The sources of phonological markedness

1. Overview

It is often argued that phonological patterns can be functionally grounded. In OT, this usually means that constraints can express functional tendencies:

- They disprefer articulatorily, perceptually, psycholinguistically difficult structures.

  Example: *NÇ ‘No nasals may be followed by voiceless obstruents.’
  NÇ sequences are articulatorily difficult. (Pater, 1996, 1999)

…but there’s not much discussion of the relationship between functional factors and constraints.

Goal of the dissertation: Investigate the connection between constraints and their functional motivations.

- How closely are the constraints and functional tendencies related?
- Are individual speakers aware of this relationship?
- Where do constraints come from?

Proposal: Functional factors can motivate constraints in two different ways.

Direct: Learners observe phonetic (etc.) facts and induce constraints which directly reflect these facts. (à la Hayes (1999), Smith (2002), Steriade (1999; 2001)…) 

- Functionally grounded constraints.
  - Induced from phonetic data
  - Literally encode phonetic facts

Indirect: Innate constraints generalize across and beyond literal phonetic facts.

- Formally grounded constraints.
  - Innate (cannot be induced)
  - Generalized from literal phonetic facts

A central difference between these two classes of constraints: Induceability.

Constraints should be induced if possible:

- If learners can collect enough external evidence to induce a constraint, innate specifications of that constraint would be redundant.

But if some constraints can’t be induced, they must be innate.

Another goal: How does constraint induction work?

The plan for this talk:

- Formally grounded constraints: Parallel phonotactic restrictions on prosodic domain edges. (Chapter 2)

  - Functionally grounded constraint: *#p
    - Phonotactic restrictions on initial p
    - Perceptual and acoustic properties of initial p (Chapter 3)
    - Computational model: How a learner could induce *#p from these phonetic facts.
      - Generally, how functionally grounded constraints can be induced. (Chapter 4)

2. Formally grounded constraints on prosodic domain edges

Proposal: Some constraints reflect, but do not directly encode, phonetic tendencies. These constraints cannot be induced from learners’ experience.

Constraints which cannot be induced must be innate and formally grounded.

Domain-edge markedness constraints are formally grounded in this way.

Observation: All prosodic domain edges are subject to parallel phonotactic restrictions.

Any segment or structure that is marked in syllable onsets (or codas) is also marked word-initially (or word-finally), phrase-initially (or phrase-finally), utterance-initially (or utterance-finally), etc.
(1) Parallel phonotactic restrictions on prosodic domain edges

<table>
<thead>
<tr>
<th>Restriction</th>
<th>Syllable</th>
<th>Word</th>
<th>Phrase</th>
<th>Utterance</th>
</tr>
</thead>
<tbody>
<tr>
<td>*?/Onset</td>
<td>Balantak</td>
<td>Nahuatl</td>
<td>Kaiwa</td>
<td></td>
</tr>
<tr>
<td>*?/Onset</td>
<td>Chamicuro</td>
<td>Carib</td>
<td>Tucano</td>
<td></td>
</tr>
<tr>
<td>*?/Onset</td>
<td>Mongolian</td>
<td>West Greenlandic</td>
<td>Kunwinjku</td>
<td></td>
</tr>
<tr>
<td>*Glide/Onset</td>
<td>child language</td>
<td>Sestu Campidanian Sardinian</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onset</td>
<td>Klamath</td>
<td>Wiyot</td>
<td>Selayarese</td>
<td></td>
</tr>
<tr>
<td>*VoiObsCODA</td>
<td>German</td>
<td>Russian</td>
<td>Yiddish</td>
<td></td>
</tr>
<tr>
<td>*ComplexCODA</td>
<td>Sedang</td>
<td>Dongolese Nubian</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CODACOND</td>
<td>Japanese</td>
<td>Garawa</td>
<td>Koromfe</td>
<td></td>
</tr>
<tr>
<td>NoCODA</td>
<td>Hua</td>
<td>Italian</td>
<td>Leti</td>
<td>Sardinian</td>
</tr>
</tbody>
</table>

⇒ Every markedness constraint which targets syllable onsets or codas is part of a domain-edge markedness constraint schema.

(2) \( M_{\text{Onset}}(\text{Onset}/\text{PCat}) \) Where \( M_{\text{Onset}} \) is some markedness constraint which targets onsets, and \( \text{PCat} \) is some prosodic domain, assign one violation for each instance of \( \text{PCat} \) in which there is a violation of \( M_{\text{Onset}} \).

e.g. *?(Onset/\( \sigma \)) *?(Onset/Word) *?(Onset/Phrase) *?(Onset/Utterance)

(3) \( M_{\text{CODA}}(\text{CODA}/\text{PCat}) \) Where \( M_{\text{CODA}} \) is some markedness constraint which targets codas, and \( \text{PCat} \) is some prosodic domain, assign one violation for each instance of \( \text{PCat} \) in which there is a violation of \( M_{\text{CODA}} \).

e.g. NoCODA/\( \sigma \) NoCODA/Word NoCODA/Phrase NoCODA/Utterance

Many of these constraints look like they’re functionally (perceptually) motivated.

**But:** There is no literal correlation between:

…all of the contexts in which perception of e.g. marked onset segments is difficult and

…all of the prosodic contexts in which these segments are dispreferred.

⇒ ? onsets are presumably hard to hear word-initially and utterance-initially.

⇒ Constraints penalize ? onsets word-initially and utterance-initially.

Not all *?(Onset/PCat) constraints correlate with perceptibility in this way.

⇒ *?(Onset/\( \sigma \)) penalizes ? in two perceptual contexts: \( V_{-}V \) and \( C_{-}V \)

⇒ ? is probably hard to hear in \( C_{-}V \)

⇒ BUT it’s probably easiest to hear in \( V_{-}V \)

If the learner were mapping its perceptual experience with ? directly to constraints:

the learner should induce constraints against ? in \( C_{-}V \) (and \( V_{-}C \)), but not in \( V_{-}V \).

(4) **Predicted:** *?\( V \) *?\( V \) \( V \)\( V \)

This sort of perception-driven phonotactic pattern is common, and is often accounted for in the Licensing by Cue framework. (Steriade, 1999, 2001)

(5) **Retroflexion:** *?\( d \)\( V \) \( C \)\( d \)\( V \) \( V \)\( d \)\( V \) Gooniyandi (McGregor, 1990)

Perception-driven induction wouldn’t lead learners to induce all of the attested *?\( \text{Onset}/\text{PCat} \) constraints.

(6) **Unexplained:** *?\( V \) *?\( V \) *?\( V \)\( V \) Balantak (Busenitz and Busenitz, 1991)

**Summary:** Domain-edge markedness constraints are **formally grounded** because:

- They express generalizations that go beyond literal phonetic facts.
- Perceptually: ? is dispreferred in some prosodic domain-initial onsets.
- Phonotactically: ? is dispreferred in all prosodic domain-initial onsets.
- They can’t be induced directly from phonetic facts, so must be innate.

3. **Functionally grounded *?\( p \)**

**Functionally grounded** constraints directly encode phonetic facts, and can be induced by learners from their phonetic experience.

To explore constraint induction in detail, I focus on one particular phonotactic constraint: *?\( p \)

(7) *?\( p \) ‘Unaspirated \( p \) cannot be word-initial.’

In Cajonos Zapotec (Nellis and Hollenbach, 1980):

- Voiceless stops are unaspirated.
- \( t \) and \( k \) contrast with \( d \) and \( g \) (respectively) in all positions.
- \( p \) and \( b \) contrast only medially and finally.
- **Initial \( p \) is banned:** *?\( p \)

The same pattern is found in Ibibio (Akinlabi and Urua, 2002; Connell, 1994; Essien, 1990).
(8) Stop contrasts in Cajonos Zapotec

<table>
<thead>
<tr>
<th>p ~ b</th>
<th>t ~ d</th>
<th>k ~ g</th>
</tr>
</thead>
<tbody>
<tr>
<td>&quot;pen&quot;</td>
<td>&quot;to&quot;</td>
<td>&quot;koc&quot;</td>
</tr>
<tr>
<td>&quot;don‘do!&quot;</td>
<td>&quot;one&quot;</td>
<td>&quot;gunny sack&quot;</td>
</tr>
<tr>
<td>&quot;gövere‘fog&quot;</td>
<td>&quot;yew&quot;</td>
<td>&quot;it can&quot;</td>
</tr>
<tr>
<td>&quot;döber‘feather&quot;</td>
<td>&quot;yidhko‘the leather&quot;</td>
<td>&quot;wágk‘firewood&quot;</td>
</tr>
<tr>
<td>jáp ‘will care for’</td>
<td>yêt ‘tortilla’</td>
<td>wák ‘it can’</td>
</tr>
<tr>
<td>ját ‘will weave’</td>
<td>zéd ‘disturbance’</td>
<td>wág ‘firewood’</td>
</tr>
</tbody>
</table>

OT premise: The constraint inventory is universal. (Prince and Smolensky, 1993/2004)

⇒ All languages – even those with #p – have *#p ranked somewhere in their grammars.


…but *#p is phonetically natural (see below), so is universal in any case.

4. Perceptual and acoustic properties of p, b, t, and d

Experimental data show that initial p is...

…uniquely perceptually difficult.

…uniquely acoustically similar to (and so confusable with) #b.

⇒ *#p restrictions correlate with initial p’s phonetic properties.

4.1. Perception

French-speaking participants heard stimuli extracted from French words with one of four consonants (p, b, t, d) in either word-initial or intervocalic position.

e.g. #pa or apa; #ba or aba; #ta or ata; #da or ada (vowels vary)

Participants were asked to identify the consonant as quickly as possible by pressing a button.

Result: #p is recognized significantly more slowly than #b. (t(88) = 2.445, p = 0.016)

This pattern is unique to word-initial p:

Medial p is not similarly slower than medial b.

#t is not similarly slower than #d.

(No comparable difficulty was found in accuracy.)

⇒ #p is uniquely perceptually difficult.

Figure 1. (a) Average reaction times (ms) in each condition, with 95% confidence intervals. (b) Average percent correct in each condition, with 95% confidence intervals.

4.2. Acoustics

There are acoustic explanations for this perceptual result.

The VOT of #p is significantly shorter than the VOT of any other voiceless stop.

#p’s burst is not significantly stronger than that of #b; all other voiceless stops have significantly stronger bursts than their voiced counterparts.

In terms of both VOT and burst intensity:

#p is more similar to #b than any other voiceless stop is to its voiced counterpart.

That is, #p is uniquely acoustically similar to #b.

This explains why #p is uniquely perceptually difficult.

…which in turn explains why #p can be phonologically banned.

⇒ There is a correlation between the phonetics and phonotactics of initial p.

*#p looks like it’s functionally grounded.
5. The computational model: Basic structure

I argue that functionally grounded constraints reflect, and are induced from, phonetic facts. Could these phonetic (perception) facts allow all learners to universally induce *#/p? This raises other general questions: How exactly does constraint induction work?

I investigate these questions using a computational model. Hayes (1999) similarly modeled the induction of articulatorily grounded constraints.

The model has three components:

Production Virtual adult speakers pronounce acoustically realistic initial and medial p, b, t, d.

Perception The virtual learner develops acoustic criteria for identifying the stops.

Induction The learner induces constraints against perceptually difficult stops.

5.1. Production

Utterances look like this:

(9) SPOKEN: "tabs!"

\[
\begin{array}{llll}
\text{Initial } t: & \text{Place} = 100 & \text{Voicing} = 0 & \text{VOT} = 47 & \text{Burst} = 61 \\
\text{Medial } b: & \text{Place} = 0 & \text{Voicing} = 100 & \text{VOT} = 0 & \text{Burst} = 52 \\
\end{array}
\]

Each utterance is a CaCu utterance: pata, baba, tada, etc.

Each stop is represented by a set of four numerical acoustic properties.

Voicing and Burst (intensity) are as measured in the acoustic experiment.

Various other cues to voicing, and to place, weren’t measured, so I added the binary cues (closure) Voicing and Place.

5.2. Perception

The learner needs to do three things with the words produced by the speaker:

Hearing The learner hears the speaker’s utterance somewhat imperfectly. (Not discussed today.)

Identification The learner guesses which initial and medial stops were produced.

The learner identifies stops using a very simple prototype model.

The learner has one prototype for each stop.

Each prototype has four coordinates: The stop’s average acoustic value for each cue.

The learner compares the coordinates of the ‘heard’ stop to those of each prototype.

The prototype closest to the heard stop is the learner’s guess.

(10) HEARD: Initial: Place = 100 Voicing = 0 VOT = 47 Burst = 61

<table>
<thead>
<tr>
<th>Initial Distance</th>
<th>Place</th>
<th>Voicing</th>
<th>VOT</th>
<th>Burst</th>
</tr>
</thead>
<tbody>
<tr>
<td>p:</td>
<td>169</td>
<td>3.9</td>
<td>4.3</td>
<td>16.5</td>
</tr>
<tr>
<td>b:</td>
<td>198</td>
<td>3.5</td>
<td>96.1</td>
<td>4.5</td>
</tr>
<tr>
<td>t:</td>
<td>21</td>
<td>94.8</td>
<td>7.4</td>
<td>30.2</td>
</tr>
<tr>
<td>d:</td>
<td>106</td>
<td>96.8</td>
<td>96.2</td>
<td>3.7</td>
</tr>
</tbody>
</table>

GUESS: Initial t (correct)

Learning The learner learns what stops sound like, based on each new piece of acoustic information.

The learner updates the locations of the prototypes to reflect new acoustic information.

(11) Initial \(t \rightarrow\) Place Voicing VOT Burst

<table>
<thead>
<tr>
<th>Place</th>
<th>Voicing</th>
<th>VOT</th>
<th>Burst</th>
</tr>
</thead>
<tbody>
<tr>
<td>95.2</td>
<td>6.6</td>
<td>31.8</td>
<td>64.8</td>
</tr>
</tbody>
</table>

This model assumes that the learner has a way of knowing which stop was actually heard.

This isn’t crucial: a more complex self-organizing model could discover categories independently. (de Boer, 2001)

5.3. Results: Perceptual realism

Over time, the learner’s ability to accurately identify stops increases, then quickly stabilizes.

The learner shows different rates of accurate perception for each stop, because some stops are more acoustically similar – and so more confusable – than others.

Ultimately, the learner demonstrates realistic perception of the stops:

Initial \(p\) is uniquely perceptually difficult, just as in the perceptual experiment.
The model is therefore a realistic representation of a human learner’s phonetic experience.

\[ \Rightarrow \] We can use this model to investigate whether (and how) learners could consistently induce the constraint \(*\#p\) from this experience.

6. Modelling constraint induction

\(*\#p\) needs to be in the grammar of every speaker of every language.

\[ \Rightarrow \] \(*\#p\) must be induced by speakers of:

- French-type languages \with \(*p\)
- Cajonos Zapotec-type languages \without \(*p\)

A tricky issue: French learners hear \(*p\), so they have direct evidence that \(*p\) is perceptually difficult. But how do CZ learners know this?

Constraints are induced from learners’ immediate linguistic experience.

\[ \Rightarrow \] Learners can refer only to their experience perceiving adult speech in inducing perceptually grounded constraints.

Learners cannot use their perceptual experience of their own (or other children’s) babbling or early speech.

If they could, this could be how CZ learners find out that \(*p\) is perceptually difficult.

BUT: Infant speech has much more articulatory variation than adult speech. (Jusczyk, 1997)

…so perceptual experience of infant speech isn’t informative about segments’ perceptibility in adult speech.

Learners need some instructions to be able to induce constraints from phonetic experience.

An innate schema which allows a learner uses to induce \(*\#p\) specifies four properties:

Definition of the induced constraints.

- \(*x/Context_2\) Assign one violation mark for every perceptually difficult segment \(x\) which occurs in \(Context_2\).

Phonological elements considered.

- Individual segments. (Could also be features, sequences, etc.)

Phonotactic positions considered.

- Word-initial position. (Not intervocally, where segments are perceptually salient.)

What makes a segment ‘perceptually difficult’.

i.e. a procedure for comparing measures of perceptibility: see below.

The model makes use of two perceptibility measures:

\[ \begin{align*}
\text{Accuracy} & \quad \text{Of all the times the learner heard } x, \text{ how often was } x \text{ accurately identified?} \\
\text{Accuracy}(x) & = \frac{\# \text{ correctly identified } x \text{ tokens}}{\# \text{ heard } x \text{ tokens}} \\
\text{False alarms} & \quad \text{Of all the times the learner guessed it heard } x, \text{ how many weren’t really } x? \\
\text{False-alarm}(x) & = \frac{\# \text{ incorrectly identified } x \text{ tokens}}{\# x \text{ responses}} \\
\end{align*} \]

(12) \(\text{Heard: Initial } p \rightarrow \text{ Initial } p \text{ accuracy } = 0\)

\(\text{Guess: Initial } b \rightarrow \text{ Initial } b \text{ false alarm } = 1\)

Comparisons of these two measures allow virtual learners of both pseudo-French and pseudo-Cajonos Zapotec (pseudo-CZ) to consistently induce \(*\#p\).

6.1. Pseudo-French: Induction from accuracy scores

A pseudo-French learner hears all four stops in all positions.

\[ \begin{array}{ccc|ccc}
\text{Pseudo-French} & \text{ Initial Cs } & \text{ Medial Cs } \\
\hline
p & b & t & d & p & b & t & d \\
\end{array} \]
When the learner hears #p and #b, it can observe that #p is recognized less accurately than #b.

Constraints should be induced only from persistent, significant perceptual difficulty.

The model needs criteria for identifying patterns of perceptual difficulty which merit being encoded in constraints.

The model labels a stop ‘perceptually difficult’ if its accuracy score meets both absolute and relative criteria:

(14) A learner labels x ‘perceptually difficult’ in Context2 if, at some point during learning:

\[
\text{Accuracy}(x/\text{Context}_2) < 0.9
\]

Perceptually difficult stops’ accuracy scores are generally low.

… and …

\[
\text{Accuracy}(x/\text{Context}_2) < \text{Accuracy}(y/\text{Context}_2)
\]

These scores must be significantly different. ($\alpha = 0.01$)

Perceptually difficult stops’ accuracy scores are lower than other stops’.

Using these criteria, the model consistently induces *#p from pseudo-French data.

6.2. Pseudo-Cajonos Zapotec: Induction from false alarm scores

Pseudo-CZ learners hear exactly what French learners do, except that they never hear #p.

(15)

\[
\begin{array}{ccc}
\text{Initial Cs} & \text{Medial Cs} \\
\text{Pseudo-French:} & p & b & t & d \\
\text{Pseudo-CZ:} & b & t & d & p \\
\end{array}
\]

Because they never hear #p, they have no accuracy scores for #p.

→ Pseudo-CZ learners can’t induce *#p based on #p’s low accuracy scores.

Pseudo-CZ learners must induce *#p on some other perceptual basis.

Learners have a unique kind of perceptual experience with phonotactic gaps:

Segments which are missing in a particular position (e.g. #p) have more false alarms than accurate identifications.

This is because the perceptual model assumes that learners:

… know which stops exist in the ambient language, and…

… try to learn what each of these stops sounds like in each context.

Because #p exists medially in pseudo-CZ, learners expect to hear #p in initial position also.

→ Learners occasionally misidentify other sounds (usually #b) as #p.

→ Learners acquire false alarms for unattested #p.

To capture this, the model also labels stops as perceptually difficult if:

(16) \[
\text{Accuracy}(x/\text{Context}_2) \geq \text{False-alarm}(x/\text{Context}_2)
\]

(17) Summary: Criteria for perceptual difficulty

A learner labels x ‘perceptually difficult’ in Context2 if, at some point during learning:

\[
\text{Accuracy}(x/\text{Context}_2) < 0.9
\]

and

\[
\text{Accuracy}(x/\text{Context}_2) < \text{Accuracy}(y/\text{Context}_2) \quad (\alpha = 0.01)
\]

… or …

\[
\text{Accuracy}(x/\text{Context}_2) \geq \text{False-alarm}(x/\text{Context}_2)
\]

Using these criteria, the model consistently induces *#p from pseudo-CZ data.
I’ve proposed a basic method for the induction of perceptually grounded constraints. This was implemented in a computational model.

**Result:** *#p* can be induced from learners’ acoustic and perceptual experience.

The model is robust in the face of phonotactically different linguistic experience:

*#p* can be consistently induced by learners of both pseudo-French and pseudo-CZ.

This model shows that *#p* is consistently inducible, and so functionally grounded.

**Formally grounded constraints:** Learners don’t seem to have enough information to induce other constraints. (Domain-edge markedness constraints)

Formally grounded constraints may be motivated (perhaps evolutionarily) by functional tendencies.

**BUT:** They cannot be induced, because they generalize beyond phonetic facts.

If constraints *can’t* be consistently induced, they **must** be innate.

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### 7. Conclusion

**Premise:** Constraints can reflect functional tendencies.

**Major question:** How can constraints and functional factors be related?

It’s useful to think about these connections from a learner’s perspective.

Learners can have two kinds of knowledge about the functional motivations for constraints.

**Functionally grounded constraints:** Learners have access to enough phonetic information to induce some constraints from their immediate linguistic experience. (*#p*)

If constraints *can* be consistently induced, they **should** be induced.

Specifying these constraints innately would be redundant.

The basic idea that constraints can be induced by learners is familiar: Hayes (1999), Smith (2002), Steriade (1999; 2001).
References


Kawahara, Shigeto. 2007. The Emergence of Phonetic Naturalness, University of Massachusetts Amherst: Doctoral dissertation.


