.

In Table 2.18, resolving the tone contact is still not urgent enough, ruling out 2.18d. The highest markedness constraint that is violated is Chain-L. However, satisfying it, as shown in candidate 2.18c, incurs a violation of high-ranked

*H/NonMin-L, because it situates a H tone at the left edge of a nonminimal foot. The next highest violated constraint, *H/Min-L, can also not be satisfied, because there is no means of moving away the first H tone from the left edge of the minimal foot. This is because tone deletion and floating tone have been assumed to be ruled out by top-ranked constraints, and a tone shift operation is not part of Gen. Instead, the winning candidate 2.18b removes a violation of Chain-R by expanding to the left. Leftward expansion is sometimes blocked by License(NonMax-R, H), but is allowed here because the second H tone is situated at the right edge of the potential nonmaximal foot.

$\sigma(\acute{\sigma}_1$ # $\acute{\sigma}_2)\sigma$	*H/NonMin-L	$\mathcal{L}$(H, Ft)	$\mathcal{L}$(NonMax-R, H)	Chain-L	*H/Min-L	Chain-R	$\mathcal{L}$(H, Min-R)	$\mathcal{L}$(H, NonMin-R)
a. $\sigma(\acute{\sigma}_1$ # $\acute{\sigma}_2)\sigma$				*	*	*!	*	**
b. ☞ $(\sigma(\acute{\sigma}_1$ # $\acute{\sigma}_2))\sigma$				*	*		*	*
c. $\sigma((\acute{\sigma}_1$ # $\acute{\sigma}_2)\sigma)$	*!				*	*	*	**
d. $\sigma(\acute{\sigma}$ # $\acute{\sigma})\sigma$				*	*	*!		*

Table 2.18: Adjacent Sponsors, step 2

A crucial result of leftward expansion is that it lines up the two spreading targets in Saghala. That is, the right edge of the minimal and nonminimal foot coincide on the same syllable. This is also why candidate 2.18b incurs one less violation of License(H, NonMin-R) than the faithful candidate; by virtue of the foot placement, the tone is now licensed by a rightmost syllable in a nonminimal foot. Because the two spreading targets are on the same syllable, there is no binary tone span at the surface; associating to the single syllable satisfies both tone licensing constraints already, so further spreading is unwarranted. This will be shown in the following steps, presented in the multi-tableau in Table 2.19.

In step 3, satisfaction of neither Chain-L nor *H/Min-L is possible. Consequently, at this stage the fusion of the two tones is optimal. This is shown by winning candidate 2.19b.

With tone fusion applied, there is an opportunity for tone to move away from the left edge of the minimal foot. This is what takes place in step 4, in candidate 2.19d. Candidate 2.19e delinks at the right edge of the foot, and therefore unnecessarily misses out on satisfaction of the licensing constraints.

$(\sigma(\acute{\sigma}_1 \# \acute{\sigma}_2))\sigma$	*H/NonMin-L	$\mathcal{L}$(H, Ft)	$\mathcal{L}$(NonMax-R, H)	Chain-L	*H/Min-L	Chain-R	$\mathcal{L}$(H, Min-R)	$\mathcal{L}$(H, NonMin-R)
Step 3								
a. $(\sigma(\acute{\sigma}_1 \# \acute{\sigma}_2))\sigma$				*	*		*!	*
b. ☞ $(\sigma(\acute{\sigma} \# \acute{\sigma}))\sigma$				*	*			
Step 4								
c. $(\sigma(\acute{\sigma} \# \acute{\sigma}))\sigma$				*	*!			
d. ☞ $(\sigma(\sigma \# \acute{\sigma}))\sigma$				*				
e. $(\sigma(\acute{\sigma} \# \sigma))\sigma$				*	*!		*	*

Table 2.19: Adjacent Sponsors, steps 3 and 4

The winning candidate at step 4 has only a single violation mark left, on the Chain-L constraint. This violation cannot be remedied because any further foot placement would be unlicensed and consequently blocked by $\mathcal{L}$(Ft, H). Consequently, there is no way to improve on the candidate, and it is selected as the output form in the next step (not shown).

In conclusion, the derivation produces the surface form $[(\sigma(\sigma\#\acute{\sigma}))\sigma]$. This fits the description of Adjacent Sponsors: Tone surfaces solely on the second sponsor syllable.

Blocked Spreading

In Blocked Spreading, two tones separated by a single syllable will both shift, but the leftmost tone will not show a binary tone span. Examples from section 2.3 are repeated in (14).

(14)
a. <u>i</u>hí <u>mbu</u>zí 'this goat'
b. <u>i</u>hí <u>me</u>zí míbwaa 'these moons are big'
c. <u>a</u>wá <u>wa</u>ná wá<u>le</u>lé 'these tall children'

The derivation of the Adjacent Sponsors pattern above has shown that the grammar is likely to apply tone fusion to tones that are in contact. Since the Blocked Spreading pattern shows two independent tones at the surface, the grammar should avoid creating a situation of tonal contact, to prevent tonal fusion. This is achieved in the derivation by letting the tones shift one at a time, beginning with the rightmost tone. The steps of the derivation are shown in Table 2.20 below.

	Form	*Comment*
0.	$\acute{\sigma}\sigma$ # $\acute{\sigma}\sigma$	Underlying form
1.	$\acute{\sigma}\sigma$ # $(\acute{\sigma}\sigma)$	Foot placement, rightmost
2.	$(\acute{\sigma}\sigma)$ # $(\acute{\sigma}\sigma)$	Foot placement
3.	$(\acute{\sigma}\sigma)$ # $(\acute{\sigma}\acute{\sigma})$	Spreading to the right edge of a minimal foot
4.	$(\acute{\sigma}\sigma)$ # $(\sigma\acute{\sigma})$	Delinking
5.	$(\acute{\sigma}\acute{\sigma})$ # $(\sigma\acute{\sigma})$	Spreading to the right edge of a minimal foot
6.	$(\sigma\acute{\sigma})$ # $(\sigma\acute{\sigma})$	Delinking
7.	$(\sigma\acute{\sigma})$ # $(\sigma\acute{\sigma})$	Convergence

Table 2.20: Steps of the Blocked Spreading derivation

The order of foot placement in steps 1 and 2 is due to rightward foot attraction, enforced by Chain-L(σ_ω). A layered foot encompassing both tones, e.g. $((\acute{\sigma}\sigma)\#\acute{\sigma})\sigma$, takes two steps to construct in Harmonic Serialism. Since the first step places a foot rightmost, the only possible layered structure after step 1 would be $\acute{\sigma}(\sigma\#(\acute{\sigma}\sigma))$, which does not cover both sponsors. Consequently, layered feet are ruled out for Blocked Spreading.

The tableaux of the derivation will skip the footing steps, and start from step 3, in Table 2.21. Since there is no room for layered feet in these examples, the constraints referring to layered feet are not shown in the tableaux.[14] In addition, since the domain is already completely footed, foot attraction constraints are inconsequential and have also been left out.

$(\acute{\sigma}\sigma)$ # $(\acute{\sigma}\sigma)$	*H/Min-L	$\mathcal{L}$(H, Min-R)	$\mathcal{L}$(ω-L, H)	OCP
a. $(\acute{\sigma}\sigma)$ # $(\acute{\sigma}\sigma)$	**	**!		
b. ☞ $(\acute{\sigma}\sigma)$ # $(\acute{\sigma}\acute{\sigma})$	**	*		
c. $(\acute{\sigma}\acute{\sigma}_1)$ # $(\acute{\sigma}_2\sigma)$	**	*		*!

Table 2.21: Blocked Spreading, step 3

At step 3, in Table 2.21 the highest markedness constraint that the grammar can satisfy is License(H, Min-R). There are two ways this can be achieved: by spreading either the left or right tone. The optimal choice is to spread the right tone, as shown by candidate 2.21b. Candidate 2.21c demonstrates why

[14] In contexts where the first sponsor is preceded by another syllable, Chain-R will motivate a leftward foot expansion, analogously to the the Adjacent Sponsors context. The tone associations are unaffected, coming out as $(\sigma(\underline{\sigma}\acute{\sigma}))\#(\underline{\sigma}\acute{\sigma})$. This is because the rightmost tone shifts first, thereby ensuring that the two tones never associate to adjacent syllables, which means there is no possibility of tone fusion.

spreading the left tone is suboptimal: it creates tonal contact in violation of OCP.

The tone spreading in step 3 opens up an opportunity for delinking. At the next step, in Table 2.22, this opportunity is taken right away by winning candidate 2.22b. Candidate 2.22c shows the result of performing more tone spreading. Although this satisfies LICENSE(H, MIN-R), it is suboptimal because it does not reduce the violation of higher-ranked *H/MIN-L.

$(\acute{\sigma}\sigma)$ # $(\acute{\sigma}\acute{\sigma})$	*H/MIN-L	$\mathcal{L}$(H, MIN-R)	$\mathcal{L}$(ω-L, H)	OCP
a. $(\acute{\sigma}\sigma)$ # $(\acute{\sigma}\acute{\sigma})$	**!	*		
b. ☞ $(\acute{\sigma}\sigma)$ # $(\sigma\acute{\sigma})$	*	*	*	
c. $(\acute{\sigma}\acute{\sigma}_1)$ # $(\acute{\sigma}_2\acute{\sigma})$	**!			*

Table 2.22: Blocked Spreading context, step 4

After this initial delinking step, the process is repeated for the left tone. Steps 5 and 6 in Table 2.23 mirror the preceding two steps; tone spreads and then immediately delinks.

$(\acute{\sigma}\sigma)$ # $(\sigma\acute{\sigma})$	*H/MIN-L	$\mathcal{L}$(H, MIN-R)	$\mathcal{L}$(ω-L, H)	OCP
Step 5				
a. $(\acute{\sigma}\sigma)$ # $(\sigma\acute{\sigma})$	*	*!	*	
b. ☞ $(\acute{\sigma}\acute{\sigma})$ # $(\sigma\acute{\sigma})$	*		*	
Step 6				
c. $(\acute{\sigma}\acute{\sigma})$ # $(\sigma\acute{\sigma})$	*!		*	
d. ☞ $(\sigma\acute{\sigma})$ # $(\sigma\acute{\sigma})$			**	
Step 7 — convergence				
e. ☞ $(\sigma\acute{\sigma})$ # $(\sigma\acute{\sigma})$			**	
f. $(\sigma\acute{\sigma})$ # $(\acute{\sigma}_1\acute{\sigma}_2)$	*!		*	*

Table 2.23: Blocked Spreading context, steps 5-7

Step 7 shows the convergence of the derivation. The tendency shown in Long Spreading to continue spreading to reach a word-initial syllable is not displayed in Blocked Spreading. Candidate 2.23f shows why: spreading the left tone to the word-initial syllable causes it to cross over into the next foot. As a consequence, it creates a violation of *H/MIN-L. This makes it suboptimal compared to the faithful candidate.

As will be shown below, the situation is different for SWIS, where tone does cross into the next foot, and the tones do come into contact.

Straddled Word-Initial Syllable

In the SWIS context, two sponsors separated by a word-initial syllable cause tone to surface on the two syllables following the first sponsor. The examples from section 2.3 are repeated in (15).

(15)	a.	il<u>ya</u> zá<u>wá</u>di	'that gift'
	b.	ilyi<u>lya</u> í<u>zí</u>so ibwaa	'that eye is big'
	c.	wa<u>lye</u> wá<u>lú</u>me wa<u>le</u>lé	'those men are big'

At the surface, SWIS looks exactly like a default context pattern, assuming only 1 sponsor. However, the foot structure reflects the fact that SWIS has two sponsors underlyingly. The foot structure, and the steps to construct it, are shown in Table 2.24.

	Form	*Comment*
0.	$\acute{\sigma}$ # $\sigma\acute{\sigma}\sigma$	Underlying Form
1.	$\acute{\sigma}$ # $\sigma(\acute{\sigma}\sigma)$	Foot placement, rightmost
2.	$(\acute{\sigma}$ # $\sigma)(\acute{\sigma}\sigma)$	Foot placement
3.	$(\acute{\sigma}$ # $\acute{\sigma}_1)(\acute{\sigma}_2\sigma)$	MinFt spreading across a word boundary
4.	$(\sigma$ # $\acute{\sigma}_1)(\acute{\sigma}_2\sigma)$	Delinking
5.	$(\sigma$ # $\acute{\sigma})(\acute{\sigma}\sigma)$	Fusion
6.	$(\sigma$ # $\acute{\sigma})(\acute{\sigma}\sigma)$	Convergence

Table 2.24: Steps of the Straddled Word-Initial Syllable derivation

As in Blocked Spreading, foot construction proceeds in right-to-left fashion. The crucially different step is step 3: in SWIS, the left tone spreads first. This sets SWIS on a different derivational path since it includes tonal contact. Tableaux for the derivations pick up at this spreading step, starting with Table 2.25.

$(\acute{\sigma}$ # $\sigma)(\acute{\sigma}\sigma)$	*H/MIN-L	$\mathcal{L}$(H, MIN-R)	$\mathcal{L}$(ω-L, H)	OCP
a. $(\acute{\sigma}$ # $\sigma)(\acute{\sigma}\sigma)$	**	**!	*	
b. ☞ $(\acute{\sigma}$ # $\acute{\sigma}_1)(\acute{\sigma}_2\sigma)$	**	*		*
c. $(\acute{\sigma}$ # $\sigma)(\acute{\sigma}\acute{\sigma})$	**	*	*!	

Table 2.25: Straddled Word-Initial Syllable context, step 3

Table 2.25 shows that after footing, it is optimal to spread to the syllable separating the two tones, as shown by 2.25b.[15] This is because this syllable is word-initial, so spreading to it satisfies LICENSE(PRWD-L, H). Since LICENSE(PRWD-L, H) outranks OCP, spreading here is applied despite creating tonal contact.

As was the case for Blocked Spreading, the spreading step is followed by a delinking step, shown in Table 2.26. Any other operation, such as tone fusion in 2.26c, is suboptimal because it does not resolve the violation of high-ranking *H/MIN-L.

$(\acute{\sigma}\ \#\ \acute{\sigma}_1)(\acute{\sigma}_2\sigma)$	*H/MIN-L	$\mathcal{L}$(H, MIN-R)	$\mathcal{L}$(ω-L, H)	OCP
a. $(\acute{\sigma}\ \#\ \acute{\sigma}_1)(\acute{\sigma}_2\sigma)$	**!	*		*
b. ☞ $(\sigma\ \#\ \acute{\sigma}_1)(\acute{\sigma}_2\sigma)$	*	*	*	*
c. $(\acute{\sigma}\ \#\ \acute{\sigma})(\acute{\sigma}\sigma)$	**!			

Table 2.26: Straddled Word-Initial Syllable context, step 4

The tonal contact is resolved in the next step, shown in Table 2.27. The winning candidate 2.27b fuses the tones, crucially repairing a violation of LICENSE(H, MIN-R) caused by the second tone, which was not associated to any right edge of a minimal foot. Fusion also reduces violations of unshown LICENSE(H, NONMIN-R), and satisfies OCP. Candidate 2.27c shows the suboptimality of spreading the right tone rightward.

$(\sigma\ \#\ \acute{\sigma}_1)(\acute{\sigma}_2\sigma)$	*H/MIN-L	$\mathcal{L}$(H, MIN-R)	$\mathcal{L}$(ω-L, H)	OCP
a. $(\sigma\ \#\ \acute{\sigma}_1)(\acute{\sigma}_2\sigma)$	*	*!	*	*
b. ☞ $(\sigma\ \#\ \acute{\sigma})(\acute{\sigma}\sigma)$	*		*	
c. $(\sigma\ \#\ \acute{\sigma}_1)(\acute{\sigma}_2\acute{\sigma})$	*		*	*!

Table 2.27: Straddled Word-Initial Syllable context, step 5

After selecting 2.27b, the derivation has reached a similar point as at the end of Long Spreading; a single violation of *H/MIN-L remains, but delinking tone to solve it would cause an unlicensed foot. Consequently, the candidate cannot be further improved upon, and the derivation converges in the next step

[15] Candidate 2.25b achieves this goal by spreading the left tone. The same violation profile is achieved by spreading the right tone leftward, i.e. $(\acute{\sigma}_1\#\acute{\sigma}_2)(\acute{\sigma}\sigma)$. There is no constraint in the set that distinguishes between these two candidates, so they are tied. The tie is inconsequential; derivations for both forms converge on the same output. Readers that prefer a situation without ties can assume a bottom-ranked constraint that militates against spreading across a foot boundary or against a foot containing multiple H tones.

(not shown). The result, as attested, has surface H tone on the two syllables following the left sponsor.

Blocked Long Spreading

Blocked Long Spreading involved two tones, where Long Spreading for the first tone was blocked because it would cause tonal contact. It was exemplified in the previous section by the data repeated in (16) below.

(16) izilya ŋgúkú nɟacé 'those little chickens'

The derivation of Blocked Long Spreading does not involve any novel processes. Consequently, the derivation is not presented with a full set of tableaux, but only with the steps in Table 2.28.

	Form	*Comment*
0.	$\sigma\acute{\sigma}$ # $\sigma\sigma$ # $\acute{\sigma}\sigma$	Underlying Form
1.	$\sigma\acute{\sigma}$ # $\sigma\sigma$ # $(\acute{\sigma}\sigma)$	Foot placement, rightmost
2.	$\sigma(\acute{\sigma}$ # $\sigma)\sigma$ # $(\acute{\sigma}\sigma)$	Foot placement
3.	$\sigma(\acute{\sigma}$ # $\acute{\sigma})\sigma$ # $(\acute{\sigma}\sigma)$	MinFt spreading across a word boundary
4.	$\sigma(\sigma$ # $\acute{\sigma})\sigma$ # $(\acute{\sigma}\sigma)$	Delinking
5.	$\sigma((\sigma$ # $\acute{\sigma})\sigma)$ # $(\acute{\sigma}\sigma)$	Rightward foot expansion
6.	$\sigma((\sigma$ # $\acute{\sigma})\sigma)$ # $(\acute{\sigma}\acute{\sigma})$	MinFt spreading.
7.	$\sigma((\sigma$ # $\acute{\sigma})\sigma)$ # $(\sigma\acute{\sigma})$	Delinking
8.	$\sigma((\sigma$ # $\acute{\sigma})\acute{\sigma})$ # $(\sigma\acute{\sigma})$	NonMinFt spreading
9.	$\sigma((\sigma$ # $\acute{\sigma})\acute{\sigma})$ # $(\sigma\acute{\sigma})$	Convergence

Table 2.28: Steps of the Blocked Long Spreading derivation

Each of the steps has an analogy to a step in one of the other derivations. Steps 1 and 2 show right-to-left foot building, comparable to the first steps of Blocked Spreading and SWIS. After this, there is a spreading and delinking step for the leftmost foot, which gets priority because it spreads to a word-initial syllable, comparable to the SWIS case. In step 5, tone in the leftmost foot has moved so that the foot can expand rightward, as in the default pattern. Steps 6 and 7 show spreading and delinking for the rightmost foot, and only then does the leftmost tone spread to the right edge of the layered foot in step 8. This order is motivated by the higher rank of LICENSE(H, MIN-R) compared to LICENSE(H, NONMIN-R), but also by the fact that spreading to the non-minimal foot edge first would cause tonal contact, which is blocked by OCP, just as in the Blocked Spreading case. After these steps, the derivation converges. While further spreading of the leftmost tone would help it reach another word-initial syllable, this is suboptimal because it would at the same time reach the left edge of a minimal foot, in violation of high-ranking *H/MIN-L. This is similar to the end state of the Blocked Spreading derivation, and it is the reason why Long Spreading is blocked by the presence of a tone on the word-initial syllable.

2.4.4 Summary

The data for Saghala were presented in section 2.3. It characterized Saghala as a tone shift language that usually had binary or ternary tonal spans. Furthermore, unexpectedly short tone spans appeared to be a result of tonal contact. On the other hand, in some cases it seemed tonal contact was avoided. Finally, there was some role to be played by word-initial syllables.

This section gave a formal account of these observations. Firstly, the tone shift process was modeled as an interaction between rightward foot attraction and tone repulsion from leftmost positions in feet. Secondly, the observation of surface tonal spans was also reinterpreted through the lens of foot structure. That is, in the account presented in section 2.4, there is nothing explicitly stating that Saghala should have surface tone spans. Rather, there are simply two targets for tone to spread to, and these targets are usually adjacent. In other words, the generalization in Saghala is that tone is always licensed by the rightmost syllable of a minimal foot, and of a nonminimal foot where possible.

The shortness of tonal spans in tone contact situations, i.e. in Adjacent Sponsors and SWIS cases, is accounted for by the combination of foot structure and tone licensing effects. In both cases, tones have merged, and the resulting tone requires association to only one rightmost syllable each of minimal and nonminimal foot. Once such a position is associated to, spreading requirements have been satisfied. Consequently, there is no drive to create long tonal spans.

Avoidance of tonal contact, where applicable, was due in part to the effect of OCP. It was also due to the tone repulsion from left foot edges; tones were discouraged from entering into the next tone's foot domain by *H/Min-L.

The significance of word-initial syllables was expressed by License(PrWd-L, H). Although low-ranked, this constraint caused the priority of spreading across word boundaries. This resulted in ternary spreading in Long Spreading contexts, and tonal contact in SWIS contexts.

The underlying form to footed surface form mappings for all cases are listed in Table 2.29.

Type	*UF*	*SF*
Default	$..\acute{\sigma}\sigma\sigma..$	$..((\sigma\acute{\sigma})\acute{\sigma})..$
Long Spreading	$..\acute{\sigma}\sigma\sigma\#\sigma\sigma..$	$..((\sigma\acute{\sigma})\acute{\sigma})\#(\acute{\sigma}\sigma)..$
Adjacent Sponsors	$..\sigma\acute{\sigma}_1\#\acute{\sigma}_2..$	$..(\sigma(\sigma\#\acute{\sigma}))..$
Blocked Spreading	$..\acute{\sigma}\sigma\#\acute{\sigma}\sigma\sigma..$	$..(\sigma\acute{\sigma})((\#\sigma\acute{\sigma})\acute{\sigma})..$
Straddled Word-Initial Syllable	$..\acute{\sigma}\#\sigma\acute{\sigma}\sigma..$	$..(\sigma\#\acute{\sigma})(\acute{\sigma}\sigma)..$
Blocked Long Spreading	$..\acute{\sigma}\sigma\sigma\#\acute{\sigma}\sigma\sigma..$	$..((\sigma\acute{\sigma})\acute{\sigma})\#((\sigma\acute{\sigma})\acute{\sigma})..$

Table 2.29: The underlying and footed surface forms for the six Saghala contexts

In conclusion, this section gave a descriptively adequate account of Saghala noun phrase tonology based on three factors. Firstly, the analysis used layered feet to define the shifting and spreading domain. Secondly, a principled constraint set regulated tone–foot interactions. Finally, the Harmonic Serialism framework enabled opaque analyses where footing precedes tone activity, which was necessary for the tone shift and tonal contact cases.

The next section will discuss this approach and compare the choices made here to other approaches taken in the literature.

2.5 Discussion

2.5.1 Finding acoustic evidence for foot structure in Saghala

The layered foot structures proposed for Saghala are based on phonological arguments. Further support for the presence of feet might be found by inspecting the acoustics. Specifically, feet might be signalled by differences in pitch, amplitude, duration, or vowel quality of the syllables involved. The ideal test cases are those contexts where the analysis predicts identical surface tones with different foot structures. An example of this is shown in (24).

(24)	a. Default	$\sigma((\underline{\sigma}\#\acute{\sigma})\acute{\sigma})\sigma$
	b. Straddled Word-Initial Syllable	$(\sigma(\underline{\sigma}\#\acute{\sigma}))(\underline{\acute{\sigma}}\sigma)$

In (24a), foot structure follows the default dactylic pattern starting from the sponsor, which is word-final. In (24b), tone comes from two sponsors underlyingly, and this is reflected in the foot structure, with each sponsor syllable contained in a different foot. Crucially, the forms are otherwise equal; in both cases, high tone surfaces only on the two syllables following the word boundary. Hence, (24) shows a metrical minimal pair, and it is possible that this metrical difference is reflected in the acoustics.

However, even if an investigation of the acoustics finds no evidence of foot structure, this is not a counterargument to a foot-based analysis. This was noted previously by Goldsmith (1992), in a footnote for his analysis of Llogoori:

> "[T]he present analysis adds to a growing body of literature that supports the position that metrical structure plays a role in the organization of language in a large number of cases in which there is no phonetic evidence of alternating stress or overt rhythm. If this is correct, as I am convinced that it is, it is more appropriate to say that metrical structure arises not when the data of a language permits it, but rather when the data of the language does not forbid it." (Goldsmith 1992:92)

In summary, further research is warranted to determine if the proposed foot structure is reflected in the acoustics of Saghala. However, the absence of such acoustic evidence does not invalidate the present proposal.

2.5.2 Alternative OT approaches to Bantu bounded tone

Within the context of OT, at least three lines of previous research on Bantu bounded tone can be recognized: Optimal Domains Theory, minimal (mis)alignment, and Headed Spans theory. In the following, these approaches are discussed and compared to the present framework.

Optimal Domains Theory (ODT) centers around the idea of relating underlying tones to surface-level tone domains (Cole and Kisseberth 1994; Cassimjee and Kisseberth 1998). Bounded tone patterns then follow from restrictions on the size of such tone domains.

Bickmore (1996) proposes an approach using minimal (mis)alignment, which derives surface tone patterns from a family of alignment and misalignment constraints that can cause tone to spread to TBUs at a minimal distance away from their sponsor. The minimal distance effect is due to the gradient evaluation of the alignment constraints.

Headed spans theory proposes that surface forms are parsed exhaustively into domains for each feature (feature spans), notably tone (Key 2007; Key and Bickmore 2014, building on McCarthy 2004). Much like in ODT, bounded patterns are derived by placing restrictions on the size of such feature spans.

Determining whether the above proposals allow for an account of Saghala tonology is beyond the scope of this chapter. However, comparisons can be made in two other aspects, proving favorable to the foot-based HS approach. Unlike the present proposal, the above proposals make two undesirable commitments, namely the stipulation of domain size and use of two-level constraints. These issues are discussed below.

Stipulation of domain size

One of the goals for any account of Bantu bounded tone is to derive tonal spans over multiple TBUs starting from a tone with only a single underlying association. To this end, ODT employs a *MonoHD constraint to enforce binary domains.

(25) *MonoHD
“A HD [High tone domain] should not be monomoraic/monosyllabic.” (Cassimjee and Kisseberth 1998:18)

Likewise, in the Headed Spans framework, binarity is achieved through SpBin(H).

(26) SpBin(H)
“Assign a violation mark for each H span that does not parse some part (i.e., at least one mora) of exactly two syllables.” (Key and Bickmore 2014:41)

In both frameworks the impetus for binarity is stipulated; it does not follow from the theory of the representation. Furthermore, neither framework has a way of accounting for ternary domains. Ternarity could be achieved by adding constraints such as *BinHD for ODT or SpTri(H) for Headed Spans, but this adds further stipulations. Furthermore, there is no account for the fact that there are presumably no constraints such as *TriHD or SpQuad(H) that could drive construction of quaternary tonal spans.

In the present approach, binarity and ternarity are linked to the nature of the foot, the size of which is motivated independently by cross-linguistic studies of stress systems and metrically driven phonological processes. A quaternary domain cannot be derived straightforwardly, matching the typological picture of Bantu bounded tone.

The maximally ternary nature of the foot in the MPK framework is itself a stipulation. However, this stipulation was made based on consideration of a wider range of language phenomena, and was not motivated by the typology of Bantu bounded tone. Consequently, getting ternarity from the representation without domain-specific stipulations is an improvement over previous approaches.

Two-level constraints

The term two-level constraint denotes a type of constraint that places well-formedness restrictions on the surface level, but also makes reference to structure at the input level. In the analysis of Bantu bounded tone, two-level constraints occur when constraint formulations use the concept of a sponsor. Sponsorship is a property of a TBU at the underlying level of representation. Making requirements on surface structure with reference to sponsors means that both levels of representation are involved. The previous approaches discussed here make use of such two-level constraints. One example is the ODT constraint Incorporate (F-sponsor), shown in (27). "F" stands for a feature in general, but for the present purpose could be instantiated as H tone.

(27) Incorporate (F-sponsor)
"[E]very F-sponsor is in a domain" (Cassimjee and Kisseberth 1998:12)

The evaluation of this constraint involves both levels of representation; H-domains are present only in surface forms, whereas the location of H-sponsors requires reference to the underlying location of the H tone.

The Headed Spans framework has a similar constraint FaithHdSp(αF) to which the same reasoning applies. In minimal (mis)alignment, alignment constraints can make reference to lexical structure. An example is (*)Align (H,L)-I/O:

(28) (*)Align (H,L)-I/O
"The left edge of a HTS [High tone span] in the output must (not) align with the left edge of a HTS in the input" (Bickmore 1996:16)

To evaluate this constraint, the grammar must compare the leftmost TBU of a tone in the input to the leftmost TBU of its corresponding tone in the output. Since both lexical and surface structure are involved in the evaluation, this is a two-level constraint.

Two-level constraints go against a core principle of OT, namely its output orientation. Consider the following criticism of these constraints from Kager (1999):

> "[Two-level constraints] function as rules, combining a structural condition (the input structure) and a repair. A theory allowing for two-level well-formedness constraints may stipulate any type of relation between the input and output, being equivalent in this respect to rule-based theory (Lakoff 1993). This power undermines standard OT's solutions to problems inherent to rule-based serialism, in particular *conspiracies* and the *Duplication Problem*. (Kager 1999:381)"

In conclusion, it is desirable to avoid the use of two-level constraints.[16] However, past approaches needed such constraints to account for opaque processes in standard OT. The handling of opacity in the present framework is relegated to Harmonic Serialism. Consequently, it no longer needs to be encoded in the constraint set. As a result, the present framework does not make use of two-level constraints.

2.5.3 Analyses with binary or flat ternary feet

Although the previous section has accomplished a descriptively adequate analysis of Saghala using layered ternary feet, it has not been shown that analyses with alternative conceptions of foot structure are infeasible. The most immediate alternatives are analyses using binary feet or flat ternary feet (Halle and Vergnaud 1987; Rice 2007; Buckley 2009). A full investigation of these alternatives is beyond the scope of this chapter, but some challenges can be pointed out. In both cases, the major challenge is finding an approach that fits all subpatterns, particularly finding a trigger for the Adjacent Sponsors context to deviate from the default pattern.

A binary feet analysis could enforce foot placement to the right of the sponsor, so that the two tones of the default pattern are the two footed syllables, i.e. $/\acute{\sigma}\sigma\sigma/\rightarrow[\sigma(\acute{\sigma}\acute{\sigma})]$. One issue here is finding constraints that drive this footing, especially if the analysis is to abstain from using two-level constraints.

This footing also raises questions for the analysis of the Adjacent Sponsors context. In the present layered feet analysis, licensing drives foot placement over both of the sponsor syllables, e.g. $/\acute{\sigma}_1\#\acute{\sigma}_2\sigma\sigma/$ maps to the intermediate form $(\acute{\sigma}_1\#\acute{\sigma}_2)\sigma\sigma$. This takes the derivation in a different direction from the default pattern and eventually allows tone to settle solely on the second sponsor syllable. However, if the binary analysis places feet next to sponsors rather than

[16] This argument against two-level constraints leans on the assumption that the adoption of any such constraint implies that all two-level constraints could plausibly be part of a grammar. However, it may be possible to motivate the adoption of a more strictly defined subclass of two-level constraints. Further research is needed on this issue. The author thanks Marc van Oostendorp and Jochen Trommer for independently pointing this out.

on them, $/\acute{\sigma}_1\#\acute{\sigma}_2\sigma\sigma/$ would map to $\acute{\sigma}_1\#(\acute{\sigma}_2\sigma)\sigma$ or even $\acute{\sigma}_1\#\acute{\sigma}_2(\sigma\sigma)$. Hence, an open challenge is motivating why either of these forms would deviate from the default pattern, which incorrectly predicts the forms to surface as $*[\sigma\#(\acute{\sigma}\acute{\sigma})\sigma]$ or $*[\sigma\#\sigma(\acute{\sigma}\acute{\sigma})]$, respectively.

An analysis with flat ternary feet can capture the entire bounding domain of the default pattern with one foot, giving $/\acute{\sigma}\sigma\sigma/ \rightarrow [(\sigma\acute{\sigma}\acute{\sigma})]$. However, some new constraints will be needed to accomplish correct tone association; with the constraint set presented here, there is no way to target the middle syllable for spreading.

Furthermore, like the binary feet analysis, the flat ternary analysis seems to have no means of distinguishing the spreading targets in the Adjacent Sponsors pattern from that of the default pattern. Presumably, $/\sigma\acute{\sigma}_1\#\acute{\sigma}_2\sigma/$ should map to either $(\sigma\acute{\sigma}_1\#\acute{\sigma}_2)\sigma$ or $\sigma(\acute{\sigma}_1\#\acute{\sigma}_2\sigma)$. Again, an open question is how a flat ternary analysis now avoids application of the default tone pattern, which would yield $*[(\sigma\acute{\sigma}\#\acute{\sigma})\sigma]$ or $*[\sigma(\sigma\#\acute{\sigma}\acute{\sigma})]$.

2.5.4 Tone–foot constraints and headedness

A previous OT proposal for relating tone and feet is De Lacy (2002). The constraint set centers around a tendency for H tones to avoid non-heads, and for L tones to avoid heads. The constraints are expressed in terms of markedness. For example, *L/HD militates against foot heads with a low tone. In languages with two tone levels, this can help to drive association of a H tone to the head of a foot. This type of constraint behaves similarly to the foot-licensing constraints of the present chapter. Both constraint types enforce high-toned footed syllables, but only to suit the needs of the foot; the constraints are indifferent to unfooted high tones. The remainder of this section discusses whether Saghala could be analyzed with De Lacy-style constraints and headed feet.

A first issue when considering a headedness-based approach for the present foot-based analysis is that the status of prominence in the layered foot needs to be clarified. The layered foot has a head syllable, which is the head of the internal foot. In addition, the syllable in the higher foot layer, called the satellite syllable, could also be interpreted as a prominent position.[17] Consequently, a structure such as in (29), with stress on the right syllable of the internal foot and with the satellite syllable on the right of the layered foot, would yield H tone on the last two syllables of the layered foot, as desired.

(29) $((\sigma{}^{\text{ˈ}}\sigma)\sigma)$

Several problems remain. Firstly, the headedness in the structure above is based only on the fact that it is needed for an interpretation in terms of

[17]MPK do not suggest that satellite syllables should universally carry prominence. Hence, satellite prominence might be best thought of as a language-specific property that Saghala happens to carry.

a headedness-based constraint set. Ideally, independent evidence should be adduced to support the left-branching amphibrach, $((\sigma'\sigma)\sigma)$, in favor of the dactyl, $(('\sigma\sigma)\sigma)$.

Secondly, the constraint set also raises issues for the analysis. Notably, the present analysis relies crucially on licensing constraints to derive the correct foot placement for tone shift, as can be gleaned from Table 2.4. A markedness-only constraint set will have to ensure that feet are properly positioned for tone association in some other way. Furthermore, under the naive assumption that all foot structures are the same as in the present analysis, there are still counterexamples to the generalizations proposed above. This will be demonstrated using a schematized form from the SWIS context, shown in (30).

(30) $(\sigma(\sigma\#\acute{\sigma}))(\acute{\sigma}\sigma)$

Firstly, if every head syllable should receive a H tone, the form in (30) should surface as $^*[(\sigma(\sigma\#\acute{\sigma}))(\acute{\sigma}\acute{\sigma})]$, assuming head syllables are always rightmost in the minimal foot. Secondly, the form in (30) surfaces with a tone linked to the non-head syllable of the second foot, which is not motivated under De Lacy's constraint set, where non-heads are preferably Low-toned.

In summary, the present analysis cannot swap out edge-based constraints for headedness-based ones without issue. However, an analysis of Saghala that posits different foot structures might successfully use headedness-based constraints. If such an analysis can be found, the question remains whether it is more desirable to refer to feet edges or headedness. Foot edge constraints may differ from headedness constraints in that they allow for direction reversals, e.g. left-edge orientation in flat binary feet, but right-edge orientation in layered ternary feet. Consequently, future typological research may provide insight into the optimal formulation of a feet-and-tone constraint set.

2.6 Conclusion

This chapter has introduced a foot-based approach to account for bounded tone shift and spread. Key elements are the adoption of a layered foot to delimit the bounding domain, the use of Harmonic Serialism to derive local effects, and the proposal of a licensing/structural markedness constraint family to relate tone and feet to each other.

The approach was demonstrated on Saghala. It successfully accounted for all six patterns. This involved dealing with the interplay of tone spread, tone shift, various cases of tonal proximity, and sensitivity to word-initial syllables. Furthermore, Saghala tonology took place in a trisyllabic domain size and with no discernable role for morphology.

The ability of the framework to deal with the Saghala patterns shows promise for its applicability to a range of Bantu bounded tone systems. Furthermore, the framework improved on previous OT proposals in two aspects:

It does not stipulate the size of the bounding domain, and it does not use markedness constraints that make reference to input structure.

Chapter 4 will explore the full typological predictions of the framework. In addition to bounded tone patterns, the foot-based nature of the framework may allow the typology to include edge-based tone and rhythmic tone with minimal adaptations.

The chapter also warrants further research on Saghala. Firstly, it can be tested if the proposed foot structures are acoustically detectable in speaker productions. Secondly, further data collection can determine if the foot-based generalization of Saghala tone has applications beyond the noun phrase domain, and if the layered foot plays a more general role in Saghala phonology. At a more general level, it is hoped that the present analysis can inspire a new foot-based perspective on the analysis of bounded tone phenomena.

Chapter 3

Layered feet and syllable-integrity violations in Copperbelt Bemba bounded tone spread

Abstract

In Copperbelt Bemba (Bickmore and Kula 2013; Kula and Bickmore 2015), bounded tone spreading occurs over a ternary domain that is sensitive to the presence and position of heavy syllables. We argue that a principled characterization of the domain follows from considering foot structure; the domain shape is that of a quantity-sensitive iamb plus one more mora. We then show that traditional binary feet (McCarthy and Prince 1986; Hayes 1995) run into trouble in capturing this ternarity. This is because the tone spreading can occur in contexts with a multitude of unparsed syllables on either side of the domain, while traditional ternarity-enabling devices revolve around the minimal presence of unparsed syllables.

We propose an alternative account using layered feet (e.g. Martínez-Paricio and Kager 2015). Specifically, we specify a nested foot with an inner iamb and a strictly monomoraic adjunct. With these foot structures in place, the generalization for tone is simply that it associates to all and only footed material.

For certain syllable weight sequences, our analysis predicts syllable-integrity violations (SIVs), where parsing consumes only the first of two tautosyllabic moras. Contrary to the common view that SIVs are universally disallowed, we embrace this result and put it in a typological context, discussing other recent evidence for SIVs. In addition, we adopt and extend an Optimality

Theory (Prince and Smolensky 1993) constraint set to model SIVs (Kager and Martínez-Paricio forthcoming), paving the way for a general typological investigation of syllable-integrity violations.

3.1 Introduction

Arguably the most common conception of a foot is that it is a syllable-parsing constituent that is by default binary, and exceptionally unary (McCarthy and Prince 1986, 1993b; Hayes 1995).[1] Languages differ in whether they parse heavy syllables into unary feet or not, and in whether the binary foot is left or right-headed. Feet with heads on the initial member are called trochees, and those with heads on the final member are called iambs. Headedness is reflected not only in the acoustic realizations of the foot constituents, but also in the quantity asymmetries that the foot allows; only iambic feet can parse a sequence of a light and a heavy syllable (denoted as $\sigma_{\mu}\sigma_{\mu\mu}$), while only trochaic feet accept the parsing of a sequence $\sigma_{\mu\mu}\sigma_{\mu}$.

The original development of these foot representations was mainly driven by considerations from stress typology. However, feet also found use in accounting for prosodic morphology, prosodic minimality, reduplication, locus of infixation, truncation, and templatic and root-and-pattern morphology (Broselow 1982; McCarthy and Prince 1986, 1993b; Itô 1990; Mester 1990, 1994; Poser 1990; Spring 1990; Crowhurst 1991, 1994; Wiese 2001; Bat-El 2005; Alderete and MacMillan 2015). In addition, binary feet have been invoked to describe the domain for a variety of phonological processes (Nespor and Vogel 1986; Dresher and Lahiri 1991; Halle and Kenstowicz 1991; Rice 1992; Mester 1994; Hayes 1995; Bennett 2012).

Binary feet theory has had to grapple with phenomena that operate over what we will loosely call a "ternary" domain, i.e. a domain whose size exceeds a binary foot by an additional mora or syllable. Several ways of dealing with ternary phenomena using binary feet have been developed, and have accounted for previously considered cases of ternarity. In this chapter, we will identify a type of ternarity that has received insufficient attention in the literature on metrical theory. We will develop this claim using data from Copperbelt Bemba which shows quantity-sensitive, ternary tone spreading (Bickmore and Kula 2013; Kula and Bickmore 2015). We will show that this ternarity cannot be captured by traditional, binary means. Consequently, we will argue for a revision of foot theory to include larger and more flexible constituents. In the course of making this argument, we will also develop a foot-based analysis of Copperbelt Bemba bounded tone spreading, and argue that it is superior to Bickmore and Kula's 2013 purely autosegmental analysis. In order to explain the relevance of the Copperbelt Bemba data, we will first give an overview of the way that ternarity has previously been handled in binary feet theory.

[1] An earlier version of this chapter was published in the proceedings of the 2016 Annual Meeting on Phonology (Breteler and Kager 2017).

At least three types of ternarity have previously been identified. Firstly, some languages target the third position from an edge. For example, in Macedonian strings of three or more syllables, stress falls on the third syllable from the right (Beasley and Crosswhite 2003), as in (2).

(2)	a.	ˈtat.kov.tsi	‘fathers’
	b.	tat.ˈkov.tsi.te	‘the fathers’
	c.	ˈri.do.vi	‘hills’
	d.	ri.ˈdo.vi.te	‘the hills’

Secondly, in Japanese, a process of word clipping can lead to tripartite forms, such as the trisyllabic loanwords in (3) (Itô and Mester 1992). Crucially, these loanwords come from longer source forms, suggesting that a clipping process is at work that has favored the tripartite outcome over other options.

(3)	a.	a.ni.me	‘animation’
	b.	te.re.bi	‘television’

Finally, some languages display iterative stress occurring every three syllables. A classic case is Cayuvava, which stresses every third syllable counting from the right, as shown with the example form in (4) (Key 1961, 1967; Levin 1985).[2]

(4) ˈca.a.di.ˈro.bo.βu.ˈru.ru.ce ‘ninety’

The binary feet solutions to the types of ternarity presented above all make use of unparsed syllables. We will refer to these approaches collectively as “Weak Layering”.

For third-from-the-edge patterns, binary feet accounts invoke extrametricality of the edgemost syllable (Liberman and Prince 1977; Hayes 1982). For the example in (2), this means that the final syllable is not visible to metrical parsing. The penultimate and antepenultimate positions are then effectively rightmost, and by that status they can be the exclusive targets of foot parsing, leading to representations such as tat.(ˈkov.tsi).<te>.

For the clipping patterns in Japanese, Itô and Mester (1992) suggest that a ternary structure can emerge from parsing preferences. They suggest that Japanese ternary forms are instances of a structure they term the “loose minimal word”, containing a binary foot and, optionally, an unparsed light syllable.[3] Thus, for the case of ‘animation’ they propose the structure [$_{\mathrm{Wd}}$ (a.ni)me].

[2] Our example focuses on the first word of a two-word string reported in Key (1967:60), which is [ˈca.a.di.ˈro.bo.βu.ˈru.ru.ce ca.a.ˈda.i.ro.ˈhi.i.ɲe] ‘ninety-nine’. The original transcription uses “č” instead of c, stating that the former represents an “alveopalatal” stop consonant (Key 1967:§0.2.1). In this alveopalatal category are also included consonants with the symbols “j”,“š”, and “ñ”. In addition, Key has no category for actually “palatal” consonants; we assume that Key’s term “alveopalatal” best matches what we would call palatal consonants.

[3] Itô and Mester credit unpublished work by McCarthy and Prince (1991a,b) for the concept of the loose minimal word.

Finally, Hayes (1995:308) proposes that ternary iterative stress languages such as Cayuvava have a parsing parameter set to Weak Local Parsing (WLP), which positions feet so that they are non-adjacent, but only minimally so. This leads to forms where binary feet are interleaved with stray light syllables. Hence, under the assumption of WLP, and with the application of extrametricality, the structure of the form in (4) comes out as (ˌca.a).di.(ˌro.bo).βu.(ˈru.ru).<ce>.

In summary, Weak Layering approaches account for ternary patterns in a binary feet theory by minimally allowing unparsed syllables. Consequently, the success of Weak Layering approaches, and by extension binary feet theory, might not extend to ternary domains that can be flanked by multiple unparsed syllables on either side. In previous literature on metrical theory, such patterns have not been identified. However, previous literature on *tonology* has long discussed phenomena that might be argued to show exactly this type of ternarity. Bickmore and Kula (2013:§6) present a survey of previous literature on ternary tone phenomena, showing that this literature goes back at least as far as Myers (1987), who reported a trisyllabic tone spreading pattern for the "North-Central" dialects (Zezuru, Korekore, and Northern Karanga) of Shona. In this chapter, we will consider bounded, ternary tone spreading data from Copperbelt Bemba (CB, Bickmore and Kula 2013; Kula and Bickmore 2015), and argue for a metrical account of the CB tone spreading domain. In pursuing such an account, we follow earlier work in assuming that metrical structure can be an organizing factor for tonal distributions, even when no claims about stress are involved (Goldsmith 1987; Downing 1990; Zec 1999; De Lacy 2002; Pearce 2006; Weidman and Rose 2006; Shimoji 2009; Chapter 2).

We believe that among the various reported cases, Copperbelt Bemba presents the clearest case of a need for a metrical account of its ternary tone phenomena. Firstly, this is because, unlike other reported cases, CB ternary tone spread is quantity-sensitive, meaning that the realization of tone depends on the sequencing of light and heavy syllables. This is a property that is classically associated with foot structure. Two other cases of ternary tone spans mentioned by Bickmore and Kula (2013:§6) are Shona (Myers 1987) and Ikalanga (Hyman and Mathangwane 1998). In these cases, different spreading rules apply within e.g. the stem, the prosodic word, and the phrase. Consequently, it might be argued for these cases that there is not clearly a ternary tone spreading target. In CB, there is no indication of such domains being involved in bounded ternary spreading (but see Kula and Bickmore 2015 for another phrasal tonal phenomenon in CB). In general, Bickmore and Kula (2013:127) state that ternary spreading is "a widespread and across the board phenomenon" in the language. Bickmore and Kula (2013:§6) further mention cases of ternary shift, i.e. cases where tone is displaced from its lexical origin and associates to a position that is two tone-bearing units away from this origin. Such phenomena are attested in Sukuma, which, generally, maps $/\acute{\mu}\mu\mu/$ to $[\mu\mu\acute{\mu}]$ (Richardson 1971; Goldsmith 1985; Sietsema 1989; Batibo 1991; Kang 1997), and Saghala, which maps $/\acute{\sigma}\sigma\sigma/$ to $[\sigma\acute{\sigma}\acute{\sigma}]$ (Patin 2009; Chapter 2). While the tonal phenomena in these languages cross ternary distances, there is no ternary tonal span at the surface, since tone has delinked from its lexical origin. Consequently, we believe the spreading case of CB is clearer than these tone shift cases in the sense that CB presents not just ternary-sized reassociation, but also demonstrates that the grammar requires surface ternarity. In conclusion, we select the example of CB ternary tone spreading to demonstrate that ternarity in natural language can come in a shape that exceeds the generative capabilities of Weak Layering approaches.

To formally describe the CB spreading domain, we will adopt layered foot representations (Bennett 2012; Kager 2012; Martínez-Paricio 2013). These representations allow for a second foot layer, which parses a typical binary foot along with an adjunct element. This enables nested, ternary constituents, such as $((\sigma\sigma)\sigma)$. As we will show, with the correct specification of parsing behavior for both foot layers, we can reduce the various shapes of the CB tone spreading domain to a single foot type. The layered feet framework retains the binary foot as a representational element, extending the representational schema rather than overthrowing it. Hence, we retain the fruits of research performed in the context of binary feet frameworks.

The CB data motivate another revision of traditional foot theory, namely the assumption of syllable integrity. That is, our account of the CB data contains instances where a foot parses one mora of a heavy syllable, but not the other. This decision is driven by the observation that under specific circumstances, CB tone spread stops in the middle of a heavy syllable. Although foot theory has traditionally assumed strict syllable integrity (Prince 1976; Hayes 1995), recent work has started to question this assumption (Martínez-Paricio 2013; Kager and Martínez-Paricio forthcoming). In this chapter, we will situate CB tone spread in this discussion, arguing that it offers the first instance of "blended" footing, which is partly syllable-parsing, and partly mora-parsing. We will also extend the Optimality Theory (OT, Prince and Smolensky 1993) constraint set for syllable-integrity violations proposed in Kager and Martínez-Paricio (forthcoming).

In the next section we describe the Copperbelt Bemba data and argue in favor of a foot-based generalization. Then, we show in section 3.3 that none of the Weak Layering approaches are suitable for an account of CB ternary tone spreading. In section 3.4, we introduce the layered feet framework and offer a layered feet analysis of the CB data. In section 3.5, we consider a more detailed model of syllable-integrity violations in our account of CB, using an OT approach. In the discussion in section 3.6, we discuss previously raised objections against syllable-integrity violations; consider and reject an alternative account of CB with binary feet; and discuss further CB data involving (near-)contact between multiple tonal autosegments. After that, the chapter concludes. Appendix A provides additional tableaux for our Optimality Theory analysis.

3.2 Ternarity in Copperbelt Bemba bounded tone spreading

All data in this section are taken from Bickmore and Kula (2013) and Kula and Bickmore (2015), which we will collectively refer to as B&K. They use the term "Copperbelt Bemba" to refer to a variety of Bemba spoken in the Copperbelt province of Zambia. Their reports also provide a comparison between CB and "Northern Bemba", the variety of Bemba discussed predominantly in previous literature on Bemba. See Hamann and Kula (2015) for a study of the phonetics of a Copperbelt Bemba speaker.

Our focus is on the facts of CB bounded high tone spreading, a process where a tone spreads across a bounded domain that is calculated relative to that tone's starting position. We call the tone-bearing unit (TBU) at this starting position the "sponsor" (following Cassimjee and Kisseberth 1998); this is the TBU that the tone is underlyingly associated to.[4] The tone spreading domain is bounded, in the sense that spreading does not iterate indefinitely to the edge of the phrase. However, the domain is larger than can be covered by any binary foot. In the following, we will go through the data to show the various ways in which the domain spans different sequences of heavy and light syllables. Then, we will discuss B&K's purely autosegmental analysis of the data, arguing that their account misses an opportunity to tie together the various weight groupings of the spreading domain in a principled way. We will go on to demonstrate the plausibility of a foot-based generalization, which will serve as the basis for the theoretical accounts considered in later sections.

We start with a discussion of some general tone facts of CB, and basic theoretical assumptions. In all respects, we closely follow B&K. There are two level tones, which we will refer to as high and low, respectively. We assume that only high level tones are active in the phonology, represented as tonal autosegments. Low tones could be inserted late in the phonological process, or as the phonetic implementation of toneless TBUs; we have no reason to prefer one of these analyses over the other. On long vowels, CB can display falling tones in addition to level tones. Rising tones are absent from the data. Because falling tone appears only on bimoraic syllables, we take the mora to be the TBU in CB, and we analyse a falling-toned syllable as one where only the first of two moras is associated with a high tone. Both light and heavy syllables can contain sponsor moras, but sponsor moras are generally leftmost in heavy syllables. It is possible to position sponsor moras as the second mora in a heavy syllable by combining a vowel-final and vowel-initial morpheme, which leads to a derived vowel (Lee Bickmore, p.c. 2015), but to our knowledge, there are no tautomorphemic cases where tone is on the second mora of a heavy syllable.

[4] By positing a spreading process and suggesting sponsors, we are making analytical claims, albeit uncontroversial ones. We believe these claims are warranted because spreading takes place across morpheme and word boundaries, and because the (near-)contact of two sponsors gives rise to deviating surface forms.

In any case, we do not have sufficient data on this issue, so we will restrict our discussion to data where sponsoring moras are syllable-initial.

In addition to bounded tone spread, other tone processes are active in CB that are relevant to the interpretation of the data. Firstly, if a tone is the rightmost tone in a phrase-final word, it spreads unboundedly to the final syllable, masking any potential ternary spreading. For this reason, many of our data have two tones, so that we can study ternarity on the leftmost tone; we will ignore rightmost tones in those cases.[5] Secondly, CB is sensitive to the contact or near-contact of tonal autosegments; tone spreading sometimes stops short of its expected target because of the presence of another tone. In other words, the Obligatory Contour Principle (OCP) plays a role in CB tone spreading. For this section, where possible, we have selected only data where the OCP is not active. We take up OCP cases in section 3.6.3 of the discussion.

3.2.1 Ternarity and quantity sensitivity

Firstly, in strings of only light syllables, tone spreads twice, covering the sponsor and the two syllables that follow, as shown in (5). Sponsors are indicated with underlining. Word-internal syllable boundaries are marked with full stops; words are separated by whitespace. We follow B&K's assessment of word status.[6] We denote syllable weight by subscripting the mora count: Light syllables come out as σ_μ and heavy syllables as $\sigma_{\mu\mu}$. Syllables with a high tone are accented, showing as $\acute{\sigma}$.

(5) $\underline{\acute{\sigma}_\mu}\acute{\sigma}_\mu\acute{\sigma}_\mu$

a. <u>bá</u>.ká.pá.ta.<u>kó</u>	'they will hate a bit'
b. <u>bá</u>.mú.lú.ki.la.<u>kó</u>	'they plait a bit for him'
c. ta.<u>tú</u>.lú.kí.lee.<u>né</u>	'we didn't plait for each other'
d. <u>bá</u>.ká.sá.lu.la bwii.no	'they will fry well'

The spreading domain shows itself to be more complicated when heavy syllables are involved.[7] The position of heavy syllables in the string matters to the outcome of tone spreading. Surface tone in cases where the sponsor itself is heavy are shown in (6); Tone spreading when the sponsor is light but the following syllable is heavy are shown in (7).[8]

[5] The source of the rightmost tone is sometimes a melodic tone pattern, where tone is a reflection of tense–aspect–mood morphology that targets specific positions, instead of being underlyingly linked to the TBU marked as sponsor (Odden and Bickmore 2014). This does not impact the generalizations we make; in either case, tone behaves as if it originated in the marked position.

[6] In particular, we follow Kula and Bickmore (2015:149) in treating the post-verbal enclitic /kó/ as part of the prosodic word.

[7] There are no instances of syllable codas in the data. Consequently, we generalize over syllable weight types under the assumption that all and only long vowels constitute heavy syllables in Copperbelt Bemba.

[8] We follow the transcription style of Kula and Bickmore (2015). That is, for data taken from Bickmore and Kula (2013), we have changed "sh" to "ʃ", and "ng" to "ŋg".

(6) $\underline{\acute{\sigma}_{\mu\mu}}\acute{\sigma}_{\mu}$

a. tu.ka.<u>l</u>éé.té.la.na.<u>kó</u> ‘we will bring for each other’
b. tu.<u>l</u>éé.mú.ʃii.ki.la bwii.no ‘we are burying well for him’

(7) $\underline{\acute{\sigma}_{\mu}}\acute{\sigma}_{\mu\mu}\acute{\sigma}_{\mu}$

a. <u>bá</u>.kéé.mbí.la.<u>kó</u> ‘they will dig for’
b. <u>bá</u>.lóó.ndó.lo.<u>lé</u> ‘that they introduce’
c. tu.ka.<u>bé</u>.léé.ŋgé.la.na.<u>kó</u> ‘we will read for each other’

With the data so far, we already have enough grounds to conclude that the term “ternary” will have to entail more than simply a rule counting to three. As the table in (8) shows, the tone spreading domain is neither strictly trisyllabic, nor strictly trimoraic; in specific cases, it is disyllabic or quadrimoraic.

(8)

	syllable count	*mora count*
$\acute{\sigma}_{\mu}\acute{\sigma}_{\mu}\acute{\sigma}_{\mu}$	3	3
$\acute{\sigma}_{\mu\mu}\acute{\sigma}_{\mu}$	**2**	3
$\acute{\sigma}_{\mu}\acute{\sigma}_{\mu\mu}\acute{\sigma}_{\mu}$	3	**4**

Before considering alternative generalizations, we complete our survey of the data with cases where the spreading domain ends in a heavy syllable.

3.2.2 Falling tones

In the data so far, all syllables affected by tone spreading had level high tones. However, this is not the case when the spreading domain ends in a heavy syllable. Rather, domain-final heavy syllables surface with a falling tone. Thus, for each of the cases we described above, there is an analogous case where the domain-final syllable is heavy instead of light, and where tone on that syllable is falling instead of level; we show these cases in (9-11).[9] Falling tones are marked with a circumflex accent, showing as $\hat{\sigma}$.

(9) $\underline{\acute{\sigma}_{\mu}}\acute{\sigma}_{\mu}\hat{\sigma}_{\mu\mu}$

a. <u>bá</u>.ká.ʃíi.ka.<u>kó</u> ‘they will bury’
b. <u>bá</u>.ká.lóo.ndo.lo.la.<u>kó</u> ‘they will introduce’
c. <u>bá</u>.ká.ʃíi.ki.la ʧi.tuu.ndu ʧaa.ŋga bwii.no
‘They will bury the bushbaby well for Chituundu’

(10) $\underline{\acute{\sigma}_{\mu\mu}}\hat{\sigma}_{\mu\mu}$

a. tu.<u>l</u>éé.lóo.ndo.lo.la.<u>kó</u> ‘we are introducing’
b. twaa.<u>l</u>éé.mwíi.mbi.la.<u>kó</u> ‘we used to dig for him’

[9] In (9b), we added a nasal consonant to the verb root *loondolol* that was absent in Bickmore and Kula’s (2013) original datum (their 18d), but present in all their other presented instances of this stem.

B&K provide a single datum showing tone spreading for the sequence $\sigma_\mu\sigma_{\mu\mu}\sigma_{\mu\mu}$. It is shown in (11). This datum has three sponsors, with tone contact occurring through spreading between the first and second sponsors. A downstep, indicated with the symbol "$^!$", indicates the transition between the two spans. We offer a discussion of tone contact in section 3.6.3. For now, we are concerned only with the tone spreading starting from /tá/, which follows the generalization mentioned above that tone spreading is analogous to spreading for the sequence $\sigma_\mu\sigma_{\mu\mu}\sigma_\mu$, except that the domain-final syllable shows a falling tone.

(11) $\underline{\acute{\sigma}_\mu}\acute{\sigma}_{\mu\mu}\hat{\sigma}_{\mu\mu}$

a. $\underline{\text{ú}}$.kú.$^!\underline{\text{tá}}$.láá.ntáa.nta.ku.$\underline{\text{kú}}$.lú 'the big stumbling'

3.2.3 Analysis: autosegmental vs. metrical

Bickmore and Kula (2013:120) present a purely autosegmental, rule-based formalization of CB bounded spreading.[10] Their account consists of two parts — an initial rule of "High Doubling" that creates a bimoraic tone span, followed by a rule called "Secondary High Doubling" (SHD) that performs the remainder of the ternary spreading.[11] The rules are presented in (12). The formulation of these rules, and especially the division of the spreading process into two parts, is motivated by data whose in-depth discussion we postpone to our section 3.6.3. For now, the crucial aspect about this data is that it shows that not all parts of the spreading are enforced equally strictly by the grammar. Spreading from the sponsor to the next mora occurs whenever space permits; but any and all further (ternary) spreading occurs only under the condition that spreading does not cause contact with other tonal autosegments or association to a word-final position.

(12) a. High Doubling (B&K)

$\mu \quad \mu$

H

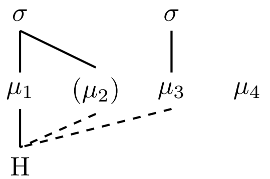
Domain: Word

Sensitive to OCP: No

[10] In Kula and Bickmore (2015), B&K present an OT analysis that also touches on bounded spreading, although its focus is on another phenomenon in CB, namely unbounded spreading. We do not discuss this analysis here because for the bounded spreading phenomena, it is incomplete. B&K apply it only to cases with exclusively light syllables; the analysis does not cover the quantity-sensitive nature of the bounded spreading domain.

[11] Our presentation has a slight graphical deviation from Bickmore and Kula (2013). We enclose μ_2 itself in parentheses, whereas in the original presentation, the domination line between the mora and its parent syllable was parenthesized. The intended meaning, to our understanding, is unchanged; the rule accepts both light and heavy initial syllables for its context, and associates tone to all moras in that initial syllable.

b. Secondary High Doubling (B&K)



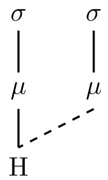
Domain: Word
Sensitive to OCP: Yes

The quantity-sensitive nature of the tone spreading pattern is expressed by the SHD rule in (12b). Specifically, it is the optional status of μ_2 that allows the pattern to apply in a similar way for e.g. both $\acute{\sigma}_\mu\sigma_\mu\sigma_\mu$ strings and $\acute{\sigma}_\mu\sigma_{\mu\mu}\sigma_\mu$ strings. Spreading runs up to μ_3; the inclusion of another mora following it, μ_4, is intended to prevent association to word-final moras.[12]

The rules in (12) accurately describe the quantity-sensitive nature of the tone spreading pattern. However, the rules do not connect this quantity sensitivity to a deeper principle. That is, the analysis implies that the strings of light and heavy syllables undergoing tone spreading in CB are grouped *arbitrarily*. This suggests that, all else being equal, the pattern of CB is equally plausible as any variation on the rules in (12) that rule-based theory allows. For example, such variant rules might contain a different number of moras or syllables, require light or heavy syllables in any given position, and allow optional elements in any given position. We believe this generative freedom does not accord with typological limits on the treatment of syllable weight. For instance, although quantity-sensitive languages generally treat a string of two light syllables similarly to a single heavy syllable (e.g. in terms of stress foot placement or reduplication (McCarthy and Prince 1986; Hayes 1995)), a rule-based formalism permits rules that run counter to this generalization. For example, the rule in (13) describes binary tone spreading taking place exclusively across a syllable boundary. This rule performs binary spreading for light syllables, i.e. $/\acute{\sigma}_\mu\sigma_\mu/ \rightarrow [\acute{\sigma}_\mu\acute{\sigma}_\mu]$, and spreads similarly from the second mora of a heavy syllable to the next syllable, or from a light syllable to the initial mora of a following heavy syllable. However, tone is static for heavy syllables with lexical High tone on the initial mora, so that $/\hat{\sigma}_{\mu\mu}/\rightarrow[\hat{\sigma}_{\mu\mu}]$.

[12] This formulation is inadequate, because the inclusion of μ_4 in the SHD rule predicts that μ_3 must be non-final for *any* secondary spreading to occur. However, it is possible for tone to spread to both moras of a heavy syllable even when that syllable is in penultimate position, as evidenced by the form [tu.ka.<u>bá</u>.ʃíí.ka bwii.no] 'we will bury them well' (Bickmore and Kula 2013:112, (20b)). In this case, the word-final mora in [tu.ka.<u>bá</u>.ʃíí.ka] matches μ_3 in the SHD context, and no fourth mora is present. This is not a major analytical problem; the rule could be repaired by making the presence of μ_3 optional.

(13) Light Syllable Spreading



To our knowledge, patterns such as that generated by the rule in (13), that prioritize spreading on a pair of light syllables to the exclusion of spreading within a heavy syllable, are unattested. In general, the typology of quantity sensitivity (QS) is an ongoing field of research, and our present aim is not to measure the accuracy of a rule-based formalism against this typology in great detail. However, we note that QS facts have played a major role in the development of metrical theory. Consequently, we claim that if a successful metrical account of the CB data can be found, this account represents not merely a fortuitous pairing of data and theory, but connects the CB data to a more principled account of quantity sensitivity in natural language than a purely autosegmental, rule-based account has to offer.

We propose, then, that the CB spreading domain indeed has more principled underpinnings; specifically, we will argue that the domain is definable through foot structure. A foot-based generalization connects the various different weight sequences of the spreading pattern to each other through the following observation: The domain is always exactly one mora longer than a quantity-sensitive iamb (Hayes 1995). We demonstrate this in Table 3.1 by showing iambs whose left edge is anchored to the sponsor TBU for each of the contexts. We discuss OCP sensitivity for a foot-based analysis in section 3.6.3.

Seen in..	*Domain shape*	*Example form and gloss*
(5)	$(\sigma_\mu \sigma_\mu) + \mu$	(bá.ká).pá.ta.kó ‘they will hate’
(6)	$(\sigma_{\mu\mu}) + \mu$	tu.(léé).mú.ʃii.ki.la bwii.no ‘we are burying for him well’
(7)	$(\sigma_\mu \sigma_{\mu\mu}) + \mu$	(bá.kéé).mbí.la.kó ‘they will dig for’
(9)	$(\sigma_\mu \sigma_\mu) + \mu$	(bá.ká).ʃíi.ka.kó ‘they will bury’
(10)	$(\sigma_{\mu\mu}) + \mu$	tu.(léé).lóo.ndo.lo.la.kó ‘we are introducing’
(11)	$(\sigma_\mu \sigma_{\mu\mu}) + \mu$	ú.kú.ꜝ(tá.láá).ntáa.nta.ku.kú.lú ‘the big stumbling’

Table 3.1: CB bounded tone spreading fits the QS iamb+mora template

We conclude that deriving this iamb+mora domain is a worthwhile goal for a formal account of CB bounded tone spreading. In the next section, we show that Weak Layering, despite having access to the quantity-sensitive iamb, is unable to capture this generalization.

3.3 Problems for Weak Layering

The previous section established that an account of CB bounded tone spreading benefits from access to a template consisting of a quantity-sensitive iamb and an additional mora. Here, we show that none of the traditional methods of deriving such ternarity using binary feet can be applied to Copperbelt Bemba.

We begin by considering extrametricality. Since extrametricality takes an edgemost element out of the equation, it is a device suitable for describing edgemost ternarity. In the case of CB bounded tone spreading, this is not useful, because the pattern is not guaranteed to occur near an edge. We demonstrate the problem for extrametricality in (14), showing a possible surface form (SF). We have "helped out" by suggesting a foot position, but crucially, marking the final syllable extrametrical does not help to determine that position, nor does it help to answer why tone spreading ends where it does.

(14) *(possible SF)* tu.(l̲éé).mú.ʃii.ki.la bwii.<no>
'we are burying for him well'

Secondly, the concept of the loose minimal word (LMW) also offers no help. Itô and Mester (1992) describe the LMW not as a separate prosodic category, but as a structure that falls out from conditions on parsing; ternarity arises as a minimality effect in strings that are just large enough to contain one foot and one unparsed syllable. However, the ternary tonal domain in CB arises also in contexts that contain a multitude of unparsed syllables.

Thus, although a prosodic word could provide a ternary domain for tone spreading, as in (15a), there is no mechanism that ensures that a Prosodic Word category is indeed placed in this position, and not somewhere else, such as in (15b).[13]

(15) a. *(possible SF)* tu.[(l̲éé).mú]$_{PrWd}$.ʃii.ki.la bwii.no
'we are burying for him well'
b. *(problematic SF)* [tu.(l̲éé)]$_{PrWd}$.mú.ʃii.ki.la bwii.no
'we are burying for him well'

[13] Itô et al. (1996) propose that the construction of minimal prosodic words is due to a principle of "Hierarchical Alignment", i.e. the alignment of constituent edges with the edges of the categories they are contained in. For our case, this could mean that the presence of foot edges induces the creation of prosodic words positioned so that they align with at least one edge of the foot. However, this leads to an incorrect prediction; in cases where a sponsor is already domain-initial, the foot would similarly be left-aligned with the domain, satisfying Hierarchical Alignment. Consequently, no prosodic word would need to be created especially for the foot, and no ternary tone spreading is predicted to take place — contrary to the CB pattern.

Finally, we consider Weak Local Parsing (WLP, Hayes 1995). Under WLP, feet are placed iteratively while leaving an unparsed light syllable between pairs of adjacent feet, where possible. Hayes derives this specification from minimality:

> "I assume that it must be the smallest definable prosodic distance, namely a single mora. Since foot construction cannot split up syllables [...] this is equivalent to a single light syllable." (Hayes 1995:308)

Thus, WLP is a suitable device for *iterative* ternarity. Again, this does not match up with the nature of CB bounded tone spreading, because it is not iterative; the presence of one tone span does not imply the presence of other tones further along the domain. However, to show that WLP is not successful even when given its fairest shot, we consider an implementation of WLP for CB tone spreading that makes some supporting assumptions. Specifically, we could assume that CB does iteratively build feet, left-to-right, which come into play only with tone spreading; tone could be assumed to spread rightward until it hits a left foot boundary.[14] In some cases, this is sufficient to make a successful prediction, such as in (16a), where the application of WLP has positioned a left foot boundary exactly a ternary distance from the start of the sponsor, /lé/. However, even with these assumptions, one property of WLP remains problematic for an account of CB tone: WLP, by design, never skips over heavy syllables. In (16b), the WLP-induced feet are not in sync with the tone span, due to a heavy syllable that is in an infelicitous position. Again assuming a left-to-right application of foot building with WLP, the string starts with two adjacent feet because WLP cannot skip over the heavy syllable /loo/. Under our assumption that tone spreads until it hits a left foot boundary, we expect tone from /bá/ to spread only once, giving *(<u>bá</u>.ká).(loo).ndo.(lo.la).<u>kó</u>, which is falsified by the CB data.

(16)	a. *(possible SF)*	(tu.<u>lé</u>é).mú.(ʃii).ki.(la bwii).no	
		'we are burying for him well'	
	b. *(problematic SF)*	(<u>bá</u>.ká).(lóo).ndo.(lo.la).<u>kó</u>	
		'they will introduce'	

In summary, because the ternary domain of Copperbelt Bemba bounded tone spreading is neither edgemost, nor related to minimality, nor iterative, all three of the Weak Layering methods fall short of accounting for it. In the next section, we introduce layered feet and show that they can be used to describe the necessary ternary domain.

[14] The best version of the WLP account should make further stipulations to ensure that sponsor syllables are never skipped.

3.4 A layered feet account of Bemba ternarity

3.4.1 Layered feet

Generally speaking, a layered foot is a maximally trisyllabic constituent that parses another foot along with some small, dependent element. This concept originated, under different names, in the seminal works of Selkirk (1980); Prince (1980). Its developmental path in the literature has been more diffuse than that of binary feet theory, surfacing occasionally throughout the 1990s (Dresher and Lahiri 1991; Rice 1992; Kager 1994). Recently, there has been a more concerted effort to explore the ramifications of layered feet representations, inspired by work on recursive prosody (Itô and Mester 2007; Itô and Mester 2013; Elfner 2015). Layered feet have been applied to a variety of foot-governed phonotactics and tonotactics (Jensen 2000; Davis and Cho 2003; Bennett 2012; Martínez-Paricio 2013; Martínez-Paricio and Kager 2017; Kager and Martínez-Paricio 2018; Chapter 2); to account for stress windows (Kager 2012); stress typology (Martínez-Paricio and Kager 2015); and edge effects typically solved with extrametricality (Buckley 2014; Kager and Martínez-Paricio forthcoming).

In our present conception of the layered foot, the inner structure consists of a flat, binary foot and an adjunct element, which might be a syllable or a mora. Because the layered foot has internal structure, we can specify the parsing properties of its constituents independently of each other. For Copperbelt Bemba, layered feet allow a specification in line with the observations we made about the pattern back in section 3.2.3, Table 3.1. The inner foot should parse as a quantity-sensitive iamb. Previous work has generally assumed syllabic adjuncts. However, we propose here that for CB, the adjunct must be specified to parse moraically, so that it always parses exactly one mora (see also Kager and Martínez-Paricio forthcoming). With these specifications, we derive representations for the CB data as shown in Table 3.2. We discuss the representation of tone contact cases such as (11) in section 3.6.3.

The layered feet in Table 3.2 overlap exactly with the tone spans. Consequently, we can further simplify our generalization for the CB bounded tone distributions: Tone surfaces on all and only footed TBUs.[15]

As a tradeoff for this simpler generalization, we have assumed a more complex foot. In particular, we have parsed the forms in (9-11) so that only the first mora of the final syllable is included in the foot. This means that these forms contain a syllable integrity violation (SIV). We show an example of this structure in Figure 3.1. Since only the first mora of the heavy syllable is footed, only that mora will be associated with the tone, leading to the desired falling tone at the surface.

The status of SIVs as a part of natural language is controversial, with the traditional view being that SIVs are universally disallowed. In the next section,

[15]See Idsardi and Purnell (1997) for the related proposal that Shingazidja “tone” is purely metrical structure.

Seen in..	*Layered footing*	*Example form and gloss*
(5)	$((\sigma_\mu\sigma_\mu)\sigma_\mu)$	((bá.ká).pá).ta.kó 'they will hate'
(6)	$((\sigma_{\mu\mu})\sigma_\mu)$	tu.((léé).mú).ʃii.ki.la bwii.no 'we are burying for him well'
(7)	$((\sigma_\mu\sigma_{\mu\mu})\sigma_\mu)$	((bá.kéé).mbí).la.kó 'they will dig for'
(9)	$((\sigma_\mu\sigma_\mu)\mu)\mu$	((bá.ká).ʃí)i.ka.kó 'they will bury'
(10)	$((\sigma_{\mu\mu})\mu)\mu$	tu.((léé).ló)o.ndo.lo.la.kó 'we are introducing'
(11)	$((\sigma_\mu\sigma_{\mu\mu})\mu)\mu$	ú.kú.$^{!}$((tá.láá).ntá)a.nta.ku.kú.lú 'the big stumbling'

Table 3.2: Layered feet capture the CB bounded tone spreading domain

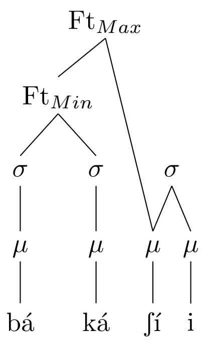


Figure 3.1: A syllable-integrity violation, causing a falling-toned heavy syllable

we discuss evidence for SIVs in other languages, and we integrate the facts of Copperbelt Bemba into an Optimality Theory account of SIVs.

3.5 Towards a typology of syllable-integrity violations

Syllable integrity is typically held to be inviolable (Hayes 1995; Hyde 2007). However, there is some evidence of SIVs in languages with purely moraic footing. Shimoji (2009) proposes a foot-based account of rhythmically alternating High and Low tone in Irabu Ryukyuan. Although Shimoji does not discuss SIVs, they are implied in the analysis; forms such as the High-High-Low-Low [á.máir] must be footed $(\text{á.má})_{\mu\mu}(\text{ir})_{\mu\mu}$ to correctly derive the tone distribution (Shimoji 2009:95; Martínez-Paricio 2013:260).

Blevins and Harrison (1999) present data on stress and tone in Gilbertese, suggesting that the language has an iterative trimoraic footing pattern. More recently, Kager and Martínez-Paricio (forthcoming) followed up on this with an explicit layered feet account of Gilbertese where heavy syllables can even be part of two different feet, for example footing the string [ni^{H}.ˈka.kaa^{H}.ˈea] "in search of him" as ((ni^{H}.ˈka).ka)((a^{H}.ˈe)a), where a superscript H indicates a preceding high-toned syllable.

We conclude that some languages parse feet strictly based on mora count, parsing moras directly where needed. On the other hand, the vast majority of the world's languages only allow feet to parse syllables — even if syllable weight, and hence mora count, might still play a role in the exact distribution of feet. For a framework with flat feet, this is the end of the story. However, the layered feet framework has two layers of organization, and therefore leads us to ask whether any language might blend these two styles of parsing. As we showed above, Copperbelt Bemba can be analyzed as the first identified case of such blended parsing — building inner feet with syllables, and adjuncts with moras. We give an overview of these various parsing styles and their resulting structures in Figure 3.2.

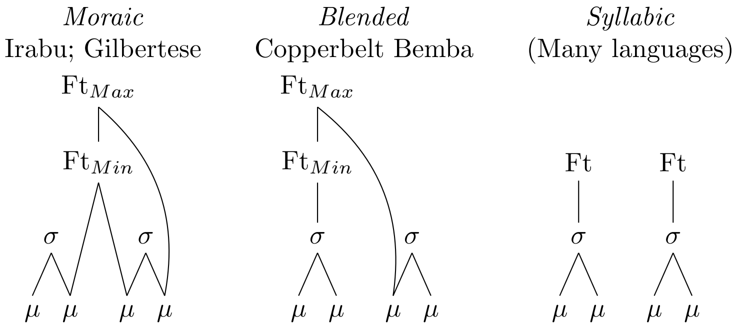


Figure 3.2: Moraic, blended, and syllabic parsing

Natural language might allow for other types of blended parsing. In order to make specific predictions, we require a more specific theory of how parsing principles are organized. In the remainder of this section, we develop such a theory.

3.5.1 Syllable-integrity violations in Optimality Theory

To make explicit the organizing components that give rise to the continuum, we use Optimality Theory (OT, Prince and Smolensky 1993) to model when and where grammars decide to violate syllable integrity. Kager and Martínez-Paricio (forthcoming) provide a previous OT implementation of SIVs with layered feet. They summarize their approach as follows:

> "In order to guide the parsing of morae into feet, three sets of constraints will be proposed: foot well-formedness constraints that restrict the moraic size of foot heads and foot dependents [i.e. adjuncts]; constraints regulating the distribution of metrical feet of different sizes within a prosodic word, which bring about ternarity; constraints that state requirements on the parsing of morae by feet. [...] syllable-integrity disrespecting metrical parsing emerges under duress of foot shape constraints, which take priority over constraints that disfavour metrical parsing of morae immediately dominated by feet." (Kager and Martínez-Paricio forthcoming:3)

The approach reflects an intuition that all else being equal, grammars will prefer syllabic parsing. It is only particular constraints on the mora count of feet or adjuncts that can throw the grammar off from this parsing preference. Kager and Martínez-Paricio show that their constraint set successfully models the Gilbertese data. While an inspection of the factorial typology of the constraint set is beyond the scope of the present work, we will suggest an amendment to the constraint set based on an application of it to the Copperbelt Bemba facts. The relevant constraint set from Kager and Martínez-Paricio (forthcoming) is defined in (17). Here, the term FtMin refers to feet that are minimal (Itô and Mester 2007), meaning that they do not themselves contain another foot. This holds for all inner feet in a layered foot, as well as flat binary feet.

(17)	*Constraint*	*Definition*
	Adjunct-μ	Assign * for every adjunct that is not monomoraic
	Parse-μ	Assign * for every mora not parsed by a foot
	Exhaustivity-μ	Assign * for every mora directly dominated by a foot
	FtMin=$\mu\mu$(Min)	Assign * for every FtMin that has less than two moras
	FtMin=$\mu\mu$(Max)	Assign * for every FtMin that has more than two moras

Firstly, the tableau in (18) shows that the ranking Adjunct-$\mu \gg$ Parse-$\sigma \gg$ Exhaustivity-μ gives rise to monomoraic adjuncts, even if it means breaking up a heavy syllable. Here, we assume that all parsings of the input will build a disyllabic foot, with the only relevant choice being whether and how to construct an adjunct. This tableau and the following ones also assume an "anchoring" scenario, i.e. only candidates that start parsing from the left edge of the string are considered. This is an acceptable simplification for Copperbelt Bemba because foot structure is always conditioned by the presence of tone. See Chapter 2 for an example of how to model this with constraints. In addition, we do not consider candidates who place the adjunct to the left of the inner foot; such forms can be excluded by top-ranking an alignment constraint that militates against them, viz. TROCHEE$_{NonMin}$ (Martínez-Paricio and Kager 2015). Finally, when tautosyllabic moras are only partially footed, both moras are written in full, broken up by the intervening foot boundary. We further indicate this by showing syllable boundaries before and after the moras, with the symbol ".". We do not indicate syllable boundaries in other cases, i.e. when symbols on either side of the boundary already denote syllables.

(18) Different ways of dealing with a heavy syllable in dependent position

$\sigma.\sigma.\mu\mu$	ADJUNCT-μ	PARSE-σ	EXHAUSTIVITY-μ
a. $(\sigma\sigma)\sigma_{\mu\mu}$		**!	
b. $((\sigma\sigma)\sigma_{\mu\mu})$	*!		
c. ☞ $((\sigma\sigma).\mu)\mu$		*	*

Candidates 18a and 18b are syllabic parses of the string, building no adjunct and a bimoraic adjunct, respectively. However, these syllabic parsings make unnecessary sacrifices; as 18c shows, it is better to violate low-ranking EXHAUSTIVITY-μ and parse only a single mora in order to find the right balance between adjunct size and parsing constraints.

The above tableau establishes a partial ranking. We now turn to a full ranking for Copperbelt Bemba, using our layered feet generalization as presented in section 3.4, Table 3.2, as our target forms. However, we will show that this is not achievable with the constraint set from Kager and Martínez-Paricio (forthcoming): A ranking paradox arises. We will end the section with suggestions on how to amend the constraint set.

Firstly, among our target forms, ADJUNCT-μ and FTMIN=$\mu\mu$(MIN) are surface-true; all forms have a monomoraic dependent, and none have a FtMin of less than two moras. In the following tableaux, we simplify the presentation by excluding these constraints and all candidates that would violate either of them. From the tableau above, we can further deduce PARSE-$\mu \gg$ EXHAUSTIVITY-μ. This leaves the position of FTMIN=$\mu\mu$(MAX). A consideration of strings starting in $\sigma_\mu\sigma_{\mu\mu}$ reveals that either EXHAUSTIVITY-μ or PARSE-μ must outrank FTMIN=$\mu\mu$(MAX), as shown in (19). In the tableau, we abbreviate EXHAUSTIVITY-μ as EXH-μ.

(19) Quantity-sensitive iambic parsing

$\sigma_\mu\sigma_{\mu\mu}\sigma_\mu$	Parse-σ	Exh-μ	FtMin=$\mu\mu$(Max)
a. ☞ $((\sigma_\mu\sigma_{\mu\mu})\sigma_\mu)$			*
b. $((\sigma_\mu.\mu)\mu).\sigma_\mu$	*!	**	

This tableau shows that parsing and syllable integrity preferences can drive a quantity-sensitive iambic parsing of the $\sigma_\mu\sigma_{\mu\mu}$ string, as in 19a. However, consideration of strings starting in a heavy syllable show that parsing in Copperbelt Bemba is not always maximized. This is demonstrated in the tableau in (20). The only way to derive this effect is by ranking FtMin=$\mu\mu$(Max) higher than Parse-μ, rather than lower.

(20) Limited parsing in heavy-initial strings

$\sigma_{\mu\mu}\sigma_\mu\sigma_\mu$	FtMin=$\mu\mu$(Max)	Parse-σ	Exh-μ
a. $((\sigma_{\mu\mu}\sigma_\mu)\sigma_\mu)$	*!		
b. ☞ $((\sigma_{\mu\mu})\sigma_\mu)\sigma_\mu$		*!	

While a full parse of the string as in 20a was optimal for strings starting in $\sigma_\mu\sigma_{\mu\mu}$, CB prefers a FtMin=$\mu\mu$(Max)-respecting parse as in 20b for strings starting in heavy syllables.

We summarize the ranking arguments from the preceding tableaux in (21).

(21)
a. Parse-$\mu \gg$ Exhaustivity-μ
Per (18), dependents break up heavy syllables

b. Parse-$\mu \gg$ FtMin=$\mu\mu$(Max)
OR
Exhaustivity-$\mu \gg$ FtMin=$\mu\mu$(Max)
Per (19), CB prefers $((\sigma_\mu\sigma_{\mu\mu})\sigma_\mu)$ to $((\sigma_\mu.\mu)\mu)\sigma_\mu$

c. FtMin=$\mu\mu$(Max) $\gg$ Parse-μ
Per (20), CB prefers $((\sigma_{\mu\mu})\sigma_\mu)\sigma_\mu$over $((\sigma_{\mu\mu}\sigma_\mu)\sigma_\mu)$

Combining (21a) and (21c), the paradox can be boiled down to the two opposing statements “Parse-μ or Exhaustivity-$\mu \gg$ FtMin=$\mu\mu$(Max)”; and “FtMin=$\mu\mu$(Max) $\gg$ both Parse-μ and Exhaustivity-μ”. The paradox can be solved by introducing another constraint into the set, which can take over the role of one of the involved constraints — thus allowing more flexibility in the ranking. Adding a constraint has the benefit of leaving intact the original constraint set, which was independently motivated. This ensures that all originally modelable patterns can still be modeled — with the new constraint adding more patterns, such as that of Copperbelt Bemba, to the factorial typology. Our preferred implementation is to divide the labor of Exhaustivity-μ.[16]

[16] One plausible alternative is to have a constraint Layering take over some of the role of Parse-σ, defined as follows:

Crucially, the two cases where Exhaustivity-μ is relevant take place in different constituents. (21b) occurs in a FtMin context, whereas (21a) occurs in the context of a FtNonMin, i.e. a foot that dominates another foot. Thus, a solution to the paradox is to state, in line with (21a), that the general Exhaustivity-μ constraint is indeed low-ranked, but that (21b) is accounted for by a higher-ranking version of Exhaustivity-μ that is specific to FtMin contexts, i.e. the constraint Exhaustivity-μ(FtMin) defined in (22).

(22) Exhaustivity-μ(FtMin)
Assign * for each mora directly dominated by a FtMin

With this addition, we can account for the parsing behavior of CB in OT. The new constraint is added above the constraint ranking used in the tableau. Thus, the final ranking comes out as { FtMin=$\mu\mu$(Min), Adjunct-μ, Exhaustivity-μ(FtMin) } $\gg$ FtMin=$\mu\mu$(Max) $\gg$ Parse-μ $\gg$ Exhaustivity-μ. We provide tableaux for all cases in Appendix A, using the expanded constraint set.

In summary, in this section we have modelled a syllable-integrity violating grammar in OT, building on results from Kager and Martínez-Paricio (forthcoming) to show that Copperbelt Bemba adds new considerations to the construction of a descriptively adequate constraint set.

3.6 Discussion

3.6.1 SIVs and multiply stressed syllables

Hyde (2007:241) raises an objection to allowing SIVs by noting that they "open the door to [...] multimoraic syllables that have stress on more than one mora." Indeed, we are not aware of the attestation of such a pattern. However, as we propose to allow SIVs, such structures could indeed be represented, e.g. $[(\sigma.\text{ˈ}\mu)(\text{ˈ}\mu.\sigma)]$. Consequently, we predict that human cognition, specifically human phonological grammar, is capable of processing these structures.

We leave the reconciliation of this prediction with the apparent non-attestation of multi-stressed syllables as an open research problem. However, we do offer one potentially relevant observation here; the evidence in favor of SIVs comes from languages with a tonal aspect, whereas the objections to it come

Layering
Assign * for each FtMax that is not layered

Layering could account for the effects we ascribed to Parse-σ in (21a) and (21b), so that Parse-σ itself can be ranked lower in accordance with (21c). We disprefer this option because we suspect that an independent pressure to construct layered feet will be problematic within a broader context, particularly in the interaction with constraints for stress systems as proposed in Martínez-Paricio and Kager (2015). Ultimately, a more in-depth consideration of the predictions of both constraint sets, and their comparison to the attested typologies, will be the best guide to deciding in favor of one over the other alternative.

from stress languages (Kager and Martínez-Paricio forthcoming). Consequently, we are hopeful that an explanation might come from extragrammatical factors. To this end, we feel our results warrant further research into the differences between tonal and non-tonal stress languages, also in terms of their acquisition, processing, and diachrony.

3.6.2 Boundary hopping: A binary feet alternative

Although we are not aware of an instance of it in the literature, here we take up one more binary feet alternative. Mirroring the bipartite structure of the layered foot, we consider a binary feet account with a two-step process, where tone first spreads to cover an iambic foot, after which a second process extends the tone span by one additional mora. Since this second process in effect causes tone to extend just beyond the foot boundary, we refer to this account as "boundary hopping". An example of a derivation is shown in (23).

(23)
1. $(\underline{\acute{\sigma}_\mu}\sigma_\mu)\sigma_\mu\sigma_\mu...$
   Build binary, iambic feet over sponsors
2. $(\underline{\acute{\sigma}_\mu}\acute{\sigma}_\mu)\sigma_\mu\sigma_\mu...$
   Spread tone through the foot
3. $(\underline{\acute{\sigma}_\mu}\acute{\sigma}_\mu)\acute{\sigma}_\mu\sigma_\mu...$
   Spread tone to the first mora following the foot

Since its specification mirrors our layered feet account, it follows that the boundary hopping account is descriptively adequate. In this respect, we might consider it on par with the layered feet account. However, boundary hopping does not enjoy the same recognition as layered feet in a broader typological context. In contrast to the variety of applications of layered feet to other phenomena which we reviewed earlier, we are not aware of any previous work that had cause to propose boundary hopping as a synchronic phonological process.

At a more general level, boundary hopping can be thought of as a satisfaction of the principle of "misalignment", a state of affairs where two edges — in this case, a foot and tone edge[17] — avoid occurring in the same place (suggested for (unfooted) tone analyses by Bickmore (1996)). However, the concept of misalignment makes unsupported typological predictions. Since misalignment is successful not just when tone spreads beyond an edge, as effected by the boundary hopping account, but also when spreading stops short of an edge, we expect the attestation of a language that features both of these strategies. That is, we would predict the existence of a language that mixes underspreading and overspreading across different contexts in order to achieve

[17] For the sake of the argument, we make the assumption that tone and feet can be thought of as having edges. A formalization of these concepts might use edgemost tone anchors and feet constituents, rather than an actual "edge" in the representation.

misalignment. To our knowledge, no such pattern is attested.[18] We conclude that boundary hopping, while achieving a descriptively adequate account of the data with flat binary feet, does not go beyond the level of an *ad hoc* account; it raises problems in a broader typological context. Moreover, as we will show in the next section, despite using flat binary feet, boundary hopping is still forced into the typologically controversial decision of allowing SIVs that we made for the layered feet account. Consequently, we consider the layered feet account preferable to the boundary hopping alternative.

3.6.3 Syllable integrity and tone (near-)contact

Bickmore and Kula (2013); Kula and Bickmore (2015) also report on contexts where multiple tones are involved. We briefly discuss the data here to show that they force the boundary hopping account to accept SIVs, but the data do not provide a way of favoring either the layered feet or boundary hopping account over the other.

If two tones are near each other, i.e. a tone is within or adjacent to the ternary domain of the tone that precedes it, then the usual generalizations on tone spreading break down for this preceding tone. Bickmore and Kula do not propose a generalization for cases where sponsors are on adjacent TBUs.[19] For the remaining cases, there are two scenarios. Firstly, if the sponsors are separated by a single mora, then the left tone will spread to this mora, and a downstep occurs between it and the second sponsor. Examples of this are shown in (24). Following Bickmore and Kula (2013), we characterize this as an exceptional violation of the Obligatory Contour Principle (OCP), which we will show is otherwise unviolated in CB.

(24) $\underline{\acute{\sigma}_\mu}\acute{\sigma}_\mu{}^{!}\underline{\acute{\sigma}_\mu}$

a. <u>bá</u>.ká.ꜝ<u>lá</u>.sá 'they will hit'

b. <u>ká</u>.lí.ꜝ<u>pa</u> 'be nervous!'

Secondly, if more than one mora separates the two sponsors but a full ternary spread from the left tone would still bring it into contact with the right tone, then the left tone will only spread as far rightward so as to leave one mora between it and the right tone, with no regard to syllable structure. This gives rise to shortened tone spans of two or three moras, as demonstrated in examples (25–27). The forms in (27) are particularly informative because they show that when a full ternary spread is blocked, CB tone spreading does

[18] Our layered feet account makes its own unsupported typological predictions with regards to SIVs and multi-stressed syllables. However, boundary hopping is not spared this fate either, as we show in section 3.6.3.

[19] There are several forms with adjacent sponsors in the examples of B&K: (21a,b; 22a) in Bickmore and Kula (2013:113–114); and the second form in (21g) in Kula and Bickmore (2015:161). In all these cases, high tone appears on all sponsors, as well as possibly spreading beyond the rightmost sponsor. There is no downstep in any of these cases, which invites an analysis involving tone fusion; we leave this to future research.

not default to a bimoraic span, but will still associate to as many moras as are available.

(25) $\underline{\acute{\sigma}_\mu}\acute{\sigma}_\mu\sigma_\mu\underline{\acute{\sigma}_\mu}$

a. bá.ká.mu.lá.sá (*bá.ká.mú.ꜝlá.sá) ‘they will hit him/her’

b. ká.lí.pi.lá (*ká.lí.pí.ꜝlá) ‘be upset at!’

(26) $\underline{\acute{\sigma}_\mu}\hat{\sigma}_{\mu\mu}\underline{\acute{\sigma}_\mu}$

a. bé.lée.ŋgá ‘read!’

b. bá.ʃíi.-kí.lé ‘bury for them!’

(27) $\underline{\acute{\sigma}_\mu}\acute{\sigma}_{\mu\mu}\sigma_\mu\underline{\acute{\sigma}_\mu}$

a. bé.léé.ŋge.lá (*bé.lée.ŋge.lá) ‘read for!’

b. tú.ʃíí.ki.lé (*tú.ʃíi.ki.lé) ‘that we bury for’

The main insight to be gained from discussing the near-contact cases is that they force a boundary hopping analysis to accept SIVs as well. Firstly, it follows from the data in (27) that the tone hop is canceled in the face of OCP violations. That is, the form *(bé.léé).ŋgé.ꜝlá, where tone has hopped past the foot boundary, is ungrammatical. Crucially, this form also excludes a possible analysis with exceptional unary feet; with unary footing and the one-mora tone hop, the account would incorrectly predict *(bé).lée.ŋge.lá. Having ruled out unary feet, we can deduce that the representations of the data in (24) must also involve a binary foot, e.g. in (ká.lí).ꜝṕa. Those cases reveal one more property of the boundary hopping analysis; it does not resort to underspreading, even when that would have avoided tone contact.

Having determined that the boundary hopping analysis involves strictly binary feet, no tone hopping if it causes tone contact, and no underspreading even if it would avoid contact, we are ready to deduce the need for SIVs from the data in (26). Without SIVs, these representations would involve a full parsing of the heavy second syllable, to ensure minimal foot binarity. Since underspreading is not an option, this would lead to the incorrect prediction of forms such as (bé.léé).ꜝŋgá. Since unary footing was also ruled out, the only option that correctly predicts tone association is a parsing with a syllable-integrity violating foot: *(bé.lé)e.ŋgá. In accordance with our earlier deductions, tone hopping is not applied to this structure in order to avoid tone contact.[20]

As for our layered feet account of CB footing, we sketch how it can integrate the data presented here. Firstly, the “minimal tone binarity” effect, i.e. the fact that tone will spread at least one mora even if this leads to an OCP violation, can be accounted for through the minimal binarity of FtMin, just as in the boundary hopping account. For the remaining cases, a dominant role must

[20]It should certainly be possible to “fix” the boundary hopping account by stipulating further rules, or by circumscribing the principles we have deduced for boundary hopping here. Although determining the extra stipulative burden of a non-SIV boundary hopping account would be an interesting result, it is not our focus; We restrict ourselves to comparing the boundary hopping account to the layered feet account at an equal footing.

be played by a moraically defined OCP constraint (Myers 1997), as well as a constraint $\mu_{Ft}\rightarrow$H that ensures that all footed positions carry a high tone. Formal definitions of these two constraints are in (28). These constraints were fully satisfied by all candidates in previous tableaux. Consequently, they do not change any of our earlier OT-based conclusions.

(28) a. $\mu_{Ft}\rightarrow$H
Assign one violation mark for each footed mora that is not associated to a high tone.

b. OCP
Assign one violation mark for each pair of adjacent moras that are associated to different tones.

Top-ranking these constraints over the footing constraints we have discussed earlier causes the grammar to avoid tone contact where possible but otherwise parse maximally. We demonstrate this for the simple case of tone contact avoidance in light syllables in the tableau in (29).

(29) Reduced parsing and spreading to avoid tone contact

$\acute{\sigma}_\mu\sigma_\mu\sigma_\mu\acute{\sigma}_\mu$	$\mu_{Ft}\rightarrow$H	OCP	PARSE-σ
a. ☞ $(\acute{\sigma}_\mu\acute{\sigma}_\mu)\sigma_\mu\acute{\sigma}_\mu$			**
b. $((\acute{\sigma}_\mu\acute{\sigma}_\mu)\sigma_\mu)\acute{\sigma}_\mu$	*!		*
c. $((\acute{\sigma}_\mu\acute{\sigma}_\mu)\acute{\sigma}_\mu)^{!}\acute{\sigma}_\mu$		*!	*

For brevity, we refrain from presenting an exhaustive OT account; we claim that our representations come out as in (30).[21]

(30)	(24)	(ká.lí).ꜝpa	'be nervous!'
	(25)	(ká.lí).pi.lá	'be upset at!'
	(26)	(bé.lé)e.ŋgá	'read!'
	(27)	(bé.léé).ŋge.lá	'read for!'

3.6.4 Implications for theories with featural domains

Although our focus in this chapter has been on binarity vs ternarity, the CB facts have implications for another debate too. We have modeled the tone spreading domain with feet, but there are alternative theories available for such domain-based spreading. Optimal Domains Theory suggests that features (such as tones) surface as headed domains, and constituents in the domain can vary in whether they "express" the domain's feature or not (Cole and

[21] As in the rest of the chapter, we are not concerned with the representation of rightmost tones. This is mainly because their behavior does not reveal anything about the metrical structure needed for CB; if rightmost tones spread at all (i.e. if they aren't underlyingly final), this is due to the unbounded spreading process in the language, which does not distinguish between heavy and light syllables. It is likely that an expanded and more exhaustively applied version of the OT analysis we present here would still place feet on rightmost tones, even if those feet do not drive or delimit tone spreading.

Kisseberth 1994; Cassimjee and Kisseberth 1998). Similarly, Headed Spans theory suggests that sponsoring features (such as tone) form headed feature spans at the surface (McCarthy 2004; applied for tone by Key 2007; Key and Bickmore 2014). In both of these frameworks, constraints on the length of the domain (or span) serve to coerce the domain to have a certain size. ODT has a constraint *MonoHD that militates against unary heads; together with constraints that minimize domain size,[22]this can cause binary domains to be optimal. In the Headed Spans account of Key and Bickmore (2014:41), binarity is enforced directly through a constraint SpBin(H) that assigns a violation mark "for each H span that does not parse some part (i.e., at least one mora) of exactly two syllables."

Fortunately, these approaches are flexible enough to accomodate ternarity because to some extent, the constraints are arbitrary (see also Chapter 2, section 2.5.2); no principle blocks the introduction of similar constraints for ternary domain sizes in order to accomodate ternary domains. However, even under the assumption of such extensions to the constraint set, these domain constraints assess violations by counting the number of constituents. This is where the contribution of CB comes in; although it is a domain-based spreading pattern, the domain size is not derivable from a counting rule. The table in (31) demonstrates this, showing the varying syllable and mora counts for all shapes of the domain. We count falling-toned heavy syllables ($\hat{\sigma}_{\mu\mu}$), where only one of two tautosyllabic moras undergoes tone spreading, as 0.5 unit of syllable association.

(31)	*Domain shape*	*Syllable count*	*Mora count*
	$\acute{\sigma}_{\mu}\acute{\sigma}_{\mu}\acute{\sigma}_{\mu}$	3	3
	$\acute{\sigma}_{\mu\mu}\acute{\sigma}_{\mu}$	2	3
	$\acute{\sigma}_{\mu}\acute{\sigma}_{\mu\mu}\acute{\sigma}_{\mu}$	3	4
	$\acute{\sigma}_{\mu}\acute{\sigma}_{\mu}\hat{\sigma}_{\mu\mu}$	2.5	3
	$\acute{\sigma}_{\mu\mu}\hat{\sigma}_{\mu\mu}$	1.5	3
	$\acute{\sigma}_{\mu}\acute{\sigma}_{\mu\mu}\hat{\sigma}_{\mu\mu}$	2.5	4

As we have argued throughout this chapter, a principled generalization of CB requires reference to syllable weight groupings, i.e. quantity-sensitive feet. We see no way of incorporating such quantity sensitivity in ODT or Headed Spans theory, especially if the aim is to avoid restating all of metrical representational theory. Consequently, we claim that the case of Copperbelt Bemba strongly favors a foot-based interpretation over accounts that use competing theoretical frameworks for tone spreading. Insofar as the goal of linguistic theory is to select a single theoretical framework to account for a maximally wide range of crosslinguistic variation, the present work supports Chapter 2 in choosing foot structure as the theoretical tool of choice for the analysis of bounded tone spreading patterns.

[22]In Optimal Domains Theory, these are the "Basic Alignment" constraints that keep the edges of the domain aligned (gradiently) with the edges of the tone sponsor.

3.6.5 Vowels before pre-nasalized consonants

Silke Hamann (p.c., June 2017) notes that all data for the sequence $\sigma_\mu\sigma_{\mu\mu}\sigma_\mu$ have a pre-nasalized onset consonant (NC) following the heavy syllable. Before NC, Bemba has no lexical contrast between short and long vowels. Furthermore, vowels before NC are phonetically shorter than lexically long vowels, as measured by Hamann and Kula (2015). Consequently, Hamann suggests that interpreting these vowels as phonologically short, i.e. monomoraic, might allow for a simpler analysis of the tone pattern.[23] In particular, the spreading pattern could be analyzed as being strictly trimoraic.

We feel that the investigation of this idea is best left to future research, when analysts are hopefully armed with more data. For now, we note several points of interest for such an investigation. Firstly, in the sequence $\sigma_{\mu\mu}\sigma_\mu$, no datum has NC following the heavy syllable. The absence of such data is unfortunate because this context could be used to check the hypothesis suggested by Hamann; If, in $\sigma_{\mu\mu}\sigma_\mu$ cases where the initial syllable precedes NC, the vowel in this supposedly heavy syllable is in fact monomoraic and spreading is strictly trimoraic, then the surface tone span is hypothesized to spread one mora further than it does in the attested cases with true long vowels, which only spread onto the light syllable immediately following the sponsor. This consideration is summarized in (32). To distinguish between various syllable constellations, we write "V" for a vowel, and "Vː" for a long vowel; we leave out non-NC consonants. We separate vowels with periods to indicate syllable breaks, but we do not commit to a syllabification of the NC portion of the string. The crucial difference is in the predicted spreading consequences depending on whether the initial-syllable vowel before NC is bimoraic and follows our analysis, as in (32b), or if it is monomoraic and spreading is strictly trimoraic, as in (32c). Future work could help establish the moraicity of VNC sequences and the nature of the bounded spreading pattern by determining the attested pattern for $\sigma_{\mu\mu}\sigma_\mu$ sequences with initial NC.

(32)	a.	Attested regular pattern	V́ː.V́.V
	b.	Predicted bimoraic-VNC pattern	V́ːNCV́.V
	c.	Predicted monomoraic-VNC pattern	V́NCV́.V́

Another point of interest for the NC cases is that among the available data is one case of vowel coalescence before NC, shown in (33). Hamann and Kula (2015:67) report that vowel coalescence leads to derived long vowels, although their examples do not include sequences with NC. Consequently, (33) might reveal whether CB also has an active vowel length neutralization process before NC.

[23] For debates on the apparent monomoraicity of vowel-plus-NC sequences in non-tonal processes, see Hyman 1992; Hubbard 1995a,b,c; Downing 2005

(33) twaa.léé.mwíi.mbi.la.kó
'we used to dig for him'
/tu-a-lée-mu-imb-il-a-kó/

Finally, as we discussed in section 3.6.3, vowels before NC pattern with lexically long vowels in creating falling tones to avoid tone contact, rather than inserting downstep as is done by lexically short vowels. All three vowel types are shown in (34) — using the transcriptions of B&K.

(34) a. bá.ká.ꜜlá.sá 'they will hit'
b. bé.lée.ŋgá 'read!'
c. bá.ʃíi.kí.lé 'bury for them!'

A monomoraic interpretation of phonological length before NC should incorporate statements about the nature of downstep, and the reason for its apparent absence in cases such as (34b).

3.7 Conclusion

Based on the reports of Bickmore and Kula (2013); Kula and Bickmore (2015), we have identified Copperbelt Bemba bounded tone spreading as displaying a type of ternarity that has been underdiscussed in the literature on metrical theory. The ternary tone spreading domain freely allows multiple unparsed syllables on either side, which we have shown poses a major problem for Weak Layering. Our account, using layered feet consisting of an inner iambic foot and an adjunct mora, successfully captured the spreading facts of CB in a single domain specification.

We have argued that both our layered feet account and a binary feet alternative require syllable-integrity violating representations. Consequently, our analysis of CB provides evidence in favor of treating SIVs as a part of representational theory. From the CB data, we have deduced a specific contribution to such a theory, arguing that constraints for SIVs in layered feet should be sensitive to the (non-)minimality of the foot type. Future research is needed to determine the broader typological predictions following from such constraint sets, as well as possible extragrammatical restrictions on the emergence of syllable-integrity violations.

We are hopeful that our metrical interpretation of the CB facts might offer some considerations for future development of metrical theory to draw on, and conversely, that metrical theory might help direct further inquiry into the nature of Copperbelt Bemba and related tone systems.

Chapter 4

Factorial typologies of foot-based tonal reassociation in Harmonic Serialism

4.1 Introduction

In some Bantu languages, tone spreads or shifts with a predictable outcome; typically, the tone will either move across a short distance, or toward an edge-defined position that might be far away.[1] Taking an autosegmental point of view, I will refer to this phenomenon as "tone reassociation", and I call the two types of reassociation "bounded" and "unbounded", respectively. I will discuss the data in more depth later, but for now I show two quick examples for the two respective types. Example (2a) shows an example of bounded shift, where a stem with an all-low pitch contour in isolation receives a High tone as a result of prefixation, although the prefix itself remains low.[2] Similarly, example (2b) shows how in a case of unbounded spreading, some prefixes can cause a High tone to spread over a chain of syllables that otherwise surface with low pitch,

[1] Supplemental materials for the replication of the calculations of the factorial typologies reported in this study are available at https://doi.org/10.6084/m9.figshare.5765472. See section 4.4.1, as well as the included readme file, for details about the contents and use of these materials.

[2] I have made an interpretation in IPA based on Olson (1964:1,12). In particular, I write [o] for the back vowel of the second-highest level among four levels of vowel height reported by Olson. Olson himself writes this vowel as [u̜], but states that this notation is motivated with relation to Swahili orthography, and that [o] might be a more common transcription. Although Olson is the original source, I have followed the presentation of Schadeberg (1978:204) for the data in (2a); Schadeberg's datum is [ɾena ɾa-mʊ́ntʊ] 'jemandes Name'.

with the High span ending at the antepenultimate syllable.[3] I will refer to the lexical tone-bearing unit (TBU) of a tone as its “sponsor”.[4] In the presentation of forms, sponsors are indicated with underlining. In addition, High tone will be marked with accents on the relevant vowels, while an absence of High tone is not marked in any way. I use hyphens to indicate morpheme boundaries. Lastly, all data is taken from previous literature. Some previous work does not present the data in the International Phonetic Alphabet. I will clarify the status of the transcriptions on a case-by-case basis.

(2) a. Bounded rightward shift in Rimi (Olson 1964)
  i. mo-nto ‘person’
  ii. ɾa-mó-nto ‘of a person’

b. Unbounded antepenultimate spreading in Phuthi (Donnelly 2009a,b)
  i. si-ja-lima-lim-el-aː-na ‘we cultivate for e.o. now and then’
  ii. ɓá-já-límá-lím-él-aːn-a ‘they cultivate for e.o. now and then’

These patterns lead to two desiderata for synchronic phonological theory; the theory should be able to answer both why such reassociation patterns are triggered, and what determines the constellations in which they surface. In the course of the 1980s, various analyses of unbounded tone reassociation invoked metrical prominence for these purposes. Downing (1990:267*ff.*) provides an overview of the literature and locates its essence in an accentual analysis of Kintandu and KiYaka tonology by Goldsmith (1987):

> “As argued by Goldsmith (1987), metrical rules, which are designed to assign prominence to certain syllables of words or phrases, seem a phonologically natural way to pick out which syllables will attract high tones, and all of the analyses just mentioned (except Kisseberth (1984)) have therefore adopted a metrical approach.” (Downing 1990:268)

As can be gleaned from this quotation, the invocation of metrical structure for reassocation patterns is motivated on distributional grounds. It does not relate to claims about non-tonal expressions of prominence; in particular, it does not relate to claims about the realization of *stress* in the relevant languages. In this chapter, I will leave the issue of stress in Bantu languages aside, focusing on a metrical analysis of the tone patterns. However, I refer the interested reader to Odden (1999), Downing (2004), and Hyman (2013) for discussions on this issue — and De Lacy (2002) for a theoretical discussion of tone-stress interactions.

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[3] I have adapted the transcriptions for Phuthi data to be in line with IPA orthography, using Donnelly (2009b:68–73,487). The original transcriptions do not have a distinction between tense and lax mid vowels; this contrast is obscured in my transcriptions as well.

[4] Assigning sponsor status is an analytical claim. Typically, these claims are based on an inspection of morphophonological alternations where surface tone distribution is best explained by positing underlying tones associated with certain (parts of) morphemes.

Some authors have also suggested a link between metrical structure and *bounded* tone reassociation. Bickmore (1996:17) sketches a synchronic use of metrical feet to account for a bounded tone shift process in Kikuyu:[5]

> "One possible metrical account of Kikuyu would be to require High displacement to the head of an iambic foot where the weak member of the foot is established by the location of an input H-toned TBU [tone-bearing unit]."

One of the first fully-implemented metrical accounts of a bounded tone pattern was presented by Sietsema (1989), who focused on High tone shift in Sukuma. In Sukuma, High tones typically shift two places rightward from their underlying position. I list some example forms in (3), following the presentation of Kang (1997).[6]

(3) Two-place shift in Sukuma (Richardson 1959, 1971)

a.	a-kʊ-kʊ-sol-a	'He will choose thee'
b.	a-kʊ-βa-sol-á	'He will choose them'
c.	kʊ-sol-anɪj-a	'to choose simultaneously'
d.	kʊ-βon-aníj-a	'to see simultaneously'

Sietsema accounted for the shifting pattern by setting up iterative binary footing, and then defining spreading and delinking rules so that a tone would end up in the foot following the one it originated in. Following the advent of Optimality Theory (OT, Prince and Smolensky 1993), the analysis was recast in OT by Kang (1997), who also made further refinements.[7] Her analysis used a rich tonal representation, where the triggering TBU was underlyingly specified for a two-tone sequence of Low and High. This tonal crowding then served as

[5]Kikuyu has been analyzed with full specification, i.e. with Low tones present in addition to Highs (Clements 1984; Gjersøe 2015); hence, it may prove to be a rather complex case of High tone shift to analyze with feet. A similar High tone shift process that is, to the author's knowledge, more amenable to an underspecification analysis is attested in Rimi (Olson 1964; Schadeberg 1979; Myers 1997).

[6]I follow Sietsema (1989) in interpreting the distinction of two sets of high vowels to be one of tense versus lax. In other respects, my transcriptions are based on Richardson (1959, 1971), who is the primary source. In (3a), Sietsema deviates from Richardson by listing the datum with tense vowels, although Richardson (1959:45) reports lax vowels. Richardson (1959) does not relate his orthography exhaustively to IPA, so the status of some consonants is unclear, although he is explicit about distinguishing bilabial fricatives from stops. For the data in (3), the main uncertainty concerns the meaning of "j" in the transcriptions. Richardson (1959) states that "y" denotes a front semi-vowel, meaning that the "j" in the data in (3) is most likely not the glide that it represents in IPA. Furthermore, Richardson (1959) uses a sequence "dy", which is suggestive of [ʤ], so this interpretation for "j" is also unlikely under the assumption that there are no redundant symbols in Richardson's orthography. I will assume here that the exact status of this consonant is not of relevance for my discussion of Sukuma's tonal pattern.

[7]Sietsema, lacking a concept of licensing, built feet from left-to-right from the start of the domain. His account is demonstrated only on forms where the position of the tone fits fortuitously with this foot structure, i.e. when tone is underlyingly on an odd-numbered TBU. Hence, Kang's analysis constitutes, roughly, a doubling of coverage of the attested data.

the basis for inducing the shift (see also Jones 2014). Thus, Sukuma's tone shift behavior was interpreted as a repair strategy to avoid the marked configuration of multiple tones associating to the same position.

Perhaps the largest technical challenge solved by Kang was how to coerce metrical structure into an arrangement that serves the purposes of the tone process. Her solution was to adopt Zoll's (1996) licensing constraints, with the following explanation:

> "The relevant constraint for Low tone is COINCIDE(L,FT-HEAD); it favors a Low tone on the head of a foot [...] [it] dominates the normal foot structure constraints[,] and in effect, due to the requirement that it start a new foot, the triggering mora disrupts the normal metrical structure." (Kang 1997:71)

In Chapter 2 I proposed a metrical analysis of bounded tone reassociation in Saghala, claiming that the presented framework was "equipped to deal with a variety of bounded tone phenomena" (13). As did Kang, I adopt licensing constraints to derive a suitable metrical structure. However, I refrain from using the tonal crowding approach as a general solution for tone shift, and in Chapter 2 I diagnosed tone shift as an opaque pattern:[8]

> "A foot-based approach to tone shift would need multiple steps: First a foot should be placed relative to a tone, and only then could the tone be shifted with reference to the foot [or footed TBUs]. This is an opaque pattern, i.e. it requires intermediate forms. However, evaluation in OT is parallel, so it does not allow for intermediate forms." (p. 15)

The analysis in Chapter 2 is cast in Harmonic Serialism (Prince and Smolensky 1993; McCarthy 2000), a constraint-based framework that allows for intermediate forms. In order to capture patterns that can reach a position that is two units away from the sponsor, such as the shift in Sukuma, I adopted a layered feet representation, where binary feet can be parsed into a

[8] Chapter 2 unnecessarily narrows down the problematic nature of tone shift in standard OT to the fact that it is parallel. In fact, parallelism by itself does leave room for a framework to deal with various types of opacity. Two examples of this are containment theory (Prince and Smolensky 1993; Revithiadou 2007; Van Oostendorp 2008; Trommer and Zimmermann 2014), where lexical material is always retained but can be specified or not specified for realization, and markedness constraints can still make reference to this structure; and OT with candidate chains (McCarthy 2007; Wolf 2008), where candidates have internal derivational structure, in the sense that every candidate is a "chain" of mappings between forms. It should also be noted that the claim in Chapter 2 was made in the context of bounded, but not unbounded, reassociation. Only *bounded* tone shift involves a dependency between the position of the foot and the tone sponsor; for unbounded tone, foot placement is predictably at the edge, and therefore not dependent on the location of the sponsor. The present work is still in agreement with the view stated in Chapter 2 on the point that metrically derived bounded tone shift in a standard OT context presents an opacity problem — assuming a "Standard OT" which uses Correspondence Theory (McCarthy and Prince 1995), no two-level constraints (Boersma 1997a:162*ff.*; Kager 1999:381), and no derivational structure in candidates.

larger, ternary constituent (Bennett 2012; Kager 2012; Martínez-Paricio 2013). Thus, Chapter 2 brings the analysis of Sukuma and other two-place patterns in line with the intuition mentioned by Bickmore (1996) that bounded tone reassociation can be thought of as taking place within a single foot constituent.

In summary, the field has identified a potential merit of metrical structure in both unbounded and bounded tone reassociation, and has developed theoretical tools to implement such metrical accounts. However, all work has focused on one or several case studies. In this chapter, I develop theories of metrical tone reassociation, and place a focus – for the first time, to my knowledge – on their typological coverage.

Based primarily on the framework from Chapter 2, I investigate two different theoretical approaches to tone association. The first approach, which I term the "licensing" approach, uses licensing constraints to regulate the relation between tone and footed TBUs. These constraints take the foot as a licensor for tone, so that tone is incentivized to associate to footed positions. Hence, the evaluation of the constraints has the tone as its point of departure, checking if any of the tone's associations lead to a footed tone-bearing unit.

There are at least two arguments against the licensing approach. Firstly, as I will demonstrate later in this chapter, the licensing approach achieves an account of unbounded patterns by using gapped tone representations. Previous literature often assumes such gapped structures are not valid representations,[9] a view championed by Archangeli and Pulleyblank (1994), who report an absence of typological motivation for gapped structures:

> "Unlike plateaus without gaps, there has been a virtually complete absence of cases where nonadjacent anchors are simultaneously affected by a process affecting [the autosegment]. There are two ways of interpreting such a lacuna [...] we take the stronger position that [this absence] is nonaccidental, that such gapped configurations are universally ruled out." (Archangeli and Pulleyblank 1994:38)

Secondly, because licensing constraints are only concerned with the relation between tones and feet, the licensing framework only indirectly relates tone to the word (or phrase). For this reason, licensing constraints need a roundabout way of constraint interaction to express the typologically common generalization that tone reassociation is *directional*, i.e. that tones only (or preferably) spread or shift in one direction, but not the other. It is possible that licensing frameworks turn out to be too flexible in this regard, and that a

[9] Voices arguing for a violable version of this NoGap principle are also represented in the literature; Cassimjee and Kisseberth (1998:41) state that "[i]t is likely, however, that most proponents of an autosegmental-based OT approach to phonology would opt to move No Gapping into the category of a violable constraint." A concrete implementation of this is the Line Crossing Constraint of Boersma (1998) *et seq.*, defined in Boersma (2009a:84) as "Lcc(*feature value, material*): [A] single instance of *feature value* in the surface form cannot span across a certain amount of *material*."

framework with a more direct means of expressing tone directionality provides a better fit to language typology or acquisition facts.

For the above reasons, I develop a second approach to metrical tone reassociation in this chapter, which is based on the idea that all tones in a domain (e.g a phonological phrase) are attracted to the left or right domain edge. I will refer to this as the "edgewise" approach. By "attraction", I mean that the grammar will incentivize tone to reassociate as close as possible to the relevant edge. In section 4.3.5, I formalize this notion with a constraint type All-Tones-L/R, thus allowing for a more direct expression of tone directionality. I will also show how the edgewise approach can deal with a variety of unbounded tone reassociation cases without introducing gapped tonal associations. There is still a crucial role for foot structure in the edgewise framework. As in the licensing framework, feet function as the domain for bounded patterns and as the mechanism of targeting edge positions in unbounded patterns.

In this chapter I will compare the licensing and edgewise approaches on their capability to generate the crosslinguistically attested variation, as well as on what other language variation they predict that human cognition could handle.[10] One matter of interest in looking at the wider set of predictions of the frameworks is the uncovering of potentially accidental gaps, i.e. patterns that are not attested but plausibly could be. In such cases, one expects that further fieldwork or literature study could hit on one of these patterns, especially if their generation is tied to a framework's core architectural properties, which were motivated by the target, attested patterns.

As I will describe in detail later in this chapter, it turns out that both frameworks are capable of generating much or all of the target, attested, patterns — with one exception for the edgewise framework.[11] In addition, a common prediction of the frameworks is that of "edge effects", where tone behavior close to an edge deviates from some default pattern seen elsewhere in the domain. Such edge effect patterns are most numerous for the licensing framework, which also predicts some of the biggest differences between of edge patterns and the default patterns they deviate from. Another result I will show for the licensing framework is that there is overgeneration in the form of various patterns that crucially rely on gapped tone structures — in confirmation of Archangeli and Pulleyblank's 1994 position that such structures should not be part of representational theory. Finally, I will show that the edgewise framework is the only one that predicts patterns sensitive to whether the distance between a sponsor and a domain edge is of odd or even length.

Section 4.2 will discuss the attested data under investigation. Section 4.3 presents the technical details of the two frameworks, defining Gen and Con

[10] I use this roundabout phrasing because the predictions are about the nature of cognition, and only indirectly about the nature of language variation. Factors outside of phonology proper impose their own limits on variation. I return to this point in section 4.5.1.

[11] The edgewise framework runs into trouble on accounting for the Saghala pattern of binary shift + binary spread. I discuss this problem in section 4.4.3.

for both licensing-style and edgewise tone association. It will also present sample derivations for both approaches. In section 4.4 I will then investigate the typological predictions of the two frameworks, based on calculations of factorial typologies. . Section 4.5 discusses non-phonological restrictions on the predicted language variation, layered feet and quaternary patterns, the non-prediction of some plausible patterns, and further data raising analytical issues for the two frameworks. After this, the chapter wraps up with a conclusion.

4.2 Data

In the following I introduce some of the attested crosslinguistic variation, in order to establish the generative target that the frameworks should strive for. As mentioned in the previous section, tone reassociation can be either bounded or unbounded. In bounded tone reassociation, the surface targets for tone can be calculated from just the location of the sponsor. For example, (4) shows forms from what Bickmore and Kula (2013:102) refer to as "Northern" Bemba.[12] Here, the surface tone targets are the sponsor itself and the syllable following it.[13] Crucially, even if more material is available after these initial two positions, it does not receive High tone, as in (4a,d).

(4) Bounded spreading in Northern Bemba

a. <u>bá</u>-ká-fik-a (kumumana)	'they will arrive at the river'
b. <u>bá</u>-ka-<u>pí</u>t-á (mumusebo)	'they will pass in the road'
c. <u>bá</u>-ka-<u>cá</u>p-á (mailo)	'they will wash tomorrow'
d. <u>tú</u>-lúb-ul-ul-<u>é</u>	'we should explain'

In unbounded tone reassociation, the surface targets for tone involve a position near an edge, which can be unboundedly far away from the sponsor. For example, in Phuthi, tone will spread from the left edge of the tone-contributing morpheme[14] to the antepenultimate syllable (Donnelly 2009a:163–164; Donnelly 2009b).

(5) Antepenultimate spread in Phuthi

a. si-ja-<u>ɓó</u>n-ís-aːn-a	'we show each other'
b. si-ja-<u>sé</u>ɓét-ís-él-aːn-a	'we use for each other'
c. <u>ɓá</u>-já-límá-lím-él-aːn-a	'they cultivate for e.o . now and then'

[12] I follow the transcriptions of Bickmore and Kula (2013), who do not state the relationship between the transcriptions and IPA. One of the original sources, Sharman and Meeussen (1955), is similarly unconcerned with this relationship, although they do indicate that the orthographic "b" is an abstraction. For labial place of articulation, Bemba has no voiced plosive, but it does have a voiced fricative (Hamann and Kula 2015).

[13] The lack of tone spreading from the domain-initial sponsors in (4b,c) is due to a language-specific avoidance of "OCP violating" structures, where adjacent TBUs carry High tone from different tonal autosegments.

[14] As I discuss below, Phuthi does not have evidence for a contrast in place of tone association within the root; it is possible that the tone is underlyingly floating, and is associated to all of its surface TBUs by the phonology.

For both bounded and unbounded tone reassociation, there is a countable maximum distance that a description makes reference to. For bounded patterns, this distance can be counted from the sponsor to the furthest target. So, for the example of Northern Bemba in (4) above, this number is two. For unbounded patterns, the distance can be counted from the edge to the tone target. So, for the example of Phuthi in (5), the number is three. Alternatively, I will refer to systems that count to two or three as "binary" and "ternary", respectively. Languages generally do not count beyond three for either bounded or unbounded patterns — I discuss one possible exception to this, Kuria (Marlo et al. 2015), in section 4.5.2.

Later in this section, in Table 4.1, I will present an overview of binary and ternary bounded and unbounded tone reassociation; first, I go over several inclusion criteria for this inventory. Firstly, in order for a language to be included, I require that the language shows some shifting or spreading pattern, and that this pattern does not rely on triggers in the phonological context. That is, I exclude languages where, for example, binary spreading occurs only across a word boundary. However, I do include patterns that are restricted to certain morphosyntactic contexts, such as patterns that obtain only in a particular tense or set of tenses. I also include patterns restricted to particular prosodic contexts. For example, the unbounded spreading pattern in Copperbelt Bemba applies only to the rightmost tone in a phonological phrase, and only if that tone is in the phrase-final word (Kula and Bickmore 2015).

As a second, related, criterion, I place some restrictions on the provenance of tone. In particular, I exclude any patterns that are attested only with "melodic High" tones, which are templatic tone patterns that reflect a particular tense or set of tenses rather than a lexical contrast, and which operate under less stringent restrictions than lexical tones (Odden and Bickmore 2014). Ideally, then, all patterns I include should come from tone that can be argued to be in a particular position underlyingly. However, for my data sample, such place of association contrasts are found only in noun phrases, whereas many of the patterns are reported based on verb data. For some languages, there might be analytical arguments favoring the view that tone association in verbs is always root-initial, but I will not pursue such language-specific analyses in depth here.

I give one example each of cases where there is a lexical contrast of tone association, and where tone provenance can only be traced back to the contributing morpheme. Firstly, (6) shows an example of contrastive place of association. The data are from Saghala (Patin 2002, 2009; Chapter 2), where tone typically surfaces on the two TBUs following the sponsor.[15] The comparison between (6a) and the other forms shows that High tone must indeed originate from the determiners. Crucial, then, is the difference between (6b) and (6c); for these two data, tone originates from the first and second TBU, respectively, in the determiner.

[15] I copy the transcriptions from Patin (2009), who does not state how the transcriptions relate to IPA. I follow Patin in treating "ilya" as disyllabic.

(6)

a.		nɟovu	‘elephant(s)’
b.	izí	nɟóvu	‘that elephant’
c.	ilya	nɟóvú	‘these elephants’

In contrast to Saghala, Digo (Kisseberth 1984) is a case where alternations show up through affixation, as demonstrated with the forms in (7).[16] High-toned verb roots, as in (7a), show uniform behavior in realizing their tone on the ultimate,[17] realized phrase-finally as a rise-fall sequence over the last two syllables. Some roots are toneless, as in (7b). Crucially, as shown in (7c), the toneless roots assimilate to the High tone behavior when combined with certain affixes, establishing that the tone patterns are not determined exclusively by the verb root, but instead by the presence or absence of lexical tone on any morpheme in the tonal domain of application. The pattern in (7a, 7b) is *the* pattern for cases with a (single) lexical High tone — modulo the caveat in footnote 17. Consequently, there is no motivation to propose a contrast in lexical association of the tone.

(7)

a. High-toned roots in Digo (Kisseberth 1984)
  - i. ku-furu-kŭt-â ‘to move restlessly’
  - ii. ku-bomŏr-â ‘to demolish’

b. Toneless roots
  - i. ku-vugurir-a ‘to untie for’
  - ii. ku-togor-a ‘to praise’

c. Unbounded ultimate shift from prefixes
  - i. ku-u-vugurĭr-â ‘to untie for us’
  - ii. a-na-togŏr-â ‘he/she is praising’

Having discussed the inclusion criteria, I present an overview of tonal reassociation patterns in Table 4.1.[18] For both shifting and spreading, Table 4.1 shows attestations of bounded and unbounded patterns that count to one, two, or three. Saghala, discussed in (6) above, stands out as the only case of a combination of bounded shift and spread. I know of no such combinations for unbounded patterns, where tone would either appear to have shifted boundedly and then spread to some edge position; or to have shifted to a position near the edge and then spread boundedly. Whether these absences constitute accidental

[16] I copy the transcriptions from Kisseberth (1984). Kisseberth does not indicate how his transcriptions relate to IPA. He does make a statement about vowel length: “Penultimate vowels are also ordinarily lengthened to some degree, but I have not indicated this lengthening in my transcriptions.” (Kisseberth 1984:107)

[17] I abstract away from the issue of depressor consonants, and from a class of verb roots affected by a process Kisseberth (1984) calls “Neutralization”, where High tones at the penult change into Low tones.

[18] References for these attestations are as follows: Ekegusii: Bickmore (1996), Copperbelt Bemba: Bickmore and Kula (2013); Kula and Bickmore (2015), Rimi: Schadeberg (1979); Myers (1997), Saghala: Patin (2009), Sukuma: Sietsema (1989), Shambaa: Odden (1982), Phuthi: Donnelly (2009a,b), Digo: Goldsmith (1990) in Bickmore (1996), Chizigula: Kenstowicz and Kisseberth (1990), Xhosa: Downing (1990).

gaps is a question best answered with a theoretical framework in hand; I return to the issue in section 4.5.3.

Description	*UF*	*SF*	*Attested for...*
Bounded spread			
Binary	$..\acute{\sigma}\sigma..$	$..\underline{\acute{\sigma}}\acute{\sigma}..$	Ekegusii
Ternary	$..\acute{\sigma}\sigma\sigma..$	$..\underline{\acute{\sigma}}\acute{\sigma}\acute{\sigma}$	Copperbelt Bemba
Bounded shift			
Binary	$..\acute{\sigma}\sigma..$	$..\underline{\sigma}\acute{\sigma}..$	Rimi
Binary shift+spread	$..\acute{\sigma}\sigma\sigma..$	$..\underline{\sigma}\acute{\sigma}\acute{\sigma}..$	Saghala
Ternary	$..\acute{\sigma}\sigma\sigma..$	$..\underline{\sigma}\sigma\acute{\sigma}..$	Sukuma
Unbounded spread			
To final	$..\acute{\sigma}\sigma..\sigma]$	$..\underline{\acute{\sigma}}\acute{\sigma}..\acute{\sigma}]$	Copperbelt Bemba
To penult	$..\acute{\sigma}\sigma..\sigma\sigma]$	$..\underline{\acute{\sigma}}\acute{\sigma}..\acute{\sigma}\sigma]$	Shambaa
To antepenult	$..\acute{\sigma}\sigma..\sigma\sigma\sigma]$	$..\underline{\acute{\sigma}}\acute{\sigma}..\acute{\sigma}\sigma\sigma]$	Phuthi
Unbounded shift			
To final	$..\acute{\sigma}\sigma..\sigma]$	$..\underline{\sigma}\sigma..\acute{\sigma}]$	Digo
To penult	$..\acute{\sigma}\sigma..\sigma\sigma]$	$..\underline{\sigma}\sigma..\acute{\sigma}\sigma]$	Chizigula
To antepenult	$..\acute{\sigma}\sigma..\sigma\sigma\sigma]$	$..\underline{\sigma}\sigma..\acute{\sigma}\sigma\sigma]$	Xhosa

Table 4.1: Attested patterns generated under the foot-based tone framework

The data in Table 4.1 will be the target for the present typological modeling. Thus, the ideal framework should present a unified account of bounded and unbounded shift and spread for domain sizes of up to three elements. While this data represents what I think is the core of the tone reassociation typology, it is not exhaustive, neither of the attested typology nor of the listed languages. For example, I do not aim to account for crosslinguistic variation in the resolution of cases of adjacent sponsors, for which a variety of repair strategies, such as tone deletion, shift, or fusion, are attested (Myers 1997). More generally, it is beyond the scope of the chapter to consider contexts with multiple tonal autosegments, but I provide some discussion of this issue in section 4.5.5. Another simplification I make is the assumption that natural language should be able to derive the listed patterns in a /High, ∅/ environment. That is, I assume that none of the listed patterns crucially depend on the presence of other tones, specifically Low tone. To my knowledge, for the languages listed in Table 4.1, only Sukuma has been analysed with a /High, Low/ system. This was proposed by Kang (1997:69) mainly on analytical grounds, but also to account for the appearance of an "utterance-final Extra Low".

This concludes my discussion of the relevant attested patterns. The next section presents the theoretical tools I will consider to model these patterns.

4.3 Theoretical framework

This section defines and motivates the two frameworks that I will compare for modeling the typology of metrical tone reassociation. The approaches, both cast in Harmonic Serialism, use a similar representational theory and have a large overlap in their constraint set. The difference is in the way they generate and constrain tone association. I will first focus on properties that the two frameworks have in common, and then define factors specific to one or the other framework. An overview of all the assumptions made for the two frameworks is provided in section 4.3.7.

4.3.1 Layered feet

One of the innovations made in Chapter 2 is the adoption of layered foot representations for the analysis of ternary patterns. In these representations, traditional flat binary feet may be parsed along with a third element into another foot constituent (Bennett 2012; Kager 2012; Martínez-Paricio 2013 *et seq.*). Thus, it instantiates a type of recursive prosody similar to that proposed in Itô and Mester (2007); Itô and Mester (2013) and Elfner (2015), except that for layered feet, it is stipulated that recursion is restricted to a single application. Consequently, the layered feet framework allows flat feet, such as the trochee ($'\sigma\sigma$); internally layered ternary feet, such as the dactyl $(('\sigma\sigma)\sigma)$; but no structures beyond this size, i.e. no quadrisyllabic, doubly-nested form $*((('\sigma\sigma)\sigma)\sigma)$, nor a case of a layered foot parsing more than one flat foot, e.g. $*(('\sigma\sigma)('\sigma\sigma))$. From the literature on recursive prosody, the layered feet framework also borrows the concepts of "(non-)minimal" and "(non-)maximal" constituents. Minimal feet are those that do not parse another foot. Maximal feet are those that are not parsed by another foot. Thus, the flat binary foot $(\sigma\sigma)$ is both minimal and maximal. In contrast, the layered foot structure $((\sigma\sigma)\sigma)$ contains a maximal (and non-minimal) outer foot layer, and a minimal (and non-maximal) inner foot layer.

For tonal reassociation, the maximally ternary range of the outer foot constituent fits with the crosslinguistic generalization of the maximally ternary nature of tonal reassociation patterns established in the previous section. For the licensing framework, bounded ternary tone processes can be described as taking place within the scope of a maximal foot constituent, and unbounded systems that target the antepenultimate as aiming for the farthest-but-still-footed position from an edge. In the edgewise association framework, described in more detail in section 4.3.5, repulsion of tone by an edgemost ternary foot leads to the prediction of preantepenultimate, i.e. fourth-from-the-edge, targeting of tone. I will return to this issue in the discussion in section 4.5.2.

To keep the typological calculations in this chapter feasible, all calculations are made with relatively short domains and small candidate sets. This is at odds with an investigation of layered feet, which requires larger domains and a significantly expanded candidate set. Specifically, to allow a layered feet framework to display iterative footing requires at minimum strings of six syllables, since the string must host minimally two layered feet. This number rises to seven or eight if one also wants to leave some room to show the effects of "foot directionality", i.e. the tendency for feet to be positioned as close as possible to the left or right side of the string. Furthermore, the candidate set grows considerably as a result of the optionality of foot layering; all candidates with only binary feet are still included, and candidates with one or more layered feet are added.

For the above reasons, I will implement the two frameworks using only traditional binary feet (McCarthy and Prince 1986; Hayes 1995), and present results in a binary feet context. In section 4.3.6 I give some examples of derivations with layered feet; and in section 4.5.2 I discuss extrapolation of the binary feet-based results to a layered feet context.

4.3.2 Harmonic Serialism

As noted in the introduction, bounded tone shift patterns present an opacity problem for standard OT (Prince and Smolensky 1993); tone reassociation should "wait" until foot structure is correctly positioned, because feet are dependent on underlying tone positions for their placement. Standard OT leaves no room for such effects;[19] all changes between input and output are evaluated in parallel. The problem is demonstrated in more detail with the tableau in Table 4.2.[20] I postpone discussing full definitions of the relevant constraints to their respective sections. Briefly, with the symbol "$\mathcal{L}$" abbreviating the term License, $\mathcal{L}$(H, Ft) drives footing over tones, All-Ft-Right pulls feet rightward, and $\mathcal{L}$(H, Ft-R) pulls tones to the right edge of the foot. I use a catch-all Faith-Link constraint to constrain any changes in tone association. Depending on different rankings, a variety of tonal reassociation outcomes are possible even in standard OT. However, the crucial result in Table 4.2 is that candidate 4.2e, which represents bounded shift, is harmonically bounded by candidate 4.2d. In other words, the tableau shows that if a tone is to be reassociated, it might as well reassociate to the position that best fits the foot, even if that means reassociating further away from the tone's lexical origin.

The solution adopted in Chapter 2 and here is Harmonic Serialism (HS, Prince and Smolensky 1993; McCarthy 2000). Harmonic Serialism is a serial variant of Optimality Theory (OT, Prince and Smolensky 1993). The main commonality of OT and HS is that they evaluate the harmony of a set of candidates using a ranked, violable constraints. The difference between the two frameworks is in the definition of Gen and Eval. HS defines Gen to carry a set of *operations* that apply a change to an input form. The candidate set is

[19] See also the caveats in footnote 8.

[20] This tableau uses licensing-style constraints, but a similar formulation is possible with edgewise association constraints using *H/Unfooted instead of License(H, Ft), and All-T-Right instead of License(H, Ft-R), and adding *H/σ to incentivize general tone delinking.

$\sigma\acute{\sigma}\sigma\sigma$		$\mathcal{L}$(H, FT)	ALL-FT-RIGHT	$\mathcal{L}$(H, FT-R)	FAITH-LINK
a.	$\sigma\acute{\sigma}\sigma\sigma$	*		*	
b.	$\sigma(\acute{\sigma}\sigma)\sigma$		*	*	
c.	$(\sigma\acute{\sigma})\sigma\sigma$		**		
d.	$\sigma\sigma(\sigma\acute{\sigma})$				*
e. ϟ	$\sigma(\sigma\acute{\sigma})\sigma$		*!		*

Table 4.2: Standard OT fails to predict bounded tone shift

then calculated as the faithful form plus all forms to which one instance of an operation has been applied. HS defines EVAL so that it feeds back into itself until no further change to the input is merited. Thus, from an underlying form, HS computes a sequence of harmonically improving forms. The final form in this sequence is the output of the phonological process.

In Chapter 2 I elaborated further on the choice of HS to solve the opacity problem with the following:

> "It should be noted that HS is motivated not just by a need to deal with opacity; compared to OT, it can lead to different typological predictions that may exclude unattested patterns (McCarthy 2000, 2010b). [...] HS lends itself particularly well to the present case, because the derivations are independent from morphological cycles." (p. 16)

Any HS implementation needs to specify the contents of GEN. For the present purposes, GEN will have an operation that can place one foot, anywhere in the string. There will be no operations to delete or move feet (following Pruitt 2010, 2012). GEN will also contain operations to link or delink a tone, although the exact implementation differs for the licensing and edgewise frameworks, as will be discussed in sections 4.3.4 and 4.3.5. As in Chapter 2, I assume there is no operation to shift a tone. To simplify the present research, I will also not consider operations to insert or delete tonal autosegments. I discuss building layered feet in section 4.3.6.

Since the focus of this chapter is on foot-based tonal reassociation, I focus on operations that manipulate metrical or tonal structure, and I do not include any operations in GEN to manipulate other, unrelated parts of representational structure. For manipulation of foot structure, only one operation is needed. It is OP:PLACE-FT, defined in (8).[21]

[21] The definition of operations involves a choice of how many representational restrictions to include in the definition of a specific operation, versus as a general principle of GEN. For example, in the definition in (8), rather than state the condition that the relevant syllables need to be unfooted, I could have stated that the application of the operation is subject to the Free Element Condition (Prince 1985:479). I do not aim to take a stance on such dilemmas in this chapter, but for the sake of clarity, I will make explicit in my definitions the conditions that all involved representational elements must adhere to.

(8) OP:PLACE-FT
Place a foot which parses two adjacent unfooted syllables.

The licensing and edgewise frameworks will add their respective operations on tone associations to flesh out GEN. I introduce these operations in the relevant subsections, where I will also show example derivations. A complete overview of the framework definitions is presented in 4.3.7.

4.3.3 Constraints on feet

Most of the constraint set involves tone, but a few constraints refer only to feet for their evaluation. The two frameworks use identical constraints for deciding whether and where to place feet. Firstly, continuing from the previous section, I follow earlier HS work in assuming that an operation is associated with (the violation of) exactly one "basic" faithfulness constraint (McCarthy 2007:77-79; McCarthy 2008:501; Elfner 2016).[22] For the present purposes, I do not need to define any additional, "non-basic" faithfulness constraints. In (9) I define DEP-FT, the faithfulness constraint that keeps OP:PLACE-FT in check.

(9) DEP-FT
Assign one violation mark if the candidate was generated by the application of OP:PLACE-FT.

The definition of DEP-FT has an analog for each other operation; the definitions of the other basic faithfulness constraints can be derived by swapping out OP:PLACE-FT for another operation. For example, the faithfulness constraint DEP-LINK is similarly opposed to the application of OP:LINK-TONE, an operation that inserts a new association link between a tone and a syllable. Consequently, in the following, I will not give explicit definitions for basic faithfulness constraints.

As for markedness constraints, both approaches have a need for a foot attraction effect. This is achieved with the classic constraint ALL-FT-RIGHT (McCarthy and Prince 1993a), defined in (10).[23]

(10) ALL-FT-RIGHT
For every foot, assign one violation mark for each syllable between that foot and the right edge of the domain.

In addition to foot attraction effects, the grammar will also need a way to coerce edgemost foot placement, so that there is an edgemost foot present for unbounded tone reassocation. This is achieved with an alignment constraint, defined in (11). I use the term "word" loosely here; depending on the domain

[22] McCarthy (2007:77): "The *basic faithfulness constraints* are ... [MAX] and [DEP] constraints ... [IDENT] ... and perhaps one or two others, such as [LINEARITY]"

[23] Martínez-Paricio and Kager (2015) argue for a different type of constraint to achieve directional footing, called "CHAIN" constraints. I make a comparison between CHAIN-L/R and ALL-FT-L/R in section 4.3.6, footnote 29, in the context of layered feet.

over which a tonal reassociation pattern operates in a given language, this constraint might instead need to align with e.g. a phonological phrase.

(11) Align-R(ω, Ft)
Assign one violation mark for every word that does not have a foot as its rightmost constituent.

For both the foot attraction and alignment effects, I have only introduced a rightward version. This is because in calculating typological predictions, symmetry is redundant; any effect that can be modeled for the right edge could be modeled on the left edge with symmetrical counterparts. Consequently, many left-edge results can be inferred without including the left-oriented constraints in the calculation. However, some patterns are likely to be excluded under this assumption. Firstly, doing the typological calculations with a unidirectional constraint set precludes the discovery of any pattern that crucially relies on the presence of both left- and right-oriented version of a constraint set. I leave the consideration of such patterns as an issue for future research. Secondly, it is possible to consider directionality per constraint, and mix right-directional Align-R(ω, Ft) with left-directional All-Ft-Left. In informal testing, I did not find major differences for the resulting typological predictions. Again, I choose to limit the scope of this project, to the exclusion of exhaustive investigation into such mixed-directionality constraint sets.

4.3.4 Tone association with a licensing approach

In the following, I fill out the licensing framework with framework-specific operation and constraint definitions. I will also provide example derivations of a bounded and an unbounded pattern.

Operations for the licensing framework

The licensing framework carries simple, minimally restricted operations for the manipulation of tone associations. Firstly, tone linking is effected through Op:Link-Tone, defined in (12). The only restriction on linking is the No-Crossing Condition (NCC, Goldsmith 1976). I assume that a tone cannot link to the same syllable twice; if the operation is applied to a tone-syllable pair that was already linked, the application is vacuous. Thus, Op:Link-Tone fits with an implementation of tone association as set membership; assuming that there is a set of syllables that T associates with, the effect of Op:Link-Tone is to add σ to this set, and *vice versa* for the set of tones that σ associates with.

(12) Op:Link-Tone
For some tone T and some syllable σ, create an association link between T and σ if doing so does not violate the NCC.

Crucially, Op:Link-Tone is free to create gapped tone constructions, as demonstrated in Figure 4.1. This is essential to the licensing approach, because it enables long-distance effects, where tone association can "jump" to a far-away position if this results in satisfying licensing constraints. I will demonstrate this with example derivations further below.

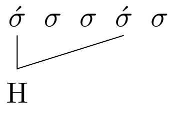

Figure 4.1: A gapped autosegmental representation

The other operation specific to the licensing approach is Op:Delink-Tone. It is the mirror image of Op:Link-Tone, with the caveat that I make the simplifying assumption that there are no floating tones. Thus, it is defined as in (13). Again, I allow for vacuous application to simplify the definition of the operation.

(13) Op:Delink-Tone
For some tone T and some syllable σ, remove an association link between T and σ if T is linked to at least one other syllable.

As I stated in section 4.3.2, I do not include tone shift or tone insertion or deletion operations in Gen. Consequently, the above definitions complete the description of Gen for the licensing approach. The freedom of association offered by the operations is balanced out by the constraint set; compared to the edgewise approach, triggers for association are relatively rare in the licensing approach. As I stated in section 4.3.2, each operation comes with its own basic faithfulness constraint. For Op:Link-Tone and Op:Delink-Tone, these are respectively named Dep-Link and Max-Link. I define the markedness constraints in detail below.

Constraints for the licensing framework

As described in the introduction, licensing constraints (Zoll 1996) have some history in the OT analysis of reassociation patterns (Kang 1997). The mechanism of licensing is that a licensee representational element is affiliated in at least one position with some licensor element or structure. For the present case, I suggest that tones seek licensing from foot structure.[24] Consequently, licensing constraints promote foot building exclusively for the purposes of tone — in any of the places where an unlicensed tone happens to be associated. Here, I assume that tone associates to syllables — simplifying away from quantity sensitivity — and that syllables are in turn parsed by feet. In discussing

[24]It is also possible to consider the reverse direction, i.e. that feet seek licensing from tone association. In the framework in Chapter 2, both of these options were represented, but I have kept the present licensing approach more restricted. I consider this in detail in section 4.5.4.

constraints that evaluate the relation between tone and feet, I will typically leave this indirect, syllable-mediated relation implicit; it is made explicit in the constraint definitions. I assume a subset of the constraints from Chapter 2, specifically the licensing constraints and the structural markedness constraints.

Firstly, (14) shows the general form of the tone licensing constraints, and (15) shows an edge-specified constraint, instantiated for the right edge.

(14) LICENSE(H, FT)
"For each H tone, assign one violation mark if it is not associated to a footed syllable." (Chapter 2:19)

(15) LICENSE(H, FT-R)
"For each H tone, assign one violation mark if it is not associated to a syllable that is rightmost in a [foot]." (Chapter 2:20)

The structural markedness constraints, defined in (16-17) below, allow for effects in the opposite direction, i.e. the delinking of tone from positions in the foot. This will be crucial to model tone shift effects, where tone needs an incentive to delink from its original position.

(16) *H/FT
"Assign one violation mark for each association between a H tone and a footed syllable." (Chapter 2:20)

(17) *H/FT-R
"Assign one violation mark for each association between a H tone and a syllable that is rightmost in a [foot]." (Chapter 2:20)

The analysis of some patterns requires delinking from unfooted syllables. Thus, the constraint set also includes a fully context-free delinking constraint *H/σ, defined in (18).

(18) *H/σ
Assign one violation mark for each association between a H tone and a syllable.

This concludes the discussion of constraints relating feet to tone in the licensing framework. I define one more constraint, which relates only to tone structure; it militates against gapped tone structures. As mentioned, gapped tone structures are essential for the analysis of long-distance tone reassociation in the licensing framework. However, all else being equal, tones should favor association close to positions that they already associate to, rather than create arbitrarily large gaps. Consequently, I include the constraint NOGAP, defined in (19).

(19) NOGAP
Assign one violation mark for each tone-syllable pair (T, σ) where σ is in a gap of T.

I define the predicate of a syllable σ being in the gap of a tone T to mean that σ is not associated to T, but there are syllables both left and right of σ (at some distance, not necessarily adjacent) that *are* associated to T.

Finally, I note that there are two faithfulness constraints specific to the licensing framework. As before, these constraints are in a one-to-one relationship with an HS operation. Specifically, I define DEP-LINK as assigning one violation mark to each candidate that is the result of applying OP:LINK-TONE; and MAX-LINK to each candidate that is the result of applying OP:DELINK-TONE.

With all the theoretical assumptions for the licensing approach in place, I show some example derivations below.

Sample derivations using tone licensing

I demonstrate the licensing framework with one example of a bounded, and one of an unbounded pattern. Firstly, the multi-tableau in Table 4.3 shows a schematized example of bounded binary spreading. The three steps of the derivation are collapsed, with arrows indicating that the winner of one step becomes the input to the next step. I abbreviate the word LICENSE to the symbol $\mathcal{L}$.

$\sigma\acute{\sigma}\sigma\sigma$	$\mathcal{L}$(H, FT)	ALL-FT-R	$\mathcal{L}$(H, FT-R)	DEP-LINK
Step 1				
a. $\sigma\acute{\sigma}\sigma\sigma$	*!		*	
b. $(\sigma\acute{\sigma})\sigma\sigma$		**!		
c. ☞ $\sigma(\acute{\sigma}\sigma)\sigma$		*	*	
Step 2				
d. $\sigma(\acute{\sigma}\sigma)\sigma$		*	*!	
e. ☞ $\sigma(\acute{\sigma}\acute{\sigma})\sigma$		*		*
Step 3 — convergence				
f. ☞ $\sigma(\acute{\sigma}\acute{\sigma})\sigma$		*		
g. $\sigma(\acute{\sigma}\acute{\sigma})\acute{\sigma}$		*		*!

Table 4.3: Binary bounded spreading, licensing framework

The first step already shows a crucial constraint interaction. It is top-ranking LICENSE(H, FT) that drives the grammar to place a foot, but this constraint underdetermines the foot's exact positioning. That decision is relegated to ALL-FT-RIGHT, which prefers feet to be more rightmost. Hence, the satisfaction of LICENSE(H, FT-R) must be postponed to the second step, where it is accomplished through spreading. After this second step, there is no way for GEN to improve the form that is under evaluation. In particular, further spreading as in 4.3g is unwarranted since it does not satisfy any constraints, and incurs needless violations of Dep-Link.[25] Consequently, the output of the phonological process starting from $/\sigma\acute{\sigma}\sigma\sigma/$ for this grammar is the form of the winning candidate in the last step, i.e. candidate 4.3f's $[\sigma(\acute{\sigma}\acute{\sigma})\sigma]$.

Next, Table 4.4 shows a sample derivation of an unbounded tone shift pattern that targets the penultimate syllable for reassociation, attested in Chizigula (Kenstowicz and Kisseberth 1990).

$\sigma\acute{\sigma}\sigma\sigma\sigma\sigma\sigma$	Align-R(ω, Ft)	$\mathcal{L}$(H, Ft)	Dep-Ft	NoGap
Step 1				
a. $\sigma\acute{\sigma}\sigma\sigma\sigma\sigma\sigma$	*!	*		
b. $\sigma(\acute{\sigma}\sigma)\sigma\sigma\sigma\sigma$	*!		*	
c. ☞ $\sigma\acute{\sigma}\sigma\sigma\sigma(\sigma\sigma)$		*		
Step 2				
d. $\sigma\acute{\sigma}\sigma\sigma\sigma(\sigma\sigma)$		*!		
e. $\sigma(\acute{\sigma}\sigma)\sigma\sigma(\sigma\sigma)$			*!	
f. $\sigma\acute{\sigma}_1\sigma\sigma\sigma(\sigma\acute{\sigma}_1)$				****!
g. ☞ $\sigma\acute{\sigma}_1\sigma\sigma\sigma(\acute{\sigma}_1\sigma)$				***
Step 3 — guaranteed convergence				
h. $\sigma\acute{\sigma}_1\sigma\sigma\sigma(\acute{\sigma}_1\sigma)$				*!**
i. ☞ $\sigma\sigma\sigma\sigma\sigma(\acute{\sigma}\sigma)$				

Table 4.4: Penultimate-targeting unbounded shift, licensing framework

The derivation uses a longer candidate to demonstrate the long distance that the pattern can cross. The grammar has a high-ranking foot edge alignment constraint, so in the first step, a foot is created at the edge. This sets up the penultimate syllable as an attractive tone association target, since it is the closest footed syllable for the as-yet-unlicensed tone in step 2. Placing a second foot is not an optimal way to license the tone because it violates Dep-Foot. Instead, the grammar favors the creation of a tonal gap, so the tone can associate to the footed syllable. In step 3, the optimal way for the grammar to resolve the gap is to delink from the sponsor location, immediately exonerating all three intermediate syllables from violating NoGap. After this, all markedness constraints have been maximally satisfied, and the derivation is guaranteed to converge.

In Table 4.4 and other tableaux, I will not show the final step of the derivation, because I deem it trivial that convergence will happen. Instead, I will write "guaranteed convergence" to indicate that a convergence step follows immediately after the last step shown. Such "guarantees" occur when a winning candidate violates markedness constraints minimally, that is it either does not violate markedness constraints at all, or there is no way of reducing violations.

[25] Candidate 4.3g does not violate the licensing constraints despite running tone out of the foot; licensing is satisfied as long as the tone is associated with at least one footed position, regardless of associations to unfooted material.

For example, for forms with one tone, the constraint *H/σ assigns the minimal number of violations, one, if the tone has a single association link — under my assumption that floating tones and tone deletion are ruled out. If a form violates all markedness constraints minimally, then there is no chance for the grammar to improve on the form; applying further operations would only needlessly incur faithfulness violations. For this reason, minimal markedness violations guarantee immediate convergence.

In a variation on the pattern from Table 4.4 where delinking is blocked by a high-ranked faithfulness constraint against removing association links, i.e. MAX-LINK, the best way for the grammar to resolve the gap is to fill it — adding association links to all intermediate syllables, one step at a time. This derives an unbounded spreading pattern instead of an unbounded shift pattern. I show this for a two-syllable gap in the multi-step tableau in Table 4.5.

$\sigma\acute{\sigma}_1\sigma\sigma(\acute{\sigma}_1\sigma)$	MAX-LINK	NOGAP	DEP-LINK
Step 1			
a. $\sigma\acute{\sigma}_1\sigma\sigma(\acute{\sigma}_1\sigma)$		**!	
b. ☞ $\sigma\acute{\sigma}_1\acute{\sigma}_1\sigma(\acute{\sigma}_1\sigma)$		*	*
c. $\sigma\sigma\sigma\sigma(\acute{\sigma}_1\sigma)$	*!		
Step 2			
d. $\sigma\acute{\sigma}_1\acute{\sigma}_1\sigma(\acute{\sigma}_1\sigma)$		*!	
e. ☞ $\sigma\acute{\sigma}\acute{\sigma}\acute{\sigma}(\acute{\sigma}\sigma)$			*
Step 3 — convergence			
f. ☞ $\sigma\acute{\sigma}\acute{\sigma}\acute{\sigma}(\acute{\sigma}\sigma)$			
g. $\sigma\acute{\sigma}\acute{\sigma}\acute{\sigma}(\acute{\sigma}\acute{\sigma})$			*!

Table 4.5: Filling up a gapped configuration, licensing framework

If delinking is blocked, as demonstrated by the failure of candidate 4.5c, the grammar can still repair the gap by filling it up if NOGAP outranks DEP-LINK. I have left out one candidate at step 1 which starts filling the gap by spreading to the rightmost of the two skipped syllables first, i.e. $\sigma\acute{\sigma}_1\sigma\acute{\sigma}_1(\acute{\sigma}_1\sigma)$. This branch of the derivation merges right back into the shown branch at step 2, when the entire gap is filled. Consequently, the tie is inconsequential to the end result.

This concludes the description of the licensing tone framework. In section 4.4.2, I will investigate its typological predictions. The results will be compared to those for edgewise tone association, which I present in the following section.

4.3.5 Edgewise tone association

In contrast to licensing, the edgewise association framework aims to avoid any gapped configurations and to provide a more direct and consistent means of enforcing tone movements. In order to avoid gaps, it gets rid of long-range tone association. Instead, tone reassociates incrementally, by linking or delinking only at the "edges" of tone spans.

The edgewise framework also no longer drives tonal reassociation through licensing effects. Instead, a constraint type ALL-TONES-L/R directly pulls tone to the left or right edge of the domain. This allows a grammar to state a general preference of directionality in tonal reassocation, regardless of how tones resolve this in different contexts. This is most pertinent in contexts with multiple tones — although I do not consider in-depth analyses of such patterns in this chapter. For example, in cases with two High tones in Digo (Kisseberth 1984), the rightmost tone shifts to the ultimate, while the other tone spreads up to the penultimate.[26] As different as the behavior of these two tones might be, the commonality is that both tones situate themselves as close as possible to the right edge — which is problematic to express in a licensing framework, but straightforwardly expressible in the edgewise framework through a sufficiently high ranking of ALL-T-RIGHT.

In the following, I define the GEN and CON components of HS that constitute the edgewise association framework, and provide some example derivations.

Operations for the edgewise framework

As was the case for the licensing framework, I define two operations for the edgewise framework: One used for linking tone, and one for delinking tone. As before, I do not consider tone shift, insertion, or deletion operations. The goal for the edgewise framework is to do away with the large tone jumps and gapped configurations that were integral to the licensing approach, and to instead proceed by iterative short-distance actions. Thus, the linking operation for the edgewise framework is limited so that it operates only at the "edges" of the current tone span. Hence, I name the operation OP:LINK-AT-EDGE, with the definition in (20). The definition is kept briefer by my simplification that there are no floating tones; but it does not preclude the addition of stipulations to deal with floating tone cases.[27]

(20) OP:LINK-AT-EDGE
For some tone T and some syllable σ, create an association link between

[26] The interpretation of the spreading behavior is supported by the blocking effect caused by depressor consonants — tone will still spread as far as it can, e.g. in a-na-tsíndzá má-dzogŏrô 'he's slaughtering roosters'. Here, the depressor consonant at the onset of the syllable *dzo* blocks the first High tone from spreading further into the phrase. The second High tone, linked to the ultimate, gets realized as a rise-fall sequence over the last two syllables. Both High tones originate from the verb; the noun in isolation has low pitch, i.e. *ma-dzogoro*.

[27] Because of the short-distance nature of the operation, the NCC can be checked more efficiently, making it a smaller demand than it was in the case of OP:LINK-TONE. For example, a tone T can link left/rightward iff there is no tone left/right-adjacent to T that is linked to left/right edge of T. In the licensing case, this has to be checked for all syllables between the tone's left/rightmost anchor and the linking target; and for *all* tones to the left/right of T, rather than just the immediately adjacent tone.

T and σ if doing so does not violate the NCC; and if σ is adjacent to a syllable associated with T.

The changes to the linking operation account for the brunt of the difference between the behavior of edgewise GEN and licensing GEN. However, some modification must be made to the delinking operation as well. This is because delinking can cause gaps too, when tone is delinked from an "interior" position in the tone span. For example, delinking creates a gap in the mapping of $\acute{\sigma}\acute{\sigma}\acute{\sigma} \rightarrow \acute{\sigma}_1\sigma\acute{\sigma}_1$. Thus, I define OP:DELINK-AT-EDGE in (21) with the extra condition that delinking must take place at the tone's edge.

(21) OP:DELINK-AT-EDGE
For some tone T and some syllable σ, remove an association link between T and σ if T is linked to at least one other syllable; and if σ is at an edge of T (i.e. if at least one syllable adjacent to σ is not linked to T).

Having thus shrunk the potential of GEN, I will show below which markedness constraints I pair with these restricted operations in order to achieve the desired range of tonal reassociation patterns. The faithfulness constraints are again only the "basic faithfulness" constraints associated with the respective operations in GEN, as discussed in 4.3.2.

Markedness constraints for the edgewise framework

With the short-range GEN described above, all the intermediate steps on the way to a long-range reassociation target need to be harmonically improving in order for the derivation as a whole to be optimal to an unbounded reassociation grammar. Since long-range targets are always near an edge, this is similar to saying that some constraint should assign more violations to tones the further away they are from the relevant edge. This would reward every act of advancement toward the edge, since doing so reduces the violation count. One might make the analogy to there being a large tone "magnet" at the edge of the domain, pulling tone association as close as it can to that edge. This is the intuition behind ALL-T-RIGHT, defined explicitly in (22).

(22) ALL-T-RIGHT
For each tone, assign one violation mark for each TBU between the rightmost anchor of that tone and the right edge of the tone domain.

With the edgewise association constraint ALL-T-RIGHT, feet no longer need to exert the "pull" that drives tonal reassociaton, since that role is taken up by the (right) edge. Consequently, the edgewise approach allows the testing of a different role for foot structure in unbounded tone reassociation. That is, rather than using feet as a long-range targeting mechanism, feet could function as the "brake" that stops tone from running into the very edge of the domain.[28] As

[28] I thank Doug Pulleyblank for encouraging me to investigate this option.

a consequence, tone then spreads only up to the edgemost unfooted syllable, meaning the antepenultimate syllable is still in range. The constraint that helps achieve this is *H/FT, already defined in (16) and repeated below as (23).

(23) *H/FT
"Assign one violation mark for each association between a H tone and a footed syllable." (Chapter 2:20)

Conversely, edgewise association also needs to be able to derive forms where association occurs only inside a foot, for bounded reassociation patterns. Since footed syllables are not privileged by licensing constraints in this framework, this effect does not fall out automatically, the way it did in the licensing framework. Consequently, I include *H/UNFOOTED, a constraint that specifically disfavors association to unfooted syllables. It is defined in (24).

(24) *H/UNFOOTED
Assign one violation mark for each association between a H tone and an unfooted syllable.

Finally, the framework is so far lacking a mechanism to favor association up to the penultimate syllable. For this, I add *H/FINAL, defined in (25).

(25) *H/FINAL
Assign one violation mark for each association between a H tone and a domain-final syllable.

Since tone association directionality is already encoded in ALL-T-RIGHT, I have chosen to leave such directionality out of the tone–foot constraints. That is, unlike in the licensing framework, constraints such as *H/FT are only instantiated in a general format, and do not have an instantiation for a specific foot edge, e.g. *H/FT-R.

This concludes my definition of CON for the edgewise association framework. In the following, I demonstrate the approach for example cases of bounded and unbounded reassociation.

Sample derivations using edgewise tone association

To demonstrate the edgewise association framework, particularly in comparison to the licensing framework, I will mirror the examples in 4.3.4 — bounded binary spreading and unbounded penultimate shift. In addition, I will show spreading to the antepenultimate, to demonstrate the role of foot structure as a blocker of tone spreading. Firstly, the multi-tableau in Table 4.6 shows a schematized derivation of a bounded spreading pattern — discussed for the licensing framework earlier in Table 4.3.

Although *H/UNFOOTED is not a licensing constraint, since it punishes *any* association of a tone to an unfooted syllable, the effect of the constraint is similar to that of licensing constraints in the context of step 1, where

*H/Unfooted forces the placement of a foot over the sponsor syllable. Comparing candidates 4.6c,d shows that All-Ft-Right has some role to play in deciding the exact foot placement, whilst 4.6e shows that this effect is not absolute. In step 2, the foot is now again the domain for bounded tone reassociation. Here, tone spreads rightward under the pressure of All-T-Right. However, as shown in step 3, spreading cannot continue to the point that the tone would leave its bounding domain, because that would violate *H/Unfooted – as demonstrated by candidate 4.6j. Hence, the derivation converges at step 3, having executed a binary spreading pattern.

σσ́σσ	*H/Unft	All-T-R	All-Ft-R
Step 1			
a. σσ́σσ	*!	**	
b. σσ́σ́σ	*!*	*	
c. (σσ́)σσ		**	**!
d. ☞ σ(σ́σ)σ		**	*
e. σσ́(σσ)	*!	**	
Step 2			
f. σ(σ́σ)σ		**!	*
g. ☞ σ(σ́σ́)σ		*	*
Step 3 — convergence			
h. ☞ σ(σ́σ́)σ		*	*
j. σ(σσ́)σ́	*!		*

Table 4.6: Binary bounded spread; edgewise association

Next, I demonstrate unbounded shift targeting the penultimate syllable. This matter was previously taken up for the licensing framework in Table 4.4. The edgewise association version of the analysis is in Table 4.7.

The derivation needs to go through more steps than in the licensing framework, because each intermediate position on the way to the penultimate needs to be individually linked to and later delinked from. After foot placement in step 1, steps 2-4 show the spreading part of the derivation; if this were a demonstration of a spreading pattern, step 4 would show convergence. The reason that it does not is that the grammar has an opportunity to reduce the violations of *H/Unfooted by delinking the initial part of the tone span — coming only at the cost of unshown Max-Link which is low-ranked by assumption. The penultimate-targeting nature of the pattern is due to *H/Final, which blocks spreading to the final syllable, as shown in candidates 4.7j,n.

A blocking effect can also be due to foot structure. As a final demonstration for the edgewise association framework, I show this effect for the case of antepenultimate spreading in the multi-tableau in Table 4.8.

σσ́σσσ	ALIGN-R(ω, FT)	*H/FINAL	ALL-T-R	*H/UNFT
Step 1				
a. *σσ́σσσ*	*!		***	*
b. ☞ *σσ́σ(σσ)*			***	*
Step 2				
c. *σσ́σ(σσ)*			***!	*
d. ☞ *σσ́σ́(σσ)*			**	**
Step 3				
e. *σσ́σ́(σσ)*			**!	**
f. ☞ *σσ́σ́(σ́σ)*			*	**
Step 4				
g. *σσ́σ́(σ́σ)*			*	**!
h. ☞ *σσσ́(σ́σ)*			*	*
j. *σσ́σ́(σ́σ́)*		*!		**
Step 5				
k. *σσσ́(σ́σ)*			*	*!
l. ☞ *σσσ(σ́σ)*			*	
Step 6 — convergence				
m. ☞ *σσσ(σ́σ)*			*	
n. *σσσ(σ́σ́)*		*!		

Table 4.7: Penultimate-targeting unbounded shift, edgewise association

σσ́σσσσ	ALIGN-R(ω, FT)	*H/FT	ALL-T-R
Step 1			
a. *σσ́σσσσ*	*!		****
b. ☞ *σσ́σσ(σσ)*			****
Step 2			
c. *σσ́σσ(σσ)*			****!
d. ☞ *σσ́σ́σ(σσ)*			***
Step 3			
e. *σσ́σ́σ(σσ)*			***!
f. ☞ *σσ́σ́σ́(σσ)*			**
Step 4 — convergence			
g. ☞ *σσ́σ́σ́(σσ)*			**
h. *σσ́σ́σ́(σ́σ)*		*!	*

Table 4.8: Antepenultimate-targeting unbounded spread, edgewise association

Again, the grammar starts with foot placement, in step 1. Afterwards, spreading proceeds towards the right edge incrementally in steps 2–3. In step 4, the foot acts as a deterrent to further spreading, because *H/FOOT outranks ALL-T-RIGHT; this makes the rightward spreading into the foot suboptimal, as demonstrated by candidate 4.8h.

This concludes my demonstration of the workings of the edgewise association framework. Its typological predictions are investigated in section 4.4.3. First, I outline some uses for layered feet below, and present an overview of all the theoretical components introduced so far in section 4.3.7.

4.3.6 Using layered feet

Here, I outline some uses for ternary feet, and make some further theoretical assumptions that they require.

I start with a consideration of the construction of layered feet. I assume that a ternary foot is the result of two separate steps of foot construction (Kager and Martínez-Paricio 2013; Chapter 2). Thus, a grammar might execute the sequence of mappings $\sigma\sigma\sigma \rightarrow (\sigma\sigma)\sigma \rightarrow ((\sigma\sigma)\sigma)$, but it is impossible to do so while skipping the intermediate step, i.e. $^*\sigma\sigma\sigma \rightarrow ((\sigma\sigma)\sigma)$. I achieve this property by relaxing the definition of OP:PLACE-FT, which I defined earlier in (8) for strictly binary feet, so that it can build either an inner or outer foot layer. The definition now involves the concept of a "parseable" constituent, which can be an unfooted syllable or a non-layered foot. Since a layered foot is not regarded as a parseable constituent, the operation is effectively limited to a single application of recursive foot placement, as stipulated in earlier work.

(26) OP:PLACE-FT
Place a foot which parses a syllable and an adjacent parseable constituent (either an unfooted syllable or a non-layered foot).

The original motivation for two-step building was that it allowed typically ternary alternating stress systems to parse a four-syllable string with two binary feet, rather than underparsing the string with a single ternary foot (Kager and Martínez-Paricio 2013). This parsing pattern is attested for Chugach (Leer 1985a,b; Martínez-Paricio and Kager 2015:483). In the context of tonal reassociation, I used two-step layered feet construction in Chapter 2 for the analysis of bounded spread and shift in Saghala. To my knowledge, no work in HS has made extensive use of one-step construction, let alone made a comparison between one-step and two-step approaches. I note one consequence specific to two-step construction for the purposes of tone reassociation here: Any feet that are placed expressly to encompass tone, either for licensing purposes or to avoid violations of *H/UNFOOTED, will do so using the minimal foot (i.e. the inner foot layer). This is because a derivation that ends up with a form where only the outer foot layer encompasses a tone, e.g.n $(\acute{\sigma}(\sigma\sigma))$, would necessarily go through an intermediate step that does not improve the candidate, i.e. with the mappings $\acute{\sigma}\sigma\sigma \rightarrow \acute{\sigma}(\sigma\sigma) \rightarrow (\acute{\sigma}(\sigma\sigma))$. Thus, at least in this respect, the two-step construction process is more restrictive than a one-step construction process.

Below, I will present two example derivations, one for each framework. In the first, I show that in order for the licensing framework to target antepenultimate syllables, tone licensing effects need to be delayed, for which I will use a special alignment constraint targeting non-minimal feet. In the second example, I show that, given some constraint interaction that promotes layered feet construction, the edgewise association framework can contain its bounded patterns to domains of a ternary size.

The multi-tableau in Table 4.9 shows a shift to the antepenultimate syllable in the licensing framework. I abbreviate the word edge alignment constraints with "/ω-R", e.g. Align-R(ω, Ft) is written as Ft/ω-R in the tableau.

As before, the approach for aiming at a position near the word edge is to first build an edgemost foot, and then execute a tone jump to the nearest licensing position. However, the crucial sophistication needed for the antepenultimate-targeting pattern is shown in step 2; the jump must be delayed, *contra* 4.9e, because the newly added constraint Align-R(ω, FtNonMin) requires that a non-minimal foot is aligned with the right word edge – a requirement satisfied by 4.9d. The comparison of 4.9g and 4.9h shows that the grammar prefers a minimum-size gap, making a tone jump to the antepenultimate the optimal strategy. After delinking in step 4, which is optimal since Max-Link is low-ranked, the derivation is guaranteed to converge since the winning form maximally satisfies all relevant markedness constraints.

Next, I demonstrate in the multi-tableau in Table 4.10 how a bounded ternary process can be derived in the edgewise association framework. I adopt the constraint *H/MaxFt with the definition in (27).[29]

[29] This is an ad-hoc constraint for the use of the ternary domain; ideally I would not distinguish between direct and indirect parsing in constraint definitions. The reason it is needed is that All-Ft-Right is resistant to the introduction of more feet, and a general foot-promoting constraint like Parse-σ would stimulate the production of binary feet over ternary ones. In general, ternary feet are better accommodated using Chain-L/R constraints as in (1).

(1) Chain-L
"For every unfooted syllable $(\sigma)_\omega$, assign a violation mark if some foot intervenes between $(\sigma)_\omega$ and the [left] edge of its containing ω." (Martínez-Paricio and Kager 2015:470)

ω denotes a prosodic word constituent, but the definition can be amended to operate on larger prosodic constituents. Chain-L focuses on pulling unparsed syllables to the left, which means any feet are ideally situated at the right edge, hence making it similar to All-Ft-Right. The crucial difference is that Chain-L doesn't punish the existence of feet *per se* — feet do not cause violations as long as they are neatly in a chain at the right edge of the domain. The Chain-L/R constraints are used with ternary feet in Martínez-Paricio and Kager (2015) and Chapter 2, but I have not used them for the binary feet in this chapter because, together with Align-R(ω, Ft), they create an overabundance of feet, especially for the short length (five syllables) of the forms in question.

$\sigma\acute{\sigma}\sigma\sigma\sigma\sigma$	Ft/ω-R	NonMin/ω-R	$\mathcal{L}$(H, Ft)	NoGap	Max-Link
Step 1					
a. $\sigma\acute{\sigma}\sigma\sigma\sigma\sigma$	*!	*	*		
b. ☞ $\sigma\acute{\sigma}\sigma\sigma(\sigma\sigma)$		*	*		
Step 2					
c. $\sigma\acute{\sigma}\sigma\sigma(\sigma\sigma)$		*!	*		
d. ☞ $\sigma\acute{\sigma}\sigma(\sigma(\sigma\sigma))$			*		
e. $\sigma\acute{\sigma}_1\sigma\sigma(\acute{\sigma}_1\sigma)$		*!		**	
Step 3					
f. $\sigma\acute{\sigma}\sigma(\sigma(\sigma\sigma))$			*!		
g. ☞ $\sigma\acute{\sigma}_1\sigma(\acute{\sigma}_1(\sigma\sigma))$				*	
h. $\sigma\acute{\sigma}_1\sigma(\sigma(\acute{\sigma}_1\sigma))$				**!	
Step 4 — guaranteed convergence					
j. $\sigma\acute{\sigma}_1\sigma(\acute{\sigma}_1(\sigma\sigma))$				*	
k. ☞ $\sigma\sigma\sigma(\sigma(\acute{\sigma}\sigma))$					*

Table 4.9: Tone shift to the antepenultimate, licensing framework

(27) *H/MaxFt
Assign one violation mark for each association between a tone and a syllable that is *directly* dominated by a maximal foot.

*H/MaxFt drives the creation of ternary feet over footed syllables containing tone, since it removes the direct parsing relation between a maximal foot and the toned syllable. Thus, after regular footing and spreading in steps 1–2, the grammar builds a layered foot to deal with the violations of *H/MaxFt. The foot layer is positioned maximally rightward, which is decided by lower-ranked All-Ft-Right. With the layered foot in place, there is one more step of spreading that the grammar can perform without running into trouble with top-ranked *H/Unfooted, as shown in step 4. Thus, the grammar accomplishes a bounded, ternary spreading pattern.[30]

$\sigma\acute{\sigma}\sigma\sigma\sigma$	*H/Unft	All-T-R	*H/MaxFt	All-Ft-R
Step 1				
a. $\sigma\acute{\sigma}\sigma\sigma\sigma$	*!	***		
b. ☞ $\sigma(\acute{\sigma}\sigma)\sigma\sigma$		***	*	**
c. $(\sigma\acute{\sigma})\sigma\sigma\sigma$		***	*	***!
Step 2				
d. $\sigma(\acute{\sigma}\sigma)\sigma\sigma$		***!	*	**
e. ☞ $\sigma(\acute{\sigma}\acute{\sigma})\sigma\sigma$		**	**	**
Step 3				
f. $\sigma(\acute{\sigma}\acute{\sigma})\sigma\sigma$		**	*!*	**
g. ☞ $\sigma((\acute{\sigma}\acute{\sigma})\sigma)\sigma$		**		***
h. $(\sigma(\acute{\sigma}\acute{\sigma}))\sigma\sigma$		**		****!
Step 4				
j. $\sigma((\acute{\sigma}\acute{\sigma})\sigma)\sigma$		**!		***
k. ☞ $\sigma((\acute{\sigma}\acute{\sigma})\acute{\sigma})\sigma$		*	*	***
Step 5 — convergence				
l. ☞ $\sigma((\acute{\sigma}\acute{\sigma})\acute{\sigma})\sigma$		*	*	***
m. $\sigma((\acute{\sigma}\acute{\sigma})\acute{\sigma})\acute{\sigma}$	*!		*	***

Table 4.10: Ternary bounded spread; edgewise association

This concludes my outline of the extensions of the theoretical framework to ternary feet. In the discussion, in section 4.5.2, I return to the issue of layered feet with regards to typological predictions.

4.3.7 Summary

In summary, I have presented two frameworks for metrical tone reassociation. For both frameworks, feet are used more sparingly than in typical iterative

[30] See Chapter 3 for an in-depth analysis of ternary spreading in Copperbelt Bemba using layered feet.

stress systems. Feet are mostly built either at the edge, or "locally" over a sponsor. The difference between the two frameworks lies mostly in the way they organize reassociation. In the tone licensing framework, GEN is given a high degree of freedom. When a foot offers itself as a licensor, a tone can readily associate, even if it involves a long-distance jump that creates a gapped configuration — assuming some licensing constraint dominates NOGAP. In the edgewise association framework, tonal reassociation proceeds incrementally. GEN is restricted so that tone linking and delinking happen only at the "edge" of the tone span. For this to happen, tone attraction is organized as a stand-alone effect through ALL-T-RIGHT.

The remainder of this section contains an overview of all the operations and constraints involved in the licensing and edgewise association frameworks, for binary feet. Firstly, all operations and their definitions are listed in Table 4.11. Table 4.12 shows which faithfulness constraints are violated by which operations. That is, for any operation, the listed faithfulness constraint is violated once by any candidate that is generated through application of that operation. Next, I list the shared markedness constraints in Table 4.13. These include foot-related constraints, as well as the non-association constraint *H/FT which the frameworks happen to share. Finally, I list the markedness constraints specific to the two frameworks in Tables 4.14 and 4.15, respectively.

In the next section, I present investigations into the typological predictions that follow from the licensing and edgewise frameworks, as derived through the calculation of factorial typologies.

Operation name	*Definition*
OP:PLACE-FT	Place a foot which parses two adjacent unfooted syllables.
OP:LINK-TONE	*(Licensing)* Link a tone to an anchor; no line crossing.
OP:DELINK-TONE	*(Licensing)* Delink a tone from an anchor; no floating tones.
OP:LINK-AT-EDGE	*(Edgewise)* Link a tone to an anchor that is adjacent to an anchor the tone is already linked to; no line crossing.
OP:DELINK-AT-EDGE	*(Edgewise)* Delink a tone from an anchor; no floating tones, no gap formation.

Table 4.11: The operations in GEN; with framework-specific tone operations

Operation name	*Faithfulness constraint*
Op:Place-Ft	Dep-Foot
Op:Link-Tone	Dep-Link
Op:Delink-Tone	Max-Link
Op:Link-at-edge	Dep-Link
Op:Delink-at-edge	Max-Link

Table 4.12: The operations in Gen with their associated faithfulness constraints

Constraint name	*Definition*
All-Ft-Right	For every foot, assign one violation mark for each syllable between that foot and the right edge of the domain.
Align-R(ω, Ft)	Assign one violation mark for each word that does not have a foot as its rightmost constituent.
*H/Ft	"Assign one violation mark for each association between a H tone and a footed syllable." (Chapter 2:20)

Table 4.13: General markedness constraints, shared between both frameworks

Constraint name	*Definition*
License(H, Ft)	For each H tone, assign one violation mark if it is not associated to a footed syllable.
License(H, Ft-L/R)	For each H tone, assign one violation mark if it is not associated to a syllable that is left/rightmost in a foot.
*H/Ft-L/R	Assign one violation mark for each association between a H tone and a syllable that is left/rightmost in a foot.
*H/σ	Assign one violation mark for each association between a H tone and a syllable.
NoGap	Assign one violation mark for each tone-syllable pair (T, σ) where σ is in a gap of T.

Table 4.14: Markedness constraints of the licensing framework

Constraint name	*Definition*
All-T-Right	For each tone, assign one violation mark for each TBU between the rightmost anchor of that tone and the right edge of the tone domain.
*H/Unfooted	Assign one violation mark for each association between a H tone and an unfooted syllable.
*H/Final	Assign one violation mark for each association between a H tone and a domain-final syllable.

Table 4.15: Markedness constraints of the edgewise association framework

4.4 Typology

This section presents the typological predictions that stem from the licensing and edgewise frameworks. I derive these predictions by considering factorial typologies, which consist of sets of optimal input-output mappings for all crucially different rankings of a constraint set. In this chapter, I do not model extragrammatical restrictions, such as issues stemming from poor learnability of a given pattern — but I briefly return to this issue in section 4.5.1 of the discussion.

In addition to the attested patterns, a factorial typology of a framework can include grammars generating many other patterns. Inspecting this wider range of patterns helps to understand how the ingredients in Gen and Con give rise to the effects that they do. Furthermore, it is an indication of how accurately the framework characterizes natural language variation, because it shows in what respects the framework's generative power exceeds the scope of natural language.

For both frameworks, I first consider whether the framework can account for all the target, attested, patterns that were presented in section 4.2, to make sure there is no undergeneration. I then present an exploration of the framework's factorial typology, to inventorize the types of non-target patterns whose attestation the framework predicts. For those patterns, I will discuss on a case-by-case basis whether the pattern is attested and if not, what factors could be the cause for this non-attestation.

In section 4.4.1 I discuss the methodology I followed to derive the factorial typologies. The results for the two frameworks are then discussed separately in sections 4.4.2 and 4.4.3. Section 4.4.4 summarizes the results, identifying common characteristics of these two varieties of metrical tone reassociation, as well as framework-particular strengths and weaknesses. A full list of all the predicted patterns for both frameworks is provided in Appendix B.

4.4.1 Methodology for the factorial typologies

The extension of a factorial typology is infinitely large, because it consists of grammars, which map an infinite set of inputs to outputs. In this sense, then, it is fundamentally impossible to exhaustively inspect the outcome of a maximal factorial typology given a finite amount of time. In the ideal case, this problem can be circumvented by considering the intension of the grammar. That is, there might be a small set of inputs whose mappings together reveal the general nature of any grammar, and can therefore substitute for the infinite set of inputs.

Unfortunately, I have found it infeasible to calculate factorial typologies even for such a fully covering subset of inputs, in two respects. Firstly, the tractability of the computations decreases with the increase of the length of the input strings. This is because a longer string offers more space for, and hence more variety of, foot placement and tone reassociation. Secondly, a larger number of inputs increases the burden on the analyst who has to interpret the results. To give some impression of the magnitude of this problem, I report the numbers for an early attempt I made at investigating a larger factorial typology. In a random sample of 7500 grammars taken from a uniformly distributed set containing all the different rankings, with string length set to 8 syllables and ternary feet and several more operations implemented, I found 546 different patterns, of which 384 were only found once. Consequently, it is possible that many other rare patterns have not even come up in the sample, so that the full factorial typology is far larger than the collection of these 546 patterns. This makes the task of interpreting the calculated variation larger and more complex. A better understanding of the variation may allow for some of this work to be automated. For example, a script could automatically recognize whether something is a bounded or unbounded pattern (or something else altogether). To the extent that the present chapter contributes to such understanding, it paves the way for future typology–theoretical research.

Because of the complexities just mentioned, I have decided on several simplifications. As indicated in section 4.3.1, although layered feet are a crucial piece of the two theoretical frameworks presented here for a full account of tone reassociation typology, they are not a part of my calculations of the factorial typology. That is, I do not include candidates with layered feet or constraints that are specific to layered feet in the calculation of the factorial typology; I will only use binary feet. In addition, I have chosen to restrict the input set to three forms, with a length of five syllables. The three forms each carry a single tonal autosegment, which is underlyingly linked in a single position. The position is contrastive, varying from the first to the third syllable in the string. Hence, the input set is $\{\acute{\sigma}\sigma\sigma\sigma\sigma,\ \sigma\acute{\sigma}\sigma\sigma\sigma,\ \sigma\sigma\acute{\sigma}\sigma\sigma\}$.

There are two reasons why I consider this input set more suitable than even smaller sets, e.g. a single four-syllable form such as $\{\acute{\sigma}\sigma\sigma\sigma\}$. As I will discuss later, some grammars in the factorial typology give special treatment to (tones associated to) the last four syllables in the domain. For this reason, length five is the minimal domain length to discover tone reassociation effects that can appear anywhere, regardless of the location of the tone's underlying association; this is also why there needs to be a form with tone on the fifth syllable from the edge. Other patterns treat only the last three syllables exceptionally. For this reason, it is useful to have forms carrying tone both on the antepenult and on the preantepenult, respectively.

There are also ways in which the present input set is too restricted to draw certain conclusions. Trivially, it is not suited for testing interactions between multiple tones, or interactions with floating tones, which in general fall outside the present research scope. Another restriction is related to the length of the string. As I mentioned, some patterns give exceptional treatment to the last four syllables, but there are also patterns that show deviating behavior on initial syllables. Consequently, if the input forms were longer, it might be possible to combine both the final–four and initial-syllable effects and still leave room for the emergence of a default pattern on the intervening syllables. I leave the task of lifting these restrictions to future research.

Having determined an input set, then, as well as Gen and Con for the respective frameworks as discussed in sections 4.3.2–4.3.5, all the necessary elements are there to calculate a factorial typology. I have performed these calculations using OT-Workplace (specifically OTWorkplace_X_90, Prince et al. 2016), using the macro FacTypHSNoOpsMain. The input spreadsheet for this macro was generated with a custom script, written in the Python programming language, that implemented HS Gen for candidates with tones and feet. The output sets are listed in full in Appendix B, section B.1. For the purposes of replication, the input and output files for the OTWorkplace process, as well as a full list of my interpretations of the patterns, are available as supplemental materials to this chapter, at https://doi.org/10.6084/m9.figshare.5765472.

The calculations yielded 73 different output sets for the licensing framework. Some of the outputs differed only in their foot structure, which in some languages might be phonetically absent. Looking only at surface tone, the number of different output sets was 51. For the edgewise framework, the calculation resulted in a set of 47 metrically different predicted patterns. Looking only at tone, there were 30 different predicted patterns. I now turn to an inspection of the types of patterns that were predicted for the respective frameworks, starting with the licensing framework.

4.4.2 Typological predictions of the licensing framework

Target patterns

I first consider the target patterns, i.e. the attested patterns listed in Table 4.1 in section 4.2. All the target patterns that are modelable with binary feet were present in the factorial typology. This result was already partly apparent from the discussion in sections 4.3.4 and 4.3.6; the licensing approach is capable of bounded and unbounded reassociation, in both a spreading and shifting fashion. These results were mainly shown for binary patterns, but also for an unbounded ternary pattern. For bounded patterns, constraints that target specific edges of specific foot types can achieve association to any and all positions in the layered feet. While this likely leads to potential overgeneration, it shows that the licensing approach is powerful enough to handle even ternary bounded reassociation patterns.

This point is underlined in particular by the analysis of the complex case of ternary half-spread and half-shift, i.e. the mapping of /$\acute{\sigma}\sigma\sigma$/ to [$\sigma\acute{\sigma}\acute{\sigma}$], as attested in Saghala (Patin 2009). Accounting for this pattern in a licensing framework was the main result of Chapter 2. Again, the adoption of a constituent that can span size three is crucial. Thus, in Chapter 2 I constructed a layered foot going rightward from the sponsor, with tone linking or delinking from all footed positions appropriately. Below, I only give an impression of the analysis, by showing the course of a schematized version of this derivation with the steps in Table 4.16.

	Form	*Comment*
0.	$\sigma\acute{\sigma}\sigma\sigma\sigma$	Underlying form
1.	$\sigma(\acute{\sigma}\sigma)\sigma\sigma$	Foot placement
2.	$\sigma(\acute{\sigma}\acute{\sigma})\sigma\sigma$	Spreading to the right edge of MinFt
3.	$\sigma(\sigma\acute{\sigma})\sigma\sigma$	Delinking from the left edge of MinFt
4.	$\sigma((\sigma\acute{\sigma})\sigma)\sigma$	Rightward foot expansion
5.	$\sigma((\sigma\acute{\sigma})\acute{\sigma})\sigma$	Spreading to the right edge of NonMinFt
6.	$\sigma((\sigma\acute{\sigma})\acute{\sigma})\sigma$	Convergence of the HS algorithm; this is the output form

Table 4.16: Steps of the derivation of Saghala bounded spread-and-shift; from Chapter 2

Taking into account these results, I conclude that the licensing approach does not undergenerate on the target patterns, that is, it offers full coverage of the attested patterns discussed in section 4.2.

Non-target patterns

In the following, I will describe various types of non-target patterns I have encountered in the output set.

Firstly, since NoGap is violable, gapped tone configurations will not only function as intermediate forms, but can also be an optimal output for a derivation.[31] Hence, the forms sometimes surface with gapped tones, mostly in what I call a "copying" pattern, where a tone will appear in a certain place only if it was also somewhere else in the input. Some predicted copying patterns are in (28). In this table, every row represents an output set for a certain grammar, listing three output forms in the first three columns that correspond to the respective input forms in the column headers. The final column gives a descriptive name to the pattern. For example, the first row lists the mappings $\{/\acute{\sigma}\sigma\sigma\sigma\sigma/ \rightarrow \acute{\sigma}\sigma\sigma(\sigma\acute{\sigma}),\ /\sigma\acute{\sigma}\sigma\sigma\sigma/ \rightarrow \sigma\acute{\sigma}\sigma(\sigma\acute{\sigma}),\ /\sigma\sigma\acute{\sigma}\sigma\sigma/ \rightarrow \sigma\sigma\acute{\sigma}(\sigma\acute{\sigma})\}$ that I describe as a final syllable copying pattern, or "final copy".

(28) *Surface gaps, or "copy" patterns (licensing framework)*

$/\acute{\sigma}\sigma\sigma\sigma\sigma/$	$/\sigma\acute{\sigma}\sigma\sigma\sigma/$	$/\sigma\sigma\acute{\sigma}\sigma\sigma/$	*Description*
$\acute{\sigma}\sigma\sigma(\sigma\acute{\sigma})$	$\sigma\acute{\sigma}\sigma(\sigma\acute{\sigma})$	$\sigma\sigma\acute{\sigma}(\sigma\acute{\sigma})$	Final copy
$\acute{\sigma}\sigma\sigma(\acute{\sigma}\sigma)$	$\sigma\acute{\sigma}\sigma(\acute{\sigma}\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\sigma)$	Penult copy
$\acute{\sigma}\sigma\sigma(\acute{\sigma}\acute{\sigma})$	$\sigma\acute{\sigma}\sigma(\acute{\sigma}\acute{\sigma})$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	Double copy

[31] This follows from the observation made for HS in McCarthy (2000) that "if one language has the mapping A→B→C, then another will have the mapping A→B (where B is the ultimate output)" , to which I add the condition that this is true if and only if the two steps in A→B→C are not characterized by the same set of ERCs (Prince 2002).

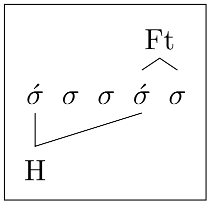

Figure 4.2: A gapped autosegmental representation, characteristic of “tone copying”

The “copying” term is only a reference to the pattern’s appearance; all effects are derived from the reassociation of a single tonal autosegment. Figure 4.2 shows the representation of an instance of tone copying for the example form $\acute{\sigma}\sigma\sigma(\acute{\sigma}\sigma)$.

The copy patterns are closely related to unbounded shift patterns; the only difference is that grammars of shift patterns apply Op:Delink-Tone, defined earlier in (13), to delink tone from its original position. Thus, for each of the grammars in (28), the framework also predicts a shifting grammar, as shown in (29).

(29) *Unbounded shifting patterns (licensing framework)*

$/\acute{\sigma}\sigma\sigma\sigma\sigma/$	$/\sigma\acute{\sigma}\sigma\sigma\sigma/$	$/\sigma\sigma\acute{\sigma}\sigma\sigma/$	*Description*
$\sigma\sigma\sigma(\sigma\acute{\sigma})$	$\sigma\sigma\sigma(\sigma\acute{\sigma})$	$\sigma\sigma\sigma(\sigma\acute{\sigma})$	Final shift
$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	Penult shift
$\sigma\sigma\sigma(\acute{\sigma}\acute{\sigma})$	$\sigma\sigma\sigma(\acute{\sigma}\acute{\sigma})$	$\sigma\sigma\sigma(\acute{\sigma}\acute{\sigma})$	Double shift

Notable is the double targeting pattern in the last row; when both the left-edge and right-edge licensing constraints are active, it is optimal to associate to both foot positions. The final-targeting and penultimate-targeting unbounded shift patterns are attested, as discussed in section 4.2. I do not know of an attestation of a double-targeting unbounded shift pattern.

To my knowledge, none of the copy patterns are attested, either. I also know of no bounded version of a copy pattern, i.e. with a mapping $\acute{\sigma}\sigma\sigma\rightarrow\acute{\sigma}\sigma\acute{\sigma}$, which could be derived with layered feet. The closest analog I am aware of are rhythmic tone patterns, where the lexical presence of one tone causes tone to surface on every second syllable in the domain. I return to the issue of rhythmic tone patterns in section 4.5.4. The complete non-attestation of copying patterns is surprising from a complexity perspective. The copying derivations are strictly shorter than their corresponding, attested, unbounded shift patterns, since shifting patterns are a combination of gapped spreading (i.e. copying) and delinking. Consequently, the non-attestation of copying cannot be the result of copying grammars being disfavored in terms of complexity; the more complex unbounded shift patterns suffer no such consequence. If, following Archangeli and Pulleyblank (1994), this should indeed be interpreted as evidence that gapped structures are representationally invalid, then the copying patterns reveal a major problem for the licensing framework, which leans on gapped tone structures for the derivation of all its unbounded patterns.

Another type of non-target pattern with gapped tone comes as a consequence of the inclusion of edge-specific constraints in the licensing framework. Specifically, edge-sensitive structural markedness constraints can block association at a particular foot edge. This leads to the prediction that some languages might categorically skip tone at a metrically targetable position. In the present set, this is illustrated by skipping the penult, using an edge-positioned foot and activity of *H/FT-L, as shown in (30).

(30) *Penult skipping (licensing framework)*

$/\acute{\sigma}\sigma\sigma\sigma\sigma/$	$/\sigma\acute{\sigma}\sigma\sigma\sigma/$	$/\sigma\sigma\acute{\sigma}\sigma\sigma/$	
$\acute{\sigma}\acute{\sigma}\acute{\sigma}(\sigma\acute{\sigma})$	$\sigma\acute{\sigma}\acute{\sigma}(\sigma\acute{\sigma})$	$\sigma\sigma\acute{\sigma}(\sigma\acute{\sigma})$	Penult skip

Again, I am not aware of the attestation of this pattern. Given the nearly complete saturation of High tones in the domain, it could be that learners would be quick to reanalyze the system as carrying Low tone on the penultimate, with default High tone elsewhere. However, for languages with a contrast of High vs. Low or toneless roots, this would not be the case, because forms that only show low pitch on the penultimate would alternate with forms that surface low-pitched throughout, suggesting the presence of lexical High tones after all. Furthermore, if such a process were indeed at play, then it might be reflected in the development of "reversive" Bantu tone systems, where the lexical specification of High and Low tones has been reversed with respect to the tonal reconstructions of Proto-Bantu forms. However, accounts of the diachrony of reversive tone systems do not involve unbounded spreading patterns such as penult skipping, but instead assign a crucial role to the incorporation of High tone from an "augment" pre-prefix (Maddieson 1976; Kaji 1996).

In essence, the patterns listed in (28-30), along with the previously mentioned target patterns and "inert" tonally faithful patterns, cover all kinds of effects that licensing grammars can generate. However, grammars can also mix the various effects presented above by making them apply only to tones in certain positions. One demonstration of such mixing are the patterns in (31). These patterns show a tone change only in the form with the underlyingly initial High tone; tone in the other forms does not move. The crucial constraint for this kind of effect is LICENSE(H, FT-R), which requires tone licensing at the right edge of a foot. For tone associated only to the initial syllable, this is an impossible goal, because with binary feet, right edges are never at the initial syllable. Consequently, the initial-High form is uniquely triggered to seek out a foot edge, while the other forms may remain inactive.[32]

[32]When there is no foot at the edge, the reverse effect can obtain, where only the initial tone is inactive because it cannot be licensed. In this case, the pattern must necessarily be a bounded one, since there is no edge foot to trigger an unbounded pattern. In addition, the pattern must go leftward, since the right-edge licensing constraint is what excludes the

(31) *Initial-only patterns (licensing framework)*

/σ́σσσσ/	/σσ́σσσ/	/σσσ́σσ/	
$(\acute{\sigma}\acute{\sigma})\sigma\sigma\sigma$	$(\sigma\acute{\sigma})\sigma\sigma\sigma$	$\sigma(\sigma\acute{\sigma})\sigma\sigma$	Initial doubling
$(\sigma\acute{\sigma})\sigma\sigma\sigma$	$(\sigma\acute{\sigma})\sigma\sigma\sigma$	$\sigma(\sigma\acute{\sigma})\sigma\sigma$	Initial binary shift
$\acute{\sigma}\sigma\sigma(\sigma\acute{\sigma})$	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\sigma\acute{\sigma})(\sigma\sigma)$	Initial final copy
$\acute{\sigma}\acute{\sigma}\acute{\sigma}(\sigma\acute{\sigma})$	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\sigma\acute{\sigma})(\sigma\sigma)$	Initial penult skip
$\acute{\sigma}\acute{\sigma}\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\sigma\acute{\sigma})(\sigma\sigma)$	Initial final spreading

As for the attestation of initial-only patterns, the bounded patterns, i.e. initial-only doubling or binary shift, resemble some of the "edge effects" that I discuss below. Although I am not aware of any attestations, I expect the patterns to be within the scope of natural language. The last three patterns, which show a long-range pattern, are unlike any type of tonal reassociation that I have come across.[33] Something should account for their non-attestation; it could be that the framework is overgenerating, but I also consider it plausible that these patterns are hard to learn. I return to the issue of learnability in section 4.5.1 of the discussion.

The initial-only unbounded patterns are reminiscent of another phenomenon, which is the distribution of lexical tone patterns in some languages. For example, in Ikoma, all nouns are either low-pitched throughout, have one single-linked High tone, or have a High tone spread over the whole noun (Aunio 2015). It would be interesting to see if licensing effects can shed any light on the generalizations obtaining for such patterns of tone distribution.

In contrast to initial-only patterns, there are also instances where a tone's proximity to an edge (here, the right edge) makes it uniquely capable of being footed or interacting with a foot. This effect is related to ALIGN-R(ω, FT), which can drive grammars to place a foot only at the right edge, and then allow interaction only with tones sufficiently close to that foot. Some examples are shown in (32).

initial tone from participating. Finally, the pattern must be a spreading pattern, because a shift would destroy the licensing status that triggered foot construction in the first place. Thus, the only type of "non-initial" pattern in the factorial typology is "non-initial bounded leftward spread", for example with the mappings $\{/\acute{\sigma}\sigma\sigma\sigma\sigma/ \rightarrow \acute{\sigma}\sigma\sigma\sigma\sigma,\ /\sigma\acute{\sigma}\sigma\sigma\sigma/ \rightarrow (\acute{\sigma}\acute{\sigma})\sigma\sigma\sigma,\ /\sigma\sigma\acute{\sigma}\sigma\sigma/ \rightarrow \sigma(\acute{\sigma}\acute{\sigma})\sigma\sigma\}$.

[33] A related effect shows up in Ndebele (Downing 1990:266), which typically has shift to the antepenultimate, but "if the high tone is originally associated with a word-initial syllable, not only is the antepenult high-toned, but also the initial syllable and all intervening syllables remain high-toned[.]" However, here the pattern coming from the initial sponsor is highly similar to that of the other sponsors; the only difference is in the treatment of the intervening syllables. Furthermore, the default pattern in Ndebele is already an unbounded pattern, which in the licensing framework would mean that there is no reason for licensing near the sponsor and hence no reason for special treatment of the initial sponsor. Consequently, I do not interpret the Ndebele facts as giving support for the need of initial-only effects as generated by the licensing framework.

(32) *Edge effects (licensing framework)*

$/\acute{\sigma}\sigma\sigma\sigma\sigma/$	$/\sigma\acute{\sigma}\sigma\sigma\sigma/$	$/\sigma\sigma\acute{\sigma}\sigma\sigma/$	
$\acute{\sigma}\sigma\sigma(\sigma\sigma)$	$\sigma\acute{\sigma}\sigma(\sigma\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\sigma)$	Edge doubling
$\acute{\sigma}\sigma\sigma(\sigma\sigma)$	$\sigma\acute{\sigma}\sigma(\sigma\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	Edge tripling
$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\sigma)$	Penult shift; edge doubling
$\sigma\sigma\sigma(\sigma\acute{\sigma})$	$\sigma\sigma\sigma(\sigma\acute{\sigma})$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	Final shift; edge tripling
$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	$\sigma\acute{\sigma}\acute{\sigma}(\acute{\sigma}\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\sigma)$	Penult shift; edge penult spread
$\sigma\sigma\sigma(\sigma\acute{\sigma})$	$\sigma\acute{\sigma}\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	Final shift; edge final spread

The patterns show a variety of ways in which the edge effect might interact with a default effect. In the first two examples, the default pattern is faithful, and only the third form shows any tonal reassociation. Then, a doubling or tripling effect in the third form can also coexist with an unbounded default pattern. In the last two examples, the edge-triggered unbounded spread from $/\sigma\acute{\sigma}\sigma\sigma\sigma/$ shows that the edge effect can extend even to the preantepenultimate syllable.

Although the naming convention might suggest that the edge effects are a completely separate phenomenon from the default pattern, the variety of edge effects is actually more constrained. This is because every combination of an edge effect and a default pattern must still arise from a single constraint ranking. For example, there is no item in the result set that represents "penult shift + edge tripling", because if the final syllable was a target for the edge pattern, it would also be a target for the default unbounded pattern.

There are attested cases of languages that show deviating behavior of tones near the edge. For example, in Zulu, Ndebele, and Xhosa, according to Downing (1990:272), the default pattern is for tone to shift to the antepenultimate, but if the morpheme contributing the tone starts at the antepenultimate, then tone will surface on the penult instead. However, I do not know of patterns where edge effects trigger a highly different pattern than the default, as is the case for example for "edge tripling" in (32), or the difference between default final shift and edge (including preantepenult-triggered) final spread in the last row – termed "final shift; edge final spread". Formalizing this, I propose to single out patterns where the span length of tones affected by the edge effect is 2 or more units longer or shorter than tones following the default pattern. For these patterns, I am skeptical about the possibility of attestation and consequently, I will judge them to be overgeneration of the framework. For the remaining majority, I conlude that the predicted edge effect patterns are either attested or accidental gaps.

The overgenerated edge effects can again be linked to the allowance of gapped tones. In these cases, the stark difference between the edge and default pattern is due to the fact that tones near the edge can create minimal gaps, which are gaps skipping exactly one syllable. The special property of minimal gaps is that they can be resolved, by which I mean that all violations (only one) of NoGap can be repaired, through a single step of gap-filling. For larger gaps, the only way of resolving NoGap immediately is delinking. Consequently, the

Pattern	*Count*
Tonally faithful	11
Faithful + initiality/edge effects	22
Bounded	6
Bounded + initiality/edge effects	19
Unbounded	9
Unbounded + edge effects	6
Total	73

Table 4.17: Counts of predicted patterns, by type (licensing framework)

overgenerating edge effect patterns are cases where the default gap resolution strategy is delinking, and exceptionally, in minimal gaps, the resolution strategy is filling.[34]

This concludes a round-up of the results. Table 4.17 shows a breakdown of the result set into the types of variation I have discussed.

The counts in Table 4.17 show that the variety of simple bounded and unbounded patterns is relatively small; the brunt of the predicted variation comes from the mingling of such patterns with deviating behavior in the initial syllable, or in the syllables near the right edge. Another thing that shows from the table is that unbounded patterns do not combine with special behavior of the initial syllable. This is expected given that deviation of the initial syllable is a consequence of the difficulty of licensing tone in this position. Unbounded patterns arise because tone is allowed to be licensed at the edge of the domain, even despite creating gaps, and so licensing the initial syllable is not an exceptional case for unbounded patterns.

Summarizing so far, the licensing framework has been shown to successfully generate all the target patterns. However, a number of non-target predictions, namely copy patterns, penult skipping, and some edge effects, seem to be cases of overgeneration tied to the nature of gapped tone structures. It will be interesting, then, to see if a framework without tone gapping can give a more accurate characterization of natural language variation. Hence, in the following, I present the factorial typology for the edgewise association framework.

4.4.3 Typological predictions of the edgewise framework

Target patterns

The edgewise association framework has an answer for simple bounded and unbounded shift or spread patterns, as was demonstrated in section 4.3.5. Consequently, all target patterns that can be analyzed with binary feet were

[34] To get spreading from preantepenultimate sponsors in this way, the minimal gap must be created by linking to the penult, and spreading from there. So, for the preantepenultimate sponsor in "final shift; edge final spread", the mapping will include the intermediate form $\sigma\underline{\acute{\sigma}}_1\sigma\acute{\sigma}_1\sigma$, with a minimal gap.

attested — with one exception. As with licensing, the case of Saghala stands out. Howevever, unlike licensing, edgewise association runs into a serious problem on this pattern. In the edgewise association framework, delinking only refers to whether a syllable is footed or not; there is no precision-delinking that will leave some foot positions alone. Thus, if Saghala were to create a ternary domain to reassociate its tones, delinking would either not apply at all, or apply to all but the edgemost tone to yield [*...$((\underline{\sigma}\sigma)\acute{\sigma})$...] rather than the attested [...$((\underline{\sigma}\acute{\sigma})\acute{\sigma})$...]. Even an appeal to foot type will not help, since both the delinking and non-delinking target are within both feet.

The problem is demonstrated in detail with the tableau in Table 4.18. I assume the derivation has proceeded successfully to the point of reaching the target form. For this to be the case, *H/Ft must outrank Max-Link, so that tone will delink from the sponsor with the goal of avoiding association to footed material. Given this, the derivation cannot converge on the target form even if it is assumed that it reaches it; the faithful, desired, candidate 4.18a is inferior to the option of further delinking represented by 4.18b.

$((\sigma\acute{\sigma})\acute{\sigma})\sigma$	*H/Unfooted	All-T-R	*H/Ft	Max-Link
a. ϟ $((\sigma\acute{\sigma})\acute{\sigma})\sigma$		*	**!	
b. ☞ $((\sigma\sigma)\acute{\sigma})\sigma$		*	*	*
c. $((\sigma\acute{\sigma})\acute{\sigma})\acute{\sigma}$	*!		**	

Table 4.18: The edgewise framework does not converge on Saghala target forms

Having noted this difficulty for the edgewise association framework, I first move on to a presentation of the framework's other predictions. I will take up the comparison to the licensing framework in more depth in section 4.4.4.

Non-target patterns

The result set for the edgewise framework's factorial typology is considerably smaller than that of the licensing framework, with 47 vs. 73 metrically different patterns. This is in large part because there are far fewer edge effect patterns predicted for the edgewise association framework. The edgewise framework presents some patterns not seen in the licensing framework, which show a sensitivity to whether the distance between the sponsor and the right edge of the domain is of even or odd length. I will present these patterns below and end with a numerical overview.

The most striking type of prediction following from the framework is a pattern where the outcome of tone association depends on whether there is an unbroken chain of feet leading to the edge of the word. I dub these "footbridge" effects; examples are in (33).

(33) *Footbridge patterns (edgewise association framework)*

/σ́σσσσ/	/σσ́σσσ/	/σσσ́σσ/	
$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\sigma\sigma)(\sigma\acute{\sigma})$	$\sigma(\sigma\sigma)(\sigma\acute{\sigma})$	Footbridge final shift
$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	$\sigma(\sigma\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	Footbridge final spread
$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\sigma\sigma)(\sigma\acute{\sigma})$	$\sigma\sigma(\sigma\acute{\sigma})\sigma$	Footbridge final shift; edge bounded shift
$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	$\sigma\sigma(\acute{\sigma}\acute{\sigma})\sigma$	Footbridge final spread; edge bounded spread

In all patterns in (33), the grammar is trying to associate tone as close as possible to the right edge, under pressure of ALL-T-RIGHT. However, because of the adjacency-based nature of OP:LINK-AT-EDGE in the edgewise approach, defined earlier in (21), all the intermediate positions need to be accessible, too. The footbridge grammars are very restrictive on this point: only footed positions are acceptable as intermediate association points, which is an effect that can be triggered by *H/FT. When there is no chain of feet from a sponsor to the edge, which can happen when the sponsor is on an odd-numbered syllable, tone reassociation cannot reach all the way to the edge. In such cases, the optimal result is a bounded effect. The difference between the top two and bottom two patterns is that in the former, ALIGN-R(ω, FT) is high-ranked, creating a "footbridge" to the antepenultimate syllable, so that the third underlying form can participate in the unbounded pattern.

The footbridge effects do not resemble any pattern that I am aware of. For example, to my knowledge there is no language that has contrastive tone at the surface only on odd-numbered sponsors and on the ultimate, which is what the "footbridge final shift" pattern comes down to. Consequently, I consider these predictions to be clear cases of overgeneration.

For another type of pattern predicted by edgewise association, feet are always in an unbroken chain from the edge, and tone association lines up neatly with feet, so that at the surface all tone spans are of odd length or all tone spans are of even length. For this reason, I refer to these patterns collectively as odd/even spreading patterns. Relevant patterns are listed in (34).

(34) *Odd/even spreading patterns (edgewise association framework)*

/σ́σσσσ/	/σσ́σσσ/	/σσσ́σσ/	
$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	$\sigma\sigma\sigma(\acute{\sigma}\acute{\sigma})$	Even-length final spread
$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	Odd-length penult spread
$(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})\sigma$	$\sigma\sigma(\acute{\sigma}\acute{\sigma})\sigma$	$\sigma\sigma(\acute{\sigma}\acute{\sigma})\sigma$	Even-length penult spread

In these patterns, a major role is played by *H/UNFOOTED, as evidenced by the delinking of tones from sponsor syllables that do not get footed, in the first two listed patterns. In addition to delinking, another strategy to satisfy *H/UNFOOTED is to place a foot over a syllable carrying a tone. In fact, this strategy is sometimes more efficient than delinking, since footing can target two tone-carrying syllables at once, thus removing two violations of *H/UNFOOTED in one derivational step. The grammars in (34) give preference to the footing repair in exactly these contexts, and they favor delinking when only one violation can be repaired with a derivational step. Hence, the length of the surface tone span grows in steps of two. In the penult spreading patterns, whether the length is odd or even depends on whether foot building starts from the edge or from the penult, which is determined by the rank of ALIGN-R(ω, FT).

I do not know of any attestations of always-even or always-odd-length spreading. The spreading effect itself is a case of unbounded spreading, whose attestation has been discussed above. The metrical nature of the pattern is more unusual; it is iterative, but conditional on another factor, here the presence of tone. If the always-even/odd patterns are part of natural language, then it might be expected that other languages can show conditional iterativity for other factors than tone. For example, one might expect a language with iterative footing as long as the footed syllables contain onsets, or [+nasal], etc. I know of no pattern that resembles such effects.

The two sets of patterns above are the only types of prediction particular to edgewise association. The edgewise approach also predicts some edge and initial-only effects, but the variation is more restricted than in the licensing approach. In particular, the only initial-only effects are the two in (35), which appear in conjunction with an unbounded pattern for the forms with non-initial sponsors.

(35) *Patterns with initial-only effects (edgewise framework)*

$/\acute{\sigma}\sigma\sigma\sigma\sigma/$	$/\sigma\acute{\sigma}\sigma\sigma\sigma/$	$/\sigma\sigma\acute{\sigma}\sigma\sigma/$	
$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	$\sigma(\sigma\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	Final spread; initial-only shift
$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\sigma)$	$\sigma(\sigma\acute{\sigma})(\acute{\sigma}\sigma)$	Penult spread; initial-only shift

From the first two forms, it may look like these patterns are further instances of even spreading. The special status of the initial becomes apparent in comparison with the behavior of the third form; that form, despite the footing of the tone, retains an odd-length tone span. It is only the initial, unfootable tone that must be shifted away here. The low number of initial-only effects in the edgewise association framework is related to the different way that tone reassociation is motivated; since ALL-T-RIGHT is not directly connected to footing status — unlike the licensing constraints — it is less sensitive to the position of the initial syllable, which is special only in the sense that it cannot be aligned with a right foot edge.

A numerical overview of the predictions of the edgewise approach is presented in Table 4.19. The clearest difference between these counts and those for the licensing framework is that the edgewise framework predicts proportionally far fewer mixed patterns, i.e. those with edge or initial-only effects in addition to a default pattern.

Pattern	*Count*
Tonally faithful	6
Faithful + edge effects	9
Bounded	2
Unbounded	17
Unbounded + initiality effects	2
Footbridge	8
Odd/even spreading	3
Total	47

Table 4.19: Tally of predicted patterns (edgewise association framework)

4.4.4 Summary

Firstly, for comparison, I repeat the numerical overview for the various patterns for the two frameworks side-by-side in Table 4.20.

Pattern	*Licensing count*	*Edgewise count*
Tonally faithful	11	6
Faithful + initiality/edge effects	22	9
Bounded	6	2
Bounded + initiality/edge effects	19	–
Unbounded	9	17
Unbounded + initiality/edge effects	6	2
Footbridge	–	8
Odd/even spreading	–	3
Total	73	47

Table 4.20: Counts of predicted patterns for both frameworks

On the target patterns, both frameworks perform perfectly or close to it. The only outstanding issue is how an edgewise approach might account for the mixed bounded pattern of Saghala, as noted above. When it comes to non-target patterns, both frameworks display edge and initiality effects, although the licensing framework produces more, and more varied, patterns of these kinds. This difference is particularly stark for initiality effects, which are almost nonexistent for the edgewise framework (only 2 patterns are predicted), whereas the licensing framework displays a wide range of initiality effects, some of which deviate strongly from the default pattern – for example, a pattern that is always tonally faithful, except for initial sponsors, which spread all the way to the final syllable. As I noted above, these egregious initial-only patterns, along with copying and skipping patterns, are a result of the possibility of tone gaps in the licensing framework. If attestations of these patterns become available, it would strengthen the evidence for a licensing-style analysis of tonal reassociation, but until such time, proponents of the licensing framework carry the burden of having to find an alternative source of explanation for the absence of initial-only, copying, and skipping patterns from natural language variation.

The edgewise framework has some problematic predictions of its own; as stated, I know of no attestation of either odd/even-length spreading patterns, nor of the footbridge patterns — with the latter not even appearing to me to be interpretable as the composition of simpler, attested patterns. Again, proponents of the edgewise approach will need to search for extra-grammatical causes for the non-attestation of such patterns. One potential avenue is to consider learnability; for both of the pattern types, some underlying forms map to the same surface form, blurring evidence of sponsor locations. For example, the "even-length penult spread" pattern in (34) maps both $/\sigma\acute{\sigma}\sigma\sigma\sigma/$ and $/\sigma\sigma\acute{\sigma}\sigma\sigma/$ to $[\sigma\sigma(\acute{\sigma}\acute{\sigma})\sigma]$. I return to considerations of learnability in section 4.5.1.

The tallies in Table 4.20 are counted while preserving the metrical structure in all patterns. Since I assume that metrical structure might be present without being expressed phonetically, it is also interesting to look only at the variation in terms of tonal structure. To this end, Table 4.21 shows the tallies for the predictions of various types of patterns where I do not distinguish patterns based on differences only in metrical structures. For example, if two patterns map $/\acute{\sigma}\sigma\sigma\sigma\sigma/$ to $[\acute{\sigma}\sigma\sigma\sigma\sigma]$ and $[\acute{\sigma}\sigma\sigma(\sigma\sigma)]$ respectively, these mappings are considered the same for the purposes of the tally in Table 4.21.

Pattern	*Licensing count*	*Edgewise count*
Tonally faithful	1	1
Faithful + initiality/edge effects	15	9
Bounded	3	2
Bounded + initiality/edge effects	17	–
Unbounded	9	7
Unbounded + initiality/edge effects	6	2
Footbridge	–	6
Even/odd spreading	–	3
Total	51	30

Table 4.21: Counts of predicted patterns, ignoring metrical structure

The reductions in numbers occur in different categories for the two frameworks. The licensing framework had eleven different ways of predicting tonally faithful patterns, which are all treated as identical for the purposes of the tonal variety tally in Table 4.21. The edgewise framework saw the largest reduction in the unbounded category, going from 17 to seven different patterns. The total number of different patterns now comes out as 51 versus 30 for the licensing and edgewise frameworks, respectively. This is a less skewed distribution than in the metrically sensitive count in Table 4.20, but with the trend in the same direction; the licensing framework generates more variety, and does so mostly through the number of edge and initiality effects that it can generate.

With this, I conclude the presentation of the results. One aspect that I have not commented on here is the *absence* of some patterns from the result set. I take up this and various other matters in the discussion section, below.

4.5 Discussion

4.5.1 Non-phonological restrictions on attestation

In assessing the accuracy of the tonal reassociation frameworks, I need to decide where to place the limits of cognition — or at least the limits of a speaker's phonological faculty. One problem in this enterprise is that such limits are not necessarily easily reachable. That is, some patterns that are perhaps handleable by a speaker's phonology might get stuck in what I will term "extra-grammatical filters"; some patterns might be processable, yet not (easily) perceptible, learnable, or diachronically construable. Thus starts the analyst's dilemma of whether to label a non-attested prediction as an accidental or essential gap in the data, which I have repeatedly grappled with in the previous section. Here, I point out some specific cases of such extra-grammatical filters that bear on one or more of the non-target predictions discussed in section 4.4.

Restricted domain length

For some patterns in the prediction sets, for example some of the footbridge patterns, a domain length of five syllables is crucial for the pattern to properly show itself — with edge effects operating over the last four syllables. With layered feet, it is likely that this number is still too low. Consequently, for these patterns to be attested, the language in question should allow for large prosodic domains of five or more syllables. This opportunity will not always present itself. First and foremost, not all languages possess the lexical or morphological ingredients to form prosodic domains this large. Secondly, it might not always be within the scope of a given fieldwork project to elicit such large domains. From this, I conclude that certain groups of patterns are at risk of being underreported by the nature of their needing a large domain for full expression.

Restricted learnability

In the discussion above, I noted that for some patterns, the prosodic domain needs to be of a certain length before the pattern can be fully expressed. However, even if that condition is met, it is not guaranteed that a learner will acquire the pattern as such. Firstly, it is possible that the learner holds a bias against particular types of patterns (Moreton 2008). If this is the case, the likelihood of attestation of such patterns goes down, even if they are perfectly processable and hence should be predicted by frameworks such as those considered here.

Secondly, even in the absence of analytic bias, the learner might not be presented with enough or sufficiently consistent evidence. For example, Jarosz (2016) simulates learning in HS with Serial Markedness constraints for various types of opacity, reporting that rate of learning depends not only on the type of opacity, but also on the distribution of evidence across the input. Learning simulations take longer to converge on data sets where crucial evidence is less frequent;[35] and learning rates are also lower on data sets with little separate evidence of the subpatterns that together make up the opaque pattern. In the present typological predictions, initial-only patterns also provide part of the evidence only in very narrow cases; as the pattern's name suggests, its full nature crucially requires a learner to absorb the necessary information from sponsor-initial cases, which might go against the evidence found in all other forms. Consequently, it is possible that the non-attestation of initial-only patterns is related to the difficulties learners would face in acquiring such patterns.

Here, I suffice with merely pointing out these factors, as an argument to caution against branding every unattested prediction as overgeneration of the model. Follow-up work in Chapter 5 investigates learning simulations of a variety of tonal reassociation patterns in detail.

4.5.2 Quaternary patterns

One of the desiderata for a framework of tonal reassociation was that it captures the generalization that such phenomena are binary or ternary. Consequently, I here take up the question whether the frameworks can predict larger-than-ternary effects, specifically quaternary ones.

In the calculations using binary feet, neither framework predicted a bounded ternary pattern. That is, there is no outcome with sets of mappings such as $\{\, \acute{\sigma}\sigma\sigma\sigma\sigma\!\rightarrow \acute{\sigma}\acute{\sigma}\acute{\sigma}\sigma\sigma,\ \sigma\acute{\sigma}\sigma\sigma\sigma\!\rightarrow \sigma\acute{\sigma}\acute{\sigma}\acute{\sigma}\sigma\}$, i.e. "ternary spreading" or $\{\, \acute{\sigma}\sigma\sigma\sigma\sigma\!\rightarrow \sigma\sigma\acute{\sigma}\sigma\sigma,\ \sigma\acute{\sigma}\sigma\sigma\sigma\!\rightarrow \sigma\sigma\sigma\acute{\sigma}\sigma\}$, i.e. "ternary shift". Extrapolating this result to an implementation with ternary feet, then, I conclude that neither framework predicts a bounded quaternary pattern.

On the other hand, in a context with layered feet, both frameworks are able to target the fourth position from the edge. For the edgewise framework, this is easily shown; given a right-aligned layered foot and a ranking *H/Ft $\gg$ All-T-Right, tone will stop at the fourth syllable from the right edge, just before the footed part of the domain. I show that a grammar can converge on

[35] Although the chapter does not explicitly state the criteria for convergence, Jarosz (p.c., September 2017) states that convergence testing was done with repeated sampling from the learner's grammar. In general, such an approach defines convergence as a situation where random sampling from the grammar reaches some required rate of correct behavior of target forms.

this state with the tableau in Table 4.22, leaving a reconstruction of possible preceding derivational steps to the reader.

$\acute{\sigma}\acute{\sigma}..\acute{\sigma}(\sigma(\sigma\sigma))$	*H/FT	ALL-T-RIGHT
a. ☞ $\acute{\sigma}\acute{\sigma}..\acute{\sigma}(\sigma(\sigma\sigma))$		***
b. $\acute{\sigma}\acute{\sigma}..\acute{\sigma}(\acute{\sigma}(\sigma\sigma))$	*!	**

Table 4.22: An edgewise grammar can converge after spreading to the preantepenultimate

Licensing in a context with ternary feet can also lead to targeting of the fourth syllable from the edge. This does require the assumption that there is some parsing mechanism that promotes the building of non-edge-adjacent feet.[36] A derivation might proceed as outlined by the steps in Table 4.23. There are two main effects here. Firstly, tone should jump to the antepenult before the pre-antepenult position becomes a valid association target. This is easily achieved by ranking LICENSE(H, FT) over the parsing mechanism that builds the second foot. The more complex part of the derivation are steps 4-5, where the newly placed foot offers the tone a better association target, causing a move "backwards" in the direction of the sponsor. One interpretation of this is that the tone moves to a position where it is licensed at a right foot edge. Thus, using LICENSE(H, FT-R) and other constraints, I model steps 4 and 5 in the tableau in Table 4.24. After step 5, a single violation of *H/σ remains, which is minimal since I do not allow tones to delink completely and become floating. Consequently, after step 5, convergence is guaranteed in step 6.

	Form	*Comment*
0.	$\acute{\sigma}\sigma...\sigma\sigma\sigma\sigma\sigma$	Underlying form
1.	$\acute{\sigma}\sigma...\sigma\sigma(\sigma(\sigma\sigma))$	Place layered foot at edge (*collapsed*)
2.	$\sigma\sigma...\sigma\sigma(\acute{\sigma}(\sigma\sigma))$	Shift to the antepenult (*collapsed*)
3.	$\sigma\sigma...(\sigma\sigma)(\acute{\sigma}(\sigma\sigma))$	Continue foot construction
4.	$\sigma\sigma...(\sigma\acute{\sigma})(\acute{\sigma}(\sigma\sigma))$	Associate to the new foot
5.	$\sigma\sigma...(\sigma\acute{\sigma})(\sigma(\sigma\sigma))$	Delink from the antepenult (*guaranteed convergence*)

Table 4.23: Steps of the derivation of pre-antepenultimate shift

I conclude that neither framework generates bounded quaternary patterns, but also that both frameworks can generate unbounded quaternary patterns. However, unbounded quaternary patterns do require a commitment of the grammar to specific foot structures — for both frameworks, it requires a ternary foot at the edge; and the licensing framework further requires a parsing mechanism that will add at least one more foot next to the edge.

To some extent, this result reflects the typology; while I do not know of any bounded quaternary patterns, a form of quaternarity-at-the-edge is attested

[36]This is another niche where the difference between ALL-FT-L/R and CHAIN-L/R becomes relevant; see the earlier footnote 29.

$\sigma\sigma ... (\sigma\sigma)(\acute{\sigma}(\sigma\sigma))$	$\mathcal{L}$(H, FT)	NOGAP	$\mathcal{L}$(H, FT-R)	*H/σ
Step 4				
a. $\sigma\sigma ... (\sigma\sigma)(\acute{\sigma}(\sigma\sigma))$			*!	*
b. ☞ $\sigma\sigma ... (\sigma\acute{\sigma})(\acute{\sigma}(\sigma\sigma))$				**
c. $\sigma\sigma ... (\sigma\sigma)(\acute{\sigma}_1(\sigma\acute{\sigma}_1))$		*!		**
Step 5 — guaranteed convergence				
d. $\sigma\sigma ... (\sigma\acute{\sigma})(\acute{\sigma}(\sigma\sigma))$				**!
e. ☞ $\sigma\sigma ... (\sigma\acute{\sigma})(\sigma(\sigma\sigma))$				*

Table 4.24: Final steps of a preantepenultimate shift derivation (*licensing*)

for Kuria (Marlo et al. 2015). Kuria has a variety of tone patterns indicating different tenses. In the "Inceptive" tense, High tone occurs on the fourth and subsequent moras counting from the left edge of the verb stem. The examples in (36a) show this for verbs in isolation, but the examples in (36b) show that the pattern applies also to combinations of verbs and nouns, where tone might even surface exclusively on the noun, although counting still proceeds from the verb stem. Following Marlo et al., I indicate the verb stem with brackets.

(36) a. Rightward spreading from the fourth stem mora on verbs (Marlo et al. 2015)
   i. to-ra-[heetok-á] 'we are about to remember'
   ii. to-ra-[koondokór-a] 'we are about to uncover'
   iii. to-ra-[kiriɣiít-a] 'we are about to scrub'
   iv. to-ra-[hootoótér-a] 'we are about to reassure'

   b. Rightward spreading from the fourth mora on verb+noun phrases
   i. to-ra-[karaaŋg-á] éɣétɔ́ɔ́kɛ́ 'w.a.a.t. fry a banana'
   ii. to-ra-[sukur-a] éɣétɔ́ɔ́kɛ́ 'w.a.a.t. rub a banana'
   iii. to-ra-[rom-a] eɣétɔ́ɔ́kɛ́ 'w.a.a.t. bite a banana'

Crucially, tone in this data is the result of tense marking, i.e. it is a so-called melodic High (Odden and Bickmore 2014); Kuria verbs do not have lexically contrastive tone. If the present result that human cognition is capable of modeling pre-antepenultimate targeting is correct, one should expect the attestation of a lexical reassociation pattern to the preantepenultimate TBU — flipping the edge orientation from Kuria — as well. To my knowledge, this is not attested, but given that quaternary patterns are already extremely rare, and that melodic tones tend to target the same positions as reassociation patterns, I do not rule out the possibility that this gap in the typology is accidental.

4.5.3 Predicted absences of functionally composed patterns

Some patterns can be thought of as the functional composition of two or more simpler patterns. For example, I describe the Saghala pattern, which performs $/\acute{\sigma}\sigma\sigma/ \rightarrow [\sigma\acute{\sigma}\acute{\sigma}]$, as "binary shift + binary spread", i.e. as the sequential application of a bounded shifting pattern and a bounded spreading pattern. While a naive approach might be to expect that any combination of patterns is possible, the strength of theoretical-typological work such as the present is that it makes more specific claims about the absences of such combined patterns. In fact, many functional compositions of attested patterns are absent from the predicted typologies of both frameworks examined here.[37] For example, there is no "unbounded Saghala", which shifts one place and then spreads, e.g. $/\acute{\sigma}\sigma\sigma\sigma\sigma/ \rightarrow [\sigma\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}]$, despite the fact that both binary shift and unbounded spreading patterns are part of the factorial typologies. Similarly, the factorial typology of the licensing framework contains no "bounded spread then copy", e.g. $/\acute{\sigma}\sigma\sigma\sigma\sigma/ \rightarrow [\acute{\sigma}_1\acute{\sigma}_1\sigma\sigma\acute{\sigma}_1]$. For these cases, this prediction-of-absence is desirable, since to my knowledge neither of these patterns is attested. In general, I leave it to future work to formulate more precisely which functional compositions one might naively expect given the attested language variation, and to investigate and explain the extent to which metrical and other approaches of reassociation are successful on those criteria.

4.5.4 Licensing feet with tone

In addition to the tone licensing constraints used here, the constraint set of Chapter 2 also included licensing constraints where the relationship between feet and tone is reversed. That is, in Chapter 2 there were foot licensing constraints such as License(Ft, H), defined in (37).

(37) License(Ft, H)
"For each foot, assign one violation mark if none of its syllables are associated to a H tone." (Chapter 2:34)

The addition of foot licensing constraints to the licensing constraint set used here would significantly expand the framework's generative capabilities. It would allow modeling of some unbounded mixed patterns, as discussed in section 4.5.3, and even bounded quaternary patterns, as discussed in section 4.5.2. I illustrate the latter with the tableau in Table 4.25. The tableau shows how a foot licensing effect can cause the grammar to span a four-syllable stretch, rather than spread adjacently.

There are also arguments in favor of adopting foot licensing constraints. In Chapter 2, the foot licensing constraints were used to control at what point in the derivation layered feet could be placed; high-ranking foot licensing constraints blocked the construction of layered feet until a point in the derivation where tone was positioned so that it could immediately license a newly constructed layered foot. While there might be other theoretical means

[37] Many of these cases are necessarily masked, e.g. when both patterns are of a spreading type or both of a shifting type. Some are predicted by the factorial typologies — the "final doubling shift" pattern can be thought of as an unbounded shift followed by a bounded spreading pattern.

$(\acute{\sigma}\sigma)(\sigma\sigma)$	$\mathcal{L}$(H, FT-R)	LICENSE(FT, H)	NOGAP
a. $(\acute{\sigma}\sigma)(\sigma\sigma)$	*!	*	
b. $(\acute{\sigma}\acute{\sigma})(\sigma\sigma)$		*!	
c. ☞ $(\acute{\sigma}_1\sigma)(\sigma\acute{\sigma}_1)$			**
d. $(\acute{\sigma}_1\sigma)(\acute{\sigma}_1\sigma)$	*!		*

Table 4.25: A quaternary tone jump can be optimal with foot licensing constraints

to derive that particular effect, other data lead to an arguably stronger case for foot licensing constraints; in some languages, tone alternates "rhythmically", surfacing on every other syllable in the domain. I show example forms of this phenomenon reported for Lamba (Bickmore 1995) in (38); another relevant case is tone in Kirundi (Goldsmith and Sabimana 1989; Hyman 2006).[38] For some of the forms in (38), no glosses were reported; I have inferred these from other glosses and descriptions of individual morphemes in the source. Following Bickmore, I indicate the start of the relevant morphological domain with an opening bracket.

(38) Rhythmic tone in Lamba (Bickmore 1995)

a. u-ku-kom-a — 'to hurt'
b. <u>ta</u>-tu-[mú-kom-a — '[inferred] we do not hurt him'
c. <u>ta</u>-tu-[lúku-kom-a — '[inferred] we are not hurting'
d. tu-[lúku-mú-kom-a — '[inferred] we are hurting him'
e. <u>ta</u>-tu-[lúku-mú-kom-a — 'we are not hurting him'

From (38a,d), it shows that the only source of High tone is the "General Negative" morpheme, /tá/. The generalization in Lamba is as follows: Starting from some morphological stratum, indicated here with opening brackets, and counting up until the verb root, assign tone to every odd-numbered TBU, under the condition that some tone is lexically contributed. Feet are the obvious device to account for such iterative, alternating tone realization; and foot licensing constraints model the required effect of ensuring that every feet receives an association with a tone. However, given the problematic typological predictions pointed out above, future work for licensing approaches might want to look for alternative analyses of rhythmic tone patterns.

The edgewise association framework is untroubled by this dilemma, since it is defined here without any licensing effects. However, this also means that it is in more dire need of a means of accounting for rhythmic tone patterns. Again, I leave a more careful consideration of these matters for future research.

[38] I use the transcriptions from Bickmore (1995). Bickmore does not state how his transcriptions relate to IPA, but he does indicate that the transcriptions at least partially follow standard Lamba orthography (Bickmore 1995:309).

4.5.5 Contexts with multiple High tones

Another testing ground for the present frameworks are tone association patterns in contexts with multiple tonal autosegments. Such contexts can introduce considerable complexity on top of a pattern found in single-tone contexts. I note two cases here, which favor the two different frameworks, respectively.

Firstly, in Copperbelt Bemba, the rightmost tone performs unbounded spreading (if it is in the phrase-final word), while the other tones show a bounded, ternary spreading pattern (Bickmore and Kula 2013; Kula and Bickmore 2015; see Jardine 2016a for a discussion of the computational complexity of this pattern). Some example forms are shown in (39).[39] Several vowel-initial sponsors have lost their surface tone. The relevant data for my point are embedded in larger data including a second phonological phrase; I have listed this phrase separately in parentheses. The gloss is based on the composition of the two phrases.

(39) Non-rightmost bounded and rightmost unbounded spread in Copperbelt Bemba

a. bá-ká-ʃíik-il-o o-mú-límí (búúpe)
 ‘They will bury Bupe for the farmer’

b. u-kú-mú-ꜝbé-lééŋg-él-ó (ó-mú-límí) ‘to read to the farmer’

c. u-kú-pát-e e-m-bálámínwé (sáaná) ‘to hate the rings a lot’

The first two data can only demonstrate part of the full pattern. Example (39a) demonstrates bounded spreading of the non-rightmost tone, rather than e.g. *bá-ká-ʃíík-íl-ó; and example (39b) demonstrates the unbounded spreading of the rightmost tone, e.g. *bé-lééŋg-él-o. Both effects are combined in (39c).

The licensing framework is suited to deal with this pattern, because it can allow hyperactivity of the rightmost tone if we presume the existence of an edgemost foot that the rightmost tone must seek licensing from. In contrast, all the non-rightmost tones are licensed by a foot *in situ*, as I suggest in general for a licensing analysis for bounded tone. Table 4.26 suggests the steps that a derivation of this pattern could take.

The data is more problematic for an edgewise association analysis. There, the unbounded spreading is the natural result of rightward tone attraction, per ALL-T-RIGHT. However, the non-rightmost tones do not follow suit; their spreading is blocked — and yet not absolutely, but only beyond a ternary span. I leave it to future work to determine whether a modified version of the

[39] In (39a), I have listed the word boundary in the middle of the long vowel, according to the groupings listed for the underlying form for this datum, which is (21b) of Kula and Bickmore (2015:159). This is also in accordance with their underlying-surface pair in (21c). The original surface structure reported for my (39a) — their (21b) — is bá-ká-ʃíik-il oo-mú-límí (búúpe), noting that as in (39), I leave the phrase boundaries implicit. In addition, I note that while Bickmore and Kula use a number of IPA symbols, they do not claim that their notation is completely in correspondence with IPA. Indeed, as I noted before for Northern Bemba, they make use of the abstract “xb” instead of writing the IPA symbol for a voiced labial fricative (Hamann and Kula 2015).

	Form	*Comment*
0.	$\acute{\sigma}_1\sigma\sigma\sigma...\acute{\sigma}_2\sigma\sigma\sigma\sigma$	Underlying form
1.	$\acute{\sigma}_1\sigma\sigma\sigma...\acute{\sigma}_2\sigma\sigma(\sigma\sigma)$	Place foot at edge
2.	$\acute{\sigma}_1\sigma\sigma\sigma...\acute{\sigma}_2\sigma\sigma(\sigma\acute{\sigma}_2)$	License rightmost tone (at Ft-R)
3.	$(\acute{\sigma}_1\sigma)\sigma\sigma...\acute{\sigma}_2\sigma\sigma(\sigma\acute{\sigma}_2)$	License other tone(s)
4.	$((\acute{\sigma}_1\sigma)\sigma)\sigma...\acute{\sigma}_2\sigma\sigma(\sigma\acute{\sigma}_2)$	Foot layering
5.	$((\acute{\sigma}_1\sigma)\sigma)\sigma...\acute{\sigma}_2\acute{\sigma}\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	Gap filling
6.	$((\acute{\sigma}\acute{\sigma})\acute{\sigma})\sigma...\acute{\sigma}_2\acute{\sigma}\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	Bounded spreading

Table 4.26: Steps of the derivation of Bemba bounded and unbounded tone

edgewise framework is capable of dealing with such problems, or whether this is a fundamental limitation of the edgewise, incrementally reassociating approach.

The behavior of multiple High tones in Shambaa (Odden 1982) shows a reverse case, where an edgewise analysis is available, but a basis for a licensing analysis seems unavailable. In Shambaa, the rightmost tone in verb stems shows spreading to the penultimate position, and other tones spread rightward up to the beginning of the next High tone, and induce a downstep on that tone. In the terminology of Odden (1982:186), there is one spreading rule, and "when Spreading applies [...] to the tone sequence HLH, the surface pattern HHꜝH results." I show some example forms in (40), reiterating that underlining indicates tone sponsoring.[40]

(40) Spreading of the non-rightmost tone in Shambaa

a.	ku-<u>ká</u>áng-a	'you were cooking for me'
b.	<u>né</u>e <u>ú</u>-kí-ní-ꜝ<u>ká</u>áng-íy-a	'you were cooking for me'
c.	<u>á</u>-á-kú-ꜝ<u>ká</u>áng-íy-a	'he's frying for you'
d.	nyu<u>mbá</u>	'house'
e.	ni-on-<u>íyé</u> nyúꜝ<u>mbá</u>	'I saw the house'

The longest tone span of a non-rightmost tone is only three syllables. However, unlike in the Copperbelt Bemba case, there is no report of bounded ternary spreading for Shambaa; nor does Odden's description suggest that there is a length limit to the process. Consequently, I assume that a theoretical framework should be able to deal with unbounded spreading of the non-rightmost tones. For the edgewise association framework, this is unproblematic, since unbounded spreading follows directly from ALL-T-RIGHT.

This time, it is the licensing framework that has the more challenging issue. For unbounded effects, the licensing approach places a foot at the edge and then associates a tone to it, possibly at the cost of creating a

[40] Although I present tone sponsoring for the High-toned verb root /káang/ "to fry" at its initial syllable, there is no lexically contrastive tone association in verb roots in Shambaa, so other analyses of the provenance of this tone are possible, such as that it is underlyingly floating. I follow the transcriptions of Odden (1982). Odden makes some clarifications about the phonetics relating to his transcriptions, but only for consonant clusters that do not occur in the data I cite. He does not state generally how the transcriptions relate to IPA.

gap. The tone that performs this association is always the edgemost tone, which is closest. Association from tones that are further away would create unnecessarily large gaps, as well as violating the (here presumably inviolable) No Crossing Condition (Goldsmith 1976). Consequently, there is no incentive for non-edgemost tones to perform unbounded reassociation. This leaves the licensing framework in want of options to account for the Shambaa pattern.

Leaving the analytical issues unresolved, I conclude that for future research, multi-tone contexts are a rich source of information about what a theory of tonal reassociation needs to be capable — and perhaps incapable — of.

4.6 Conclusion

In this chapter, I have followed the theoretical preliminaries of two types of foot-based tone reassociation frameworks to their broader typological implications. I contrasted a licensing-style framework, where tones seek some footed position to associate to, with an edgewise association framework, where tone attempts to reassociate as close as possible to an edge of a prosodic domain. Both frameworks showed the ability to deal with much or all of the attested crosslinguistic variation that I have considered in the chapter. To my knowledge, this study contains a methodological novelty in that it compares two factorial typologies for related frameworks, instead of working with a single framework and corresponding factorial typology. The main methodological difference is that with the present approach, one can investigate not only the exact contents of a given factorial typology, but also the overlap between factorial typologies for different frameworks. A case of overlap in the predicted typologies provides insight into the core properties of an analytical approach, regardless of its exact implementation. Thus, in the present study, the frameworks shared the prediction of exceptional tonal interactions at positions near the edge of the prosodic domain. The fact that edge effects show up in both cases despite the different approaches to tone association in the two frameworks suggests that this is a general typological prediction of foot–tone interaction frameworks.

There are also some divergent predictions between the two frameworks. Under licensing, the calculated factorial typology contains far more edge-based variation, and allows for such edge patterns to be more distinct from a given default pattern. Under the edgewise framework, the factorial typology includes patterns that yield tone spans that are always odd-length or always even-length. In addition, the edgewise framework predicts "footbridge" patterns, where the distance between a sponsor and an edge determines whether a form surfaces with a bounded or an unbounded reassociation pattern.

Many of the predictions mentioned above are, to my knowledge, not attested, and in some cases, I have marked patterns as being likely cases of overgeneration on the part of the relevant framework. However, these conclusions are best drawn in a broader context than just that of the phonological faculty. Consequently, the present results encourage future work in related areas, such as the acquisition of tone and abstract (foot) structure, articulatory and auditory biases in tone processing, and diachrony of tonal and rhythmic patterns. In particular, the initial-only patterns of the licensing framework and the footbridge patterns of the edgewise framework might inspire future research into how speakers learn and process patterns where some forms show bounded (tonal) phenomena, while other forms show unbounded effects.

Even within the scope of phonology, the present work has left much unexplored. Future work could expand the present investigation by considering underlying forms of other lengths and with sponsors in other positions, to get a more complete picture of the predicted typological variation. There are also further challenges available to test the validity of foot–tone analyses on attested patterns. In particular, foot–tone frameworks should be tested on contexts where multiple tonal autosegments are adjacent, since languages vary in their resolution strategies (e.g. Myers 1997). Finally, other possible extensions to the present frameworks involve sensitivity to syllable structure(e.g. Hyman 1992), and an expanded repertoire of phonological repair strategies, including e.g. tone fusion and fission.

In conclusion, I have aimed to contribute to an understanding of the typological implications of foot-based analyses of tonal reassociation by considering the typological coverage of the factorial typologies of two different frameworks for foot-based tonal reassociation. I look forward to new insights into this issue coming from the research avenues mentioned above, as well as theoretical advances in phonology, and attestation of enlightening patterns due to future fieldwork.

Chapter 5

Learning hidden metrical and tonal structure and lexical forms with GLA

Abstract

This chapter simulates the learning in an Optimality Theory context of hidden tonal and metrical structure and lexical forms for a set of phonological patterns showing tonal reassociation, where tone is realized in positions that it does not occupy at the lexical level (also called tone spreading or tone shifting). The selection of patterns is based on prior typological work reported in Chapter 4, where I analyzed the variation in terms of foot structure. Some of the patterns tested here have been attested, while others are considered overgeneration on the part of the factorial typology in Chapter 4. The present simulations serve to determine whether the overgeneration can be accounted for in terms of learnability. In particular, I hypothesize that the unattested patterns are overall less learnable than the attested patterns.

In the example data provided to the learner, all foot structure, autosegmental structure, and lexical tonal information is hidden, which means that the learner will have to deduce lexical information through a consideration of alternations, and piece together surface phonological generalizations that are consistent with all the data. Learners use the Gradual Learning Algorithm (GLA) with Stochastic OT and Robust Interpretive Parsing (RIP). In previous studies, the learning task involved only unidirectional ambiguity, generally in the production direction; production starting from a given meaning could lead to an error, but comprehension starting from a given overt form was guaranteed to lead to a correct meaning. This study presents the first case of bidirection-

ally ambiguous RIP learning, where the learner detects and learns from both production and comprehension errors.

As hypothesized, successful convergence is higher for learners of attested patterns than for learners of unattested patterns. This typological fit does not hold up when learning only from production errors, showing that the present learning task provides an argument for bidirectional error detection. From a typological perspective, the present study enhances the foot-based account of tonal reassociation typology from Chapter 4 by offering a means of explaining away potential overgeneration from the perspective of learnability.

5.1 Introduction

Since the advent of Optimality Theory (OT, Prince and Smolensky 1993), there has been an interest in simulating the acquisition of OT grammars.[1] Because grammatical knowledge in OT is expressed through constraint ranking, algorithms for learning in OT revolve around the task of finding a constraint ranking that is consistent with the linguistic examples that the learner has received from their environment, which I will term the *adult* data. The pioneering work of Tesar and Smolensky (1993, 1998); Tesar (1995) led to the development of an algorithm called Error-Driven Constraint Demotion (EDCD). The EDCD algorithm performs *online* learning, meaning that adult forms are processed one at a time, and any intermediate learning updates influence later learning. The algorithm is also an instance of *error-driven* learning; learning updates are triggered whenever, and only when, the learner has reason to think that they have made an erroneous generalization. For EDCD, this happens through *virtual production*; the learner compares the adult behavior to what the learner's own grammar would have them produce. If these two behaviors do not match, the learner concludes that an error has been detected. This error detection triggers a learning update. In the case of EDCD, the learning update entails the demotion of constraints, to the effect that the ranking no longer favors the child's virtual production over the observed adult behavior. EDCD learners provably (Tesar and Smolensky 1998, 2000; Boersma 2009b) converge on a target grammar, under two conditions. Firstly, that there exists a grammar that is consistent with the data; and secondly, that the data is fully transparent, i.e. that the learner has access to all the information contained in an adult form.

Relaxing this second criterion leads to a more challenging research avenue; that of *hidden structure learning*, where some information about adult forms is withheld from the learner. The most studied hidden structure learning task for phonological acquisition is that of learning foot structure, where learners are exposed to adult forms that signal the locations of syllable stresses, but

[1] Supplementary materials for this chapter are available at https://doi.org/10.6084/m9.figshare.5765970. These materials include files to support replication of the results presented here.

where learners must decide themselves how this relates to the location of feet. For example, with binary feet, a string $\sigma\text{'}\sigma\sigma$ might be footed $(\sigma\text{'}\sigma)\sigma$ or $\sigma(\text{'}\sigma\sigma)$. To address hidden structure learning, Tesar and Smolensky (2000) proposed Robust Interpretive Parsing (RIP). Briefly, learners using RIP that are confronted with hidden structure will use their current grammar to select an optimal structural interpretation for the adult form they are processing. In other words, learners fill in any gaps in their knowledge about the form using their best guess, and then proceed with the learning process as usual, for example using EDCD. A common practice in RIP studies is to supply the learner with mappings between an *overt* form, which represents the information closest to phonetic reality and might not carry some phonological information such as foot structure, and a form at the deepest level of processing considered in the study. This way, the task that remains for RIP is to fill in any intervening levels between overt and deep form.

Research in OT acquisition has gone on to spawn a variety of learning approaches. The present chapter is cast in the context of the Gradual Learning Algorithm with Stochastic OT (GLA, Boersma 1997b, 1998; Boersma and Hayes 2001). Like EDCD, GLA is online and error-driven. In addition, it has also been combined with RIP to address hidden structure learning — posting higher convergence rates than EDCD/RIP in direct comparisons (Apoussidou and Boersma 2003, 2004; Boersma 2003; Boersma and Pater 2016). GLA stores stochastic grammatical knowledge by assigning *ranking values* to constraints. Whenever candidates need to be evaluated, the GLA learner samples a constraint ranking by ordering the constraints according to their *disharmony*, which is sampled for each constraint from a Gaussian distribution centered at the constraint's ranking value. The fact that the ranking values fall on a continuous scale allows the learning updates of GLA to be *gradual*, by tweaking the ranking values, as opposed to the wholesale reranking of constraints performed in an EDCD learning update. Finally, although it is not relevant for the learning task at hand, I note that GLA learners are also able to learn free variation and gradient markedness, showing sensitivity to frequencies of occurrence in the adult data (Boersma and Hayes 2001).

Early research on hidden structure learning with GLA showed that learners with Stochastic OT and RIP can successfully learn adult behavior whilst dealing with hidden metrical structure (Apoussidou and Boersma 2003, 2004; Boersma 2003). Later studies turned their attention toward learning multiple levels of representation simultaneously. Thus, Apoussidou (2007) demonstrated that GLA learners can be successful on a task where both metrical structure and aspects of the underlying form are hidden. To model this, Apoussidou included a deeper level of representation, called *meaning*, in Gen. For example, in the case of learning stress in modern Greek, the learner might be presented with a pair of meaning and overt form such as 'gondola-Nom.Sg' [ˈɣondola]. This pair still lacks two levels of structural interpretation; for example, the learner might favor lexical forms and foot placement such that the learner arrives at the full candidate 'gondola-Nom.Sg' |ˈɣondol-|+|-ˈa| /(ˈɣon.dol)a/ [ˈɣondola]

(Apoussidou 2007:187*ff.*). To regulate the relation between meaning and lexical form, Apoussidou added *lexical constraints* to the constraint set (Boersma 2001). For example, the choice of the stress-bearing root |ˈɣondol-| is favored over stressless |ɣondol-| by the lexical constraint in (2).

(2) *|ɣondol-| 'gondola'
"Don't connect the meaning 'gondola' to an unstressed root |ɣondol-|."
(Apoussidou 2007:176)

Boersma and Van Leussen (2017) expanded the inquiry into learning multi-level hidden structure with a learning task involving three hidden layers, namely hidden morphological structure and lexical and surface phonological structure. They implemented learning simulations of a multi-level analysis of French liaison, expanding on Boersma (2007). In addition to choosing a masculine or feminine suffixal morpheme, their learners have to make two choices about phonological and phonetic content. Firstly, whether schwa is absent or present, and second, whether nasality is carried by a vowel or a coda consonant. Both of these choices occur across multiple levels. For example, learners must decide whether a given underlying form does or does not contain schwa, and whether schwa is phonologically inserted or deleted, and whether it is realized or not in the phonetic form.

One limitation of the studies above is that the adult data pairs are only ambiguous in one direction. For example, using Apoussidou's Greek example from before, while the meaning 'gondola-Nom.Sg' could be realized in the learner's production with a variety of different overt forms, the only available meaning for e.g. the adult overt form [ˈɣondola] that the learner would consider was 'gondola-Nom.Sg'. Consequently, the adult data in Apoussidou (2007) is ambiguous in the production direction, but unambiguous in the comprehension direction; see Hamann et al. (2009) for, to my knowledge, the only reverse case, where the learning task is ambiguous in the comprehension direction but unambiguous in the production direction. In this chapter, I address this limitation by simulating a learning task that is *bidirectionally* ambiguous, so that a given meaning (or more generally, a given form at the deepest level of processing) could be realized with various overt forms, and a given overt form might be interpreted as signaling various different meanings. Concomitantly, I will use bidirectional error detection (Hamann et al. 2009; Boersma 2011), so that the learner can learn from errors detected in production as well as in comprehension. The task involves hidden structure at two levels of representation. At the surface phonological level, the learner has to decide not only on metrical structure, but also on *autosegmental* (tonal) structure (Leben 1973; Goldsmith 1976). Autosegmental structure is ambiguous when a feature appears on multiple adjacent feature-bearers. For example, given a disyllabic high-toned form, written here as $\acute{\sigma}\acute{\sigma}$ with acute accent denoting high tone, learners need to decide whether high tone on the two syllables is specified by a single, multiply associated autosegment, or by two separate high autosegments. The other level where structure is hidden in the present learning task is the lexical level. Thus, learners will have to decide on underlying forms while simultaneously deciding on metrical and autosegmental structural interpretations. Unlike Boersma and Van Leussen (2017), I will not consider constraints on morphemic structure, or hide morphemic information. Consequently, for the present learning task I will collapse meaning and morphemic structure into one level of representation.

The present learning task is inspired by tone shifting and spreading patterns, as found mainly in Bantu languages. Briefly, the common aspect among these patterns is that tone is *reassociated* from its lexical origins to its surface phonological targets (Bickmore 1996; Chapter 4). For example, a one-place shifting pattern might map underlying $|\acute{\sigma}\sigma|$ to surface $/\sigma\acute{\sigma}/$, as attested, among other languages, in Rimi (Olson 1964; Schadeberg 1979; Myers 1997). Tone reassociation phenomena obscure the underlying form; if the adult form contains a High-toned syllable, it is uncertain whether that tone was in the same position lexically, or if it spread or shifted to the surface location. The learner will have to piece this together from alternations, i.e. by considering different forms and finding what conditions determine whether a given morpheme surfaces as low or high. In general, whether a given syllable is a target for reassociation is not dependent on qualities inherent to that syllable, but it depends on its position relative to one or both of the following: The edge of the relevant prosodic domain, and the lexical source position of the tone. Consequently, theoretical accounts of tonal reassociation phenomena have proposed a variety of abstract prosodic structures to be at play. This chapter takes as its point of departure the proposal for a foot-based interpretation of tonal reassociation patterns as laid out in Chapters 2 and 4. However, this dissertation is far from the first work to frame the phenomenon with feet, as I will discuss below.

In addition to investigating whether tone–foot interaction analyses can be learned, another aim for this chapter is to investigate where the learner *fails* (Boersma 2003). Such learning failures can be informative about the typological predictions that follow from a given OT constraint set. The present context for such typological predictions is the theory–typological study from Chapter 4, which found that the metrical tone reassociation analysis allows for the generation of various unattested patterns, which are potentially pathological predictions. Using the present learning approach, it is possible to see whether these unattested-but-predicted patterns are disfavored from a learning perspective. If this is indeed the case, it offers an explanation for why those patterns are unattested despite their modelability within the metrical tone reassociation framework.

As I will show, underlying forms and tonal and metrical structural interpretations for a variety of attested tone reassociation patterns are moderately or highly learnable given only mappings between morphemic structure and overt forms. In addition, I will show that there is a stark divide between success rates for the attested patterns and for the unattested patterns predicted in Chapter 4: Success rates for the unattested patterns will be shown to be at or near zero, despite the availability in the hypothesis space of suitable constraint rankings to generate the unattested patterns. Furthermore, I will show that this typological fit of the results depends crucially on aspects of the learning algorithm, particularly the bidirectional formulation of RIP, as well as a decision to exclude harmonically bounded candidates from Gen.

Overall, this study shows that GLA learners with Stochastic OT and RIP can learn hidden underlying forms, metrical structure, and autosegmental structure at the same time. In addition, in conjunction with the theory–typological work in Chapter 4, this study paints a picture of a hypothesis space for metrical analyses of tonal reassociation phenomena that is sufficiently rich to account for the attested linguistic variation, and suitably biased towards the attested variation in terms of learnability.

Section 5.2 goes into more detail about the natural language patterns that are at the root of this learning task. Section 5.3 describes the metrical analysis of the data, building towards a formalization of the learning targets. Section 5.4 describes the methods used in the present study. The results are presented in section 5.5, where I also describe some modes of learning failure for the various target patterns. Finally, in section 5.6, I present results with various alternative settings of the learning parameters and I discuss limit cycles and the role of harmonic bounding, as well as various opportunities for further research — after which the chapter concludes.

5.2 Data: Tonal reassociation patterns

In many Bantu languages, lexical tone is not static, but can surface in other positions than its lexical provenance, and in some languages avoids surfacing in this original lexical position altogether.[2] Using more common terminology, the supposed lexical origin of a tone is termed its "sponsor" position (Cassimjee and Kisseberth 1998), and the processes that occur are termed "spreading" and "shifting". As in Chapter 4, I will also refer to these processes collectively as "tonal reassociation". The diagnosis of sponsor positions typically follows from a consideration of alternations. For example, data such as in (3) support the analysis that in Sukuma, high tone is repositioned two places to the right of its lexical origin (data cited from Kang 1997, and originally from Richardson 1959, 1971; see also Sietsema 1989).[3] This is because the same morphemes

[2]This exposition largely parallels that of Chapter 4.

[3]None of the relevant sources clarify exhaustively how their transcriptions relate to the International Phonetic Alphabet. I follow Sietsema (1989) in interpreting a distinction among high vowels as a difference in tenseness; for all other matters, my transcriptions are based on the original fieldwork from Richardson (1959, 1971). Richardson (1959) is clear about the distinction between bilabial fricatives and plosives. He is not specific about the meaning of the symbol "j", which is problematic because the description of his orthopgraphy suggests that "j" does not denote the glide [j] or the affricate [ʤ]. In the end, I assume that any considerations about the status of segments do not impact the facts about tone in Sukuma.

that carry high tone in (3b,d) surface as low in (3a,c). That is, for the pair of (3a,b), the final instance of [a] alternates with [á], and for (3c,d) [anɪj] alternates with [aníj]. The contrast must be explained by the alternation in morphemes occurring two positions earlier in the string; high tone can be accounted for if it is posited that the pronoun /βá/ and the verb root /βón/ provide it in (3b,d), respectively. Consequently, here and in the following, I will indicate suggested sponsors with underlining.

(3) Two-place shift in Sukuma

a.	a-kʊ-kʊ-sol-a	'He will choose thee'
b.	a-kʊ-<u>βa</u>-sol-á	'He will choose them'
c.	kʊ-sol-anɪj-a	'to choose simultaneously'
d.	kʊ-<u>βon</u>-aníj-a	'to see simultaneously'

Most tonal reassociation patterns are analyzed in the literature as having a /High, ∅/ system, meaning that syllables can carry a lexical High tone or be toneless, rather than having a fully specified opposition between High versus Low (Hyman 2001). I will make the simplifying assumption that this is an apt analysis for all the patterns discussed here (see also Chapter 4:96).

A common distinction made in the literature is to divide tonal reassociation patterns into "bounded" and "unbounded" types. The property that is bounded or unbounded is the distance between a sponsor and its reassociation target. Sukuma is an example of a bounded reassociation pattern; the target position of surface tone has an upper bound of two places to the right of the sponsor position, even if the prosodic domain within which the reassociation process takes place grows large. For unbounded patterns, a larger prosodic domain enables a larger distance between the sponsor and its domain target. For example, in Phuthi, as exemplified in (4), high tone in verb phrases spreads from the sponsor to the antepenultimate position (Donnelly 2009a,b).[4] Hence, there is no *a priori* phonological bound on the distance between the sponsor and the reassociation target, since the sponsor could be arbitrarily far away from the antepenultimate position in the verb phrase, although in practice, this distance is limited by the size and compositional possibilities of the morphemes involved.

(4) Unbounded antepenultimate spreading in Phuthi

a. si-ya-lima-lim-el-aa-na
'we cultivate for each other now and then'

b. <u>bá</u>-yá-límá-lím-él-aan-a
'they cultivate for each other now and then'

Chapter 4 expands on a typological overview of tonal reassociation patterns from Bickmore (1996). I reproduce the parts of this overview relevant to the

[4] Transcriptions for Phuthi data are in IPA orthography; I used Donnelly (2009b:68–73,487) for adaptation from Donnelly's transcription. The only exception to this that I am aware of is the distinction between tense and lax mid vowels, which was not incorporated into Donnelly's transcriptions.

present chapter in Table 5.1.[5] Not all the patterns are relevant because there are differences between the present theoretical framework and that of Chapter 4, as I will discuss in section 5.3.

Description	*UF*	*SF*	*Attested in ...*
Bounded spread	$..\acute{\sigma}\sigma..$	$..\underline{\acute{\sigma}}\acute{\sigma}..$	Ekegusii
Unb. spread to final	$..\acute{\sigma}\sigma..\sigma]$	$..\underline{\acute{\sigma}}\acute{\sigma}..\acute{\sigma}]$	Copperbelt Bemba
Unb. spread to penult	$..\acute{\sigma}\sigma..\sigma\sigma]$	$..\underline{\acute{\sigma}}\acute{\sigma}..\acute{\sigma}\sigma]$	Shambaa
Unb. shift to final	$..\acute{\sigma}\sigma..\sigma]$	$..\underline{\sigma}\sigma..\acute{\sigma}]$	Digo
Unb. shift to penult	$..\acute{\sigma}\sigma..\sigma\sigma]$	$..\underline{\sigma}\sigma..\acute{\sigma}\sigma]$	Chizigula

Table 5.1: Some attested variation of tonal reassociation patterns

Previous work on the analysis of tonal reassociation patterns has typically sought to derive the targets of reassociation as a result of certain prosodic structure (cf. Bickmore 1996). This mostly concerns various forms of metrical structure (Downing 1990; Kang 1997; Idsardi and Purnell 1997; Chapters 2–4), although some more general domain-based theories have been proposed (Cassimjee and Kisseberth 1998; Key 2007). The present work adopts a metrical analysis along with licensing constraints, following the program of the earlier chapters of this dissertation. In the next section, I will go into detail about the constraint set.

5.3 Analysis

5.3.1 Tone licensing and structural markedness

This section describes the analytical framework for tone reassociation patterns that will shape the hypothesis space for the learner in the present learning simulations. The framework follows up on earlier theory–typological work in Chapter 4. At the core of my approach are foot–tone interactions based on licensing (see also Kang 1997). For example, the tableau in Table 5.2 shows how a requirement to license a tone with a footed position, expressed by License(H, Ft), can drive the construction of feet, even in positions where foot placement is marked. I also list the definitions of the relevant constraints in (5, 6), taken from Chapters 2 and 4. As I will show, all interaction is based only on foot constituency, without any reference to stress or headedness of feet.

(5) License(H, Ft)
"For each H tone, assign one violation mark if it is not associated to a footed syllable" (Chapter 2:19).

[5] References for these attestations are as follows: Ekegusii: Bickmore (1996), Copperbelt Bemba: Bickmore and Kula (2013), Shambaa: Odden (1982), Digo: Goldsmith (1990), in Bickmore (1996), Chizigula: Kenstowicz and Kisseberth (1990).

(6) ALL-FT-RIGHT
For every foot, assign one violation mark for each syllable between that foot and the right edge of the domain (McCarthy and Prince 1993a).

$\|\sigma\sigma\acute{\sigma}\sigma\sigma\|$	LICENSE(H, FT)	ALL-FT-RIGHT
a. $/\sigma\sigma\acute{\sigma}\sigma\sigma/$	*!	
b. ☞ $/\sigma\sigma(\acute{\sigma}\sigma)\sigma/$		*
c. $/\sigma\sigma\acute{\sigma}(\sigma\sigma)/$	*!	
d. $/\sigma(\sigma\acute{\sigma})\sigma\sigma/$		**!

Table 5.2: Licensing drives foot placement

The constraint set further includes constraints used to derive tonal reassociation with relation to specific positions within the foot. Thus, there are licensing constraints targeting a specific edge, such as LICENSE(H, FT-R); and there are markedness constraints that militate against tone association in footed positions, such as *H/FT-L. The example in Table 5.3 shows how these constraints can conspire to effect a shifting-type reassociation.[6] The related constraints are defined in (7, 8).

(7) LICENSE(H, FT-R)
"For each H tone, assign one violation mark if it is not associated to a syllable that is rightmost in a [foot]"(Chapter 2:20).

(8) *H/FT-L
"Assign one violation mark for each association between a H tone and a syllable that is [left]most in a [foot]" (Chapter 2:20).

$\|\acute{\sigma}\sigma\|$	LICENSE(H, FT-R)	*H/FT-L
a. $/\acute{\sigma}\sigma/$	*!	
b. $/(\acute{\sigma}\sigma)/$	*!	*
c. $/(\acute{\sigma}\acute{\sigma})/$		*!
d. ☞ $/(\sigma\acute{\sigma})/$		

Table 5.3: Edge-specific constraints in action

[6] This is a toy example meant to demonstrate various constraint effects. In general, the bounded shift pattern is not derivable in parallel OT (Chapter 2, section 2.2.3, and Chapter 4:fn. 8).

5.3.2 Additions to the constraint set

The constraint set used here has two additions to that of Chapter 4. Firstly, the set has been made symmetrical. Breteler deliberately chose to keep the original constraint set asymmetrical, focusing on effects at the right edge of the domain. Consequently, the constraint set included right-edge-oriented ALIGN-R(ω, FT) and ALL-FT-RIGHT, but not their left-edge-oriented counterparts. The advantage of asymmetry is that it reduces the size of the required computations. However, in the context of learning, asymmetry introduces a bias to the learner; if the constraint set only allows modeling of right-edge patterns, the learner does not get to prove themselves in the face of ambiguity between left-oriented and right-oriented patterns, as well as patterns that mix left-edge orientation for some constraints with right-edge orientation for others. Consequently, in the present work, I ensure that for each constraint referring to the right edge of a foot or word domain, there is a mirror image of the constraint referring to the left edge. Concretely, I have added ALIGN-L(ω, FT) and ALL-FT-LEFT to the constraint set.

A second addition to the constraint set is LICENSE(FT, H), defined in (9). Its effect is to militate against feet that are tonally empty, while accepting feet that have at least one syllable associated to a tone. This constraint was proposed previously in Chapter 2. In a broader typological context, it has a role in accounting for "rhythmic tone" systems where tone appears on alternating TBUs (e.g. Lamba, Bickmore 1995); for such systems, assuming iterative footing, LICENSE(FT, H) drives tone to associate to every foot (see also De Lacy 2002). For the present simulations, it tempers the tendency of the learner to place feet frivolously. The duo of ALL-FT-L/R already penalizes foot placement, but its effect is tied too much to edge-orientedness; in grammars with low-ranked ALL-FT-LEFT, feet can freely surface at the right edge, and *vice versa* for ALL-FT-RIGHT and the left edge. The need for LICENSE(FT, H) is also a consequence of the transition from Harmonic Serialism to Optimality Theory, which I will discuss in more detail shortly below. In HS, feet are typically placed one at a time (Pruitt 2010, 2012), meaning that less important feet are placed later, and therefore do not interfere with the crucial positioning of licensing feet placed earlier in a derivation.

(9) LICENSE(FT, H)
Assign one violation mark for every foot that is not licensed by a tone (i.e. has no constituent syllable associated with a tone).

The full set of markedness and faithfulness constraints, along with definitions, is presented in Table 5.4. The design of the constraint set builds on previous work. In particular, the foot alignment constraints benefit from work on alignment by McCarthy and Prince (1993a). Similarly, the licensing constraints are indebted to the extensive discussion of licensing by Zoll (1996).

The list in Table 5.4 is exhaustive for the markedness and faithfulness constraints, but does not constitute the full constraint set yet. A set of

Constraint	*Definition*
	Foot placement
All-Ft-L/R	For every foot, assign one violation mark for each syllable between that foot and the left/right edge of the domain.
Align-L/R(ω, Ft)	Assign one violation mark for each word that does not have a foot as its left/rightmost constituent.
License(Ft, H)	Assign one violation mark for each foot that is not licensed by a tone (i.e. has no constituent syllable associated with a tone).
	Tone licensing
License(H, Ft)	For each H tone, assign one violation mark if it is not associated to a footed syllable.
License(H, Ft-L/R)	For each H tone, assign one violation mark if it is not associated to a syllable that is left/rightmost in a foot.
	Tone non-association
*H/Ft	"Assign one violation mark for each association between a H tone and a footed syllable" (Chapter 2:20).
*H/Ft-L/R	Assign one violation mark for each association between a H tone and a syllable that is left/rightmost in a foot.
*H/σ	Assign one violation mark for each association between a H tone and a syllable.
	Faithfulness
Max-Link	For every tone T and every syllable σ, assign one violation mark if T and σ are associated in the underlying form but not in the surface form.
Dep-Link	For every tone T and every syllable σ, assign one violation mark if T and σ are associated in the surface form but not in the underlying form.

Table 5.4: The markedness and faithfulness constraints used for the learning simulations

constraints that relate morphemes to underlying forms will be needed as well. We discuss those constraints later, in section 5.4.2.

5.3.3 Serial and parallel typology

Chapter 4 presented a typological investigation of the tone licensing framework, calculating a factorial typology of the constraint set. This is relevant for the present chapter in two respects. Firstly, the factorial typology represents the variety of rankings that the learner might adopt. Consequently, it delimits what the learner can achieve, and indicates between which competing hypotheses the learner must deliberate. Secondly, a theory–typological investigation raises issues that learning simulations can shed light on. Chapter 4 found that the factorial typology included a variety of patterns that might not have an analog in natural language, which I will refer to collectively as “non-target” patterns. This points to a potential failure of the theory, in that it overgenerates with respect to these patterns. However, an alternative explanation for the mismatch between the variety predicted by the factorial typology and that found in the field is that the non-target patterns are less learnable (Boersma 2003); this would make them less diachronically stable, and ultimately, less likely to be attested by linguistic fieldwork. Consequently, this study takes the findings of Chapter 4 as a point of departure, comparing the learnability of attested patterns to non-target patterns.

A major difference between this study and that in Chapter 4 is the choice of grammar framework. Chapter 4 uses Harmonic Serialism (HS, Prince and Smolensky 1993; McCarthy 2000), a variation on Optimality Theory where evaluation occurs serially through gradual changes from the lexical to the surface phonological form, rather than optimizing globally by considering all candidate surface forms in parallel. Because of these differences, learning approaches for OT don’t necessarily carry over in full to HS — in particular, HS learners benefit less than OT learners when it comes to learning from the identity map, i.e. error detection in production when assuming observed surface phonological forms as input lexical forms (Tessier 2011; Tessier and Jesney 2014). A concrete learning algorithm applicable to both OT and HS is provided by Jarosz (2015, 2016), who presents an algorithm called Expectation-Driven Learning (EDL), based on the Expectation–Maximization algorithm (EM, Dempster et al. 1977; see also Staubs and Pater 2016 for an alternative approach to learning in HS). Like EM, EDL iteratively updates a set of stochastic parameters by alternating between an Expectation step, where the algorithm checks how accurately its current stochastic settings match the observed data, and a Maximization step, where the outcome of the Expectation step is used to update the stochastic settings. For the application to phonological learning, the stochastic parameters in EDL include binary lexical features and pairwise constraint rankings, which represent the likelihood that for a given pair of constraints, one outranks the other. Jarosz shows that EDL can handle online learning of hidden surface structure, and batch learning of hidden lexical structure in OT. Jarosz (2016) demonstrates online EDL in an HS context, to learn phonological patterns with varying degrees of opacity. Although these results are promising, Jarosz's work has not (yet) produced the result that combines these individual findings; it has not been shown that EDL can successfully learn hidden lexical and surface structure in HS, which is the result that would be relevant to the present study. In addition, Jarosz's implementation of the learning algorithm is not publicly available. For these reasons, building upon the results of Jarosz (2015, 2016) falls outside the scope of this study; instead, I will perform the learning simulations in the context of Optimality Theory. I will first outline the findings from Chapter 4 in the HS context, and then discuss the transposition of these findings to the present OT context. In section 5.6.2 of the discussion, I consider the implications of switching between these frameworks in more detail.

Chapter 4 found that all attested patterns, as listed here in section 5.2 in Table 5.1, can be represented in HS using some ranking of the tone licensing constraint set. The prediction of non-target patterns had two main causes. The first type of prediction is related to the decision in Chapter 4 to allow gapped tone representations, where a tonal autosegment can be associated to a non-contiguous span of TBUs. For example, the grammar might generate the mapping $|\acute{\sigma}\sigma\sigma| \rightarrow [\acute{\sigma}_1\sigma\acute{\sigma}_1]$, where the subscript index indicates that high tone on both syllables stems from association to the same tonal autosegment. The constraint set of Chapter 4 contained NoGap, which militated against gaps, but for grammars where this constraint was ranked sufficiently low, it was possible that a form with gapped tone was optimal. Thus, several types of patterns with surface tone gaps were among the non-target typological predictions of the HS factorial typology (HSFT) in Chapter 4.

The second source of non-target predictions is related to behavior at word edges. Chapter 4:125 found that tones near the right edge had more possibilities for interaction with feet than tones that were further away. Examples of these patterns, dubbed "edge effects", are presented in (10). Each pattern is listed with a descriptive name, and consists of three mappings between underlying forms, listed in the column headings, and surface forms, listed in the same row as the pattern name.

(10) *Edge effects*

Pattern	$\|\acute{\sigma}\sigma\sigma\sigma\sigma\|$	$\|\sigma\acute{\sigma}\sigma\sigma\sigma\|$	$\|\sigma\sigma\acute{\sigma}\sigma\sigma\|$
Edge doubling	$/\acute{\sigma}\sigma\sigma(\sigma\sigma)/$	$/\sigma\acute{\sigma}\sigma(\sigma\sigma)/$	$/\sigma\sigma\acute{\sigma}(\acute{\sigma}\sigma)/$
Edge tripling	$/\acute{\sigma}\sigma\sigma(\sigma\sigma)/$	$/\sigma\acute{\sigma}\sigma(\sigma\sigma)/$	$/\sigma\sigma\acute{\sigma}(\acute{\sigma}\acute{\sigma})/$
Penult shift; edge doubling	$/\sigma\sigma\sigma(\acute{\sigma}\sigma)/$	$/\sigma\sigma\sigma(\acute{\sigma}\sigma)/$	$/\sigma\sigma\acute{\sigma}(\acute{\sigma}\sigma)/$
Final shift; edge tripling	$/\sigma\sigma\sigma(\sigma\acute{\sigma})/$	$/\sigma\sigma\sigma(\sigma\acute{\sigma})/$	$/\sigma\sigma\acute{\sigma}(\acute{\sigma}\acute{\sigma})/$

Another type of edge-based interaction occurred at the left edge of the domain. This is due to a special property of the initial sponsor: It is uniquely unable to be licensed by a right foot edge (assuming strictly binary feet). This property could be mirrored at the right edge, but sponsors at that position were not considered in Chapter 4. Several patterns exploited this special status of the initial sponsor to effect "initial-only" patterns, where only the form with the initial sponsor shows any tonal reassociation. Some examples are shown in (11), originally discussed in Chapter 4:124.

(11) *Initial-only patterns*

Pattern	$\vert\acute{\sigma}\sigma\sigma\sigma\sigma\vert$	$\vert\sigma\acute{\sigma}\sigma\sigma\sigma\vert$	$\vert\sigma\sigma\acute{\sigma}\sigma\sigma\vert$
Initial binary spread	$/(\acute{\sigma}\acute{\sigma})\sigma\sigma\sigma/$	$/(\sigma\acute{\sigma})\sigma\sigma\sigma/$	$/\sigma(\sigma\acute{\sigma})\sigma\sigma/$
Initial binary shift	$/(\sigma\acute{\sigma})\sigma\sigma\sigma/$	$/(\sigma\acute{\sigma})\sigma\sigma\sigma/$	$/\sigma(\sigma\acute{\sigma})\sigma\sigma/$
Initial gap to final	$/\acute{\sigma}\sigma\sigma(\sigma\acute{\sigma})/$	$/(\sigma\acute{\sigma})\sigma(\sigma\sigma)/$	$/\sigma(\sigma\acute{\sigma})(\sigma\sigma)/$
Initial final spreading	$/\acute{\sigma}\acute{\sigma}\acute{\sigma}(\acute{\sigma}\acute{\sigma})/$	$/(\sigma\acute{\sigma})\sigma(\sigma\sigma)/$	$/\sigma(\sigma\acute{\sigma})(\sigma\sigma)/$

Since the present chapter employs OT rather than HS, the learner faces a different hypothesis space than the one suggested by the factorial typology in Chapter 4. In order to determine which of the patterns from the HSFT are representable with parallel OT, I calculated the factorial typology for the present constraint set, in parallel OT, using OTSoft (Hayes et al. 2013). The input file used a version of Gen that is similar to that described for the learning simulations in section 5.4, except that it did not consider morpheme structure and that it considered only the three underlying forms used in Chapter 4, i.e. $\vert\acute{\sigma}\sigma\sigma\sigma\sigma$, $\sigma\acute{\sigma}\sigma\sigma\sigma$, $\sigma\sigma\acute{\sigma}\sigma\sigma\vert$.[7] In running the OTSoft calculations, the software detected ties in the input file. These ties were preserved, but none of the following discussion crucially depends on this decision. Since my present interest is in the learnability of the patterns, I use the OT factorial typology (OTFT) only to select suitable patterns to test on; I refrain from an extensive discussion of its full range of predictions.

Indeed, a variety of patterns found for the HSFT is not representable under the present parallel OT approach. The OTFT does not include the attested pattern of binary shift, which has e.g. the mapping $\vert\sigma\acute{\sigma}\sigma\sigma\vert\rightarrow[\sigma\sigma\acute{\sigma}\sigma]$. This was expected; the difficulty of representing tone shift in parallel OT was noted before in Chapter 2, section 2.2.3, and Chapter 4:fn. 8, and was a motivation for the adoption of HS in those studies in the first place. With regard to the non-target patterns, the OTFT does not allow for the representation of about half of the patterns listed in Chapter 4. Since I assume here that representational theory does not include gaps, all of the non-target patterns relating to surface tonal gaps are not included in the OTFT. In addition, some of the edge effect and initial-only patterns are not available in the OTFT, which I ascribe to the difference between serial and global evaluation (McCarthy 2000, 2010b). All remaining patterns will be included in the present learning simulations. I present a full list of these patterns in the next section, which goes into detail about all aspects of the implementation of the learning simulations. Appendix C lists some patterns that are representable in both HS and OT, but that were not part of the discussion of Chapter 4 and consequently will not be considered for the simulations in this chapter.

[7]The supplemental materials, available at https://doi.org/10.6084/m9.figshare.5765970, contain the input file used for calculation of the OTFT, so that the calculation can be replicated.

5.4 Methods

In this section, I describe the learning task and the methods used to run the learning simulations. I start by discussing forms and related constraints at the deepest level of processing that I consider, in section 5.4.1. Afterwards, in section 5.4.2, I list the target languages, i.e. the various sets of adult mappings that learners will be presented with. Then, I discuss what the hypothesis space of the learner comprises of, in section 5.4.3. Section 5.4.4 motivates and defines bidirectional learning with Robust Interpretive Parsing, which accomodates both comprehension-directed learning and production-directed learning. Finally, other aspects of the learning algorithm are detailed in section 5.4.5.

5.4.1 Morpheme forms and lexical constraints

Before presenting the full list of patterns, I discuss some matters of representation and denotation.

The mappings that each pattern consists of are different from those in section 5.3. In that section, I described the phonological part of the mappings, giving underlying forms and surface forms. However, it is exactly the learnability of knowledge at the lexical and surface phonological levels that I want to test in simulations. Consequently, following the approach of Apoussidou (2007); Boersma and Van Leussen (2017), I hide these levels of representation and instead present the learner with the overt form, which carries only an abstraction of pitch information and syllable structure, and a deeper level of representation preceding the lexical level that I will call the morpheme level. Below, I first discuss my definition of the morpheme level; I discuss the type of structures available at the other levels, including at the overt level, in section 5.4.3.

For the purposes of this study, the morpheme level collapses semantic and morphological information. That is, I make the simplifying assumption that when the learner processes an adult utterance, the learner has a sufficient, unambiguous understanding of the meaning associated with that utterance, as well as the composition of morphemes that gave rise to this meaning. Since I am testing on abstract patterns, the meanings are arbitrary, and I do not denote them explicitly. Instead, any meaning is uniquely identified by the composition of the morphemes in a morpheme form.

In the present learning simulations, morpheme forms are always concatenations of five morphemes. For example, a morpheme form <A+b+c+d+e> represents a linear sequence of the morphemes <A>, <b>, etc. To the learner, the particular letters do not have any meaning; all they know is that these morphemes are different from one another. Rather, the choice of letters is an aid to the reader. I write morphemes in uppercase when they are a plausible sponsor of tone; an uppercase morpheme corresponds to an underlying High tone in the patterns listed in Chapter 4. For example, in the Binary Spreading pattern, the morpheme form <A+b+c+d+e> is associated with two high-toned syllables in the overt form, whereas <a+b+c+d+e>, which swaps out <A> for <a>, shows no high tone whatsoever. Alternations like these typically motivate analysts to suggest that <A> is the morpheme contributing high tone, and that its associated underlying form must therefore be $|\acute{\sigma}|$. While the learner might come to the same conclusion, this is in no way enforced by the analytical framework. In fact, learners are free to posit the exact opposite analysis, where <A> is toneless and <a> is high — if their consideration of the evidence leads them there. As I did in the discussion of the data earlier in section 5.2, I restrict the present investigation to the contrast of High-toned vs. toneless syllables, leaving aside alternative representations involving e.g. Low tone. I discuss the combinatorial possibilities in Gen in depth in section 5.4.3, and potential extensions to Gen in section 5.6.6.

Another reader's aid included in the morpheme form notation is that the first five letters of the alphabet correspond to the five respective positions in the string. For example, the first position in the string alternates only between <a> and <A>, and these morphemes never appear elsewhere in the string. There is no alternation in the last two morphemes; every adult mapping ends in <d+e>. I discuss the lifting of some of these restrictions in section 5.6.6.

The status of tone is the only choice that has to be made regarding lexical forms; besides this, all forms necessarily contain one nondescript syllable. As stated, I provide the learner with lexical constraints to manage their preferences about underlying forms. There are eight morphemes in total, <A, a, B, b, C, c, d, e>, and for each morpheme the learner might favor either a High-toned or toneless lexical form. For each of these sixteen possibilities, I include a *lexical constraint* in the constraint set (Boersma 2001). Examples of lexical constraints for the morphemes <A, a> are provided in Table 5.5.

Constraint	*Definition*
*a/H	Assign one * for every instance of <a> that corresponds to a High-toned syllable in the lexical form.
*A/H	Assign one * for every instance of <A> that corresponds to a High-toned syllable in the lexical form.
*a/∅	Assign one * for every instance of <a> that corresponds to a toneless syllable in the lexical form.
*A/∅	Assign one * for every instance of <A> that corresponds to a toneless syllable in the lexical form.

Table 5.5: The lexical constraints used for the learning simulations, exemplified for <a> and <A>

Lexical constraints regulate correspondence between morphemic and lexical structure. Taking the constraint *a/H as an example, a high rank for this constraint means that the grammar will avoid candidates that pair <a> with a High tone. This means that the grammar will favor candidates that contain another morpheme, i.e. <A>, or candidates that do not have a High tone in the lexical form corresponding to <a>. Lexical constraints place no restrictions on other levels of representation. In particular, they are completely blind to surface phonological structure; in this respect, lexical constraints are different from faithfulness constraints — using the latter term for constraints that refer to correspondence relations between lexical and surface phonological structure (McCarthy and Prince 1995).

5.4.2 Inputs and target behavior

I investigate the learning of a variety of tonal reassociation patterns. As discussed previously, I draw from Chapter 4 for both the attested patterns (section 5.2) and a number of what I will term "non-target" patterns related to the licensing framework that, to my knowledge, are unattested (section 5.3). I have selected only those patterns that can be represented with some ranking in the present parallel OT framework (section 5.3.3). The full list of patterns that are under consideration is presented in Table 5.6. As before, I give a descriptive name to indicate the generalization that the pattern represents. All mappings have the same morpheme forms, listed in the column headers. The first three columns list morpheme forms suggestive of first, second, and third syllable sponsors, respectively. The fourth column lists a morpheme form that is suggestive of a toneless string; for all patterns, this morpheme form indeed maps to a toneless surface form. The presence of this mapping is a crucial ingredient of the adult examples for the learner; it is the only mapping that is completely toneless, allowing the learner to study alternations of tone-carrying vs. toneless forms that differ only in a single morpheme slot. At the bottom of the table, I also list the relative frequencies with which these mappings will be presented in the course of learning. The frequency of the toneless mapping is higher than that of the other mappings; the learner is exposed to an equal number of toneless and tone-carrying overt forms. I take up the discussion of frequency distributions again in section 5.6.6.

Choosing these mappings allows the present study to stay close enough to the findings of Chapter 4 to make a comparison between learning results and typological results. It also binds this study to many of the same simplifying assumptions. Thus, I do not consider adult mappings that contain forms that have more than one tone span, or that feature tone insertion or deletion, or that vary syllable count across alternations. I discuss such possible expansions of the investigation in section 5.6.6.

To summarize, the learner's task will be to come to a grammar that reproduces the adult behavior by deciding a correct weighting of all the constraints, presented in Table 5.4 and 5.5, on the basis of exposure to mappings between morpheme and overt forms, as presented in Table 5.6. Since all lexical and phonological structure is left out of the adult examples, the learner is free to fill this in themselves. In the following, I discuss Gen, which contains all the representational options that the learner can choose from.

Pattern	<A+b+c+d+e>	<a+B+c+d+e>	<a+b+C+d+e>	<a+b+c+d+e>
Binary Spreading	$[\acute{\sigma}\acute{\sigma}\sigma\sigma\sigma]$	$[\sigma\acute{\sigma}\acute{\sigma}\sigma\sigma]$	$[\sigma\sigma\acute{\sigma}\acute{\sigma}\sigma]$	$[\sigma\sigma\sigma\sigma\sigma]$
Penult Spreading	$[\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}\sigma]$	$[\sigma\acute{\sigma}\acute{\sigma}\acute{\sigma}\sigma]$	$[\sigma\sigma\acute{\sigma}\acute{\sigma}\sigma]$	
Final Spreading	$[\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}]$	$[\sigma\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}]$	$[\sigma\sigma\acute{\sigma}\acute{\sigma}\acute{\sigma}]$	
Penult Shift	$[\sigma\sigma\sigma\acute{\sigma}\sigma]$	$[\sigma\sigma\sigma\acute{\sigma}\sigma]$	$[\sigma\sigma\sigma\acute{\sigma}\sigma]$	
Final Shift	$[\sigma\sigma\sigma\sigma\acute{\sigma}]$	$[\sigma\sigma\sigma\sigma\acute{\sigma}]$	$[\sigma\sigma\sigma\sigma\acute{\sigma}]$	
Final Doubling Shift	$[\sigma\sigma\sigma\acute{\sigma}\acute{\sigma}]$	$[\sigma\sigma\sigma\acute{\sigma}\acute{\sigma}]$	$[\sigma\sigma\sigma\acute{\sigma}\acute{\sigma}]$	
Initial-Only Binary Spreading	$[\acute{\sigma}\acute{\sigma}\sigma\sigma\sigma]$	$[\sigma\acute{\sigma}\sigma\sigma\sigma]$	$[\sigma\sigma\acute{\sigma}\sigma\sigma]$	*(idem)*
Initial-Only Binary Shift	$[\sigma\acute{\sigma}\sigma\sigma\sigma]$	$[\sigma\acute{\sigma}\sigma\sigma\sigma]$	$[\sigma\sigma\acute{\sigma}\sigma\sigma]$	
Initial-Only Final Spread	$[\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}]$	$[\sigma\acute{\sigma}\sigma\sigma\sigma]$	$[\sigma\sigma\acute{\sigma}\sigma\sigma]$	
Edge Doubling	$[\acute{\sigma}\sigma\sigma\sigma\sigma]$	$[\sigma\acute{\sigma}\sigma\sigma\sigma]$	$[\sigma\sigma\acute{\sigma}\acute{\sigma}\sigma]$	
Penult Shift, Edge Doubling	$[\sigma\sigma\sigma\acute{\sigma}\sigma]$	$[\sigma\sigma\sigma\acute{\sigma}\sigma]$	$[\sigma\sigma\acute{\sigma}\acute{\sigma}\sigma]$	
Relative frequency	1	1	1	3

Table 5.6: The mappings representing all the patterns to be learned

5.4.3 Constructing Gen

I generated the full list of candidates using a custom script written in Python. In order to describe the nature of Gen, I will here describe the logic of the script. The script starts building candidates from the overt forms. I make the simplifying assumption that overt forms are already discretized into abstract syllables. All overt forms used are five syllables long. Each syllable can be specified as carrying high pitch or low pitch; for strings of length 5 this means that there are $2^5 = 32$ possible overt forms.[8]

Next, every overt form is given all possible tonal interpretations. I assume that any syllable without high pitch is toneless. That is, given an overt form $[\sigma\sigma\acute{\sigma}\acute{\sigma}\sigma]$, the high-pitched syllables could be the realization of two separate tonal autosegments associated to adjacent anchors, i.e. $/\sigma\sigma\acute{\sigma}_1\acute{\sigma}_2\sigma/$, or the realization of a single autosegment associated with two anchors, i.e. $/\sigma\sigma\acute{\sigma}_1\acute{\sigma}_1\sigma/$. I exclude gapped tone; whenever one or more toneless syllables intervene between two high-pitched anchors, the tonal interpretation will assign different autosegments to those two anchors. I also assume that association lines never cross (Goldsmith 1976).

Next, each tonal form is interpreted in all possible ways with foot structure. At this stage, foot placement is not sensitive to the position of tone. Thus, every tonal form has the same number of footings. I assume strictly binary, headless feet; there is no stress in any of the candidates. This means that for a string of length five, the number of different footings comes out to eight.[9] The outcome of the footing process gives the complete phonological surface forms, which carry both autosegmental and metrical structure.

The mapping from surface to underlying forms involves the potential undoing of tonal reassociation. I have made several simplifying assumptions about this process. One major assumption is that every syllable is its own morpheme. This has the consequence that there are no multiply-associated

[8] Although the input patterns and ideal underlying forms never involve more than one contiguous tone span, it is important that "non-contiguous" auditory forms such as $[\sigma\acute{\sigma}\sigma\acute{\sigma}\sigma]$ are also included. This is because such forms allow the learner to diagnose its errors. For example, the learner might have acquired a constraint ranking where the optimal production involves a form with two tonal autosegments and a non-contiguous overt form. Virtual production will now lead to the detection of an error, since no learning datum for any pattern involves such overt forms. If the range of overt forms were restricted to those with a single high tone span, production of the non-contiguous overt form could never have been considered, and the erroneous constraint ranking might have gone undetected.

[9] With strictly binary headless feet, the number of different footings of a string follows the Fibonacci pattern. Informally, I derive this from the observation that a string of length n can be decomposed into its head, or initial member, and a tail, the remainder of the string. If the head is an unfooted syllable, the number of remaining footing options is $\text{Foot}(n-1)$, and will include the fully unfooted string. If the head is a foot, the number of remaining footing options is $\text{Foot}(n-2)$, and will exclude the fully unfooted string. Thus, the recursive definition for $\text{Foot}(n) = \text{Foot}(n-1) + \text{Foot}(n-2)$, just as the Fibonacci function. The initial terms also follow the Fibonacci function; $\text{Foot}(1) = 1$ because the string σ can only be footed without any feet; Foot (2) = 2 because the string $\sigma\sigma$ has two footings: $\{\sigma\sigma, (\sigma\sigma)\}$. The main consequence of this for the present chapter is that, for length 5, there are 8 different footings: $\sigma\sigma\sigma\sigma\sigma$, $(\sigma\sigma)\sigma\sigma\sigma$, $\sigma(\sigma\sigma)\sigma\sigma$, $\sigma\sigma(\sigma\sigma)\sigma$, $\sigma\sigma\sigma(\sigma\sigma)$, $(\sigma\sigma)(\sigma\sigma)\sigma$, $(\sigma\sigma)\sigma(\sigma\sigma)$, $\sigma(\sigma\sigma)(\sigma\sigma)$.

tones in the underlying forms, since a lexical tone can be a part of only one lexical item. In addition, I do not model tone fusion or fission, so that the number of tonal autosegments never differs within a pair of underlying and surface form. Finally, I do not model tonal metathesis, so I do not consider candidates that have swapped the ordering of tones or syllables.

At the final step in the candidate generation process, I connect each of the underlying forms to all of the morpheme forms. As I mentioned, I assume that all underlying forms are monosyllabic. Since every form has five syllables, this means that all morpheme forms have five parts. However, as discussed in section 5.4.1, I only offer a morphemic contrast on the first three syllables; the morphemes for the last two syllables are always the same. In addition, morpheme contrasts are separate for each syllable. For example, the first syllable alternates only between <A> and <a>, and the second for <B, b>, etc. In total, there are 2^3=8 different morpheme forms per underlying form.

In summary, a candidate consists of a morpheme, lexical, surface, and overt form. Morpheme and overt forms range freely over the full possibility space, so that all combinations of these two forms are represented by some candidate. The relation between overt form and surface form is one of structural interpretation, and is therefore more restricted. The relation between surface and underlying form is a phonological mapping, which is also subject to several restrictions and simplifying assumptions. The relation between underlying forms and morpheme forms is not restricted by Gen.

Constructing Gen according to the description above, I derive a list of 48,128 candidates. This list contains many candidates that are harmonically bounded, meaning that there is no ranking under which they are a winning candidate. As I will discuss in detail in section 5.6.3, the inclusion of harmonically bounded candidates poses problems for correct learning. Consequently, I have chosen to perform the learning simulations with a candidate set that does not contain any harmonically bounded candidates. I have used a custom algorithm written in Python for the removal of harmonically bounded candidates. The algorithm closely follows the approach presented in Samek-Lodovici and Prince (2005).[10] After removal, 8648 candidates remain in the set. The same result was found by performing harmonic bounding removal in Praat. The supplementary files to this chapter include listings of all candidates, and separately of all non-harmonically-bounded candidates.[11]

[10]For purposes of replication, I note here a roundabout approach to harmonic bounding removal for the present Gen that reduces working memory load. Since harmonic bounding never occurs because of lexical constraints, because the constraint set and the representational inventory are both symmetrical, it is possible to leave this layer out of the harmonic bounding removal process entirely. This cuts the constraint set in half and reduces the candidate list by a factor 8. In order to make sure that different lexical forms do not compete with one another, I then ran harmonic bounding removal separately for each lexical form.

[11]The supplementary files for this chapter are available at https://doi.org/10.6084/m9.figshare.5765970.

In the following, I will describe the learning algorithm that the candidate list will be used for. First, I cover the bidirectional reformulation of Robust Interpretive Parsing, below.

5.4.4 Bi-directional learning with Robust Interpretive Parsing

In the original presentation of Robust Interpretive Parsing (RIP), Tesar and Smolensky (2000) outline an algorithm that requires both comprehension-oriented and production-oriented interpretations from the learner, as in the citation below (see also Tesar 1998, 1999):

> "Given an overt form, interpretive parsing is used to determine the optimal interpretation of that overt form (under the learners ranking). That full structural description includes an underlying form. Production-directed parsing is applied to that underlying form to obtain the structural description assigned to the underlying form by the learners ranking." Tesar and Smolensky (2000:61)

For the comprehension-oriented part of this process, this phrasing can be understood as suggesting that the learner works back from overt form all the way to underlying form. However, in Tesar and Smolensky's study, the retrieval of the underlying form was trivial; Tesar and Smolensky simulated the learning of foot structure, meaning that the underlying form was already contained in the overt form, because it was always a string of unmarked syllables of the same length as the surface and overt forms. Consequently, the practice of RIP, from its advent, has been to compare a candidate based on the complete adult *mapping* with a candidate where only the adult underlying form is fixed. When RIP is rephrased in this way, it is asymmetrical, since it compares the complete mapping only to the production-oriented alternative, but not to the comprehension-oriented one. In other words, there is an untapped opportunity to learn from the comprehension side, by considering candidates where only the adult overt form is fixed, and the learner selects optimal forms at the other levels of representation according to their current grammar. This observation was made earlier by Boersma (2006, 2007, 2011) and Hamann et al. (2009), as expressed for instance in the following:

> "Technically, these four learning algorithms [for learning across various levels] can probably be subsumed under a scheme where the 'correct' intermediate representations are based on an optimization where two more peripheral representations (e.g. overt form and meaning) are kept fixed, and two possibly 'incorrect' candidates are computed by keeping only one of the peripheral representations fixed." (Boersma 2007:2043)

I demonstrate the point more visually in Table 5.7, where I use the term "deep form" as a general term for the level of processing that is the furthest away from the overt form in a given simulation.

	Candidates	
RIP candidate		
Adult Deep Form	→ Learner's parse ←	**Adult Overt Form**
Virtual production		
Adult Deep Form	→ Learner's parse →	Learner's Overt Form
Virtual comprehension		
Learner's Deep Form	← Learner's parse ←	**Adult Overt Form**
	Error detection	
Learn from production:	RIP candidate ∼ Virtual production	
Learn from comprehension:	RIP candidate ∼ Virtual comprehension	

Table 5.7: A symmetric conception of RIP

As the table shows, virtual comprehension and production are each other's mirror image, fixing only one of the two sides of the adult mapping. Consequently, there are two opportunities for error detection; the learner can compare the RIP candidate, where both of the adult forms are used and only hidden structure is decided on by the grammar, to the candidate found in virtual production, as well as the one found in virtual comprehension. There is no qualitative difference about processing errors in comprehension; the comparison comes down to the consideration of violation marks, just as in the case of production.

The tableau in Table 5.8 shows an example of bidirectional error detection and the associated learning updates (see Boersma 2006:3 for an earlier example of such a tableau). Here, both of the virtual candidates are different from the RIP candidate. This means that the learner detects two errors for a single exposure to the adult mapping <a+B+c>→[$\sigma\acute{\sigma}\acute{\sigma}$]. Both of the virtual candidates beat the RIP candidate on DEP-LINK. Since the learner takes RIP to be the accurate interpretation, the violation of DEP-LINK constitutes a double incentive to rank the constraint lower, to make sure that the RIP candidate is optimal even in virtual production and comprehension. This is indicated with a double rightward arrow. The RIP candidate also violates the lexical constraints *c/∅ because it associates <c> with a toneless lexical form; see section 5.4.1, especially Table 5.5, for a definition of the lexical constraint format. The virtual production suffers the same fate, because it is similarly constrained in the choice of morphemes. The virtual comprehension candidate differs from virtual production here, because it is free to optimize for morpheme selection. Consequently, it selects the different morpheme <C> instead, and fares better on *c/∅. This causes the learner to decrease the ranking value of *c/∅, a decision which it would not have made if it only considered the virtual production candidate here. Finally, the two licensing constraints are favorable for the RIP candidate compared to the virtual candidates, and therefore receive an increase in ranking value. Here, the virtual production candidate stands out in selecting a different overt form — a freedom that the other two candidates do not have.

<a+B+c> [$\sigma\acute{\sigma}\acute{\sigma}$]		DEP-LINK	*c/∅	$\mathcal{L}$(H, FT-L)	$\mathcal{L}$(H, FT-R)
RIP	<a+B+c>$\lvert\sigma\acute{\sigma}_1\sigma\rvert/\sigma(\acute{\sigma}_1\acute{\sigma}_1)/[\sigma\acute{\sigma}\acute{\sigma}]$	* → →	* →		
Prod	<a+B+c>$\lvert\sigma\acute{\sigma}_1\sigma\rvert/\sigma(\acute{\sigma}_1\sigma)/[\sigma\acute{\sigma}\sigma]$		*		← *
Comp	<a+B+C>$\lvert\sigma\acute{\sigma}_1\acute{\sigma}_2\rvert/\sigma(\acute{\sigma}_1\acute{\sigma}_2)/[\sigma\acute{\sigma}\acute{\sigma}]$			← *	← *

Table 5.8: Bidirectional error detection triggers ranking updates

To my knowledge, all previous RIP studies (with one exception discussed below) have shared the property I noted above for Tesar and Smolensky (2000) that the deep form is contained in the overt form (including Apoussidou and Boersma 2003; Apoussidou 2007; Boersma and Van Leussen 2017). Under those conditions, fixing the overt form implies a fixed deep form too, so the RIP candidate and the virtual comprehension candidate are optimizing over the same candidate set. This means that they are identical and that virtual comprehension will never lead to an error or learning update. The one exception in the literature is due to Hamann et al. (2009), who study the learning of lexical knowledge by detecting errors in comprehension. However, their study has the same property of unidirectional ambiguity as the RIP studies above, but for the reverse direction; in their study, fixing the deep form guarantees errorless selection of the overt form. Consequently, learners in their conditions only learn from errors in comprehension, but never from errors in production.

In the present study, the deep form is ambiguous given only the overt form and *vice versa*. Consequently, the choice between a unidirectional and bidirectional learning is, for the first time, meaningful. Since I see no reason to break the symmetry of learning from both production and comprehension, and previous literature has argued for the merits of both, I will assume for the learning simulations that the learning algorithm detects errors bidirectionally. In section 5.6.1, I will compare results found with bidirectional error detection to those with both types of unidirectional error detection.

5.4.5 Learning procedure

I used Praat version 6.0.25 (Boersma and Weenink 2017) for all learning simulations. I constructed an .OTMulti file for use in Praat, using the list of candidates as described in section 5.4.3 above and the constraints as discussed earlier in sections 5.3 and 5.4.1. This file represents the hypothesis space for the learner. The learning data was stored separately in .PairDistribution files, with weights and forms according to the description in section 5.4.2.

A single learning trial involved the following. All rankings for the OTMulti object are reset, so that constraint weights and disharmonies are set to 100. The decision strategy of the OTMulti object is set to "Optimality Theory". The "Learn" routine is run on the OTMulti object and the co-selected PairDistribution file (in the Praat GUI, this routine is available through the button labeled "Learn..."). I used mostly standard parameter settings, with one exception; learning repetitions were set to 10,000 instead of the default 100,000. All parameters and their settings are listed in Table 5.9.

Parameter	*Setting*
Evaluation noise	2.0
Update rule	symmetric all
Direction	bidirectionally
Initial plasticity	1.0
Replications per plasticity	10,000
Plasticity decrement	0.1
Number of plasticities	4
Rel. plasticity spreading	0.1
Store history every	0

Table 5.9: Settings for the learning simulations in Praat

Briefly, these settings entail that the learner goes through four stages of learning, at every stage sampling 10,000 times from the distribution of adult mappings. After every stage, the plasticity of the learner decreases to a tenth of its previous value. This influences the amount by which ranking values of constraints are changed whenever a learning update is executed. As Boersma (2008:8) explains, "this allows fast learning for young learners and accurate learning for older ones." For every adult mapping the learner processes, the learner samples a new constraint ranking from its stochastic grammatical knowledge. This is done by selecting a disharmony value for every constraint, which is sampled from a Gaussian distribution whose mean is that constraint's ranking value; the standard deviation is the "evaluation noise" parameter, which is here set to 2.0. Then, the learner performs bidirectional learning, comparing the RIP candidate to the production-direction and comprehension-direction candidates, and potentially spotting up to two errors, as I discussed above in section 5.4.4. For error correction, all candidates favoring the learner's candidate over the RIP candidate are decreased in ranking value, and all favoring the RIP candidate are increased in ranking value (through the "symmetric all" update rule), with the size of the ranking value change dependent on the current plasticity. Again, the plasticity value is the mean of a Gaussian distribution, and the "relative plasticity spreading" parameter is the standard deviation. A current plasticity value is sampled from this distribution once per error, so that for a learning update based on a single error, all ranking values are affected equally. If an adult mapping triggers errors in both directions, the two errors will be processed independently, and each error samples its own plasticity value.

After 40,000 adult data, the learning trial is complete. The relevant product of a trial are the ranking values of the constraints, which represent the stochastic grammatical knowledge that the learner has acquired in the course of the trial. I discuss how I tested successful convergence of the learner on the pattern it was presented with in section 5.5.1, after which I will turn to a presentation and interpretation of the results.

5.5 Results

5.5.1 Calculation of convergence rates

At the end of a learning trial, I tested whether the learner had converged on a desired state. The procedure for successful convergence testing is as follows. First, I sampled a constraint ranking from the learner's stochastic grammatical knowledge by selecting the OTMulti object in Praat and choosing the routine "Evaluate.." from the "Evaluate" menu. Noise was set at the default value of 2.0. With this ranking, I tested whether all relevant adult mappings were correctly reproduced in both directions. That is, if the set of adult mappings contains a pair of a deep form D and an overt form O, then I required the grammar to produce overt O when given deep form D, and to comprehend deep D when given overt form O. Since all adult mappings were between morpheme and auditory forms, this means that the learner is free to decide on the lexical and phonological structure associated with these mappings. If the learner correctly reproduced both sides of all involved mappings, this counted as one success. I repeated this test for a total of 1,000 times. If the learner achieved a success rate of at least 95%, i.e. success on at least 950 out of 1000 trials, I considered this a case of convergence on the adult behavior. Conversely, failure to reach 950 successful trials disqualified the learner from successful convergence.

For some patterns, there is neutralization in the production direction. For example, for unbounded shift patterns, such as Final Shift, three of the adult mappings contain the same auditory form, namely {<A+b+c+d+e>, <a+B+c+d+e>, <a+b+C+d+e>}→[$\sigma\sigma\sigma\sigma\acute{\sigma}$]. In cases like these, learners cannot be expected to reliably reproduce the adult perceptual mapping, since the OT grammar has no way to simultaneously select multiple winners. Consequently, for such patterns, the success criterion is relaxed, and the learner is evaluated only on production. This applies to the following patterns: Penult Shift, Final Shift, Final Doubling Shift, Initial-Only Binary Shift, and Penult Shift with Edge Doubling.

For some learning tasks, the freedom of learners to construct their own lexicon poses a risk; it could be that learners lexicalize facts that, under the OT assumption of Richness of the Base, should have been acquired as grammatical knowledge of a phonological generalization. This is called the Subset Problem (see e.g. Alderete and Tesar 2002; Jarosz 2015:40). It is an important consideration when determining convergence criteria, since arguably, learners showing the correct behavior for the example cases might still be said to have failed to find the correct generalization. Fortunately, this is not a concern for the present simulations, because there is no chance of such undesirable lexicalization. This is because of a combination of two factors: All patterns involve reassociation across morpheme boundaries, and all patterns contain the toneless mapping (i.e. the pair <a+b+c+d+e> [$\sigma\sigma\sigma\sigma\sigma$]). Consequently, as soon as the learner attempts to lexicalize an autosegmental structure that is the result of reassociation, it has to assign lexical High tone to a morpheme that also appears in the toneless mapping, which will lead to incorrect predictions. For example, if a learner of the Final Shift pattern — representing a generalization where tone reassociates from its lexical origin to the final position — were to posit that the final morpheme has an underlying High tone, it will incorrectly predict final High tone for the toneless mapping, and hence the relevant trials will not be counted as successes.

5.5.2 Convergence rates for all patterns

For each pattern, I ran simulations for one hundred learners. I present the results, in the form of percentages of successfully converged learners, in Table 5.10.

The table consists of two parts, for the attested and non-target patterns. With the exception of highly learnable Final Doubling Shift, the success rates show the same divide: Learning for attested patterns is overall much higher than for the non-attested patterns. Consequently, the results support an explanation of the overgeneration of the licensing framework from the perspective of learnability; non-target patterns, while representable, might be less likely to be attested because they are harder to learn.

Among attested patterns, convergence rates were lower for penult-targeting patterns than for final-targeting patterns. One factor that could be responsible for this is that penult-targeting patterns are more ambiguous in terms of the hidden structures that suggest them. For example, forms in the Penult Shift pattern, i.e. [$\sigma\sigma\sigma\acute{\sigma}\sigma$], might be footed as /$\sigma\sigma\sigma(\acute{\sigma}\sigma)$/ or /$\sigma\sigma(\sigma\acute{\sigma})\sigma$/, whereas for a Final Shift form, i.e. [$\sigma\sigma\sigma\sigma\acute{\sigma}$], the only structural interpretation is /$\sigma\sigma\sigma(\sigma\acute{\sigma})$/.

The above considerations extend to the case of non-target Final Doubling Shift, which is similar to Final Shift in having unambiguous foot structure. In this sense, it is unsurprising that learners of Final Doubling Shift have a

Pattern	*Successful learners*
Attested patterns	
Binary Spread	96%
Final Spread	66%
Penult Spread	63%
Final Shift	85%
Penult Shift	79%
Non-target patterns	
Final Doubling Shift	71%
Edge Doubling	18%
Init-Only Bin. Spread	0%
Init-Only Bin. Shift	24%
Init-Only Final Spread	0%
Penult Shift, Edge Doubling	23%

Table 5.10: Rates of successful convergence for all patterns (N=100)

rate of convergence that rivals the attested unbounded patterns. Consequently, based on OT-typological and learnability results, Final Doubling Shift should be included in predictions of tonal reassociation typology.

For the Binary Spreading pattern, almost all leaners successfully converged on the adult behavior. In the following, I will discuss obstacles in the learning process that prevented higher success rates for the remaining patterns.

5.5.3 Learning failures for attested unbounded patterns

Compared to the non-target patterns, the scores for the attested unbounded patterns are relatively high, but they are not at ceiling. In learners that did not converge successfully, two types of misanalyses are prevalent. For spreading patterns, learners sometimes misinterpret spreading as the presence of multiple tonal autosegments. For shifting patterns, learners sometimes misinterpret the trigger for shift, analysing shifting as foot–tone avoidance instead of licensing. I discuss both these problem states in more detail below.

In some cases, spans of high-pitched syllables are interpreted as deriving from different tonal autosegments. Using example forms from the Final Spreading pattern, I give one example in Table 5.11.

In the tableau in Table 5.11, a licensing-based spreading analysis of the Final Spreading pattern competes with a multi-tone interpretation.[12] Several

[12]This tableau does not include a candidate that spreads without foot structure, i.e. with surface form /*σ́σ́σ́σ́σ́*/. This is because this form is harmonically bounded; under the present constraint set, spreading serves no purpose unless it is to license the tone at a footed position.

<A+b+c+d+e>$[\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}]$	*H/Ft	License(H, Ft)	*b/H
a. <A+b+c+d+e> $\lvert\acute{\sigma}\sigma\sigma\sigma\sigma\rvert$ $/\acute{\sigma}\acute{\sigma}\acute{\sigma}(\acute{\sigma}\acute{\sigma})/$ $[\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}]$	*!		
b. <A+b+c+d+e> $\lvert\acute{\sigma}_1\acute{\sigma}_2\acute{\sigma}_3\acute{\sigma}_4\acute{\sigma}_5\rvert$ $/\acute{\sigma}_1\acute{\sigma}_2\acute{\sigma}_3\acute{\sigma}_4\acute{\sigma}_5/$ $[\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}]$		*****	*

Table 5.11: RIP candidates for a final spreading pattern showing a licensing and multi-tone analysis

constraints militate against the former, including all variations of *H/Ft. If such a constraint dominates all the licensing constraints as well as all the relevant lexical constraints, exemplified here by *b/H, then the grammar's optimal analysis is one where the underlying form has five different tones, all of which surface.

The multi-tone analysis is not a desirable learning state because it cannot account for tonal alternations in positions where there is no morphological alternation. That is, in the multi-tone analysis, surface high tone on a given syllable is typically accounted for by positing high tone at the same position in the underlying form. However, some surface syllables vary between high and low for a single morpheme, and hence for a single underlying form. Here, the multi-tone analysis runs into trouble. For example, in production, multi-tone analyses might map the morpheme form for the (adult) toneless string to an auditory form with several high tones, i.e. <a+b+c+d+e>$\rightarrow[\sigma\sigma\acute{\sigma}\acute{\sigma}\acute{\sigma}]$.

Multi-tone analyses are not only the *result* of learner misconceptions about the relation between morphemes and underlying structure, but also a *cause* of them. For example, during testing, some learners showed RIP candidate <A+b+c+d+e> $\lvert\acute{\sigma}_1\acute{\sigma}_2\acute{\sigma}_3\acute{\sigma}_4\acute{\sigma}_5\rvert$ $/\acute{\sigma}_1\acute{\sigma}_2\acute{\sigma}_3\acute{\sigma}_4\acute{\sigma}_5/$ $[\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}]$ with virtual comprehension candidate <A+B+c+d+e> $\lvert\acute{\sigma}_1\acute{\sigma}_2\acute{\sigma}_3\acute{\sigma}_4\acute{\sigma}_5\rvert$ $/\acute{\sigma}_1\acute{\sigma}_2\acute{\sigma}_3\acute{\sigma}_4\acute{\sigma}_5/$ $[\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}]$. Here, the difference between the two candidates is whether the morpheme in the second position should be <b>or <B>.[13] The erroneous selection of <B> in

Since I have excluded all harmonically bounded candidates from Gen, this candidate is never considered by the learner. I discuss this issue in detail in section 5.6.3.

[13]Since my focus is on the effects of the learning update, I do not discuss in detail why the learner selected these candidates. Briefly, the grammar must favor a multi-tone analysis over a licensing analysis, meaning that licensing constraints are outranked by markedness constraints punishing foot placement or foot–tone association. In addition, the lexical constraints must be ranked so that <A+B+c+d+e> is the optimal morpheme form for comprehension from $[\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}]$. This means *C/H outranks *c/H, and analogous rankings obtain for <d+e>.

virtual comprehension causes an update, which I demonstrate with the tableau in Table 5.12.

<A+b+c+d+e>[$\acute\sigma\acute\sigma\acute\sigma\acute\sigma\acute\sigma$]		*b/H	*B/H
RIP	<A+b+c+d+e> $\lvert\acute\sigma_1\acute\sigma_2\acute\sigma_3\acute\sigma_4\acute\sigma_5\rvert$ $/\acute\sigma_1\acute\sigma_2\acute\sigma_3\acute\sigma_4\acute\sigma_5/$ [$\acute\sigma\acute\sigma\acute\sigma\acute\sigma\acute\sigma$]	$* \rightarrow$	
Comp	<A+B+c+d+e> $\lvert\acute\sigma_1\acute\sigma_2\acute\sigma_3\acute\sigma_4\acute\sigma_5\rvert$ $/\acute\sigma_1\acute\sigma_2\acute\sigma_3\acute\sigma_4\acute\sigma_5/$ [$\acute\sigma\acute\sigma\acute\sigma\acute\sigma\acute\sigma$]		$\leftarrow *$

Table 5.12: An error update driven by virtual comprehension, away from the adult grammar

Since the RIP candidate and virtual comprehension candidate are not identical, the learner detects an error. The blame for this error is assigned to the lexical constraints associated with <B>. Thus, the learner increases the ranking value of *B/H and decreases that of *b/H. This update moves the grammar away from the adult behavior, which I expect relates <B> with a lexical High tone, and <b> with a toneless lexical form. Consquently, this is an instance where learning from virtual comprehension might be unhelpful.

The second problematic grammar state I discuss is one that surfaces mainly in the analysis of shift patterns. The analysis of shift patterns is complicated by the fact that the grammar space includes cases where tone shifts because of foot–tone avoidance, driven by constraints such as *H/Foot. I show this with the tableau in (5.13).

$\lvert\acute\sigma\sigma\sigma\sigma\sigma\rvert$	Align-L(ω, Ft)	*H/Ft	Max-Link	Dep-Link
a. $/\acute\sigma\sigma\sigma\sigma\sigma/$	*!			
b. $/(\acute\sigma\sigma)\sigma\sigma\sigma/$		*!		
c. ☞ $/(\sigma\sigma)\acute\sigma\sigma\sigma/$			*	*
d. ☞ $/(\sigma\sigma)\sigma\acute\sigma\sigma/$			*	*
e. ☞ $/(\sigma\sigma)\sigma\sigma\acute\sigma/$			*	*

Table 5.13: Tone–foot association markedness can trigger shift to a variety of positions

High-ranking Align-L(ω, Ft) and *H/Ft together ensure that a foot is placed at the left edge and that any lexical tone is moved away from the footed syllables, as demonstrated by candidates (5.13a,b). The tableaux is tied for the winner between three candidates that shift the tone to one of the three unfooted syllables. These candidates are tied because the constraint set offers no means of deciding where the tone should land after it shifts away. This is a consequence of transporting the analytical framework to parallel OT. In a Harmonic Serialist environment, the tone shift would have an intermediate step where the tone is gapped, and because of NoGap, it would consistently favor the target position for shift that creates the smallest gap. In Praat, ties are handled by selecting a winner at random. Thus, when the shift-as-avoidance strategy is applied, a form will randomly shift to any of the last three positions. In some cases, this might turn out to be correct, whereas in other cases the same ranking will fail. In general, the analysis falls short of the present success criteria because it cannot consistently pick the correct winner.

It is beyond the scope of my investigation to determine whether learners get stuck indefinitely in the shift-as-avoidance misanalysis. Consequently, I do not exclude the possibility that the problem of this misanalysis becomes smaller when the learner takes in more adult data, or when learning is performed with more evaluation noise.

Although the shift-as-avoidance analysis works only for shifting patterns, it can appear even in the course of learning spreading patterns. Specifically, the availability of shift-as-avoidance enables alternative hypotheses about the lexical status of the second and third syllable. I turn again to the case of multi-tone analyses in the Final Spreading pattern for an example; One learner analyzed the pair <a+b+C+d+e> $[\sigma\sigma\acute{\sigma}\acute{\sigma}\acute{\sigma}]$ as if it had a tone shift from the second to the third position, so that tone was underlyingly on <b> rather than <C>. The full candidate for this is <a+b+C+d+e> $|\sigma\acute{\sigma}_1\sigma\acute{\sigma}_2\acute{\sigma}_3|$ $/(\sigma\sigma)\acute{\sigma}_1\acute{\sigma}_2\acute{\sigma}_3/$ $[\sigma\sigma\acute{\sigma}\acute{\sigma}\acute{\sigma}]$.

In the discussion section, particularly section 5.6.6, I consider alternatives to the present analytical framework that do not have the same problematic ties for shift-as-avoidance candidates.

5.5.4 Learning failures for non-target patterns

With the exception of Final Doubling Shift, whose successful convergence rate is on par with that of the attested unbounded patterns, all non-target patterns have much lower convergence rates than the attested patterns. Here, I describe the types of states that learners for these different patterns were in at the end of their trials. For every pattern, I will first repeat the associated adult mappings presented to the learner.

Edge Doubling

Firstly, although Edge Doubling, shown in Table 5.14, is representable in parallel OT, the analysis is of a more complicated nature than it was in Chapter 4. There are several rankings that yield the correct overt forms. One example

Morpheme form	*Overt form*	*Relative frequency*
<A+b+c+d+e>	$[\acute{\sigma}\sigma\sigma\sigma\sigma]$	1
<a+B+c+d+e>	$[\sigma\acute{\sigma}\sigma\sigma\sigma]$	1
<a+b+C+d+e>	$[\sigma\sigma\acute{\sigma}\acute{\sigma}\sigma]$	1
<a+b+c+d+e>	$[\sigma\sigma\sigma\sigma\sigma]$	3

Table 5.14: The mappings representing Edge Doubling

of an Edge Doubling analysis is the set of forms shown in (12), calculated with OTSoft (Hayes et al. 2013).

(12) *An analysis of Edge Doubling*

a. $|\acute{\sigma}\sigma\sigma\sigma\sigma|$ $/(\acute{\sigma}\sigma)\sigma(\sigma\sigma)/$ $[\acute{\sigma}\sigma\sigma\sigma\sigma]$

b. $|\sigma\acute{\sigma}\sigma\sigma\sigma|$ $/(\sigma\acute{\sigma})\sigma(\sigma\sigma)/$ $[\sigma\acute{\sigma}\sigma\sigma\sigma]$

c. $|\sigma\sigma\acute{\sigma}\sigma\sigma|$ $/\sigma\sigma\acute{\sigma}(\acute{\sigma}\sigma)/$ $[\sigma\sigma\acute{\sigma}\acute{\sigma}\sigma]$

In general, the parallel solution to achieve Edge Doubling involves manipulating foot structure in such a way that footing of a High-toned third syllable falls out differently from the other two cases. This typically means that the third syllable remains unfooted, so that tone will spread to a foot aligned at the right edge for licensing purposes.

It is possible that these analyses are challenging for the learner because there is no consistent support for some of the crucial sub-rankings. For example, the analysis for the forms in (12) involves alignment of feet to both edges, but there is no consistent tone presence at either edge to signal this requirement — as opposed to, for example, the Final Shift pattern, where high tone surfaces at the right edge in all cases involving tone.

The learner's misanalyses of Edge Doubling involve a multi-tone interpretation of the spread tone. Some learners do show alignment of a foot at the right edge, a first motion towards the correct analysis. However, we do not expect this to be a case where the learner was simply not given enough adult examples; for the attested patterns, the learner could hone in on correct generalizations within mere hundreds of examples, well within the 40,000 examples that were offered.

Initial-Only Binary Shift

In Initial-Only Binary Shift, shown in Table 5.15, tone contributed by the morpheme in the first slot, i.e. <A>, surfaces in the second-syllable position, while tones from other morphemes surface faithfully (assuming the analyst's underlying forms). Unsurprisingly, then, the largest source of confusion for the learner is the lexical form of the morphemes <A, B, b>. In particular, learners tend to put weight in the doomed hypothesis that <b> carries

Morpheme form	*Overt form*	*Relative frequency*
<A+b+c+d+e>	$[\sigma\acute{\sigma}\sigma\sigma\sigma]$	1
<a+B+c+d+e>	$[\sigma\acute{\sigma}\sigma\sigma\sigma]$	1
<a+b+C+d+e>	$[\sigma\sigma\acute{\sigma}\sigma\sigma]$	1
<a+b+c+d+e>	$[\sigma\sigma\sigma\sigma\sigma]$	3

Table 5.15: The mappings representing Initial-Only Binary Shift

a high tone. This hypothesis is easily disproven by the toneless mapping <a+b+c+d+e>→$[\sigma\sigma\sigma\sigma\sigma]$, where <b> does not contribute a high tone. The toneless mapping is highly frequent, yet this does not by itself prevent the learner to go astray about the nature of <b>.

It is likely that comprehension-oriented learning is a source of confusion here.There are two adult mappings containing $[\sigma\acute{\sigma}\sigma\sigma\sigma]$, but at the time of analysis, the learner can pick only one. As the learner becomes confident in the high-toned nature of <B>, it will consistently miscomprehend in the context of the adult pair {<A+b+c+d+e>, $[\sigma\acute{\sigma}\sigma\sigma\sigma]$}, as it will instead select <a+B+c+d+e> in virtual comprehension.

To some extent, these confusions are inherent to any shifting pattern. An additional difficulty in the case of Initial-Only Binary Shift is that there is no shift target that is consistent across all cases; tone from the third morpheme surfaces on the third syllable, rather than the second syllable. In this sense, the pattern is strictly more complex than cases such as Penult Shift. However, this observation is not sufficient to explain why the discrepancy in learning outcomes between Initial-Only Binary Shift and Penult Shift is as large as it is (55 percentage points); I leave this as an issue for future research.

Initial-only Final Spread

Morpheme form	*Overt form*	*Relative frequency*
<A+b+c+d+e>	$[\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}]$	1
<a+B+c+d+e>	$[\sigma\acute{\sigma}\sigma\sigma\sigma]$	1
<a+b+C+d+e>	$[\sigma\sigma\acute{\sigma}\sigma\sigma]$	1
<a+b+c+d+e>	$[\sigma\sigma\sigma\sigma\sigma]$	3

Table 5.16: The mappings representing Initial-Only Final Spread

Learners showed virtually minimal performance on Initial-only Final Spread, shown in Table 5.16; no learner displayed adult behavior more than once in 1000 times. An example set of forms taken from the OTSoft output suggests footing as in (13).

(13) *An analysis of Initial-Only Final Spread*

a. |σ́σσσσ| /σ́σ́σ́(σ́σ́)/ [σ́σ́σ́σ́σ́]

b. |σσ́σσσ| /(σσ́)σσσ/ [σσ́σσσ]

c. |σσσ́σσ| /σ(σσ́)σσ/ [σσσ́σσ]

All tones associate to a footed position, indicating that licensing is crucial to this analysis. All-Ft-Right plays a role in the analysis as can be seen from the first form, since foot placement is rightmost. The crucial ranking that restricts this rightmost spreading to the first form is that *H/Ft-L $\gg$ All-Ft-Right. Because of this, the optimal choice for the other forms is to place the foot with the right edge over the sponsor, to avoid tone association to the foot's left edge. In the learning simulations, all learners fail to find this analysis, and opt instead for a multi-tone analysis of the spreading, as discussed for the attested patterns in section 5.5.3.

Initial-Only Binary Spread

Morpheme form	*Overt form*	*Relative frequency*
<A+b+c+d+e>	[σ́σ́σσσ]	1
<a+B+c+d+e>	[σσ́σσσ]	1
<a+b+C+d+e>	[σσσ́σσ]	1
<a+b+c+d+e>	[σσσσσ]	3

Table 5.17: The mappings representing Initial-Only Binary Spread

Contrary to some of the other patterns, the analysis of the Initial-Only Binary Spread pattern, shown in Table 5.17, is not complex. In fact, the OTSoft output states that only three strata are needed to account for the pattern. I outline one of the analyses in the tableau in Table 5.18.

As the tableau shows, high-ranking faithfulness and licensing to the right edge of the foot take care of all the necessary effects. Yet, none of the learners managed to converge on the desired behavior. Instead, learners analyse the spreading with a multi-tone analysis. Consequently, some learners suspect that <b> is lexically High-toned, based on learning from the pair <A+b+c+d+e>[σ́σ́σσσ]. Others, having concluded that <B> carries high tone, miscomprehend the adult spreading in [σ́σ́σσσ] by selecting <A+B+c+d+e>.

In the OTSoft output, three of the constraints on feet, namely All-Ft-L/R, Align-L/R(ω, Ft) and Align-L(ω, Ft), are in the lowest-ranked stratum. Indeed, this is necessary for the analysis, in order to provide freedom for feet to bend to the requirements of License(H, Ft-R). However, learners don't come to this conclusion, leaving All-Ft-L/R at a higher-than-bottom rank and often even aligning feet at the left edge. It could be that realizing the

$\lvert\acute{\sigma}\sigma\sigma\sigma\sigma\rvert$	Max-Link	License(H, Ft-R)	Dep-Link
a. /$\acute{\sigma}\sigma\sigma\sigma\sigma$/		*!	
b. ☞ /$(\acute{\sigma}\acute{\sigma})\sigma\sigma\sigma$/			*
c. /$(\sigma\acute{\sigma})\sigma\sigma\sigma$/	*!		*
$\lvert\sigma\sigma\acute{\sigma}\sigma\sigma\rvert$			
d. /$\sigma\sigma\acute{\sigma}\sigma\sigma$/		*!	
e. ☞ /$\sigma(\sigma\acute{\sigma})\sigma\sigma$/			
f. /$\sigma(\acute{\sigma}\acute{\sigma})\sigma\sigma$/			*!
g. /$(\sigma\acute{\sigma})\sigma\sigma\sigma$/	*!		*

Table 5.18: Spreading from initial but not third position, due to right-foot-edge licensing

low ranking value of these foot constraints is a severe challenge to the learner. Feet play a relatively separate role from tone until the learner has deduced that licensing constraints are important. Consequently, in the absence of licensing effects, there is little incentive for learners to make different decisions about footing in RIP vs virtual production or comprehension. As long as footing is constant across all modes of interpretation, any learning updates will not affect the footing constraints. However, without a change in footing constraints, learners might have difficulty updating their grammar so that licensing becomes more appealing.

Penultimate shift, Edge Doubling

Morpheme form	*Overt form*	*Relative frequency*
<A+b+c+d+e>	[$\sigma\sigma\sigma\acute{\sigma}\sigma$]	1
<a+B+c+d+e>	[$\sigma\sigma\sigma\acute{\sigma}\sigma$]	1
<a+b+C+d+e>	[$\sigma\sigma\acute{\sigma}\acute{\sigma}\sigma$]	1
<a+b+c+d+e>	[$\sigma\sigma\sigma\sigma\sigma$]	3

Table 5.19: The mappings representing Penult Shift with Edge Doubling

Although some learners find their way to successful convergence, the majority of the learners for the Penultimate Shift, Edge Doubling pattern in Table 5.19 fall prey to the general problem of analyzing shifting as foot avoidance, discussed earlier in the context of the attested patterns, among others with the tableau in Table 5.13 on page 171.

5.6 Discussion

5.6.1 Comparison to unidirectional error detection

In section 5.5, I performed the learning simulations with bidirectional learning, as described in section 5.4.4, detecting errors both from a production and comprehension direction. Here, I compare bidirectional and unidirectional learning. Table 5.20 repeats the earlier results for bidirectional error detection, and adds results for learners that detect errors only in production or only in comprehension, respectively. Apart from error detection style, I have not changed any parameters of the algorithm or the convergence rate calculations.

Error detection:	*Bidirectional*	*Production*	*Comprehension*
Convergence rates for attested patterns			
Binary Spread	96%	0%	0%
Final Spread	66%	60%	0%
Penult Spread	63%	47%	0%
Final Shift	85%	50%	0%
Penult Shift	79%	33%	0%
Convergence rates for non-target patterns			
Final Doubling Shift	71%	51%	0%
Edge Doubling	18%	36%	0%
Init-Only Bin. Spread	0%	0%	0%
Init-Only Bin. Shift	24%	5%	0%
Init-Only Final Spread	0%	0%	0%
Penult Shift, Edge Doubling	23%	32%	0%

Table 5.20: Rates of successful convergence (N=100) for learners with bidirectional, production-only, and comprehension-only error detection

Perhaps the most immediately apparent result in Table 5.20 is the outcome for learners with comprehension-only error detection: for all patterns, all learners failed to reach successful convergence. In other words, the information learners retrieve from comprehension errors is, by itself, not sufficient for the algorithm to form grammars that meet the current success criteria. The successful convergence criterion was formulated to reward bidirectional adult-like behavior in the default case, and production-direction adult-like behavior for patterns that neutralize, such as long-distance shifting patterns. Future work might test if comprehension-only learners do well on other criteria, particularly on comprehension-only adult-like behavior. This could reveal more about the relative contributions from production-only and comprehension-only error detection, respectively.

Learners with production-only error detection also saw a major decline in success rates, although not as extreme as that for comprehension-only learners. The most dramatic result for production-only learners is that the successful convergence rate for Binary Spreading went from near-ceiling to floor. Another major discrepancy is found between the convergence rates for Final Shift and Penult Shift, dropping 35 and 46 percentage points, respectively. For the rest, convergence rates for most patterns dropped by 15–20 percentage points. Two patterns showed higher convergence rates: Edge Doubling and Penult Shift with Edge Doubling.

Production-only learners showed no general effect for patterns with homophony. For example, convergence rates did not increase for the Final Shift pattern, despite the widespread occurrence of comprehension errors the learner must have encountered due to the fact that all tone-carrying forms surfaced with tone only on the final syllable.

Overall, the results show that bidirectional error detection provides the best fit with the typological considerations for the present patterns, outperforming both types of unidirectional error detection both in terms of typological fit and raw success rates. Future work on other types of phonological patterns is needed to see if this result holds in the general case.

5.6.2 HS-OT mismatches

As discussed in section 5.3.3, I have made a compromise between two different, if related, theories of grammar; I have investigated potential overgeneration as it was diagnosed for a factorial typology in Harmonic Serialism using a learning approach that bestows an Optimality Theory architecture on its learners. One effect of this compromise is a limit in scope; only those patterns have been included that are both relevant in the HS context and representable in the OT context. Another effect is that the connection between learnability and typology is now undesirably indirect. The explanatory power of the present results, namely that unattested patterns in the factorial typology are shown in the present simulations to be harder to learn, holds up only insofar as learnability findings in an OT setting carry over to an HS setting.

Future work can address these issues by carrying out a follow-up study using a learning approach couched in Harmonic Serialism, so that the factorial typology and learning results can be compared directly and with full coverage of relevant patterns. In general, the present results could benefit from future work comparing learning in HS and OT settings. Such comparison studies could have the benefit of requiring less elaborate Con and Gen modules than used here, and providing more general insight into the properties of learning in different grammar frameworks.

5.6.3 Harmonic bounding avoidance

In the present simulations, I have chosen to apply harmonic bounding avoidance (HBA), so that Gen does not include any harmonically bounded candidates. Here, I will show the obstacle that harmonically bounded candidates can present in learning, by comparing results with HBA against results of simulations without it. I will also identify an undesirable learning scenario which arises in the presence of harmonically bounded candidates, where learners are stuck on non-target behavior and cannot get out despite the learning update. I will generalize beyond the present constraint set, arguing that this learning scenario will be present in any hypothesis space for domain-based feature reassociation. Afterwards, I will comment on the general desirability and plausibility of HBA.

The impact of HBA on the present learning simulations

In Table 5.21 I compare the results presented in section 5.5 with new simulations that were performed with a "full" Gen that contains harmonically bounded candidates as well. This shows the impact that the decision of HBA has on the present learning simulations.

	Gen *with HBA*	*Full* Gen
Convergence rates for attested patterns		
Binary Spread	96%	5%
Final Spread	66%	52%
Penult Spread	63%	5%
Final Shift	85%	12%
Penult Shift	79%	8%
Convergence rates for non-target patterns		
Final Doubling Shift	71%	63%
Edge Doubling	18%	2%
Init-Only Bin. Spread	0%	0%
Init-Only Bin. Shift	24%	0%
Init-Only Final Spread	0%	0%
Penult Shift, Edge Doubling	23%	3%

Table 5.21: Rates of successful convergence for simulations with HBA vs. full Gen (for both, N=100)

Compared to the results with HBA, the results for simulations with full Gen show a drastic drop in successful convergence rates across the board. Again, as noted in section 5.5, the relatively high learnability of Final Doubling Shift stands out — now even in comparison with the attested patterns. Final Spread also retains a relatively high convergence rate. Although this might suggest that final-targeting patterns and spreading patterns enjoy better learnability rates in a full GEN, such an effect would have to be a composite one, since patterns with only one of these two properties are still near floor levels of convergence; final-targeting but not spreading Final Shift has dropped to 5%, and spreading but not final-targeting Penult Spread to 12%.

Below, I will identify a problematic learning scenario that contributes to this decrease in convergence rates.

Harmonically bounded candidates invite infinite learning updates

Early tests on the binary bounded spreading pattern, which maps e.g. $\acute{\sigma}\sigma\sigma\sigma\sigma \rightarrow (\acute{\sigma}\acute{\sigma})\sigma\sigma\sigma$, showed a pervasive mode of failure where learners got stuck in a mode of non-target behavior.[14] In this mode, the learner has correctly analyzed the morphological alternations, and located the tone in the underlying form. However, the learner refrains from mediating the tone spread through foot structure. Thus, the learner considers candidates such as in (14)

(14) $<$V+w+x+y+z $>$ $|\acute{\sigma}\sigma\sigma\sigma\sigma|$ $/\acute{\sigma}\acute{\sigma}\sigma\sigma\sigma/$ $[\acute{\sigma}\acute{\sigma}\sigma\sigma\sigma]$

This behavior represents the analysis that the pattern is maximally overt, i.e. that no hidden structure is involved and that spreading happens by itself, without any trigger from other phonological considerations. While it might seem natural for such minimalistic analyses to be part of the hypothesis space of the learner, this analysis actually poses an obstacle to learning. Spreading behavior such as by the candidate in (14) does not satisfy any markedness constraint in the constraint set, which means that the candidate is harmonically bounded by the fully faithful, non-spreading candidate. As I will show, this situation gives rise to a problematic learning scenario described in Tesar and Smolensky (2000:§4.4.2) as "The Optimal Interpretation Is Harmonically Bound." The harmonic bounding in this type of learning scenario does not occur exclusively with faithful candidates — indeed, the faithful candidate was not involved in the instance discussed by Tesar and Smolensky. However, for domain-based feature reassociation frameworks, of which the present framework is a specific instance, I claim that this learning scenario will always occur with comparison to the faithful candidate. In the following, I will show the details of the problem. In order to show the general nature of the learning scenario as it relates to domain-based feature reassociation, I will frame the discussion with more abstract constraints and candidates.

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[14] I refrain from using the term learning "state" to avoid the suggestion that this scenario only occurs in one specific state of the learning algorithm, i.e. with one specific set of ranking values. Rather, the scenario arises for a range of different sets of ranking values, as long as there is a high likelihood of the relevant partial constraint rankings. Instead, I will use the terms learning "scenario" and "behavioral mode".

I divide the driving forces of the grammar into three parts. Firstly, the faithful candidate is faced with some markedness problem (represented by the constraint MARKED), whose resolution requires both the construction of a domain and featural reassociation.[15] Both of these repairs come at a price; building the domain violates *STRUC, and performing the reassociation incurs violations of a general faithfulness constraint, FAITH. In addition, for candidates, I will write IN for the underlying form (assuming a perfect morphology-lexicon mapping), and OUT for the overt form. I will denote a domain-based interpretation of OUT as $[\text{OUT}]_{STRUC}$. Using this notation and terminology, I first distinguish two perceptual strategies, as shown in Tableau (5.22).

[OUT]	MARKED	*STRUC	FAITH
a. |IN| /$[\text{OUT}]_{STRUC}$/ [OUT]		*	*
b. |IN| /OUT/ [OUT]	*		*

Table 5.22: Recognizing IN from OUT with and without hidden structure

Here, candidate (5.22a) represents the domain-based interpretation of the data, and (5.22b) the "flat" comprehension corresponding to the candidate shown earlier in (14). Which of the two candidates is considered optimal depends on the ranking of MARKED and *STRUC. Thus, if earlier learning experiences have pushed *STRUC up so that it reliably outranks MARKED, the grammar will consider (5.22b) the optimal form for comprehension. However, from a production perspective, this candidate can never be optimal. I show this with the tableau in (5.23).

|IN|	MARKED	*STRUC	FAITH
a. |IN| /$[\text{OUT}]_{STRUC}$/ [OUT]		*	*
b. |IN| /OUT/ [OUT]	*		*!
c. |IN| /IN/ [IN]	*		

Table 5.23: Production from IN to OUT with and without hidden structure, or staying faithful

[15]At first blush, this description of markedness properties might appear needlessly complex to the reader. However, these properties are definitional of a domain-based reassociation analysis. If the constraint set includes a potentially optimal analysis that can achieve the desired reassociation without constructing a domain, then there is no need for the supposition of hidden structure, nor the acquisition of hidden structure generalizations. I can see one exception to this for problem sets where some alternations require hidden structure, while others do not. I leave this consideration to future research.

In addition to the mappings considered for comprehension, I also list an entirely faithful mapping, in (5.23c). This candidate was not available in comprehension because it does not contain the auditory form [OUT]. Now that it is in the tableau, it harmonically bounds (5.23b), since it has the same failure on Marked while avoiding violations of Faith. Consequently, even when a grammar contains high-ranked *Struc, favoring the mapping in (5.22b, 5.23b) for comprehension, it will prefer the faithful mapping in (5.23c) for production. While this gives rise to an error for the learner to learn from, the crucial problem with this situation is that the ranking update does not change anything in comprehension or production. In the case of Tesar and Smolensky (2000:67), whose simulations use Constraint Demotion, the learner could identify the problematic constraints but "cannot determine what to demote them below". In a GLA context, the learning update will decrease the ranking value of the offending constraint, Faith, every time this error is detected, meaning that this ranking value will sink ever lower over time. This was described before by Boersma and Van Leussen (2017) for their simulations as a "pumping" process.

To summarize, in this learning scenario, the learner uses RIP to analyse the adult form according to the "flat" analysis in (5.22b, 5.23b). Production yields (5.23c) instead, leading to the detection of an error, but the only constraint reranking that this can trigger is a lowering of Faith, which favors the incorrectly produced form. Consequently, there is no change in ranking between *Struc and Marked, so the learner will infinitely persist in this misanalysis.

Desirability of harmonic bounding avoidance

I have established above that for the present Gen, the inclusion of harmonically bounded candidates creates a possibility for the learner to get stuck in a non-target learning scenario. This learning scenario is an instance of a more general phenomenon in error-driven learning, where the learner's updates cause them to revisit earlier behavioral modes, leading to an endless cycle of familiar learning updates. The avoidance of cyclic updates such as those in section 5.6.3 above was a motivation to run the present simulations with a pruned Gen instead, that contained only candidates that were not harmonically bounded. In general, I see at least three ways in which the adoption of harmonic bounding avoidance (HBA) to avoid cyclic updates might be unwarranted. Firstly, it might be argued that the assumption of HBA on Gen is not biologically plausible, and is therefore unsuited for the purposes of modeling (biological) human learning. I take up this matter of plausibility separately, in section 5.6.3.

Another issue with HBA is that it remains to be proven whether hypothesis spaces without harmonically bounded candidates have strictly fewer possibilities for cyclic updates. Tesar and Smolensky (2000) already identified cyclic updates that did not involve harmonically bounded candidates, so HBA does not guarantee complete elimination of cyclic updates. Perhaps it is possible to construct hypothesis spaces where the application of HBA increases the odds of the learner to get caught in a scenario leading to cyclic updates. Moreover, it remains to be proven whether learning scenarios associated with cyclic updates have a strictly negative impact on convergence rates; perhaps it is possible to construct hypothesis spaces where the learner can benefit from learning updates triggered by behaviors involved in cyclic updates — given the assumption of enough noise to exit the cycle afterwards.

Finally, it is also possible to consider cyclic updates as legitimate learning outcomes. Cyclic updates that consistently produce the same structural interpretations, such as those for the learning scenario discussed in 5.6.3 above, converge on fixed behavior, even if some ranking values are pumped infinitely. Other cyclic updates, that go between two or more different analyses of the adult mappings, will require further interpretation on the part of the analyst. These updates could be interpreted as a source of optionality in the grammar. Alternatively, under an assumption of decreasing plasticity, learners in these update cycles could be expected to end up in any of the behavioral modes in the cycle, settling on that behavior. I leave it to future work, particularly on learning and diachrony, to build further understanding about the interpretation of cyclic learning scenarios.

Plausibility of harmonic bounding avoidance

As I alluded to above, studies using HBA in learning might need to defend this choice against the objection that HBA is not cognitively plausible, because it is computationally costly. Firstly, I note that the exact computational cost of HBA is an ongoing topic of research (e.g. Riggle 2009). Consequently, the facts are not settled; the objection that HBA is computationally costly is an *intuition*, and future research might show that for HBA in general or for particular, partial implementations of it, this intuition is not borne out.

Secondly, while computational complexity might be one dimension for judging learning studies, it is not the only one. Studies like the present are *modeling* language acquisition, and the contribution they make to predictions and explanations of typology and human behavior should factor into the studies' evaluation as well. Moreover, it is the evaluation of these predictions that might convince one to change one's beliefs about the nature of the human language faculty. For example, if implementing HBA generally allows for a more accurate account of typology and language acquisition, this could be construed as evidence in favor of theories that state that Gen is inherently optimized for HBA, or whose computational cost for implementing HBA is lower.

5.6.4 Further investigation of learning failures

In sections 5.5.3 and 5.5.4 I discussed some obstacles for learners to converge on adult behavior, as well as the types of behavior that failed learners displayed. I suggested that non-target patterns might offer less consistent evidence to learners about crucial constraint rankings. Future research could make this notion more specific, and test for differences between the attested and unattested patterns on such consistency measures. Similarly, future work might investigate whether there are other measures on which the attested and unattested groups of patterns differ and which are related to learning, such as proportion of consistent rankings (r-volume, Bane and Riggle 2008; Riggle 2010).

In error-driven learning, learnability also depends on the information that learners can recover from error detection. By extension, learnability depends on the conditions under which learners will commit informative errors in the first place. Consequently, for a deeper understanding of learnability in error-driven approaches, more research — and more tooling — is needed about the relation between the possible errors that learners can commit in a given hypothesis space and the grammars that follow from learning updates based on these errors.

5.6.5 The role of phonetic detail

In this study, I have assumed that tonal, autosegmental structure is ambiguous given the overt form. For example, a disyllabic high tone span could signal either one or two tonal autosegments in the phonological structure. However, many languages show special phenomena in contexts where different tonal autosegments are associated to adjacent tone-bearing units, either avoiding or repairing the structure in the phonology, or indicating the structure in the phonetics with (non-contrastive) downstep. Hence, in many if not all languages, it might be unnecessary for the learner to be concerned about ambiguities of tonal structure; if the difference is relevant, the learner can expect the language to signal it anyway.

There are still several arguments against dropping this assumption of structural ambiguity. Firstly, it is not clear how else the learner should treat these structures *before* acquiring enough knowledge about the overt signal to deduce tonal structure from phonetics alone. Second, it is also possible that the lack of this ambiguity in languages is an epiphenomenon of learning, so that it should not be interpreted as evidence about representational theory.

Lastly, the point of autosegmental ambiguity is broader than just tone alone, but applies to all matters of feature spreading. To my knowledge, the doubts I have expressed about tonal ambiguity do not arise for other harmony patterns.

5.6.6 Potential expansions for future research

There are myriad options to subject the present results to further scrutiny, either by seeing how stable the result is under slightly different circumstances, or whether the same result holds for strictly harder tasks. In the following, I go over some such options.

Other GEN

In this chapter, I have restricted GEN to systems that contrast High syllables with toneless ones. However, it is not generally obvious to analysts, let alone to learners learning from phonetic input, that a given language has this contrast, and not for example a contrast of High versus Low, or even a three-way contrast /High, Low, ∅/ (Hyman 2001). Learning simulations could play a role in settling these discussions.

This chapter has also offered only limited options for resolutions of "OCP" situations, where different tonal autosegments associate to adjacent TBUs. An expanded GEN could make the learning task more realistic by including candidates that represent tone fusion, fission, insertion or deletion analyses.

Another restrictive assumption in this chapter was that all morphemes were monosyllabic. Allowing the learner to posit polysyllabic morphemes would make the learning of underlying forms more realistic. Conversely, a similar expansion would be to allow morphemes that consist purely of tone, i.e. floating tone morphemes. In a practical sense, such expansions probably merit the dissociation of morphemic structure and meaning into distinct levels of representation (Boersma and Van Leussen 2017), to give the learner more freedom about morphemic analyses.

The above-mentioned alternatives are all expansions upon the basic GEN I have assumed in this chapter. It is also possible to depart from some of these basic assumptions. For example, the present simulations could be compared to simulations with domain-based schemes of representation other than foot structure, such as Optimal Domains Theory (Cole and Kisseberth 1994; Cassimjee and Kisseberth 1998).

Other adult data

The adult mappings used for the present study are limited in several ways. Firstly, they are limited in terms of structure; all forms are the same length, and contain at most one tone span. More variation along these dimensions, even for the same patterns, would increase the realism of the task and the reliability of the results. Another limitation is that the study tested only one kind of frequency distribution, where the toneless mapping was equally frequent as all the tone-carrying mappings. The toneless form is a rich source of information about alternations, since (barring deletion) it is only consistent with the interpretation that all the morphemes in the toneless mapping have toneless lexical forms. Consequently, varying the balance between toneless and tone-carrying mappings might affect the learnability of the patterns, and is a means of testing the reliability of the present results.

An arguably more ambitious endeavor for future work is to perform simulations with more realistic adult data. The adult data in the present study was already "pre-processed", offering syllabic structure and a discretized contrast between high and low pitch. Future work could, for example, include the acquisition of generalizations about syllable structure into the learning task, or could expose the learner to continuous pitch contours.

Other Con

One problematic feature of the present constraint set is that it has ties for shift-as-avoidance analyses, as discussed in section 5.5.3. Other implementations of Con could easily improve on this. One option to consider is the edge-oriented tone association framework proposed and compared to the licensing framework in Chapter 4. In the edgewise association framework, tone association is evaluated gradiently with respect to an edge, so that shifting across different distances yields different numbers of violations depending on how close to the edge the tone ends up reassociating. Another possibility is to gradiently punish association as it moves further away from the sponsor (Bickmore 1996).

Other learning parameters and algorithms

The present simulations have used a fixed set of parameters. Consequently, future work could see if the present results hold up under different parameter settings. In particular, there could be an effect for the choice of update rule (Apoussidou 2007; Boersma and Van Leussen 2017). In addition, it is possible that learnability results are different with more or less evaluation noise (Jarosz 2013; cf. Boersma and Hayes 2001:80).

Beyond other parameter settings, there is a wealth of other (fallible) learning algorithms to consider. Staying within the context of GLA/RIP, both Biró (2013) and Jarosz (2013) have made proposals to enhance RIP. More fundamentally different learning algorithms have also been used in previous literature, such as learning based on proportion of consistent rankings (r-volume, Bane and Riggle 2008; Riggle 2010), maximum entropy (Goldwater and Johnson 2003; Hayes and Wilson 2008), and Bayesian learning (Jarosz 2015).[16]

Comparing the present results to simulations with these various frameworks and settings can help confirm or reject the present findings that harmonic bounding avoidance and bidirectional error detection are integral to typologically accurate learning simulations. Conversely, the present learning task offers a test to these alternative approaches; simulations whose results are not in accordance with typological expectations must find some other explanation about the attestation and non-attestation of various tone reassociation patterns.

[16] Another major line of research, developing out of EDCD, involves inconsistency detection and monotonously increasing faithfulness violations for increasingly disparate candidates (output-driven maps, Tesar 2004; Akers 2012; Tesar et al. 2003; Tesar 2014, 2017). This approach relates less directly to the present work because its focus is on infallible learners, whereas the present interest is in building arguments built on learning failures.

5.7 Conclusion

In this chapter I have simulated error-driven, gradual, online learning of Optimality Theoretic grammars for sets of learning examples with hidden phonological structure, specifically hidden lexical forms, foot structure, and autosegmental structure. One innovation of the approach was to allow bidirectional error detection (Hamann et al. 2009; Boersma 2011), where learners not only test whether their intuitions about *production* match the adult behavior, but also whether their intuitions about *comprehension* do so. Another major technical choice for the present simulations was to exclude all production-direction harmonically bounded candidates from Gen.

The learning task was inspired by typological work on tonal reassociation in Chapter 4, which predicted a range of attested and unattested patterns for an analytical framework using foot–tone interactions based on licensing. I found that overall, learnability results corresponded to the divide between attested and unattested patterns. Learners of attested patterns had high rates of successful convergence, ranging from 63–96%. This demonstrates that the suggested phonological analysis is learnable, even when lexical forms and foot and tone structure are hidden. Learners of unattested patterns showed far lower rates of successful convergence, showing a divide between the attested and unattested patterns. This divide offers an account for the non-attestation of some of the predicted patterns of the foot–tone licensing framework; these patterns are absent because their poor learnability makes it unlikely that they will arise and be diachronically stable.

Finally, I have shown that the typological divide in the results, as well as the high convergence rates for the attested patterns, rely crucially on the assumptions of bidirectional error detection and harmonic bounding avoidance. Consequently, I conclude that the present study has identified a mutually reinforcing combination of a learning algorithm and an analytical framework that together help explain the typology of tonal reassociation.

Chapter 6

Discussion & Conclusion

This dissertation started off from an interest in the typology of tonal reassociation patterns. One goal of the dissertation has been to give an overview of the attested variation, but mainly, the dissertation has aimed to answer theoretical questions that arise in relation to tonal reassociation.

Analytically, the dissertation set out to address what phonological principles could trigger such reassociation in the first place, and what principles determine the target tone-bearing units to which tones are reassociated. From the outset of the research, a guiding intuition has been that the interaction of *foot structure* with tone might offer solutions to these problems. Following the development of theory to answer these questions, the dissertation expressed an interest in how well that theory can account for the *typology* of tonal reassociation, i.e. to account for the attestation or non-attestation of various patterns. In addition to considering this typological issue purely on the basis of the theoretical framework, the dissertation sought to determine whether the *learnability* of various predicted attested and unattested patterns within the context of the developed framework supports — or even enhances — the present typological account.

In this concluding chapter, I will first summarize the results of the thesis, in the following section. Then, section 6.2 gives general suggestions for future research, and section 6.3 is dedicated to a comparison to representations with feature domains, such as Optimal Domains Theory (Cassimjee and Kisseberth 1998). Section 6.4 wraps up with a general conclusion.

6.1 Summary of results

The most thorough elaboration of this dissertation's analytical framework was given in Chapter 2. In addition to adopting layered foot representations (Bennett 2012; Martínez-Paricio 2013; Martínez-Paricio and Kager 2015), I argued for a constraint set that uses licensing constraints (Zoll 1996; Kang

1997). In addition, I showed that under standard assumptions, Optimality Theory (OT, Prince and Smolensky 1993) does not allow sufficient reference to the underlying form to account for bounded tone shift, which led me to instead adopt Harmonic Serialism (HS, Prince and Smolensky 1993; McCarthy 2000, 2010a). In Chapter 2, I applied this framework to the case of Saghala noun phrase tonology, accounting for the full range of tonal behaviors reported by Patin (2009). This result constitutes the first constraint-based account of the Saghala data. I present this outcome as Result 1.

> Result 1. The foot-licensing framework can account for a realistic data set as found for Saghala (Patin 2009), which features a variety of tone spread and shift behaviors, over binary and ternary domains, with restrictions on adjacency of tonal autosegments and interactions between tone and word-initial syllables.

Result 1 is important in a more general sense because in the typological study in Chapter 4, whose findings I will discuss further below, I sacrificed depth of coverage for breadth; I did not investigate every reassociation pattern in the same depth as Saghala. Consequently, the study in Chapter 2 serves as a proof of concept, demonstrating the framework's flexibility in the face of a variety of tonal phenomena.

The other language-specific study of this dissertation focused on ternary bounded tone spreading in Copperbelt Bemba (Bickmore and Kula 2013; Kula and Bickmore 2015). The focus in this study was on representational issues; the study highlighted the quantity-sensitive nature of the tone spreading pattern and argued for the suitability of layered feet to account for this pattern. Quantity sensitivity is one of the classical domains of application for foot structure. Consequently, the foot-based analysis of Chapter 3 supports the view that feet are well-suited to accounting for tonal reassociation patterns, as compared to a purely autosegmental formalism (e.g. De Lacy 2002; Pearce 2006). In addition, Chapter 3 considered the analysis in the context of metrical theory, arguing that layered feet enable a superior account of the data compared to classic binary feet (McCarthy and Prince 1986; Hayes 1995). I summarize the outcome of this study in Result 2.

> Result 2. The size of the domain for ternary bounded tone reassociation in Copperbelt Bemba (Bickmore and Kula 2013) is dependent on syllable weight, following exactly the grouping of a quantity-sensitive iamb plus an additional mora. This grouping is predicted to occur under layered feet theory (Kager and Martínez-Paricio forthcoming), but not under a traditional binary feet approach (McCarthy and Prince 1986; Hayes 1995).

Result 2 complements the other studies in the dissertation because it motivates the use of feet from a different angle than that of typology.

As stated earlier, the typological angle itself is most deeply investigated in Chapter 4. One of the aims of this chapter was to establish the attested crosslinguistic variation and to test the ability of foot-based frameworks to account for the attested patterns. Throughout the chapter, I compared the *licensing-style* framework developed in Chapter 2 with an alternative foot-based framework where tone association is driven by constraints that attract tone to an edge; in this *edgewise* framework, foot structure more indirectly constrains tonal reassociation. Both frameworks were powerful enough to generate most or all of the attested patterns I considered; I highlight this fact in Result 3.

> RESULT 3. The licensing-style foot–tone framework can account for all single-sponsor cases of bounded and unbounded binary and ternary reassociation; the edgewise framework accounts for all cases except Saghala-style bounded shift and spread.

Establishing coverage on the attested patterns was part of a larger investigation into the full typological predictions of the two foot–tone frameworks, per their factorial typologies. I found that the licensing and edgewise foot–tone frameworks share a prediction of "edge effects", i.e. patterns that predict a deviating pattern for sponsors at the third or even fourth position from the edge. The fact that this kind of pattern appeared in the typological predictions of both licensing and edgewise frameworks suggests that it is a core property of foot-based frameworks in general. There were also some potentially erroneous predictions specific to the respective frameworks. The licensing framework made various predictions of unattested patterns having to do with surface tonal gaps. These include gapping to specific positions, having a split between a default bounded pattern and an unbounded pattern in specific contexts, and spreading patterns that skip over particular metrically targetable positions. On the side of the edgewise framework, there were various predictions of unattested patterns that had to do with counting. The framework was found to predict "footbridge" patterns that alternate between a bounded and unbounded reassociation outcome depending on whether the sponsor is on an odd- or even-numbered syllable; and the framework predicts "odd/even" spreading patterns that require surface tone spans to be always odd or always even. I summarize these findings in Result 4.

> RESULT 4. Licensing-style and edgewise frameworks both predict edge effects. Licensing frameworks overgenerate with respect to gapped tone configurations; edgewise frameworks overgenerate with respect to counting patterns.

Based on the typological predictions calculated in Chapter 4, I investigated the learnability of a range of attested and unattested patterns that were representable with the licensing framework. To avoid the need to develop and implement a learning algorithm for Harmonic Serialism (cf. Jarosz 2015, 2016), I instead cast this study in Optimality Theory. I used the Gradual Learning

Algorithm (GLA, Boersma 1997b, 1998; Boersma and Hayes 2001), and modeled the learning task as a hidden structure learning problem, where both lexical forms and surface phonological structure were hidden (Apoussidou 2007; Boersma and Van Leussen 2017). The learner made use of Robust Interpretive Parsing (RIP, Tesar and Smolensky 2000) to deal with structural ambiguity. A technical innovation in the chapter had to do with the fact that the example data presented to the learner were ambiguous not only from a production direction, but also from a comprehension direction. As a consequence, there was the potential for error detection in two directions; I adopted a reformulated version of RIP that leveraged both production and comprehension errors for the learning simulations (Hamann et al. 2009; Boersma 2011; Boersma and Van Leussen 2017). Another technical choice defended in the chapter was to perform learning with a candidate list that does not contain harmonically bounded candidates. A first result of the chapter, presented in Result 5, is that with this set-up, learners of attested tonal reassociation patterns had a successful convergence rate upwards of 63%.

> Result 5. Using GLA with Stochastic OT, RIP, bidirectional error detection, and a Gen that excludes harmonically bounded candidates, a variety of attested tonal reassociation patterns are moderately or highly learnable.

The typological interest of the study in Chapter 5 was to see if learnability was higher for attested patterns than for unattested patterns, since this could serve as an explanation for why the unattested patterns are unattested despite their representability in the licensing framework. Indeed, this was true of the investigated patterns. On the whole, successful convergence was far lower for unattested than attested patterns — with the exception of an unattested pattern where tone shifts to the final two positions in the prosodic domain. I state this outcome in Result 6.

> Result 6. Except for Final Doubling Shift, the representable-but-unattested patterns of the licensing framework are far less learnable than the attested patterns.

In summary, in this dissertation I have considered a foot-based analysis of the typology of tonal reassociation from various perspectives. In addition to showcasing the analytical framework for Saghala noun phrase tonology, I investigated the general typological tendencies of foot-based tone frameworks through a calculation of factorial typologies, comparing licensing-style and edge-oriented tone association constraints. I gave independent motivation for foot structure based on the quantity-sensitive nature of bounded tone spreading in Copperbelt Bemba. Finally, using learning simulations of hidden lexical and surface phonological structure, and bidirectional RIP, I showed that representable-but-unattested patterns of the licensing framework were less learnable than attested patterns, providing grounds for an explanation of the former patterns' non-attestation. Consequently, the combination of learning framework and analytical framework offers an enhanced typological account of tonal reassociation patterns.

6.2 Future research

For most analytical problems raised in this dissertation, I have provided *possibility* results; I have shown that the problem can be solved, under the theoretical assumptions I make. However, possibility results do *not* imply that the present theoretical assumptions are *necessary*. Although I have argued for the desirability of the present theoretical assumptions — in fact, the major theoretical tools used here, i.e. layered feet, licensing constraints, and Harmonic Serialism, were all proposed independently from the problem of tonal reassociation typology — it is a hallmark of progress in linguistic theory that other possible theoretical assumptions will be pitted against the ones made here. Consequently, in this section I will go through various choices to discuss what a possible replacement for any part of this dissertation's theoretical assumptions should be capable of if it is to retain the present successes.

Another aspect concerning future research is that even with the theoretical assumptions staying as they are, it is possible to expand the scope of the studies performed here. This is particularly the case for the open-ended typology and learning problems studied in Chapters 4 and 5, respectively. Briefly, some relevant expansions are the addition of representations using other tonal categories than High, the addition of tone insertion, deletion, and fusion effects, and the inclusion and analysis of phenomena pertaining to the presence and adjacency of multiple tonal autosegments and depressor consonants. I discuss these and other possibilities in detail in sections 4.5.5 and 5.6.6.

6.2.1 Replacing layered feet

One of the arguments for the adoption of (layered) feet in this dissertation is that they offer an analytical and typological account of the distances between reassociation targets and sponsors or edges. That is, as a counting device, layered feet can account for the ternary nature of some reassociation patterns, and since layered feet are themselves maximally ternary, they also account for the typological generalization of maximal ternarity (cf. Chapter 4:§4.5.2). In addition, feet are also the classical analytical means of dealing with quantity sensitivity, which was shown to be a factor in the analysis of Copperbelt Bemba bounded tone spreading in Chapter 3 (see also Pearce 2006).

Currently, the main representational alternative to feet are approaches using featural domains, instantiated by Optimal Domains Theory (Cole and Kisseberth 1994; Cassimjee and Kisseberth 1998) and Headed Spans (McCarthy 2004). As discussed in sections 2.5.2 and 3.6.3, domain sizes for these approaches do not have a natural limit, and must be restricted to a maximally ternary size through stipulation in order to perform analyses similar to the ones presented here. Moreover, there is no aspect of quantity sensitivity built into these representations. Consequently, these approaches are in need of further elaboration before they can fully replace feet for the present results. I consider the comparison between the present framework and feature domain-based approaches in more detail in section 6.3 below.

An even more radical departure from the adoption of layered feet is to use no organizing constituent for tone reassociation at all. This approach has potential in the context of a strand of computational research that describes phonological generalizations using automata and logical formulas (e.g. Rogers et al. 2013; Jardine 2016b for tone). The focus in this work is on determining the model-theoretic complexity that these descriptions must allow for, i.e. the expressivity of the logic used or the properties allowed of automata, in order to capture patterns in natural language. In this context, counting to finite length is among the least complex effects. Consequently, descriptions of bounded tonal reassociation and of targets near edges can be described by spelling out the involved tone-bearing units, similar to the way this might be done in the contexts of rules in rule-based frameworks. Moreover, describing ternary phenomena is no more problematic than describing binary ones. However, it is still an open problem whether the computational approach can place an upper limit on how high counting goes; as it stands, the approach does not have a way to account for the fact that tonal reassociation patterns are generally *maximally* ternary.

One way of deriving maximal ternarity that does not rely on the representation is by deriving it from circumstances surrounding the learning process. An example comes from work on languages with so-called stress windows, where stress is realized exclusively within a "window" positioned at an edge of the prosodic domain. Stress windows never exceed ternary size (Kager 2012); Staubs (2014, 2015) argues, using simulations of learning, that this is because most plausible example data for learners is biased against quaternary or larger window sizes, because the stress domains are not large enough to provide crucial evidence for large stress windows. It follows from Staubs' results that under certain assumptions about the language learning process and the adult data provided to learners, a dedicated ternary representation is not needed to derive the maximally-ternary nature of stress window typology.

The approaches from computational phonology and from learning biases offer inspiration for alternative ways of deriving the counting effect and the maximal ternarity of layered feet, but fall short on the other job for which the present dissertation has used feet, namely analyzing quantity sensitivity. Future work in functional phonology might determine factors biasing speakers towards the adoption of certain types of quantity sensitivity. Where this pertains to quantity-sensitive tone phenomena, it might be fruitful to adopt a less discretized conception of tone representations than autosegmental theory, as done for example in the Tonal Center of Gravity approach (Barnes et al. 2012).

6.2.2 Replacing Harmonic Serialism

The main motivation to adopt Harmonic Serialism was that, under some assumptions about parallel Optimality Theory (discussed in fn. 8 of Chapter 5), OT cannot analyse bounded tone shift patterns because it cannot make sufficient reference to the underlying position of tone. In addition to enabling this referencing, a noted advantage of Harmonic Serialism was that its serial nature is not tied to any morphosyntactic levels, unlike frameworks such as Stratal OT (Bermúdez-Otero 1999; Kiparsky 2000). I consider this an advantage because tone shift is not generally taken to be a process that takes place exclusively over multiple morphosyntactic levels. Consequently, potential replacements of the Harmonic Serialism component should be considered specifically with reference to bounded shift cases, and if they rely on morphosyntactic levels, should be accompanied by crosslinguistic evidence that shift patterns generally proceed over the course of multiple morphosyntactic stages.

One alternative to HS is to allow OT grammars to use two-level constraints, i.e. constraints that relate underlying structure to surface structure. This is the approach used in Optimal Domains Theory and Headed Spans theory, and in a different form, in Turbidity theory and various approaches developed from there (Goldrick 2000). I discuss such approaches in more detail in section 2.5.2. Briefly, a general problem with allowing two-level constraints — which might be avoidable in some implementations — is that it can weaken OT's commitment to accounting for "conspiracies", by allowing the stipulation of specific repair strategies for specific underlying structures (Kager 1999:381).

Future work on tonal reassociation typology that does not use Harmonic Serialism could also reveal to what extent HS has influenced the present results. One such influence is likely due to the fact that HS applies changes one at a time. Because of this, operations that are applied earlier in the derivation limit the range of possibilities for operations that are applied subsequently; that is, HS displays *primacy* effects. This is especially the case for foot placement; as I have assumed throughout this dissertation, the application of a foot placement operation cannot be undone (Pruitt 2010), so feet placed later in a derivation are blocked from using any of the syllables that are already footed. For example, an HS grammar with a constraint ranking that prioritizes tone licensing, and only secondarily prioritizes syllable parsing and right-edge foot directionality, might process a string $/\sigma\acute{\sigma}\sigma\sigma/$ so that it comes out as $[\sigma(\acute{\sigma}\sigma)\sigma]$. After this, no further (binary) feet will be placed, because there is not enough space to place any. In contrast, an OT grammar with the same priorities has the option of achieving all three goals — tone licensing, syllable parsing, and rightward foot directionality — in parallel, with the output $[(\sigma\acute{\sigma})(\sigma\sigma)]$. In Chapter 5, I calculated both OT and HS factorial typologies (FTs) for the licensing framework. For the OTFT, there were no problematic gaps in the typological predictions beside the expected loss of bounded shift patterns, suggesting that the idiosyncrasies of HSFTs are minor in comparison to OTFTs.

Nevertheless, future work is needed to determine how the nature of HS relates to its typological predictions (McCarthy 2010b).

6.2.3 Replacing licensing constraints

The constraint set must allow the grammar to generate the various kinds of tonal reassociation that have been discussed here. It is likely that any constraint set will be divided into parts along the lines distinguishing the various subcategories of the typological variation. Thus, some constraints must be responsible for the difference between bounded and unbounded patterns, and some other constraints must be specifically in charge of differentiating between spreading and shifting patterns. Past approaches have distinguished bounded and unbounded patterns through a contrast between minimal and maximal reassociation, where some constraint promotes liberal spreading, which generates unbounded patterns; and where some other constraint reins in this spreading so that it applies minimally, making e.g. binary spreading optimal (Cassimjee and Kisseberth 1998; Key 2007). The use of this contrast is most easily upheld by considering only binary bounded patterns, although Bickmore (1996) succeeds in formulating constraints so that a three-unit span can also be considered as minimal in some respect. In the licensing approach, one "switch" that can be toggled to change between bounded and unbounded spread is the relative ranking of NoGap, which can block long-range tone jumps that create gapped autosegmental representations. At a more fine-grained level, the present framework has used feet of various shapes and sizes to settle the exact size of bounded patterns and the exact target of unbounded ones. For future work, constraint sets should be able to distinguish bounded against unbounded patterns, and particularly be able to account for varying domain sizes even within either category. In this respect, perhaps the biggest challenge is for frameworks to be able to deal with a quantity-sensitive, bounded ternary domain, as attested in Copperbelt Bemba (Bickmore and Kula 2013; Kula and Bickmore 2015), discussed here in Chapter 3.

Another dimension on which constraint sets have to differentiate various patterns is the difference between spreading and shifting patterns. The typology of spreading and shifting patterns is mostly mirrored; the targets for spreading patterns that are furthest from the sponsor have counterparts in the targets for shifting patterns (see Chapter 4, especially Table 4.1, for an overview of attested patterns). Consequently, for the most part, the distinction between spreading and shifting can be achieved by adding constraints promoting delinking (or in a featural domains context, non-expression), both generally and in specific contexts. For example, the general form of such a constraint in the licensing framework was $*\mathrm{H}/\sigma$, and a specific constraint was *H/Ft-L, promoting delinking from leftmost positions in feet. The case of Saghala discussed in Chapter 2 stands out as being more complex, since there is more than one surface target — in fact, the edgewise association framework considered in Chapter 4 failed to account for this pattern, specifically. Consequently, future frameworks aimed at accounting for the full range of tone shift typology stand to benefit particularly from a consideration of the Saghala pattern.

6.3 Implications for Optimal Domains Theory

In the OT literature on Bantu tone, the most popular alternative to the present foot-based tonal reassociation approach is a featural domains approach, as instantiated by Optimal Domains Theory (ODT, Cole and Kisseberth 1994; Cassimjee and Kisseberth 1998) and Headed Spans theory (McCarthy 2004; Key 2007; Key and Bickmore 2014). In the following, I will focus on a comparison to ODT, although all arguments should apply virtually identically to Headed Spans theory.

Some preliminary considerations about ODT were presented in the discussion of the Saghala and Bemba chapters, specifically sections 2.5.2 and 3.6.4, respectively. Briefly, these pointed out two challenges for ODT; how to construct ternary High domains as needed for both Saghala and Bemba, and how to construct domains in a quantity-sensitive way as needed for Bemba. It is possible that ODT adopts part of the solutions presented here, by establishing a relation between High domains and metrical structure. A move in this direction can be found in Cassimjee and Kisseberth (1998:79); in order to effect targeting of the antepenultimate position for reassociation in Xhosa, Cassimjee and Kisseberth propose an Avoid Prominence constraint, which militates against the inclusion of prominent syllables in High domains. In Xhosa, they suggest, the prominent position is the penultimate syllable. Consequently, under pressure of Avoid Prominence, the construction of the High domain halts at the antepenultimate, before reaching the prominent penultimate position. Although Cassimjee and Kisseberth do not commit to a specific representation of prominence on the penultimate, I presume that some kind of metrical structure, for example foot structure, is involved. However, the present dissertation has shown that the combination of foot structure and autosegmental structure, by itself, is already a potent pairing, capable of generating a wide range of attested patterns of tonal reassociation. Consequently, future work is needed to determine what benefits ODT offers compared to autosegmental representations if metrical structure remains unchanged and highly able to interact with tone, as proposed in this dissertation. Put differently, future work could investigate whether the adoption of featural domains allows for a streamlining of metrical representational theory or of the constraint set relating to metrical structure.

One potentially illuminating difference between ODT and the present foot-based approach is the status of tone-bearing units that are between the origin and the target of reassociation, especially in unbounded patterns. In the foot-based framework, these positions are typically not footed, and if the reassociation is a shifting pattern, the intermediate positions will not even be associated to. In contrast, since ODT builds contiguous domains, it consistently incorporates all intermediate tone-bearing units in the relevant tone's High domain. For the cases of reassociation discussed in this dissertation, this difference in philosophy does not relate to any difference in predictions. However, languages where tone reassociation interacts with so-called depressor consonants (e.g. Kisseberth 1984), whose presence can interrupt spreading or truncate the reassociation distance so that the reassociation target ends up in front of the depressor, are an interesting proving grounds for future comparisons between the foot-based and domain-based approaches. Under a domain-based approach, such depressor consonants are incorporated in the High domain; consequently, the representation is conducive to an interaction between the presence of depressors and the (non-)expression of tone (for an implementation, see Volk 2011:§8.4). In the foot-based approach presented here, there is no guarantee that the depressor consonant will be footed; any effects stemming from the presence of the depressor will have to be resolved based on autosegmental principles. This suggests that foot-based approaches are without their most flexible tool, the foot, for the analysis of depressor consonants. Future work will have to determine whether foot-based autosegmental approaches can still generate the variety of attested depressor consonant phenomena, or whether featural domains are key in providing an account of depressor consonant behaviors.

6.4 Conclusion

In conclusion, this dissertation has incorporated recent findings in Saghala (Patin 2009) and Copperbelt Bemba (Bickmore and Kula 2013) into the typological discussion on tonal reassociation, establishing that analytical frameworks should be equipped to deal with bounded and unbounded ternarity for spreading and shifting, and in addition with the bounded mixed shift and spread pattern as instantiated by Saghala, and with quantity sensitivity as instantiated by the bounded ternary spreading in Copperbelt Bemba. The dissertation has focused on an analytical framework that uses layered feet to capture ternarity, licensing constraints to relate feet to tone, and Harmonic Serialism to deal with opacity. Using theoretical investigations into the predicted typology of the framework and assessments of the learnability of various predicted tone reassociation patterns, the dissertation has established a serious contender for an account of the typology of tonal reassociation.

Nevertheless, as I have suggested in discussion sections throughout this dissertation, the present account is far from exhaustive. More data reports, offering further theoretical challenges, are available; and new fieldwork will no doubt treat us to surprising additions to this crosslinguistic inventory. Thus, the typology of tonal reassociation continues to offer a wealth of ideation to the adventurous analyst; I hope this dissertation provides some guidance along the way.

Appendix A

All tableaux for Copperbelt Bemba single-sponsor parsing

This appendix, supplementing Chapter 3, contains the full set of tableaux for parsing in Copperbelt Bemba, using the new constraint EXHAUSTIVITY-μ(FTMIN) we proposed in section 3.5. Since our feet could never parse more than three syllables, the relevant inputs are restricted to $2^3 = 8$ different options for the two types of syllable weight. However, for strings beginning with a heavy syllable it is never optimal to parse four moras, as can be gleaned from tableaux (7, 8). Thus we show only six strings, leaving out $\sigma_{\mu\mu}\sigma_{\mu}\sigma_{\mu\mu}$ and collapsing the two cases of initial $\sigma_{\mu\mu}\sigma_{\mu\mu}$.

As before, we restrict GEN to generate only candidates that parse the leftmost syllable; and only candidates with monomoraic dependents that are to the right of the FtMin, and minimally bimoraic FtMin. When moras in heavy syllables are not parsed together, we write $\mu\mu$ instead of $\sigma_{\mu\mu}$. In these cases, periods indicate syllable boundaries. We repeat the relevant constraint definitions from (17) and (22) in (2) for convenience. In the tableaux, EXHAUSTIVITY-μ(FTMIN) is abbreviated as EXH-μ-MIN, FTMIN=$\mu\mu$(MAX) as $\mu\mu$MAX, PARSE-μ as PARSE, and EXHAUSTIVITY-μ as EXH-μ.

(2)	*Constraint*	*Definition*
	EXHAUSTIVITY-μ(FTMIN)	Assign * for every mora directly dominated by a FtMin
	FTMIN=$\mu\mu$(MAX)	Assign * for every FtMin that has more than two moras
	PARSE-μ	Assign * for every mora not parsed by a foot
	EXHAUSTIVITY-μ	Assign * for every mora directly dominated by a foot

(3)

$\sigma_\mu\sigma_\mu\sigma_\mu$	Exh-μ-Min	$\mu\mu$Max	Parse	Exh-μ
a. ☞ $((\sigma_\mu\sigma_\mu)\sigma_\mu)$				
b. $(\sigma_\mu\sigma_\mu)\sigma_\mu$			*!	

(4)

$\sigma_\mu\sigma_\mu\sigma_{\mu\mu}$	Exh-μ-Min	$\mu\mu$Max	Parse	Exh-μ
a. ☞ $((\sigma_\mu\sigma_\mu).\mu)\mu$			*	*
b. $(\sigma_\mu\sigma_\mu)\sigma_{\mu\mu}$			**!	

(5)

$\sigma_\mu\sigma_{\mu\mu}\sigma_\mu$	Exh-μ-Min	$\mu\mu$Max	Parse	Exh-μ
a. ☞ $((\sigma_\mu\sigma_{\mu\mu})\sigma_\mu)$		*		
b. $(\sigma_\mu\sigma_{\mu\mu})\sigma_\mu$		*	*!	
c. $((\sigma_\mu.\mu)\mu).\sigma_\mu$	*!		*	**
d. $(\sigma_\mu.\mu)\mu.\sigma_\mu$	*!		**	*

(6)

$\sigma_\mu\sigma_{\mu\mu}\sigma_{\mu\mu}$	Exh-μ-Min	$\mu\mu$Max	Parse	Exh-μ
a. ☞ $((\sigma_\mu\sigma_{\mu\mu}).\mu)\mu$		*	*	*
b. $(\sigma_\mu\sigma_{\mu\mu})\sigma_{\mu\mu}$		*	**!	
c. $((\sigma_\mu.\mu)\mu).\sigma_{\mu\mu}$	*!		**	**
d. $(\sigma_\mu.\mu)\mu.\sigma_{\mu\mu}$	*!		***	*

(7)

$\sigma_{\mu\mu}\sigma_\mu\sigma_\mu$	Exh-μ-Min	$\mu\mu$Max	Parse	Exh-μ
a. ☞ $((\sigma_{\mu\mu})\sigma_\mu)\sigma_\mu$			*	
b. $(\sigma_{\mu\mu})\sigma_\mu\sigma_\mu$			**!	
c. $((\sigma_{\mu\mu}\sigma_\mu)\sigma_\mu)$		*!		
d. $(\sigma_{\mu\mu}\sigma_\mu)\sigma_\mu$		*!	*	

(8)

$\sigma_{\mu\mu}\sigma_{\mu\mu}$	Exh-μ-Min	$\mu\mu$Max	Parse	Exh-μ
a. ☞ $((\sigma_{\mu\mu}).\mu)\mu$			*	*
b. $(\sigma_{\mu\mu})\sigma_{\mu\mu}$			**!	
c. $(\sigma_{\mu\mu}\sigma_{\mu\mu})$		*!		

Appendix B

All predicted patterns of the two Harmonic Serialism factorial typologies

This appendix, supplementing Chapter 4, lists the full results for the factorial typologies calculated for the licensing and edgewise frameworks, respectively. Patterns that were discussed in Chapter 4 are identified by name; if a pattern is attested, it is listed as "✔ Pattern X".

B.1 All licensing patterns

Table B.1: The full result set of the licensing framework's factorial typology

	$/\acute{\sigma}\sigma\sigma\sigma\sigma/$	$/\sigma\acute{\sigma}\sigma\sigma\sigma/$	$/\sigma\sigma\acute{\sigma}\sigma\sigma/$	
1.	$\acute{\sigma}\sigma\sigma\sigma\sigma$	$\sigma\acute{\sigma}\sigma\sigma\sigma$	$\sigma\sigma\acute{\sigma}\sigma\sigma$	
2.	$\acute{\sigma}\sigma\sigma\sigma\sigma$	$(\sigma\acute{\sigma})\sigma\sigma\sigma$	$\sigma(\sigma\acute{\sigma})\sigma\sigma$	
3.	$\acute{\sigma}\sigma\sigma\sigma\sigma$	$(\acute{\sigma}\acute{\sigma})\sigma\sigma\sigma$	$\sigma(\acute{\sigma}\acute{\sigma})\sigma\sigma$	
4.	$(\acute{\sigma}\sigma)\sigma\sigma\sigma$	$(\sigma\acute{\sigma})\sigma\sigma\sigma$	$\sigma(\sigma\acute{\sigma})\sigma\sigma$	
5.	$(\acute{\sigma}\acute{\sigma})\sigma\sigma\sigma$	$(\sigma\acute{\sigma})\sigma\sigma\sigma$	$\sigma(\sigma\acute{\sigma})\sigma\sigma$	Initial doubling
6.	$(\sigma\acute{\sigma})\sigma\sigma\sigma$	$(\sigma\acute{\sigma})\sigma\sigma\sigma$	$\sigma(\sigma\acute{\sigma})\sigma\sigma$	Initial binary shift
7.	$(\acute{\sigma}\acute{\sigma})\sigma\sigma\sigma$	$(\acute{\sigma}\acute{\sigma})\sigma\sigma\sigma$	$\sigma(\acute{\sigma}\acute{\sigma})\sigma\sigma$	
8.	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\sigma\sigma)$	
9.	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\sigma\acute{\sigma})(\sigma\sigma)$	
10.	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\sigma\acute{\sigma})(\sigma\sigma)$	
11.	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\sigma\acute{\sigma})(\acute{\sigma}\sigma)$	

12.	$(\acute\sigma\sigma)\sigma(\sigma\sigma)$	$(\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\sigma\acute\sigma)(\sigma\sigma)$	
13.	$(\acute\sigma\sigma)\sigma\sigma\sigma$	$\sigma(\acute\sigma\sigma)\sigma\sigma$	$\sigma\sigma(\acute\sigma\sigma)\sigma$	
14.	$(\acute\sigma\acute\sigma)\sigma\sigma\sigma$	$\sigma(\acute\sigma\acute\sigma)\sigma\sigma$	$\sigma\sigma(\acute\sigma\acute\sigma)\sigma$	✔ Binary spread
15.	$(\sigma\acute\sigma)\sigma\sigma\sigma$	$\sigma(\sigma\acute\sigma)\sigma\sigma$	$\sigma\sigma(\sigma\acute\sigma)\sigma$	✔ Binary shift
16.	$(\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\sigma\acute\sigma)(\sigma\sigma)$	$\sigma\sigma(\sigma\acute\sigma)\sigma$	
17.	$(\acute\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\acute\sigma\acute\sigma)(\sigma\sigma)$	$\sigma\sigma(\acute\sigma\acute\sigma)\sigma$	
18.	$(\acute\sigma\sigma)\sigma(\sigma\sigma)$	$\sigma(\acute\sigma\sigma)(\sigma\sigma)$	$\sigma\sigma(\acute\sigma\sigma)\sigma$	
19.	$\acute\sigma\sigma\sigma(\sigma\sigma)$	$(\acute\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\acute\sigma\acute\sigma)(\sigma\sigma)$	
20.	$\acute\sigma\sigma\sigma(\sigma\sigma)$	$(\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\sigma\acute\sigma)(\sigma\sigma)$	
21.	$\acute\sigma\sigma\sigma(\sigma\sigma)$	$(\acute\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\sigma\acute\sigma)(\acute\sigma\sigma)$	
22.	$\acute\sigma\sigma\sigma(\acute\sigma\acute\sigma)$	$(\acute\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\acute\sigma\acute\sigma)(\sigma\sigma)$	
23.	$\acute\sigma\acute\sigma\acute\sigma(\acute\sigma\acute\sigma)$	$(\acute\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\acute\sigma\acute\sigma)(\sigma\sigma)$	
24.	$\sigma\sigma\sigma(\acute\sigma\acute\sigma)$	$(\acute\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\acute\sigma\acute\sigma)(\sigma\sigma)$	
25.	$\acute\sigma\sigma\sigma(\sigma\acute\sigma)$	$(\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\sigma\acute\sigma)(\sigma\sigma)$	Initial final copy
26.	$\acute\sigma\acute\sigma\acute\sigma(\sigma\acute\sigma)$	$(\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\sigma\acute\sigma)(\sigma\sigma)$	Initial penult skip
27.	$\acute\sigma\acute\sigma\acute\sigma(\acute\sigma\acute\sigma)$	$(\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\sigma\acute\sigma)(\sigma\sigma)$	Initial final spread
28.	$\acute\sigma\sigma\sigma(\acute\sigma\acute\sigma)$	$(\acute\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\sigma\acute\sigma)(\acute\sigma\sigma)$	
29.	$\acute\sigma\acute\sigma\acute\sigma(\acute\sigma\acute\sigma)$	$(\acute\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\sigma\acute\sigma)(\acute\sigma\sigma)$	
30.	$\sigma\sigma\sigma(\acute\sigma\acute\sigma)$	$(\acute\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\sigma\acute\sigma)(\acute\sigma\sigma)$	
31.	$\sigma\sigma\sigma(\sigma\acute\sigma)$	$(\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\sigma\acute\sigma)(\sigma\sigma)$	
32.	$(\acute\sigma\sigma)\sigma(\sigma\acute\sigma)$	$(\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\sigma\acute\sigma)(\sigma\sigma)$	
33.	$(\acute\sigma\sigma)\sigma(\sigma\acute\sigma)$	$(\acute\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\acute\sigma\acute\sigma)(\sigma\sigma)$	
34.	$(\acute\sigma\sigma)\sigma(\sigma\acute\sigma)$	$(\acute\sigma\acute\sigma)\sigma(\sigma\sigma)$	$\sigma(\sigma\acute\sigma)(\acute\sigma\sigma)$	
35.	$\acute\sigma\sigma\sigma(\sigma\sigma)$	$\sigma\acute\sigma\sigma(\sigma\sigma)$	$\sigma\sigma\acute\sigma(\sigma\sigma)$	
36.	$\acute\sigma\sigma\sigma(\sigma\sigma)$	$\sigma\acute\sigma\sigma(\sigma\sigma)$	$\sigma\sigma\acute\sigma(\acute\sigma\sigma)$	Edge doubling
37.	$\acute\sigma\sigma\sigma(\sigma\sigma)$	$\sigma\acute\sigma\sigma(\sigma\sigma)$	$\sigma\sigma\acute\sigma(\acute\sigma\acute\sigma)$	Edge tripling
38.	$\acute\sigma\sigma\sigma(\sigma\sigma)$	$\sigma\acute\sigma\sigma(\sigma\sigma)$	$\sigma\sigma\sigma(\acute\sigma\acute\sigma)$	
39.	$\acute\sigma\sigma\sigma(\sigma\sigma)$	$\sigma\acute\sigma\sigma(\sigma\sigma)$	$\sigma\sigma\sigma(\sigma\acute\sigma)$	
40.	$\acute\sigma\sigma\sigma(\sigma\sigma)$	$\sigma\acute\sigma\sigma(\sigma\sigma)$	$\sigma\sigma\sigma(\acute\sigma\sigma)$	
41.	$\acute\sigma\sigma\sigma(\acute\sigma\sigma)$	$\sigma\acute\sigma\sigma(\acute\sigma\sigma)$	$\sigma\sigma\acute\sigma(\acute\sigma\sigma)$	Penult copy
42.	$\acute\sigma\acute\sigma\acute\sigma(\acute\sigma\sigma)$	$\sigma\acute\sigma\acute\sigma(\acute\sigma\sigma)$	$\sigma\sigma\acute\sigma(\acute\sigma\sigma)$	✔ Penult spread
43.	$\acute\sigma\acute\sigma\acute\sigma(\acute\sigma\acute\sigma)$	$\sigma\acute\sigma\acute\sigma(\acute\sigma\acute\sigma)$	$\sigma\sigma\acute\sigma(\acute\sigma\acute\sigma)$	✔ Final spread
44.	$\acute\sigma\sigma\sigma(\acute\sigma\acute\sigma)$	$\sigma\acute\sigma\sigma(\acute\sigma\acute\sigma)$	$\sigma\sigma\acute\sigma(\acute\sigma\acute\sigma)$	Doubling copy
45.	$\sigma\sigma\sigma(\acute\sigma\acute\sigma)$	$\sigma\acute\sigma\acute\sigma(\acute\sigma\acute\sigma)$	$\sigma\sigma\acute\sigma(\acute\sigma\acute\sigma)$	
46.	$\sigma\sigma\sigma(\acute\sigma\acute\sigma)$	$\sigma\sigma\sigma(\acute\sigma\acute\sigma)$	$\sigma\sigma\acute\sigma(\acute\sigma\acute\sigma)$	
47.	$\sigma\sigma\sigma(\acute\sigma\acute\sigma)$	$\sigma\sigma\sigma(\acute\sigma\acute\sigma)$	$\sigma\sigma\sigma(\acute\sigma\acute\sigma)$	Double shift

48.	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	$\sigma\acute{\sigma}\acute{\sigma}(\acute{\sigma}\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\sigma)$	Penult shift; edge penult spread
49.	$\sigma\sigma\sigma(\sigma\acute{\sigma})$	$\sigma\acute{\sigma}\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	Final shift; edge final spread
50.	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\sigma)$	Penult shift; edge doubling
51.	$\sigma\sigma\sigma(\sigma\acute{\sigma})$	$\sigma\sigma\sigma(\sigma\acute{\sigma})$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	Final shift; edge tripling
52.	$\sigma\sigma\sigma(\sigma\acute{\sigma})$	$\sigma\sigma\sigma(\sigma\acute{\sigma})$	$\sigma\sigma\sigma(\sigma\acute{\sigma})$	✔ Final shift
53.	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	✔ Penult shift
54.	$\acute{\sigma}\sigma\sigma(\sigma\acute{\sigma})$	$\sigma\acute{\sigma}\sigma(\sigma\acute{\sigma})$	$\sigma\sigma\acute{\sigma}(\sigma\acute{\sigma})$	Final copy
55.	$\acute{\sigma}\acute{\sigma}\acute{\sigma}(\sigma\acute{\sigma})$	$\sigma\acute{\sigma}\acute{\sigma}(\sigma\acute{\sigma})$	$\sigma\sigma\acute{\sigma}(\sigma\acute{\sigma})$	Penult skip
56.	$(\acute{\sigma}\sigma)\sigma(\sigma\sigma)$	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\sigma)$	
57.	$(\acute{\sigma}\sigma)\sigma(\sigma\sigma)$	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	
58.	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	
59.	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\acute{\sigma})$	
60.	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	
61.	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma\sigma\sigma(\sigma\acute{\sigma})$	
62.	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	
63.	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\acute{\sigma})$	
64.	$(\acute{\sigma}\sigma)\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\sigma)(\sigma\sigma)$	$\sigma\sigma\acute{\sigma}(\sigma\sigma)$	
65.	$(\acute{\sigma}\sigma)\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\sigma)(\sigma\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\sigma)$	
66.	$(\acute{\sigma}\sigma)\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\sigma)(\sigma\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	
67.	$(\acute{\sigma}\sigma)\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\sigma)(\sigma\sigma)$	$\sigma(\sigma\acute{\sigma})(\acute{\sigma}\sigma)$	
68.	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\sigma\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	
69.	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\sigma\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\acute{\sigma})$	
70.	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\sigma\acute{\sigma})(\sigma\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	
71.	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\sigma\acute{\sigma})(\sigma\sigma)$	$\sigma\sigma\sigma(\sigma\acute{\sigma})$	
72.	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\sigma\sigma)$	$\sigma(\sigma\acute{\sigma})(\acute{\sigma}\sigma)$	
73.	$(\acute{\sigma}\sigma)\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\sigma)(\sigma\sigma)$	$\sigma(\sigma\acute{\sigma})(\sigma\sigma)$	

B.2 All edgewise patterns

Table B.2: All results of the edgewise framework's factorial typology

	$/\acute{\sigma}\sigma\sigma\sigma\sigma/$	$/\sigma\acute{\sigma}\sigma\sigma\sigma/$	$/\sigma\sigma\acute{\sigma}\sigma\sigma/$	
1.	$\acute{\sigma}\sigma\sigma\sigma\sigma$	$\sigma\acute{\sigma}\sigma\sigma\sigma$	$\sigma\sigma\acute{\sigma}\sigma\sigma$	
2.	$\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}\sigma$	$\sigma\acute{\sigma}\acute{\sigma}\acute{\sigma}\sigma$	$\sigma\sigma\acute{\sigma}\acute{\sigma}\sigma$	✔ Penult spread
3.	$\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}$	$\sigma\acute{\sigma}\acute{\sigma}\acute{\sigma}\acute{\sigma}$	$\sigma\sigma\acute{\sigma}\acute{\sigma}\acute{\sigma}$	✔ Final spread
4.	$\sigma\sigma\sigma\sigma\acute{\sigma}$	$\sigma\sigma\sigma\sigma\acute{\sigma}$	$\sigma\sigma\sigma\sigma\acute{\sigma}$	

5.	$\acute{\sigma}\acute{\sigma}\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	$\sigma\acute{\sigma}\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	
6.	$\sigma\sigma\sigma(\acute{\sigma}\acute{\sigma})$	$\sigma\sigma\sigma(\acute{\sigma}\acute{\sigma})$	$\sigma\sigma\sigma(\acute{\sigma}\acute{\sigma})$	
7.	$\sigma\sigma\sigma(\sigma\acute{\sigma})$	$\sigma\sigma\sigma(\sigma\acute{\sigma})$	$\sigma\sigma\sigma(\sigma\acute{\sigma})$	✔ Final shift
8.	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	$\sigma\sigma\sigma(\acute{\sigma}\acute{\sigma})$	Even-length final spread
9.	$\sigma(\sigma\sigma)(\sigma\acute{\sigma})$	$\sigma(\sigma\sigma)(\sigma\acute{\sigma})$	$\sigma\sigma\sigma(\sigma\acute{\sigma})$	
10.	$\acute{\sigma}(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	$\sigma(\sigma\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	
11.	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	$\sigma(\sigma\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	Final spread; initial-only shift
12.	$\sigma\sigma\sigma\acute{\sigma}\sigma$	$\sigma\sigma\sigma\acute{\sigma}\sigma$	$\sigma\sigma\sigma\acute{\sigma}\sigma$	✔ Penult shift
13.	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	✔ Penult shift
14.	$(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})\sigma$	$\sigma\sigma(\acute{\sigma}\acute{\sigma})\sigma$	$\sigma\sigma(\acute{\sigma}\acute{\sigma})\sigma$	Even-length penult spread
15.	$(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})\sigma$	$(\sigma\acute{\sigma})(\acute{\sigma}\acute{\sigma})\sigma$	$\sigma\sigma(\acute{\sigma}\acute{\sigma})\sigma$	✔ Penult spread
16.	$(\sigma\sigma)(\sigma\acute{\sigma})\sigma$	$\sigma\sigma(\sigma\acute{\sigma})\sigma$	$\sigma\sigma(\sigma\acute{\sigma})\sigma$	
17.	$\acute{\sigma}\acute{\sigma}\acute{\sigma}(\acute{\sigma}\sigma)$	$\sigma\acute{\sigma}\acute{\sigma}(\acute{\sigma}\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\sigma)$	✔ Penult spread
18.	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	Odd-length penult spread
19.	$\sigma(\sigma\sigma)(\acute{\sigma}\sigma)$	$\sigma(\sigma\sigma)(\acute{\sigma}\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	✔ Penult shift
20.	$\acute{\sigma}(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\sigma)$	$\sigma(\sigma\acute{\sigma})(\acute{\sigma}\sigma)$	✔ Penult spread
21.	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\sigma)$	$\sigma(\sigma\acute{\sigma})(\acute{\sigma}\sigma)$	Penult spread; initial-only shift
22.	$(\acute{\sigma}\sigma)\sigma\sigma\sigma$	$\sigma(\acute{\sigma}\sigma)\sigma\sigma$	$\sigma\sigma(\acute{\sigma}\sigma)\sigma$	
23.	$(\acute{\sigma}\acute{\sigma})\sigma\sigma\sigma$	$\sigma(\acute{\sigma}\acute{\sigma})\sigma\sigma$	$\sigma\sigma(\acute{\sigma}\acute{\sigma})\sigma$	✔ Binary spread
24.	$(\sigma\acute{\sigma})\sigma\sigma\sigma$	$\sigma(\sigma\acute{\sigma})\sigma\sigma$	$\sigma\sigma(\sigma\acute{\sigma})\sigma$	✔ Binary shift
25.	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\sigma\sigma)(\sigma\acute{\sigma})$	$\sigma\sigma(\sigma\acute{\sigma})\sigma$	Footbridge final shift; edge bounded shift
26.	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\sigma\sigma)(\acute{\sigma}\sigma)$	$\sigma\sigma(\sigma\acute{\sigma})\sigma$	
27.	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\sigma)$	$\sigma\sigma(\acute{\sigma}\acute{\sigma})\sigma$	
28.	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	$\sigma\sigma(\acute{\sigma}\acute{\sigma})\sigma$	Footbridge final spread; edge bounded spread
29.	$(\acute{\sigma}\sigma)\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\sigma)(\sigma\sigma)$	$\sigma\sigma(\acute{\sigma}\sigma)\sigma$	
30.	$\acute{\sigma}\sigma\sigma(\sigma\sigma)$	$\sigma\acute{\sigma}\sigma(\sigma\sigma)$	$\sigma\sigma\acute{\sigma}(\sigma\sigma)$	
31.	$\acute{\sigma}\sigma\sigma(\sigma\sigma)$	$\sigma\acute{\sigma}\sigma(\sigma\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\sigma)$	
32.	$\acute{\sigma}\sigma\sigma(\sigma\sigma)$	$\sigma\acute{\sigma}\sigma(\sigma\sigma)$	$\sigma\sigma\acute{\sigma}(\acute{\sigma}\acute{\sigma})$	
33.	$\acute{\sigma}\sigma\sigma(\sigma\sigma)$	$\sigma\acute{\sigma}\sigma(\sigma\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\sigma)$	
34.	$\acute{\sigma}\sigma\sigma(\sigma\sigma)$	$\sigma\acute{\sigma}\sigma(\sigma\sigma)$	$\sigma\sigma\sigma(\acute{\sigma}\acute{\sigma})$	
35.	$\acute{\sigma}\sigma\sigma(\sigma\sigma)$	$\sigma\acute{\sigma}\sigma(\sigma\sigma)$	$\sigma\sigma\sigma(\sigma\acute{\sigma})$	
36.	$\acute{\sigma}\sigma\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\sigma)(\sigma\sigma)$	$\sigma(\sigma\acute{\sigma})(\sigma\sigma)$	
37.	$\acute{\sigma}\sigma\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\sigma)$	$\sigma(\sigma\acute{\sigma})(\acute{\sigma}\sigma)$	

38.	$\acute{\sigma}\sigma\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	$\sigma(\sigma\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	
39.	$\acute{\sigma}\sigma\sigma(\sigma\sigma)$	$\sigma(\sigma\sigma)(\sigma\acute{\sigma})$	$\sigma(\sigma\sigma)(\sigma\acute{\sigma})$	
40.	$\acute{\sigma}\sigma\sigma(\sigma\sigma)$	$\sigma(\sigma\sigma)(\acute{\sigma}\sigma)$	$\sigma(\sigma\sigma)(\acute{\sigma}\sigma)$	
41.	$\acute{\sigma}\acute{\sigma}\acute{\sigma}(\sigma\sigma)$	$\sigma\acute{\sigma}\acute{\sigma}(\sigma\sigma)$	$\sigma\sigma\acute{\sigma}(\sigma\sigma)$	✔ Antepenult spread
42.	$\sigma\sigma\acute{\sigma}(\sigma\sigma)$	$\sigma\sigma\acute{\sigma}(\sigma\sigma)$	$\sigma\sigma\acute{\sigma}(\sigma\sigma)$	✔ Antepenult shift
43.	$(\acute{\sigma}\sigma)\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\sigma)(\sigma\sigma)$	$\sigma(\sigma\acute{\sigma})(\sigma\sigma)$	
44.	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\sigma)$	$\sigma(\sigma\acute{\sigma})(\acute{\sigma}\sigma)$	
45.	$(\acute{\sigma}\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\acute{\sigma}\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	$\sigma(\sigma\acute{\sigma})(\acute{\sigma}\acute{\sigma})$	Footbridge final spread
46.	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\sigma\sigma)(\sigma\acute{\sigma})$	$\sigma(\sigma\sigma)(\sigma\acute{\sigma})$	Footbridge final shift
47.	$(\sigma\acute{\sigma})\sigma(\sigma\sigma)$	$\sigma(\sigma\sigma)(\acute{\sigma}\sigma)$	$\sigma(\sigma\sigma)(\acute{\sigma}\sigma)$	

Appendix C

Representable patterns not included in the learning simulations

This appendix, supplementing Chapter 5, lists representable patterns not used in the learning simulations.

The learning simulations included all patterns that were discussed in Chapter 4 and that were representable in OT with the present constraint set. However, the patterns discussed in Chapter 4 were only a selection of the total factorial typology, included for demonstrative purposes. Consequently, there exist some patterns that were included in both the original HS and the current OT factorial typologies, but that have not been used in learning, because they were not part of the discussion of Chapter 4. I present the full list of these representable-but-untested patterns in Table C.1. Together with the faithful mapping and the tested patterns in section 5.4.2, Table 5.6, these make up the complete intersection of the HS and OT factorial typologies.

Pattern	$\|\acute{\sigma}\sigma\sigma\sigma\sigma\|$	$\|\sigma\acute{\sigma}\sigma\sigma\sigma\|$	$\|\sigma\sigma\acute{\sigma}\sigma\sigma\|$
Leftward binary spread	$[\acute{\sigma}\sigma\sigma\sigma\sigma]$	$[\acute{\sigma}\acute{\sigma}\sigma\sigma\sigma]$	$[\sigma\acute{\sigma}\acute{\sigma}\sigma\sigma]$
Leftward bin spr; initial rightward	$[\acute{\sigma}\acute{\sigma}\sigma\sigma\sigma]$	$[\acute{\sigma}\acute{\sigma}\sigma\sigma\sigma]$	$[\sigma\acute{\sigma}\acute{\sigma}\sigma\sigma]$
Leftward bin spr; edge rightward	$[\acute{\sigma}\acute{\sigma}\sigma\sigma\sigma]$	$[\acute{\sigma}\acute{\sigma}\sigma\sigma\sigma]$	$[\sigma\sigma\acute{\sigma}\acute{\sigma}\sigma]$
Leftward bin spr; init+edge right	$[\acute{\sigma}\acute{\sigma}\sigma\sigma\sigma]$	$[\acute{\sigma}\acute{\sigma}\sigma\sigma\sigma]$	$[\sigma\sigma\acute{\sigma}\acute{\sigma}\sigma]$
Leftward bin spr; init right; edge fin spread	$[\acute{\sigma}\acute{\sigma}\sigma\sigma\sigma]$	$[\acute{\sigma}\acute{\sigma}\sigma\sigma\sigma]$	$[\sigma\sigma\acute{\sigma}\acute{\sigma}\acute{\sigma}]$
Leftward bin spr; init right; edge fin dbl shift	$[\acute{\sigma}\acute{\sigma}\sigma\sigma\sigma]$	$[\acute{\sigma}\acute{\sigma}\sigma\sigma\sigma]$	$[\sigma\sigma\sigma\acute{\sigma}\acute{\sigma}]$
Initial-only final shift	$[\sigma\sigma\sigma\sigma\acute{\sigma}]$	$[\sigma\acute{\sigma}\sigma\sigma\sigma]$	$[\sigma\sigma\acute{\sigma}\sigma\sigma]$
Edge final shift	$[\acute{\sigma}\sigma\sigma\sigma\sigma]$	$[\sigma\acute{\sigma}\sigma\sigma\sigma]$	$[\sigma\sigma\sigma\sigma\acute{\sigma}]$
Edge binary shift	$[\acute{\sigma}\sigma\sigma\sigma\sigma]$	$[\sigma\acute{\sigma}\sigma\sigma\sigma]$	$[\sigma\sigma\sigma\acute{\sigma}\sigma]$
Final doubling shift; edge final spr	$[\sigma\sigma\sigma\acute{\sigma}\acute{\sigma}]$	$[\sigma\sigma\sigma\acute{\sigma}\acute{\sigma}]$	$[\sigma\sigma\acute{\sigma}\acute{\sigma}\acute{\sigma}]$

Table C.1: Untested patterns that are representable in both HS and OT licensing frameworks

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English summary

A foot-based typology of tonal reassociation:

Perspectives from synchrony and learnability

In one sentence, this dissertation addresses theoretical issues concerning the phonological analysis and formal learnability of certain kinds of tone patterns found in human languages. In this summary, I will "unpack" the sentence above. The summary has four main parts. First, I will explain what phonology is about, in general. Then, I will explain what I mean by "tone", and I will give an example of a tone pattern I have studied. Next, I will outline previous research, my motivation for the studies, and the core of my proposal. Finally, I will describe each of the four studies that I presented in this dissertation. I will end with a brief conclusion section.

Phonology

If you say the word "pet" five times in a row and you are not a robot, each time your pronunciation will be a tiny bit different. And yet, any English-speaking judge would award you with full points, because all your five versions of "pet" would be perfectly understandable. The minds of English speakers have a system that can take the five different versions of "pet" you said and boil them down to the same thing. The study of *phonology* is about this systematic handling of speech sounds.

The phonology centers in our minds are busy places. For example, they are also active in the pronunciation of "cats" and "dogs". Both of these words have an "s", to indicate the plural. However, this plural marker is pronounced noticeably differently for these two animals! The "s" in "cats" sounds similar to that of "ocelots" and "wasps". But the "s" in "dogs" sounds different, and more like that in "pugs" or "lizards".

What's going on with this "s"? Phonologists have debated about the best analysis. In this dissertation, I follow the tradition of so-called "generative" phonology, which started with work by Chomsky and Halle (1968). This theory says that our minds come up with speech plans on the fly. So, the first draft of the speech plan for “dogs” comes straight from our memory; we just put all the things we want to say next to each other, making “dog” + “s”. But things don’t end there. Our minds have a so-called phonological “grammar”, which checks whether a speech plan needs editing before the instructions are sent out to our muscles for pronunciation. The grammars of English speakers react differently when plural “s” follows “t” or “p” than when it follows “g” or “d”. So, even though our memories store only one way of saying plural “s”, it can come out differently in “dogs” than in “cats” because *our grammars can change the speech plan* for “s”. Now you know why I say phonology centers are busy places: Speech plans are being revised at the last second all the time! And sometimes, the changes are quite radical. When I talk about tone below, I will show an example of a major speech plan change.

Generative phonology also has something to say about differences between languages. There is tremendous *variation* among the languages of the world. Of course different languages have different words, so speakers’ memories contain different speech plans. In addition, languages can also have wildly different grammars! Nevertheless, generative phonologists believe that we have a *universal* gift for human language. That is, under the right circumstances, any infant could grow up learning any human language in the world.

Grammars, variation, and a universal gift for language — in the description so far, these concepts are quite abstract. Phonologists are eager to make these things as concrete as possible, by collecting and analyzing lots of facts about lots of languages. This way, they can determine the logic by which a speaker’s grammar operates. Also, they can point out the similarities and differences of grammars for different languages. Such insights help us to get at the nature of human language capacity.

Discovering the nature of everything involving all human languages is a grand effort. In my dissertation, I only make a humble contribution to this effort. I have focused on a subproblem, for which I specially selected certain tone languages. I have analyzed the grammar of these languages, as well as the variation among the languages. In the next section, I explain what tone is, and what is special about the tone languages I have looked at.

Tone

Most of the world’s languages have a contrast between two or more pitch-based categories, called *tones*. I will demonstrate this with examples from a language called Bemba. To be precise, this is Bemba the way it is spoken in the Copperbelt province of Zambia, as reported by Kula and Bickmore (2015). In Bemba, the absence or presence of High tone makes a difference for the meaning of what is being said. I show two phrases from Bemba in (2). I use an áccént to mark vowels that carry a High tone.

(2) a. lúk-á 'vomit!'
b. luk-á 'weave!'

The verb root for the phrase in (2a) is *lúk* 'to vomit', which should be said with a high pitch. A Bemba listener will understand that the high pitch signals the High tone category. On the other hand, if we were to say the same string of sounds with a lower pitch in the first syllable, as in (2b), a Bemba listener would experience that we are saying a different word. This time, it sounds to Bemba ears as if we are using the verb root *luk* 'to weave', which does not have a High tone.

For those of us not so well-versed in Bemba, it might be difficult to tell these verbs apart if we were to hear them. But the *analysis* of what is going on is simpler. In the memories of Bemba speakers, some verbs are stored with a High tone. Others are stored without a High tone. We can tell which is which just by listening to the pitch of the relevant vowel (or by making a recording and analyzing it in a software package).

Bemba also has more complex behavior in store for us. Some words sound low-pitched when spoken by themselves, but high-pitched when said within a longer sentence. The Bemba grammar rears its head: It can change the speech plans for tones! As Kula and Bickmore (2015) have pieced together, there are sentences where High tones can "stretch out" rightward beyond their original position. This stretching can go on all the way until the end of the sentence. I have picked an example where only the first word is stored in memory with a High tone, while all the words that follow are stored without High tone. This way, when the grammar comes in to change the speech plan for the tone, there is lots of space to see where the tone ends up. The example is shown in (3). There are some phonetic symbols in the example. They are not important for the story about tone, but if you are curious: ʃ sounds like "sh" in "Shetland pony", ʧ sounds like "ch" in "chicken", and ŋ sounds like "ng" in "lemming".

(3) *Stored in memory:* bákamuʃiikila ʧitundu ʧaŋga buino
Planned speech: bákámúʃííkílá ʧítúúndú ʧááŋgá bwíínó
Meaning: 'They will bury the bushbaby well for Chitundu'

The first line shows the sentence with the words as they are stored in memory. The grammar intervenes in the forming of this sentence. The result is shown in the second line. High tone has stretched out all the way until the end. In all, High tone has been realized on *sixteen* additional vowels!

This dissertation is all about patterns where the grammar intervenes in the speech plan for tones. The pattern in (3) above was one example of this. There are at least a couple dozen more varieties of such patterns in other languages. With a technical term, I call these "tonal reassociation" patterns. Most cases of tonal reassociation are reported for "Bantu" languages, spoken in Central, Eastern, or Southern Africa. Some of these cases are among the most complex patterns found in phonology. In the next section, I talk about previous research on tonal reassociation, and about my own proposals for its analysis.

Analyzing tonal reassociation

Many researchers study tonal reassociation within a single language. They test what happens to tone in all sorts of different sentences. This has led to many books and articles that describe the complex tone systems hidden in everyday speech for those languages. But as I said earlier, it is also important to think about comparisons between languages. Some studies are devoted to this topic, which is called “typology”. Typological studies collect facts from different languages. This way, we know what patterns are out there — we call these patterns “attested”. It is also interesting to think about patterns that are “unattested”, meaning they are not displayed by any language. If a pattern is unattested, we can ask why that is so. This might tell us something about our universal gift for language, and its limits. It could also be a clue about other factors that influence language variation, such as language change, or the limits on first language acquisition.

Although there is some existing literature about tonal reassociation typology, it is becoming slightly dated. New developments in phonological theory and new reports about language data are waiting to play their part in the discussion. In addition, I believe there is an opportunity to improve on previous work. All previous literature has been somewhat restricted in demonstrating the coverage of its theory. That is, for a given theory, it is not clear what patterns it says should be attested, and which ones should be unattested. Typological work on other phenomena, such as stress patterns, usually does better in this regard. For tonal reassociation, things are a bit harder because there are so many possibilities to take into account. Fortunately, there is software that can help to clarify the coverage of a typological theory. A final shortcoming of the previous literature is that there is no research into the relation between typology and learnability. Again, for other phonological concepts such as stress patterns, some researchers have used computer simulations of learning to explain variation in stress patterns across languages. The thinking goes that if simulations show that a pattern is hard to learn, this can be a reason why a language is not attested. In this way, we can separate unattestedness into different baskets; some patterns might be unattested because our minds aren’t equipped to handle them, while others might be unattested because they are difficult to learn.

The reasons above motivated me to do the research in this dissertation. I wanted to study new language data and theory, and see if they have consequences for the analysis and typology of tonal reassociation. I also wanted to be more precise about the coverage of theories for the typology of tonal reassociation. Lastly, I wanted to simulate the learning of tonal reassociation patterns, to see if this helps to explain language variation.

To accomplish the goals above, I need a theory of tone grammars. In this dissertation, I propose such a theory. One of its core ideas is to use a phonological unit called the "foot". A foot is an abstract unit that groups together two or three syllables. Feet are a common tool in phonological theory. They show up in the analysis of stress, reduplication ("word copying"), abbreviations, etc. In the dissertation, I propose a theory about the interaction between tones and feet. The nature of this interaction varies by language. In most of the cases, the foot is leading, and tone "reacts" to the position of the foot. For example, in some languages the foot works like a magnet, attracting tone to the syllable where the foot is. In other languages, the foot has the opposite effect, repelling tone from footed positions. Lastly, in some languages the foot is positioned right over the tone, and all tonal changes happen within the foot's boundaries.

The four studies

I reported on four studies in Chapters 2–5 of this dissertation. Now that I have explained the general topic of the dissertation, I can say something about the details of each study.

In Chapter 2, I made a case study of tonal reassociation in Saghala (Patin 2009). In the following, I will write σ to mean "any given syllable". In Saghala, what starts out in memory as $\acute{\sigma}\sigma\sigma$ ends up by default as $\sigma\acute{\sigma}\acute{\sigma}$. There are also circumstances that cause different patterns. We know of five such alternative patterns. Making an analysis of the Saghala tone patterns was the first test for my foot–tone theoretical framework. Much of the chapter is about developing and motivating this framework. In the end, the case study was successful; using the framework, it was possible to define a grammar that generates all of the tonal patterns the way they are attested for Saghala.

Chapter 3, written together with René Kager, is a second case study. It studies Copperbelt Bemba, but focuses on a different pattern from the one described above. In the case of Chapter 3, the pattern is that a tone stretches out to cover up to two syllables following its underlying position, so $\acute{\sigma}\sigma\sigma$ goes to $\acute{\sigma}\acute{\sigma}\acute{\sigma}$. In fact, the exact outcome of this tonal process depends on the properties of the syllables involved. The tone pattern is different for syllables with short vowels than for syllables with longer vowels. I will leave the details aside, but the crucial part of this is that such sensitivity to syllable properties is traditionally analyzed with foot structure. For this reason, the Copperbelt Bemba case gives an extra reason to use foot structure as a basis for the theoretical framework that I have proposed. What's more, the Bemba facts are relevant to a discussion about foot theory in general. A common assumption in previous literature is that the foot is a maximally binary unit, meaning that it contains at most two units. However, in the Bemba pattern, tonal reassociation can operate over three syllables and take a variety of forms. Because of these facts about Bemba, we concluded in Chapter 3 that foot theory should include more flexible, three-syllable foot structures.

In Chapter 4, I considered the typology of tonal reassociation. I looked at data from a variety of languages. (Check out Table 4.1 on page 96 for an overview of the patterns and languages.) I checked whether the foot–tone framework has an analysis for the attested languages. On this point, I found that the framework is quite flexible and capable of providing analyses for all the patterns I looked at. I found that the framework also allows for some unattested patterns. This could point to a problem; maybe the framework is not restrictive enough. That would mean that it does not give much insight into the limits of variation. I organized the problematic unattested patterns into various types, for follow-up work in Chapter 5. Lastly, I developed a second version of the foot–tone framework that worked slightly differently. Again, I looked at how it dealt with attested and unattested patterns. This framework performed slightly worse. Still, by seeing what these two versions of the framework had in common, we can learn about the foot–tone relation in general. One result was that the theory predicts the most tonal activity near the edges of sentences, because those are the most common places for feet to be in.

Lastly, then, Chapter 5 was about computer simulations testing the *learnability* of attested and unattested tonal reassociation patterns. I tested if the attested patterns were learnable in the first place, and if so, whether they were more easily learnable than the unattested patterns that were also part of the predictions of the foot–tone framework. Overall, the answer to both those questions was "yes"; a variety of attested patterns showed high success rates in learning simulations, while success rates for most of the unattested patterns were far lower. The simulations used "error-driven" learning, where a (simulated) learner checks how well their own behavior lives up to the standard that is set by the examples in their environment. I showed that for tonal reassociation patterns, it is crucial that learners check for errors in their behavior in two directions: both when applying their grammar to a form from memory in order to speak, and when retrieving a form from memory in order to comprehend. In this way, the chapter also contributed to research with learning simulations in general.

Conclusion

In summary, in this dissertation I gave a theoretical analysis of the grammar of two important recent cases of tonal reassociation. I showed that both those cases can be analyzed with a framework that uses the foot to drive tonal reassociation. In addition, I looked at the broader consequences of the theoretical framework that I developed. By involving a learnability aspect, I showed that the predictions from the framework are better than they seemed from a purely theoretical point of view.

I made many choices about my theories and methods. These choices are interesting to researchers even if they work on slightly different things. As I mentioned, the case study of Copperbelt Bemba in Chapter 3 connects to the general debate on foot structure. In addition, I made several findings about the best way to conduct the learnability simulations in Chapter 5. Those findings are relevant to the wider field of phonological learnability studies. Of course, the dissertation has consequences for researchers working on tonal reassociation as well. The dissertation raises the bar for future work in some ways. Future studies should take into account the recently reported facts of Saghala (Chapter 2) and Copperbelt Bemba (Chapter 3), among others. These languages might place heavier demands on theories of tonal reassociation than there were before. In addition, the study in Chapter 4 shows that it is doable, even for a complex topic like tonal reassociation, to determine a broad picture of what a theoretical framework predicts. By demonstrating the methodology and proposing general interpretations of the results, the chapter has enabled future work to calculate even larger, more meaningful result sets. Finally, the connection that was found in Chapter 5 between typology and learnability is very relevant for future work. It shows that a pure theory approach is not the only way to go. Some proposals might not do too well on paper, but work out beautifully by involving other aspects such as learnability simulations.

Throughout the dissertation, I have also pointed out simplifications I made, and I have pointed to further (fascinating!) data or ideas that I did not manage to put in the dissertation. Together, these matters form an agenda of challenges that future work can now begin to tackle.

Nederlandse samenvatting

Een typologie van tonale herassociatie met voetstructuur:

Perspectieven vanuit synchronie en leerbaarheid

In één zin gezegd gaat deze dissertatie over theoretische kwesties rondom de fonologische analyse en formele leerbaarheid van bepaalde soorten toonpatronen in menselijke talen. In deze samenvatting zal ik bovenstaande zin "uitpakken". De samenvatting heeft vier hoofddelen. Eerst zal ik in het algemeen uitleggen wat fonologie inhoudt. Daarna leg ik uit wat ik bedoel met "toon" en geef ik een voorbeeld van een toonpatroon dat ik bestudeerd heb. Vervolgens geef ik een schets van eerder onderzoek op dit gebied, van de motivering van mijn eigen onderzoek, en van de aard van mijn voorstel. Als laatste kan ik dan wat uitgebreider ingaan op elk van de vier studies die ik in dit boek heb aangeboden. De samenvatting wordt afgerond met een korte conclusiesectie.

Fonologie

Als je vijf keer achter elkaar het woord "dinosaurus" probeert te zeggen en je niet een robot bent, zal je uitspraak elke keer nét ietsje anders zijn. Toch zou elke Nederlandssprekende jury je de volle punten geven voor je poging, omdat alle vijf je versies van "dinosaurus" prima te begrijpen zijn. De verstandelijke vermogens van sprekers van het Nederlands bevatten een systeem waarmee jouw vijf verschillende versies van "dinosaurus" kunnen worden herleid tot hetzelfde begrip. Onderzoek in de *fonologie* gaat over deze systematische verwerking van spraak.

Het is erg druk in het fonologiecentrum in ons verstand. Daar wordt bijvoorbeeld ook werk gemaakt van de uitspraak van woorden als "hond" en "eend". Deze woorden eindigen op een "d", maar in de uitspraak klinkt die "d" eerder als een "t", zodat de woorden rijmen op "lont" en "(hij) leent". Wel klinkt de "d" duidelijk door in het meervoud: "honden" en "eenden".

Wat is er aan de hand met die "d"? Fonologen discussiëren nog over de beste interpretatie van de feiten. In deze dissertatie volg ik de zienswijze van de zogenoemde “generatieve” fonologie, die zijn oorsprong kent in het werk van Chomsky en Halle 1968. Deze theorie zegt dat mensen op het moment dat ze besluiten iets te gaan zeggen een vers plan-van-uitspraak opstellen. De eerste kladversie van zo’n plan komt recht uit het geheugen. Zo maken we bijvoorbeeld het meervoud “honden” uit “hond” + “en”. Maar aan de “t”-achtige uitspraak van het enkelvoud “hond” zien we dat er meer aan de hand is. Ons taalvermogen kent een zogeheten “grammatica” die checkt of er aan een plan-van-uitspraak nog iets moet worden gewijzigd voordat het opgestuurd kan worden naar onze spieren voor de daadwerkelijke articulatie. De grammatica’s van sprekers van het Nederlands grijpen in wanneer een woord gepland staat om te eindigen op een “d”, en maken er een “t”-klank van, zoals in “hond” en “eend”. Ook al bestaat er in ons geheugen dus maar één versie van “hond”, toch komt de “d” in het enkelvoud en het meervoud op twee verschillende manieren naar buiten omdat *onze grammatica’s het plan-van-uitspraak kunnen aanpassen*. Nu begrijp je misschien waarom ik zei dat het erg druk is in fonologiecentra: er worden constant revisies gemaakt van plannen-van-uitspraak! Soms voert de grammatica zelfs vergaande wijzigingen door. Als ik het straks over toon heb, zal ik een voorbeeld geven van een grote planwijziging.

Generatieve fonologie heeft ook iets te zeggen over verschillen tussen talen. Er is een rijkdom aan *variatie* te vinden in de talen van de wereld. Natuurlijk hebben verschillende talen hun eigen woorden, dus de geheugens van sprekers zijn al gevuld met verschillende plannen-van-uitspraak. Daarbovenop kenmerken talen zich door sterk uiteenlopende grammatica’s! Toch zijn generatieve fonologen van mening dat mensen een *universele* aanleg hebben voor taal. Dat wil zeggen dat elk kind in principe zou kunnen opgroeien tot moedertaalspreker van elke mogelijke taal.

Grammatica’s, variatie en een universele aanleg voor taal — tot nu toe klinken die concepten erg abstract. Fonologen willen deze dingen zo concreet mogelijk invullen, door allerlei kennis te verzamelen over allerlei talen. Met genoeg kennis over een taal kunnen fonologen bepalen hoe de grammatica voor die taal in elkaar steekt. Door meerdere talen in dit proces te betrekken kunnen we ook bepalen wat voor verschillen en overeenkomsten er zijn tussen grammatica’s voor verschillende talen. Zulke inzichten leiden uiteindelijk naar een algemeen begrip van de menselijke aanleg voor, en omgang met, taal.

Het ontrafelen van de ware aard van alles wat te maken heeft met enig mogelijke menselijke taal is een gigantische onderneming. In mijn proefschrift lever ik hieraan een bescheiden bijdrage. Ik heb me beziggehouden met een deelprobleem, waarvoor ik specifiek heb gekeken naar bepaalde toontalen. Ik heb de grammatica van deze talen geanalyseerd, alsook de variatie onder de talen. In de volgende sectie leg ik uit wat toon is, en wat er zo speciaal is aan de toontalen die ik onderzocht heb.

Toon

De meeste talen in de wereld maken een onderscheid tussen twee of meer klankcategorieën op basis van toonhoogte. Die categorieën noemt men *tonen*. Ik zal dit demonstreren aan de hand van voorbeelden uit een taal genaamd Bemba. Om precies te zijn gaat het hier om Bemba zoals dat gesproken wordt in de Copperbelt-provincie van Zambia, waarbij ik me baseer op het verslag van Kula en Bickmore 2015. In het Bemba verandert de betekenis van wat er gezegd wordt afhankelijk van de aan- of afwezigheid van een Hoge toon. (Ik schrijf Hoge met hoofdletter H omdat het de naam van de categorie aanduidt.) In het voorbeeld in (2) toon ik twee zinnetjes uit het Bemba. Ik gebruik een áccént om de klinkers te markeren die een Hoge toon dragen.

(2) a. lúk-á ‘kots!’
 b. luk-á ‘weef!’

De werkwoordsstam voor het zinnetje in (2a) is *lúk* ‘kotsen’, wat op een hoge toonhoogte uitgesproken dient te worden. Een goed verstaander van het Bemba zal dan begrijpen dat de hoge toonhoogte een aanduiding is voor de Hoge tooncategorie. Als we daarentegen dezelfde reeks klanken zouden uitspreken met een lagere toonhoogte op de eerste lettergreep, zoals in (2b), zou de Bemba-verstaander ervaren dat we een ander woord zeggen. Dan zou het namelijk klinken alsof we de werkwoordsstam *luk* ‘weven’ gebruiken, die geen Hoge toon heeft.

Voor degenen onder ons die het Bemba niet zo onder de knie hebben lijkt het misschien lastig om deze werkwoorden op gehoor uit elkaar te houden. Maar de *analyse* van wat er aan de hand is, is een stuk simpeler. In het geheugen van een Bemba-spreker zijn sommige werkwoorden opgeslagen met een Hoge toon, en andere niet.

Bemba kent ook complexere patronen. Sommige woorden worden uitgesproken met een lage toonhoogte wanneer ze op zichzelf staan, maar kunnen met een hogere toonhoogte worden uitgesproken wanneer ze in een zin staan. Dat komt door de grammatica van het Bemba: die is in staat het plan-van-uitspraak van tonen te veranderen! Kula en Bickmore hebben uitgevonden dat er zinnen zijn waarbij de Hoge toon naar rechts toe “uitgespreid” wordt voorbij zijn eigen klinker. Die spreiding kan zelfs doorgaan tot aan het einde van de zin. Ik heb een voorbeeldzin uitgezocht waarin alleen het eerste woord in het geheugen is opgeslagen met een Hoge toon, terwijl alle daaropvolgende woorden zonder Hoge toon zijn opgeslagen. Op die manier is er veel “ruimte” om te zien wat er met de toon gebeurt wanneer de grammatica in het spel komt. De voorbeeldzin staat in (3). In dat voorbeeld gebruik ik ook een paar fonetische symbolen. Ze zijn niet van belang voor het verhaal over toon, maar voor de nieuwsgierige lezer: ʃ klinkt als “sh” in “Shetlandpony”, ʧ klinkt als “ch” in “chille chihuahua’s checken”, en ŋ klinkt als “ng” in “orang-oetan”.

(3)	*In het geheugen:*	bákamuʃiikila ʧitundu ʧaŋga buino
	Uitspraak:	bákámúʃííkílá ʧítúúndú ʧááŋgá bwíínó
	Betekenis:	‘Ze zullen de galago goed begraven voor Chitundu’

De eerste regel geeft de woorden weer zoals ze zijn opgeslagen in het geheugen. De grammatica mengt zich in het plannen van de uitspraak van deze zin. Het resultaat daarvan staat op de tweede regel. De Hoge toon is helemaal tot aan het einde van de zin uitgespreid. In totaal weerklinkt de toon daardoor op *zestien* extra lettergrepen!

Deze dissertatie is volledig gericht op patronen waar de grammatica eisen stelt aan het plan-van-uitspraak van toon. Het patroon in (3) hierboven is daarvan een voorbeeld. Er zijn nog minstens een paar tientallen andere varaties op zulke patronen, in andere talen. Mijn technische term voor deze patronen is dat het gevallen zijn van “tonale herassociatie”. De meeste gevallen van tonale herassociatie komen voor in zogeheten “Bantoe”-talen, gesproken in Centraal-Oost-, en Zuidelijk Afrika. Sommige gevallen van herassociatie behoren tot de complexte patronen in de fonologie. In de volgende sectie bespreek ik voorgaande literatuur over tonale herassociatie en mijn eigen voorstel voor de analyse ervan.

Tonale herassociatie analyseren

Veel onderzoekers hebben tonale herassociatie bestudeerd in één taal. Ze bekijken dan wat er met toon gebeurt in allerlei verschillende soorten zinnen. Dit heeft vele beschrijvingen opgeleverd van de complexe toonsystemen die zich verschuilen in het dagelijks taalgebruik van sprekers van de betreffende talen. Maar zoals ik eerder al zei is het ook belangrijk om verschillende talen met elkaar te vergelijken. Sommige studies zijn gewijd aan dit onderwerp, dat “typologie” wordt genoemd. Typologisch onderzoek bundelt feiten over verschillende talen. Zodoende krijgen we een overzicht van de bestaande variatie van patronen — die patronen bestempelen we als “geattesteerd”. Het is ook interessant om na te denken over “niet-geattesteerde” patronen, dat wil zeggen patronen die in geen enkele taal voorkomen. Als een patroon niet geattesteerd is, kunnen we ons de vraag stellen: waarom niet? Die non-attestatie zou ons iets kunnen vertellen over de aard van onze universele aanleg voor taal, en de grenzen ervan. Het zou ook een aanwijzing kunnen zijn over andere factoren die taalvariatie beïnvloeden, zoals taalverandering of de begrenzingen aan eerstetaalverwerving.

Er bestaat al wetenschappelijke literatuur over de typologie van tonale herassociatie, maar die begint wat gedateerd te raken. Nieuwe ontwikkelingen op het gebied van fonologische theorie en nieuwe veldwerkverslagen over taalpatronen liggen klaar om in de discussie betrokken te worden. Verder vallen er mijns inziens ook nog dingen te verbeteren ten opzichte van het bestaande onderzoek. Alle voorgaande literatuur heeft zich maar in beperkte mate uitgelaten over het bereik van hun analyses. Daarmee bedoel ik dat het tot nu toe nauwelijks expliciet werd gemaakt welke patronen volgens een gegeven theorie allemaal wel geattesteerd zouden moeten zijn of juist niet. Typologische studies naar andere fonologische fenomenen, zoals klemtoon, zijn hier vaak duidelijker in. Voor tonale herassociatie is het lastiger om expliciet te zijn, omdat er zo veel mogelijkheden zijn om rekening mee te houden. Gelukkig is er in de loop der tijd ook software ontwikkeld die kan helpen bij het berekenen van de consequenties van een theorie. Een andere tekortkoming in eerdere literatuur over tonale herassociatie is dat er geen onderzoek is gedaan naar de interactie tussen typologie en leerbaarheid. Wederom bestaat zulk onderzoek wel voor bijvoorbeeld klemtoontypologie, waar onderzoekers hebben laten zien dat het mogelijk is om een deel van de variatie in klemtoonpatronen te verklaren aan de hand van leerbaarheid. Dat argument gaat als volgt: als simulaties van het leerproces laten zien dat sommige patronen moeilijk te leren zijn, kan dat een verklaring zijn voor de non-attestatie van die patronen. Op die manier kunnen we non-attestatie verder uitsplitsen naar oorzaak: sommige patronen zijn niet geattesteerd omdat ons verstand niet uitgerust is voor het omgaan met dat patroon, terwijl andere patronen niet geattesteerd zijn omdat ze moeilijk te leren zijn.

De bovenstaande redenen waren voor mij de aanleiding om het onderzoek in deze dissertatie uit te voeren. Ik wilde nieuwe taaldata en nieuwe theorieën bestuderen en kijken of ze consequenties hebben voor de analyse en typologie van tonale herassociatie. Ik wilde ook preciezere uitspraken kunnen doen over het bereik van typologische theorieën over tonale herassociatie. Daarnaast wilde ik leersimulaties uitvoeren voor tonale herassociatie, om te kijken of dat bijdraagt aan een uitleg van de bestaande taalvariatie.

Om bovenstaande doelen te bereiken heb ik een theorie over toongrammatica's nodig. In deze dissertatie doe ik een voorstel voor zo'n theorie. Een cruciaal begrip in dat voorstel is een fonologische structuur die de "voet" wordt genoemd. Een voet is een abstract stukje structuur dat twee of drie opeenvolgende lettergrepen groepeert — net zoals die lettergrepen op hun beurt meerdere klanken groeperen. Voeten zijn een welbekend begrip in de fonologie. Ze worden gebruikt bij de analyse van klemtoon, reduplicatie (het "verdubbelen" van delen van woorden), afkortingen, etc. In de dissertatie stel ik een theorie voor over de interactie tussen tonen en voeten. Die interactie verloopt verschillend voor verschillende talen. In de meeste gevallen is de voet leidend, en "reageert" de toon op de positie van de voet. De voet heeft soms bijvoorbeeld de functie van een soort magneet, die toon aantrekt naar de lettergreep waarop de voet geplaatst is. In andere talen heeft de voet het tegenovergestelde effect, en houdt hij de toon weg van de lettergrepen die door de voet gegroepeerd zijn. Ten slotte zijn er talen waarin de voet bovenop de lettergreep met de toon staat, en alle tonale herassociatie zich binnen de grenzen van de voet afspeelt.

De vier studies

In Hoofdstukken 2–5 van deze dissertatie heb ik verslag gedaan van vier studies. Nu ik het algemene onderwerp van de dissertatie heb besproken, kan ik ingaan op de details van elk van deze studies.

In Hoofdstuk 2 heb ik een *case study* gemaakt van tonale herassociatie in de taal Saghala (Patin 2009). Vanaf nu schrijf ik het symbool σ voor "een willekeurige lettergreep". Ik gebruik nog steeds accenten (bv. $\acute{\sigma}$) om aan te duiden waar er Hoge toon is. In Saghala wordt een uit het geheugen opgediepte reeks $\acute{\sigma}\sigma\sigma$ uiteindelijk standaard uitgesproken als $\sigma\acute{\sigma}\acute{\sigma}$. Er zijn ook zinnen met eigenschappen die tot andere patronen leiden dan dit standaardpatroon. We kennen vijf van die alternatieve patronen voor het Saghala. Het maken van een analyse voor al deze patronen was de eerste test voor mijn theoretische framework met voet–toon interactie. Een groot deel van het hoofdstuk is gewijd aan het ontwikkelen en motiveren van dit framework. De case study was uiteindelijk een succes: met gebruik van het framework bleek het mogelijk om een grammatica te beschrijven die precies alle tonale patronen genereert zoals ze voor het Saghala geattesteerd zijn.

Hoofdstuk 3, geschreven samen met René Kager, is een tweede case study. Hier gaat het om Copperbelt Bemba, dat al eerder langskwam, alleen ligt de focus in Hoofdstuk 3 op een ander patroon in de taal. Copperbelt Bemba kent namelijk ook een patroon waarbij toon zich uitspreidt naar slechts de twee volgende lettergrepen. In de abstracte notatie: $\acute{\sigma}\sigma\sigma$ gaat naar $\acute{\sigma}\acute{\sigma}\acute{\sigma}$. Eigenlijk is het complexer: de precieze uitkomst van dit tonale proces hangt af van de eigenschappen van de lettergrepen die erbij betrokken zijn. De uitkomst is anders voor lettergrepen met korte klinkers dan voor die met lange klinkers. Verdere details laat ik achterwege, maar essentieel hieraan is dat zulke gevoeligheid voor de eigenschappen van lettergrepen een kwaliteit is die typisch aan voetstructuur wordt toegekend. Het geval van Copperbelt Bemba vormt daarom een extra reden om voetstructuur te gebruiken als basis voor het theoretische framework dat ik heb voorgesteld. De voet-gebaseerde analyse van de Bemba-feiten is zelfs relevant voor de algemene theorie over voetstructuur. Een standaardaanname in de literatuur is dat de voet maximaal twee lettergrepen beslaat. In het Bemba-patroon opereert tonale herassociatie echter over een spanne van drie syllables, op verscheidene manieren. We trekken daarom in Hoofdstuk 3 de conclusie dat de voetinventaris moet worden uitgebreid met een flexibele, drielettergrepige voet.

In Hoofdstuk 4 kijk ik naar de typologie van tonale herassociatie. Ik heb patronen verzameld uit een reeks verschillende talen. (Zie Tabel 4.1 op pagina 96 voor een overzicht van de patronen en talen.) Ik heb gecheckt of het voet–toon-framework een analyse biedt voor de geattesteerde patronen. De uitkomst was dat het framework vrij flexibel is en inderdaad voor alle patronen waar ik naar heb gekeken een analyse biedt. Ik vond ook dat het framework sommige niet-geattesteerde patronen voorspelt. Dit kan wijzen op een probleem: misschien is het framework niet restrictief genoeg. Als dat het geval is, geeft het framework alsnog weinig inzicht in de grenzen van menselijke taalvariatie. Ik heb de problematische niet-geattesteerde patronen geordend, om ze in Hoofdstuk 5 vanuit de leerbaarheidsinvalshoek te bestuderen. Ten slotte heb ik een tweede versie van het voet–tone-framework ontwikkeld die net iets anders in elkaar steekt. Wederom heb ik bekeken hoe het framework omgaat met geattesteerde en niet-geattesteerde patronen. Dit framework presteert ietsje minder goed. Desalniettemin stelt de vergelijking tussen de twee versies van het framework me in staat om algemene eigenschappen van voet–toon-analyses op het spoor te komen. In het hoofdstuk vond ik zo het resultaat dat de theorie veel tonale activiteit voorspelt in de buurt van zinsranden, omdat voeten daar het vaakst voorkomen.

De laatste studie, in Hoofdstuk 5, ging over computersimulaties om de *leerbaarheid* van geattesteerde en niet-geattesteerde tonale herassociatiepatronen te testen. In de eerste plaats heb ik gekeken of geattesteerde patronen uberhaupt leerbaar zijn, en zo ja, of ze dan ook makkelijker te leren zijn dan de ongeattesteerde patronen die deel uitmaakten van de voorspellingen van het voet–toon-framework. Kort gezegd was het antwoord op beide vragen “ja”: meerdere geattesteerde patronen bleken zeer consistent leerbaar te zijn, terwijl de slagingspercentages voor het leren van niet-geattesteerde patronen bleven steken op een veel lager peil. De simulaties werkten met een “vergissingsgedreven” leeralgoritme, waarbij een (gesimuleerde) leerder checkt of het eigen gedrag overeenkomt met het voorbeeldgedrag dat de leerder oppikt uit de omgeving. Ik heb laten zien dat het voor tonale herassociatiepatronen cruciaal is dat leerders zichzelf controleren op vergissingen in twee richtingen: zowel wanneer ze hun grammatica toepassen op plannen-van-uitspraak uit het geheugen alvorens die uit te spreken, als wanneer ze de grammatica en informatie uit het geheugen gebruiken om spraak van anderen te begrijpen. Deze laatste uitkomst was nog niet eerder gevonden in ander fonologisch leerbaarheidsonderzoek, en de studie levert daarmee dan ook een algemene bijdrage aan dit veld.

Conclusie

In deze dissertatie heb ik een theoretische analyse gegeven van twee belangrijke, recent gerapporteerde gevallen van tonale herassociatie. Ik heb laten zien dat beide gevallen geanalyseerd kunnen worden met een framework dat voetstructuur gebruikt om tonale herassociatie te reguleren. Verder heb ik het bredere scala aan consequenties onderzocht dat volgt uit het theoretische framework dat ik heb ontwikkeld. Met de toevoeging van een leerbaarheidsanalyse heb ik laten zien dat de voorspellingen van het framework scherper zijn dan ze vanuit een puur theoretisch perspectief leken.

Ik heb veel keuzes gemaakt over de theorie en de methoden die ik gebruikt heb. Die keuzes zijn ook interessant voor andere onderzoekers, zelfs als ze niet precies aan hetzelfde onderwerp werken. Zoals ik eerder zei heeft de case study van Copperbelt Bemba in Hoofdstuk 3 betrekking op de algemene theorie van voetstructuur. Verder heb ik een aantal inzichten opgedaan over het uitvoeren van de leerbaarheidsstudie in Hoofdstuk 5. Toekomstige studies met leerbaarheidssimulaties kunnen hiervan profiteren. Uiteraard heeft de dissertatie ook consequenties voor toekomstig onderzoek naar tonale herassociatie zelf. Zo hebben toekomstige studies rekening te houden met de feiten van Saghala (Hoofdstuk 2) en Copperbelt Bemba (Hoofdstuk 3). Deze talen verzwaren de eisen die worden gesteld aan een goede theorie van tonale herassociatie. Verder heeft de studie in Hoofdstuk 4 laten zien dat het mogelijk is, zelfs voor een complex onderwerp als tonale herassociatie, om expliciet te zijn over het bereik van een theoretisch framework. Door de methodologie te demonstreren en de resultaten te interpreteren heb ik in dat hoofdstuk de basis gelegd voor de berekening van grotere, betekenisvollere sets van voorspellingen in toekomstig werk. Ten slotte is ook het verband tussen typologie en leerbaarheid zoals getoond in Hoofdstuk 5 hoogst relevant voor toekomstig werk. Het laat zien dat een puur (synchroon-)theoretische aanpak niet de enige juiste is. Sommige theoretische voorstellen doen het op zichzelf misschien niet zo goed, maar kunnen uiteindelijk prachtig op hun plek vallen door ook andere aspecten in het onderzoek te betrekken, zoals leerbaarheidssimulaties.

Op vele punten in de dissertatie heb ik gewezen op versimpelende aannames die ik heb gemaakt, en op verdere (fascinerende!) data of ideeën die ik niet in de dissertatie heb weten te verwerken. Tesamen vormen deze zaken een onderzoeksagenda waar we ons in de toekomst op kunnen storten.