

## Paradoxes of MaxEnt markedness

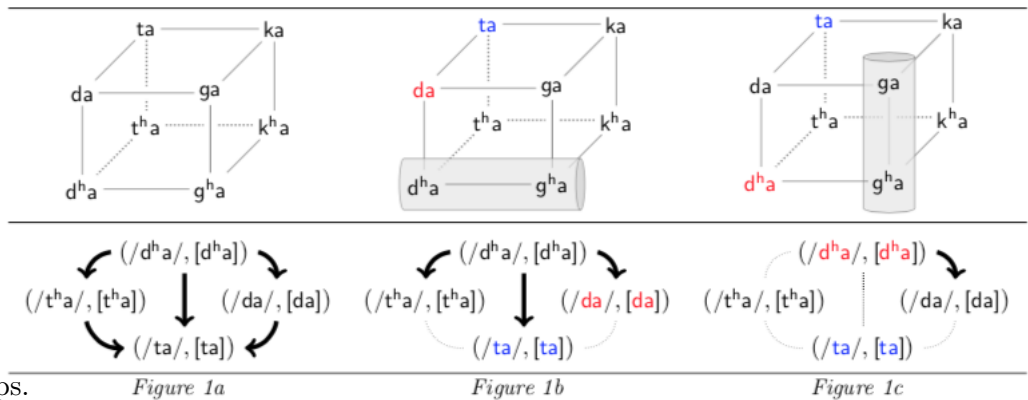
We present a general result about markedness in MaxEnt (ME) and derive from it a score of paradoxes for ME phonology that clearly set ME apart from Stochastic (or noisy) HG (SHG).

**Main result.** A typology of probabilistic phonological grammars satisfies the **implicational universal**  $(\mathbf{x}, \mathbf{y}) \rightarrow (\widehat{\mathbf{x}}, \widehat{\mathbf{y}})$  provided the probability of realizing the underlying form  $\widehat{\mathbf{x}}$  as the surface form  $\widehat{\mathbf{y}}$  in the consequent is always at least as high as the probability of realizing the underlying form  $\mathbf{x}$  as the surface form  $\mathbf{y}$  in the antecedent (Anttila & Magri 2017). For instance, the implication  $(/\text{cost}\#\text{us}/, [\text{cos.us}]) \rightarrow (/ \text{cost}\#\text{me}/, [\text{cos.me}])$  says that the probability of t-deletion is always at least as high before **consonants** as it is before **vowels** (Coetzee and Kawahara 2013). We focus on cases where the underlying and surface forms coincide in both the antecedent (i.e.,  $\mathbf{x} = \mathbf{y}$ ) and the consequent (i.e.,  $\widehat{\mathbf{x}} = \widehat{\mathbf{y}}$ ). The resulting implication  $(\mathbf{y}, \mathbf{y}) \rightarrow (\widehat{\mathbf{y}}, \widehat{\mathbf{y}})$  thus says that the antecedent form  $\mathbf{y}$  is more **marked** than the consequent form  $\widehat{\mathbf{y}}$ . To study ME markedness implications, let us say that a non-faithful candidate is only **one step away** from an underlying form (in the direction of some faithfulness constraint  $F_0$ ) if it violates  $F_0$  only once and it violates no other faithfulness constraints. Let us say next that a form is only **one step away** (in the direction of  $F_0$ ) **from violating** a markedness constraint  $M$  if it does not actually violate  $M$  but it is very close to violating it because all its non-faithful candidates that closely resemble it (that are only one step away in the direction of  $F_0$ ) do violate  $M$ . Our main result is boxed below. The rest of the abstract shows that this generalization about ME markedness is phonologically paradoxical.

*If  $(\mathbf{y}, \mathbf{y}) \rightarrow (\widehat{\mathbf{y}}, \widehat{\mathbf{y}})$  is a ME universal and the antecedent form  $\mathbf{y}$  is one step away from violating a markedness constraint  $M$  (in some direction  $F_0$ ), the consequent form  $\widehat{\mathbf{y}}$  is as well.*

**Paradoxes.** We consider stops that differ in voicing, aspiration, and place and assume they are candidates of each other. We posit the faithfulness constraints  $\text{IDENT}_{[\text{voice}]}$ ,  $\text{IDENT}_{[\text{spread}]}$ , and  $\text{IDENT}_{[\text{place}]}$ . As for the markedness constraints, we start with  $*[+\text{voice}]$  and  $*[+\text{spread glottis}]$  (Lombardi 1999).

Let us focus on coronal stops. In SHG, they satisfy the markedness implications in fig. 1a: voicing and aspiration are more marked (have lower probability) than voiceless unaspirated stops.



So far, these implications all survive in ME. Yet, classical Greek and Vietnamese (Thompson 1965) allow voiced stops and aspirated stops but not stops that are both voiced and aspirated. These languages motivate the constraint  $M = *[+\text{voice}, +\text{spread}]$  that penalizes the forms in the cylinder in fig. 1b. The addition of  $M$  does not affect the SHG markedness implications because  $M$  does not conflict with the markedness of voicing and aspiration. The situation is different in ME. Let's focus on the implication  $(/\text{da}/, [\text{da}]) \rightarrow (/ \text{ta}/, [\text{ta}])$ . Neither **da** nor **ta** violates  $M$  (neither belongs to the cylinder). If we move from **da** one step away downward (in the direction of  $F_0 = \text{IDENT}_{[\text{spread}]}$ ), we get to **d<sup>h</sup>a** which does violate  $M$  (it belongs to the cylinder). But if we move from **ta** one step away downward we get to **t<sup>h</sup>a** which does *not* violate  $M$  (it does not belong to the cylinder). Hence, the antecedent **da** is one step away from violating  $M$  but the consequent **ta** is not. The implication  $(/\text{da}/, [\text{da}]) \rightarrow (/ \text{ta}/, [\text{ta}])$  thus fails in ME. Analogous considerations hold for  $(/\text{t<sup>h</sup>a}/, [\text{t<sup>h</sup>a}]) \rightarrow (/ \text{ta}/, [\text{ta}])$ . The upshot is that voicing  $(/\text{da}/, [\text{da}])$  and aspiration  $(/\text{t<sup>h</sup>a}/, [\text{t<sup>h</sup>a}])$  are not marked in ME but can paradoxically have a larger ME probability than  $(/\text{ta}/, [\text{ta}])$ .

**More paradoxes.** Not everything is lost in ME though: the three markedness implications in fig. 1b that share the antecedent  $(/\text{d<sup>h</sup>a}/, [\text{d<sup>h</sup>a}])$  are universals of ME relative to the current constraints. So far, ME thus does capture the generalization that voicing and aspiration gang up to yield the worst

of the worst. Yet, Thai has voicing contrast at labial and coronal place but lacks a voiced velar stop (Sherman 1975, Locke 1983), presumably because voicing is harder to sustain at the velar place (Ohala 1983). We thus add the constraint  $M = * [+voice, +dorsal]$  that penalizes the forms in the cylinder in fig. 1c. Again, the addition of  $M$  does not affect the SHG universal markedness implications. The situation is different in ME. Let's focus on the implication  $(/d^ha/, [d^ha]) \rightarrow (/ta/, [ta])$ . Neither  $d^ha$  nor  $ta$  violates  $M$  (neither belongs to the cylinder). If we move from  $d^ha$  one step away rightward (in the direction of  $F_0 = IDENT_{[place]}$ ), we get to  $g^ha$  which does violate  $M$  (it belongs to the cylinder). But if we move from  $ta$  one step away rightward, we get to  $ka$  which does *not* violate  $M$  (it does not belong to the cylinder). Hence, the antecedent  $d^ha$  is one step away from violating  $M$  but the consequent  $ta$  is not. The markedness implication  $(/d^ha/, [d^ha]) \rightarrow (/ta/, [ta])$  thus fails in ME: the ganging-up of voicing and aspiration does not yield the worst of the worst in ME. The markedness implication  $(/d^ha/, [d^ha]) \rightarrow (/t^ha/, [t^ha])$  fails analogously. In the end, only the markedness implication  $(/d^ha/, [d^ha]) \rightarrow (/da/, [da])$  survives in ME. But this lonely survivor in fig. 1c is paradoxical, for two reasons. First, the fact that  $d^ha$  always has smaller ME probability than  $da$  but can have larger ME probability than  $ta$  is paradoxical: it reverses the expected markedness asymmetry between  $da$  and  $ta$ . Second, the fact that  $d^ha$  always has smaller ME probability than  $da$  but can have larger ME probability than  $t^ha$  is paradoxical: it predicts a phonologically spurious asymmetry between voicing ( $da$ ) and aspiration ( $t^ha$ ).

**Paradoxes everywhere.** Once we have understood the logic of these paradoxes, we can replicate them in every corner of segmental phonology. Here are some more examples. **(A)** Fig. 2a plots the combinations of values of the features [nasal], [continuant], and [place]. The implication  $(/\beta/, [\beta]) \rightarrow (/b/, [b])$  captures the generalization that (non-strident) voiced fricatives are more marked than the corresponding stops (Jakobson 1941): they are typologically rarer (Maddieson 1984), more difficult to produce (Ohala 1983), and acquired later (Smith 1973). Yet, this sensible markedness implication cannot be a universal of ME. Here is why. Nasal fricatives are particularly marked (they are rare, almost never contrastive, usually resulting from nasal spreading: Shosted 2006), motivating the markedness constraint  $M = * [+nasal, +continuant, -sonorant]$ , plotted as the cylinder in fig. 2a. Intuitively,  $M$  is irrelevant to the comparison between  $\beta$  and  $b$  (neither is nasal). Yet, the markedness implication  $(/\beta/, [\beta]) \rightarrow (/b/, [b])$  fails in ME because its antecedent  $\beta$  is one step away (in the direction of  $F_0 = IDENT_{[nasal]}$ ) from violating  $M$  while the consequent  $b$  is not. **(B)** Fig. 2b plots the combinations of values of the vowel features [back], [high], and [round]. The implication  $(/o/, [o]) \rightarrow (/i/, [i])$  captures four generalizations. First, rounding is marked (epenthetic vowels are never rounded: Lombardi 2003). Second, rounding is particularly marked for non-high vowels (Kaun's 2004 RoLo). Third, back vowels are marked (they are rarely epenthetic: de Lacy 2006, §7.2.5). Finally, non-high vowels are marked (at least outside of prosodic heads: de Lacy 2006, p. 68). Yet, this sensible markedness implication cannot be a universal of ME. Here is why. Rounding is particularly marked for front vowels, motivating the markedness constraint  $M = * [+round, -back]$  (Kaun's 2004 RoFro), plotted as the cylinder in fig. 2b. Intuitively,  $M$  is irrelevant to the comparison between  $o$  and  $i$  (neither violates it). Yet, the implication  $(/o/, [o]) \rightarrow (/i/, [i])$  fails in ME because its antecedent  $o$  is one step away (in the direction of  $F_0 = IDENT_{[round]}$ ) from violating  $M$  while the consequent  $i$  is not. **(C)** Finally, fig. 2c plots the combinations of values of the features [voice], [place], and [length] (featural encoding of phonological length is not crucial to the argument). The implication  $(/g/, [g]) \rightarrow (/k/, [k])$  captures the markedness of voicing at the velar place, already mentioned above. Once again, this sensible markedness implication cannot be a universal of ME. Here is why. Voicing is particularly hard to sustain for geminates (Ohala 1983), motivating the markedness constraint  $M = * [+voice, +long]$ , plotted as the cylinder in fig. 2c. Intuitively,  $M$  is irrelevant to the comparison between  $g$  and  $k$  (neither is geminated). Yet, the markedness implication  $(/g/, [g]) \rightarrow (/k/, [k])$  fails in ME because its antecedent  $g$  is one step away (in the direction of  $F_0 = IDENT_{[length]}$ ) from violating  $M$  while the consequent  $k$  is not.

**Conclusion.** The failure of these sensible markedness implications suggests that ME has formal properties such as the one boxed above that make it unsuitable as a model of phonology.

