Optimality Theory
Overview

- Rule-based model
- OT basics
- Variation
- Experimental approaches
What is phonology?

Sound patterns (of human languages)

- Alternation
- Static
Alternation patterns in English

- **t-r**
  - write [rait]
  - writ-er [raif ər]

- **s-z-əz**
  - dog-[Z], book-[S], bus-[əZ]
Analysis of t-ᵣ alternation in early generative phonology

- **Rule** (tapping or flapping)
  - \( t \rightarrow r / V \_ \_ V \)

- **Derivation**
  - UR \( /rait/ \) \( /rait-r/ \)
  - Tapping
  - SR \( [rait] \) \( [rai f-r] \)

(UR = Underlying R, SR = Surface R)
Analysis of s-z-əz alternation in rule-based model

Rule (Voicing assimilation)

• /z/ → [-voice] / [-son, -voice] __ #

Rule (V-epenthesi sis)

• ∅ → ə / [+sibilant] __ [+sibilant]
**Derivation: s-z-εz alternation**

- **UR**: book-/[s] dog-/[z] bus-/[εz]
- **V-epe**: -- -- ε
- **VoiAssi**: s -- --
- **SR**: book-/[s] dog-/[z] bus-/[εz]
Static sound patterns in English

What *sounds* and *sound sequences* are allowed in words/morphemes?

<table>
<thead>
<tr>
<th>Allowed</th>
<th>Sounds</th>
<th>Sound Sequences</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>p, t, k, b, d, g, m</td>
<td>dz#, pt#, #bl</td>
<td>adz, concept, blame</td>
<td></td>
</tr>
<tr>
<td>Disallowed</td>
<td>ö, ü, x, β, !</td>
<td>*ds#, *pd#, *#bd</td>
<td>*a[ds], *conce[pd], *[bd]ame</td>
</tr>
</tbody>
</table>
Early generative phonology model

Why \( p, t, k, b, d, g, m \ldots \) allowed?

English phoneme inventory
- \{ \( p, t, k, b, d, g, m \ldots \) \}
- Notice: \( \ddot{o}, \ddot{u}, x, \beta, ! \ldots \) are excluded

Why \*ds\#, \*pd\#... disallowed?

Morpheme Structure Constraint (MSC)
- \*[-son, \( \alpha \)voice][-son, -\( \alpha \)voice]\#
Static patterns in Early generative phonology model

- **English phoneme inventory**
  - \{ p, t, k, b, d, g, m ... \}

- **Morpheme Structure Constraint (MSC)**
  - *[-son, \(\alpha\)voice][-son, -\(\alpha\)voice]#

- **phoneme inv \(\rightarrow\) MSC**
  - *\[V, -back, +round]\n  - (/ö, ü/ are not allowed to occur.)
The basic structure of phonology (Early generative phonology)

Underlying R $\leftrightarrow$ MSC/phoneme inv

$\downarrow$

$\downarrow$

$\downarrow$

$\leftarrow$ Rules

Surface R

- Alternation: rule
- Static patterns: MSC
- Phonologists’ job: discover right rules (and rule orderings)
Alternations often occur for the purpose of obeying static morpheme internal generalizations.

book-[s], *book-[z] → Voicing Assim R
concept, adz, *ads → MSC

Two different devices are used to capture the same generalizations.
Several formally distinct rules or conditions work towards achieving the same target structure.

- CC $\rightarrow$ CC
- CVC (V-epen: $\emptyset$ $\rightarrow$ V / C___C)
- $\emptyset$C (C-del: C $\rightarrow$ $\emptyset$/ ___ C)
Hiatus avoidance in Korean Verb inflection

- 먹-다 → 먹-어
- 막-다 → 막-아
- 쓰-다 /s’i-ə/ [sØə] stem-V del
- 자-다 /ca-a/ [ca] Degemination
- 주-다 /cu-ə/ [cwə] Glide Formation
A summary of problems for early generative phonology

- Duplication
- Conspiracy
- Extrinsic rule ordering
Overview

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Optimality Theory


Optimality Theory

- Constraints are the primary content of the grammar.
- No rules at all.
- Constraints explain both static and alternation patterns.
Basic scheme

- **Markedness** constraint (on the output)
- **Faithfulness** constraint: input = output
- The actual output is the one that best satisfies the constraints, i.e. optimal output.
- **GEN** generates every conceivable output corresponding to the input.
Traditional rule-based model: conveyer belt system

\[ UR \rightarrow \text{Rule}_1 \rightarrow \text{Rule}_2 \rightarrow \ldots \rightarrow \text{Rule}_n \rightarrow SR \]

↑
MSC
UR/input
↓
Gen
↓
cand₁, cand₂, cand₃ ...
↓
Eval: ranked constraints
↓
SR/optimal output
Optimality Theory

UR /bʌs-z/
↓
Gen
↓
bʌsz, bʌsəz bʌz, bʌnz, sʌbz ...
↓
Eval: ranked constraints
↓
SR [bʌsəz]
OT analysis:
(i) **alternation**: book[s], dog[z],
(ii) **static**: adz, concept

● **Constraint**
  - Markedness: \([-\text{son}, \alpha vc][-\text{son}, -\alpha vc]\#\)
  - Faithfulness: ID(vc) (“do not change voicing value”)

● **Ranking:**
  - \([-\text{son}, \alpha vc][-\text{son}, -\alpha \text{ vc}]\# >> ID(vc)\)
# Tableaux

**alternation**

<table>
<thead>
<tr>
<th>book-/z/</th>
<th>*[αvc][−αvc]#</th>
<th>ID(vc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. book[z]</td>
<td>*!</td>
<td></td>
</tr>
<tr>
<td>ii. book[s]</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>

**static**

<table>
<thead>
<tr>
<th>/æds/</th>
<th>*[αvc][−αvc]#</th>
<th>ID(vc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. æds</td>
<td>*!</td>
<td></td>
</tr>
<tr>
<td>ii. ædz</td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>
Richness Of The Base (ROTB)

- No language-specific limitations on possible underlying forms.
- Everything is thus explained by constraint interaction, i.e., the grammar.
- No phoneme inventory & MSC.
Constraint

Markedness: *CC

Faithfulness:

- Max-C ("don’t delete C")
- Dep-V ("don’t insert V")

Conspiracy:

(i) CC → ∅C, (ii) CC → CVC
### Tableau: CC → CVC

<table>
<thead>
<tr>
<th>/apka/</th>
<th>*CC</th>
<th>Max-C</th>
<th>Dep-V</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. apka</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ii. ə apəka</td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>iii. aØka</td>
<td></td>
<td>*!</td>
<td></td>
</tr>
</tbody>
</table>
Constraint evaluation

- **Violable.**
  - For the satisfaction of the dominant constraint, lower-ranked constraints must be sacrificed.  
  Cf. Constraints in traditional theories

- **Strict Domination**
  - violation of higher-ranked constraints cannot be compensated for by satisfaction of lower-ranked constraints.
### Strict Domination

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cand 1</td>
<td>*!</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cand 2</td>
<td></td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>
• In OT, constraints are basically universal. Thus, typology = individual language.

• Language-specific differences must be due to the difference in the rankings.

• OT analyses make typological predictions by reranking constraints of different types (factorial typology).
Overview

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Variation

**Free variation**
- Different pronunciations for same morpheme/word
- lost $\sim$ los∅ (books)

**Lexical variation**
- same pronunciation for same morpheme/word
  - ĭnf[ə]rmātion vs. cònd[ɛ]nsātion
Recent approaches: attempt to explain occurrence of variants & their frequency.
Free Variation in OT

- Partially Ordered Constraints theory (Kiparksy (1993) and Anttila (1997 et seq.))

Approaches with Numerically-valued constraints
- Stochastic OT (Boersma & Hayes 2001)
- Harmonic Grammar (HG)
An OT analysis of English final t/d deletion: e.g., los(t)

- **Markedness constraint:**
  - \( *Ct# \) ("No word-final consonant cluster ending in a coronal stop")

- **t/d deletion:** \( *Ct# >> Max-C \)

- **No deletion:** \( Max-C >> *Ct# \)
### Tableau: /lɔst/ [lɔst] ~ [lɔs∅]

<table>
<thead>
<tr>
<th>/lɔst/</th>
<th>Dep-V</th>
<th>Max-C</th>
<th>*Ct#</th>
<th>*Complex_Coda</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. ʃ lɔst</td>
<td></td>
<td></td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>ii. ʃ lɔs∅</td>
<td></td>
<td></td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>iii. lɔs∅t</td>
<td>*!</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Tie in ranking:** X
- **Free ranking:** O
Partially Ordered Constraints theory: Anttila’s model

- Strata for constraints
- Strict ranking for constraints in separate strata
- Free ranking within strata

English (hypothetical grammar 1)
- Strata 1: Dep-V
- Strata 2: Max-C, *Ct#
- Strata 3: *ComplexCoda
Predictions about frequency (gr 1)

English (hypothetical grammar 1)

- **Strata 1:** Dep-V
- **Strata 2:** Max-C, *Ct#
- **Strata 3:** *ComplexCoda

**Strata 2:** only 2 possible rankings

- Max-C >> *Ct# → lost in 50%
- *Ct# >> Max-C → los∅ in 50%
### English (hypothetical grammar 2)

- **Strata 1:** Dep-V
- **Strata 2:** Max-C, *Ct#, *ComplexCoda

<table>
<thead>
<tr>
<th>6 possible rankings</th>
<th>Optimal output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max-C &gt;&gt; *Ct# &gt;&gt; *Comp</td>
<td>last</td>
</tr>
<tr>
<td>Max-C &gt;&gt; *Comp &gt;&gt; *Ct#</td>
<td>last (2/6 = 33%)</td>
</tr>
<tr>
<td>*Ct# &gt;&gt; Max-C &gt;&gt; *Comp</td>
<td>losØ</td>
</tr>
<tr>
<td>*Ct# &gt;&gt; *Comp &gt;&gt; Max-C</td>
<td>losØ</td>
</tr>
<tr>
<td>*Comp &gt;&gt; Max-C &gt;&gt; *Ct#</td>
<td>losØ</td>
</tr>
<tr>
<td>*Comp &gt;&gt; *Ct# &gt;&gt; Max-C</td>
<td>losØ (67%)</td>
</tr>
</tbody>
</table>
One disadvantage

- Cases where the probability distribution between two variants is strongly skewed in favor of one of them
- ex. 99% deletion vs. 1% retention.
- 100 rankings are needed. Only one of them must favor one variant. → Unlikely
Stochastic OT

- Constraint evaluation: no difference from standard OT
- A difference from standard OT: speakers do not memorize the constraint ranking, but constraint “score” (ranking value).

<table>
<thead>
<tr>
<th>Dep-V</th>
<th>Max-C</th>
<th>*Ct#</th>
</tr>
</thead>
<tbody>
<tr>
<td>115</td>
<td>88</td>
<td>83</td>
</tr>
</tbody>
</table>
Stochastic OT

- Each time the grammar is used to evaluate a candidate set, the values are converted to a corresponding ranking:
  - Dep >> Max-C >> *Ct#
- Optimal output = [lost]
Stochastic OT

- **Noisy evaluation:**
- Before transforming the numerical values into a ranking, each one is perturbed by adding a (+/-) number, taken from a normal distribution.

<table>
<thead>
<tr>
<th>Dep-V</th>
<th>Max-C</th>
<th>*Ct#</th>
</tr>
</thead>
<tbody>
<tr>
<td>115+2</td>
<td>88-5</td>
<td>83+3</td>
</tr>
<tr>
<td>(117)</td>
<td>(83)</td>
<td>(86)</td>
</tr>
</tbody>
</table>

- **Ranking:** Dep >> *Ct# >> Max-C
- **Optimal output** = [loss]
\[ C_1 = \text{Max-C}, \ C_2 = *\text{Ct#} \]
\[ \text{Max-C} \gg *\text{Ct#}: 95\% \ [\text{lost}] \]
\[ *\text{Ct#} \gg \text{Max-C}: 5\% \ [\text{loss}\emptyset] \]
Stochastic OT

- Advantage over POC:
  - Skewed probability distributions are possible.
(Nosy) Harmony Grammar

- No ranking
- Constraint weights are adopted to indicate the importance of one constraint relative to others.
## A weighted constraint tableau

<table>
<thead>
<tr>
<th>/lost/</th>
<th>*Ct#</th>
<th>Max-C</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. £ lɔsØ</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>ii. lɔst</td>
<td>-1</td>
<td>-2</td>
</tr>
</tbody>
</table>

- **Harmony**: the sum of the weighted constraint scores.
- **Variation**: noise in constraint values (like in Stochastic OT)
Free Variation in OT

- Partially Ordered Constraints theory
- Stochastic OT
- Harmonic Grammar (HG)
## Lexical variation

**Lexically, not phonologically, conditioned variation**

- **English vowel reduction**
  - comp[ə]nsation → comp[ə]nsate
  - cond[ɛ]nsation → condɛnse
  - inf[ə]rmation → infɔrm

- **Lexical strata in Japanese**
Constraints active in Japanese

- SyllStruc: NoComplexOns, CodaCond...
  - *sma, *ebzo
- *VcdGem:
  - “No voiced obstruent geminates”
  - *abba, *dd, *gg
- No-[p]
  - “no (single) [p],”
  - nippoN ‘Japan’, *paka, *nipoN.
- PostNasVoi
  - “Post-nasal obstruents must be voiced”,
  - tombo ‘dragonfly’, *tompo.
### Lexical strata in Japanese

*(Ito & Mester 1995)*

<table>
<thead>
<tr>
<th>SyllStruc</th>
<th>Yamato (native)</th>
<th>Sino-Japanese</th>
<th>Foreign</th>
<th>Unassimilated Foreign</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>sma</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td><em>ebzo</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>VcdGem</em></td>
<td><em>agga</em></td>
<td></td>
<td></td>
<td>doggu</td>
</tr>
<tr>
<td>No-[p]</td>
<td><em>paka</em></td>
<td></td>
<td>sepaado</td>
<td>peepaa</td>
</tr>
<tr>
<td>PostNasVoi</td>
<td><em>anta</em></td>
<td>sampo, hantai</td>
<td>kompyuutaa, santa</td>
<td></td>
</tr>
</tbody>
</table>
### Lexically specific rankings in Japanese (multiple co-grammars)

<table>
<thead>
<tr>
<th>Yamato (native)</th>
<th>Sino-Japanese</th>
<th>Foreign</th>
<th>Unassimilated Foreign</th>
</tr>
</thead>
<tbody>
<tr>
<td>SyllStruc</td>
<td>SyllStruc</td>
<td>SyllStruc</td>
<td>SyllStruc</td>
</tr>
<tr>
<td>*VcdGem</td>
<td>*VcdGem</td>
<td>*VcdGem</td>
<td>Faith</td>
</tr>
<tr>
<td>No-[p]</td>
<td>No-[p]</td>
<td>Faith</td>
<td>*VcdGem</td>
</tr>
<tr>
<td>PostNasVoi</td>
<td>Faith</td>
<td>No-[p]</td>
<td>No-[p]</td>
</tr>
<tr>
<td>Faith</td>
<td>PostNasVoi</td>
<td>PostNasVoi</td>
<td>PostNasVoi</td>
</tr>
</tbody>
</table>
### OT analysis
*(w/ lexically specific rankings)*

/sampo/

Yamato: *[sampo], [sambo]*  
Sino-J:  [sampo], *[sambo]*

Yamato

<table>
<thead>
<tr>
<th>/sampo/</th>
<th>Syll Struc</th>
<th>*Vcd Gem</th>
<th>No-[p]</th>
<th>PostNas Voi</th>
<th>Faith: ID(vc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. sampo</td>
<td></td>
<td></td>
<td></td>
<td>*!</td>
<td></td>
</tr>
<tr>
<td>ii. sambo</td>
<td></td>
<td></td>
<td></td>
<td>*</td>
<td></td>
</tr>
</tbody>
</table>
### OT analysis
(w/ lexically specific rankings)

/sampo/  
Yamato: *[sampo], [sambo]  
Sino-J: [sampo], *[sambo]

#### Sino-Japanese

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>i. ʃ sampo</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>*</td>
</tr>
<tr>
<td>ii. sambo</td>
<td></td>
<td></td>
<td></td>
<td>*!</td>
<td></td>
</tr>
</tbody>
</table>
Lexical variation in OT

- Lexically specific rankings (co-grammars)
- Lexically specific constraints
Lexically specific constraints (a single grammar)

- Replication or cloning of Faithfulness constraints, each indexed for a vocabulary stratum

- Faith/Yamato
- Faith/Sino-Japanese
- Faith/Assimilated-Foreign
- Faith/Unassimilated-Foreign
(single) Ranking in Japanese

- Syllstruc
  - Faith/Unassimilated-Foreign
  - *VcdGem
  - Faith/Assimilated-Foreign
  - No-[p]
  - Faith/Sino-Japanese
  - PosNasVoi
  - Faith/Yamato
### OT analysis

(w/ lexically specific constraints)

/sampo/ Yamato: *[sampo], [sambo]
Sino-J: [sampo], *[sambo]

<table>
<thead>
<tr>
<th>/sampo/</th>
<th>Faith/S-J</th>
<th>PostNa</th>
<th>Faith/Y</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yamato</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>i. sampo&lt;sub&gt;Y&lt;/sub&gt;</td>
<td>![ ]</td>
<td>![ ]</td>
<td>*!</td>
</tr>
<tr>
<td>ii. sambo&lt;sub&gt;Y&lt;/sub&gt;</td>
<td>![ ]</td>
<td>![ ]</td>
<td>*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>/sampo/</th>
<th>Faith/S-J</th>
<th>PostNa</th>
<th>Faith/Y</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sino-J</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>i. sampo&lt;sub&gt;S-J&lt;/sub&gt;</td>
<td>![ ]</td>
<td>![ ]</td>
<td>*</td>
</tr>
<tr>
<td>ii. Sambo&lt;sub&gt;S-J&lt;/sub&gt;</td>
<td>![ ]</td>
<td>![ ]</td>
<td>*!</td>
</tr>
</tbody>
</table>
One disadvantage of lexically specific rankings:
→ Massive duplication of constraints required by lexical exceptions
Overview

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- Experimental approaches
Experiments are increasingly popular in phonological theorizing.

This is also true of OT.
Testing alternative analyses within OT, comparing OT vs. non-OT analyses,

Justifying a constraint and constraint ranking, testing OT hypotheses, and

Providing (variation) data for OT analysis

Today’s topic. OT hypothesis about typological markedness.
Some patterns recur across languages.

“Typologically unmarked patterns”

Why do certain patterns recur?

OT: constraints are universal.

Constraints responsible for language universals are part of individual speakers’ mental grammar.
Nature vs. Nurture

- **Nature**: e.g. OT

- **Nurture**: e.g. Evolutionary Phonology
  - Speakers simply know regularities concerning words in their own language.
  - Language universals are not mentally represented.
Why FORM_UNMARKED > FORM_MARKED across languages?

FORM_MARKED is more frequently mispronounced or misperceived than FORM_UNM.
3 possible patterns

\[
\text{FORM\_UNM, FORM\_MARKED}
\]

• (i) Lg A \( O > O \)
• (ii) Lg B \( O \quad X \)
• (iii) Lg C \( X \quad X \)
• None \( X \quad O \)

❖ Do speakers have relative cognitive preference of
\text{FORM\_UNM} over \text{FORM\_MARKED}?

➢ OT: Yes in all A, B & C.
➢ EP: Yes in A & B, but No in C.
Main research question

- Do speakers know universal patterns of linguistic elements which are absent from their language?

- OT: Yes
- EP: No
One recent experimental study addressed this question.

- Berent, Iris, Tracy Lennertz, Jongho Jun, Miguel Moreno and Paul Smolensky (2008)
Language universals on #CC

$\text{blif} > \text{bnif} > \text{bdif} > \text{lbif}$

Korean with almost no #CC

Hypothesis: Korean speakers prefer typologically favored #CC.

Berent, Lennertz, Jun, Moreno & Smolensky (2008)
Sonority sequencing universals:

- Large rise: **blif**
- Small rise: **bnif**
- Plateau: **bdif**
- Fall: **lbif**

Sonority sequencing universals:

- Large rise: **blif**
- Small rise: **bnif**
- Plateau: **bdif**
- Fall: **lbif**

Stop [b, d] Nasal [n] Liquid [l]
Phonological repair in the perception (and production) of unattested sequences: e.g., tla $\rightarrow$ tela, snow

Prediction: marked onsets should be more likely to cause repair than less marked ones.

Onset markedness: bl > bn > bd > lb

Repair: blif $\rightarrow$ belif < bnif $\rightarrow$ benif
Experiments

Stimuli

- **Mono-syllabic:** blif, bnif, bdif, lbif
- **Di-syllabic:** belif, benif, bedif, lebif

- **Experiment 1:** syllable count
- **Experiment 2:** Identity judgment
Exp 1: syllable count

❖ One or two syllables?

Audio stimuli
- Mono-syllabic: 🎧 blif, bnif, bdif, lbif
- Di-syllabic: 🎧 belif, benif, bedif, lebif
Results of Exp 1 (syllable count):
Proportion correct

- mono-syllabic: , di-syllabic: ▲
Exp 2: identity judgment

Are these two identical?

Audio stimuli

- Identical: blif-blif, lbif-lbif
- Repair related: blif-belif, lbif-lebif
Results of Exp 2 (identity judgment)

- Accuracy and response time:

![Graph showing accuracy and response time for different sonority distances and word pairs.](attachment:image.png)

- **bl-bel**
- **bn-ben**
- **bd-bed**
- **lb-leb**

Sonority distance:
- Large rise
- Small rise
- Plateau
- Fall

Word pairs:
- (blif-belif)
- (bnif-benif)
- (bdif-bedif)
- (lbif-lebif)
Findings confirm the hypothesis

More marked in typology
→ More errors in the experiment
Errors of Mono-syl stimuli (Exp 1):
\[ blif < bnif < bdif < lbif \]
Difficulty in auditory perception
\[ blif < bnif < bdif < lbif \]

Accuracy with identical items was nearly perfect: lbif–lbif, lebif-lebif

Errors of di-syl stimuli (Exp 1):
\[ belif > benif > bedif > lebif \]
belif - blif ??? lebif – lbif ?
Alternative 2: Mispronunciation (Motor) difficulties in pronunciation

- Errors of Mono-syl stimuli (Exp 1):
  \[ \text{blif} < \text{bnif} < \text{bdif} < \text{lbif} \]
- Difficulty in pronunciation:
  \[ \text{blif} < \text{bnif} < \text{bdif} < \text{lbif} \]
- Participants did not articulate the sequences overtly.
- Errors of di-syl stimuli (Exp 1):
  \[ \text{belif} > \text{benif} > \text{bedif} > \text{lebif} \]
Conclusion

- Adult human brains possess knowledge of universal properties of linguistic structures absent from their language.
- consistent with OT.
Limitations of the conclusion

• Based on the investigation of only a few languages such as Korean (and English).

• How speakers of different languages converge on the same universal knowledge remains to be seen.
Overview

- Rule-based model
- OT basics
- Variation
- Experimental approaches
감사합니다

Thank you