Prosody: speech rhythms and melodies

5. Syllables and Prosody Modelling

Dafydd Gibbon

Guangzhou Prosody Lectures, November 2016
Schedule

Week 1:
01 *Forms and functions of prosody: models and methods*
   Nov. 2 (Wednesday) 2:30pm--4:30pm
02 *Forms and functions of prosody: prosodic semantics*
   Nov. 4 (Friday) 10am--12pm

Week 2:
03 *Basics of digital phonetics*
   Nov. 8 (Tuesday) 10am--12pm
04 *Pitch Stylisation: tone and intonation*
   Nov. 8 (Tuesday) 2:30pm--4:30pm

Week 3:
05 *Syllables and Prosody Modelling*
   Nov.15 (Tuesday) 10am--12pm
06 *Speech Timing: durations and rhythm*
   Nov.15 (Tuesday) 2:30pm--4:30pm
Ranks of Grammar and their Interpretations

Multilinear Grammar – Ranks and Interpretations (MLG-RI) Architecture

- **Syntagmatic structures**
  - DIALOGUE
  - TEXT
  - SENTENCE
  - CLAUSE
  - PHRASE
  - INFLECTED WORD
  - COMPOUND WORD
  - DERIVED WORD
  - MORPHEME
  - PHONEME

- **Conceptual-intentional interpretation**
  - dialogue act turns
  - narrative, inference
  - modality, predication, quantification, description
  - iteration, nesting
  - linear morphosyntax
  - iterative word-formation
  - form-meaning atoms
  - coding atoms

- **Multimodal interpretation**
  - Auditory
    - dialogue and text prosody
    - intonation: phrasing, continuation, focus marking
    - phrase tone and accent
    - word formation tone and accent
    - tone and accent distinctive features
  - Visual
    - greeting and turn gestures
    - structure indicating beat, iconic and deictic gestures
    - deictic gestures
    - lexical iconic, metaphoric, nonce gestures
Syllables and Prosody
Syllables

• In this list of prosodic functions
  • Phonemic (tones, pitch accents, stress accents)
  • Morphemic (grammatical morphemes, syncategorematic linking morphemes)
  • Phrasal (intonation, rhythm)
  • Utterance, text (intonation, rhythm)
  • Discourse (turn-taking intonation, rhythm)

  – the unit ‘syllable’ does not appear anywhere
  – yet syllables are the units linked with prosodic forms

• Do we detect some kind of contradiction there?
Attempts at Defining the Syllable
Trying to Define the Syllable

● Intuitively clear by ostensive definition:
  – definition by showing (giving examples)

● Not so clear when looked at in detail
  – some phonological approaches reject the syllable:
    • Generative Phonology, Beats & Bindings Phonology

● Many approximations:
  • Phonetic definitions
  • Phonological definitions
  • Lexical definitions
  • Grammatical definitions
  • Discourse definitions
Trying to Define the Syllable: Sound

• Phonetic definitions
  • Articulatory:
    – segment of speech with an aperture curve: closed (narrow) to wide to closed (narrow) – tongue, jaw, ...
    – segment of speech with an effort curve from low to high to low
  • Acoustic:
    – a segment of speech with an energy curve: low to high to low
  • Perceptual:
    – a segment of speech with a sonority curve from low to high to low

• Phonological definitions
  • the smallest unit of sound structure
  • a vocalic segment preceded and followed by optional consonantal segments
  • the carrier of prosodic forms (TBU, Tone Bearing Unit)
Trying to Define the Syllable: Sound

- **Phonetic definitions**
  - **Articulatory:**
    - segment of speech with an aperture curve: closed (narrow) to wide to closed (narrow)
    - segment of speech with an effort curve: from low to high to low
  - **Acoustic:**
    - a segment of speech with an energy curve: low to high to low
  - **Perceptual:**
    - a segment of speech with a sonority curve from low to high to low

- **Phonological definitions**
  - the smallest unit of sound structure
  - a vocalic segment preceded and followed by optional consonantal segments
  - the carrier of prosodic forms (TBU, Tone Bearing Unit)
Trying to Define the Syllable: Grammar

• Lexical definition
  • the smallest realisation of a lexical morpheme (grammatical morphemes may be non-syllabic)

• Grammatical definition
  • the shortest possible sentence: “John!”, “Stop!”, ...

• Discourse definition
  • the shortest possible utterance: “Ouch!”, “Yes!”, “Psst!”
    (though “Psst!” is a borderline case, and “Ssssh!” is more so)
Articulatory Phonetic Definition of Syllable
Articulatory phonetic definition

- A syllable is a segment of speech with a degree of opening from closed or narrow through wide to closed or narrow

Typically:
- stop
- fricative
- liquid
- glide
- nasal

Typically:
- vowel
- diphthong
Also frequent:
- nasal
- liquid

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Articulatory phonetic definition

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Simplified oral cavity model:

Typically:
- stop
- fricative
- liquid
- glide
- nasal

Also frequent:

Typically:
- vowel
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Articulatory phonetic definition

- A syllable is a segment of speech with a degree of opening from closed or narrow through wide to closed or narrow.

Computational model:

V

C₁

V

C₂

\[ \begin{align*}
C_1 & \in \{\text{stop}_1, \text{fricative}_1, \text{nasal}_1, \text{liquid}_1, \text{glide}_1\} \\
C_2 & \in \{\text{stop}_2, \text{fricative}_2, \text{nasal}_2, \text{liquid}_2, \text{glide}_2\} \\
V & \in \{\text{vowel, diphthong, nasal, liquid}\}
\end{align*} \]

Set of major syllable types

- V
- CV
- VC
- CVC

Finite State Automaton (FSA, State Machine, ... )
Articulatory phonetic definition

Equivalent computational models with different degrees of complexity

Nondeterministic

Deterministic
Articulatory phonetic definition

The computational model is a map which defines routes through a space of possible syllables, known as a state machine or finite state automaton (FSA):

1. Move along the initial arrow to the initial state, s₀.
2. Then either skip to state s₂, or take C₁, and move to s₁.
3. At s₁ take V and move to s₂.
4. At s₂ either terminate or take C₂ and move to s₃.
5. At s₃ terminate.

C₁ ∈ {stop₁, fricative₁, nasal₁, liquid₁, glide₁}
C₂ ∈ {stop₂, fricative₂, nasal₂, liquid₂, glide₂}
V ∈ {vowel, diphthong, nasal, liquid}
Articulatory phonetic definition

The computational model is technically known as a state machine or finite state automaton (FSA), as it requires only finite working memory, in this case only one current state at a time.

\[ FSA = < S, s_0, F, V, R > \]

i.e. a set of states \( S \), an initial state \( s_0 \) in \( S \), a set of final states \( F \) in \( S \), a set of symbols \( v_i \) in vocabulary \( V \) and a set of rules \( R \) of triples \( < s_i, v_j, s_k > \) for transitions between two states.

\[ C_1 \in \{ \text{stop}_1, \text{fricative}_1, \text{nasal}_1, \text{liquid}_1, \text{glide}_1 \} \]
\[ C_2 \in \{ \text{stop}_2, \text{fricative}_2, \text{nasal}_2, \text{liquid}_2, \text{glide}_2 \} \]
\[ V \in \{ \text{vowel}, \text{diphthong}, \text{nasal}, \text{liquid} \} \]
Acoustic Phonetic Definition of Syllable
Syllables

Do we detect some kind of contradiction there?

- Not really:
  - there are many definitions of “syllable”
  - but for all these definitions:
    the syllable is the unit with which prosodic patterns such as tones, pitch accents and rhythms are associated
Syllables

• Syllables in some languages (e.g. English) may be defined
  – stressed or unstressed
    • main correlates: long vs. short; change of pitch
  – strong (long nucleus) or weak (short nucleus)
**Acoustic phonetic definition**

- A syllable is a segment of speech from low to high to low energy
Perceptual Phonetic Definition of Syllable
Perceptual phonetic definition

• A syllable is a segment of speech with a *sonority curve* from low sonority through high sonority to low sonority
  
  – sonority scale (inverse: consonant strength scale):
    • open vowel
    • closed vowel
    • glide
    • liquid
    • nasal
    • fricative
    • obstruent (stop)
Perceptual phonetic definition

- Approximation to IPA vowel diagramme:
  - sonority scale
    - vowel open
    - vowel closed
    - glide
    - liquid
    - nasal
    - fricative
    - obstruent (stop)

Perceptual phonetic definition

- Approximation to IPA consonant table:

  - sonority scale
    - vowel open
    - vowel closed
    - glide
    - liquid
    - nasal
    - fricative
    - obstruent (stop)

Perceptual phonetic definition

- Rhythmic oscillation:

  - sonority scale
    - vowel open
    - vowel closed
    - glide
    - liquid
    - nasal
    - fricative
    - obstruent (stop)

Complexity of Syllable Structure
Syllable Complexity

• A key structural question:
  • How complex are syllables?
  • How different are syllables in different languages

• For example: are syllables
  • hierarchically structured (or more complex)?
    - traditional syllable theory
    - metrical phonology
  • flat, i.e. with linear structure?
    - generative theory
      - generative: early – no syllables; late – flat, only nucleus
    - autosegmental and prosodic theory
      - parallel, usually linear tiers of feature bundles
    - linear and multilinear computational phonology:
      - Finite State Phonology (Johnson; Koskenniemi; Kay; Karttunen; Gibbon)
Syllables: flat hierarchy and flat string models

Syllables: hierarchical models

By User:Crissov - self-made, from scratch, Public Domain,
https://commons.wikimedia.org/w/index.php?curid=20330203
Syllables: hierarchical models (right-branching)

By User:Crissov - self made, from scratch, Public Domain,
https://commons.wikimedia.org/w/index.php?curid=20330044
Syllables: flat string models revisited

We can use an FSA to define a set of strings

\[ C_1 \in \{\text{stop}_1, \text{fricative}_1, \text{nasal}_1, \text{liquid}_1, \text{glide}_1\} \]
\[ C_2 \in \{\text{stop}_2, \text{fricative}_2, \text{nasal}_2, \text{liquid}_2, \text{glide}_2\} \]
\[ V \in \{\text{vowel}, \text{diphthong}, \text{nasal}, \text{liquid}\} \]
Articulatory phonetic definition

Equivalent computational models with different degrees of complexity

Nondeterministic

Deterministic
Mandarin Syllables
Syllables: Mandarin

• Traditional distinction:
  • initials
  • finals
  • represented in a two-dimensional model:
    – the ‘Pinyin table’

• Challenge:
  – What would a hierarchical model look like?
  – What would a linear model look like?
    • without tone
    • with tone:
      – autosegmental / prosodic / multilinear
**Syllables: the Mandarin Pinyin Chart**

<table>
<thead>
<tr>
<th>Pinyin</th>
<th>a</th>
<th>ai</th>
<th>ao</th>
<th>an</th>
<th>ang</th>
<th>ou</th>
<th>e</th>
<th>ei</th>
<th>en</th>
<th>eng</th>
<th>33 vowels with addition of o and ueng(ong) =35</th>
</tr>
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<td>source: unknown</td>
</tr>
</tbody>
</table>

**Source:** unknown
Query:

The pinyin table shows actual, lexical syllables, each presumably corresponding to at least one character in writing. Is it possible to fill in the gaps? That is, invent new possible syllables for which no character exists, including new syllables created by combining existing syllables with new tones?

For English, yes. Example:
Blends and new brand names in English, such as “Bic”, “brunch”, ...
This is what linguistic rules predict.

For Mandarin?
Can the gaps in the pinyin table be filled in? Yes, in principle:
pia, tia, dia, mia, ...

Problem: there is no character for these phonologically possible syllables (though pinyin is suitable).
Syllables: Mandarin tone

Problem 1:
The meaning of the syllable–tone line is different from the others: it means parallel syntagmatic structure. The other lines mean ‘immediate domination’ / ‘constituent structure’. The sequential syntagmatic structure in the syllable is simply represented left-to-right.

Solution:
A grammar with parallel linear (multilinear) structures.

Problem 2:
Linear syntagmatic sequences in syllables are easy to represent. Linear sequences of syllables are also easy to represent.

But what about tone sequences - ‘tone sandhi’?
- possible sequences of tones
- associations of tones with syllables (as Tone-Bearing Units – TBUs)

Solution:
Again – a grammar with multilinear structures:
- autosegmental phonology
- multilinear finite state phonology
**Problem 2:**
Linear syntagmatic sequences in syllables are easy to represent. Linear sequences of syllables are also easy to represent.

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**Solution:**
Again – a grammar with multilinear structures:
- autosegmental phonology
- multilinear finite state phonology
Syllables: Mandarin tone

• There are several autosgmental models

• I will look at two aspects of a solution to the ‘tonal grammar’ problem:
  – the syllable:
    • a flat, linear model
    • a grammar for the flat linear model
  – tone sequences:
    • a grammar for tone sandhi, due to Martin Jansche
Syllables: Mandarin list (transcription, not pinyin)

ʔ-e ʔe ʔa ʔaŋ ʔai ʔan ʔao ʔe ʔen ʔer ʔi ʔin ʔja ʔjan ʔjao ʔje ʔjon ʔjou ʔou ʔu ʔwa ʔwan ʔwai ʔwen ʔwei ʔwen ʔwo ʔy ʔyn ba ban bai ban bao be ben bi bin bij bjan bjao bje bo bu c-i ca can cai can cao ce cen cogen cou cu cwan cwei cwen cwo ch-i cha chan chao che cheh chen chon chou chu chwan chwai chwan chwei chwen chwo da dan dai dan dao de den dei di din djan djao dje djou don dou du dwan dwei dwen dwo dzan dze dzi din dzin dzja dzjan dzjao dzje dzjon dzjou dzy dzyn fa fan fe fen fo fou fu ga gan gai gan gao ge gen gei gen gon gou gu gwa gwan gwai gwan gwei gwen gwo ha han hai han hao he hen heh hen hon hou hu hwa hwan hwai hwan hwen hwo ka kan kai kan kao ke ken ken kon kou ku kwa kwai kwan kwei kwen kwo le la lan lai lan lao le len lei li lin lijan lijan ljao lje ljou lon lou lu lwan lwen lwo ly ma man mai man mao me men mei men mi min mijn mjao mje mo mou mu ne na naŋ nai nan nao ne neŋ nei nen ni nin nj aŋ njao nje njou noŋ nou nu nwan nwo ny pa paŋ pai pan pao peŋ pei pen pi pin pjan pjao pje po pou pu qan qe qi qin qja qjan qjan qjao qje qjon qjou qy qyn r-i ran ran ran rao re ren ren ren rou ru rwan rwei rwen rwo s-i sa san sai san sao se sen sen son sou su swan swei swen swo sh-i sha shan shai shan shao she shen shei shen shou shu shwa shwan shwaŋ shwai shwan shwei shwen shwo ta tan tai tan tao te ten ti tin tjan tjao toŋ tou tu twan twei twen two xan xe xi xin xja xjan xjao xje xjon xjou xy xyn z-i za zan zai zan zao ze zen zei zen zon zon zou zu zwan zwei zwen zwo zh-i zha zhan zhai zhan zhao zhe zhen zhen zhon zhoun zhou zhu zhwa zhwan zhwai zhwan zhwei zhwen zhwo
Syllables: Mandarin list (transcription, not pinyin)

?-e ʔan ʔe ʔa ʔan ʔai ʔan ʔao ʔe ʔen ʔer ʔi ʔin ʔja ʔjan ʔjao ʔje ʔjon ʔjou ʔou ʔu ʔwa ʔwan ʔwai ʔwen ʔwei ʔwen ʔwo ʔy ʔyn ba baŋ bai ban bao beŋ bei ben bi biŋ bin bjap bjao bje bo bu c-i ca can cai can cao ce cen con cou cu cwen cwo ch-i cha chan chao che chen cho chou chu chwan chwei chwen chwo da dan dai dan dao de deŋ dei di diŋ djap djao dje djou don dou du dwen dwei dwen dwo dzan dze dzi dzo dzy dzyn fa faŋ fai fap fao faŋ faŋ faŋ faŋ fep faŋ fep feŋ fei fen fo fou fu ga gaŋ gai gan gao ge geŋ gei gen gon ghou gu gwa gwang gai gan gao ge geŋ gei gen gon ghou gu gwa gwang gai gan gao ge geŋ gei gen gon ghou gu gwa gwang gai gan gao ge geŋ gei gen gon ghou gu gwa gwang gai gan gao ge geŋ gei gen gon ghou gu gwa gwang gai gan gao ge geŋ gei gen gon ghou gu gwa gwang gai gan gao ge geŋ gei gen gon ghou gu gwa gwang gai gan gao ge geŋ gei gen gon ghou gu gwa gwang gai gan gao ge geŋ gei gen gon ghou gu gwa gwang gai gan gao ge geŋ gei gen gon ghou gu gwa gwang gai gan gao ge geŋ gei gen gon ghou gu gwa gwang gai gan gao ge geŋ gei gen g...
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397 syllables
Syllables: a flat grammar for Mandarin phonotactics

464 potential syllables vs. the 399 actual (lexical) syllables based only on the Pinyin Chart

Compact representation: only one transition between nodes – phoneme set represented by one member.
Syllables: a flat grammar for Mandarin phonotactics

Compare the models

**Disadvantage of linear model:**
Full model is very non-general and difficult to read.

**Advantage of linear model:**
The patterns show phonotactic subtleties better than the tree model.

DEMONSTRATION
http://wwwhomes.uni-bielefeld.de/gibbon/Syllables/Mandarin/mandarin-syll-fst-gl-na.html
Syllables: a flat grammar for Mandarin phonotactics

Compare the models

4 positions in each:
initial–medial–nucleus–coda

Full non-compact model.
Syllables: a flat grammar for Mandarin phonotactics
English Syllables
Syllables: a selection from English (31761 items!)

... ðɜː ðɜːð ðɜːʃ ðɜːθ ðɜːʒ ðɜːb ðɜːd ðɜːdʒ ðɜːf ðɜːg ðɜːk ðɜːl ðɜːld ðɜːm ðɜːmθ ðɜːn ðɜːp ðɜːs ðɜːst ðɜːt ðɜːv ðɜːz ðəʊ ðəʊð ðəʊʃ ðəʊθ ðəʊʒ ðəʊb ðəʊd ðəʊdʒ ðəʊf ðəʊg ðəʊk ðəʊl ðəʊld ðəʊm ðəʊmθ ðəʊn ðəʊp ðəʊs ðəʊst ðəʊt ðəʊtʃ ðəʊv ðəʊz ðɛð ðɛŋ ðɛŋθ ðɛŋk ðɛʃ ðɛθ ðɛz ðɛb ðɛd ðɛf ðɛθ ðɛz ðɛdz ðɛf ðɛgt ðɛk ðɛks ðɛkt ðɛl ðɛʃ ðɛlθ ðɛld ðɛldʒ ðɛlf ðɛlk ðɛls ðɛlt ðɛltʃ ðɛlv ðɛm ðɛmp ðɛn ðɛnθ ðɛnd ðɛnz ðɛnθ ðɛnt ðɛntʃ ðɛnz ðɛp ðɛps ðɛpt ðɛs ðɛsk ðɛsp ðɛst ðɛt ðɛʃ ðɛv ðɛz ðið ðiŋ ðiŋθ ðiŋk ðiʃ ðiθ ðiʒ ðið ðid ðidʃ ðidθ ðidʒ ðidz ðidz ðif ðift ðig ðik ðiks ðikt ðil ðilʃ ðiθ ðid ðidʒ ðif ðilt ðilʃ ðilv ðim ðimf ðimp ðin ðinθ ðind ðindʒ ðins ðint ðintʃ ðinz ðip ðiŋ ðis ðisp ...
English has so many potential syllables (31761) because the maximum length of an English syllable is 6 (cf. /strikt/) rather than 4 for Mandarin, and the number of phonemes is higher.

Multiplication over all positions thus leads to a much higher number, even if tones are included in Mandarin.

Reason? Complex historical development with many influences and changes.
English has so many potential syllables (31761) because the maximum length of an English syllable is 6 (cf. /strikt/), excluding affix phonemes, rather than 4 for Mandarin, and the number of phonemes is higher.

Multiplication over all positions thus leads to a much higher number, even if tones are included in Mandarin.

An improvement would be to separate the diphthongs and long vowels into two morae, making the coda structures less heterogeneous.

DEMONSTRATION
http://wwwwhomes.uni-bielefeld.de/gibbon/Syllables/english-syllables-demo.html
Ranks of Grammar and their Interpretations

Multilinear Grammar – Ranks and Interpretations (MLG-RI) Architecture

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Summary: what you should know about by now

• Syllables:
  – different definitions at different ranks
  – tone-bearing / accent-bearing units (TBU, ABU)
  – different syntagmatic structures in different languages
  – basis of different rhythms of different languages
  – minimal morpheme
  – minimal word
  – minimal sentence
  – minimal utterance