2 Grammatical vs. lexical stress

2.1 Introduction

In the pre-linguistic stage (if there is any) infants probably experience the language they are exposed to as an impenetrable speech stream. Stress functions as a help to break up the speech stream into smaller, processable units. But different languages make different use of stress. In languages where stress serves a word boundary marker, it would come in handy for the child to know that a stressed syllable signals the beginning or end of a word. However, the child does not know that stress is a boundary marker unless she knows the word boundaries. In languages where stress carries information about the morphological components of the word, the child does not know this until she knows these components and can link them to stress. In short, the language-acquiring child no more knows the function of stress in her mother tongue in advance than she knows how to assign the correct stress pattern. Learning the stress pattern of a language is complicated by the fact that stress is only the overt manifestation of covert, not directly observable structure of a word, like metrical feet. Stress is the clue for the child to construct feet, but languages make use of different patterns of feet, and stress is sometimes ambiguous with respect to foot structure: whereas one language might interpret a trisyllabic form with medial stress, \([\sigma \sigma \sigma]\), as having a trochaic rhythm /\sigma (\sigma \sigma)\/, other languages might interpret it as having an iambic rhythm /\sigma (\sigma) \sigma/. This complication is tackled in the present approach on the learning of stress patterns and hidden structures. The three languages modelled in this book stand for three different kinds of stress systems: Latin as a weight-sensitive language in chapter 4, Pintupi as a weight-insensitive language with rhythmical stress in chapter 5, and Modern Greek as a weight-insensitive language with lexical stress in chapter 6.

This chapter provides the background for the metrical analyses of the different languages that will be modelled in chapters 4 to 6. Throughout the dissertation, the expression “stress” refers to word stress.\(^8\) I give a short

\(^8\) Stress can be classified in different ways. The concrete phonetic manifestation of stress and its learnability is not a subject in this dissertation; I assume that the languages modelled in this book realize stress in at least one of the correlates
classification of word stress in sections 2.2-2.4 and a basic approach in section 2.5 to how stress is handled in Optimality Theory (Prince & Smolensky 1993). Section 2.6 discusses the constraint families used, while section 2.7 briefly discusses the shape that overt forms can take in this book. Section 2.8 summarizes.

2.2 Typological grass roots

I basically assume that stress patterns are rhythmically organized (Liberman & Prince 1977) by feet (e.g. Prince 1976a; Halle & Vergnaud 1978; McCarthy 1979ab, Selkirk 1980b). A foot is the metrical constituent that groups smaller units within a word, such as syllables or moras, into bigger units. Each foot has exactly one head syllable (marked with ‘s’ for ‘strong’; ‘w’ stands for ‘weak’), and each prosodic (i.e. content) word has exactly one head foot, no matter how many feet it contains, as illustrated in figure 2.

(2) Metrical constituents

The foot inventory adopted here consists of maximally binary feet (as in Hayes 1991, 1995). Feet with a strong-weak pattern are called trochees, and feet with a weak-strong pattern are called iambs:

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duration, intensity, loudness, pitch or clarity. I therefore regard a stressed syllable as a syllable that jumps out in one way or the other compared to unstressed syllables in a word.

9 I assume that the syllable is the intermediate level between moras and feet; otherwise, it would be predicted that foot boundaries can fall within a syllable.

10 Although intriguing, ternary stress systems and systems with level stress are not discussed here.
(3) Foot inventory

Trochee: ($\sigma \sigma$), ($\sigma$)  Iamb: ($\sigma \delta$), ($\delta$)

The following two subsections outline the distinction between grammatically assigned stress and lexically assigned stress, which I use throughout the book. I refer to grammatically assigned stress when talking about stress that is predictable from the grammar (i.e. when there is a “rule” or a ranking of structural constraints that determines the stress of a word). I talk about lexically assigned stress when stress is not (fully) predictable by the grammar, but when the grammar interacts with the lexicon in order to determine stress.

2.3 Grammatical stress systems

Grammatically assigned stress can serve as a word boundary marker by stressing the first or last syllable of a word. Grammatically assigned stress can also serve as a marker of phonetically salient syllables, as in weight- or quantity-sensitive languages.

A language is called quantity-sensitive if stress is assigned depending on the structure of a syllable, i.e. depending on the weight of a syllable. The weight of a syllable is determined by the number of moras it contains. A syllable with a short vowel has one mora and is light, and a syllable with a long vowel has two moras and is heavy. Coda consonants can count a mora, but this is not universal. In some languages coda consonants are moraic, making the syllable heavy (e.g. Yana; Sapir & Swadesh 1960), but in other cases the coda does not contribute to the weight of a syllable (e.g. Khalkha Mongolian; Walker 1997; or Ancient Greek). In quantity-sensitive languages with trochaic rhythm, feet are ideally bimoraic: they should contain exactly two moras. Feet with a strong-weak pattern are then called moraic trochees (Hayes 1991). Moraic trochees can either consist of two light syllables (‘$\sigma$’) containing one mora (‘$\mu$’) each, or of one heavy syllable containing two moras, as illustrated in (4).

11 Usually it is assumed that only the rime of a syllable can contain moraic elements. A famous exception is Pirahã (Everett & Everett 1984, Everett 1988), where the onset contributes to the weight of a syllable. Gordon (2005; see references therein) discusses twelve other languages.
An example of this kind is Latin, modelled in chapter 4. Latin has phonemic vowel length and stresses the pre-final (penultimate) syllable if heavy, otherwise the antepenultimate syllable.

Iambics are weight-sensitive if they consist either of a light syllable followed by a stressed light or heavy syllable, or of one heavy syllable (Hayes 1995):

(5) Iambics

<table>
<thead>
<tr>
<th></th>
<th>or</th>
<th></th>
<th>or</th>
</tr>
</thead>
<tbody>
<tr>
<td>σµ</td>
<td>σµ</td>
<td>σµµ</td>
<td>σµµ</td>
</tr>
</tbody>
</table>

If a language does not employ any weight distinctions (e.g. it does not have distinctive vowel length or moraic codas) stress cannot be sensitive to weight. The language is *trivially quantity-insensitive* (as Kager 1992 calls it), and stress is assigned by e.g. the alignment to word edges. Trochees are in this case syllabic trochees (Hayes 1991) and contain two syllables, regardless of the syllable structure. This is illustrated in (6):

(6) Syllabic trochees

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>σµ</td>
</tr>
</tbody>
</table>

Next to this kind of stress system are languages that do have weight distinctions, but assign stress independently of the weight of a syllable. Kager (1992) classifies these languages as *truly quantity-insensitive*, stating at the same time that these languages assign stress not completely independently from weight. If these languages have trochaic feet, the feet take the form of *generalized trochees* (Hayes 1991, 1995): feet are preferably disyllabic, else bimoraic, as in (7):
(7) Generalized trochees

| \( * \) | else | \( * \) |
| \( \sigma \) | \( \sigma \) | \( \sigma_{\mu\mu} \) |

These truly quantity-insensitive languages reveal some sort of weight-sensitivity in that e.g. the assignment of secondary stress is weight-sensitive, or in that the language has a bimoraic word minimum. For instance in Estonian, main stress as well as secondary stress is assigned by linking together syllabic trochees (Prince 1980, Kager 1992). However, in words with an odd number of syllables the last syllable is footed (and thereby stressed) only if heavy. Chapter 5 will deal with another quantity-insensitive language, Pintupi (Western Australia; Hansen & Hansen 1969). It is traditionally analyzed as having syllabic trochees assigned from left to right, leaving final syllables unfooted in words with an odd number of syllables.

2.4 Lexical stress systems

Lexical stress systems assign stress on the basis of marks in the underlying form of a word. While there are some languages which seem to have straightforward marks for stress (in the sense “stress the syllable in the output that is stressed in the underlying form”) there are others that involve more than that, supposedly foot structure (e.g. Inkelas 1998 for exceptional stress in Turkish). Revithiadou (1999) proposed for Modern Greek (the language that will be modelled in chapter 6) that morphemes can be underlyingly marked for “strong” or “weak” accents. Stress in Modern Greek is limited to the last three syllables of a word, but within this range it can occur on any syllable. Morphemes can be stressed, unstressed, pre- or post-stressing. Stress is largely determined by the lexical specifications of the morphemes of a word, and their interaction with each other. The challenge that lexical stress systems pose to a theory of learnability is that it involves the modification of the lexicon, a far more complex task for the learner than solely adjusting the grammar. This is shown in chapter 6.

The next section gives a brief introduction of how stress is handled in OT, and discusses the constraint families that are used in the computer simulations.
2.5 Stress in Optimality Theory

According to OT (Prince & Smolensky 1993), all languages of the world share the same set of violable constraints, and the languages differ only in the ranking of these constraints, i.e. their relative degree of importance. The hierarchical ranking of all the constraints constitutes the grammar of a language. In this section, I explain how a ranking of constraints determines the stress pattern in a language.

Standard OT is production-directed. A speaker of a given language chooses an underlying form (the input to the grammar) from a set of lexical items. On the basis of this underlying form she then chooses a surface form (the output of the grammar) from among a set of possible output candidates. These candidates are provided by the function GEN, which can generate by Freedom of Analysis (Prince & Smolensky 1993:6, McCarthy & Prince 1993b:21) any possible linguistic structure. The candidate chosen as the optimal one from all these candidates is the one that satisfies the highest-ranked constraints best. At the same time it might abundantly violate lower-ranked constraints. This process of evaluation is portrayed in a tableau, where the candidates are compared with respect to their fulfilment or violation of the constraints.

This can be applied to stress assignment. Phonologists generally agree that while in some languages stress can be assigned by referring to word edges (e.g. “always stress the first syllable in a word”), the analysis of other languages requires one to assume that syllables are grouped into hidden structures called feet. Every foot has one stressed syllable. For the purposes of this section and the next, I only consider disyllabic feet. Imagine a simplified foot inventory, where feet are disyllabic and are either trochaic (σ σ) or iambic (σ σ). Consider now the small universal constraint set in (8), where two constraints (IAMBIC and TROCHAIC) are responsible for the placement of the stressed syllable within the foot, and two constraints ALIGNFT-R and ALIGNFT-L are responsible for the placement of the foot within the word. These four constraints are among the many that have been proposed in the literature to account for generalizations on the phenomena of metrical phonology.
(8) Constraints on metrical constituents

IAMBIC: The rightmost syllable in a foot is the head syllable.
TROCHAIC: The leftmost syllable in a foot is the head syllable.
ALIGNFT-R (AFR): Align the right edge of the foot with the right edge of the word.
ALIGNFT-L (AFL): Align the left edge of the foot with the left edge of the word.

The constraints IAMBIC and TROCHAIC (short for Prince & Smolensky’s 1993 RHYTHMTYPE=IAMBIC/TROCHAIC) stem from the observation that languages tend to have either iambic or trochaic feet, rather than a mix of them (McCarthy & Prince 1986, Kager 1996, Van de Vijver 1998). AFR and AFL stem from the observation that languages tend to have feet that are either close to the beginning or to the end of a word, or tend to assign feet iteratively starting either near the beginning or near the end of the word.

Consider now an underlying form with three syllables, represented in pipes |σσσ|. If we assume that stress is assigned purely by the grammar (i.e. the language at hand does not have lexical stress), then we have at least the four different candidates shown in tableau [9]. The four candidates have different main stresses, denoted as “σ”, and different foot structures, denoted by parentheses. Suppose now that in a specific language the highest ranked (i.e. most important) constraint is IAMBIC and the lowest ranked constraint is AFL. This ranking is denoted in the tableau by sorting the constraints from left to right. The asterisks (violation marks) in the tableau depict which candidates violate which constraints. The candidates /(σ σ) σ/ and /σ (σ σ)/ both violate the highest ranked constraint IAMBIC, since they contain a trochaic foot. These violations are marked with a “!” because they are the crucial violations that rule out these two candidates from further consideration. The choice between the remaining two candidates /((σ δ) σ)/ and /σ (σ δ)/ cannot be made by the two highest ranked constraints IAMBIC and TROCHAIC, since these two constraints have an equal number of violations for these two candidates. The matter is decided by AFL, which prefers the candidate /((σ δ) σ)/, since this form has a left-aligned foot, unlike /σ (σ δ)/. The grey cells in the tableau are those that do not contribute to the determination of the winning form. The winning candidate itself is denoted by ‘σ’.
Chapter 2

(9) An iambic left-aligning language

<table>
<thead>
<tr>
<th>Underlying:</th>
<th>IAMBIC</th>
<th>TROCHAIC</th>
<th>AFL</th>
<th>AFR</th>
</tr>
</thead>
<tbody>
<tr>
<td>/σ σ σ /</td>
<td>*</td>
<td></td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>/σ (σ σ) /</td>
<td>*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>/σ (σ σ) /</td>
<td>*</td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>/σ (σ σ) /</td>
<td></td>
<td></td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

The language in tableau (9) is an iambic left-aligning language: the foot in the winning candidate is iambic and a result of the ranking IAMBIC >> TROCHAIC. The left-alignment within the word is the result of the ranking AFL >> AFR.

An early assumption in OT is that any ranking of the constraints should correspond to a possible language. OT thus makes typological predictions. If we assume, for instance, a universal grammar with the four constraints AFL, AFR, TROCHAIC and IAMBIC, these constraints can be ranked in 24 different ways, and in the extreme case this could lead to 24 different types of languages. We get a different type of language if TROCHAIC dominates IAMBIC, as in tableau (10) stress is on the first syllable, due to a trochaic foot that is aligned at the left edge of the word.

(10) A trochaic left-aligning language

<table>
<thead>
<tr>
<th>Underlying:</th>
<th>TROCHAIC</th>
<th>IAMBIC</th>
<th>AFL</th>
<th>AFR</th>
</tr>
</thead>
<tbody>
<tr>
<td>/σ σ σ /</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>/σ (σ σ) /</td>
<td>*</td>
<td></td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>/σ (σ σ) /</td>
<td></td>
<td>*</td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>/σ (σ σ) /</td>
<td></td>
<td>*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

If iambic foot structure is preferred, and AFR outranks AFL, then stress will be on the last syllable in the output, as in tableau (11).
(11) An iambic right-aligning language

<table>
<thead>
<tr>
<th></th>
<th>IAMBIC</th>
<th>TROCHAIC</th>
<th>AFR</th>
<th>AFL</th>
</tr>
</thead>
<tbody>
<tr>
<td>/σ σ σ/</td>
<td><em>!</em></td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>/σ (σ σ)/</td>
<td><em>!</em></td>
<td>*!</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>/σ (σ σ)/</td>
<td></td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

If, however, the trochaic foot form is preferred, and AFR outranks AFL, stress will be on the second syllable, as in tableau (12).

(12) A trochaic right-aligning language

<table>
<thead>
<tr>
<th></th>
<th>TROCHAIC</th>
<th>IAMBIC</th>
<th>AFR</th>
<th>AFL</th>
</tr>
</thead>
<tbody>
<tr>
<td>/σ σ σ/</td>
<td><em>!</em></td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>/σ (σ σ)/</td>
<td><em>!</em></td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>/σ (σ σ)/</td>
<td></td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

The typological possibilities of these four constraints is now exhausted. The 24 possible rankings lead to only four different types of languages, since changing the ranking of the alignment constraints with respect to the foot form constraints does not lead to any new types of languages. Within this simple set of constraints, IAMBIC only competes with TROCHAIC, and AFR with AFL. The rankings predict that in the language in (9) feet will be ranked at the left edge in every word. And since every foot in this language is iambic, stress will always be on the second syllable in a word. In the language shown in (10) stress will always be on the first syllable in a word, since here the foot form is trochaic, but feet are still ranked at the left edge of a word. The language in (11) will always have final stress, since feet are iambic and are aligned at the right edge of the word. Finally, the language in (12) will always have stress on the pre-final (penultimate) syllable. So whenever a linguistic principle is translated into an OT constraint, it should make typological predictions about languages. As we have seen, though, not all constraints have to be in competition with each other.

What we have also seen (and that brings us closer to the learnability problem) is that there are actually two grammars here, shown in (9) and (12) that show the same overt stress pattern in trisyllabic words, namely stress on
the second syllable, as demonstrated by Tesar & Smolensky (1996, 1998, 2000). In other words, the two surface forms /$(\sigma \delta) \sigma$/ and /$(\delta \sigma)\sigma$/ share the same overt form [$(\sigma \delta \sigma)$] (at least if there are no other phonetic cues such as iambic lengthening or trochaic shortening etc.). A child can only observe stress in the overt form, but not foot structure, this is something she has to assign herself. In the case of [$(\sigma \delta \sigma)$], the learner cannot learn the ranking of constraints of her language from trisyllabic words alone. She will crucially depend on the presence of other, either shorter or longer forms, to figure out the exact ranking. Luckily, most languages do employ words with more and less than three syllables. The next section outlines the constraint families that are used in the simulations.

2.6 Constraints for stress

The different levels of representation in figure (1) of chapter 1 are connected through different families of constraints, illustrated in figure (13). Underlying forms are connected to surface forms by faithfulness constraints, and to meaning by lexical constraints. Surface forms are restricted by structural constraints. Between surface forms and overt forms operate cue constraints (Boersma 1998; Escudero & Boersma 2003), which I do not discuss here.

(13) The levels of representations and their constraints

Section 2.6.1 discusses structural constraints for grammatical stress systems. Section 2.6.2 discusses the family of faithfulness constraints on stress, and section 2.6.3 discusses the family of lexical constraints for the learning of underlying forms.
2.6.1 Structural constraints for metrical phonology

Grammatical stress systems are determined by the ranking of structural constraints. The structural constraints applied in the simulations of chapter 4 and 5 are based on the constraint set of Tesar & Smolensky (2000) that contains twelve widely accepted structural constraints on metrical phenomena, listed in (14):

(14) Tesar & Smolensky’s (2000) constraint set

AFL: The left edge of a foot is aligned with the left edge of a word.
AFR: The right edge of a foot is aligned with the right edge of a word.
FOOTBINARITY (FTBIN): Feet are binary on the mora or syllable level.
FOOTNONFINAL (FTNONFIN): The head syllable of a foot is not final in the foot.
IAMBIC: The rightmost syllable in a foot is the head syllable.
MAIN-LEFT (MAIN-L): The leftmost foot in a word is the head foot.
MAIN-RIGHT (MAIN-R): The rightmost foot in a word is the head foot.
NONFINALITY (NONFIN): The final syllable is not included in a foot.
PARSE: Every syllable is included in a foot.
WORD-FOOT-LEFT (WFL): The left word edge is aligned with a foot.
WORD-FOOT-RIGHT (WFR): The right word edge is aligned with a foot.
WEIGHT-TO-STRESS PRINCIPLE (WSP): Heavy syllables are stressed.

The alignment constraints AFL and AFR (McCarthy & Prince 1993a) make sure that a foot is aligned with one of the edges of a word. Their violation is gradient: AFL is assigned one violation mark for every syllable between the left edge of the word and the left edge of every foot. In a candidate with five light syllables such as /σ (σ σ)(σ σ)/, AFL is violated four times: once for the first foot, three times for the second foot. In a grammar where AFL is high-ranking, the number of feet in a word is kept to a minimum, since any additional foot would incur at least one constraint violation. AFL and AFR were introduced as constraints, and therefore as a part of Universal Grammar, because languages tend to start footing at the periphery of words.

The constraints MAIN-L and MAIN-R (termed as such in Tesar & Smolensky 2000; based on EDGEMOST by Prince & Smolensky 1993, and ALIGN(PrWd, Edge, H(PrWd), Edge) by McCarthy & Prince 1993b) are similar to AFL and AFR, but apply only to the foot that contains the main stress. Thus, a candidate like /σ (σ σ)(σ σ)/ violates MAIN-L three times, while it violates MAIN-R not at all. MAIN-L and -R have their raison d’être
as part of the universal constraint set because languages might differ whether they assign main stress to the first or the last foot within a word, rather than assigning main stress to the middle foot of a word with e.g. three feet, */(σ σ)(σ σ)(σ σ)/.

The two WORDFOOT-alignment constraints WFL and WFR (McCarthy & Prince 1993b) favour candidates in which at least one foot is aligned with the word edge. This is different from AFL/AFR and MAIN-L/MAIN-R. WFL and WFR are not gradient, but binary: they are assigned a single violation regardless of how many syllables are between the word and the foot edge. Thus, a candidate like */(σ σ)(σ σ)*/ violates WFL only once, while it would violate e.g. AFL twice. The same candidate violates AFR twice, but not WFR.

The constraint NONFINAL (inferred from Liberman & Prince 1977, Hayes 1980; introduced as OT constraint by Prince & Smolensky 1993) expresses extrametricality: it is violated if the last syllable is parsed (included) in a foot. This constraint prefers */(σ) σ/ over */(σ σ)/. Note that WFR and NONFINAL have complementary violations on the word level: a word that violates WFR does not violate NONFINAL, and a word that violates NONFINAL does not violate WFR. Syllable extrametricality (i.e. when the final syllable does not count in the assignment of metrical structure) is a well-known phenomenon in metrical processes, but extrametricality as such can apply to other constituents such as segments or feet. The rationale behind such a constraint might be that the least salient part of the word is ignored, or that it leaves more room for boundary tones, if you exclude the final element from the metrical analysis (Norval Smith, p.c.).

The constraint PARSE (Prince & Smolensky 1993, McCarthy & Prince 1993) favours candidates in which all syllables are parsed into feet. It is assigned one violation mark for each unfooted syllable. Thus, the candidate */(σ σ)(σ σ) σ/ violates PARSE three times. This constraint, if high-ranking, maximizes the number of feet (or the size of a foot): if it outranks both AFL and AFR, the language tends to have secondary stress. If AFL or AFR outranks PARSE, words tend to contain a single foot with main stress. It is practically inevitable to assume a constraint like PARSE if one wants to explain stress systems that have secondary stress.

The constraint FTNONFIN (Tesar 1998) favours candidates with trochaic feet such as */(σ σ)(σ σ)/. However, degenerate feet consisting of only one syllable, like */(σ)/, violate this constraint. The constraint IAMBIC favours candidates with iambic feet like */(σ σ)/, and this constraint is not
violated in degenerate feet like /((σ))/. This asymmetry in the formulation of the two foot form constraints (other than in TROCHAIC/IAMBIC we have seen in section 2.5) leads to complementary violations on the foot level: FTNONFIN is assigned one violation mark for each occurrence of /((σ 1))/ or /((σ))/, and IAMBIC for each occurrence of /((σ σ))/.

The WSP (Prince 1990; OT-version in Prince & Smolensky 1993) favours candidates that have stress on a heavy syllable (represented as ‘H’; light syllables are represented as ‘L’; primary stress is represented with ‘1’, and secondary stress is represented with ‘2’). Every heavy syllable that is not stressed in a form causes a violation of this constraint. Thus, /((L2 H) H (H1) L)/ violates WSP twice (once for the unfooted H, once for the H in the first foot’s weak position). A candidate like /((L H2)(H2)(H1) L)/ does not violate WSP, because each heavy syllable carries either primary or secondary stress. Like PARSE, this constraint tends to maximize the number of feet (though less strongly), and it prefers sequences of heavy monosyllabic feet like (H1)(H2) to superheavy feet like (H1 H). This constraint can also override the foot form constraints: even in a basically trochaic language (FTNONFINAL/TROCHAIC >> IAMBIC), a high-ranked WSP can force the occurrence of an iambic foot (L H1). The rationale behind this is the earlier mentioned phenomenon of making salient syllables even more prominent.

FTBIN (Prince & Smolensky 1993) is the constraint on foot size: feet should be binary with respect to either syllables or moras. This constraint is assigned a violation mark for every monosyllabic light foot, i.e. (L1) and (L2), whereas feet like (L1 H) and (H H2) do not violate this constraint (for the purpose of this dissertation, I do not admit feet in candidates with more than two syllables in GEN).

The list of structural constraints for stress is not exhaustive, but captures a great deal of metrical phenomena. Some add-ons will become necessary for modelling Latin and Pintupi stress, and will be introduced in sections 4.2.2.3, 5.2.2 and 5.2.3. The constraints used in the simulations of lexical stress systems are discussed next.

2.6.2 Faithfulness constraints for lexical stress

The metrical constraints presented in the section above are structural constraints and hold on surface forms. In languages without lexical stress,
structural constraints is all you need: their ranking will tell you where to stress a word. Stress is less (or not at all) predictable from the grammar if lexical specifications come into play. In languages with lexical stress, morphemes can be underlingingly stressed. In interaction with structural constraints, these underlying specifications determine the stress in the surface form. This is ensured by faithfulness constraints. The faithfulness constraints I employ in chapter 6 are based on Correspondence Theory (McCarthy & Prince 1995:14):

(15) Correspondence:
Given two strings \( S_1 \) and \( S_2 \), **correspondence** is an relation \( \mathcal{R} \) from the elements of \( S_1 \) to those of \( S_2 \). Elements \( \alpha \in S_1 \) and \( \beta \in S_2 \) are referred to as **correspondents** of one another when \( \alpha \mathcal{R} \beta \).

Following Revithiadou (1999), I assume faithfulness constraints that relate underlying stress to stress in surface forms. Underlying stress has a correspondent in the surface form (ensured by MAX), and stress in the surface form has a correspondent in the underlying form (ensured by DEP). Contrary to Revithiadou (1999), who paints a bigger picture of morphologically determined stress, I content myself for the purpose of this dissertation to the four simplified constraints in (16), which make a difference between faithfulness to lexically stressed roots, and faithfulness to lexically stressed affixes.

(16) Faithfulness to stress:
\[ \text{MAX(Root): A root that is stressed in the underlying form is also stressed in the surface form.} \]
\[ \text{DEP(Root): A root that is stressed in the surface form is also stressed in the underlying form.} \]
\[ \text{MAX(Affix): An affix that is stressed in the underlying form is also stressed in the surface form.} \]
\[ \text{DEP(Affix): An affix that is stressed in the surface form is also stressed in the underlying form.} \]

The MAX constraints are violated whenever a stress of the underlying form is not realized in the surface form. The DEP constraints are violated whenever there is a stress inserted on the surface form although the corresponding underlying form does not have stress.
Grammatical vs. lexical stress

In the next chapter I introduce the concept of the lexical constraints that enable the learning of underlying forms. I argue that faithfulness constraints are not enough for the learning of underlying forms, because with faithfulness and structural constraints alone a new underlying form would be created for alternating surface forms. A form /tã µµ k/ ‘day’ would faithfully be mapped onto an underlying form |taµµk|, and a form /tã µµ gµµ / ‘day-Nom.Pl’ would faithfully be mapped onto an underlying form |tagµµ|. A learner would not necessarily realize that the two forms share the same morpheme, but create two allomorphs |taµµk| and |tagµµ| for it without even knowing that they are allomorphs. I propose that the learner needs to be able to make a connection between these forms, which is achieved by linking the form to the meaning ‘day’, as outlined in the next section.

2.6.3 Lexical constraints for underlying stress

As will become evident in chapter 6, we need more and other constraints than metrical and faithfulness constraints to model lexically assigned stress, and underlying forms in general. These lexical constraints link meaning to underlying forms and are based on Boersma (2001) and Escudero (2005); unlike Boersma’s and Escudero’s proposed constraints, the lexical constraints I assume are formulated in a do not connect the meaning ‘XY’ to an underlying form |xy|-manner. For instance, there are constraints as don’t connect the meaning ‘dog’ to the form |kat|, which militate against the connection of a meaning to a form that is already occupied with another meaning, in this case ‘cat’. But there are also constraints as don’t connect the meaning ‘cat’ to the form |kat|. In the comprehension process (outlined in §3.2 and 3.3), these constraints suppress, and thereby guide, lexical access. In the production process (outlined in §3.4), these constraints suppress, and thereby guide, lexical retrieval. Depending on the ranking of these constraints, there will only be one optimal underlying form for a meaning. The learner needs to acquire a ranking of these constraints that will enable her to compute the appropriate forms for communication. These lexical constraints need not be innate but could rather be very language-specific. The learner needs to be equipped with the ability to create these constraints, and that these constraints only emerge on the moment the learner encounters a new meaning along with a new form. In this sense, these constraints are hypotheses about how an
underlying does *not* look like. Since these constraints have a very language-specific character, they will be discussed in more detail in section 6.3.1, where they are applied to Modern Greek.

### 2.7 The form of overt forms

We have encountered the grammatical restrictions in this chapter that are necessary for modelling stress. A note on the shape of overt forms is advisable. For the purposes of chapter 3, overt forms are represented with \( \sigma \)-symbols like \( [\sigma \delta \sigma] \). In the computer simulations in chapters 4 and 5, the input to the learners is always labelled for syllable and word boundaries. In the chapter on Latin, the input consists of word-like forms with syllables labelled as heavy (‘H’) or light (‘L’). In the chapter on Pintupi, the input consists of word-like forms with syllables labelled as consonantal (‘C’) and vocalic (‘V’) structure. In the chapter on Modern Greek, the input consists of Modern Greek words where the C- and V-slots are actually filled with segmental information.

All inputs have in common that they are overt in the sense that with respect to metrical information, they are only labelled for main and secondary stress, but not for foot structure. The virtual learners have to choose the appropriate foot structure (and sometimes the appropriate moraic structure) themselves.

### 2.8 Summary

This chapter provided the linguistic ingredients to the computer simulations of chapters 4, 5 and 6. I outlined the distinction between grammatical and lexical stress systems, and between weight-sensitive and weight-insensitive stress systems. To model grammatical stress, structural constraints are needed, while for the modelling of lexical stress, faithfulness and lexical constraints play a crucial role. The following chapter discusses the ingredients for learnability. Section 3.1 provides an introduction to learnability in OT. The different modelling processes perception, recognition, virtual production and error detection are discussed in sections 3.2 to 3.5. The two different reranking strategies I apply and compare are discussed in section 3.6. The case of learning from pairs of surface and underlying forms is outlined in section 3.7. I summarize in section 3.8.