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The Revised Max Onset: Syllabification and Stress in English  
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Abstract

Syllabification determines syllable weight, which in turn determines word stress and foot structure. Many proposals of syllabification assume some version of Max Onset. I propose that Max Onset be replaced with Revised Max Onset. Unlike Max Onset, which observes the Law of Initials but not the Law of Finals, Revised Max Onset observes both. In addition, Revised Max Onset assumes simultaneous evaluation of syllabic and metrical structures, made possible in a constraint-based analysis. I show that (i) Revised Max Onset is better than Max Onset when measured against a common set of criteria, (ii) Weight-Stress Principle is stronger than previously thought, and (iii) words with exceptional syllabic or metrical structures are far fewer than previously thought.

1. Syllabification and syllable weight

A typical syllable contains a main vowel, or the nucleus. The part before the nucleus is the onset and the part after the nucleus is the coda. The part consisting of the nucleus and the coda is also called the rime, and the part consisting of the onset and the nucleus is called the ‘body’ (Vennemann 1988). The terms are illustrated in (1).

(1) Onset, nucleus, coda, body, and rime of a syllable

Word	Onset	Vowel	Coda	Body	Rime
/prɪnt/ <i>print</i>	/pr/	/ɪ/	/nt/	/prɪ/	/ɪnt/
/sɪt/ <i>sit</i>	/s/	/ɪ/	/t/	/sɪ/	/ɪt/
/ɪt/ <i>it</i>	none	/ɪ/	/t/	/ɪ/	/ɪt/
/ðə/ <i>the</i>	/ð/	/ə/	none	/ðə/	/ə/

Syllabification is a procedure that groups sounds of a word into syllables. There are different theories of syllabification. Consider the English word *extra*, which can be syllabified in different ways, shown in (2), where brackets represent syllable boundaries.

(2) Different ways to syllabify *extra* /ɛkstrə/

Syllabification	Proponent	Requirements
a. [ɛkstr][ə]	None	Possible onset
b. [ɛkst][rə]	Hoard (1971)	Max Stressed Onset, Max Coda
c. [ɛks][trə]	Lowenstamm (1981)	Max Onset, Sonority
d. [ɛk][strə]	Pulgram (1970)	Max Onset
e. [ɛ][kstrə]	None	Possible coda

It is generally agreed that every syllable should have a possible onset and a possible coda, to be specified shortly. Thus, no analysis proposes (2a), because [kstr] is not a possible coda.

Similarly, no analysis proposes (2e), because [kstr] is not a possible onset. But opinions differ on how to create possible onsets and codas, as seen in (2c)-(2d).

(2b) is proposed by Hoard (1971), based on two requirements: (i) the onset of a stressed syllable should be maximized (Max Stressed Onset) and (ii) the coda should be maximized (Max Coda). In *extra*, because the second syllable has no stress, which means it need not maximize its onset, and so the first syllable takes all the consonants it can as its coda, leaving only /r/ to the second syllable. A similar analysis is proposed by Bailey (1978) and Wells (1990).

(2c) is proposed by Lowenstamm (1981), who assumes that the onset should be maximized for all syllables (Max Onset), plus the requirement that consonants in the onset should have increasing sonority. Following Jespersen (1904), Lowenstamm assumes the sonority scale ‘vowel > glide > sonorant > fricative > stop’, where a vowel has the greatest sonority and a stop has the least. According to the scale, the sequence /st/ does not have increasing sonority; therefore, /st/ cannot fit into an onset but must split into two syllables.

(2d) is proposed by Pulgram (1970), who also assumes Max Onset for all syllables, but without the sonority requirement. Thus, the onset of the second syllable is [str].

Let us consider another example. The English word *whisky* /wɪski/ has four proposed analyses, shown in (3). In (3c), [s] is ‘ambisyllabic’, which means it belongs to both the first syllable and the second, so that the first syllable is [wɪs] and the second is [ski].

(3) Four ways to syllabify *whisky* /wɪski/

Analysis	Proponent	Requirements
a. [wɪ][ski]	Halle and Vergnaud (1987)	Max Onset
b. [wɪsk][i]	Hoard (1971)	Max Stressed Onset, Max Coda
c. [wɪ[s]ki]	Kahn (1976)	Max Onset, ambisyllabic rule
d. [wɪs][ki]	Pulgram (1970)	Max Onset, possible rime

(3a) is proposed by Halle and Vergnaud (1987), based on Max Onset. (3b) is proposed by Hoard (1971), based on Max Stressed Onset and Max Coda, as discussed above. (3c) is proposed by Kahn (1976), based Max Onset first, followed by an ‘ambisyllabic’ rule that allows a stressed vowel to use the following consonant as its coda, even if the consonant is already in the onset of the following syllable. (3d) is proposed by Pulgram (1970), based on two requirements: (i) Max Onset, discussed above, and (ii) possible rime. Because [ɪ] is not a possible rime (no word in American English ends in /ɪ/), the first syllable cannot be [wɪ] but must be [wɪs].

The analysis in (3) can be achieved in other ways, too. For example, Prince and Smolensky (1993) obtains (3a) by the requirements Onset (syllables must have an onset) and No Coda (syllables must have no coda). Hammond (1999) obtains (3b) by the requirement Max Coda when there are two (or more) consonants between vowels. Lowenstamm (1981) obtains (3d) by Max Onset and a sonority requirement, as discussed above, according to which /sk/ cannot fit in an onset but must split between two syllables.

Many studies have attempted to determine syllable boundaries through experiments. However, native intuition does not always offer clear answers. There are cases where agreement is easy to obtain. For example, all native speakers reject [ɛkstr][ə] and [ɛ][kstrə] for *extra*, and all accept [æt][ləs] for *atlas*, [bə][ɡɪn] for *begin*, and [hou][təl] for *hotel*. However, native agreement is hard to obtain on words like *whisky*, *city*, and many others, although there is some preference for [...VC][V...] over [...V][CV...] if the first vowel is short and stressed (Treiman and Danis 1988; Krakow 1989; Treiman and Zukowski 1990; Turk 1994; Kessler and Treiman 1997;

Krakow 1999; Eddington et al. 2013). Therefore, most proposals on syllabification rely to theoretical considerations, in particular how onsets and codas should be formed.

Let us take a close look at what a possible syllable is. A common view is that a syllable is possible if (i) its initial sequence can be found at the beginning of a word and (ii) its final sequence can be found at the end of a word (Pulgram 1970). Let us follow Vennemann (1988) and use the terms the Law of Initials and the Law of Finals, rephrased in (4) and (5), to define the common view.

- (4) The Law of Initials (LOI)  
The initial sound sequence of a syllable (i.e. the body) ought to be found in the initial sound sequence of a word.
- (5) The Law of Finals (LOF)  
The final sound sequence of a syllable (i.e. the rime) ought to be found in the final sound sequence of a word.

Several comments are in order. First, the LOI applies to the body of a syllable, which includes the main vowel. This way the LOI can rule out syllables like [sfæt] and [sfɛn], correctly, because no word starts with [sfæ] or [sfɛ]. If the LOI only applies to the onset, then [sfæt] and [sfɛn] would satisfy the LOI (contrary to the judgment of native intuition), because the onset [sf] is found in *sphere*. Second, the LOF applies to the rime of the syllable, which includes the main vowel. This way the LOF can rule out a syllable like [kæ], because no word ends in the rime [æ]. If the LOF only applies to the coda, then a syllable like [kæ] would satisfy the LOF, because it simply lacks a coda, and many words end with no coda. Third, the LOI and the LOF apply to the surface form of a word. For example, the surface form of *Canada* is [kænədə]. If we syllabify it as [kæn][ə][də], then both the LOI and the LOF are satisfied. However, if the LOF applies to the underlying form of *Canada*, which according to Chomsky and Halle (1968) is [kænədə], where the first two vowels are both [æ], then [kæn][æ][də] would violate the LOF, because the second syllable ends in [æ], yet no English word does.

To illustrate the application of the LOI and the LOF, consider various ways to syllabify the word *extra*, shown in (6). When the LOI or the LOF is violated, an asterisk is shown. When the LOI or the LOF is satisfied, a check mark is shown, and a sample word is given in parentheses, with relevant sounds underlined.

(6) LOI and LOF in the syllabification of *extra* / ɛkstrə/

Syllabification	LOF	LOI
a. [ɛkstr][ə]	*	✓ ( <u>a</u> bout)
b. [ɛkst][rə]	✓ ( <u>te</u> xt)	✓ ( <u>re</u> peat)
c. [ɛks][trə]	✓ ( <u>in</u> dex)	✓ ( <u>tr</u> adition)
d. [ɛk][strə]	✓ ( <u>de</u> ck)	✓ ( <u>str</u> ategic)
e. [ɛ][kstrə]	*	*

In (6a), there is a violation of the LOF, because no word ends in [ɛkstr]. (6a) satisfies the LOI though, because there are words that start with [ə], such as about. In (6e), there is both a violation of the LOF, because no word ends in [ɛ], and a violation of the LOI, because no word

starts with [kstrə]. In the other three cases, both the LOI and the LOF are satisfied. Next, we consider the LOI and the LOF in the syllabification of *whisky*, shown in (7).

(7) LOI and LOF in the syllabification of *whisky* (in American English)

Syllabification	LOF	LOI
a. [wɪ][ski]	*	✓ ( <i>scheme</i> )
b. [wɪsk][i]	✓ ( <i>risk</i> )	✓ ( <i>east</i> )
c. [wɪs][ki]	✓ ( <i>miss</i> )	✓ ( <i>keen</i> )
d. [wɪs][ki]	✓ ( <i>miss</i> )	✓ ( <i>keen</i> )

In (7a), the LOF is violated, because no word in American English ends in [ɪ]. In the other three cases, both the LOI and the LOF are satisfied. The example shows that an unqualified Max Onset may violate the LOF, whereas qualified Max Onset satisfies both the LOI and the LOF.

Next, let us evaluate various approaches by the LOI and the LOF. Since the ambisyllabic analysis of Kahn (1976) complicates syllable structure, without obvious advantages over the analysis of Pulgram (1970), we do not consider it further. Instead, we consider Hoard (1971), Lowenstamm (1981), Halle and Vergnaud (1987), and Pulgram (1970). Their analyses of *Debra* and *essay* are shown in (8) and (9)

(8) LOI and LOF and the analysis of *Debra* /dɛbrə/

Analysis	Proponent	Requirements	LOF	LOI
[dɛb][rə]	Hoard	Max Stressed Onset, Max Coda	✓	✓
[dɛ][brə]	Lowenstamm	Max Onset, Sonority	*	✓
[dɛ][brə]	Halle & Vergnaud	Max Onset	*	✓
[dɛb][rə]	Pulgram	Max Onset, possible rime	✓	✓

(9) LOI and LOF and the analysis of *essay* /ɛsei/

Analysis	Proponent	Requirements	LOF	LOI
[ɛ][sei]	Hoard	Max Stressed Onset, Max Coda	*	✓
[ɛ][sei]	Lowenstamm	Max Onset, Sonority	*	✓
[ɛ][sei]	Halle & Vergnaud	Max Onset	*	✓
[ɛs][ei]	Pulgram	Max Onset, possible rime	✓	✓

In *Debra*, the second syllable has no stress. For Hoard (1971), the coda of the first syllable should be maximized, yielding [dɛb][rə], which satisfy both the LOF and the LOI. For Lowenstamm (1981), [br] is a good onset, because it has increasing sonority, yielding [dɛ][brə], where [dɛ] violates the LOF, because no word ends in [ɛ]. Similarly, the analysis of Halle and Vergnaud (1987) violates the LOF. Finally, the analysis of Pulgram (1970) satisfies both the LOI and the LOF.

In *essay*, the second syllable has secondary stress. For Hoard (1971), its onset should be maximized, yielding [ɛ][sei], where [ɛ] violates the LOF. Similarly, the analyses of Lowenstamm (1981) and Halle and Vergnaud (1987) violate the LOF. For Pulgram (1980), ‘possible rime’ requires the first syllable to be [ɛs], yielding [ɛs][ei], which satisfies both the LOI and the LOF.

In summary, while all analyses assume some version of Max Onset, only Pulgram's version observes the LOF. Let us redefine the two versions in (10) and call them Max Onset and Revised Max Onset.

(10) Two versions of maximizing the onset:

Max Onset: Maximize the onset, under the LOI but not the LOF.

Revised Max Onset: Maximize the onset, under both the LOI and the LOF.

Given the new definitions, Hoard (1971) assumes Max Onset for stressed syllables and Max Coda otherwise. Lowenstamm (1980) assumes Max Onset, with an additional requirement for a consonant sequence to have increasing sonority in the onset. Halle and Vergnaud (1987) assumes Max Onset. Finally, Pulgram (1970) assumes Revised Max Onset, which also ensures that all rimes are possible.

Let us now consider syllable weight, which is based on the length of the rime. A syllable is light if the rime consists of a short vowel without a coda, otherwise the syllable is heavy. In English, a long vowel is one that can end a stressed syllable. In American English, long vowels include [i: u: ei ou ai au oi α: ɒ: ɜ:], as in *see, two, day, go, buy, how, boy, spa, law, and fur* respectively. A short vowel is one that cannot end a stressed syllable, such as [ɪ ʊ ε ʌ], as in *sit, book, bed, and bud*, or one that is unstressed only, such as [ə ə̃]. The vowel [æ] is usually thought to be short as well (Chomsky and Halle 1968), although it is phonetically long and does occur in some marginal words, such as *nah* [næ:]. Finally, unstressed word final [i u] are sometimes treated as short (Halle and Vergnaud 1987). In (11) we summarize vowel length in American English.

(11) Vowel length in American English

Long	[i: u: ei ou ai au oi α: ɒ: ɜ:]
Short	[ɪ ʊ ε ʌ], [ə ə̃], ([æ])
Special cases	unstressed word final [i u] are short

Given the definition of syllable weight and vowel length, it is clear that different ways of syllabification lead to different weight patterns. Consider the word *whisky*, whose syllabification and weight patterns are shown in (12). For visual clarity, a hyphen is added between syllables in the columns under Rime and Weight. In addition, H and L are shorthand notations for heavy and light syllables respectively.

(12) Syllabification and syllable weight for *whisky* /wɪski/

Syllabification	Rime	Weight	Shorthand
[wɪ][ski]	[ɪ]-[i]	light-light	LL
[wɪsk][i]	[ɪsk]-[i]	heavy-light	HL
[wɪs][ki]	[ɪs]-[i]	heavy-light	HL

In (12), [ɪsk] and [ɪs] are both called heavy, although [ɪsk] has an extra consonant. To distinguish them, VCC (such as [ɪsk]) and VVC (such as [aʊn] in *council*) are sometimes called 'super-heavy', in contrast to VC and VV, which are regular heavy. However, the distinction is of little consequence for our discussion and is not made here.

## 2. Proposals of word stress in English

Word stress in English is sensitive to syllable weight, in the sense that heavy syllables tend to attract stress (Lieberman and Prince 1977; Halle and Vergnaud 1987; Prince 1992; Hayes 1995). Let us consider two approaches to word stress assignment, which we can call deterministic and non-deterministic.

### 2.1. Deterministic assignment of word stress

In the deterministic approach, there is a specific set of requirements or rules for word stress assignment, and each given sequence of phonemes has just one solution. Some words satisfy all the requirements, yield the expected solution, and are considered to have regular stress patterns. Other words fail to satisfy one or more of the requirements, do not yield the expected solution, and are considered to have exceptional stress patterns.

The deterministic approach is proposed by Halle and Vergnaud (1987) and Hayes (1995). For illustration, let us consider the analysis of main stress in English nouns. According to Halle and Vergnaud (1987: 227), the stress pattern of English nouns is as in (13).

- (13) Main stress in English nouns (Halle and Vergnaud 1987: 227):  
Main stress is on the penultimate syllable if it is heavy (e.g. *agenda, marina*)  
Else main stress is on the antepenultimate syllable (e.g. *Canada, Mexico*)

To obtain the proposed stress pattern, Halle and Vergnaud (1987) propose an ordered set of rules, which we rephrase in (14), where H is a heavy syllable, L is a light syllable, and parentheses over H or L indicate foot boundaries. A general assumption in metrical phonology is that every foot has a stress and every stress implies a foot. In a trochaic foot with two syllables, stress falls on the one on the left.

- (14) Ordered rules for assigning main stress in English nouns (Halle and Vergnaud 1987):
- a. Syllabify according to Max Onset.
  - b. Exclude the final syllable (if the word has two or more syllables).
  - c. Build a trochaic foot from the right, which can be (H), (HL), or (LL).
  - d. Else build (L) instead.

In (15) we show the analysis of some English nouns, both regular ones and exceptional ones, where \* indicates a violation of a rule in (14). Halle and Vergnaud (1987) consider word final [i] to be short in some words, such as *city*, which need not concern us.

## (15) Analysis of some English nouns according to (14)

Word	(14a)	Weight	(14b)	(14c)	(14d)	Comment
<i>agenda</i>	[ə][gɛn][də]	LHL	LH<L>	L(H)<L>		regular
<i>marina</i>	[mə][ri:][nə]	LHL	LH<L>	L(H)<L>		regular
<i>Canada</i>	[kæ][nə][də]	LLL	LL<L>	(LL)<L>		regular
<i>lemon</i>	[lɛ][mən]	LH	L<H>		(L)<H>	regular
<i>city</i>	[sɪ][ti]	LL	L<L>		(L)<L>	regular
<i>Mexico</i>	[mɛk][sə][ko:]	HLH	HL<H>	(HL)<H>		regular
<i>Tennessee</i>	[tɛ][nə][si:]	LLH	*	LH(H)		(14b) violated
<i>Japan</i>	[dʒə][pæn]	LH	*	L(H)		(14b) violated
<i>banana</i>	[bə][næ][nə]	LLL	LL<L>	*	L(L)<L>	(14c) violated
<i>textile</i>	[tɛk][stail]	HH	*	*		(H)(H)

The first six words are regular and the last four exceptional. In *Tennessee* and *Japan* (14b) fails to exclude the final syllable, which acquires main stress. In *banana*, (14c) fails to build (LL); as a result, (14d) builds (L) instead. In *textile*, both syllables have stress, where the first has main stress and the second has secondary stress. This means that (14b) fails to exclude the final syllable (because excluded syllables cannot be assigned stress). In addition, (14c) fails to assign main stress to the final syllable; instead, main stress appears on the preceding syllable. It is worth noting, too, that although *lemon* and *city* are thought to be regular words, their foot (L) is in fact exceptional, because it is not among the preferred feet in the first step of foot construction (14c). We shall return to this point.

Hayes (1995) offers a similar analysis, except that he only assumes two regular foot types, (H) and (LL), each having two moras. His analysis is rephrased in (16) and illustrated in (17).

## (16) Rules for assigning main stress in English nouns (Hayes 1995):

- a. Syllabify according to Max Onset.
- b. Exclude the final syllable (if the word has two or more syllables).
- c. Build a moraic trochee from the right, which can be (H), or (LL).
- d. Else build (L) instead.

## (17) Analysis of some English nouns according to (16)

Word	(16a)	Weight	(16b)	(16c)	(16d)	Comment
<i>agenda</i>	[ə][gɛn][də]	LHL	LH<L>	L(H)<L>		regular
<i>marina</i>	[mə][ri:][nə]	LHL	LH<L>	L(H)<L>		regular
<i>Canada</i>	[kæ][nə][də]	LLL	LL<L>	(LL)<L>		regular
<i>lemon</i>	[lɛ][mən]	LH	L<H>		(L)<H>	regular
<i>city</i>	[sɪ][ti]	LL	L<L>		(L)<L>	regular
<i>Mexico</i>	[mɛk][sə][ko:]	HLH	HL<H>	(H)L<H>		regular
<i>Tennessee</i>	[tɛ][nə][si:]	LLH	*	LH(H)		(14b) violated
<i>Japan</i>	[dʒə][pæn]	LH	*	L(H)		(14b) violated
<i>banana</i>	[bə][næ][nə]	LLL	LL<L>	*	L(L)<L>	(14c) violated
<i>textile</i>	[tɛk][stail]	HH	*	*		(H)(H)

It can be seen that the exceptional words for Hayes (1995) are exactly the same as those for Halle and Vergnaud (1987). English word stress can also be analyzed in the framework of Optimality Theory (e.g. Pater 2000), again with the same set of exceptional words.

To deal with exceptional words, the deterministic approach has to mark them in some way, so that they do not undergo the same rules or requirements as regular words. For example, Halle and Vergnaud (1987) and Hammond (1999) propose that some English words have a lexical mark on a given syllable, which means it must be stressed. Similarly, Pater (2000) proposes that English words are divided into different classes, so that they are subject to different constraints. Such proposals essentially acknowledge that English word stress is not completely predictable.

## 2.2. Non-deterministic assignment of word stress

In the non-deterministic approach, there is also a specific set of requirements or rules for word stress assignment, but a given sequence of phonemes can satisfy the requirements in more than one way. As a result, all words are good and no word is exceptional. I discuss two proposals of the non-deterministic approach, Burzio (1994) and Duanmu (2007).

### 2.2.1. Burzio (1994)

The proposal of Burzio (1994) is summarized in (18), where  $\sigma$  represents either H or L. Thus, the foot type ( $H\sigma$ ) can be (HL) or (HH) and ( $\sigma L\sigma$ ) can be (HLH), (HLL), (LLH), or (LLL).

(18) Constraints for word stress in English (Burzio 1994):

- a. Max Onset.
- b. Main stress falls on the first foot from right.
- c. The only good feet are ( $H\sigma$ ) and ( $\sigma L\sigma$ ), both being trochaic.
- d. A word can end in a ‘null vowel’.
- e. A final L can be left outside of a foot.

The analysis applies to not just nouns but all English words. For illustration, some examples are shown in (19), where we use  $\emptyset$  to represent a null vowel. A syllable with a null vowel is treated as L. Following Chomsky and Halle (1968), Burzio considers an unstressed final [i] to be short vowels.

(19) Analysis of some English nouns according to (18)

Word	Syllabification	Foot	Foot type	Comment
<i>agenda</i>	[ə][gən][də]	L(HL)	( $H\sigma$ )	
<i>marina</i>	[mə][ri:][nə]	L(HL)	( $H\sigma$ )	
<i>Canada</i>	[kæ][nə][də]	(LLL)	( $\sigma L\sigma$ )	Max Onset
<i>lemon</i>	[lɛ][mə][n $\emptyset$ ]	(LLL)	( $\sigma L\sigma$ )	Max Onset, null vowel
<i>Mexico</i>	[mɛk][sə][ko:]	(HLH)	( $\sigma L\sigma$ )	
<i>Japan</i>	[dʒə][pæn][n $\emptyset$ ]	L(HL)	( $H\sigma$ )	Null vowel, geminate [nn]
<i>pan</i>	[pæn][n $\emptyset$ ]	(HL)	( $H\sigma$ )	Null vowel, geminate [nn]
<i>banana</i>	[bə][næn][nə]	L(HL)	( $H\sigma$ )	Geminate [nn]
<i>sardine</i>	[sar][di:][n $\emptyset$ ]	H(HL)	( $H\sigma$ )	Null vowel
<i>alpine</i>	[æɪ][pai][n $\emptyset$ ]	(HH)L	( $H\sigma$ )	Null vowel
<i>city</i>	[sɪt][ti]	(HL)	( $H\sigma$ )	Geminate [tt]

The analysis of *Canada* [kæ][nə][də] (LLL) and *lemon* [lɛ][mə][nØ] (LLL) show that Burzio assumes Max Onset that ignores the Law of Finals. If so, *banana* ought to yield an ill-formed result [bə][næ][nə] L(LL), where (LL) is not in his inventory of good feet. For *banana* to yield L(HL), Burzio makes the claim that *banana* has a geminate consonant [nn], so as to yield a well-formed foot (HL). Similarly, words like *city* have a geminate consonant in order to yield (HL) and avoid (LL). Finally, Burzio assumes that every word ends in a vowel; those that end in a consonant have a final ‘null vowel’. This way, words that have final stress, such as *pan* and *Japan*, also have a good foot (HL), rather than a bad foot (H). It is worth noting that Max Onset applies to the null vowel, too, so that *pan* must have a geminate [nn], otherwise it would become [pæ][nØ], yielding an ill-formed foot (LL).

The point of interest here is that Burzio’s constraints can be satisfied in more than one way. For example, the weight pattern HHL can yield the foot structure (HH)L, as in *alpine*, or H(HL), as in *sardine*.

Like the deterministic approach, the non-deterministic approach assumes that English word stress is not fully predictable, because each word may choose its own way to satisfy the set of requirements. However, unlike the deterministic approach, which treats some words as regular and some exceptional, Burzio treats all English words to be equally well formed, at least with regard to syllable structure and foot structure, although as Burzio acknowledges, evidence for geminate consonants is rather weak.

It can be seen that Burzio’s analysis has several problems. First, it is unclear what the relation is between the two good feet. Burzio suggests that they have similar weight values, and he proposes a rather idiosyncratic way of calculating the total weight of a foot. But if we assume the traditional view that H has two moras and L has one, Burzio’s feet range from three moras in (HL) to five in (HLH), which is quite a range. Still, why is (LHL) a bad foot, while (HLL) and (LLH) are good ones, even though they all have four moras each? Similarly, why is (LH) a bad foot, while (HL) is a good one, even though they both have three moras each? Second, trisyllabic feet are fairly rare and metrical theory would be simpler without assuming them. Third, most people consider the second syllable of *alpine* to have secondary stress (e.g. Chomsky and Halle 1968; Halle and Vergnaud 1987), yet Burzio considers it to have no stress; the same problem can be raised for *verify* (LLH) and *notify* (HLH), where the final H is often thought to have secondary stress. Finally, Burzio assumes inconsistent syllabification for the syllable with main stress. For example, the first syllable in *city* is heavy, whereas that in *Canada* is light, even though (HLL) is an allowable foot in his analysis. Obviously, the problem arises from (i) the assumption of Max Onset and (ii) the desire to disallow (LL) and (LH). Max Onset yields LLL for *Canada*, but would also yield unwanted (LL) for *city* and *banana*. To avoid (LL), Burzio proposes that some words have an abstract ‘geminate’ consonant, such as [nn] in *banana* [bənænnə] and [tt] *city* [sitti], even though he acknowledges that the proposal is ad hoc.

### 2.2.2. The present analysis

I would like to offer a better version of the non-deterministic approach, without the problems in Burzio’s analysis. First, I propose that English has both moraic trochee (Hayes 1995) and syllabic trochee (Halle and Vergnaud 1987), similar to Chinese (Duanmu 2007). The proposal differs from a common view that a language can only choose one foot type (at its lowest level of metrical structure). However, there is good evidence that a language can have both. For example, as discussed in Duanmu (2007), there is a contrast in Chinese between heavy syllables, which

can carry stress and tone, and light syllables, which cannot carry stress or tone. This calls for counting moras, so that each heavy syllable is moraic feet. In addition, Chinese has a strong requirement for a minimal word to be disyllabic and a strong preference for certain word length combinations over others, which calls a disyllabic trochee as well. English is similar to Chinese in the sense that stress is sensitive to syllable weight, which means that English must count moras (Hayes 1995). In addition, in many English words main stress is on the third syllable from the right, and a syllabic trochee is a simple way to account for it (Halle and Vergnaud 1987).

According to Duanmu (2007), there are only three well-formed foot structures, shown in (20), where x represents stress, a dot represents a syllable boundary, and 0 represents an unstressed syllable. Among the three foot structures, (mm) is a heavy syllable, which is always stressed. In (HL), only the first syllable has stress. In (HH), both syllables have stress, but the first has more.

(20) Three well-formed foot structures (Duanmu 2007)

Name	Shorthand	Structure
Moraic trochee	(mm)	x ( mm )
Syllabic trochee	(HL)	x ( x 0 ) ( mm ) . m
Syllabic trochee	(HH)	x ( x x ) ( mm ) . ( mm )

It is worth noting that there is no stressed L. This means that, unlike Halle and Vergnaud (1987) and Hayes (1995), for whom (L.L) is a possible foot, in the present analysis it is not. The present analysis agrees with two facts. First, in Chinese, where syllable boundaries are clear, no L can carry stress or tone. Second, in English no stressed final syllable is L, even though both Halle and Vergnaud (1987) and Hayes (1995) allow L to be an exceptional foot. Moreover, as we have seen above, while syllable boundaries are not always obvious in English, Revised Max Onset can ensure that all stressed syllables are H.

It is also worth noting that, in (HH), there is no stress clash, because at the moraic level, the two stresses are separated by an unstressed mora. In addition, by treating (HH) as a regular foot, we avoid a problem in previous analyses. Specifically, in Halle and Vergnaud (1987), for words like *alpine* and *moron*, main stress is assigned to the second syllable, and then a special rule is used to shift the stress to the left. Similarly, Burzio (1994) has to make the unusual claim that the second syllable in words like *alpine* and *moron* has no secondary stress, contrary to many other people's judgment. In the present analysis, such words need no special treatment.

The proposed foot structures can be derived from two well-known constraints, Foot Binariness and the Weight-Stress Principle, shown in (21), along with two additional constraints, Revised Max Onset, Parse2 and Main Stress, to account for syllabification and word stress in English.

- (21) Constraints on syllabification, foot structure, and word stress  
 Foot Binarity (FtBin): Every foot must have two beats.  
 Weight-Stress Principle (WSP): H has stress; L has no stress.  
 Revised Max Onset (RMO)  
 Parse2: Two free beats must form a foot.  
 Main Stress: Main stress must be that of a syllabic foot.  
 Null Beat: A null beat counts as L and is realized as a pause or pre-pause lengthening.

Foot Binarity requires a moraic foot to contain two moras and a syllabic foot to contain two syllables (Prince 1980). The WSP has two parts. The first part is similar to what Prince (1992) calls the Weight-to-Stress Principle, which requires H to be stressed. The second part is similar to what Prince (1992) calls the Stress-to-Weight Principle, which excludes (m.m) or (LL) from being a possible foot, because there is a stressed L. Prince (1992) rejects the second part of the WSP, in part because many English words, such as *sanity*, *banana* and *city*, seem to have a stressed L. However, as I have shown, the problem arises from Max Onset. If we assume Revised Max Onset instead, then both parts of the WSP can be maintained.

Parse2 requires every heavy syllable to form a moraic foot and have stress, because it contains two moras (two moraic beats). In addition, Parse2 disallows two adjacent free syllables (two syllabic beats). On the other hand, Parse2 allows one L to be left alone (without a foot). Now it can be seen that there is an overlap between the WSP and Parse2, both requiring H to be stressed. A possible solution is to replace the WSP with a requirement that a moraic foot cannot contain a syllable boundary, or \*(m.m). Interestingly, although Hayes (1995) allows (m.m) as a possible foot, he needs a constraint to prevent a syllable from being split by a foot boundary, i.e. m(m.m) for HL, (m.m)m for LH, and (m.m)(m.m) for LHL. It can be seen that \*(m.m) is sufficient to rule out such cases.

Main Stress agrees with the fact that stress in words like *France* or *Berlin* is just as strong as main stress in *nation*, *Chicago*, or *compensation*; this is achieved by the representation that in all these words main stress falls on a syllabic foot. Finally, Null Beat claims that the constraint is physically real and verifiable; this accounts for the well-known fact that a stressed pre-pause English syllable is much longer than a stressed non-final one (Price et al. 1991).

With the above constraints, let us consider the analysis of some English words, whose syllables and foot structures are shown in (22).

- (22) Analysis of some English words according to (21)

Word	Syllables	Foot	Comment
<i>agenda</i>	[ə][gɛn][də]	L(HL)	
<i>marina</i>	[mə][ri:][nə]	L(HL)	
<i>Canada</i>	[kæn][ə][də]	(HL)L	
<i>lemon</i>	[lɛm][n]	(HL)	Syllabic [n]
<i>Mexico</i>	[mɛk][sə][ko:]	(HL)(mm)	
<i>Japan</i>	[dʒə][pæn]Ø	L(HL)	Null beat
<i>pan</i>	[pæn]Ø	(HL)	Null beat
<i>banana</i>	[bə][næn][ə]	L(HL)	
<i>sardine</i>	[sar][di:n]Ø	(mm)(HL)	Null beat
<i>alpine</i>	[æɪ][paɪn]	(HH)	
<i>city</i>	[sɪt][i]	(HL)	

The analysis shows that the same CV string, such as CVCVCV in *Canada* and *banana*, can satisfy the constraints in more than one way and yield more than one good solution. It can be shown, too, that every English word has at least one way to satisfy all the constraints.

### 3. A set of criteria

Let us now evaluate various approaches to syllabification and stress assignment, using a common set of criteria. It is reasonable to say the criteria in (23) are desired for all approaches.

(23) A common set of criteria to satisfy:

LOI (the Law of Initials)

LOF (the Law of Finals)

WSP (the Weight-Stress Principle)

FtBin (Foot Binary)

No Marking: Avoid marked words (exceptional words).

The LOI, the LOF, the WSP, and FtBin have been discussed above. No Marking aims to minimize exceptional or marked words. The evaluation of various approaches to syllabification and stress assignment is shown in (24), where HV refers to Halle and Vergnaud (1987).

(24) Evaluation of approaches to syllabification and stress assignment

	LOI	LOF	WSP	FtBin	No Marking
Max Onset	✓	*	*		
RMO	✓	✓	✓		
HV (MO); Hayes (MO)	✓	*	*	*	*
Burzio (MO)	✓	*	*	✓	*
Present (RMO)	✓	✓	✓	✓	✓

As discussed above, Max Onset ignores the LOF, because it creates stressed light syllables, such as the first syllable in *Canada* [kæ][nə][də] and *very* [vɛ][ri], which are not found in word-final positions. In addition, such stressed light syllables violate the WSP. In contrast, RMO always satisfies the LOI, the LOF, and the WSP. There are two reasons. First, word-initial vowels are common, which means that syllables without an onset can still satisfy the LOI. Second, stressed word-final syllables are always heavy and satisfy the WSP, and consequently, the LOF requires stressed nonfinal syllables to be syllabified in the same way, which means they always satisfy the WSP, too.

Next we consider stress assignment and foot structure. First, in the deterministic approach, both Halle and Vergnaud (1987) and Hayes (1995) assume Max Onset, which violates the LOF and the WSP, as just discussed. In addition, because they assume the exclusion of the final syllable, words like *very* and *city* will end up with just one short syllable, which is made into a foot by itself, which violates FtBin, regardless of whether we assume moraic feet (Hayes 1995) or syllabic feet (Halle and Vergnaud 1987). Finally, in the deterministic approach, some words are regular and some exceptional, which violates No Marking.

Although Burzio (1994) assumes a non-deterministic approach, he assumes Max Onset, too. Therefore, his analysis violates the LOF. In addition, to make sure that words like *city*, *very*,

and *disco* have a stressed heavy syllable, as required by the foot ( $H\sigma$ ), these words have to be marked with an underlying geminate consonant, which violates No Marking.

The present analysis assumes RMO, which always satisfies the LOI, the LOF, and the WSP. In addition, given the null beat that is available in pre-pause position, a fact that is independently motivated, FtBin is always satisfied, so is No Marking. Moreover, the inclusion of (HH) as a good foot avoids the need to treat words like *disco* and *alpine* as exceptional ones that need special marking or undergo different requirements of rules.

#### 4. Why does Max Onset ignore the LOF?

Given the obvious advantages of RMO, as just seen, one would wonder why there are analyses that choose Max Onset instead. The main reason, it seems to me, is the traditional assumption in generative grammar that phonology consists of an ordered set of rules. Specifically, there is an assumption that syllabification precede stress assignment and vowel reduction. For illustration, consider the analysis of *Canada*. According to Chomsky and Halle (1968), English has a rule, given in (25), which reduces unstressed short ([-tense]) vowels to [ə].

- (25) Vowel Reduction in English (Chomsky and Halle 1968: 111)  
 [-stress, -tense, V] → [ə]

In addition, according to Chomsky and Halle (1968), the underlying form of *Canada* is [kænædə]. The first [æ] shows up in *Canada*. The second [æ] shows up as [ei] in *Canadian*, after other rules that need not concern us. Now let us consider how [kænædə] can be syllabified, before stress is assigned. Some options are shown in (26).

- (26) Possible syllabifications of *Canada* [kænædə]

Method	Syllables	LOF	Stress
Max Onset	[kæ][næ][də]	**	
Max Coda	[kæn][æd][ə]		*
Max First Coda	[kæn][æ][də]	*	

If we syllabify according to Max Onset, the LOF is violated by the first two syllables. If we syllabify according to Max Coda, the LOF is satisfied, but the second syllable causes a problem for stress assignment: It is H yet it does not attract stress. If we maximize the coda of the first syllable only (and maximize the onset of other syllables), the second syllable still violates the LOF. In summary, given Chomsky and Halle's analysis of underlying forms, if syllabification precedes stress assignment, there is no way to satisfy the LOF, without causing problems for stress assignment.

A solution is available if we give up the assumption that syllabification precedes stress assignment and assume instead that they can be evaluated simultaneously. The solution is made possible in a constraint-based analysis (Prince and Smolensky 1993). For illustration, consider the analysis of the string CVCVCV, which represents words like *Canada*, *banana*; *Sicily*, *committee*, etc. Assuming the constraints discussed earlier, possible syllabifications and foot structures of this string are shown in (27), where Main refers to the requirement for main stress to fall on a syllabic foot.

(27) Possible analyses of CVCVCV: many good solutions and many bad ones

CVCVCV		FtBin	WSP	RMO	Parse2	Main
[CVC][ə][Cə]	(HL)L	✓	✓	✓	✓	✓
[Cə][CVC][ə]	L(HL)	✓	✓	✓	✓	✓
[CVC][ə][Cə]	(mm)LL	✓	✓	✓	*	*
*[Cə][CV][Cə]	L(LL)	✓	*	✓	✓	✓
*[CV][Cə][Cə]	(LL)L	✓	*	✓	✓	✓
*[CV][Cə][Cə]	(L)LL	*	*	✓	*	*

Of the six options shown, only two satisfy all the constraints, represented by *Canada* for (HL)L and *banana* for L(HL). The other four analyses violate one or more of the constraints. It is worth noting that it is of little consequence for the present analysis whether *Canada* has an underlying form [kænədə], as proposed by Chomsky and Halle (1968), or whether it is simply [kænədə], as proposed by Burzio (1996). Similarly, let us consider another string CVCCVV, shown in (28), where VV is a long vowel or diphthong.

(28) Possible analyses of CVCCVV: many good solutions and many bad ones

CVCCVV		FtBin	WSP	RMO	Parse2	Main
[CVC][CVV]	(HH)	✓	✓	✓	✓	✓
[Cə][CCVV]Ø	L(HL)	✓	✓	✓	✓	✓
[CVC][CVV]Ø	(mm)(HL)	✓	✓	✓	✓	✓
*[CVC][CVV]	(mm)(mm)	✓	✓	✓	*	*
*[CVCC][VV]	(HH)	✓	✓	*	✓	✓
*[CV][CCVV]	(LH)	✓	*	*	✓	*
*[Cə][CCVV]	L(mm)	✓	✓	✓	✓	*
*[CVC][CVV]Ø	H(HL)	✓	*	*	✓	✓
*[CVCC][VV]Ø	(mm)(HL)	✓	✓	*	✓	✓

Of the various options, just three are good, (HH) as in *disco*, L(HL) as in *supply*, and (mm)(HL) as in *Bantu*. Let us consider why other options are not possible.

For *disco*, the foot structure cannot be (mm)(mm), because (i) the two syllables have not formed a syllabic feet, hence violating Parse2 at the syllable level, and (ii) main stress is not in a syllabic foot, violating Main Stress. The foot cannot be (LH) either, because the first syllable has stress, yet it is L, hence violating the WSP. The syllable structure cannot be [CV][CCVV] [di][skou], which violates RMO, because no word ends in a stressed [i]. The syllable structure cannot be [CVCC][VV] [disk][ou], which violates RMO, because there is no reason for [k] to be in the coda of the first syllable, rather than in the onset of the second.

For *supply*, the foot structure cannot be L(mm), because (i) there are two free syllables, violating Parse2, and (ii) the main stress is not in a syllabic foot, violating Main Stress. The syllable structure cannot be [CVC][CVV] [səp][lai] either, because (i) the first syllable is H but has no stress, violating the WSP, and (ii) there is no reason for [p] to be in the first syllable, a violation of RMO.

Finally, in *Bantu*, the syllable structure cannot be [CVCC][ VV] [bænt][u:], which violates RMO, because there is no reason to include [t] in the first syllable. In addition, the stress pattern cannot be H(HL), where the initial H has no stress, violating WSP.

We have seen then that syllabification, foot structure, and stress can be evaluated simultaneously. In addition, in a non-deterministic approach, there are many ways to be well formed (i.e. to satisfy the constraints of grammar), while there are many ways to be ill formed as well (i.e. to violate one or more constraints). Therefore, the proposed analysis has explicit predicative power.

## 5. Conclusions

I have shown that Max Onset, a widely used rule for syllabification, satisfies the Law of Initials (LOI) but violates the Law of Finals (LOF). In contrast, the Revised Max Onset (RMO) satisfies both. In addition, Max Onset creates stressed light syllables and violates the Weight-Stress Principle (WSP), whereas RMO does not.

I have shown, too, that Max Onset is the only option in a derivational approach to phonology (e.g. Halle and Vergnaud 1987), where a word undergoes a set of ordered rules, first those for syllabification and then those for stress assignment. In contrast, in a constraint-based approach to phonology, where syllabification and stress assignment are evaluated simultaneously, RMO becomes possible.

I have also compared two approaches to stress assignment. In the deterministic approach (e.g. Halle and Vergnaud 1987; Hayes 1995; Hammond 1999), some words are thought to be regular and others exceptional. In contrast, in the non-deterministic approach, all words are regular and no word is exceptional. The non-deterministic approach is achieved by keeping the constraints that are observable by all words, and leaving out the constraints that are violated by 'exceptional' words. For example, in the deterministic approach, there is a requirement to skip the final syllable, which is observed by *Canada* but violated by *banana*. In the non-deterministic approach, there is no such requirement, and a word can choose to skip the final syllable, as *Canada* does, or not to, as *banana* does. Both approaches agree that English word stress is not completely predictable and lexical markings are required. In the deterministic approach, the markings indicate which words are regular and which exceptional. In the non-deterministic approach, the markings indicate which way a word chooses to satisfy the constraints.

The present analysis shows that some phonological constraints are much stronger than previously thought. For example, RMO ensures that every stressed syllable is heavy, which supports the second part of the WSP, i.e. not only must heavy syllables be stressed (a point Prince 1992 argues for), but light syllables must be unstressed (a point Prince 1992 believes to be frequently violated). Similarly, in the deterministic approach, where the final syllable is skipped, *Canada* has a binary foot, but *banana* does not. In the present approach, both *Canada* and *banana* have a binary foot, so do all other words. Thus, contrary to a central claim in Optimality Theory that all constraints are in principle violable (Prince and Smolensky 1993), some constraints seem much less so, if at all.

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