Incomplete Neutralization and the Blueprint Model of Production

Scott Nelson (Stony Brook) & Jeffrey Heinz (Stony Brook)

Overview The division of labor between the phonetic and phonological modules in generative linguistics has often been allocated such that phonology handles the discrete and symbolic aspects of a language's sound system, while the phonetics transforms the symbols either into, or from, continuously varying acoustic and/or articulatory representations. (Pierrehumbert 2002) refers to this as the "modular feedforward" model. This type of model struggles with accounting for incomplete neutralization where two segments are neutralized phonologically, but maintain a measurable phonetic distinction. While some explanations of this phenomenon blur the lines between phonetics and phonology, this paper provides an alternate approach by restructuring the architecture of the modular feedforward model. The resulting model is referred to as the BLUEPRINT MODEL OF PRODUCTION and maintains many of the assumptions of the modular feedforward model while also being able to explain incomplete neutralization data. It also does so while maintaining discrete phonological representations. Final devoicing (Port and O'Dell 1985; Port et al. 1981; Slowiaczek and Dinnsen 1985) is used as an example case.

Background Final devoicing, the process in which underlying voiced obstruents surface as voiceless in syllable/word-final position, is well studied in both the phonological and phonetic traditions. (1) shows examples from German.

(1) a. /bad+en/ → [baden] 'to bathe'
b. /bad/ → [bat] 'bath'
c. /bat+en/ → [baten] 'asked'
d. /bat/ → [bat] 'ask'

While this process appears to eliminate the voicing contrast between obstruents in final position, a series of phonetic experiments has established meaningful acoustic and perceptual differences between underlying voiceless segments and derived voiceless segments, suggesting that the neutralization is incomplete (Port and O'Dell 1985; Port et al. 1981). Of important note is that the way in which the acoustic properties of derived voiceless segments and faithful voiceless segments differ is such that the properties of the former are in the direction of what we may expect for a voiced segment in that position. Furthermore, the level of incompleteness is modulated by extra-linguistic factors (Port and Crawford 1989), which we will refer to as *Intent* following Gafos and Benus (2006). The development of the BLUEPRINT MODEL OF PRODUCTION is driven by these two facts.

The blueprint model of production One reason that the modular feedforward model struggles with accounting for incomplete neutralization is because the phonetics module only has access to phonological surface forms. In contrast, the BLUEPRINT MODEL OF PRODUCTION makes both the lexical representations and the phonological grammar an input to the phonetics module. A scaling value representing *Intent* can also act as an input. The architecture of the BLUEPRINT MODEL OF PRODUCTION is shown in Figure 1.

While giving the phonetics module direct access to the lexicon and phonological grammar may seem like a large departure from the modular feedforward model, it is actually a straightforward reconceptualization when viewed as a series of mathematical functions. This can be seen by examining the *types* of functions (Pierce 2002) whose notation is derived from the lambda calculus (Barendregt et al. 1984). Specifically it relies on function

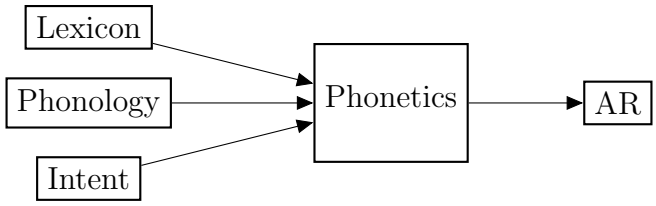

Figure 1: A visual representation of the BLUEPRINT MODEL OF PRODUCTION.

application which itself is a function of two arguments – one of type A, another a function of type $A \to B$ – and which outputs something of type B. Formally its type is written as $A \to (A \to B) \to B$. The modular feedforward model can be thought of as the function in (2a) where the Phonetics module A takes a surface form SR as its input and outputs an articulatory representations AR. 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 underlying form UR. As such, we can replace (2a) with (2b). Finally, the $(UR \to SR)$ map is actually the phonological module P. In other words, (2a) is equivalent to (2c) below.

(2) a. $A :: SR \to AR$
b. $A :: UR \to (UR \to SR) \to AR$
c. $A :: UR \to P \to AR$
d. $A :: L \to P \to I \to AR$

We can further add the *Intent* value I as an input to A and change UR to the entire lexicon L in order to generalize the model over all lexical items (Roark and Sproat 2007). As (2d) shows, we end up with a Phonetics function A that takes three things as its input: the lexicon, the phonology module, and an intent value, and returns an articulatory representation AR. From this perspective, it is not strange for the phonetics module to reference underlying form values directly during implementation.

Despite the analysis presented here focusing on the abstract computational level of the BLUEPRINT MODEL OF PRODUCTION, the full paper also presents an algorithmic implementation to directly model empirical phenomena. An AR output value is computed by taking the exponentially weighted sum of what the phonetic output would look like based on the UR values alone and what it would look like based on the SR values alone. The weighting is done based on the *Intent* values such that higher values indicate more influence of the UR. The paper shows how the output values match the aforementioned experimental results.

Conclusion The BLUEPRINT MODEL OF PRODUCTION is able to explain incomplete neutralization without diminishing the role of phonology as a discrete, symbolic function from underlying to surface forms. Future work using this model may show that it can also account for other segmental phenomena at the phonetics-phonology interface such as epenthetic vowel duration, phonetic evidence of deleted segments, and absolute neutralization.

References

Barendregt, Hendrik P et al. (1984). *The lambda calculus*. Vol. 3. North-Holland Amsterdam.
Gafos, Adamantios I and Stefan Benus (2006). "Dynamics of phonological cognition." *Cognitive science* 30.5, pp. 905–943.
Pierce, Benjamin C (2002). *Types and programming languages*. MIT press.
Pierrehumbert, Janet (2002). "Word-specific phonetics." *Laboratory phonology* 7.
Port, Robert F and Michael L O'Dell (1985). "Neutralization of syllable-final voicing in German." *Journal of phonetics*.
Port, Robert and Penny Crawford (1989). "Incomplete neutralization and pragmatics in German." *Journal of phonetics* 17, pp. 257–282.
Port, Robert, Fares Mitleb, and Michael O'Dell (1981). "Neutralization of obstruent voicing in German is incomplete." *The journal of the Acoustical Society of America* 70.S1, S13–S13.
Roark, Brian and Richard Sproat (2007). *Computational approaches to morphology and syntax*. Vol. 4. Oxford University Press.
Slowiaczek, Louisa M and Daniel A Dinnsen (1985). "On the neutralizing status of Polish word-final devoicing." *Journal of phonetics*.