A Computational Method for Evaluating Theories of Phonological Representation

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Phonologists have long argued that phonological grammars should express **natural** generalizations as a result of **simple** rules or constraints.

- We define ‘simple’ in terms of an independently motivated notion of computational complexity.
- In formal language theory, simple means **small, connected** substructures.
Overview

- We ask of a representational theory:
  - Does it express natural generalizations with small, connected substructures?
  - Does it express unnatural generalizations with larger structures?
- We establish that features and tiers differentiate natural and unnatural processes by this metric
- Larger point: unifying computation and phonological information
  - How are representations organized such that salient properties of sounds are connected?
Naturalness vs. simplicity

- Phonologists have long argued that phonological grammars should express **natural** processes as a result of **simple** rules or constraints

**Naturalness**
- **Empirical** property
- Typologically frequent
- Phonetically grounded
- e.g. assimilation, dissimilation

**Simplicity**
- **Representational** property
- ‘Fewer symbols’
- Restricts arbitrariness
Naturalnes vs. simplicity

- Halle (1962, p. 381–2):
  
  \[ R_1: k \rightarrow \text{tf} / \{ i, e, æ \} \quad \text{and} \quad R_2: k \rightarrow \text{tf} / \{ p, r, a \} \]

- Hyman (1975, p.104): “[S]implicity can be quantified by counting features, and only a theory which requires that segments are composites of features will differentiate between real and spurious generalizations”
What and how should we be counting?

Minimum description of pattern depends on how grammar is encoded (Rogers et al., 2013)

How do we encode non-linear representations (Kornai, 1995)?

Complexity classes of patterns offer an encoding-independent notion of simplicity (Rogers et al., 2013)
Simplicity (in detail)

- In hierarchy of Strictly $k$-Local formal language classes (SL$_k$; McNaughton and Papert, 1971), complexity of pattern corresponds to its $k$-value.
- The $k$-value is the size of the forbidden piece of string connected by adjacency.
- $*td$ is SL$_2$
  \[
  \{\text{ata, ada, utu, uda, atta, adda, uttu, ...}\} \quad \text{(no atda, utda, ...)}
  \]
- $*utd$ is SL$_3$
  \[
  \{\text{ata, ada, utu, uda, atta, adda, uttu, atda...}\} \quad \text{(atda, but no utda)}
  \]
Simplicity (in detail)

- $\mathsf{SL}_1 \subsetneq \mathsf{SL}_2 \subsetneq \mathsf{SL}_3 \subsetneq \cdots \subsetneq \mathsf{SL}_k \subsetneq \cdots \subsetneq \mathsf{SL}$

This applies to Strictly Piecewise classes (*s...f) as well (Rogers et al., 2010)
Naturalness distinctions in $k$-values

- We extend notion of $k$-value to graphs representing nonlinear phonological structures (Jardine, 2016)
- Goal of representational theory: $k$ for natural constraint is less than $k$ for unnatural constraint
- For example, *[−voi][+voi] is common, while *[ma] is not
- Both are $SL_2$:
  - $\{*td, dt, tb, bt, pb, \ldots, sz\}$
  - *ma
Naturalness distinctions in $k$-values

**String representations**

\[
\begin{align*}
\text{T} & \rightarrow \text{D} \\
\text{m} & \rightarrow \text{a}
\end{align*}
\]

*TD  
**natural**  
$k = 2$

*ma  
**unnatural**  
$k = 2$
Naturalness distinctions in $k$-values

String versus featural representations

Features in a “bottle brush” representation (Hayes, 1990) with no order on tier (Kaye, 1985)
Naturalness distinctions in $k$-values

Featural representations

*[-voi][+voi]

natural

$k = 4$

*ma

unnatural

$k \geq 6$
Naturalness distinctions in $k$-values

- Formal support for Chomsky and Halle (1968)’s idea of feature-counting
- We can independently support other representational primitives, i.e. autosegmental tiers (order relation between like features)
Naturalness distinctions in $k$-values

- Navajo (Cook 1978): $^[+\text{ant}]...[-\text{ant}]$ (Strictly Piecewise)
- Constraints against arbitrary features, e.g., $^[+\text{ant}]...[-\text{voi}]$ are unattested
- Constraint against different values of same feature is natural, against different features is unnatural
Naturalness distinctions in $k$-values

- Current assumption: no order between like features

```
+co +sy -co +sy +co -sy
```
Naturalness distinctions in $k$-values

- Current assumption: no order between like features

$$\text{[s o b o]}$$

- $^[+\text{ant}]...[-\text{ant}]$
Naturalness distinctions in $k$-values

- Current assumption: no order between like features

- $*[+\text{ant}]...[-\text{ant}]$
Naturalness distinctions in $k$-values

Order only on root tier

\[+a\] \[\rightarrow\] \[R\] \[\rightarrow\] \[\ldots\] \[\rightarrow\] \[R\] \[\rightarrow\] \[+a\] \[\rightarrow\] \[R\] \[\rightarrow\] \[\ldots\] \[\rightarrow\] \[R\] \[\rightarrow\] \[−v\]

*\[+ant]...[−ant]\*

natural

\[k = 4\]

*\[+ant]...[−voi]\*

unnatural

\[k = 4\]
Naturalness distinctions in $k$-values

Adding order between like features

![Graph showing naturalness distinctions](image-url)
Naturalness distinctions in $k$-values

Order on feature tiers

* [+ant]...[−ant]
  natural
  $k = 2$

* [+ant]...[−voi]
  unnatural
  $k = 4$
Discussion

- Independent motivation for phonological tiers
- More general idea: relations in autosegmental structure connect natural classes of features
- How does feature geometry (Sagey, 1986; Clements, 1991; Clements and Hume, 1995) accomplish this?
- How to apply same metric for mappings? (Chandlee, 2014; Chandlee and Lindell, prep)
- How can this reduce search space of constraints for a learner (c.f. Hayes and Wilson, 2008)?
Conclusion

- ‘Simple’ constraints refer to **small, connected** pieces of structures
- This prefers representations organized such that
  - natural classes of features are closely connected
  - unnatural classes require traversing many points in representation
- Natural constraints are less cognitively complex than unnatural constraints
- Step towards unifying formal complexity and phonological substance
Thank You

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References II


Appendix: Encoding and description length

Sequences of ‘A’s and ‘B’s which end in ‘B’ (EndB)

Regular Grammar: \( S_0 \rightarrow AS_0, S_0 \rightarrow BS_0, S_0 \rightarrow B \)

DFA: 

Regular Expression: \((A + B)^*B\)

Sequences of ‘A’s and ‘B’s which contain an odd number of ‘B’s (OddB)

Regular Grammar: \[ S_0 \rightarrow AS_0, S_0 \rightarrow BS_1, \]
\[ S_1 \rightarrow AS_1, S_1 \rightarrow BS_0, S_1 \rightarrow \varepsilon \]

DFA: 

Regular Expression: \((A^*BA^*BA^*)^*A^*BA^*\)

Fig. 1. Minimal descriptions: strings which end in ‘B’ vs. strings with an odd number of ‘B’s.

(Rogers et al., 2013, p. 93)
“It should be observed in this connection that although definition (9) has commonly been referred to as the “simplicity” or “economy condition,” it has never been proposed or intended that the condition defines “simplicity” or “economy” in the very general (and still very poorly understood) sense in which these terms usually appear in writings on the philosophy of science.”

(Chomsky and Halle, 1968, pp. 334–335)