Secondary stress in two varieties of Portuguese and the Sotaq optimality based computer program[*♥]

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Abstract

Although BP and EP place primary stress exactly at the same position, secondary stress positioning is remarkably different, as can be noticed below. The examples present some possible instances of secondary stress (rhythmic stress) placement in both European and Brazilian Portuguese according to native speakers of each of the varieties. The syllables bearing primary stress are in bold and those bearing secondary stress are underlined:

EP: (1) a. A inteligência da catalogadora foi determinante ~

b. A inteli**gên**cia da cataloga**do**ra **foi** determi**nan**te ~

c. A inteli**gên**cia da cataloga**do**ra **foi** determi**nan**te ~

d. A inteli**gên**cia da cataloga**do**ra **foi** determi**nan**te

BP: (2) a. A inteli**gên**cia da cataloga**do**ra **foi** determi**nan**te ~

b. A inteli**gên**cia da cataloga**do**ra **foi** determi**nan**te

EP: (3) a. A moderniza**ção foi** satisfa**tó**ria ~

b. A moderniza**ção foi** satisfa**tó**ria

BP: (4) a. A moderniza**ção foi** satisfa**tó**ria.

EP: (5) a. A cataloga**do**ra compreen**deu** o tra**ba**lho da pesquisa**do**ra ~

b. A cataloga**do**ra compreen**deu** o tra**ba**lho da pesquisa**do**ra

BP: (6) a. A cataloga**do**ra compreen**deu** o tra**ba**lho da pesquisa**do**ra ~

b. A cataloga**do**ra compreen**deu** o tra**ba**lho da pesquisa**do**ra

The facts of primary and secondary stress in Portuguese favor Van der Hulst's (1997) position, according to which primary and secondary stresses are not derived by the same algorithm. Van der Hulst notes that, in the majority of languages, the assignment of primary stress does not depend on prior exhaustive footing. Indeed, the assignment of primary and secondary stresses in Brazilian and European Portuguese is clearly independent.

In this paper we assume that primary stress in Portuguese is part of the language's lexical information. That is, it is not assigned by the computational system of the language. Our assumption is based on the fact that, although it is well-known that Portuguese main stress falls in one of the last three syllables, none of the current analyses of Portuguese is able to successfully predict which of the three last syllables will be stressed without an extraordinary use of lexical extrametricality, as shown below.

Since many Portuguese words bear primary stress on the last syllable if it is heavy, many researchers have postulated that primary stress is assigned by constructing non-iterative moraic trochees from right to left. This is the analysis assumed, for instance, by Bisol (1992), Mateus (1975, 1983), Massini-Cagliari (1995), among many others. However, something must be said about the great number of nouns ended in light syllables that bear a stress on the last syllable (e.g. *sofá*) and about the great number of words with antepenultimate stress (e.g. *pérola*). There are also many words with penultimate stress even when the last syllable is heavy (e.g. *cadáver*). According to this analysis, most of the exceptions are dealt with via lexical extrametricality.

Given the high number of words that remain unaccounted for by an analysis that postulates moraic trochees for Portuguese, Lee (1994) revisits Camara (1953) and postulates that /e/, /a/ e /o/ in final position of nouns are thematic vowels and are outside the stress domain. According to Lee, Portuguese stress domain is the root, not the stem, and primary stressing relies on a non-iterative iambic pattern. According to this analysis, words like *mesa* bear stress on the penultimate syllable because their last vowel is a thematic vowel, that is, a suffix, and it is, therefore, outside the stress domain. And words like *sofá* bear stress on the last syllable because they do not have a thematic vowel. Although this analysis has the advantage of decreasing the number of exceptions, it is circular because we only know that a vowel is thematic (i.e. a suffix) once we know whether it is stressed. In addition to its circularity, this analysis still has many exceptions since the words with an antepenultimate stress pattern and the words ending by a heavy syllable bearing a penultimate stress pattern remain unaccounted for.

In conclusion, both types of analysis require an extraordinary amount of lexical extrametricality to solve the great number of exceptions, which suggests that it is more economical to postulate that primary stress is phonemic. This kind of conclusion is already widely assumed for Spanish, whose main stress phenomena are quite similar to Portuguese (Harris 1983). According to Hayes (1995:96), "main stress in Spanish is phonemic, though it can be predicted to a fair extent by complex lexical rules, whose character continues to be debated".

It is well-known that secondary stressing in Brazilian Portuguese, like Spanish, follows a binary pattern (Carvalho 1988, Collischonn 1993, Abaurre & Galves 1998, among others). Like Spanish, the exceptions to a binary alternation in BP are cases of initial dactyls (see Harris 1989 for Spanish and Colllischonn 1993 for Brazilian Portuguese). There is no consensus, however, on the description of secondary stressing in European Portuguese. D'Andrade & Laks (1991) have claimed that secondary stresses are assigned via binary feet construction in EP, and Carvalho (1988/1989) claims that secondary stress is assigned via ternary feet.. More recently, Frota (1998) and Vigário (1998) have claimed that secondary stressing is not obligatory and, if it happens, it tends to be unbounded in EP. Given the lack on consensus on EP, we decided to set a corpus for analysis. Our analysis of secondary stress is based on a corpus of 20 sentences which were read three times by three native speakers of Portuguese from Lisbon, Portugal, and by two native speakers of Portuguese from São Paulo, Brazil. The data have been transcribed on the basis of auditive perception, but spectrograms were used as support for the phonetic transcription. Our analysis holds for a normal rate of speech in sentences that convey new information, as in headline news. Slow, deliberate speech can lead to stress patterns that will be disregarded here. For instance, it is well known that a different stress pattern may result from what intuitively feels like special emphasis on a particular element.

2. A description

Our data confirm that Brazilian Portuguese secondary stress follows a rarely violated binary (two-syllable) pattern. The exceptions to the binary system are mostly cases of the so-called initial dactyl (Prince 1983). That is, there is an initial ternary alternation (the initial dactyl) when the stress domain has an odd number of syllables (Collischonn 1993). The initial dactyl is not obligatory, however. For instance, according to Collischonn (1993) a word like *satisfatória* can be stressed as *satisfa***tó***ria*, an example of the initial dactyl, or as *satisfa***tó***ria*.

It is well known that Spanish presents the same phenomenon (Harris 1983, 1989, Roca 1986). Our data, however, shows that Harris (1989) analysis is not enough for the BP data. Harris, within Metrical Theory, has suggested an analysis for Spanish which states that the two variants represent alternative outcomes to the resolution of a stress clash. On Harris's analysis, secondary stress in Spanish is applied by building trochees from right to left on the syllables preceding the syllable bearing main stress. If we allow degenerate feet at an intermediate stage of the derivation, the sort of clash shown in 7 will result. Initial dactyls can then be derived by applying a rule of rightward destressing and reparsing, whose effects are shown in 8, where one syllable in the middle of the word (*ti*) is left unparsed. The other option is to resolve the clash with leftward destressing, as shown in 9.

```
( 7 ) (                          x   )
      ( x ) (x    )(x  ) (x  )(x   )
       σ     σ  σ σ σ σ σ σ σ  σ
       constantinopolitanismo

( 8 ) (                        x    )    →    (                        x    )
      ( x )         (x  )(x  )(x    )         ( x         )   (x   )(x  )(x    )
       σ      σ σ σ σ σ σ σ σ  σ                σ     σ   σ σ σ σ σ σ σ  σ
       constantinopolitanismo                    constantinopolitanismo

( 9 ) (                          x    )
              (x    )(x   )(x  ) (x   )
       σ      σ σ  σ σ  σ σ σ σ  σ
       constantinopolitanismo
```

Hayes (1995) points out that "the crucial point of Harris's analysis is that it relies on a temporary degenerate foot, set up in the middle of the derivation (7), that either is expanded into a proper foot by destressing and reparsing, or is itself deleted." In neither case the degenerate foot surfaces and Hayes maintains that it shows that the crucial point of the Spanish phonology is the presence of a constraint that bans degenerate feet.

One could argue that the same analysis could be employed for BP. Our data, however, shows that this analysis faces empirical problems, as discussed below.

An acoustic analysis of the BP facts shows that many words containing an odd number of syllables have undergone vowel deletion, which resulted in a perfect binary system. In other words, the syllable that Harris supposes to be left unparsed is actually not realized. Thus, the word *satisfa**tó**ria* was actually realized as *satsfa**tó**ria*, where the vowel /i/ has been deleted, resulting in a perfect binary structure ((satsfa)$_\Sigma$ (**tó**ria)$_\Sigma$). One could argue that the one strategy employed for Brazilian Portuguese to avoid degenerate feet is vowel deletion instead of simply reparsing. Thus, an analysis along the lines of Harris's proposal could be offered, provided that a rule of /i/ deletion is added. The phenomenon of vowel deletion in Brazilian Portuguese, however, shows that the facts are more complex than a metrical analysis can predict. The words containing an odd number of syllables are the target for vowel deletion, which suggests that we are indeed looking at a language that prefers to avoid degenerate feet, as claimed by Hayes. The realizations in 10 and 11, however, are problematic for Metrical Theory because, if secondary stress results from an alternation of stressed and non-stressed syllables from right to left on the syllables preceding the syllable bearing main stress, there would be no reason for vowel deletion because there are four syllables preceding the syllable with main stress in *investiga**dor*** and in *moderniza**ção***, and therefore a perfectly binary alternation would result. The prosodically-induced vowel deletion of 10 and 11 only makes sense if we assume that there is a constraint that forces binary feet (i.e. (in vest)$_\Sigma$ (ga **dor)**$_\Sigma$) and (mo dern)$_\Sigma$ (za **ção)**$_\Sigma$), and there is no need to introduce directionality (right to left counting) in order to obtain binarity via perfect alternation between strong and weak syllables, as predicted by a Metrical Theory analysis.

(10) O in ves ti ga dor já lhe de vol veu o di nhei ro.

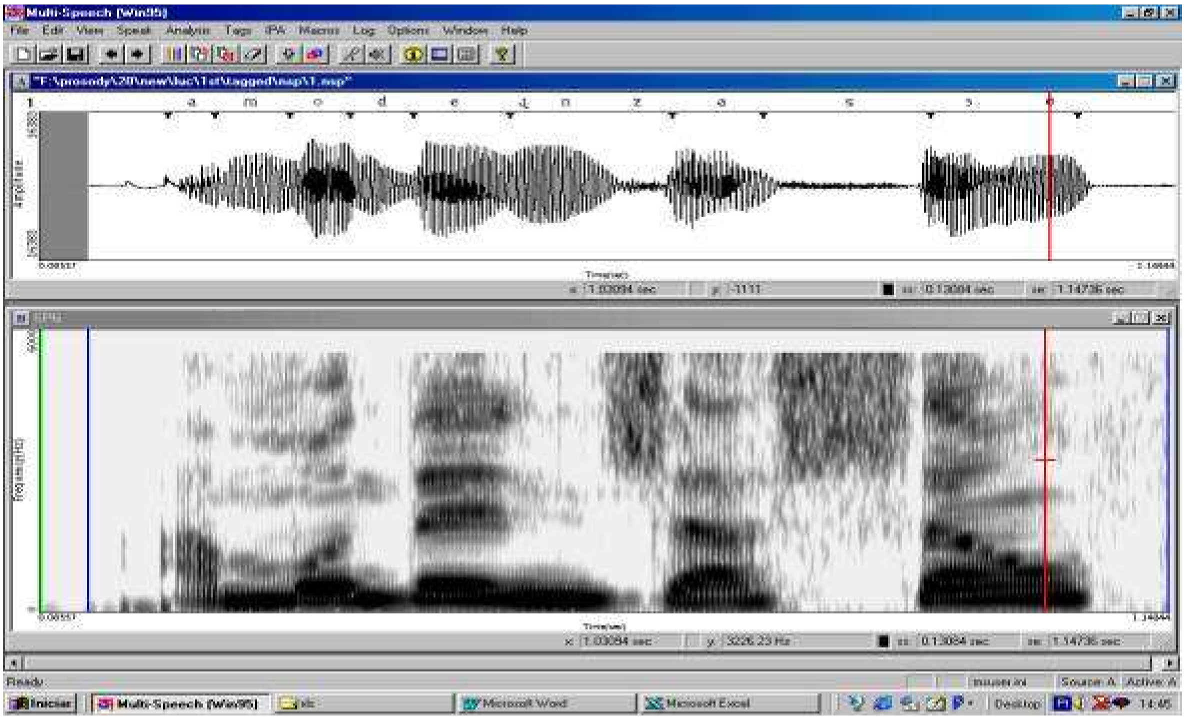
[win vest ga **dor já** lhe de vow **vew:** di **nhei** ro]

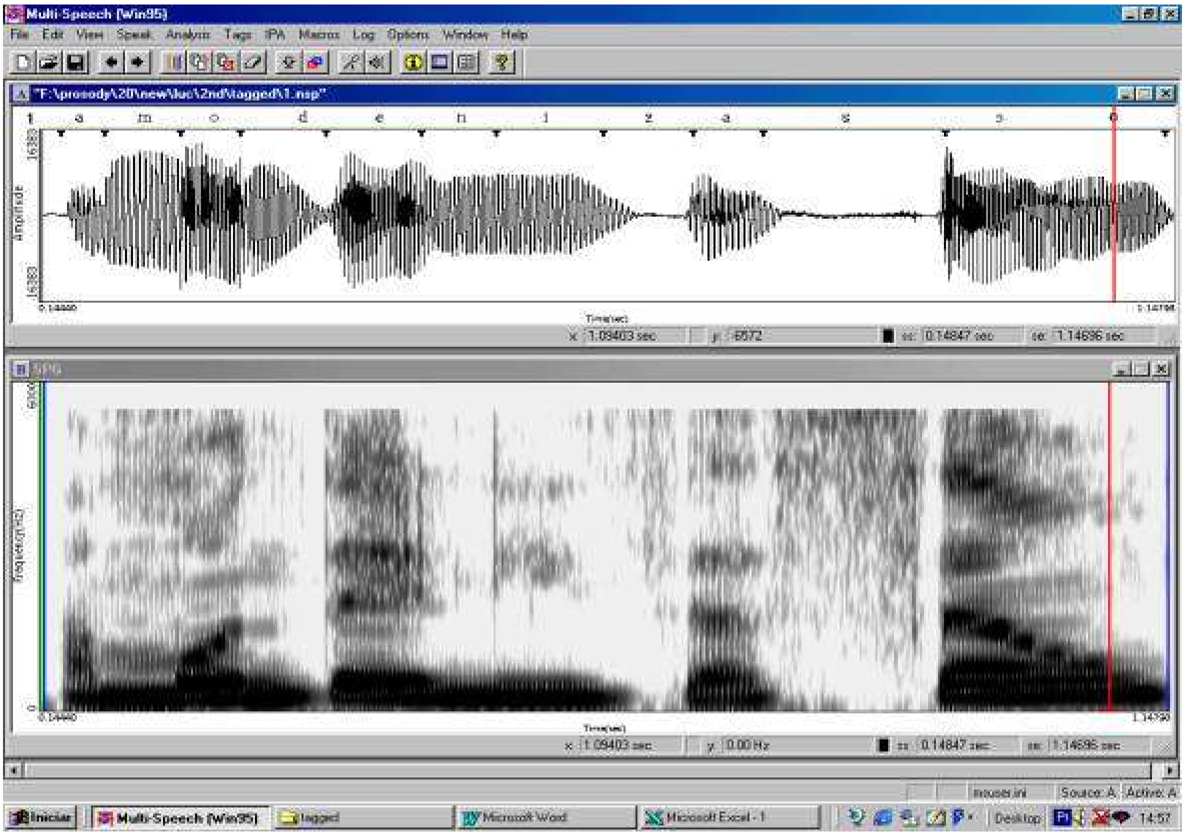
(11) A modernização foi satisfatória

[a mo dern za **ção foi** sats fa **tó** ria]

True dactyls only occur in BP when no vowel can be deleted. For instance, in the large majority of cases, the vowel to be deleted is /i/; if one, however, deletes the /i/ that follows the /l/ in the word *inteligência*, the /l/ would resyllabify as a coda. But /l/ in coda position is pronounced as [w] in BP. That is, the output would differ considerably from the input. An word-initial /i/ also resists deletion. Therefore, the word *inteligência* does not contain an /i/ that can be omitted. We will propose in the next section that the facts of Portuguese result from a conflict of forces instead of from a computation of alternating strong and weak syllables like it has been widely assumed for Spanish and also for Brazilian Portuguese within Metrical Theory (Collischonn 1993). In this system we will derive the facts of initial dactyl without postulating degenerate feet that never surface. Such degenerate feet represent cases of absolute neutralization and it is widely accepted that absolute neutralization must be avoided given the problems that it may bring for language acquisition. Since our OT analysis makes it possible to generate cases of initial dactyl where there are no cases of vowel deletion, it may be the case that our analysis can be extended also to Spanish avoiding absolute neutralization also for that language.

A process of vowel deletion that forces a binary system has been noticed before for primary stress (Bisol 2000, among others). For instance, it is well known that words like *pérola* 'pearl' are often realized as *perla*. This paper represents the first time that a similar phenomenon has been noticed for secondary stressing. Abaurre (1979) discusses several cases of vowel deletion in BP, but the phenomenon is not associated with foot binarity. Below are the acoustic configurations of the word *modernização*, where the first spectrogram attests the mentioned vowel deletion and the second spectrogram shows the same word with no vowel deletion.





European Portuguese differs from Brazilian Portuguese in that it is not a binary system. In European Portuguese the beginning of a sentence tends to be prominent, as noticed already by Frota (1998) and Vigário (1998). This fact can be noticed in the example below:

(12) O investiga**dor já** me ofere**ceu** di**nhei**ro ~
O investiga**dor já** me ofere**ceu** di**nhei**ro.

But we find in our corpus other prominences at the beginning of smaller domains (cf. A cataloga**do**ra compren**deu** o tra**ba**lho da pesquisadora). Here, we refer to such domain as phonological word.[1] Evidence for this comes from the sentences below:

A abelha rainha oferece frequentemente frutas.
A abelha rainha frequentemente oferece frutas.
A catalogadora compreendeu repentinamente o trabalho da pesquisadora.
A catalogadora repentinamente compreendeu o trabalho da pesquisadora.

As can be notice above, there is no difference in stressing if an adverb precedes or follows a verb. If the phonological word, rather than the phonological word, were the relevant domain, a prominence in the adverb should not be allowed when the verb precedes the adverb. The fact that an adverb can intervene between the verb and its object suggests that the verb has moved from its base-position next to the object to a higher functional projection. The adverb might then be left-adjoined to VP, where it follows the moved verb (Costa 1998: 19-36). The right edge of the verb itself, not being phrasal in nature, does not trigger a phonological word boundary (Selkirk 1986). That is, the verb and the adverb is a single phonological word. Since the initial position of an adverb can bear a prominence in the sequence verb-adverb, we have evidence that the relevant prosodic domain is shorter than a phonological word.

The important fact is that EP shows unbounded secondary footing. The transcription of our data by three native speakers of EP does not indicate either binary or ternary alternations.

Another point where EP and BP differ concerning secondary stressing is that functional words can bear secondary stress in EP (*A catalogadora ~ A catalogadora*). That is, EP accepts the placement of a secondary stress on either the functional word that starts a phonological word or on the first syllable of the first lexical word of a phonological word. In BP, functional words never bear stress in a non-emphatic pronunciation. Finally, EP and BP differ in that only EP has the option of not assigning any secondary prominences in a word (cf. O investiga**dor** já lhe devol**veu** o di**nhei**ro).

The variation on secondary stress placement in both EP and BP is problematic for a Metrical Theory analysis because, in a derivational analysis, we would have to postulate that one form is default and derive the other form via re-arrangement rules. Since EP accepts a range of variation that includes even the possibility of not assigning any secondary stresses, the re-arrangement rules for EP could be so complex as to make a derivational analysis unwieldy.

To sum up, an analysis in OT terms has the advantages of : (i) generating all the facts of both Brazilian and European Portuguese without postulating any cases of absolute neutralization; (ii) not forcing the usage of the notion of directionality, thus implying a simplification of the phonological theory; and (iii) being able to generate variant forms in parallel.

3. An Optimality Analysis

We now describe our OT model.

We are working with the following assumptions. The inputs will be sentences in a language (in our case, BP or EP). The structures assigned by *Gen* to each input are decompositions into feet. In the footing yielded by *Gen*, each syllable is contained in exactly one foot. Furthermore, this model entails a specific locality restriction on the type of constraints we are willing to consider: each constraint ought to be checkable by considering each foot individually, *or* by checking each pair of adjacent feet. It turns out that most constraints already used in other OT work can be expressed this way, so we are not handicapping ourselves too much. One important aspect of our model is that we have not restricted ourselves to a strict ranking of the constraints, but have completely accepted the possibility of a stractified dominance hierarchy. The reason for that is large amount of free variation observed in our data, and the impossibility of accounting for it with strict hierarchies.

The constraints found to be relevant to this analysis are the following. Note that we describe each constraint that follows in two forms: an intensional form (in italics), giving an idea, and a formal form, telling when a violation mark must be assigned.

A. Faithfulness Constraint. In OT, markedness and faithfulness contraints are inherently conflicting (Prince & Smolensky 1993). The ranking of faithfulness and markedness constraints decide what is preserved from the lexicon. We employ a faithfulness constraint to guarantee that primary (phonemic) stresses be preserved, since, as seen before, primary stresses in BP and EP are identical and are not changed by the application of secondary stresses. This faithfulness constraint is based on Correspondence Theory (McCarthy & Prince 1995), and it is named after the family of constraints labelled Maximality (Max) constraints that guarantee that lexical material will not be deleted:

Maxst: *Deletion of lexical stresses is not allowed.* Violated by a foot containing a phonemic stress (i.e. a syllable that is stressed at the input) not tagged as bearing main stress.

B. Markedness Constraints. Markedness constraints require that output forms follow certain well-formedness criteria. Markedness constraints refer to the output only and are blind to the lexicon. If there is no faithfulness constraint conflicting with markedness constraints, the lexicon can be completely modified. The following markedness constraints, conflicting with Maxst, generate the Portuguese secondary footing. The different ranking of these markedness constraints generate the different rhythm of Brazilian and European Portuguese:

FootBin/BinGrad: *Feet must be binary.* It is well-known that stress languages have a clear tendency for rhythmic patterns and that the binary rhythm is the most common one (Hayes 1995). A binary rhythm is enforced in OT by the prosodic markedness constraint FootBin that was first formulated by Prince (1980) and adopted by (Prince & Ssmolensky 1993). It is violated by a foot that does not have exactly two syllables. BinGrad is a gradient form of the same restriction: long feet count one violation for each syllable exceeding the initial two.

Parse: *All syllables must be parsed into feet.* Kager (1999) points out that FootBin does not suffice to generate a binary rhythm (i.e. binary alternation of weak and strong syllables). This requires that all syllables must be parsed by feet (Hayes 1980, Halle & Vergnaud 1987, Prince & Smolensky 1993). Violated by each syllable, which is not a functional word, not included in a foot.

Trochee: *All feet must be left-headed* (Hayes 1995) . Violated by a foot whose head is not its initial syllable.

It follows from the rhythmic property of natural languages that adjacent stressed syllables are avoided, as well as adjacent non-stressed syllables. Constraints enforcing stress clashes have their roots in pre-OT work for instance Liberman 1975, Liberman & Prince 1977, Prince 1983, Hammond 1984, Selkirk 1984. We use the following constraints that work against stress clashes and lapses:

NoClash: *No stressed syllables can be adjacent.* Violated by a pair of successive feet whose head are adjacent.

ClashInt: *No stressed syllables within a lexical word can be adjacent.* Similar to NoClash, but penalizes stress clashes within the same word.

ClashExt: *No stressed syllables in successive words can be adjacent.* Similar to NoClash, but penalizes clashes across words.

NoLapse: *No adjacent unstressed syllables inside a word-medial foot* (Green & Kenstowicz 1995). Violated by a foot occurring not at the beginning or at the end of a lexical word containing two adjacent non-stressed syllables.

C. Alignment Constraints. The notion of alignment originated in Prosodic Phonology (Selkirk 1986). Alignment serves to define the domains of prosodic constituents. In OT, the notion of alignment was first used by Prince & Smolensky (1993) (e.g. the Edgemost constraints) and developed by McCarthy & Prince (1993). McCarthy & Prince propose that all linguistic domains must be defined in terms of generalized alignment constraints. We employ the following constraints to define the stress domains of Portuguese. The different ranking of these constraints will generate the different secondary stress domains of Brazilian and European Portuguese. Recall that the BP domain is the lexical word, since a functional word never bear stress, while the EP allows the entire phonological word to be the secondary stress domain once a functional word can bear secondary stress.

Rightmost: *Align (Hd-FT, Right, PrWd, Right)*. It is well known that all known natural languages have primary stress on an edge window, and Rightmost just places the window for Portuguese. The constraints named after Edgemost (Prince & Smolensky 1993) align the strongest foot (or head foot) with a specified edge of the word. Rightmost aligns the head foot with the right edge of a lexical word and guarantees that no secondary footing be generated at the right edge of a lexical word. Violated by a foot bearing primary stress not containing the last syllable of a word.

IntLex: *A lexical word must be a prosodic word.* Many languages require that lexical words be stressed, while functional words need not be stressed and are prosodically dependent on lexical words (Kager 1999). This is a strong requirement of BP. Violated by a foot containing syllables which belong to different words, even if one of these words is a functional word.[2]

Align (Ft, L, PHW L): *Every foot has its left boundary at the left edge of a phonological word*. It is typical of stress languages that prosodic or syntactic constituents have a single prosodic peak (culminative property of stress). This is important for EP that allows one secondary stress per phonological word. Following McCarthy & Prince this fact is enforced by an alignment constraint. Since this constraint aligns the left boundary of a feet with the left boundary of a phonological word, it forces the inclusion of functional words in a foot. Violated by a regular foot whose left boundary is not the left edge of a phonological word.

Trochee: *All feet must be left-headed* (Hayes 1995). Hayes (1995) proposes that feet must be left-headed (trochees) or right-headed (iambs). In OT this is enforced by alignment constraints. We emply Trochee that aligns the head of a foot with its left boundary. Violated by a foot whose head is not its initial syllable.

One should get an intuitive picture of the dynamics of the main conflicts among these constraints, in order to appreciate their significance.

Aligh conflicts with FootBin/BinGrad because the first enforces that the left edge of every foot must coincide with the left edge of a phonological word, generating unbounded feet, and the latter forces the generation of binary feet disregarding their alignment with other constituents. Since Aligh is higher than FootBin in EP, this variety shows unbounded feet. The opposite is true for BP. Parse also conflicts with FootBin/BinGrad when a word has an odd number of syllables, since, in this case, binary feet is impossible. Recall that BP has cases of initial dactyls. This is generated by a tie between Parse and BinGrad in the ranking. If a dactyl is generated BinGrad is violated once. But if only binary feet are generated in a word with an odd number of syllables Parse is necessarily violated. Since these constraints are equally ranked, it does not matter which constraint is violated. If BinGrad is violated, the dactyl is generated ($\underline{\sigma}\sigma\sigma$). If Parse is vilated, one generates the other attested pattern, tha is, $\sigma\underline{\sigma}\sigma$. In other words, the free variation is generated without restructuring rules. See below about the possibility of erasing a vowel.

In opposition to Aligh is also IntLex, since the latter requires a functional word to be extrametrical while the first forces that a functional word be included in the stress domain because it requires that the left edge of every foot to coincide with the left edge of a phonological word. In BP functional words are always extrametrical and this is guaranteed in our analysis by placing IntLex higher in the hierarchy than Aligh in this dialect. In EP there is a variation in stressing a functional word or the first syllable of a lexical word. This is guaranteed in our analysis by not ranking IntLex and Aligh in EP and by placing Trochee high in the ranking. Since these constraints are equally ranked, it does not matter which constraint is violated. If Aligh is respected, the functional word is included in the foot, if IntLex is respected, the functional word becomes extrametrical. Trochee guarantess that, in any case, the first syllable of the foot be the head syllable, generating stressed functional words when Aligh is respected.

The conflict between ClashExt and Trochee generates avoidance of stress clashes between words in BP. Note, however, that since these constraints are relatively low ranked, there are cases of clashes in BP across words. Since Trochee is high in EP, stress clashes across words are frequently generated.

Next comes Maxst, which for the experiments we have done has surfaced as undominated. There are, however, circumstances of primary stress retraction in PB, as discussed by Sandalo & Truckenbrodt (2002). In the OT system, this fact can be captured by other constraints that are not listed here and that dominate Maxst. In future developments of this work, these constraints will be explored.

Note that, following the assumptions of OT, we use the same constraints with different rankings to derive BP and EP stress patterns. There is, however, a noticeable partial exception, namely

FootBin/BinGrad. All the constraints, except for one, have categorical violations. FootBin/BinGrad is a manifestation of a same constraint with different ways to compute violation. While violations of FootBin are computed as categorical, violations of BinGrad are gradient. Recall that a long foot will compute as a single violation of FootBin, whereas for BinGrad the number of violations increases with the length of the foot. The strong preference for binary feet in BP has been attested in many works (Bisol 1992, Collischonn 1993, Lee 1994, Massini-Cagliari 1995). Moreover, our handling of the data showed that FootBin is too weak a constraint for generating the correct facts of BP, while BinGrad is too strong for EP, even if very lowly ranked.[3]

Recall that BP shows a phenomenon of vowel deletion induced by rhythm. It is well known that EP also undergoes vowel deletion (Mateus 1975, 1983). We could not employ constraints to handle the BP/EP facts because the phenomenon of vowel deletion has not been fully understood, for both Portuguese varieties, until the present point of this research. In other words, we had to avoid handling vowel deletion automatically at this point of our project because we do not have a complete description of the facts yet. It is, however, crucial to implement the BP rhythmic vowel deletion in order to generate the correct facts relative to secondary stress in this variety of Portuguese, as it will be approached in the next section.

There follows the ranking that we propose for BP and EP, respectively:

Maxst : Rightmost : ClashInt >> IntLex >> BinGrad : Parse : NoLapse >> ClashExt >>Trochee >> Align

Maxst: Rightmost : ClashInt >> Trochee >> Align : IntLex >> Parse >> ClashExt >> FootBin : NoLapse

In constructing an OT tableau, one draws one line for each possible output, that is, for each footing, in our case. As we will see later, tableaux are totally impractical for this model, since even moderately sized inputs have an extremely large number of possible outputs. Even a computer would not be able to list all those outputs, so a true mathematical optimization approach has to be taken to find the true optimal solutions without exaustively searching all possibilities. Therefore, we developed a computer program to test our analysis.

4. Sotaq

In most of the current OT literature, a given analysis is tested manually via manipulation of a very restricted amount of data, usually consisting of words or very short phrases. We have developed a computer program, named sotaq, for automatic testing of various different constraint hierarchies on a robust amount of data, thus providing more substantive evidence for our analysis. [4]

Here we present an abridged description of sotaq, explaining some of its underlying algorithms. A more detailed explanation will be presented elsewhere.[5]

Roughly speaking, sotaq is fed a constraint hierarchy and it processes sentences assigning secondary stresses according to the corresponding OT model. The constraints explained earlier are all implemented. As can be seen from their definition, their computation requires information about syllabification, lexical stresses, lexical words and phonological words. While much of this information could be computed automatically from the sentences, at this point they are given in the input. This complicates the input slightly, but makes sotaq a leaner program, concentrated on its main task.

Recall that we had to avoid handling vowel deletion automatically at this point of our project because we do not have a complete description of the facts yet. Therefore, we informed sotaq manually what we know about vowel deletion (via spectrogram analysis of our corpus). We marked with a + the BP vowels that can be deleted. The program does not count as a violation of BinGrad any foot containing three syllables one of which contains a vowel marked by +.

Other processes of ressyllabiffication, like those resulting from the application of vocalic sandhi rules, or internal diphthongization are also important, and our tests and data clearly shows so. At this moment we have not dealt with those phenomena yet, but they will be duly considered in the future.

The input for sotaq is a collection of sentences, each one being a collection of *tagged syllables.* Each of these is a phonological syllable in an actual Portuguese utterance, preceded by a numerical tag that encodes some properties of that syllable. Some such properties are: whether it starts a word, whether it has a primary stress, whether a vowel can be erased in speech. Here is an example:

```
6 O 10 in 0 ves 16 ti 0 ga 1 dor 7 já  2 lhe 10 de 0 vol 1 veu 6 o
2 di 1 nhei 0 ro.
```

The tag for a syllable is a sum of values as such:

O: 2 (starts a word) + 4 (starts a phonological word)

in: 2 (starts a word) + 8 (secondary stress[6])

já: 1 (primary stress) + 2 (starts a word) + 4 (starts a phonological word)

ti: 16 (vowel may be erased).

The constraints may refer to the tags; actually, sotaq processes only the tags in its search for the optimal stresses; the textual syllables are used only to produce human-readable output[7].

When the program is called, the name of the file containing sentences tagged as above is specified, together with a constraint hierarchy. Here are two examples of sotaq' s output; we use the same input sentence, with two different rankings.

Example 1: The ranking used was:

Maxst : Rightmost : ClashInt >> IntLex >> BinGrad : Parse : NoLapse >> ClashExt >>Trochee >> Align

This is the one proposed for BP. The output was:

```
I:  A in·te·li·gên·cia da ca·ta·lo·ga·do·ra foi de·ter·mi·nan·te
   [ |  ~~   ^^^   [ |~~   ~~   ^^  [^^^|  ~~~   ^^^ +
O: |a |in|TEli|GÊNcia |da |CAta|LOga|DOra |FOI |deTER|miNANte [0]
O: |a |INteli|GÊNcia |da |CAta|LOga|DOra |FOI |deTER|miNANte [2]
Total cost: 2027.
19 syllables.
2 optimal footings.
+147667381 possible footings (tableau lines)
```

Example 2: The ranking used was:

MAXST : Rightmost : ClashInt >> Trochee >> Align : IntLex >> Parse >> ClashExt >> FootBin : NoLapse

This is the one proposed for EP. The output was:

```
I:  A in·te·li·gên·cia da ca·ta·lo·ga·do·ra foi de·ter·mi·nan·te
   [ |~~     ^^^   [ |~~        ^^  [^^^|        ^^^
O:  |a |INteli|GÊNcia |da |CAtaloga|DOra |FOI determi|NANte [0]
```

O: |A inteli|GÊNcia |da |CAtaloga|DOra |FOI determi|NANte [2]
O: |a |INteli|GÊNcia |DA cataloga|DOra |FOI determi|NANte [2]
O: |A inteli|GÊNcia |DA cataloga|DOra |FOI determi|NANte [4]
Total cost: 6003.
19 syllables.
4 optimal footings.
+147667381 possible footings (tableau lines)

In each case, the line labeled I and the following one describe the input. The first line is the textual sentence, the second describes tags. A [marks the beginning of a phonological word, a | marks the beginning of a lexical word; a syllable is underlined with carets (^^^^) if it bears a primary stress, and it is underlined with tildes (~~~) if secondary stress was auditorily perceived. Further, a + under a vowel means that it may be deleted in speech.

Each output line is labeled O. The syllables that get stress are capitalized. Bars | show footing into metric feet; note how on each regular footonly one syllable is stressed. To the right of each line there is a number in square brackets, indicating the number of syllables in which the stress differs from the auditory transcription. Thus, in both examples one of the solutions fits the transcription. The annex presents results on several different sentences, and it was not always the case that the reading was matched by a solution.

As both examples show, for a given hierarchy sotaq may ascribe several different patterns of secondary stresses to given input sentence. Those are all equally good. Note that the bracketed number on the right may be misread as some sort of relative quality between solutions; actually, they only represent the proximity of the solution to a single observation point. Let us analyze the two solutions given in Example 1, to see where the violations actually occur, and how variety can emerge from the constraints. Those solutions differ only on how the fragment `inteli` is parsed. Before analyzing this difference, we have a table with the common feet to both solutions, showing which constraints are violated:

	MAXST	Rightmost	ClashInt	IntLex	BinGrad	Parse	NoLapse	ClashExt	Trochee	Align
`|a`										

GÊNcia										*
da										
CAta										*
LOga										*
DOra										*
FOI					*					
deTER									*	*
miNANte									*	*
violation count		0		0		1		0	2	6

Note that the last segment, `miNANte`, even though it contains three input syllables, does not violate BinGrad. That is because the vowel in the last syllable, `te`, has been tagged as erasable, so sotaq predicts it actual deletion in speech.

The two solutions differ in how the three syllables `in-te-li` are parsed into feet. In the first solution, we see `in|TEli`. Here, `in` violates parse, and `TEli` violates align. In the second solution, we see `INteli`. This one violates BinGrad and align. Since parse and BinGrad are equally ranked, those two footings have the same violation count. So, at the end, the violation count, following the columns in the table, is 0,0,2,0,2,7. This sequence is encoded in the total cost reported by sotaq, 2027 in this case.

It is worth noticing how the attested variety can only be achieved here by virtue of the equal rank of Parse and BinGrad. If one insisted in a strict ranking, only one of the two solutions would have been optimal, and the other would be lost.

Sotaq is entirely written in perl, so it is supposed to run on any system where perl is installed. We have only used it in Unix-like systems, however. It is normally called as

```
sotaq --rank xxxx file
```

where `xxxx` is a description of a constraint hierarchy, and `file` is the name of an input file containing tagged phrases. The `xxxx` for example 1 above was `MAXST:rightmost:clashint%intlex%parse:bingrad:nolapse%clashext%trochee%align`. Other command line options exist for more control on the output, experimentation with some nonstandard constraints, and also for experimentation with somewhat fuzzy hierarchies (a simple mathematical idea, with no current linguistic support).

A word on sotaq's innards. The possible feet are treated as nodes in an acyclic directed graph, so that a footing becomes a directed path between the single source and the single sink. The constraint hierarchy yields positive real costs assigned to nodes and edges, in such a way that finding the OT-preferred footing becomes the problem of finding shortest source-sink paths. That is done by a variation of Dijkstra's Algorithm, with few implementation optimizations, as we do not expect to run sotaq on overly long utterances.

5. Testing a corpus

Our proposed has been tested by means of the sotaq program using two types of data: isolated senteces and text fragments. We present here a list of five sentences tested by sotaq for both EP and BP. The sotaq outputs were given to eleven native speakers of BP and three native speakers to EP in order to judge their adequacy. All the speakers agreed that all the outputs are attestable. Sotaq does not generate any ungrammatical stressing. Each sentence was read by a speaker of each variety of Portuguese, and the observed secondary stresses were annotated. In this way, one can actually get an impression of the adequacy of the model to reality, regardless the judgements of the 14 native speakers mentioned above.

The run results were slightly reformatted, since the long lines sotaq produces would be hard to read in print. Note that we cannot work with tableaux lines given the number of possible outputs to be tested. For instance, there are 51092 possible outputs for the first sentence. Thus, sotaq gives the grammatical outputs only and the number os possible outputs that could be generated. It is interesting to note that, although a huge number of possible outputs were always evaluated, only a few is given as grammatical by sotaq, what corresponds to reality.

Test 1

MAXST:rightmost:clashint%intlex%bingrad:parse:nolapse%clashext%trochee%align lu

Active constraints, absolute weights, relative weights:

align: 1

```
  bin grad:        1000
  dep st:        100000
  lex integr:     10000
  nolapse:         1000
  parse:          1000
  rightmost:     100000
  trochee:          10
  ext noclash:      100
  int noclash:   100000
# Frase 1
# Lu2-11.wav
#
I:   A   mo · der · ni · za · ção   foi   sa · tis · fa · tó · ria
   [   |~~         +       ^^^ [ ^^^ | ~~   +        ^^
O:  |a |MOderni|zaÇÃO |FOI |SAtisfa|TÓria [0]
Total cost: 1214.
12 syllables.
1 optimal footing.
+51092 possible footings (tableau lines).
# Frase 2
# Lu2-11.wav
#
I:   A   in · te · li · gên · cia   da   ca · ta · lo · ga · do · ra
   [   |     ~~       ^^^      [    | ~~       ~~       ^^
   foi   de · ter · mi · nan · te
 [ ^^^ |     ~~~       ^^^   +
O:  |a |in|TEli|GÊNcia |da |CAta|LOga|DOra |FOI |deTER|miNANte [0]
O:  |a |INteli|GÊNcia |da |CAta|LOga|DOra |FOI |deTER|miNANte [2]
Total cost: 2027.
19 syllables.
2 optimal footings.
+147667381 possible footings (tableau lines).
#
# Frase 3
# Lu2-11.wav
#
I:   O   in · ves · ti · ga · dor   já   de · vol · veu · o   di ·
```

```
  [  |~~        +       ^^^ [ ^^ | ~~        ^^^   + |
nhei · ro
^^^^
O:  |o |INvesti|gaDOR |JÁ |DEvol|VEUo |di|NHEIro [0]
Total cost: 2215.
14 syllables.
1 optimal footing.
+400542 possible footings (tableau lines).
#
# Frase 4
# Lu2-11.wav
#
I:  O   or · ga · ni · za · dor   a · pre · sen · tou   a   ca ·
  [  |~~       ~+       ^^^ [    ~~~        ^^^ [   |~~
ta · lo · ga · do · ra
    ~~       ^^
O:  |o |ORgani|zaDOR |aPRE|senTOU |a |CAta|LOga|DOra [1]
Total cost: 36.
17 syllables.
1 optimal footing.
+20383750 possible footings (tableau lines).
#
# Frase 5
# Lu2-11.wav
#
I:  A   fal · ta   de   mo · der · ni · za · ção   é   ca · tas ·
  [  | ^^^     [    | ~~        +       ^^^ [ ^ | ~~
tró · fi · ca
^^^    +
O:  |a |FALta |de |MOderni|zaÇÃO |É |CAtas|TRÓfica [0]
Total cost: 1215.
15 syllables.
1 optimal footing.
+1167180 possible footings (tableau lines).
#
```

[frases] > ../sotaq --count --rank

MAXST:rightmost:clashint%trochee%align:intlex%parse%clashext%footbin:nolapse

marina

Active constraints, absolute weights, relative weights:

align: 1000

dep st: 100000

binary foot: 1

lex integr: 1000

nolapse: 1

parse: 100

rightmost: 100000

trochee: 10000

ext noclash: 10

int noclash: 100000

Frase 1

Marina2-11.wav

#

I: A mo · der · ni · za · ção foi sa · tis · fa · tó · ria

[~ | ^^^ [^^^ | ^^

O: |A moderniza|ÇÃO |FOI satisfa|TÓria [0]

O: |a |MOderniza|ÇÃO |FOI satisfa|TÓria [2]

Total cost: 4013.

12 syllables.

2 optimal footings.

+51092 possible footings (tableau lines).

#

Frase 2

Marina2-11.wav

#

I: A in · te · li · gên · cia da ca · ta · lo · ga · do · ra

[| ~~ ^^^ [| ~~ ^^ [

foi de · ter · mi · nan · te

^^^ | ^^^

O: |a |INteli|GÊNcia |da |CAtaloga|DOra |FOI determi|NANte [0]

O: |A inteli|GÊNcia |da |CAtaloga|DOra |FOI determi|NANte [2]

O: |a |INteli|GÊNcia |DA cataloga|DOra |FOI determi|NANte [2]

O: |A inteli|GÊNcia |DA cataloga|DOra |FOI determi|NANte [4]

Total cost: 6003.

19 syllables.

4 optimal footings.

+147667381 possible footings (tableau lines).

Frase 3

Marina2-11.wav

#

I: O   in · ves · ti · ga · dor   já   de · vol · veu   o   di ·

   [| ~~   ^^^ [^^ | ^^^ [|

nhei · ro

^^^^

O: |o |INvestiga|DOR |JÁ devol|VEU |o |di|NHEIro [0]

O: |O investiga|DOR |JÁ devol|VEU |o |di|NHEIro [2]

Total cost: 5114.

14 syllables.

2 optimal footings.

+400542 possible footings (tableau lines).

#

Frase 4

Marina2-11.wav

#

I: O   or · ga · ni · za · dor   a · pre · sen · tou   a   ca ·

   [| ~~   ^^^ [~   ^^^ [| ~~

ta · lo · ga · do · ra

              ^^

O: |o |ORganiza|DOR |Apresen|TOU |a |CAtaloga|DOra [0]

O: |O organiza|DOR |Apresen|TOU |a |CAtaloga|DOra [2]

O: |o |ORganiza|DOR |Apresen|TOU a cataloga|DOra [1]

O: |O organiza|DOR |Apresen|TOU a cataloga|DOra [3]

Total cost: 5015.

17 syllables.

4 optimal footings.

+20383750 possible footings (tableau lines).

#

Frase 5

Marina2-11.wav

#

I: A   fal · ta   de   mo · der · ni · za · ção   é   ca · tas

   [| ^^^   [| ^^^ [^ | ~~

· tró · fi · ca

^^^

O: |a |FALta |DE moderniza|ÇÃO |É catas|TRÓfica [2]

O: |a |FALta de moderniza|ÇÃO |É catas|TRÓfica [1]

O: |a |FALta |de |MOderniza|ÇÃO |É catas|TRÓfica [2]

Total cost: 5014.

15 syllables.

3 optimal footings.

+1167180 possible footings (tableau lines).

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remaining errors are of course our own. The names of the authors are arranged in alphabetical order. A first attempt to approach rhythmic differences between EP and BP in terms of constraint ranking was proposed in Abaurre & Galves (1998) and in Sandalo, Abaurre & Galves (1999).

[1] See Vigário (2002) for a discussion on the importance of this domain in EP.

[2] In Kager (1999) this constraint is GrWd=PrWd.

[3] Note that there is a controversy in the literature on whether to use gradient constraints. McCarthy (2002) argues against gradient constraints, but the necessity of gradiency is frequently observed (see Padgett 2002). The implications of this choice for language acquisition remain to be investigated. If gradient constraints show to be indeed a necessity, it may be the case that specific the way (gradient or categorical) to compute violations of a constraint is not innate, but acquired via exposition to the input.

[4] An earliest version of such a program was conceived and implemented by Pierre Collet and Antonio Galves; the current version is a new implementation, building on their initial ideas.

[5] Mandel, in progress. The sotaq computer program can be downloaded from http://www.ime.usp.br/~tycho/prosody/ in order to test our analysis with further data or to test any other OT nalaysis, provided that new constraints are loaded.

[6] This secondary stresses were also obtained through auditory perception, and the transcriptions can be used to check sotaq's result. This way, one may test the OT model's predictiveness.

[7] Currently there are no user-friendly facilities for preparing input for sotaq. A better user-interface is already being designed, and will be implemented RSN.