Foot structure enables strict locality in phonological processes

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Introduction: This paper provides support for the existence of metrical foot structure (Liberman and Prince 1977, Halle and Vergnaud 1987, Hayes 1995) from a two perspectives. First, using the measure of function complexity provided by Formal Language Theory (FLT), it is shown that foot parsing is a computational aid for segmental alternation processes that otherwise would depend on an overt even/odd syllable count. Specifically, input-output maps that are properly *subsequential* (Mohri 1997) – and thus more complex – when foot structure is not present are rendered *input strictly local* (ISL; Chandlee 2014) when foot structure is present. Creation of foot structure itself is *output strictly local* (OSL; Chandlee and Heinz 2018). While ISL and OSL functions are formally local, the more complex properly subsequential functions are not, and so foot structure preserves a formal notion of locality that is lost in its absence. Second, further evidence comes from patterns where feet are not only a computational aid, but *necessary* to derive the correct output. Despite the assertion of Bennett (2013) that metrical structure is justified only by the unique properties of stress, this evidence does not come from stress, but rather from patterns where a segmental alternation occurs *outside* of a foot, and is not explainable by other reasonable means. One example of this comes from deletion of coda glottal stops in Capanahua (Loos 1969), which applies foot-externally to syllables it would not normally apply to foot-internally. Without parsing of Capanahua words into feet, this process has no explanation. Thus, syllables that are not parsed to feet provide direct evidence for their existence.

Background: One relevant class of functions is the subsequential class, which has well-understood automata-theoretic properties and is relevant to phonology (Jardine 2016, Payne 2017). Roughly, these can express long-distance generalizations, such as vowel harmony with transparent segments (Heinz and Lai 2013). Other relevant classes are the ISL (Chandlee 2014) and OSL (Chandlee and Heinz 2018) classes, which capture a notion of locality in the input (for ISL) and output (for OSL), and are formally less complex than the subsequential class. Intuitively, the output of an ISL function depends entirely on some finite number of previous input symbols. A wide range of common phonological processes are ISL, such as deletion and epenthesis. Similarly, the output of an OSL function depends on the previous output symbols. Processes that apply iteratively, such as rhythmic application of stress, are in general OSL (Dolatian et al. 2021).

Feet and computation: Feet are a computational aid in the placement of stress and other phonological processes. Consider the following input-output pairs, one footed and one unfooted:

(1) a. $\sigma\sigma\sigma\sigma\sigma\sigma \mapsto \acute{\sigma}\sigma\acute{\sigma}\sigma\acute{\sigma}\sigma$ b. $(\sigma\sigma)(\sigma\sigma)(\sigma\sigma) \mapsto (\acute{\sigma}\sigma)(\acute{\sigma}\sigma)(\acute{\sigma}\sigma)$

A stress pattern such as this one that iterates stress to every other syllable starting with the first can be found in Murinbata (Street and Mollinjin 1981). In (1a), no foot structure is present in the input. This means that iterative placement of stress has no input structure to rely on – it must be defined recursively with reference to the output string itself i.e., place an additional stress if a stress is present two syllables away in the *output*, making it OSL. In (1b), foot structure is now present in the input, and so no reference to the output is required. Thus, feet give the string structure that an ISL function can use to place stress by referring to foot boundaries.

One caveat is that creation of feet is itself an iterative OSL process, proceeding in the same way as placement of stress in (1a), i.e. further foot boundaries are inserted depending on the location of the previous foot boundary in the output. So, whether the derivation employs iteratively created feet, or stress is placed iteratively by itself, the total map in each case is subject to output locality.

However, there are cases where the presence or lack of foot structure has measurable implications for locality and the complexity of the function that computes the process. One example comes from the alternation of the nominal plural suffix in Urarina (Olawsky 2006, Gonzalez 2011). When the suffix is preceded by an odd number of moras, it surfaces as [kʉ.rʉ]. After an even number of mora, it surfaces as [ʉ.rʉ] instead, with no onset /k/. Consider the following forms, where an unfooted example is shown above and a footed example below (suffix underlined for clarity):

(2) odd: le.ra.no.-kʉ́.rʉ 'macana (fish-PL)' even: ka.tʃa.-ʉ́.rʉ 'man-PL'
(le.ra.)(no.-kʉ́.)rʉ (ka.tʃa.)(-ʉ́.rʉ)

As in (1), when foot structure is present, the alternation can be determined with reference to the input alone. When the first syllable of the suffix is adjacent to a right foot boundary, select the [kʉ.rʉ] variant. When adjacent to a left foot boundary, select [ʉ.rʉ]. However, when there is no foot structure, there is nothing input *or* output local (with no reported iterative stress) to help decide which allomorph is appropriate. Instead, the process must rely on an explicit even/odd count of the entire word up to the suffix, which requires a more complex properly subsequential function to compute. Intuitively, this is because parity is a "meta-property" of the word, and has nothing to do with what symbols are found in the input or output. This demonstrates that, by parsing the word into binary constituents, feet provide a pseudo-parity count in a way that is fundamentally local. Feet enable the kind of "counting" that is observed in phonology and obviate the need for explicit parity counting, which – as Parker (1998) argues – is ad hoc and unnecessary in phonology.

Feet are necessary: In addition to evidence from complexity, there are also cases where foot structure appears necessary – not just preferable – to capture the attested pattern. One example comes from Capanahua (Loos 1969, Elias-Ulloa 2006). In Capanahua, a coda glottal stop is deleted if it occurs in an even-numbered syllable:

(3) a. (tʃáʔ.tʃi.)-kin 'to poke (him)' b. (pí.-tʃa.)(tʃi.-kin) 'to poke (him) in the ribs'

In (3a), the first syllable of the root meaning "to poke" occurs in an odd syllable, and the glottal coda surfaces. When the prefix meaning "ribs" is attached (3b), the root begins in the second syllable of the word, and so the coda is deleted. Crucially, this alternation also occurs in syllables that are unfooted – even if they are in an odd-numbered syllable, where deletion is unexpected:

(4) a. (túʔ.ku.)(-taʔ.-ki) 'it is a frog' b. (hú.ni)-ta 'the man'

In (4a), the evidential suffix is in an odd syllable and so surfaces with its coda. However, the coda is deleted in (4b), even though it is occurs in an odd syllable. Thus, overt parity counting could not properly express the generalization – reference to foot structure is necessary to derive the correct output form. It is unlikely that this is caused by a word-final effect, as monosyllabic words surface with their glottal coda: [raʔ] 'maybe, probably'; [tsoʔ] 'admonishment' (Loos and Loos 1998).

Conclusion: In sum, persuasive evidence for the existence of metrical structure comes from computation, in addition to the traditional arguments (Hayes (1995) for an overview of some of these). Specifically, feet allow phonological processes that otherwise require parity counting to be analyzed locally. Further evidence for feet comes from cases in which the input-output map crucially depends on them. Though the claim of Bennett (2013) that the foot is not just a rhythm counter is well-supported, patterns like Urarina, Capanahua, and many others (see Gonzalez 2018) suggest that this *is* one role that foot structure can play. The assertion that the unique hierarchical properties of stress motivate metrical structure in a way that processes such as deletion or epenthesis do not is reasonable. However, if the existence of metrical structure is justified at all, then it can be referred to elsewhere in the phonology – not just for stress patterns.

Selected references: Chandlee (2014). Strictly local phonological processes. • Gonzalez (2018). A typology of stress and foot-sensitive consonantal phenomena. • Hayes (1995). Metrical stress theory. • Loos and Loos (1998). Diccionario Capanahua-Castellano. • Olawsky (2006). A grammar of Urarina.