Syllable-Based Phonology as Input into the C/D Model: The Case for American English

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SUMMARY: A syllable-based phonological description of a language should represent all the meaningful oppositional patterns within the syllabic domain. Syllable feature underspecification allows for parsimony of description and provides a framework in which to capture dialectal variation of phonetic implementation in natural discourse. Given the entire syllable as the domain, syntagmatic relationships evince rules for co-occurrence among feature sets in onset, coda, nucleus, and any affixes. In English, syllable features demonstrate that the same phoneme in syllable onset and coda functions differently, with constraints restricting tautosyllabic co-occurrence. Moreover, the grammar of English phonology requires a coda feature in every non-reduced syllable.

Key words: syllable-based phonology, syllable features, syntagmatic phonology, English syllable structure, C/D Model, voicing contour principle,

1. Introduction

What do native native speakers of any language (English, Japanese, Spanish, Chinese, etc.) know about the sound patterning of that language? In their language dialect, speakers can usually decide if a particular sound pattern actually occurs within their own lexicon. Moreover, a speaker can generally judge whether a particular sound pattern could occur within the lexicon of their language, even if they do not know that word.

A hypothetical example of a word that does not currently exist in English, but might possibly exist as phonologically well formed, is */skrkt.t/, created by changing the onset place feature of 'strict' (/s//indicates phonemoidal transcription, see Fujimura and Erickson 1996). A naive native speaker of English would probably guess immediately that that sound pattern was impossible in English, but almost certainly could not specify why it was impossible. Trying to understand why */skrkt.t// cannot be an English word, has led to this current research on syllable structure and tautosyllabic phonological constraints. What do young children, as learners of their first language, absorb as the sound patterning rules of their language? How do we "uncover" the rules that we use every time we speak, e.g., */skrkt/ versus 'strict' [skrkt] versus 'squeaked'[skw1Jkt]? When we naturally learn the sound patterns of our first language early in life, we learn to avoid syllables that are not congruent with the phonology of that language. As we become competent speakers, we develop an acute "ear" for what are possible word sounds, licit phonological patterns, versus impossible "words", those patterns that violate the syntagmatic and/or paradigmatic constraints of a given language's phonological system. Our work, as phonologists, is to analyze and make explicit the syntax of phonology, those structured sound patterns that our ears intuitively identify.

2. Voicing Contour Principle

Fujimura (1996) stated, "According to the C/D model, the entire syllable generally cannot contain more than one continuous stretch of voicing. ...more than one island of voicing cannot exist within one syllable; if there is more than one in a continuous time domain, that indicates the existence of more than one syllable. The voicing contour principle, as this may be called, is the most robust and directly observable phonetic contour principle." However this constraint is a phonetic principle and may not reflect a particular language's phonological rules. Nevertheless, this phonetic principle appears to reflect English phonological rules and syllable structure. Accordingly, a word like 'button'
which is sometimes realized phonetically as [bʌŋ], has an obstructant coda for the first syllable, whether this is realized phonetically as the place-specified apical stop, a glottal stop, or something else, and an apical nasal coda for the second syllable. The vowel of the second, reduced syllable may be specified simply as \{vocalic\}. In our view, so-called “syllabic nasals” or “syllabic ‘l’s or ‘r’s” in reduced syllables are the pertinent sonorant feature in coda plus the unspecified vocalic feature.

3. The Syllable as the Minimal Contrastive Unit for Phonology

This paper discusses the minimal forms for words, lexical entries or phrases. For the sake of simplicity, only monosyllabic English words are cited. Syllables are the minimal utterable units of language (Ladefoged 2001, de Saussure 1931) and are the units of concatenation. In our analysis, the syllable is the domain for phonological contrast. Syllables are also the units of organization for phonological patterns, e.g., for language learning of minimal sound patterns, the smallest unit for instruction should be the syllable, not “phoneme.” A syllable-based phonological description of a language should represent all the meaningful oppositional patterns, with minimal redundancy, within the domain of each syllable. Phonetics differs from language to language, dialect to dialect, person to person, in terms of system parameter setting (Fujimura and Williams, 2015). The following diagram illustrates syntagmatic versus paradigmatic syntactic elements (Figure 1):

![Figure 1 Syntagmatic versus paradigmatic syntactic elements. Syntax = together ordering.](image)

Syllable components must include a vocalic nucleus and may include a consonantal onset, coda, and any p-fixes or s-fixes. This 3-component model comprises a syllable nucleus with optional onset and optional coda. Syllable structure is language-dependent, but any syllable must have some minimal vocalic nucleus feature. This may be intuitive for Japanese speakers because Japanese uses kana, a syllabary, with a very few optional coda features, not an alphabet, in addition to kanji.

Syllable features, which phonologically specify individual syllables, phonetically evoke (1) onset consonantal gestures, (2) coda consonantal gestures, (3) vocalic gestures (phonetic status contour) of the syllable, including gestures that are often called glides, and (4) consonantal gestures for syllable affixes, i.e., p-fixes and s-fixes, if any in the language. Under specification, as a general notion for avoiding specification of non-contrastive differences within the syllabic domain, allows for parsimony of description and provides a framework in which to capture **dialectal variation** of phonetic implementation in natural discourse. The superscripts \(^{\text{O}}, \text{C}, \text{P}^{\text{,}}\) etc., indicate that the feature in question is specified for syllable onset, coda, and p-fix components, respectively. Vocalic feature names are distinct from consonantal features and are given for the entire syllable without any syllable component designation. A pair of curly brackets surrounds the unordered set of features specified for each syllable.

4. Syntagmatic Phonology

In syllable-feature based phonology, where the domain is the entire syllable, there are syntagmatic relationships between feature sets in onset, coda, and nucleus, and any affixes. These relationships evisce the rules or constraints for co-occurrence of features within a syllable. Phonological syllabic rules for co-occurrence of features between adjacent syllables also exist, and although they have yet to be verified for specific languages, we are in the process of mapping rules for English polysyllabic words.

For American English, the set of tautosyllabic features for each syllable component is organized paradigmatically in this analysis as follows (Table 1):

In English, syllable onset features are optional, as are s-fixes. However, at least one feature must be specified for the syllable nucleus. Also all stressed syllables must have at least one coda feature, but in reduced syllables, syllable coda features are optional. There appears to be a limit on the total number of features that may be specified for any given English syllable. If there
are many onset features specified, then there tends to be fewer coda features and vice versa. Monosyllabic English words may have the maximum number of total syllable features specified, as opposed to any syllable in a polysyllabic English word. S-fixes may only occur in word-final syllable position, which by default includes monosyllabic words. S-fix and nucleus features do not appear to interact with this onset-coda maximum feature relationship. An example of a word that has features specified for every syllable component in English is ‘sixths’:

{fricative⁰, apical⁰, stop⁰, dorsal⁰, fricative⁵-¹, interdental⁵-², fricative⁵-³, close, front},
while ‘twelfths’ has obstruct and sonorant features in both onset and coda:

{stop⁰, apical⁰, labialized⁰, fricative⁰, labial⁰, lateral⁰, interdental⁵-¹, fricative⁵-², front}.

Both words have the maximum of 9 syllable features specified for an English syllable.

The issue of which features may co-occur within a syllable is a syntagmatic component of the grammar of the sound patterning of a particular language, i.e., its phonology. This feature system may include non-segmental syllabic or lexical features, such as tone, pitch accent, orality, etc., as syllabic or concatenatory features in various languages. This concept distinguishes the syllable feature approach from phonemes, which do not evince a syntagmatic structure other than concatenation and coarticulation—phonotactics. These co-occurrence patterns need to be understood in order to capture the sound patterning of a language, and young children learn these rules when acquiring their first language.

Accidental holes in the paradigmatic framework of syllables differ from syntagmatic constraints. If we have a syntagmatic consonantal framework of \{labial⁰, stop⁰, voice⁰, apical⁰, stop⁰\}, with differing vocalic features \{close, front\}, \{front\}, \{open\}, \{vocalic\}, and \{back\}, as in ‘bit’, ‘bet’, ‘bat’, ‘but’, ‘bought’, but no *[but], \{labial⁰, stop⁰, voice⁰, apical⁰, stop⁰, close, back\}, that omission is accidental, not syntagmatic, given that a similar syllable does occur with the nucleus feature \{back\}, as in ‘put’, without the onset feature \{voice⁰\}, and ‘book’, with the coda place feature \{dorsal⁰\}, in place of \{apical⁰\}.

Conversely, that there is ‘spit’ and ‘spic’, but no *‘spip’, is not an accidental hole in the paradigm. Rather, it is a syntagmatic constraint, as is *(skik,’ where ‘skip’ and ‘skit’ are well formed, because the onset feature \{spirantized⁰\} cannot co-occur with the same place feature in tautosyllabic coda without the addition of another coda manner feature (exceptions ‘stat’ and ‘stet’ noted below). Although ‘skip’ and ‘skit’ are well formed, *(skik’ cannot occur as an English syllable. But in addition to ‘kick’, ‘skin’, and ‘kink’, ‘skink’ can occur because the concurrent coda manner feature \{nasal⁰\} is added.

In phonology we need to distinguish probabilistic or heuristic constraints (statistical tendency) from phonological constraints. For example, ‘flail’ or ‘fall’ \{fricative⁰, liquid⁰\} occurs in English syllable onsets, but not *(vail’, nor *(vail’ \{fricative⁰, voice⁰, liquid⁰\} because this is a phonological constraint in English onsets, but not, for example, in Slavic or French onsets. However, \{fricative⁰, voice⁰, lateral⁰\} is not constrained in English syllable coda, e.g., ‘solve,’ while \{fricative⁰, voice⁰, rhotic⁰\} is probabilistically constrained in English coda, e.g., ‘dwarves’, \{voice⁰\} concomitant with \{fricative⁰-¹\} of the plural form of ‘dwarf.’

We also need to recognize that some phonological patterns are stratum sensitive. In English, the primary substrates are Anglo-Saxon and Norman French, but there are significant phonological differences with atypical patterns due to words from other substrates. For example, the onset features of ‘sphere’, \{spirantized⁰, fricative⁰\}, only occur in the Greek substrate, while ‘stet’ or ‘stat’, \{spirantized⁰, stop⁰, apical⁰, stop⁰\}, where the same features that co-occur with \{spirantized\} in onset are used without \{spirantized\} in coda, are found only in the Latin substrate. Although the onset features of ‘Gwent’, \{stop⁰, dorsal⁰, voice⁰, labialized⁰\}, occur only in Welsh loanwords, the same onset, minus \{voice⁰\}, i.e., \{stop⁰, dorsal⁰, labial-
5. English Syllable Features

5.1 English Obstruents

Obstruent features combine manner and place feature specifications in onset or coda. The implementation typically involves a severe obstruction of the vocal tract by the crucial articulator. In English, obstruent manner features in onset or coda are: {stop}, {fricative}, {spirantized}, {interdental}, {nasal}, and {glottal} (onset only). Except for {nasal}, which always has the unspecified phonological feature {voice}, and {spirantized} and {glottal}, which do not co-occur with {voice}, the remaining obstruent features, {stop}, {fricative}, and {interdental}, may be specified for {voice}. This feature specification results in the implementation of all gestures in the pertinent and, in the case of coda, adjacent syllable components (including s-fix) within the syllable with vocal fold vibration in typical phonetic situations.

5.2 Place Features

Place, as a phonological feature, is specified at most once in the same syllable component (onset or coda) in English. These place features in onset or coda are: {labial}, {apical}, {coronal}, and {dorsal}. The feature {coronal} combines only with {stop} or {fricative} in English, in contrast with Chomsky and Halle 1968.

5.3 S-Fix and Interdental

In any s-fix, {stop}, {fricative}, {interdental}, or {spirantized} is the only feature specification. The implementation always involves the front part of the tongue (the tip or blade). The manner feature {interdental} is an exceptional feature. It involves no place specification and is always implemented by the tip of the tongue as the crucial articulator, producing acoustic signals more or less like the frication noise produced by nearly the same apical articulator.

5.4 The Feature {glottal}?

The manner feature {glottal} is also exceptional in that its implementation produces a weak frication noise similar to that produced in implementation of {fricative}. This manner feature excludes any concomitant feature specification except a glide feature ({labialized} or {palatalized}), in the same syllable component, and it occurs only in onset. Examples include: {labialized, glottal}, which contrasts minimally in most dialects, e.g., ‘where’, with ‘wear’ and ‘hair’. ‘when’ vs. ‘wen’ or ‘hen’, ‘which’ vs. ‘witch’ or ‘hitch’, ‘whether’ vs. ‘weather’ or ‘heather’, ‘why’ vs. ‘Wye’ or ‘high’, ‘while’ vs. ‘wile’ or ‘hile’, ‘whale’ vs. ‘wail’ or ‘hale’, ‘whence’ vs. ‘wince’* or ‘hence’, etc. *Depending on dialect.

An example of the onset features {palatalized, glottal} is ‘hue’, which contrasts minimally with ‘you’ and ‘who’.

5.5 English Spirantized in Onset and Coda

The so-called consonant sequence /skl/ in ‘sky’ or ‘ask’ is represented completely by our features {spirantized, dorsal}, where {spirantized}, a complex obstruent manner feature (in parallel to {stop}, {fricative}, and {nasal}), is associated with one place feature {labial}, {apical}, or {dorsal}. Oral interrupted spirantized in English occurs in both syllable onset and coda and in syllable s-fix, e.g., ‘taxed’ /tak.st/. Nasal spirantized /sm, sn/, ‘smack’, ‘snack’, and oral continuant spirantized /st/, ‘sphinx’, are restricted to syllable onset. English cognates come in spirantized and prothetic spirantized variants: ‘stop’ vs. ‘estop’, ‘spouse’ vs. ‘Espouse’, ‘special’ vs. ‘especially’, etc., in onset only. French has three variants, ‘étude’, ‘studio’, ‘estudiantine’, etc., also only in onset.

5.6 Tautosyllabic Examples

Onset {spirantized} cannot be combined tautosyllabically with the same place in coda unless there is a concomitant coda feature, except marginally in abbreviated Latin substrate expressions for {apical}, e.g., ‘ster’, ‘stat’. Nasal and fricative spirantized (/sm, /sn/, and /st/), which are limited to onset, follow this constraint as well. The concomitant coda feature may be any {sonorant} feature or {voice}. For example, ‘skag’, ‘skulk’, ‘spoo’, and ‘smaar’ do exist as words despite sharing the same place feature in onset and coda because they have a concomitant coda feature {voice}, {lateral}, {glide}, and {rotated}, respectively, in addition to the place feature associated with the coda obstruent feature.

6. English Syllable Coda Features

Every stressed syllable in English requires a coda element of either robust consonantal features, like
obstruent place and manner specifications, or more
amorphous sonorant consonantal features, like liquids,
Either lateral or rhotic, and glides. English glides con-
 sist of the underspecified coda lengthening feature/\H/,
in addition to the onset and coda glides of palatalized
/\J// or labialized /\W//. While sonorant nasal and glide
features occur in Japanese syllable coda, obstruent and
liquid coda features do not (see Fujimura and Williams
2008 for sokuon) and need special attention from the
Japanese learner of English.

6.1 English Coda Constraints
‘aye’ {palatized[^c], open} may not co-occur with
coda features of coronal stop or coronal fricative or
dorsal voiced stop or dorsal nasal. ‘oy’ {palatalized[^c],
back} may only co-occur with coda features of apical
stop, fricative, or nasal, or coronal. ‘au’ {labialized[^c],
open}, as in ‘bough or ‘ouch’, only co-occurs with apical
stops, fricatives, or nasal, or interdentals, coronal
stops, or lateral in coda. ‘hour’ may be pronounced as
a monosyllable, {labialized[^c], rhotic[^c], open} or as two
syllables, {labialized[^c], open} {rhotic[^c], vocalic}.

Rhotic and lateral may not co-occur with
interdental+voice, coronal fricative+voice, and
dorsal nasal. If {rhotic[^c], lateral[^c]}, the vowel is limited to
{vocalic} or {open}, e.g., ‘earl’, ‘girl’, ‘curl’, ‘merle’,

In coda, nasal does not co-occur with
{labial[^c], voice[^c], stop[^c]}, {dorsal[^c], voice[^c], stop[^c]}, or
{interdental[^c], voice[^c]} or any coronal fricative. If {nasal[^c]}
and obstruent ‘voice co-occur at the end of the word, as
in ‘tens’ or ‘tend’, the fricative or stop feature is s-fix by
rule, i.e., {nasal[^c], fricative[^c]} or {nasal[^c], stop[^c]}. Additionally,
labial nasal co-occurs only with voiceless labial,
e.g., ‘lamp’, and apical nasal co-occurs only with
voiceless apical, as well as either voiceless or voiced
coronal stop. Dorsal nasal only occurs with voiceless
dorsal stop, e.g. ‘think.’

7. Features of the American English Vowel System

The English vowel system is not as complicated as
many describe, if you look at it from a syllabic point
of view. English vowel specifications are limited to
five features, {close, open, front, back, vocalic}, in
this schema. All English vowels are {vocalic}, but the
feature {vocalic} need not be specified for most vowels
because additional features distinguish them. When
{vocalic} is the only feature specified, then it refers to
the vowel quality that is not specified by any additional
feature.

\begin{align*}
   i &= \text{close, front} \quad \text{‘bit’} \\
   e &= \text{front} \quad \text{‘bet’} \\
   \varepsilon &= \text{open} \quad \text{‘bat’} \\
   u &= \text{close, back} \quad \text{‘book’} \\
   o &= \text{back} \quad \text{‘bought’} \\
   V(\lambda/\alpha) &= \text{vocalic}, \text{as in ‘but’ [unreduced vowel]} \\
   &\quad\text{or ‘uh’ or ‘the’ [reduced vowel]} \\
\end{align*}

7.1 Nucleus Features

If your dialect maintains the ‘cot/caught’ distinction,
then the feature {open} is added to distinguish
‘cot’={open, back} from ‘caught’={back}. \( V(\lambda/\alpha) = \text{vocalic} \), as in ‘uh’, is always a reduced vowel. If,
for example, the canonical citation form of 'the' is used, a palatalized glide forms the obligatory coda, phonetically [œj], and the feature specification becomes (interdental<sup>o</sup>, voice<sup>o</sup>, palatalized<sup>c</sup>, front, close). However, the reduced form of 'the', /ðə/, is simply (interdental<sup>o</sup>, voice<sup>o</sup>, vocalic), and it is the most frequently uttered word in English. All English vowels, except schwa (reduced [vocalic]), must have a coda element in one-syllable words or in any stressed syllable of polysyllabic words. The default feature [vocalic] is always underspecified, and it does not need a coda feature in a reduced syllable, but [vocalic]) in a phonologically non-reduced position [œ] requires some coda feature, as in 'but', [bat], [labial<sup>o</sup>, stop<sup>o</sup>, voice<sup>o</sup>, apical<sup>c</sup>, stop<sup>c</sup>, vocalic].

7.2 Vowel Plus Coda Glides

American English vowels plus a coda glide include:

- iJ = (close, front, palatalized<sup>c</sup>) 'bee'
- ej = (front, palatalized<sup>c</sup>) 'bay'
- ahJ = (open, glide<sup>c</sup>) 'spa'/'Bahl'/ 'balmy'
- uW = (close, back, labialized<sup>c</sup>) 'boo'
- oW = (back, labialized<sup>c</sup>) 'beau'
- aW = (open, labialized<sup>c</sup>) 'bough'
- aj = (open, palatalized<sup>c</sup>) 'buy'
- oJ = (back, palatalized<sup>c</sup>) 'boy'

Rhotic coda in American English includes [œR= {vocalic, rhotic<sup>c</sup>}], as in 'burr'], and schwa, [œR= {vocalic, rhotic<sup>c</sup>}], as in the second syllable of 'never' (and never a stressed syllable!).

Onset glides are also consonantal features: 'cute' //kjUWt/; vs. 'coon' //kUWt/ and 'ute' //juWt/; and 'quick' //kwik/; vs. 'kick' //kik/; and 'wick' //wik/; where they occur in syllable onset, rather than syllable coda. The examples 'cute' //kjUWt/ and 'ute' //juWt/ have both onset and coda glides.

7.3 Vowel versus Vowel Plus Glide

This fundamentally 6-vowel system might help Japanese speakers relate to the American English vowel system. It shows how the //a// of 'bat' [æ] open relates to the //aH// of 'bath' (humbug) or 'spa' [œ open, glide<sup>c</sup>]; the //aJ// of 'buy' [open, palatalized<sup>c</sup>]; and the //aw// of 'bough' [open, labialized<sup>c</sup>], in terms of the same vowel plus differing consonantal coda features.

7.4 Syllabic Phonological Framework

This approach to American English vowels must be framed within the whole phonological system: the syllable as the domain, consonantal features in onset, coda, and s-fix, and overall vocalic syllable features.

This 5-feature vowel system only works if you understand that every stressed syllable must have at least one coda feature, either a glide feature (/J, W/), a liquid, a nasal, or an obstruent, e.g.,

- bah!, buy, bough
- bar, ball
- bam!, ban, bang
- bap, blab, bat, bad, back, bag, bath, bathe, baffle/le/
- half, *bav/ have, bass, Baz/ has, bash, batch, badge, asp, bast, bask, etc.

Also, just to make life interesting for ESL students, English allows the same place glide in onset and coda e.g., 'ye' //ijI/ and 'woo' //wuW/. The minimal pair 'yield' and 'eel' differ in the presence or absence of a palatalized glide feature in onset, as does the onset labialized glide in 'woos' versus 'ooze.'

8. English Onset Features

8.1 English Onset Constraints

Only one place specification may occur in onset (or coda). Maximally only one obstruent and one sonorant (liquid or glide) may co-occur in onset, e.g., 'cute', 'quit', 'croup', 'cluck.' Two glides may not co-occur. Complex nasal //sm, sn,/. complex fricative //sf,/. coronal stop //c, y/. voiced apical fricative //zl,/. voiced interdental //b,/. and apical nasal //n/ do not co-occur with any sonorant feature in onset. Labial (voiceless) fricative //fl,/. and labial nasal //m/ only co-occur with {palatalized<sup>o</sup>, close, back} //jw,/. e.g., 'few', 'music.'

Lateral only co-occurs with complex labial //sp,/. labial and dorsal stops //p, b, k, g/; voiceless labial and apical fricatives //f, s//. Rhotic co-occurs with complex stops //sp, sl, sk,/. labial, apical, and dorsal stops //p, b, t, d, k, g/; and voiceless labial, interdental, and coronal fricatives //f, th, sh/. Labialized glide co-occurs with dorsal complex stop //sk,/. apical and dorsal stops //t, d, k /, and voiceless interdental, apical, and dorsal fricatives //f, s, h/. Dorsal voiced stop //g/ marginally co-occurs with labialized glide, but only in Welsh subracte, e.g., 'Guinevere', the Anglo-Norman form of Welsh 'Gwenhwyfar': Palatal glide + //u/ usually co-occurs with labial or dorsal obstruents. It doesn't co-occur with coronal stops and is optional (pronounced with and without palatalization) in apical complex and simplex stops, apical voiceless fricative, and apical nasal.

9. So What?

In English, syllable features demonstrate that the
same “phoneme” in syllable onset and syllable coda functions differently with different rules and constraints. The co-occurrence of onset and coda features tautosyllabically is restricted by multiple rules. These are not probabilistic or heuristic constraints or “holes,” but part of the grammar of English phonology. We need to attend to characteristics of sound patterning, which are largely ignored because they are the default, and try to understand why these patterns are expected within the overall framework of English phonology, in effect, to derive a probabilistic phonological field theory from the information available in the lexicon (Goldsmith 2002).

10. Future Research Questions

We have assigned syllable feature values to almost 12,000 English monosyllabic words, thereby creating a database of about half a million feature-coded cells. What is the optimal way to access, manage, and parse the information in this large database? How can we better understand the global co-occurrence patterns of features, that is, a deep understanding of the “forest ecology”, not simply the individual “trees”? This implies understanding how the normal incidence of “holes”, probabilistic or heuristic constraints, differs from phonological constraints against co-occurrence.

More quantitatively, what can a syllable feature approach contribute to speech technology, especially as an interface between text and speech (Wilhelms-Tricario 2015)? How can we quantify the informational value of phonological features, both tautosyllabically and heterosyllabically within polysyllabic words? Given a limit on the total number of onset and coda features that may be specified for any given English syllable, what is the nature of the posited trading relationship between tautosyllabic onset and coda features? In analyzing polysyllabic words, how do we explain the relationship between the number of features in a syllable, and the total number of syllables in a word?

Lastly, for polysyllabic English words, what are the syntagmatic phonological rules and constraints for the co-occurrence of features between contiguous syllables, including features of heterosyllabic codas, i.e., interactions between coda1 and coda2?

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