# Incomplete Neutralization is No Problem for Formal Phonology

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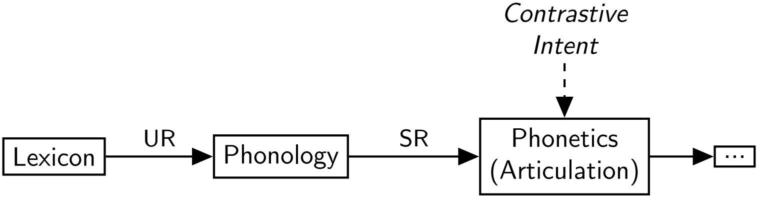
# Overview

- Traditional generative feed-forward models assume the output of phonology/input to phonetics is an SR.
- Processes of incomplete neutralization (e.g. - final devoicing) appear to require reference to both UR and SR and/or representations with continuous phonetic substance.
- Using function application, we argue that the input to the phonetics module includes information about both UR and SR, and therefore contains everything necessary to account for the facts of incomplete neutralization without altering any of the following assumptions:
  1. Feed Forward/Modularity
  2. Substantive phonological representations.
  3. Discrete phonological representations.

# A Model of the Speech Production Pipeline



- Lexicon provides UR as input to Phonology.
- Phonology maps UR to SR.
- Phonology provides SR as input to Phonetics.
- *Contrastive Intent* is extra-linguistic information used to scale the articulation (Gafos and Benus, 2006).

# Modules as functions

- It is possible to view the various modules as functions (Roark and Sproat, 2007; Heinz, 2018)
- The input to the phonetics module is no longer an SR, but rather the phonological module itself (alongside the *contrastive intent value*):
  - $Phonetics(Intent, Phonology(Lexicon))$
- We will later show that this move allows for the phonetic module to have access to both UR and SR.
- This furthermore allows any gradience seen in incomplete neutralization to be the result of phonetic implementation, therefore allowing the phonological representations to remain discrete and as substance free as one would like.

# Substance in Generative Phonology

- The debate on phonetic substance in phonology can be traced back to the final chapter of *The Sound Pattern of English* **(Chomsky and Halle, 1968).**
- Three major divisions since:
  1. Phonetically based phonology **(Hayes et al., 2004).**
  2. Substance free phonology **(Hale and Reiss, 2000).**
  3. No formal phonology **(Ohala, 1990; Port and Leary, 2005).**
- One battleground for this debate has been the incomplete neutralization of final-devoicing.

# Final Devoicing

- Final-devoicing is thought to neutralize the contrast between final obstruents in their surface realizations.

## Examples from German

| | |
|---|---|
| /bad+en/ → [baden] ‘to bathe’ | /bat+en/ → [baten] ‘asked’ |
| /bad/ → [bat] ‘bath’ | /bat/ → [bat] ‘ask’ |

# Final Devoicing

- From a phonological perspective, neutralization is straightforward to model with either rules or constraints:
  1. [-sonorant] $\rightarrow$ [-voice] / _]$_\sigma$
  2. IDENT-Onset$_{\text{voice}}$ $\gg$ *VdObs $\gg$ IDENT$_{\text{voice}}$
- These both predict that an SR [-voice] segment that was derived from a [+voice] UR segment should be identical to one that was [-voice] in both UR and SR.
- A series of phonetic experiments have shown that this is not the case **(Port et al., 1981; Port and O'Dell, 1985; Port and Crawford, 1989, amongst *many* others).**

# Final Devoicing

- In both perception and production, there have been cues to whether or not a surface [-voice] segment derived from an underlying [+voice] segment.
- There have been various solutions for how to account for this data:
  1. Some phonetic implementation rules happen before phonological rules **(Dinnsen and Charles-Luce, 1984; Slowiaczek and Dinnsen, 1985).**
  2. Phonology and phonetics are implemented simultaneously **(Port and O'Dell, 1985; Ernestus and Baayen, 2006; Gafos and Benus, 2006).**
- All of these solutions assume either phonetic substance being available to phonology or the elimination of any meaningful distinction between the two modules.

# Intermediate Summary

- Incomplete neutralization appears to pose a problem for traditional generative assumptions.
- Is there a way to salvage the modular view? ...Yes
- If so, do we need phonetic substance within phonology to account for the facts? ...No
- We will now show how to formally account for this and informally implement it.

# Function Application

- Our argument relies on showing the types of functions following Wadler (1989) which is derived from the lambda calculus **(Barendregt et al., 1984).**
- Function application is a type of function with two arguments:
  1. One of type $A$.
  2. Another, a function of type $A \to B$.
- Its output is something of type $B$.
- The type assigned to function application is thus $A \to (A \to B) \to B$.

# Abbreviations

The following abbreviations will be used in our analysis:

| | | | | | |
|---|---|---|---|---|---|
| *L* | *Lexicon* | *UR* | *UnderlyingRepresentation* | *I* | *Intent* |
| *P* | *Phonology* | *SR* | *SurfaceRepresentation* | | |
| *A* | *Articulation* | *AR* | *ArticulatoryRepresentation* | | |

# Analysis

1. We can start with the traditional view of the speech production pipeline as sketched previously. This is one in which the Phonetics module receives an $SR$ and an $I$ value, and returns an articulatory representation $AR$.

   $A :: I \to SR \to AR$

2. By the definition of function application, we know that $SR$ is actually the result of a function $UR \to SR$ that has been applied to some $UR$. As such, we can replace the function above with the one below.

   $A :: I \to UR \to (UR \to SR) \to AR$

3. Finally, the $(UR \to SR)$ map is actually the phonological module $P$. In other words, the function we started with in (1) is equivalent to the one below.

   $A :: I \to UR \to P \to AR$

# Analysis

- $A :: I \rightarrow UR \rightarrow P \rightarrow AR$
- We now have a function based view of the phonetics (articulation) module $A$ that receives three things as its input:
  1. An intent value $I$
  2. A lexical item $UR$.
  3. A phonological map $P$ which is equal to $UR \rightarrow SR$.
- Its output is an articulatory representation $AR$.
- From this perspective, it is not strange for the phonetics module to be able to reference the $UR$ during implementation.

# Implementation: Contrastive Intent

- Port and Crawford (1989) show that the level of incompleteness can be scaled based on how salient a contrast is.
- Gafos and Benus (2006) modeled this as *Contrastive Intent*, an extra-linguistic variable that was tied to how much a speaker wanted to maintain some contrast they were aware of (through orthography, morphology, etc...).
- In our model, *Contrastive Intent* is a scaling value that alters how much the UR affects the articulatory representation.
    1. *Contrastive Intent* $= w \in [0, 1]$.
    2. *SR* has a weight of $1 - w$.
    3. *UR* has a weight of $0 + w$.
- Phonetics module maps features into an articulatory representation as the weighted average of UR and SR values.
- For a feature like [voice], it would map to gestures affecting VOT, duration of preceding vowel, burst duration, and so on.

# Implementation: Final Devoicing

- Assume that one of the articulations [voice] controls affects burst duration such that [+voice] maps to 20ms and [-voice] maps to 80ms.
- Input item is the German word /ʁad/.
    1. Phonetics module sees $\left\langle \begin{bmatrix} \text{-sonorant} \\ +\text{ voice} \\ \vdots \end{bmatrix}, \begin{bmatrix} \text{-sonorant} \\ \text{- voice} \\ \vdots \end{bmatrix} \right\rangle$ as a UR-SR pair for the final segment in the word.
    2. Assuming a *contrastive intent* value $w = 0.2$, the burst duration value we would take the *UR* [+voice] value and multiply it by $0 + 0.2$. We would get $20 \cdot (0 + 0.2) = 4$ms. For the *SR* [-voice] value we would take the [-voice] value and multiply it by $1 - 0.2$. So here we would get $80 \cdot (1 - 0.2) = 64$ms.
    3. Summing these together results in a burst duration of 68ms.
- The final burst duration for [d] is still more similar to a fully [-voice] segment, but is incomplete in the sense that it is still influenced by the *UR* value.

# Conclusion

- Phonetic implementation module has access to both UR and SR.
- This was shown by appealing to the mathematical properties of various modules when viewed as functions.
- Importantly, this required no other change in assumptions, but instead a change in perspective.
- By viewing things this way, the phonetic facts of incomplete neutralization are accounted for without getting rid of modularity and without necessitating phonetic substance into the phonology module.

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