Modeling markedness with a split-and-merger model of sound change

Andrea Ceolin  
University of Pennsylvania  
Department of Linguistics  
ceolin@sas.upenn.edu

Ollie Sayeed  
University of Pennsylvania  
Department of Linguistics  
sayeedo@sas.upenn.edu

1 Background

The concept of ‘markedness’ has been influential in phonology for almost a century. Theoretical phonology used it to describe some segments as more ‘marked’ than others, referring to a cluster of language-internal and language-external properties (Jakobson, 1968; Haspelmath, 2006). We argue, using a simple mathematical model based on Evolutionary Phonology (EP; Blevins, 2004), that markedness is an epiphenomenon of phonetically grounded sound change.

2 Model: random splits and mergers

We propose a simple abstract model of sound change as a discrete-time stochastic process of random splitting and merging of phonemic categories. In the split-and-merger model, sound change belongs to a class of random fragmentation and aggregation processes (Banavar et al., 2004), whose fixed points are power-law frequency distributions over the elements being split and merged. It has been shown that phoneme type and token frequencies in natural languages do indeed follow a power-law distribution, specifically a Yule-Simon distribution (Simon, 1955; Tambovtsev and Martindale, 2007; Martin, 2007).

Say the phoneme inventory of a language is a set of segments \( \{x_i\} \), where the \( i \)th segment \( x_i \) has frequency \( p^i_t \) at time step \( t \). At each stage, we apply either a split or a merger to the language with equal probability:

- To apply a split, pick a random pair of segments \( x_i, x_j \) with \( i \neq j \). Take away half of \( x_i \)’s probability mass, and add it to the existing probability mass of \( x_j \).

\[
p^{i+1}_t := \frac{p^i_t}{2}
\]

- Mergers follow a similar algorithm, except that all of \( x_i \)’s probability mass is transferred to \( x_j \).

\[
p^{i+1}_t := 0
\]

\[
p^{j+1}_t := \frac{p^i_t + p^j_t}{2}
\]

\[
p^{k+1}_t := p^k_t
\]

- Define a function \( P_S(x_j) \) such that \( P_S(x_j) \geq 0 \) and \( \Sigma P_S(x_j) = 1 \); this is a probability distribution representing the probability that the \( j \)th segment \( x_j \) will have its frequency increased when another segment splits. When the splitting algorithm calls for picking a random pair of segments \( x_i, x_j \), pick \( x_j \) randomly according to the distribution \( P_S(x_j) \).

- Define a second probability distribution \( P_M(x_i) \), representing the probability that \( x_i \) is lost in a merger. When the merging algorithm calls for picking a random pair of segments \( x_i, x_j \), pick \( x_i \) randomly according to \( P_M(x_i) \).

Say that segments with low \( P_S(x_j) \) are ‘split-wise marked’, and segments with high \( P_M(x_i) \) are ‘mergerwise marked’. In other words, marked segments are segments that either do not tend to be created after a split, or do tend to be lost in a merger.

3 Predictions: within-language and across-language frequency

Empirically, across-language phoneme frequencies correlate well with within-language frequencies (Gordon, 2016). We show that a split-and-merger model derives this link from stochastic sound change.
We run a simulation of the split-and-merger process for 500 iterations with a set of 20 segments arbitrarily labeled \{a, b, c, ..., t\}. We assume that segment frequencies are uniform as a starting point. In addition, six segments \{u, v, ..., z\} are assigned an initial value of zero. In the sound change simulation, either a split or a merger is applied to the phonemic inventory at each iteration with equal probability. Simulations of the split-and-merger model in action show long-tailed distributions emerging out of an initial flat distribution, qualitatively in line with the results from random fragmentation and aggregation models (Figure 1).

3.1 Splitwise markedness
We re-run the simulation first implementing splitwise markedness. In this simulation, ‘a’ is ‘unmarked’ with respect to the other segments by having a probability of increasing its frequency after a split which is higher than that of the other segments, and ‘b’ is ‘marked’ by having a probability of increasing its frequency after a split which is lower. The probabilities are determined by a parameter \( r \), which represents the ratio between the probability of the ‘unmarked’ and the ‘marked’ segments with respect to the others. This value quantifies how ‘unmarked’ or ‘marked’ a segment is with respect to the others.

In a first experiment, we track the average frequencies of ‘a’ and ‘b’ across 1000 parallel runs, and we also track the number of runs in which they survive, interpreting each independent run as a separate language. We then compare these numbers with the frequencies exhibited by segments which are neither ‘unmarked’ nor ‘marked’, for example ‘c’.

Figure 2 shows the average frequencies in the languages in which ‘a’, ‘b’ and ‘c’ survive, and it shows that ‘a’ has a higher average than ‘c’ and ‘b’, while these latter segments do not exhibit a clear difference.

Table 1 shows both within- and across-language frequencies for different values of \( r \). Interestingly, increasing the value for \( r \) has the effect of increasing the difference between ‘a’ and the other symbols, but it does not have any effect on ‘b’. On the other hand, across-language frequencies are clearly distinct, and ‘a’ and ‘b’ display frequencies different from the neutral segment ‘c’. These differences become more salient as \( r \) increases.

This experiment shows that when we add a diachronic bias, ‘unmarked’ segments display higher frequencies both within- and across-languages, while the effect for ‘marked’ segments appears to be limited to across-language frequencies. This might follow from the fact that while splitwise marked segments tend to appear less in languages, their within-language frequencies are dependent on other factors, for instance the frequency of the segments from which they split or their likelihood of merging with other segments. In the next subsection, we investigate mergerwise markedness.

3.2 Mergerwise markedness
We repeat the simulation modeling mergerwise markedness. This time, ‘a’ is ‘unmarked’ with re-
Table 1: Average within- and across-language frequencies for three segments which differ in terms of splitwise markedness, with different values of \( r \). Confidence intervals at 95% are reported for within-language frequencies. We also report confidence intervals at 95% for across-language frequencies, which we obtained by repeating the whole experiment 100 times.

| Markedness | Within-language | Across-language |
|------------|-----------------|-----------------|
| \( r=2 \)  |                 |                 |
| ‘a’ (Unmarked) | 0.063 (±0.006) | 0.572 (±0.003) |
| ‘c’ (Neutral)  | 0.057 (±0.007) | 0.475 (±0.003) |
| ‘b’ (Marked)   | 0.056 (±0.008) | 0.410 (±0.003) |
| \( r=5 \)    |                 |                 |
| ‘a’ (Unmarked) | 0.081 (±0.006) | 0.702 (±0.003) |
| ‘c’ (Neutral)  | 0.058 (±0.007) | 0.452 (±0.003) |
| ‘b’ (Marked)   | 0.052 (±0.008) | 0.348 (±0.003) |
| \( r=10 \)   |                 |                 |
| ‘a’ (Unmarked) | 0.099 (±0.008) | 0.773 (±0.002) |
| ‘c’ (Neutral)  | 0.052 (±0.007) | 0.423 (±0.003) |
| ‘b’ (Marked)   | 0.058 (±0.008) | 0.311 (±0.003) |

4 Conclusions

Both the power-law frequency distribution of phonemes in a language and the cluster of properties associated with ‘markedness’ can be thought of as epiphenomena of phonetically grounded sound change. A stochastic split-and-merger model predicts the attested language-internal and typological correlations. In particular, mergerwise markedness appears to be responsible for higher within- and across-language frequencies for ‘unmarked’ segments and lower frequencies for ‘marked’ segments, while splitwise markedness mainly affects ‘unmarked’ segments.

Figure 3: Summary of the final within-language frequencies for ‘a’, ‘c’ and ‘b’, which are modeled in terms of mergerwise markedness, after 1000 parallel runs, with \( r=10 \).

Table 2: Average within- and across-language frequencies for three segments which differ in terms of mergerwise markedness, with different values of \( r \). Confidence intervals at 95% are reported for within-language frequencies. We also report confidence intervals at 95% for across-language frequencies, which we obtained by repeating the whole experiment 100 times.

| Markedness | Within-language | Across-language |
|------------|-----------------|-----------------|
| \( r=2 \)  |                 |                 |
| ‘a’ (Unmarked) | 0.065 (±0.006) | 0.652 (±0.003) |
| ‘c’ (Neutral)  | 0.056 (±0.007) | 0.485 (±0.003) |
| ‘b’ (Marked)   | 0.052 (±0.008) | 0.320 (±0.003) |
| \( r=5 \)    |                 |                 |
| ‘a’ (Unmarked) | 0.071 (±0.006) | 0.836 (±0.002) |
| ‘c’ (Neutral)  | 0.051 (±0.005) | 0.509 (±0.003) |
| ‘b’ (Marked)   | 0.045 (±0.008) | 0.173 (±0.002) |
| \( r=10 \)   |                 |                 |
| ‘a’ (Unmarked) | 0.072 (±0.005) | 0.924 (±0.002) |
| ‘c’ (Neutral)  | 0.050 (±0.005) | 0.548 (±0.003) |
| ‘b’ (Marked)   | 0.032 (±0.007) | 0.109 (±0.002) |
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