Uncertainty as an Organizing Principle of Phonological Systems

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Enhancement Contexts

- Certain contexts tend to attract enhanced phonological patterns
  - sounds with better acoustic/auditory cues
  - greater number of phoneme categories
- Word level: word-initial position
- Sub-lexical level:
  - prosodically prominent positions (e.g. stressed syllables, long vowels)
  - segmentally prominent positions (e.g. pre-vocalic consonant, **C**V)

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Reduction Contexts

- By contrast, reduced phonological patterns tend to occur in the complement contexts
  - sounds with weaker acoustic/auditory cues
  - fewer number of phoneme categories
- Word level: word-final position
- Sub-lexical level:
  - prosodically non-prominent positions (e.g. unstressed syllables, short vowels)
  - segmentally non-prominent positions (e.g. nasal consonant before another consonant, V**N**CV)

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Previous explanations

Several interrelated explanations have been proposed:

- processing considerations (Cutler (various), Beckman 1997, Smith 2004): earlier parts of words are important for speech processing; how do other "prominent" positions fit in when not word-initial?
- perceptual salience (e.g. Steriade 1997): optimize perceptual distinctiveness of sounds; how do word effects fit in?
- functional needs (e.g. Boersma 1997): interacting functional constraints (e.g. ease of articulation, perceptual distinctiveness) operate on features to generate observed outputs; contextual prominence?

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Our goal

- To provide a unified account of the patterns of enhancement and reduction that occur at sub-lexical, lexical and higher levels.

- Leading idea: Language is conceived of a system of optimizing communication through efficiently **resolving uncertainty** in the mapping between signal and meaning.
- Patterns of enhancement and reduction can be seen as responses to the need to reduce uncertainty associated with predicting the outcome of a message.

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A starting point: Communication

- Language involves the transmission of information.
- Speakers encode the message onto a signal; listeners decode the signal back onto a message.
- Linguistic signals are structured in terms of nested and ordered categories
  - Features → phonemes → larger sublexical units → words → phrases → …
- For the listener, the process of decoding a signal can be thought of as *the problem of mapping a noisy signal onto the intended categories*.

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Why is this a 'problem'?

Noise in the channel (in the environment, in production, in perception...) and the possibility of more than one outcome introduces uncertainty in the signal-category mapping.

→ Consequently, successful information transmission is dependent on the resolution of uncertainty in the mapping between the signal and the message.

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Resolution of uncertainty

- It is well-established from psycholinguistic and phonetic research that we use two general types of information to resolve uncertainty in signal-category mappings:
  - top-down information from our knowledge of the system, e.g.,
    - possible lexical categories in the sentence context
    - possible phonemic contrasts in a given segmental context
  - bottom-up information from the signal itself, e.g. phonetic cues
- Bayes' Rule provides a way to conceptualize this and unify these two types of information.

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Bayes' Rule and resolution of uncertainty in signal-message mapping

The probability of the category C in the context

The probability that the signal S is produced, given the category C

The probability of the category C given the signal S in the context

$$p(C|S,ctxt) = \frac{p(C,ctxt)p(S|C)}{\sum_i p(C_i,ctxt)p(S|C_i)}$$

S = the speech signal
C = a category
ctxt = contextual information

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Anything that increases the value of the numerator decreases the uncertainty in the mapping from a signal S to a category C.

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What types of manipulations decrease uncertainty in the mapping from a signal to a category?

- Bottom-up via the signal: increase phonetic distinctiveness
  - Increases p(S|C), the probability of the signal given the category.
- Top-down via the system: decrease the number of categories expected in the context
  - Increases p(C, ctxt), the probability of the category in context

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The Resource Issue

- Manipulations are constrained by the fixed number of resources available given the system.
  - e.g. We don't have endless amounts of effort to improve the signal. For the speaker, effort relates in part to articulatory effort. For the listener, it relates to attention.

→ Optimal communication systems deploy resources strategically, in ways that are most efficient for communicating the message.

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Manipulating Redundancy

- In *A Mathematical Theory of Communication* (1948), Claude Shannon proved mathematically that communicating a message through a noisy channel can approximate the ideal when the substance used to encode the message is manipulated in specific ways.
- Redundancy in the signal is increased in contexts of higher uncertainty, and decreased in contexts of lower uncertainty.
- Note that redundancy does not imply wastefulness. Rather, redundancy means that there are multiple cues to the same message.

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Language as a communication system

- Given that language is a communication system, we expect it to function like communication systems more generally.
- A plethora of laboratory findings are consistent with this expectation.
  - language users pay more attention to elements in prominent positions (e.g., Cutler, Hawkings & Gilligan 1985, MacWhinney 2005, Jurafsky & Martin 2008**)**, tend to enhance or hyperarticulate elements in such positions (e.g., Lindblom 1990), and reduce and delete elements in non-prominent positions (e.g., Lavoie 2002).

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Modulating uncertainty in usage

- Psycholinguistic evidence that details of speech are modulated to distribute uncertainty evenly across the signal:
  - Word choice and uncertainty at the sentence level (Levy & Jaeger 2007)
  - Phonetic detail and uncertainty at the levels of word and syllable (Van Son & Pols 2003, Aylett & Turk 2004)

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Prediction

Under the assumption that patterns in grammar originate as patterns of usage, phonological patterns should also show the effects of modifying the message in a way that responds to the degree of uncertainty associated it.

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Resolving Uncertainty: Predictions for phonology

Two responses to resolving uncertainty in a noisy system:

1. increase the predictiveness of the signal by adding more or better cues (low level response)
2. decrease the number of competing outcomes (higher level response)

When uncertainty is low:

1. decrease predictiveness of cues
2. increase the number of possible outcomes

- Recall that these responses relate back to the two terms in Bayes' rule.

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Structure of the remainder of the talk

Present evidence consistent with the notion that many phonological patterns optimize uncertainty levels.

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Maximizing Information

There are different positions within a word that could be modified in order to reduce uncertainty.

Most efficient

↓

Concentrate information in places where it is going to be most effective in resolving uncertainty.

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Word Processing

- Psycholinguistic evidence shows that parsing words is incremental; we start making decisions about what words are before the end of the word.
- Lexical access is generally achieved on the basis of the initial part of the word (Cutler et al. 1985, Marslen-Wilson 1989, Marslen-Wilson & Zwitserlood 1989).
- This means that information occurring earlier in the parse will reduce uncertainty more than information occurring latter.

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Predictions for phonological patterns at the word-level

All else being equal:

1. The inventory of available phonemic contrasts should be higher earlier in the word.
2. Better phonetic cues should be favored earlier in the word.

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Category differences: Root-initial vs. non-initial
(Beckman 1997)

language	*inventory includes*	*initial σ*	*non-initial σ*
Tuva (Turkic) (Krueger 1977)	plain & glottalised vowels	plain & glottalised vowels	no glottalised vowels
!Xóõ (Bushman) (Traill 1985)	click & non-click consonants	click & non-click consonants	no clicks
Tamil (Christdas 1988, Bosch & Wiltshire 1992)	high, mid & low vowels round & unround vowels	high, mid & low vowels round & unround vowels	no mid vowels no round vowels
Turkic family (Comrie 1981, Kaun 1995)	round & unround vowels	round & unround vowels	round vowels only after a round vowel in the initial syllable
Shona (Bantu) (Fortune 1955)	high, mid & low vowels	high, mid & low vowels	mid only after mid in the initial syllable
Dhangar-Kurux (Dravidian) (Gordon 1976)	oral & nasal vowels long & short vowels	oral & nasal vowels long & short vowels	no nasal vowels no long vowels
Shilluk (Nilotic) (Gilley 1992)	plain, palatalised & labialised consonants	plain, palatalised & labialised consonants	no palatalised or labialised consonants
Malayalam (Dravidian) (Wiltshire 1992)	labial, dorsal & a variety of coronal consonants	independent place of articulation in coda position	place of articulation in coda must be shared by following onset
Bashkir (Turkic) (Poppe 1964)	high & non-high vowels front and back vowels	high & non-high vowels front and back vowels	no high vowels front/back only in agreement with σ_1 vowel
Damin (Lardil secret language) (Hale 1973)[5]	Lardil segments, plus nasalised clicks, bilabial & velar ejectives, ingressive lateral fricative	Lardil segments, plus nasalised clicks, bilabial & velar ejectives, ingressive lateral fricative	no clicks, ejectives or lateral fricative

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Word-level phonetic cue differences

Fortition in word-initial position:

Luganda (Cole 1967): gemination in word-initial position

Class 5 (SG)	Class 6 (PL)	
ggi	ma-gi	'egg'
ddaala	ma-daala	'ladder'
zzike	ma-zike	'chimpanzee'
jjuba	ma-yuba	'dove'
gg^{w}aanga	ma-waanga	'nation'
ddaanga	ma-laanga	'lily'

Lenition in word-final position:

American English: debuccalization of /t/ word-finally, e.g. cat [kæt] ~ [kæʔ]

"of all phonological positions word-initial is the most resistant to deletion." (Harris 2009)

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Predictions for phonological patterns at sub-lexical level

All else being equal:

1. The inventory of phonemic contrasts should be greater in prosodically or segmentally prominent positions, e.g.
   - prosodic prominence, stress, length
   - segmental context: in contexts where cues are salient (e.g. contexts where cues are not masked, are dissimilar from neighbouring sounds)
2. Phonetic cues should be enhanced in prosodically or segmentally prominent positions

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Differences in category number

- Stressed syllables vs. unstressed syllables
  - more vowel categories in stressed position (e.g. English)
- Onset position vs. coda postion
  - Cypriot Greek: Consonant fortition in onset position after a consonant (excluding nasals and liquids) (Newton 1972)
  - Porteño Spanish: Glides /y, w/ are pronounced as homorganic obstruent fricatives in syllable-initial position (Lozano 1979).

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Differences in cue quality

- Segmentally and/or prosodically (non-)prominent positions: reduction (e.g. assimilation, lenition) commonly targets sounds in contexts where the cues are weak

E.g. syntagmatically similar sounds

/nl/ reduction (Seo 2004)

➔ [ll] in Klamath, Ponapean, Toba Batak, Moroccan Arabic, Leti, Korean, Uyghur

➔ [nn] in Tatar, Yakut

➔ [n] in Zoque

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Getting from phonetic variation in usage to phonological patterns in grammar

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'Variationist/Usage Based/Evolutionary' models propose a causal link between utterance level biases and the development of abstract patterns

(see work by Baudoin de Courtenay, Ohala, Lindblom, Blevins, Pierrehumbert, Bybee and many others)

- Based on evidence that:
  - Detailed variants of the same word coexist and compete in the mental lexicon;
  - Variants arise under the influence of biases in articulation, perception, transmission;
  - Rule-like behavior arises from generalization over existing, remembered words.
    - Existing patterns contribute biases to language production and perception, creating feedback.

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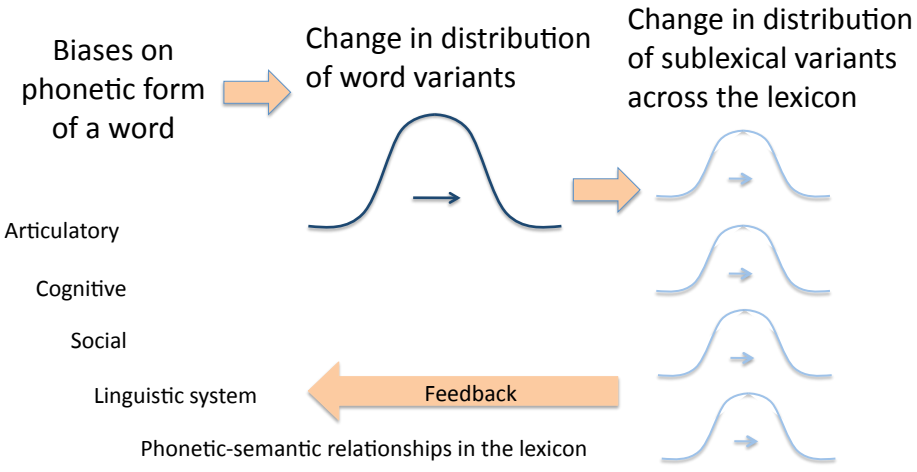

Theoretical/Linguistic evidence:

e.g., Baudouin de Courtenay 1895, Ohala 1989, Lindblom 1990, Blevins 2004, Bybee 2001, Christiansen & Chater 2008

Hay and Maclagan 2012, reviewed in Ernestus 2011

Wang 1969, Bybee 2002, Phillips 2006

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Summary

- Language is a system for the transmission of information.
- The form of many phonological patterns is consistent with the hypothesis that grammars evolve to distribute information efficiently across the signal.
- Psycholinguistic evidence for corresponding biases in speech production is consistent with evolutionary/exemplar models for grammatical pattern development.

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System evolution

- The evidence suggests that there's a causal link between the variation that people produce and the patterns observed in phonological systems.
- Both phonetic and phonological patterns provide evidence consistent with the view that the signal is manipulated to resolve message uncertainty.
- This suggests that language systems evolve to concentrate information in places where they're going to do more work.

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The Primacy of Words

- The emphasis in this approach is on the message (word).
- We resolve uncertainty with regards to a certain category level and the evidence is consistent with the hypothesis that the most important level is the word and not the phoneme.
- All of the phenomena discussed are consistent with the word-level analysis while only a subset are consistent with the phoneme level analysis,
  - e.g. why delete a consonant at the end of the word? It's because it does little work in identifying the **word**, not what the phoneme is.

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Conclusion

When language is viewed from the perspective of a system designed for the transmission of information, enhancement and reduction can be seen as mechanisms aimed at resolving uncertainty regarding a message.

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