Cyclic stress in Chamorro revisited

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The phonological cycle hypothesis proposes that the phonology reapplies successively to each sub-constituent of a word, starting with the smallest morphological constituent (Chomsky, Halle, and Lukoff 1956, Chomsky and Halle 1968, et seq.). Variants on this basic idea have been widely influential in phonological theory, including versions with a Strict Cycle Condition (Kean, 1974; Mascaró, 1976), versions that are stratal rather than cyclic, with only a finite number of levels (Kiparsky, 2000; Bermúdez-Otero, 2011), and recent phase based proposals (Marvin, 2002; Piggott and Newell, 2005). A common theme is that phonology can be sensitive to hierarchical constituent structure inside words. In this squib, we point to evidence that the relevant morphological structure is not constituency.

Cyclic phonological theories predict that interactions at a distance between prefixes and suffixes can be sensitive to their relative height. For example:

(1) **Trigger:** $[_B\ [_A$ Prefix $[\ [\ \cdots\ ]\ ]\ ]_A$ Higher Suffix $]_B$

(2) **Non-trigger:** $[_B\ [_A$ Prefix $[\ [\ \cdots\ ]$ Lower Suffix $]\ ]_A\ ]_B$

Cyclic reapplication predicts possible grammars where a suffix triggers a process affecting a prefix only on cycle B, not on cycle A, thus, only when it is higher. Stress is a domain in which this prediction can be tested, because action at a distance is possible. Stress assignment in Chamorro (Chung 1983) has been described in precisely these terms, apparently requiring direct phonological reference to the morphological scope of suffixes with respect to stressed prefixes. Interestingly, however, Chamorro does not require any phonological *comparison* between prefixes and suffixes. Because of this, it can be described by without referring to actual constituents, and instead only limited, local structural information.

We claim that there is a typological gap: patterns (like Chamorro) that are sensitive to relative structural height of a prefix and a suffix are never sensitive to the phonological content of both, while patterns sensitive to the phonological content of both a prefix and a suffix (illustrated by a pattern from Nez Perce) are never sensitive to their relative height.

In light of this gap, we suggest that phonology does not have access to the full constituent structure of complex words. This gap is predicted if the phonological compotent is limited to finite-state computations, a restriction that is empirically well supported but incompatible with the full power of cyclic theories. We also show that a recent proposal, that phonological processes are limited to subsequential functions (a subset of the finite state computations), is also compatible with the facts, and points to a second typological gap.

1 The stress sytems of Chamorro and Nez Perce

We focus on two stress patterns where prefixes and suffixes interact. In both cases this interaction arises as a result of lexical accent (lexical marking of particular items for stress). The first is Chamorro, analyzed cyclically by Chung (1983). In Chamorro, whether an accented prefix gets primary stress depends on its height relative to any suffixes.

Stress in Chamorro is generally penultimate, but can surface elsewhere in the presence of lexical accent. Certain prefixes are lexically accented, and these attract stress leftwards.[1]

(3)	a.	mantíka	b.	mímantika
		/mantika/		/mí-mantika/
		'fat'		'abounding in fat'

This stress attraction is disrupted, however, by any suffix that is structurally higher than the marked prefix: in such cases, stress is again penultimate.

(4)	a.	mimantikáña	b.	ákwentusi
		[[mí mantika] ña]		[á [kwentus i]]
		'more abounding in fat'		'to speak to one another'

This pattern obviously suggests that the phonology is sensitive to morphological information. Chung suggests that this sensitivity is due to the phonological cycle: stress is recalculated with the addition of each affix: only when a prefix is higher than any suffix can its accent escape re-assertion of the regular penultimate stress pattern.[2]

Notice, however, that Chamorro stress does not require any direct comparison between lexically accented prefixes and the suffixes that outscope them: the phonology needs to know that some suffix outscopes an accented prefix, not which suffix does so.

By contrast, stress in Nez Perce is sensitive to the phonological properties of both prefixes and suffixes, but is insensitive to their relative scope. As in Chamorro, stress in Nez Perce is generally penultimate, but can be attracted by lexically accented morphemes, including prefixes. Default penultimate stress is illustrated in (5):[3]

(5)	a.	pískis	b.	pìskísne	c.	hàníisa	d.	hànisáaqa
		/piskis/		/piskis-ne/		/hanii-see/		/hanii-seeqa/
		door		door-obj		make-incomplete		make-recent

Both roots and affixes can bear lexical accent. When multiple accents occur in a word, the default pattern is for the rightmost non-final accent to surface with primary stress.

[1] All Chamorro generalizations and examples are drawn from Chung 1983.

[2] Chung's data indicates that existing stresses are demoted to secondary. This does not affect our argument, and so we will leave secondary stresses out.

[3] All Nez Perce generalizations and examples are drawn from Crook 1999.

(6) pàaynóosàqa
/páay-núu-seeqa/
arrive-toward-recent

There is a subpattern for verbal prefixes with lexical accent, where stress appears on the leftmost lexically accented prefix (in the absence of any accented suffix).[4]

(7) a. cúukwece
/cúukwe-cee/
know-incomplete
'I know'

b. néesepèsilèwcùkwece
/nées-sepée-siléew-cúukwe-cee/
pl.obj-caus-by.seeing-know-incomplete
'I make you know by seeing'

Lexically accented suffixes disrupt this leftwards stress shift, but do *not* need to scope higher to do so. In the examples below, the accented directional suffix *(n)úu* 'toward' transitivizes an intransitive root. It thus takes semantic (and, we assume, morphosyntactic) scope below both the causative prefix *sepée* and the plural object agreement prefix *nées*. Though these prefixes consistently attract stress away from accented roots, as seen in (7), the accented suffix retains stress in the examples in (8).[5]

(8) a. hìnàspàynóosa
/hii-nées-páay-núu-see/
3-plob-arrive-toward-inc
'He arrives to them'

b. hìnàsàpapàynóoca
/hii-nées-sepée-páay-núu-cee/
3-plob-caus-arrive-toward-inc
'He makes them arrive to him'

What is important about these cases is that the suffix that attracts stress rightwards is hierarchically "inside" the accented prefix. This suggests that the pattern is not sensitive to the relative scope of the prefix and suffix. The bracketing is illustrated in (9).

(9) a. [nées [sepée [páay núu]]]
b. not *[[nées [sepée [páay]]] núu]

In Nez Perce, accented prefixes compete with accented suffixes: the rule is that (non-final) suffixes win. The suffix need not be higher than the prefix. The pattern is not sensitive to relative height, but it is sensitive to the phonological content of both (lexical accent).[6]

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[4]Nez Perce nouns show a different pattern: in the absence of any lexical accent, stress on nouns is required to surface on the noun root, even if that results in stress to the left of the penultimate syllable.

[5]See Crook (1999) for evidence that this stress shift does not occur with unaccented suffixes. That the directional suffix is below the scope of the plural object marker is also illustrated by the fact that the addition of *(n)úu* changes which argument is identified as plural (see Crook 1999, p. 480).

[6]As far as we know, there are no accented suffixes in Nez Perce that structurally "outscope" an accented prefix, and so we cannot show any case in which the winning suffix is structurally higher than the prefix. This leaves the pattern open to an alternate, structure-sensitive analysis, in which accented suffixes get stress only when they are structurally *lower* than an accented prefix. This is an implausible generalization under a cyclic theory, but would be a counterexample to the typological generalization we introduce below.

2 A typological gap: simultaneous height and content

We know of no stress sytem that combines the morphological sensitivities of Chamorro and Nez Perce. We propose that this is a principled gap, and that it is impossible for a language to compare the relative height of prefixes and suffixes while also comparing phonological properties of those affixes. This means there can be no stress pattern like (10).

(10) *Winner by Height, If Special:*
  a. [ti [[[tú be] tá] to]] $\rightarrow$ titubetáto
  b. [ti [[rú [be tá]] to]] $\rightarrow$ tirúbetato
  c. [ti [[[tú be] sa] to]] $\rightarrow$ titúbesato

In the *Winner by Height, If Special* (WHIS) pattern, two lexical accents compete to bear primary stress, one on a prefix, and the other on a suffix. As in Nez Perce, if one of the two is not lexically accented, then the other will win. As in Chamorro, the winner is the one that is structurally outermost (unlike in Chamorro, only when both are accented).

WHIS is a prediction of the phonological cycle, and its apparent nonexistence is therefore significant. In what follows, we suggest that the nonexistence of WHIS lends support to proposals that phonology is limited to (a subset of) finite-state computations.

3 Phonology is finite-state

In contrast to syntax, which in the earliest days of generative grammar was shown to go beyond finite state computations (Chomsky 1957, et seq.), phonological patterns do not show any evidence of going beyond finite state power. All the phonological theories on the market give grammars that can be translated into finite state devices, once we restrict our attention to the parts of the theories that actually get used (Johnson 1972, Kaplan and Kay 1994, Frank and Satta 1998, Graf 2010). This difference has been used to argue that phonology and syntax are distinct modules (Heinz and Idsardi 2011, Berwick et al. 2011).

A finite state automaton reads a string and uses its contents to determine a path through a finite number of states. When the end of the string is reached, it halts and either accepts the string, if it is in one of a special set of accepting states, or rejects it if not. These devices define sets of strings (they compute the characteristic function of certain sets).

Chomsky's argument against finite state syntactic theories was that they would fail to generate unbounded center embeddings in relative clauses: *the man* [*the dog bit*] *ran*, *the man* [*the dog* [*the cat was afraid of*] *bit*] *ran*, … . One way to see this pattern is that, for any surface string with this kind of embedding, the number of verbs must always be exactly equal to the number of subjects. That finite state computations could never compute these sets drastically reduces the space of possible theories of syntax, regardless of what kinds of structures those theories assign to these sentences, and regardless of their meaning.

In phonology we are interested in mappings from possible underlying forms, including relevant morphological information, to surface strings (by "mapping" we mean an entire set of legitimate pairs, not just one). The theory of phonology should predict which mappings have possible grammars (computations), and which do not.

One way to use finite state automata to deal with mappings is to see pairs of strings, as in (11a), as strings of pairs, as in (11b). This enrichment is necessary in order to move from computations that just deal with surface properties, like “stress the penultimate vowel,” to ones that deal with underlying properties as well, like “stress the first lexical accent.” To encode morphological information, we can add elements to the string that will eventually get deleted, for example open and close brackets (the [and] symbols), as in (11c).

(11) a. sśśs → s**ś**ss, śśśs → **ś**sss, …

b. $\begin{array}{c|c|c|c} s & \acute{s} & \acute{s} & s \\ s & \mathbf{\acute{s}} & s & s \end{array}, \begin{array}{c|c|c|c} \acute{s} & \acute{s} & \acute{s} & s \\ \mathbf{\acute{s}} & s & s & s \end{array}, \ldots$

c. $\begin{array}{c|c|c} \acute{s} & \acute{s} & s \\ s & \mathbf{\acute{s}} & s \end{array}, \begin{array}{c|c|c|c|c|c} \acute{s} & [& \acute{s} & \acute{s} & s &] \\ \mathbf{\acute{s}} & & s & s & s & \end{array}, \ldots$

A finite state automaton licensing strings of pairs is called a finite state transducer, and is subject to the same limitations. Just as it is impossible for a finite state automaton to match subjects to verbs, or count them, it is impossible for a finite state transducer to make sure there are as many [symbols as] symbols in the input. Another way of looking at the limitation, rather than in terms of counting, is to think about the material between matched [and] symbols. The limitation, from that perspective, is finding arbitrary constituents.

For example, a finite state function could never insert k instances of a syllable, where k is the level of nesting. A finite state function could also never change [t] to [s] whenever a higher constituent contained [i]—the dependency between the underlying–surface pair (t → s) and [i] could be, for example, between a prefix and a suffix. Computing this function requires identifying the constituent containing [t].

(12) $\begin{array}{c|c|c|c|c|c|c|c} [& t & a & [& t & i &] &] \\ & t & a & & t & i & & \end{array}, \begin{array}{c|c|c|c|c|c|c|c} [& [& t & a &] & t & i &] \\ & & s & a & & t & i & \end{array}, \begin{array}{c|c|c|c|c|c|c|c|c|c|c|c} [& [& t & a & [& t & i &] &] & t & u &] \\ & & t & a & & t & i & & & t & u & \end{array}$

WHIS, rather than changing [t] to [s] whenever a higher constituent contains [i], makes an underlying accent unstressed or secondary stress whenever a higher constituent contains an underlying accent. In the next section, we give a more detailed informal proof that WHIS is not finite state, and suggest that this accounts for the fact that WHIS is unattested.

4 WHIS is not finite-state

In proving that a computation is not finite-state, the key is to think of the input string as two parts, w followed by v. Whether wv is accepted or rejected depends on what state the hypothetical automaton ends in, which in turn depends on what state it is in after reading w, what state it then goes to after reading v, and nothing else. There are infinitely many different possible values of w, but, since there are only finitely many states, eventually, the computation must loop back on itself, going back into a previous state.

One way of proving that a computation is not finite state is to reason about v as a function of w. The Myhill–Nerode Theorem (Nerode 1958) states that, given an arbitrary string w, and the set of acceptable strings L according to a finite-state computation, w falls into one of a finite set of equivalence classes, defined by what strings v make $wv \in L$.

For example, suppose a computation accepts all strings of zero or more a's and b's where all the b's must follow all the a's: ab, $aaab$, $abbb$, aa, bbb, … (a^*b^*). This gives three equivalence classes. If w is all a's, it can be extended by v consisting of zero or more a's followed by zero or more b's. All $w \in a^*$ are equivalent in that they are extendable by $v \in a^*b^*$. If w is a sequence of a's followed by one or more b's, it is extendable by v having zero or more b's. All $w \in a^*bb^*$ are extendable by $v \in b^*$. Finally, any other w is not extendable in L. The set of extensions for $w \notin a^* \cup a^*bb^*$ is $\{\}$. These three disjoint sets of possible w make up the whole set of possible strings, thus, the computation is finite state.

In contrast, consider the computation accepting only matched pairs (ab, $aabb$, $aaabbb$, …). The possible extensions of $w = aa$ are $v = bb$, $abbb$, $aabbbb$, …. Not one of these is a possible extension of $w = a$, or $w = aaa$, or $w = aaaa$, or anything else. The total number of a and b must always be equal, and so each w defines its own unique class of extensions. There are infinitely many possible w's, thus this computation is not finite state.

When the symbols are pairs, the problem is the same. We factor out the question of whether the brackets are properly matched in the input: we assume the morphosyntax yields only licit structures. The question is, instead, whether there is any computation which will give the right pattern, *when* its input is restricted to only legitimate morphological structures.

In the case of WHIS, we can reduce the problem to the distribution of one pair, (Ṕ→**Ṕ**): accent realized as surface stress in a prefix. WHIS is the pattern where (Ṕ→**Ṕ**) is possible only if there is no higher accented suffix Ś; otherwise we only get (Ṕ→P).[7]

Consider w with an accented prefix realized as stressed, two nodes higher than the root:

(13) $\ldots$ (Ṕ → **Ṕ**) $\ldots$ [$\ldots$ [$\sqrt{\text{Root}}$

An extension containing Ś→S will only be legitimate if Ś is lower than Ṕ. That means that any v of the following form will be a valid extension:

(14) $\ldots$] $\ldots$ (Ś → S) $\ldots$] $\ldots$, with no following Ś→S or Ś→**Ś**

On the other hand, a v of the following form will never be a valid extension:

(15) $\ldots$] $\ldots$] $\ldots$ (Ś → S) $\ldots$

Now consider a w with the prefix one node higher than in (13):

(16) $\ldots$ (Ṕ → **Ṕ**) $\ldots$ [$\ldots$ [$\ldots$ [$\sqrt{\text{Root}}$

Now, an extension of the form (15) will always be valid. Thus the set of valid extensions is different. It is easy to show that it is different at each level we put P at. Thus the computation is not finite state. Thus, if WHIS existed, phonology could not be finite state.

The problem is not solved by the fact that proper bracketing is the domain of the morphology. This would only be a solution if the morphology could filter out the extensions that distinguish the different classes of w, so that the phonological computation would not have

[7] Similarly, (Ś→**Ś**) is only possible if there is no higher Ṕ, and, otherwise, we can only get (Ś→S); but the dependency of the prefix on the suffix turns out to be enough.

to deal with classifying them. We will see an example of this when we look at Chamorro. However, as far as the morphology is concerned, (15) is a legitimate extension of both (13) and (16); it is up to the phonology to decide which to accept.

5 Chamorro is finite-state

Chamorro is not WHIS. The crucial idea is that, if it is only the presence or absence of a higher suffix that matters to whether we get (Ṕ→**Ṕ**) or (Ṕ→P), then it does not matter what becomes of the bracketing to the right of Ṕ. For this to be true, we need two further assumptions. The first is binary branching. The second is that only non-null morphemes introduce brackets that will be passed on to the phonology, so that no vacuous cycles are seen by the phonology.[8] Given these two assumptions, when there is an overt suffix structurally higher than (Ṕ→P), we will find the sequence [[somewhere to its left: binary branching guarantees that any higher suffix will generate such a sequence, and the lack of vacuous structure guarantees that [[is not inserted with an empty prefix. We can construct a finite state machine relying on the fact that the sequence …[[…(Ṕ→**Ṕ**) is always illicit.

6 Phonological processes are subsequential

The finite state property holds of not only individual phonological processes, but entire phonological grammars. Tighter restrictions have been discovered to hold empirically on individual processes. Chandlee and Heinz (2012) proposed that phonological processes belong to a subset of the finite state computations called the subsequential functions.[9]

Subsequential functions are the functions that can be computed by subsequential transducers (the left subsequential functions), plus the functions that can be computed by reversing the string and then applying a subsequential transducer (the right subsequential functions). The details of subsequential transducers are not relevant here; the idea is that they cannot use arbitrary lookahead to see whether a particular change (a→b) is licensed.

Here is a pattern which is finite state, but not subsequential: given an accented prefix and an accented suffix, the prefix is stressed if it is higher, *or* if the suffix is not rightmost.

(17) *Gentler Winner-by-Height-If-Special:*
   a. [tú [be tá]] → túbeta
   b. [[tú be] tá] → tubetá
   c. [ti [[tú [be tá]] to]] → titúbetato

[8] We know of no phonological patterns that require sensitivity to phonologically vacuous morphological cycles. Morphological alternations, by contrast, might be, as in Pinker (1999)'s proposal that the difference in the English past tense between [flajd] (regular, as in baseball "flyed out") and [flu] (irregular) arises due to [flayd] containing an extra layer of vacuous structure (i.e. a reverbalized nominalization). Under no standard analysis, however, is this alternation purely phonological. It is universally attributed instead to morphological properties of the two environments: either separate lexical entries, as in lexicalist approaches, or in locality constraints on root-triggered "Readjustment Rules" in a theory like Distrubuted Morphology. True counterexamples would be any cases of derived environment effects triggered by empty cycles (and not merely by vacuous application of a rule—though these cases do not seem to exist either: see Wolf 2008).

[9] See also Heinz and Lai 2013, Chandlee 2014. For details on subsequential functions and transducers, see Schützenberger 1977, Mohri 1997.

d. [ti [[[tú be] tá] to]] → titúbetato

Gentler Winner-by-Height-If-Special (G-WHIS) is sensitive to relative scope, but it is finite state.[10] As in Chamorro, we can check if an accented prefix has a pair of empty brackets to its left to determine if it there is a higher suffix. We also check to see if the rightmost suffix is accented. As the composition of any two finite state transducers is finite state, we compose the two and get a finite state transducer for G-WHIS.

On the other hand, G-WHIS is neither left subsequential nor right subsequential. To show that a function is not left subsequential, one needs to show that the condition for a non-faithful input–output pair, (a change), includes some *finitely close* element on the right (or that it is only triggered on the left). Once a hypothetical left subsequential transducer for G-WHIS reached [[, it would be unable to determine whether to license a (Ṕ→**Ṕ**) or a (Ṕ→P) until it reached the last suffix, arbitrarily far away. Thus G-WHIS is not left subsequential. It is also not right subsequential, because the computation over the reversal is not left subsequential. Consider the string in reverse: an initial (originally final) Ś will be realized as (Ś→**Ś**) or (Ś→S), depending on whether there is a Ṕ[[some unspecified distance away. Since G-WHIS is neither left nor right subsequential, it is not subsequential.

Chamorro is both left and right subsequential, since only the local environment [[matters to the realization of Ṕ. Nez Perce is not left subsequential, but it is right subsequential (unlike in G-WHIS, Ś does not depend on Ṕ in any way for its realization; the rightmost non word-final accented suffix is always stressed). Both Chamorro and Nez Perce stress placement conform to the generalization that phonological processes are subsequential.

7 Conclusion

Stress assignment in Chamorro looks like it uses the full power of the phonological cycle. If this were the right analysis, determining the boundary between the old domain the new domain would have the net effect of locating where each constituent begins and ends. As we have seen, with the right morphological representation, Chamorro can be analyzed making use of only local information. This is important, because unbounded use of constituency in this way (as predicted by cyclic theories) exceeds the established outer computational limits of phonology. If the WHIS pattern, which would require non finite state computation in phonology, is attested, the generalization that phonology is finite state must be re-evaluated.

The facts we have presented here have nothing to do with serial feeding between cyclic domains, unlike most of the arguments for and against cyclicity. However, the finite state generalization implies that, if cyclic feeding is real, its domains cannot be true constituents.

We have assumed that the Chamorro pattern holds for unboundedly many levels of nesting. Since the prefixes and suffixes in question belong to a closed class, some division into strata could of course be found. That division would need to be evaluated independently. If a stratal theory proved to be tenable in general, the question of unbounded nesting would not arise. A bounded version of WHIS would be finite state, but it would nevertheless be

[10] Notice this is different from Nez Perce. Nez Perce is sensitive to whether the suffix is rightmost, but it is insensitive to the relative scope of prefixes and suffixes.

impossible for the same reason as G-WHIS: it would not be subsequential. In either case, there is a principled reason for both WHIS and G-WHIS to be impossible.

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