THE ERROR-DRIVEN RANKING MODEL OF THE ACQUISITION OF PHONOTACTICS

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Modeling problem

Knowledge of the *phonotactics* of a language is knowledge of the distinction between licit and illicit sounds and sound combinations. For instance, English speakers know that *blik* could be a licit English word while *bnik* could not, although both are unattested. In carefully controlled experimental conditions, nine-month-old infants already react differently to licit and illicit sound combinations (Jusczyk et al. 1993). They thus display knowledge of phonotactics at an early stage, when other linguistic abilities are still not fully developed. In particular, *morphology* is still lagging behind, so that the child has still no access to phonological alternations (Hayes 2004). Another crucial property of the acquisition of phonotactics is *gradualness*: the target adult grammar is approached through a path of intermediate stages, illustrated in (1) with some spontaneous productions of two English learning children attempting to say *clock(s)*, from McLeod et al. (2001). We see reduction of the target onset cluster /kl/ with sonority-driven preservation of the obstruent (/kl/ → [k]); reduction to the fronted obstruent (/kl/ → [t]); etcetera.

(1)

2:3	**2:5**	**2:6**	**2:8**
tʌk	lʌk	dk	flʌk
tʌk	lʌk	dʌk	θlʌk
	flʌkθ	klʌkθ	θlʌk
	klʌkθ		

2:8	**2:10**	**2:11**	**3:1**
kʌk	kəlʌːk	klʌk	klʌk
kʌk	kʌk	klʌk	klʌk
kʌk	kəlʌk	klʌks	
	kəlʌk	kʌk	

We need a computationally efficient learning model that explains how phonotactics can be acquired fast and easily; that makes sense of the fact that its acquisition is possible even before morphology makes alternations available; and that is able to model the observed stepwise progression towards the target adult phonotactics.

Sketch of the model

I work within the phonological framework of *Optimality Theory* (OT; Prince and Smolensky 2004, Kager 1999). In the strongest, classical formulation of the OT framework, the constraint set is universal, shared by children and adults and thus needs not be learned. The acquisition of phonotactics thus consists of the problem of learning a constraint ranking that captures the target adult phonotactics. How could such a ranking be systematically inferred? Suppose that markedness constraints are initially ranked at the top and faithfulness constraints at the bottom, yielding the smallest language that consists of unmarked forms only. Over time, the learner receives a stream of data from the target adult language. For instance, at a certain time the learner might receive the word *clock*, that provides evidence that the cluster /kl/ is licit, and should therefore be realized faithfully as [kl]. The learner checks whether its current constraint ranking accounts for this faithful mapping /kl/→[kl]. Suppose that the learner currently ranks the markedness constraint ∗Dorsal high and the faithfulness constraint Max low, thus incorrectly predicting the cluster [kl] to be unavailable because, say, reduced to [t]. Because of this error, the learner slightly re-ranks the constraints. For instance, it can slightly demote the relevant markedness constraints (such as ∗Dorsal, that incorrectly penalizes the desired faithful mapping /kl/→[kl]). And it can slightly promote the relevant faithfulness constraints (such as Max, that correctly penalizes the undesired reduction /kl/→[t]). These slight re-rankings continue until faithfulness and markedness constraints intersperse in a ranking consistent with the target adult language, so that the learner makes no more mistakes. This is the OT *error-driven ranking model* of the acquisition of phonotactics (Tesar and Smolensky 1998, Boersma 1998).

The intermediate rankings entertained by the model on its way to the final grammar correspond to intermediate learning stages such as those in (1), thus modeling the observed gradual, stepwise progression towards the target adult phonotactics. Furthermore, the model is trained on faithful mappings (such as /kl/→[kl]), so that it only looks at surface phonology and does not require alternations, that will become available only later on, when morphology kicks in. Finally, the model does not keep track of previously seen forms, and thus does not impose unrealistic memory requirements. Its cognitive plausibility has made this error-driven ranking model very popular in the OT acquisition literature (Gnanadesikan 2004, Boersma and Levelt 2000, Bernhardt and Stemberger 1998 a.o.; but see also Tesar 2004 and Tessier 2009 for critical discussion).

Main computational question

Despite the fact that the error-driven ranking model is mainstream in the OT acquisition literature, very little work has been done so far to put it on sound computational grounds. In particular, the OT computational literature has mainly focused on *batch* ranking algorithms, that are easier to develop because can glimpse at the entire batch of data at once, contrary to the acquisitionally more realistic stepwise *error-driven* algorithms (cf. Tesar and Smolensky's (1998) *Recursive Constraint Demotion*; Hayes's (2004) and Prince and Tesar's (2004) biased variants thereof; Riggle's (2004) *ERC-Union Learner*; or Riggle's

(2008) *r-volume Learner*). Thus, only little is currently known concerning the computational properties of the model.

Tesar and Smolensky (1998) develop the first error-driven ranking algorithm, called *Error Driven Constraint Demotion* (EDCD). Its signature property is that it demotes offending constraints to a lower position, but does not promote virtuous constraints. Lack of constraint promotion allows Tesar and Smolensky (1998) (but cf. also Boersma 2009) to prove that EDCD *converges*, namely it eventually settles on a final ranking consistent with the target adult phonotactics, after a feasible number of mistakes.

This talk explores from a computational perspective how well EDCD fares as a concrete implementation of the cognitively plausible error-driven ranking model of the acquisition of phonotactics. As recalled above, phonotactics is the knowledge of licit vs illicit sounds and sound combinations. As EDCD converges, then its final grammar successfully rules in every *licit* form (otherwise, the algorithm could still make mistakes and thus cannot have converged). Yet, it could rule in too many forms, and thus fail at restrictiveness. A convergent error-driven algorithm is *correct* provided that the final grammar entertained at converge also rules out any *illicit* form. Correctness is a pressing issue for the theory of error-driven models: as we only have control on the initial ranking and the re-ranking rule, the acquisition path described by the model, and in particular its final grammar, are crucially governed by the stream of data, so that the model behaves as a leaf in the wind of data. It is for this reason that most of the OT computational literature has focused on more powerful batch algorithms.

Main result

This talk contributes the first result on correctness of EDCD, in the form of the following Theorem. Roughy, it says that EDCD is correct on any language for which the relative ranking of the faithfulness constraints is irrelevant (so called $\mathcal{F}$-*irrelevant* languages). And that correctness holds under no assumptions on the constraint set, apart from a mild assumption on the generating function (*symmetry*). Here are the details.

Standard OT assumes *total* rankings of the constraint set. Thus, every ranking ranks any two faithfulness constraints relative to each other. And there is therefore no way to formalize the intuition that the relative ranking of the faithfulness constraints does not matter. To overcome this problem, let me switch to *partial* rankings. Let me say that a partial ranking *generates* a language provided that each of its total refinements generates that language according to the usual definition of OT (see also Yanovich 2011). A language is called $\mathcal{F}$*-irrelevant* iff it can be generated by a partial ranking that does not rank any two faithfulness constraints relative to each other, thus formalizing the intuition that the relative ranking of the faithfulness constraints does not matter.

As noted above, the error-driven ranking model of the acquisition of phonotactics assumes that the phonological target (the underlying form) and the corresponding production (the winner surface form) coincide. Thus, the sets of underlying and surface forms need to coincide. And the generating function can be construed as a binary relation on the set of phonological forms. I can thus assume that the generating function is *symmetric*, in the sense that [rat] is a candidate for the underlying form /rad/ iff vice versa [rad] is a candidate for /rat/.

With these preliminaries, I can now state the main result of this talk as the following theorem, which represents the first formal result on correctness of the error-driven ranking model of the acquisition of phonotactics.

Theorem — If the generating function is symmetric, EDCD is correct on any $\mathcal{F}$-irrelevant language.

This result does not extend from EDCD to other implementations of the error-driven model, such as Boersma's (1998) *Gradual Learning Algorithm* (GLA). This shows that learning $\mathcal{F}$-irrelevant languages is not trivial.

Discussion

Crucially, it turns out that $\mathcal{F}$-irrelevant languages make up most of any OT typology. In fact, correctness is measured here from the point of view of phonotactics. Thus, a ranking needs to distinguish between licit and illicit forms, but it needs not learn how exactly an illicit form should be repaired. As the relative ranking of the faithfulness constraints mainly governs the repair strategies, it turns out to be irrelevant in most of the cases. As $\mathcal{F}$-irrelevant languages represent the vast majority of any typology, the preceding theorem provides a substantial result on EDCD correctness. And thus also provides solid computational support for the error-driven ranking model endorsed by the OT acquisition literature.

Supplementary material

Informal sketch of the proof

Suppose that EDCD is trained on a certain target adult language. Consider a partial ranking that generates that language. This ranking enforces in principle four types of ranking conditions: a faithfulness constraint needs to be ranked above another faithfulness constraint (2a); a markedness constraint needs to be ranked above a faithfulness constraint (2b); a markedness constraint needs to be ranked above another markedness constraint (2c); or a faithfulness constraint needs to be ranked above a markedness constraint (2d).

(2) a. $\begin{array}{c} F \\ | \\ F' \end{array}$ b. $\begin{array}{c} M \\ | \\ F \end{array}$ c. $\begin{array}{c} M \\ | \\ M' \end{array}$ d. $\begin{array}{c} F \\ | \\ M \end{array}$

If the target language is $\mathcal{F}$-irrelevant, then the relative ranking of the faithfulness constraints does not matter. Thus, ranking conditions of type (2a) are not important for correctness. Furthermore, it turns out that EDCD always gets right ranking conditions of type (2b) when trained on an $\mathcal{F}$-irrelevant language (this property does not extend to the GLA). We are thus left with the ranking conditions of type (2c) and (2d). Suppose one such condition is important for correctness, so that it is crucial for EDCD to learn it. It can be crucial for one of two reasons. One reason is that, if EDCD fails to learn that ranking condition, then its final ranking will fail at *consistency*, namely it will fail to rule in some licit form. Another reason is that, if EDCD fails to learn that ranking condition, then its final ranking will fail at *restrictivity*, namely it will fail to rule out some illicit form. It turns out that, if the generating function is symmetric and the target language is $\mathcal{F}$-irrelevant, then the ranking conditions of type (2c) and (2d) are only crucial for consistency, never for restrictiveness. This means in turn that EDCD will always get these ranking conditions of type (2c) and (2d) right, as it is guaranteed to converge, namely to end up with a final ranking consistent with the target language.

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